Combining tools and processes to facilitate Coastal Environmental Decisions which reflect well-informed societal preferences

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ABSTRACT

There are no structured methodologies for making coastal environmental decisions, and the public participation that is required by U.S. law occurs in an ad hoc manner. Subsequently, most decisions made for coastal common property resources do not reflect societal preferences and the outcomes do not provide efficient allocations. There is a need to combine Economics and Decision Theory to first determine, then achieve the necessary conditions for making 'good' coastal environmental decisions and improve the outcomes.

To determine how to make 'good' decisions, the factors that typically complicate coastal decisions are first identified. Then 'good' environmental decisions are defined; conditions similar to those used for a well functioning Market System are adopted, that is: i) the stakeholders must be well-informed, ii) the stakeholders' preferences must be included and iii) flexible and adaptable decisions must be achieved. This research then identifies families of analytical tools that can help overcome the complicating factors.

Instead of using one tool or process, this research focuses on using a number of tools within a commonly recommended process to overcome or reduce the severity of the complicating factors. A case study is used to show how Multiple Objective Utility Functions, Mental Maps, Simulation models and Uncertainty Analysis tools can be used in sequence to assist the generally recommended steps of good decision-making. This study provides evidence that these four families of tools should be used in combination to make 'good' environmental decisions. These tools enable the decision makers to achieve the necessary conditions for good decisions in the Coastal Environment, because they i)elicit and transfer knowledge about qualitative and quantitative factors, ii) elicit and combine stakeholders' preferences and iii) enable adaptable decisions.

The case study demonstrates that no one tool can help achieve every step of decision-making, overcome all the complicating factors, or obtain all the necessary conditions. Combining tools in a structured method offers the best results. The necessary conditions can be more easily achieved so that the chosen alternative will more closely reflect well-informed societal preferences.

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Chapter I. Introduction

The purpose of this dissertation is to explore decision-making tools and processes that help make 'good' coastal environmental decisions. This chapter provides an overview of the work.

A. THESIS

The objective of this dissertation is to help those who make decisions about Common Property Resources[1] find tools and methods that enable the chosen alternatives to more closely reflect society's preferences than most decisions currently made. The question addressed here is "What families of economic and decision-making tools, processes or methods are best suited to assist decision makers, stakeholders and / or managers in making good coastal environmental decisions?" Used alone, many market-based techniques, economic methods and decision-making tools are often inadequate for choosing alternatives that reflect society's aggregate values.

To make decisions about how to efficiently allocate environmental common property resources, a wide range of tools should be explored and reviewed to analyze the advantages and shortcomings of each. To make these good decisions, the tools need to assist with:

a) having well-informed stakeholders
   i) eliciting the best available information
   ii) transferring the information to the stakeholders
b) incorporating the stakeholders' well-informed preferences into the final choice
   i) eliciting the stakeholders' preferences
   ii) combining them to choose an alternative

The thesis promoted in this research is that there is no one tool or one method that can achieve good allocation decisions for common property resources. Different families of tools should be used within the widely recommended steps of good decision-making to achieve good allocation decisions, decisions that reflect society's aggregate values. The result of this

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[1] **'Common Property Resources'** are those not exclusively controlled by a single agent or source. If access is not restricted, the resource can be exploited on a first come, first serve basis. **'Public Goods'** are goods that exhibit consumption indivisibility. They are fully accessible to all. One person's consumption does not diminish another person's consumption. (i.e. air, coastal water, a view) It is important to note that many goods that are thought of as environmental Public Goods may actually be Common Property Resources. For example, a coastal view may be considered a Public Good if only ten people want to look at the view. If hundreds, thousands or millions of people want to appreciate the view, then it is likely that the view will not be accessible to all; one person's 'consuming' the resource *will* diminish other people's consumption. Many coastal and ocean resources are in fact 'Common Property Resources.'

research will be to propose a set of decision-making tools, processes and / or methods that can help make 'good' decisions. A 'good' decision is difficult to define; it will be explored as part of this work in Chapter III.[2]

B. OBJECTIVES AND IMPORTANCE

As stated above, this dissertation's objective is to help those who make allocation decisions for common property resources. There is an increasing need to better allocate common property resources as they become relatively scarce. There are greater demands for environmental resources, such as clean coastal waters; quiet, non-crowded beaches; fish; clean air; non-polluted river water; as the world population grows, yet the quantity of these resources are fixed or are decreasing.[3] Due to a combination of anthropogenic and natural forces, incremental degradation has occurred causing enormous damage to coastal systems in the last thirty years. For instance, anthropogenic forces that have destroyed habitats include inadequate waste water treatment plants and toxins and nutrients from land runoff. Coastal structures have caused shoreline erosion. Natural phenomena such as droughts and hurricanes have intensified many problems. Marine recreational activities, fisheries, real estate developments, etc. have not achieved their potentials, since there have been long term economic losses suffered by and from these activities. It is necessary to spend more effort determining how to better allocate coastal resources, for both present and future uses.

Allocation of coastal common property resources can not be left to the Market System; too often this causes them to be woefully mis-allocated and / or neglected. Often governments intervene to prevent these resources from being neglected, but the governments' methods may not necessarily improve the allocation. Many environmental decisions have not been optimal or even satisfactory in the long run.[4]

There are many researchers and practitioners using different tools and methods for various environmental decisions, but no one tool has been found satisfactory for many coastal environmental decisions. There is a plethora of current research and discussion on

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[2] One commonly used definition for a better group decision is 'Pareto admissible.' **Dorfman** and Jacoby (1969) define Pareto admissible as "there exists no feasible alternative that some interested parties regard as superior and no group regards as inferior." It is the set of decisions that best reflect the group's values (the best decision) when there are multiple criteria. The problem is how to determine when you have reached this point. One must know all parties' interest and values. **See Chapter III** for a full discussion.
[3] Many coastal resources are becoming more scarce, some in absolute terms, such as certain species of fish, and some in relative terms, such as the fixed amount of coastal land compared to the increasing human population.
[4] See **Chapter II** for a discussion of environmental cases in the coastal environment where complicated decisions have resulted in less than optimal results.

environmental economics. There is also a wide range of tools that are often applied to private and public sector decision-making. Many researchers use one tool and discuss how it can be applied to many decisions, including environmental decisions. There is a need, though, to systematically look at the problem of environmental decision making, then apply the appropriate science at the right time. Only a few researchers have systematically attempted to understand the capabilities and limits of many methods and tools; fewer still have suggested how to overcome the limits by using a number of tools together. This research has found no such systematic research or surveys for environmental decision-making. (See Chapter V for a full discussion.)

Choosing tools that can overcome the complicating factors and using them within the recommended steps of good decision-making increases the likelihood that the necessary conditions for a good decision outcome will be achieved. This work will discuss which families of tools are appropriate, at what stage of decision-making they are most helpful, and why. A case study will provide evidence showing how a number of tools together can achieve a good decision. Future environmental decisions can use the results of this work, a template that specifies which families of tools to use in a prescribed order, and steps to be followed. This research will create a more structured method for making good coastal decisions.

C. Notes and Assertions

1. The Market System often fails to efficiently allocate many environmental resources

The Market System is often inadequate for allocating natural resources or environmental amenities. Common property resources do not meet all the conditions necessary for an efficient allocation and Environmental Externalities exist.[5] (Pindyck and Rubinfeld, 1991; Tietenberg, 1992; any micro economics text). In coastal cases, examples abound: Fishermen often over-fish, attempting to harvest the existing fish before their competitors diminish the resources and to increase their near-term income, rather than ensure long term sustainable stocks. Bacterial and chemical toxins from industries and urban runoff enter harbors and bays, causing beaches and shellfish beds to close. Boats and ships leak oil and other toxins, killing wildlife and habitats. Increased farming on land increases the nutrient runoff and turbidity that causes eutrophication in watersheds and coastal waters. Coastal construction, such as jetties and inlets, increase the rate of erosion elsewhere along the shore.

[5] ''Externalities' occur when an individual does not bear all the consequences of his or her action, when the welfare of an individual depends not only on his or her own activities, but also on other individual's activities. Externalities can be either positive or negative.

As coastal resources become relatively more scarce, they can no longer be allocated using the Market System on a first come, first serve basis. Coastal environmental resources can not be optimally allocated by laissez-faire. The coast and coastal waters provide many common property resources , but they are susceptible to 'The Tragedy of the Commons' (Hardin, 1968) and many of these resources are declining.[6]

Some environmental economic methods attempt to incorporate the environmental externalities into the market structure. Tradable permits, bubble pollution policies and licensing limits all attempt to internalize the environmental externalities, that is, to encourage industries and individuals to treat Common Property Resources more like privately owned resources. This may be successful and appropriate in a subset of environmental problems when only one or two of the necessary conditions for a successful market outcome have been violated, or when most of the inputs and outputs are privately owned. There are, though, environmental decisions where most of the necessary conditions for a efficient allocation by the Market System are not met. (See diagram in Appendix I.) Can environmental economic tools work in these cases? Probably not.[7] These types of decisions need to be understood, dissected and analyzed. Other decision-making methods may need to be applied in these cases.

2. Coastal management programs have been developed to protect natural resources from over-exploitation

Many people have recognized that coastal common property resources do need to be managed, due to the Market System's inefficient distributions. Governments are attempting fulfill the need with different types of coastal management programs. In the US, coastal management and protection programs include the National Estuary program administered by EPA; the National Coastal Zone Management program; the National Marine Sanctuary program under the National Oceanic and Atmospheric Agency (NOAA); Shoreline Protection program under the Army Corps of Engineers, and the Federal Emergency Management Administration, etc. Unfortunately, it is not always true that the public sector will manage coastal resources better than the Market System; the old USSR is one example of how the environment suffered more degradation under governmental decision-making.

It is difficult for the government agencies or other organizations to determine how to manage, allocate and distribute coastal common property resources. The choices among preservation,

[6] Many examples are discussed in **Chapter II** and throughout the dissertation.
[7] This topic is discussed more fully in **Chapter IV**.

conservation, development and use are not easy. The best tools and methods from decision-making sciences and environmental economics should be sought and applied when making these difficult, complicated decisions.

3. Assertion: Sub-optimal environmental decisions are often made because the value of environmental amenities are difficult to quantify[8]

There are difficulties in trying to place monetary equivalents on many of i) the benefits provided by coastal environmental resources, ii) the benefits provided by the ecological systems that support them[9] and iii) the costs of not having the resources. Natural resources and ecological systems have intrinsic as well as economic value. Many people attempt, albeit often unsuccessfully, to quantify the many user, option and existence values.[10] The most easily quantified components of the environment and ecological links are those used directly by humans (i.e., the fish we eat or the beaches where we swim); still environmental economic tools can measure only a fraction of these human use values. Some of the option and existence values can be captured, but often there is little confidence in the numbers generated. It is difficult to understand the value of an environmental amenity when all the information and linkages associated with that amenity are not understood. It is difficult to put a dollar value on an amenity when there is great uncertainty about many of it's aspects.

In environmental decision-making, the non-monetary benefits and costs are not easy to quantify; subsequently these non-monetary factors are often omitted from the decision-making process. For example, in San Francisco Bay, it was easy to quantify the cost of a new pipe system to deliver fresh water to agricultural and urban users, and it was easy to quantify the benefits of increased farming incomes that the piped water system allowed. Conversely, it was difficult to quantify the losses that would result from a piped water system, that is, the lost benefits provided by the natural flow of water, such as the lost income from commercially important fisheries and spoiled recreational areas. The piped system was built; as the free flowing river water decreased, and the resources it supported declined and some of the ecosystems' resources and the benefits they provided were lost.

Quantifying the losses of these environmental resources did not occur until many years after the pipe was built, after the stakeholders and government officials were *certain* of the lost

[8] See **Chapter IV** for a full discussion of these topics.
[9] Incremental loss of parts of the ecological system may seem harmless, merely linear degradation over time. In actuality, though, a threshold may be reached and catastrophic, nonlinear losses may occur over short time periods.
[10] See **Chapter IV, Section C** for definitions of these values.

resources. While it was difficult to accurately *predict* the losses, it has been difficult to accurately quantify the losses, even after they have occurred. For example, it has been difficult quantifying the cost of lost fisheries, and even more so quantifying the costs of lost wetlands on all marine and terrestrial life, and the benefits of clean water flushing the Bay; the user values are easier to quantify than the existence and option values. Most people agree that benefits do exist, but few agree as to what they are and how they should be quantified. If major decisions involving large capital investments were made that affect the environment, they are difficult and costly to undo, even if they were made with incomplete information and uncertainty. The piped system continues to divert fresh water from its the San Francisco Bay.

4. Assertion: There are many factors that complicate environmental decision making

Not only is it difficult to place monetary equivalents on many environmental resources, but there are many factors that complicate environmental decision-making. Researchers and scholars in the decision-making field recognize that social problems, including environmental decisions, involve complicating factors:

> "Frequently, social problems appear to be so complex as to be un-solvable. High-quality decision-making requires the decision maker to see through the problem and its complexities." (Hwang et al, 1987)

> "It is almost a categorical truism that decision problems in the public domain are very complex. They almost universally involve multiple conflicting objectives, nebulous types of non repeating uncertainties, costs and benefits accruing to various individuals, businesses, groups and other organizations... and effects that linger over time and reverberate throughout the whole societal superstructure." (Keeney et al, 1976)

As Varis says, a complex decision environment is one in which there are "interrelations of quantities of very different character" or variables from multiple disciplines. This complex decision environment exists in environmental decisions and has so far

> "not allowed formal optimization approaches in environmental decision-making... Accordingly, the decision is often made at a political level, at which the rationalities and objectives driving the decision-making are very interrelated and complex. The quest for the ability to analyze and support environmental decisions is immense." (Varis, 1989)

There is a need to use a structured, analytical approach to help enable good environmental decisions. Although environmental decisions are often made within the political system, the focus of this work is to find the families of tools or methods that can be used within the political process. This work does not focus on the wide range of dynamics found in the political process, but focuses only on the management functions and decision-making steps within the political process. To find a structured, analytical approach, the science of economics and decision-making should be explored to find the best approach for environmental decisions.

To begin, one must first understand and categorize the types of complicating factors inherent in environmental decisions. Then one must look for the tools, methods and processes that can overcome these complicating factors. All parts, the "multiple conflicting objectives, ...the uncertainties, ...the various individuals, businesses, groups and other organizations" need to be considered to achieve good environmental decisions. Sub-optimal decisions are often made because important information was excluded from the decision-making process, because no one knew how to incorporate it. For example, in 1975, the Army Corps of Engineers decided to renourish the beach in Manatee County, Florida. One of the concerns for the local residents was the resulting damage to fisheries or sea turtles, but these concerns were excluded from the original proposal and the discussion. Scientific information about the fish and turtle was complex, difficult to assess and incomplete in its conclusions, so it was excluded from the decision-making, ignored by the Corps of Engineers. As a result, the local residents did not contribute their share of the project funding, and the 1975 decision was never implemented. It was not until 1992, when the decision was remade incorporating the citizens' concerns and the best available information, that the beach was finally renourished.

Many factors have been inadequately included in coastal environmental decisions. Long term ecological losses are often entirely omitted due to great uncertainties and unknowns. Decision makers should not ignore the complicating factors or worse yet, ignore the problem and take no action. With many mitigation problems, inaction is often the most dangerous alternative. Better optimization / environmental decision-making tools must be found and used, so the available information can be used and the complicating factors overcome.

5. Assertion: The best approach for reaching effective environmental decision depends on what complicating factors are involved

Because it is not possible to capture the value of each environmental amenity affected by an environmental decision, the overall goal should be reviewed, that is to make good decisions about how to allocate the resources for present and future uses. It is widely accepted that there is no one best decision-making tool, but that the best tool depends on the set of complicating factors. There is a need to explore a wide range of economic and decision-making tools and methods to find those that can overcome the complicating factors inherent in coastal environmental decisions. Buffa (1981) suggested the following be determined:

i) The nature of the environmental problem. For example, can it be forecast with relative certainty or is risk a major factor to be considered in the decision... What complexities are inherent in the problem?

ii) The nature of the relationships among the problem's important elements. If the relationship can be expressed mathematically, it is relatively easy to analyze. If not, can the relationships be expressed in words and understood well enough to manipulate?

This research will attempt to find the analytical tools that overcome the complicating factors of environmental decisions. To find the tool(s) that achieve this, the research will:

i) Look at the types of complicating factors inherent in specific environmental problems;

ii) Find the families of tools that can help overcome the complicating factors;

iii) Analyze how the tools can be used.

Although there may be no one perfect tool, a systematic exploration of all families of tools is undertaken here. The goal is to determine which families are best suited for a given situation. This research will find a set of tools that can help make better coastal environmental decision than most of the tools presently in use. It will discuss which families of tools are appropriate, at what stage of the decision-making process they are most helpful, and why.

D. Work-Plan

After dissecting the decision-making process, understanding its components and categorizing the complicating factors, one can then better understand how to improve the decision-making process. After dissecting the parts, it is then possible to construct a new, improved process, using tools that overcome the complicating factors. To find these tools, this research will:

i) Review seven coastal cases to understand how decisions are presently being made and to derive a comprehensive list of the complicating factors under which most coastal environmental decisions are made.

ii) Define the necessary conditions of good decision-making, by reviewing methods typically used to allocate resources. Understand what typically constitutes a good allocation decision and what is involved in a good outcome..

iii) Review the field of Decision Theory and the recommended steps for good decision-making as they apply to common property resource decisions.

iv) Find the families of tools and methods that can overcome the complicating factors in environmental decisions by reviewing Economics and Decision Theory.

v) Review the methods and tools other researchers and practitioners are using.

vi) Choose one case study to analyze in-depth, and chronicle its decision outcome.

vii) Propose an appropriate set of tools to use for the same in-depth case study to see if they could assist in making a good decision.

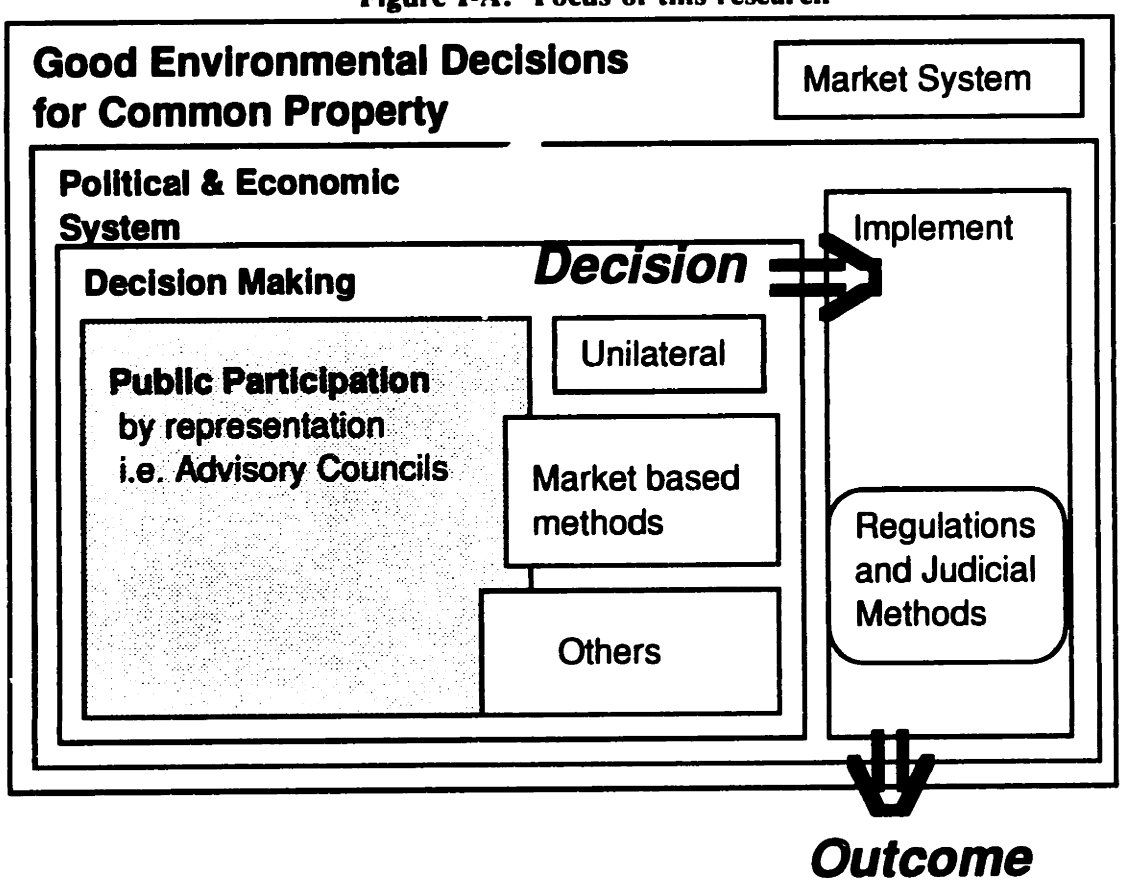
viii) Compare the actual decision with the proposed process to analyze the differences.

ix) Build a framework specifying the processand recommending the families of tools appropriate for future environmental decisions, to ensure that the complicating factors are overcome and the necessary conditions for good decisions are met.

E. SCOPE

The intent of this research is to help policy-makers, government groups, businesses, citizen groups and individuals make good coastal environmental decisions. This work focuses on decisions that concern common property resources in the marine / coastal area. The results of this work should be applicable at the individual, group, local, state and national levels for non-marine environmental decisions as well, such as those which involve air and rivers.

Figure I-A: Focus of this research

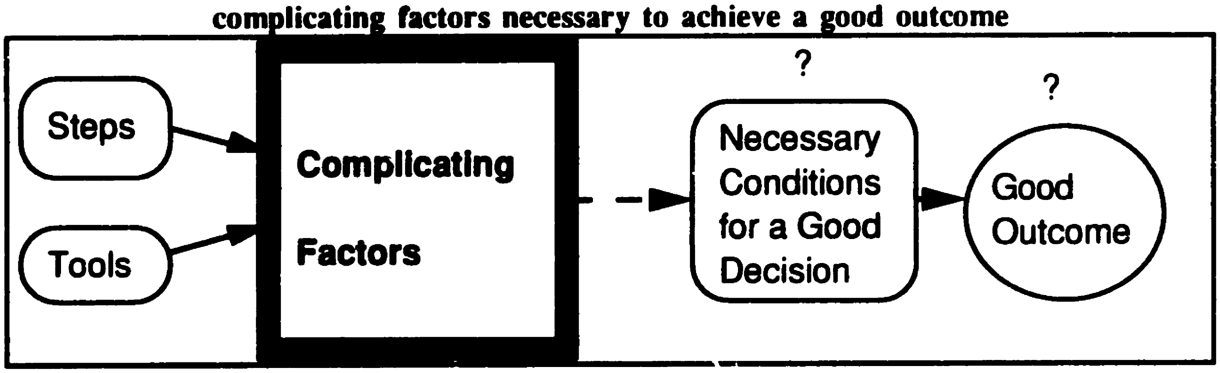


The coastal environment is used here, because it provides many cases of common property resources that are poorly allocated (i.e. fish and clean coastal water). Coastal resources are representative of many environmental resources, because they are limited and have already begun to show the effects of neglect, mismanagement and mis-allocation. It is within the last 25+ years that the U.S. as a community is beginning to recognize the importance of coastal resources and is attempting to manage them better.

E. Conclusions

This dissertation proposes that there is no one method or tool that can achieve a good decision in most circumstances. A wide range of allocation methods and decision-making tools need to be explored in a systematic way to find the tools that can help coastal environmental decision-makers choose alternatives that better reflect society's collective values. To find the tools most helpful, it is important to first understand why coastal environmental decisions are difficult to make. First, it is necessary to determine if there are any complicating factors common to many coastal environmental decisions. Then one can look for the tools that best overcome these factors. Chapter II reviews seven different coastal cases, and identifies some key common factors that have inhibited good decisions.

Figure I - B: Tools and processes used separately can not always overcome the many complicating factors necessary to achieve a good outcome



Chapter II. The factors that make it difficult to reach effective Decisions about Coastal Resources

This chapter reviews seven coastal environmental cases to extract the factors that complicated the decision-making. Nine types of common complications were found for coastal environmental decision-making, then compared to the different categories of complications found in general decision-making. This helped reduce the nine factors into three categories, focusing the search for tools that can help overcome the complicating factors and lead to good environmental decisions.

A. DETERMINING THE NINE COMPLICATING FACTORS FOUND IN MANY COASTAL ENVIRONMENTAL DECISION CASES

After reviewing seven coastal cases and the conditions under which the decisions had to be made, a list of common complicating factors was developed. There were common factors that caused the resource allocation decisions to be less than efficient and /or the decision process to be difficult. These factors are:

1. so much data and information that all of it is not adequately considered
2. criteria and variables that cannot accurately be reduced to monetary terms
3. criteria and variables from multiple-disciplines and areas of expertise
4. interdependencies among environmental decisions
5. uncertainty about cause and effect and lack of data
6. one-time decisions with high stakes
7. various ways to consider the time frame of the project
8. various ways to consider the geographical scope of the project
9. multiple people (stakeholders, decision makers, etc.) with different preferences

The meaning of each complicating factor may not be obvious, so it is best to first discuss the definitions before reviewing their origin.

1. So much data and information that all of it is not adequately considered

For many coastal environmental problems, the decision makers often have to consider an great amount of information. Many decisions require knowledge concerning hundreds, thousands or more variables, including physical factors such as the biological and chemical effects, the subsequent economic effects, and the human preferences.

"Improved approaches are needed to fully apply the Nation's information and knowledge base to estuarine and coastal resource management and environmental quality problems. A relatively small portion of what is actually known by experts, both within the science community and at large, is often brought to bear on problems." (Basta, 1993)

Not only is it difficult to collect all of what is known in one place, so that all stakeholders have access to the information, but it is also difficult for stakeholders to use all of the available information. The human brain can only consider and process a certain amount of data at one time, and almost always, environmental decisions exceed the capacity. To simultaneously juggle the many pieces of information at once, considering them all when trying to optimize a decision, often tools must be used to assist with the abundance of information.

2. Criteria and values that can't accurately be reduced to monetary terms

Some parts of environmental decisions can be represented in monetary terms, such as the cost of sand to nourish a beach the first time, the cost of sand transport, or the average income of commercial fishermen. Other parts of environmental decision are difficult and some are impossible to find the equivalent dollar values. What is the value of fresh air? Life on earth, as we know it, can not exist without air, and yet humans typically pay $0 for air. What is the value of clean water? How can one accurately measure the value of the wetlands, fisheries and recreation in the San Francisco Bay? What is the monetary equivalent of the lost resources from the Exxon Valdez spill? There are methods for obtaining estimates of the recreational value, but even those who use them realize they are often not accurate? Many environmental decisions involve variables on which it is difficult to place an accurate dollar values.

3. Criteria and variables from multiple disciplines, from many fields of expertise

Many environmental decisions require knowledge from a broad range of topics: from the biology of plants and animals to the costs of designing coastal construction; from the mechanics of water forces on beach erosion to public policy and government jurisdictions; from the economics of fishing income to the ecology of coastal habitats. There is no one 'expert' or one field of expertise that can alone determine the best solution.

"Although many agree that the Nation's coastal resources and environmental quality are suffering, few have been able to diagnose the causes accurately and recommend possible cures. The cures will require: a) more holistic, systemic thinking and b) a willingness on the part of all scientists, managers, policy makers, and the public to establish higher trust levels and to risk different approaches." (Basta, 1993)

"New roles and institutional partnerships between the management and scientific communities must be forged to make the collection and synthesis of technical data possible." (Ehler, 1994)

There are many fields of expertise required to make good environmental decisions, all of which need to be combined and included in environmental decisions.

4. Interdependencies of environmental decisions

With environmental decisions and ecological processes, there are many cause and effect links that humans don't fully understand or know exist. Researchers and practitioners who work in the area are continuously uncovering new links. For example, if pesticides are used on land, marine life is damaged by runoff. If the use of carbon fuels increases, global weather patterns are affected, and sea temperatures increase, which increases the number of diseases in coral reefs. Many processes and variabies are interdependent, although not all of them may be fully understood. The interdependencies can be dynamic, that is they change over time, or can be cyclical, that is variable A affects variable B, which in turn affects variable A again.

5. Uncertainty about cause and effect

Natural processes and living systems are complex, and there is uncertainty concerning their many parts. With natural phenomenon, such as hurricanes and rainfall, there is uncertainty as to the timing, intensity and frequency of events. With living systems such as reef habitats or bay marine life, there is even more uncertainty. First, they are affected by natural phenomenon where there is uncertainty. Second, many of the variables they are affected by have been identified, but there is uncertainty in the linkages, uncertainty about how some of the variables interact. Third, and most severe, there is typically uncertainty as to the list of variables that affect any living system. Because of the uncertainty in the living systems and natural phenomenon, there is also uncertainty in how these systems impact humans and vice versa.

There are great "uncertainties in resource and environmental quality assessment, (for example in cause and effect relationships, socioeconomic impact, the effects of management actions, etc.)." (Basta, 1993)

The most advanced scientific research can not predict with 100% certainty the causes and effects of most events in the environment. As humans focus on specific environmental and ecological problems, and more effort is placed on certain areas of research, more is learned. There is less uncertainty about cause and effect, about the reasons why certain living systems behave as they do, about some physical processes. We will never know everything, though, so we can not wait until there is complete certainty before decisions are made. Decision makers must be satisfied with using the most relevant information and knowledge available at the time of decision, which requires that scientists provide their best judgments based on the data available at that time. The decision-making process must accommodate the uncertainty and the growing body of knowledge, and the scientists, managers, stakeholders, etc. must share the risks of the decisions.

6. One time decision with high stakes

Environmental decisions are sometimes one-time decisions with high stakes. Many environmental decisions include making decisions on resources that are one of a kind. The decisions can not be made over and over, allowing the decision maker to learn from mistakes or be satisfied with the statistical average of the many outcomes.[11] For example, if a marine species becomes extinct, it might cause catastrophic effects to the marine food web. Other examples might be; should a dam be built, the land flooded, and the ecological system changed? Should a wetland be drained, converted to farmland, and again the ecosystem changed? Should a beach be renourish with any type of sand, and risk irreversible changes to the habitat, or should more money be spent to renourish it with similar sand? Should the beach not be renourished, taking the chance that the recreational and tourism industry die? Should a river be straightened by building a canal, or should it be left alone, even if the surrounding land is prone to flooding?

Many environmental resources are relatively rare, and their interrelationships are not well understood. If a bad decision is made, sometimes the environmental resource can not be replaced or take tens or hundreds of years to replace. It may not be acceptable to make a mistake concerning an environmental resource, and learn from it for future decisions.

7. Various ways to consider the time frame of the project

"Analysts must constantly make tradeoffs between what is right for the present generation and what is right for future generations." (Keeney, 1976) When environmental decisions are made, should a time frame of 10 years, 20 years, 50 years or infinity be considered? For renourishing a beach, should the decision be optimized for 20 years so that the present hotel owners can benefit from increased tourism, or for infinity so that future generations can enjoy the beach? With some business decisions, a clear boundary can be placed on the end of the decision life cycle, but with environmental decisions, it is very difficult to determine when the

[11] In some situations, it may be possible to make the decision in steps or change the decision, so it may be possible to learn from previous decisions. This is not always the case, though.

effects of the decisions will end. The time frame is also not well-defined because the resources' ownership is ambiguous; are common property resources owned by all those people alive today or also owned by future generations? It is difficult, if not impossible, to determine the correct time frame for an environmental decision.

8. Various ways to consider the geographical scope of the project

With environmental decisions, it is often difficult, if not impossible to draw a physical boundary around the area which the decision will affect. If a ten mile strip of beach is renourished, it is affected by the ocean tides offshore, and the shore activity up and down the coast. It also affects regional economics and may affect the coastal ecosystem. The air and water in environmental area are fluid and travel outside the region. Since no one fully understands all the biological, chemical or physical processes that occur within the defined 'geographic boundaries' of an environmental decision, one can not be sure that the effects don't spill over to other geographic areas.

9. Many people with different preferences (i.e. - subjective human values)

With environmental decisions, often i) there are multiple government agencies who have jurisdiction in the affected area and ii) there are a great number of individual citizens affected by the decision. Because the Market System often fails to allocate environmental resources efficiently, government or private agencies become involved to ensure that the resources are not ignored.

> "The process of decision-making is undergoing a fundamental change. Decisions that had formerly been an almost single resource-use problem made by a single institution are now multiple resource-use decisions and the domain of many institutions. Resource management problems that were primarily Federal, are now Federal and State and in many cases local. No single institution has all the necessary authorities nor resources to fully resolve the multiple resource-use problems confronting us." (Basta, 1993)

Not only are multiple agencies involved in environmental decisions, but there are often laws mandating that private citizens, the stakeholders, partake via public input. For example, there is the National Environmental Policy Act of 1972 (NEPA).

> "Complexity arises when there is more than one decision maker. The preferred solution must be agreed on by all interested groups. The analysis must be extended to account for the conflicts among different groups who normally have different goals." (Hwang, 1987)

There are many people who are legally mandated to partake and who have power in the decision-making process. The more people involved, the greater the number of judgments, preferences and interests that need to be included, which complicates the decision making.

B. Developing the List from Coastal Environmental Cases

The list of nine complicating factors was developed by reviewing seven coastal environmental problems. Three of the seven cases are reviewed in this chapter and the other four cases can be found in Appendix II-A. This was done for brevity and to reduce repetition.

1. Boston Harbor

There is a need for more accurate valuation of the waters and waterfront of Boston Harbor. Until the 1980's, the value of the water in the Harbor had been grossly undervalued, neglected and ignored. Boston Harbor had long been used as a dumping ground for wastes; Boston's wastewater was underwent only primary treatment, the sludge was piped out and dumped in the outer Harbor and many industries dumped there wastewater into the Harbor's tributaries. In 1972, the Clean Water Act required that all wastewater treatment plants use secondary treatment. This Act instated blanket regulations, requiring the same technology in every city in the US, for every situation, regardless of the costs or the resources being protected.

In 1979, the Boston Metropolitan District Commission applied for a waiver to the 1972 Act, proposing a 7 mile outfall pipe instead of secondary treatment, but the waiver was denied by the EPA in 1983. Boston's MDC reapplied, proposing a 9.2 mile outfall pipe with diffusers, but again the waiver was denied in 1985. In the early 1980's, the City of Quincy sued the MDC for causing pollution along Quincy's shoreline and the Conservation Law Foundation also filed a federal suit against the MDC; this caused the courts to become involved in the decision. In 1984, a number of cases were brought to court regarding whether new sewer hookups should be allowed, since they would intensify the problem. The issue was settled when EPA decided that no new hookups would be allowed until an independent sewage authority was created; the Massachusetts Water Resource Authority was created and held responsible for the actions of the MDC. The Quincy and Conservation Law Foundation cases were settled by a court mandate for a sewage system improvement. (Dolin, 1992)

The court decision required that the MWRA build a new 1270 million gallon per day primary treatment plant and a 1080 mgd secondary treatment plant. It also required it build a 9.5 mile outfall pipe with 55 diffusers to bring sewage away from the harbor. A sludge treatment plant was opened in Quincy in 1991, making fertilizer pellets out of the sludge, instead of dumping the sludge in the Harbor. The primary treatment plant and the outfall pipe are scheduled to be on line in 1995 and the whole system should be in operation by 1999. MWRA has also worked to reduce the amount of raw sewage entering the harbor via the Combined Sewer Overflows in rainy weather.

The benefits of the cleaner water have already been seen in 1995. Beach closings have decreased by 50%. (Dolin, 1992) Bacterial contamination is the lowest its been in 50 years. (Aubrey et al, 1993) Zinc and cooper levels have decreased by 75% and Chromium, lead and nickel contamination are down 50%, since the early 1980's. (Hepler, 1994) The water quality standards of the Clean Water Act are now typically met in Boston Harbor.

The increase in water quality has led to increased waterfront development, and more value being placed on waterfront amenities. The Charlestown Naval Yard was renovated for more than 2.5 million square feet of office and living space in the 1980's and an additional 2.3 million square feet is to be developed. (Boston Redevelopment Authority, 1994) A national Historic Park has been declared on 30 acres of this area. Boston Harbor Islands were declared a National Treasure in 1994. (Studds, 1994) Harbor Lights, a 4000+ seat amphitheater was created on one of the Islands. The New England Aquarium is building a new wing to better utilize their water front views. New parks and recreational areas are being created in much of the waterfront area, etc.

While the benefits are more apparent in the last few years, there was much opposition to the court mandates. First, an MIT Civil Engineering professor, Dr. Donald Harleman, claims that chemically enhanced primary treatment could be used to achieve the same results as secondary treatment, but with less sludge produced and at least $1 billion dollars cheaper. The EPA claims that his conclusions are unscientific and wrong. Opposition has also come from Boston water users, since MWRA and therefore the users have had to pay the entire bill. In 1985, by the time the court made its decision and Boston was forced to construct a new waste water treatment facility, federal assistance money was no longer available for building secondary treatment facility. MWRA has had to raise its own money by raising sewer and water rates, which will costs the users more than 6 billion dollars for the project's capital costs alone.

The court's 1985 decision determined the 'value' of clean water in Boston Harbor for the rate payers and all those affected by Boston Harbor waters; the recognized 'value' jumped from nearly 0 to more than $6 billion. Between 1985 and 1991, the annual sewage cost for a family of four in Boston increased from $200 to $410, and the rate is predicted to go as high as $1000 per year by the year 2000. Before 1985, Boston had significantly lower sewer rates than other major cities, but it is likely that Boston will soon have the highest rates in the United States.

In this case, the decision-making environment has been complicated due to:

a. A great deal of information - There was a great deal of information about the long term affects of sewage, toxins, sludge, etc. and about pollution sources. There was also a great deal of information about the potential for replenishment of the living systems and of clean water if the pollution was reduced. There was also a great deal of information concerning the stakeholders' preferences for clean water versus low water bills.

b. Criteria and variables that can't accurately be reduced to monetary terms - The value of the resources in Boston Harbor are unknown. They are more than $0, and may be more or less than the $6+ billion that Boston water users will pay for the revitalize some of the resources. The court decision to enforce a regulation required that a certain amount of money be spent, but never considered the possible monetary equivalents of the resources that it was trying to revive, since these were too difficult to assess.

c. Criteria and values from multiple disciplines, using expertise from many fields - To determine the 'best' solution, the decision should have considered the biological processes of the Harbors plant and animal life, the physical transport of nutrients and toxins through the Bay, the engineering of primary treatment methods other than secondary treatment, the economics of improved fishing industries, the economics of increased waterfront value, etc. There is information from many disciplines that needed to be combined.

d. Interdependencies among environmental decisions - The was and still is a significant number of interdependencies in the Boston Harbor decision. In the past, wastewater from private homes and industries affected the water quality and marine life in the Harbor, which affected the economics of the fishing industry, the value of waterfront property and the recreational habits of Boston residents. In the current decision, building the wastewater treatment facility has affected every user's water and sewage bills, the improvements in the water quality has raised the value of waterfront property, the outfall pipe might affect Cape Cod's water quality, etc.

e. Uncertainty about cause and effect / evolving scientific data - There was and still is a great deal of uncertainty in the Boston Harbor decision. There was uncertainty about the most efficient and cost effective method for treating the water and meeting the water standards. It is unknown to what degree cleaner water will enable the plants and animals to replenish themselves. It is unknown whether mollusks and benthic organisms will be safe for consumption, or if the mud in the Harbor will always be full on toxins. It is unknown whether local beaches will be closed in the future and how often, and unknown whether increased boating will affect the whales in Boston Harbor. It is unknown whether the new outfall pipe carry excess nutrients to Cape Cod and cause algae blooms there, and unknown whether the outfall pipe will affect the newly designated National Marine Sanctuary at Stellwagen Bank. Great numbers of unknowns affect the decision's outcome.

f. Various ways to consider the time scope of the project - Some people saw a short time frame as appropriate, trying to determine the expected benefits from the project in 20 years, for example. Others were more concerned with a longer time frame, with many environmental groups concerned with decades and centuries, therefore willing to spend more money even if $6 billion worth of benefits were not seen within 20 years.

g. Various ways to consider the geographical scope of the project - The appropriate scope may not be just the cities and towns that pay for Boston sewage and water services. It may also include any town that borders Boston Harbor or it may include Cape Cod and the Stellwagen National Marine Sanctuary. An appropriate geographic scope may be the entire North Atlantic coast.

h. Multiple groups that value things differently - There are many cities and towns that border the Harbor, and many people who affect the Harbor every time they use water. With many decision makers, there are conflicting goals for the best use of the water and the waterfront. The Harbor suffered from the Tragedy of the Commons. The decision to reduce the pollution inputs and clean the water was not made after eliciting the stakeholders' preferences about the resources, though; the decision was made by the regulations of the 1972 Clean Water Act and upheld by the Courts.

2. San Francisco Bay

There is less freshwater flow into the San Francisco Bay than there was 50 years ago, because there have been many water diversion projects in northern California. These projects take fresh water from the Bay's tributaries and bring it to farmers and municipalities throughout California, but they decrease the flushing ability of the San Francisco estuary. Removal of soluble wastes in the estuary are dependent on high river discharge, so the decreased freshwater flow causes sediments, pesticides and nutrients to fill the Bay. (Berger, 1990)

This has in turn caused the marine and wetland life in the Bay to die off. The pollutants have resulted in restrictions on shellfish harvesting and consumption, warnings on consumption of Bay area ducks and fish and noteworthy declines in fish and fowl populations. State Mussel Watch studies indicate significant contamination by pesticides such as chlordane, DDE, dildrin and PCB. This occurs primarily from agricultural runoff and hydrocarbon contamination from urban runoff. Selenium levels are elevated due to both oil refineries and leaching from irrigated agricultural land.

Decreased freshwater flows have also caused intrusion of saltwater into historically freshwater areas. This converts brackish marsh into salt marsh, altering the characteristics of these wetlands area. The ecology of the area changes, displacing populations dependent on a certain salinity in their habitat. Saltwater intrusions have also contaminated farmlands in the lower Delta areas, resulting in the losses of agricultural resources. (San Francisco Estuary Project, 1993)

This case has been complicated by the following factors:
a. A great deal of information - There is a need to include recreational, industrial, logging, agricultural and residential concerns in Northern and Southern California when trying to best allocate the natural resource, freshwater. It is difficult to consider all the information at the same time when making a decision.

b. Criteria and values that can't accurately be reduced to monetary terms - The worth of a brackish marsh for fish nurseries is not understood well enough to put a dollar value on it. It is also difficult to put a monetary term on an extra gallon of water to a farmer or resident during a drought. The value of fresh water river flow to the San Francisco residents, fishermen and recreationalists are also difficult to determine.

c. Criteria and variables from multiple disciplines, requiring expertise from many fields - Some of the disciplines that the San Francisco Bay Management Plan needs to consider are the economics of recreation and farming in California; the biology of river fish and estuarine fish; the engineering of piped water systems; hydrology; marine and aquatic biology; farming practices, etc. All must be considered to make the best decision.

d. Interdependencies of environmental decisions - The choice of how much water to divert for drinking and farming affects the health of the Bay's habitats, which affects its fisheries, and its recreational worth. If the Bay becomes too unhealthy, fewer people will be attracted to living in the area which affects the economics of the area. It also affects how much water would need to be diverted for drinking.

e. Uncertainty about cause and effect - It is unknown how much freshwater can be diverted while still achieving an acceptable water quality in the Bay and it is uncertain how much the retrieval of marsh areas due to diverted freshwater flow will affect the levels of nutrients and toxins. It is also uncertain how much rainfall there will be to supply the freshwater flow and when the rain will come. It is unknown at what level of river flow the fish stocks are affected and what fish stocks could be expected for different levels of river water flow. There are a great number of uncertainties in the decision.

f. Various ways to consider the time frame of the project - To make a decision for the San Francisco Bay, it is necessary to consider both the short and long term. It is not known whether the focus should be on restoring the Bay's flushing capacity, so that future generations can enjoy recreating on the Bay, or if the immediate economics of farmers in Southern California is more important. It is not known whether freshwater flows should be replaced so that fish stocks can return in 20 years or 50 years. There are many questions about the appropriate time frame.

g. Various ways to consider the geographic scope of the project - It is not known whether the freshwater resource should be allocated by just considering the Bay's water body and existing wetlands, or if it should also include the entire San Francisco Bay watershed area. It might also include most of northern and southern California, allocating the freshwater among all of the State's residents. An appropriate geographic scope is difficult to determine.

h. Multiple groups that value things differently - There are groups that want to take water out of the tributaries, such as the California farmers that need water for their crops and urban residents that need drinking water. Conversely, there are also those who benefit from keeping freshwater in the tributaries and in the Bay, such as salmon fishermen and those who use the recreational amenities. The Bay affects and is affected by many people in northern and southern California, and the decisions being made attempt to consider the objectives and preferences of many people.

3. Miami Beach re-nourishment

In the early 1970's, Miami's beaches were eroding, resulting in more narrow strips of sand beaches, non-existent in some places. These smaller beaches were less attractive to tourists, so tourist and recreational-based revenues for the community decreased. In addition, the erosion posed physical threats to the beach resorts and other coastal constructions. It was likely that buildings' foundations and other structures would become unstable if action was not taken. (**Dade County** - Beach Erosion Publication)

In 1976, a decision was made to renourish the beaches using a sandbar offshore. The project was successful; tourism picked up as did city revenues in a very short time period. During many hurricanes and storms, the berm from the sand beaches protected coastal construction. To date, no ecological or environmental damage has been noted from the renourishment project. The beach has been renourished every 5 to 10 years, as was predicted in the original plan. (Grant et al, 1994)

Un-predicted, though, the sandbar offshore will soon be depleted, so Miami Beach must now look for another source of sand. They have decided that they do want to continue renourishing the beach, but must decide between using sand from the Caribbean or from the interior of Florida. Sand from the Caribbean is cheaper to transport and fill the beach with, but the grain size is slightly smaller,[12] and it may contain marine or coastal species that do not presently exist in Florida; this may upset the ecological system. Also, the sand is whiter, which is better for recreational purposes, but it may damage the sea turtle nests on Miami Beach, killing the eggs or altering the ratio of female to male offspring. The sand from the interior of Florida is the correct grain size and ecologically compatible, but is more expensive to transport. (Zaneski, 1993) Using Florida's sand will help the economy of central Florida, though.

Complicating factors include:

a. Variables and criteria from multiple disciplines, requiring many fields of expertise - To arrive at the best decision, information about Miami city economics and tourist expenditures is needed, as well as information about the economics of interior Florida. Biological information

[12] It is desirable to have the same grain size for stability.

about Florida sea turtles and about marine life from Caribbean island sand is needed. Information about coastal engineering is needed to determine optimal grain size and predict along shore sand movements. These are just a few of the different disciplines required.

b. Interdependencies of environmental decisions - The decision to renourish the beach not only affects the economy of Miami Beach and the interior part of Florida that would be the source of sand, but it also affects down-shore beaches. It would affect the health of sea turtles and potentially many other forms of sea life. Near shore habitats might be destroyed if sand of a finer grain size was used and increased turbidity in the shallow waters.

c. Criteria that can not accurately be reduced to monetary terms - It is possible to quantity the difference in purchasing and transport cost of the Caribbean versus Floridian sand, but it is more difficult to quantify the difference in tourism and recreational revenue from the two types of sand. It is also difficult to quantify the cost of altering the ecosystem, such as affecting the sea turtle nesting grounds or importing a foreign species that upsets the Miami ecosystem.

d. Uncertainty about the cause and effect - In the original decision, there was no contingency plan for what action to take in the event that the offshore sandbar would be depleted. Even though the project engineers understood the mechanics of shore sand erosion, they did not understand and could not monitor all the erosion patterns of offshore sand well enough to know when the sand bar would be depleted. A new decision must now be made.

In determining how to protect the beach now, there is still uncertainty. It is not known how long the beaches will last if Caribbean sand is used and how long if inland Floridian sand is used. It is not known whether sand from the Caribbean or from inland Florida will be depleted and when. The ecological repercussions of the Caribbean sand is not known. It is also not known whether the Caribbean sand will compact and become cement-like when exposed to the heavier wave forces in Miami. There are still many unknowns in the decision.

e. One time decision with high stakes - It is not known if Caribbean sand is used, will the ecological balance of Miami's beaches be disturbed forever. It is also not known whether the whiter sand will disturb the sea turtle life cycle and destroy the species. If the finer sand is used and compacts, become cement-like due to Miami's heavier wave action, it is possible that the coastal sand movements and wave forces might be altered for tens, even hundreds of years.

f. Various ways to consider the time frame of the project - With most capital or building decisions, a 20 to 50 year time frame is used, so it seems plausible to use a 20-50 year time frame to consider the benefits of beach renourishment in preserving coastal construction. Focusing on the possible introduction of a new species that damage the existing food web and the existing ecosystem, or the possible extinction of the sea turtles species, a longer time frame seems more appropriate. It is not known whether a time frame such as 100 years, 1000 years or infinity be used for the sand renourishment project.

g. Various ways to consider the geographical scope of the project - With the first decision to renourish the beaches in 1976, the geographical scope of the project was drawn around the shore beaches, the neighboring businesses and the offshore sandbar. Now the decision makers must once again decide what is the geographic scope. If only Miami's economy is of concern, then the Caribbean sand is cheaper. If the decision is made thinking of the welfare of all of south Florida, then it may be more likely that the Florida sand would be used, since it helps central Florida's economy. It may be desirable to also include the down-current beaches, since they benefit from Miami Beach renourishment.

f. Multiple groups that value things differently - Coastal hotels, the local citizens, the State government and the Federal government all have different objectives and preferences, yet they all have a say in the decision. Coastal hotels want low priced sand that lasts long and attracts tourists. Local citizens want to enjoy the beaches, minimize current taxes and increase the economic strength of the area. The Federal government wants to reduce the number of imports and wants to promote buying American goods. The State wants to increase the economy of Miami and the economy of inland Florida and wants to protect the wildlife that might be affected by beach nourishment. The preferences of all the groups must be incorporated into the one decision.

4. Chesapeake Bay, Florida Keys, Manatee County and the Exxon Valdez

The other four cases reviewed can be found in Appendix II-A.

C. Focusing the Search for Tools to Overcome the Complicating Factors

To find tools that can overcome these nine complicating factors, the nine should be compared to the different categories of complications found in most decision-making. Decision Theory often categorizes tools based on complicating factors they address, so an understanding of complicating factors found in general decision-making will assist in judging different families of tools. Comparing the nine environmental factors with the general decision-making factors helps reduce the nine to a smaller number, thus focusing the search for helpful tools.

1. Reviewing the categories of complicating factors found in many types of decisions

There are many different categories of decisions and different types of decision-making environments. Many experts in Decision Theory generally recognize the following types of complicating factors in many different decisions.

a. Static vs. Dynamic

Some decision environments are static over time. The factors do not change, nor do the inter-relationships among the factors change. The optimal alternative at time = 0 will also be the best decision at time = 1000.

Conversely, dynamic decisions have variables that change over time. There might be items outside of the decision makers control that will change the value of the variables and their inter-relationships over time. For example, trees grow over time, and more people populate the earth. These two changing variables affect decisions such as the amount of paper products to produce, the amount of wood furniture to construct and the amount of carbon dioxide each country should be allowed to emit. Most environmental decisions have factors with dynamic interdependencies.

b. Linear vs. Nonlinear and Cyclical

Some decisions involve linear inter-relationships. A affects B which affects C and D. B, C and D do not affect A, though. An effect would never in turn also be a cause.[13]

Non-linear relationships among different variables can take on a few forms; the non-linear form most relevant to environmental decisions are cyclical inter-relationships. Cyclical inter-relationships occur when A affects B, B affects C, and C then affects A. An effect can also be a cause. For example, more adults may populate the earth, which may cause more babies to be born, which will probably cause more adults to populate the earth. Cyclical inter-relationships often leads to non-linear, exponential change. Environmental decisions typically have variables with cyclical interdependencies.

[13] Linear also denotes that the relationship between two variables is always first order, i.e., not exponential.

c. Certainty vs. Uncertainty

Some decisions are made where all the relevant information is known with certainty. Every variable and every inter-relationship between each pair of variables is known with certainty. The decision, then, involves manipulating the data so that an optimal alternative is chosen.

Other decisions need to be made under uncertainty. Variables that are not known with certainty can come in two different forms: risk and uncertainty.

> "*Risk* refers to chance in the form of known probabilities, but excludes unquantified uncertainty...*True Uncertainty* refers to formulations in which decision outcomes depend explicitly on events that are not controlled by the decision makers and whose resolutions are known to the agent only after the decision is made. Statistical decision theory typically falls under this heading." (Fishburn, 1970)

A form of true Uncertainty is also when all the relevant factors or all the inter-relationships cannot be identified. Environmental decisions are often made with risk and true uncertainty in the form of statistical distributions and unidentified variables.

d. Repetitive vs. One time decisions

Some decisions are made for situations that happen over and over again. For example, how much raw materials should be used in the production of white paper? The decision maker might choose one alternative, find it's not achieving the optimal solution and then change or fine-tune the decision so a better outcome is achieved in future iterations. Not only is there the chance to learn from mistakes in this situation, but the statistical average of all the outcomes may be an acceptable outcome.

Other decisions are one time decisions with high stakes. The decision maker has only one chance to choose one alternative. The decision cannot be changed. The traditional examples in the literature are lotteries and betting. Some environmental decisions are also one-time, high-stake decisions. For example, during the Exxon Valdez cleanup, it was not known whether dispersants should have been used or not, but the decision makers could not make the decision again in a week, a month or a year. Other examples might be whether or not a dam should be built; whether or not a coral reef should be destroyed to increase the number of sandy beaches for tourism; and whether or not a seawall should be built or a harbor inlet created.

Sometimes environmental decisions can be made over time, and information learned from the first phases of the decision can be applied to decisions later on. Other times, though, one decision must be made. There may be repercussions and results that are not reversible, but these results are uncertain until after the decision is made. These are one-time, high stake decisions.

e. Structured vs. Non-structured

Herbert Simon, the 1978 Nobel laureate in economic science, differentiated between two extreme situations regarding 'structured-ness' of decision problems. At one end of the spectrum are the well-structured problems that are "repetitive and routine, and for which a standard model has been worked out." Simon termed these 'programmed' problems. At the other end of the spectrum are the poorly structured problems, called 'non-programmed' by Simon, "which are novel and non recurrent." (Turban, 1988) Environmental decisions are often non-structured decisions, and this dissertation attempts to provide some structure to these problems.

f. Individual vs. Group decision-making

Individual decision-making is defined as one individual or one group with one unified set of preferences and objectives has the power and responsibility to make the decision. He, she or they are not required to consult or include others in the decision-making process. There is only one set of preferences and objectives guiding the choice.

Group decision-making occurs when there are many people, all with different preferences and objectives, influencing the decision-making process. Group decision-making is usually understood to be the reduction of many different individual preferences to a single alternative, either by conflict or by compromise. (Hwang, 1987) Decision-making in the public domain, including environmental decisions, often affects groups of people instead of isolated individuals. Environmental decisions typically have many people with different preferences, which means that it is Group decision making.

g. Single criterion vs. Multiple criteria

Single criterion decision-making exists when there is only one criterion relevant for evaluating the alternatives. It can also be defined as there being only one criterion of overriding importance, such as profit or loss. Single criterion decision-making approaches and techniques *may* be used to help some 'quasi' multiple-criterion cases. They can be used to identify a subset of alternatives, smaller than the original set of alternatives, that are roughly equivalent, based on the one criterion of overriding importance. The other, secondary considerations, would be brought into play to choose among alternatives that were 'close' on the primary criterion.

True Multi-Criteria Decision Making exists when there is no one criterion of overriding importance. There are multiple criteria of approximately equal importance. The one alternative chosen is judged on many criteria and may need to achieve many objectives simultaneously. (Buffa et al., 1981; Daellenbech et al., 1983) Often, when there are multiple groups with multiple values, the participants can not agree to one criterion of overriding importance, so it is multi-criterion decision-making. Environmental decisions typically must consider multiple criteria of approximately equal importance, because there are multiple objectives.

There are other ways one could separate and define different types of decisions, but these categories help refine the nine complicating factors found in environmental decision-making. Environmental decisions typically:

a) have dynamic interdependencies
b) have cyclical interdependencies
c) are made with both risk and true uncertainty
d) are one-time, high-stake decisions
e) are non structured
f) involve group decision-making
g) have multiple criteria.

2. Reducing the nine Complicating factors into three groups

After reviewing the list of nine complicating factors found in coastal environmental decision-making and the list of factors from decision-making in general, it is possible to reduce the list of nine into three main types: i) inadequate information management, ii) uncertainty and iii) multiple people with multiple values. The other factors might be thought of as subsets of these three main types.

a. Inadequate Information Management

Inadequate Information Management often leads to non-optimal environmental decisions. There is a great need for excellent information management because with environmental decisions there exists:

i) **A great deal of information so that it is difficult to include it all** - When there is a great deal of information, it is difficult for decision makers to consider all parts at once. Humans are good at determining and intuiting the *relationship* among different data; we are not very good, though, at simultaneously juggling many pieces of information at once, considering them all when trying to optimize a decision. (High Performance, iThink Manual, 1992) Many decision makers are moving towards computer aided decision-making to help resolve the problem of managing the information, since the computer is well-suited to keeping track of a large amount of data at once. If humans build the models which follow their reasoning and logic, then the computer can be used as a tool that helps consider all the data at once, does record-keeping and executes human's input and logic.

ii) **Multiple criteria that cannot be accurately reduced to monetary terms** - If all criteria could be reduced to an equivalent dollar value, then all criteria could be compared and combined using their dollar equivalents. It would be easy to incorporate a large amount of information, because there would be a common denominator, and all criteria could be condensed into one number. Unfortunately, with environmental decisions this is not possible, so it is necessary to compare and consolidate many criteria using other means.

iii) **Criteria which are from multiple disciplines, requiring expertise from many areas** - Since expertise from many disciplines must be included, there is a need to explicitly show the interconnections among different disciplines. There is no way an expert from any one field can make the best decision. Since there is a need to combine many fields of expertise from many different disciplines, there is a need to organize the information so that it is obvious how each part fits into the whole. There is also a need to find methods that can make it easy for experts from any one area to understand the whole problem. This would allow many experts to know how their specific knowledge can be utilized and fit into the whole.

iv) **Interdependencies of environmental decisions (cyclical and dynamic)** - There is a special need to organize the information in such a ways as to accommodate cyclical and dynamic interdependencies. Since there is so much information that typically needs to be considered from many different disciplines, and there are often interdependencies among the different variables, then it is necessary to organize the information so that the linkages are obvious. It is not desirable to have long lists of information where there are no linkages.

The information in all complex environmental decisions needs to be well managed so that large amounts of information can be included, multiple criteria with dissimilar scalar units can be compared, information from many disciplines can be understood as part of the whole, and it is easy to see the linkages.

b. Uncertainty

Three of the complicating factors can be described as different forms of uncertainty:

i) **One-time decision with high stakes** - These exist when there is uncertainty in the outcome and one or some of the possible outcomes could be disastrous. If there was no uncertainty in the outcome, then the decision makers would simply avoid the alternatives with disastrous, high-stake outcomes.

ii) **Various ways to consider the time frame of the project** - This means there is uncertainty as to the most appropriate time frame to use when making a decision. The decision makers can not pre-determine if it is appropriate to use a one year time frame or infinite years.

iii) **Various ways to consider the geographical scope of the project** - This means that there is uncertainty as to the most appropriate geographic scope for the decision. For example, it is difficult to determine if the geographic scope should be a polluted bay or the entire watershed.

c. Many people with multiple preferences

This typically exists for two reasons. First, because there are so many decision makers and second, there is no one dominant preference or objective for all decision makers. [14]

These three groups of complicating factors are a simplified version of the nine types. Condensing the list of nine complicating factors into three major groups will help when searching for tools to help make good decisions. Once tools have been found that can overcome these three general complicating factors, then tools will be applied to a case study. All nine complicating factors will again be reviewed to analyze how well each was overcome. This will ensure that the essence and subtleties of all nine are not lost by condensing them into three.

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[14] The existence of one complicating factor often increases the likelihood that another might exists. For example, the larger the geographic scope, the more people the decision affects, which leads back to a higher number of differing preferences and objectives (multiple people with different objectives and who prefer different things). The multiple people with different objectives might also lead to different groups who want to consider different time frames (i.e., the business cycle, a decade, a lifetime or our children's lifetime).

D. CONCLUSIONS -

This chapter discussed the review of seven coastal cases, three which were discussed in the chapter and four in the appendix, to produce the initial list of nine generic complicating factors. Decision Theory was reviewed to understand the types of complicating factors that are found in many decisions. The list of nine factors was then reduced to three, so that a more focused and fruitful search of tools and methods could be conducted. Another requirement for finding tools to improve environmental resource allocation decisions is to have some definition of what denotes a 'good' decision. If a decision makers are trying to improve their decisions, how can they judge if one decision is better than another? The next chapter addresses this question.

Chapter III. Necessary Conditions for making Good Allocation Decisions

This aim of this research is to propose a set of decision-making tools, processes and / or methods that can help to make 'good' allocation decisions for coastal environmental resources. 'Good' is difficult to define, though. This chapter reviews the concept of 'good' outcomes and the disciplines most often used to allocate resources and make decisions: Economics and Decision Theory. These two disciplines are explored to find the required characteristics for making 'good' allocation decisions, to understand the necessary conditions.

A. ATTEMPTING TO REACH THE BEST OUTCOME

One obvious definition of a 'good' decision is one that would produce the 'best' outcome, the results of implementing the chosen alternative. Judging the outcome is relatively easy for 'repetitive, routine and structured' decisions, for which a standard model has been worked out. The decision maker might choose one alternative, find it is not achieving the best outcome, and then change or fine-tune the decision so a better outcome is produced in future iterations. Not only is there the chance to learn from mistakes in repetitive, structured decision making, but the statistical average of all the outcomes may be an acceptable outcome.

As discussed in Chapter II, many environmental decisions are one- time, high stakes decisions; they can not be made repeatedly, allowing the decision maker to learn from mistakes or be satisfied with the outcomes' statistical average.[15] For environmental decisions, the final outcomes occur over many years, decades, centuries or even longer, and at times the decisions are irreversible. This makes it difficult to wait for the final outcome before judging if it is a 'good' environmental decision. Used alone, this definition of a good decision does little to help.

Since it is difficult to use only the final outcome to judge an environmental decision, it would be useful to determine other methods or conditions for achieving 'good' outcomes. First, in cases where the final outcomes do not occur for many years, decision makers often judge alternatives based on predicted outcomes. In Environmental decision making, judging the 'good-ness' of a decision often depends on the predicted outcomes. One must always

[15] In some situations, it may be possible to make the decision in steps, or change the decision, so it may be possible to learn from a previous decision. This is not always the case, though.

beware, though, that there is uncertainty in any predicted outcome. While no prediction may be 100% accurate, the decision makers should feel confident that they have the most accurate predictions possible.

In addition to predicted outcomes, one can also review other decisions to see what processes, elements or necessary conditions often lead to decisions with 'good' outcomes. These processes, elements and conditions can then be adapted and used for making 'good' environmental decisions. Ensuring that the necessary conditions are met, and that good predictions are made, it will be more likely that 'good' environmental decisions with 'good' outcomes are made.

B. Using Economics to Define the Necessary Conditions for 'Good' Allocation Decisions

Economics is concerned chiefly with analyzing the production, distribution and consumption of goods and services. The field of economics, the study of resource allocation decisions, concludes that certain elements should be present.

1. Necessary Conditions for a Good Decision in an efficient Market System

The Market System serves as a method for allocating many resources, both human-made and natural resources, from how many sailboats are manufactured to who owns waterfront property with an ocean view. The necessary conditions for efficiently allocating resources in the Market System are reviewed to indicate what conditions might contribute to an efficient allocation of *non-market* resources.

An efficient Market System works extremely well for maximizing the total utility of both consumers and producers, for the public and the private sectors, *if* all the necessary conditions of an Efficient Market System are met. These are the following:

- i) privately owned input and output factors
- ii) perfect information (no uncertainty)
- iii) producers and consumers who are all price takers (i.e., no monopolies, oligopolies or non-competitive input markets)
- iv) no barriers to entry

(See Pindyck and Rubinfeld, 1995, or any other basic microeconomics texts for more information.)

a. Privately owned input and output factors

The first condition, that there are privately-owned input and output factors, can not be met for many environmental resources. Moreover, this dissertation specifically focuses on coastal environmental resources where there is no private ownership, on common property resources. It can *not be assumed* that the Market System will attain a 'good' allocation decision for these types of resources, and in *actuality* the Market System typically does not achieve efficient allocations for these resources. The other three necessary conditions for an efficient Market System should still be explored, though, to see what could be learned for making 'good' environmental decisions.

b. Perfect information - Well informed stakeholders

The second necessary condition, 'perfect information' means that the decisions must be made by well-informed people or groups. When consumers are making decisions about what they would like to purchase, they need to know exactly what they are obtaining by spending their money, and what they are giving up by not spending that money elsewhere. They need to know the outcome. For example, there is perfect information when a consumer buys an apple instead of an orange, because the consumer knows the outcome. Likewise, when decisions are made about the environment, it is also desirable for the stakeholders to have perfect information. This may not be entirely possible since there is uncertainty in environmental decisions, but there is a need to move towards perfect information, enabling all stakeholders to have the best available information.

Perfect information also means that every decision maker has the same information. Even if *all* the information can not be known, there is still a need for every stakeholder to have the same information concerning the decision. Different decision makers should not possess different pieces of the total available information known, nor should any one decision maker possess more information than any one else. No one should have an information advantage; they should all be equally well-informed. Well-informed stakeholders is a requirement for making good non-market environmental decisions.

c. Preferences of all stakeholders are reflected

The last two necessary conditions for an efficient Market System are:

iii) producers and consumers who are all price takers (no monopolies, oligopolies, etc.)

iv) no barriers to entry.

These necessary conditions exist to insure that every person has some say in what is consumed and what is produced. Consumers 'vote' on how to allocate resources by spending their dollars on certain goods. Producers 'vote' on what to produce depending on the costs of inputs and the revenues from outputs. If there were oligopolies or monopolies, then a few large groups would have great control over some resources or the means to produce some goods. Likewise, if there were barriers to entry, the existing producers would have great control over a desirable good, because new producers could not enter a lucrative market. With monopolies and barriers to entry, a few powerful groups receive an unfair advantage in the allocation process, and the 'votes' of all consumers and producers would not determine the allocation of resources. If these two necessary conditions are not met, then the resources are not allocated efficiently, and society's collective utility is not maximized.

To determine an efficient allocation, the preferences of all producers and consumers should be included and no one person should have too much power. These requirements can be adopted for environmental allocation decisions as well, even though it is not possible for the consumers to vote using dollars. All stakeholders should be involved, and their interests and preferences must be considered. No one group of stakeholders should have too much power; it should be evenly divided among all the owners of the common property resource, among all the stakeholders.

In many environmental decisions, it may not be possible to elicit preferences from every stakeholder. When this is true, representatives from different stakeholder groups should be involved, stating their preferences and sharing the decision-making power. Some governmental agencies and groups have mandated public participation in environmental decision-making, and many private groups also promote public participation, recognizing that good decisions can only be made when the stakeholders are involved.[16] It is important to ask, though, do these stakeholders simply attend meetings, or do they truly contribute to the decision? Are the preferences of the stakeholder groups well represented and balanced appropriately?

> "...the process (of environmental decision making) has become one of direct and active public participation... Although this change has been evolving for some time, little or no serious thought has been given to how best to orchestrate direct participation into efficient and effective consensus building process." (Basta, 1993)

[16]An example of a government group at the federal level is Congress and of a private group, the Sierra Club. Congress mandates public participation through NEPA and the Sierra Club states it as a necessary condition for good environmental decisions.

Reviewing the necessary conditions of an efficient Market System indicates that necessary conditions for good environmental decisions are:

- all stakeholders must be well-informed and
- the preferences of all stakeholders or their representatives must be included.

2. Economic's definition of 'Good' Choice for an individual and society

Defining a few commonly used economic terms will also help to further explore what constitutes a 'good' decision or choice.

a. The definition of Preferences, Utility and a 'Good' Choice for an individual

Referring again to an efficient Market System and privately-owned goods, "Consumer *choice* can be viewed in two related parts:

i) the analysis of the budget line which constrains the choices a person can make and

ii) the study of consumer *preferences*." (Pindyck and Rubinfeld, 1995)

The first item, the concept of 'budget line' differs for private goods versus environmental common property resources. With common property resources, there is no apparent price to pay, so the 'consumers' are not individually constrained by their own budgets or incomes. Because individuals do not have to pay, each might attempt to take all the resources. (Tragedy of the Commons, see Hardin, 1968) Each individual is only constrained by things such as:

i) the total amount of the good that exists,

ii) how much other consumers are using or have used the resource and

iii) how much effort the consumer is willing to expend to obtain the good.

There is *no budget constraint for each individual*, but instead there is a *physical limit of the good* that translates into an *aggregated societal constraint*. Collectively, society can not consume more than what physically exists, although often people try.[17] Since each individual is far less constrained, the notion of a collective societal constraint must be used for common property resources. With these types of environmental decisions, though, often consensus is difficult to reach because not everyone knows or agrees on the physical constraints of the system.

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[17] It is important to note that there is a difference between what physically exists in the system in the short term, and the physical limits for long term existence of the resources, or sustainable use.

The second item relevant for Consumer Choice is 'preferences.' Consumer preferences can be represented as either an Indifference Curve, used when there are only two goods, or as a Utility Function, used to rank and order a consumer's preferences involving three or more goods.[18] "Utility, the level of satisfaction that a person gets from consuming a good or undertaking an activity, ... is most often used to summarize the preference ranking of a collection of goods." (Pindyck and Rubinfeld, 1995) For example, if buying one mango makes a person happier than purchasing three bananas, then the mango gives the person more utility.

Different consumers often have different Indifference Curves or Utility Functions for the same group of goods. One person may prefer three oranges, while another would prefer one mango. Any one person may even change his or her preferences for the same goods at different times of the year. For example, many people would prefer iced tea rather than hot tea during the summer, but the decision would be reversed in the winter. Likewise, for environmental amenities, each stakeholder prefers a different combination of goods. There is no one true, universal preference or 'value' for a good.

Each individual must combine both preferences and constraints to determine his or her best choice. In the Market System, an individual consumer's 'best' decision exists when:

i) his or her satisfaction is maximized. The maximizing choice must give the consumer the most preferred combination of goods and services.

ii) the choice accounts for the limited budget available.

(Pindyck and Rubinfeld, 1995) With environmental goods, it is not possible to use individual constraints to determine the best choice, since there is no budget constraint for each individual. As discussed above, the aggregated societal constraint, the physical limit of the good, must be used instead. This requires that to determine the best choice, the individual preferences must be aggregated as well.

b. Societal value of a resource requires aggregating individuals' Preferences and Constraints after the individuals are well informed

To determine the *societal* value for resources, individuals' preferences and the constraints must be aggregated, since they vary among individuals and goods. When all the conditions of the Market System are met, the *aggregate* of all individual choices (consumers and producers) is represented by the market price of a good. Each individual's preferences and all constraints

[18] A Utility Function is obtained by attaching numbers to each group or market basket of goods. If Market Basket A is preferred to Market Basket B, then the number attached to A will be higher than B. If a utility is assigned to each possible outcome and the expected utility of each alternative is calculated, then the best course of action for any decision maker is the alternative with the highest expected utility.

are combined to make the *best individual choices*, which in turn makes society's collective *best resource allocation decisions.* The Market System acts to:

i) combine individual budget constraints and resource constraints, and

ii) combine preferences of many individuals.

An efficient allocation also depends on the order in which these two conditions are met. In the Market System, the consumers have perfect information, *then* they make decisions about what goods they would like to buy. One would not expect an efficient allocation of resources to be made if the consumers' had to choose, and *then* became well informed. Likewise, when the conditions of an efficient Market are not met, and / or there is no market price for a good,[19] there is still a need to make good resource allocation decisions.

In environmental decision making, *the stakeholders need to be well-informed before their preferences are elicited.* Often, decisions are made which incorporate the preferences of stakeholders, but the stakeholders are not informed about the constraints of the system. Many environmental economists recognize the need for stakeholders to be well informed, in Stated Preferences Methods such as Contingent Valuation, but it is difficult to achieve; there is much uncertainty, and it is difficult to transfer the best available information to the stakeholders. Good decisions can not be achieved, though, unless the stakeholders have the opportunity to become well-informed about the physical and economic aspects of the system, about the constraints of the system, before their preferences are elicited. Without this, the decision can not be an accurate representation of society's collective values.

Reviewing the basic microeconomics of Individual Choice, Preferences and Utility, and translating this to decisions made outside the Market System, indicates the requirements for making a good allocation decision for environmental resources. To ensure good allocations in both the *market system* and for *environmental* decisions:

i) the constraints of the physical system have to be considered *and then*

ii) the consumers' preferences must be elicited and incorporated.

When this happens, it is likely that a good choice has been made. It is likely that there has been a good resource allocation decision, that the decision reflects society's collective values.

[19] When the Market System is used, the price represents an 'aggregate' or collective social value, but it is important to remember that the 'value' of a good is higher for some individuals and lower for others. When an individual's preference or value for a good is higher than the price paid, there is consumer surplus. Likewise, when a producer can produce a good for less than the price obtained in the market place, there is production surplus. Since total societal welfare equals the consumer surplus plus the producer surplus, total welfare is not represented solely by the market price. Marginal Welfare = Price * Quantity, but not the Total Welfare, or the total societal value

3. Pareto Admissible - denotes efficient allocation has been reached

Pareto Admissible is a widely accepted definition of a good decision outcome. Pareto Admissibility is defined as "when there exists no feasible alternative that some interested parties regard as superior and none regard as inferior." (Dorfman and Jacoby, 1969) This means that if there is any alternative that can improve the decision, that makes at least one person better off without making others worse off, it should always be pursued. It is only when there exist *no* alternatives that make at least one person better off without making others worse off that Pareto Admissible is achieved.

'Pareto Admissible' is similar to 'Pareto Optimal,'[20] but 'Pareto Admissible' is used for decisions made outside the Market System, and when there are multiple decision makers and multiple criteria that can not be reduced to one common scalar. The decision, therefore, can not be maximized on just one scalar measure, or optimized in just one dimension. Instead of there being just one good alternative, with Pareto Admissible there may be a set of good alternatives.[21] Pareto Admissible alternatives are the *set* of decisions that reflect a group's collective values when there are multiple objectives and criteria. (See also Goicoechea, 1982; **Zoints, 1982** and any texts on resource allocation outside the Market System.)

The question remains, though, how does one reach or obtain a 'Pareto Admissible' decision. To better understand this, one can review and dissect the definition of 'Pareto Admissible.' First, all 'interested parties' need to have some input as to what they 'regard as superior.' The decision can not be made by just one person or a few people determining what is superior or inferior. The preferences of all interested parties, of all the stakeholders need be elicited and included to determine which alternatives make some people better off, and which make them worse off.

Second, if the stakeholders know all the issues and tradeoffs, then it is likely they can identify and create many good alternatives. The more alternatives identified that focus on the real issues and problems, the more likely Pareto Admissible alternatives are formulated and are not overlooked. The decision makers must feel assured that 'there is no feasible alternative'

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[20] Allocation decisions in the Market System are said to be Pareto Optimal if no arrangement of the allocation could benefit some people without hurting at least one other person. Allocations that do *not* satisfy this definition are *sub-optimal.*

[21] Another commonly used definition for Pareto Admissible is the Non-dominated solution. This is defined as "a subset of the feasible region. The main characteristic of the non-dominated set of solutions is that for each solution outside the set, but still within the feasible region, there is a non dominated solution for which all objective functions are unchanged or improved, and at least one which is strictly improved." (Goicoechea, 1982)

that is better, so they must feel confident that they have explored and considered all of the most relevant alternatives. The stakeholders must also know enough about the predicted outcomes of their choice to judge what is a 'superior' alternative. In order to formulate and judge, the stakeholders must be well-informed.

Third, Pareto Admissible denotes that both the alternative and the decision making process are flexible and adaptable. Pareto Admissible is reached only "when there exists no feasible alternative" that is superior for all stakeholders. If at any time during the decision making process or after an alternative is chosen, a different alternative 'exists' that is closer to Pareto Admissible, then it should be pursued. If the decision becomes outdated due to changes in the physical or economic system, for instance, then a different alternative may become 'superior.' If a new, more 'Pareto Admissible' alternative is identified after an initial alternative is chosen, then it may need to be changed; Pareto Admissibility denotes that no opportunities are missed. There must be the ability to amend any chosen alternative, altering it if necessary so that the 'superior' alternative can be achieved. There is a need for the chosen alternative and the decision making process to be somewhat flexible and adaptable, so that if an alternative is closer to Pareto Admissible, it can be adopted.

Reviewing the definition of Pareto Admissible, indicates the three main necessary conditions:

i) stakeholders preferences must be elicited and included in the chosen alternative and

ii) stakeholders are well informed so that choice formulation is thorough and stakeholders can judge the predicted outcomes.

iii) decision is adaptable and flexible

4. Summary: Three Necessary Conditions for making a Good Decision

This section has reviewed some basic economics to help understand how to make a 'good' decision, that is what constitutes and what are the necessary conditions for 'good' decisions. First, the Market System shows that there is a need for perfect information and a need for all stakeholders to be included, so that no one group has too much power. Second, using the Market System's definition of an individual's best choice, the constraints must be incorporated into the decision, and the utility derived from the chosen alternative must be 'maximized.' Third, the definition of Pareto Admissible indicates that the stakeholders need to be well informed to identify many good alternatives. Pareto Admissible indicates that to determine who is made better off and who is made worse off, the stakeholders' preferences need to be elicited. It also denotes that alternatives that move towards Pareto Admissible should always be pursued, which requires the decision to be flexible and adaptable.

These three definitions are similar. There is a need for all stakeholders to possess the best available information, so they can create good alternative solutions and help determine the physical constraints of the system.

i) The stakeholders must be well-informed:

- The most relevant information must be elicited
- The best available information must be transferred to the stakeholders.

The decision-making process then needs to elicit, collect and combine the stakeholders' preferences so that the alternatives can be judged according to a 'superior' societal utility, and the decision makers can identify who will be made better or worse off.

ii) Stakeholders preferences must be included in the decision:

- Stakeholders' preferences must be elicited
- Stakeholders' preferences must be combined to make the decision.

Finally, the decision should not be rigid and should be changed if a better decision is found.

iii) The decision making process and chosen alternative should enable flexibility and adaptability.

The first two necessary conditions must also happen in a prescribed order; the decision makers must be well-informed before the final preferences are elicited. If all three necessary conditions are met, if the stakeholders are all well-informed *then* their preferences are included, and the decision is flexible, then it is likely that the decisions made will accurately reflect society's collective values of the resources and will not be outdated.

C. Using Decision Theory to define the Steps of Good Decision-Making

Reviewing Decision Theory, one also learns that it is more likely that a good decision will be reached if one follows the recommended steps of a good decision process. Decision-making:

> "is a process rather than an act. Although it involves choices from the set of feasible alternatives, decision-making is also concerned with the *generation of alternatives*. Decision-making is a dynamic process with all its components changing and evolving during its course: alternatives are added and removed, the *criteria* for their evaluation as well as the relative importance of criteria are in a dynamic flux, the interpretation of the outcomes vary, human values and preferences are reassessed." (Goicoechea, 1982)

Many experts agree that there are multiple steps in a good decision process, although they may differ somewhat on what each step is called. (Keeney and Raiffa, 1976; Goicoechea 1982;

Hwang et al, 1987; Saaty 1990; Turban 1988; etc.) In general, the problem solving steps / sequential procedure of decision-making include:

i) Define problem, overall goal and objectives

ii) Formulate criteria

iii) Formulate choices

iv) Complete Sensitivity analysis

v) Choose options

vi) Implement

Different steps should have greater or less emphasis, depending on the problem type and the decision environment. To begin with, it will be assumed that all steps are equally important for environmental decisions.

1. Define Problem, Overall Goal and any Objectives

This step means formally thinking about and agreeing to what is the problem and the overall goal. It can include i) searching and scanning for problem symptoms, ii) identifying the problem, iii) exploring the reasons the problem exists, and iv) defining the groups or organization's objectives. (Turban, 1988) To make good decisions, there should be no misunderstandings about what exactly is the problem and the overall goal. Good decision-making requires determining very specifically what is desired in the problem solution and everyone must agree to it; it is the overall goal. With some decisions, there may also be multiple objectives that are desired for the one decision; if this is the case, then these multiple objectives also need to be identified under the overall goal. These initial preferences and objectives should be elicited and recorded, because often if stakeholders do not feel that their opinion and perspective have been recognized, they are not open to learning and exploring new ideas.

2. Formulate Criteria

"This is the task of recognizing the aspects of the system that will be affected by the chosen alternative." (Buffa and Dyer, 1981) It is identifying the criteria on which to base the decision. Buffa and Dyer comment that it may be the most difficult and the most important task in the analysis.

3. Formulate Choices

This is the method of generating, searching and pooling ideas for a solution. It can be done by brainstorming, by methodically considering all viable alternatives, or by a combination of different techniques. Choice formulation may be either defining the boundaries on a range of possible solutions, or it may be developing and recording discrete alternatives.

4. Complete Sensitivity Analysis

This step requires predicting the outcomes of different alternatives, then determining how much the outcome may change if any inputs are altered. "Sensitivity analysis attempts to help managers when they are not certain about the accuracy or relative importance of information, or when they want to know the impact of changes in the (variables)." (Turban, 1988) Sensitivity analysis is especially helpful when there is uncertainty, to determine how much the predicted outcome changes if the value of a variable changes. It can also be useful when there is certainty, to determine how much a particular variable can vary without changing the optimal solution

5. Choose an Option

This step includes using various methods and criteria to disqualify alternatives and to review the qualified alternatives. It is the act of making a single recommendation.

6. Implement

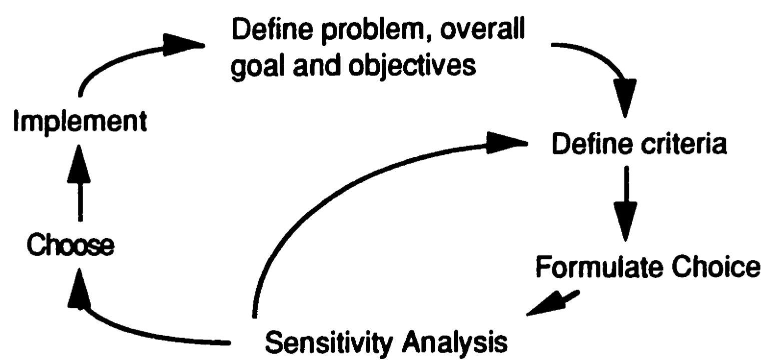
This is the method of acting on a chosen alternative, putting it into place. It requires executing, administering and controlling the chosen alternative. Poor implementation can negate the benefits of having chosen a good alternative.

If these recommended steps of good decision-making are followed, then it is more likely that a good decision will be reached and a good outcome will occur. (See Appendix III-A for additional characteristics of a good decision outcome.) It is important to understand that these six steps are not necessarily linear, though. Decision making is a process and the steps are best completed in an iterative fashion.

> "To attempt any formal analysis of a complex decision problem requires an *articulation* of the decision maker's *objectives* and an identification of *attributes* useful for indicating the extent that these objectives are achieved. Unfortunately, these objectives and attributes are not simply handed to us in an envelope at the beginning of an analysis. The intertwined *processes* of articulating objectives and identifying attributes are basically creative in nature." (Buffa and Dyer, 1981)

Often the second, third and fourth steps, 'Formulate Criteria,' 'Formulate Choices' and 'Sensitivity Analysis,' are best completed if they are repeated in an iterative fashion being revisited many times. By defining the criteria, it helps the decision makers brainstorm new, perhaps better alternatives to meet the criteria. After completing 'Sensitivity Analysis' one should return to 'Formulating Choices' to include what was learned and to create new, better alternatives. Likewise, formulating new alternatives may enlighten the decision makers about important criteria or help them refine and develop existing criteria. In general, though, it is best if all six steps are viewed as an iterative decision making process.

Figure III - A: The commonly recommended steps for good decision making



D. A WORKING DEFINITION OF A 'GOOD' ALLOCATION DECISION: COMBINING THE SIX STEPS WITH TWO REQUIREMENTS

The criteria that will be used to determine what is a 'good' environmental decision will be based on the summary from basic Economics and from Decision Theory. The three necessary conditions need to be somewhat meshed with and 'built into' the recommended steps to better ensure that they are met. First, stakeholders need to be involved throughout the process, not only in Step 5 when the options are being chosen; they need to be involved in the first four steps as well, when the decision's parameters are being defined. This gives stakeholders the ability to direct and steer the decision-making process, to ensure that it focuses on their concerns. It is best to define the stakeholders' roles and determine their representatives from the beginning, before Problem, Goal and Objective Definition.

Second, defining the stakeholders at the beginning, enabling them to participate *throughout* the decision-making process, makes it easier for the stakeholders to become well-informed. As stated earlier, *the stakeholders need to be well-informed before the final choice is made*, so that the preferences include the constraints of the system. Of course, the entire decision making process is often a process of inform the stakeholders and vice versa, the decision making process benefits from having well-informed participants. This second requirement is used as a check to ensure that the stakeholders have become as well-informed as reasonably possible *before making the choice*. The third requirement, flexible and adaptable decisions, might be achievable under a wide variation of situation, so rather than prescribe a situation in the beginning, this requirement will be checked for at the end of the decision making process.

To ensure that two of the necessary conditions are met during the decision-making process, they have been added to the recommended steps of good decision-making as requirements:

Requirement 1) Ensure all stakeholders are represented

Step 1) Define problem, overall goal and objectives

Step 2) Formulate criteria

Step 3) Formulate choices

Step 4) Sensitivity Analysis

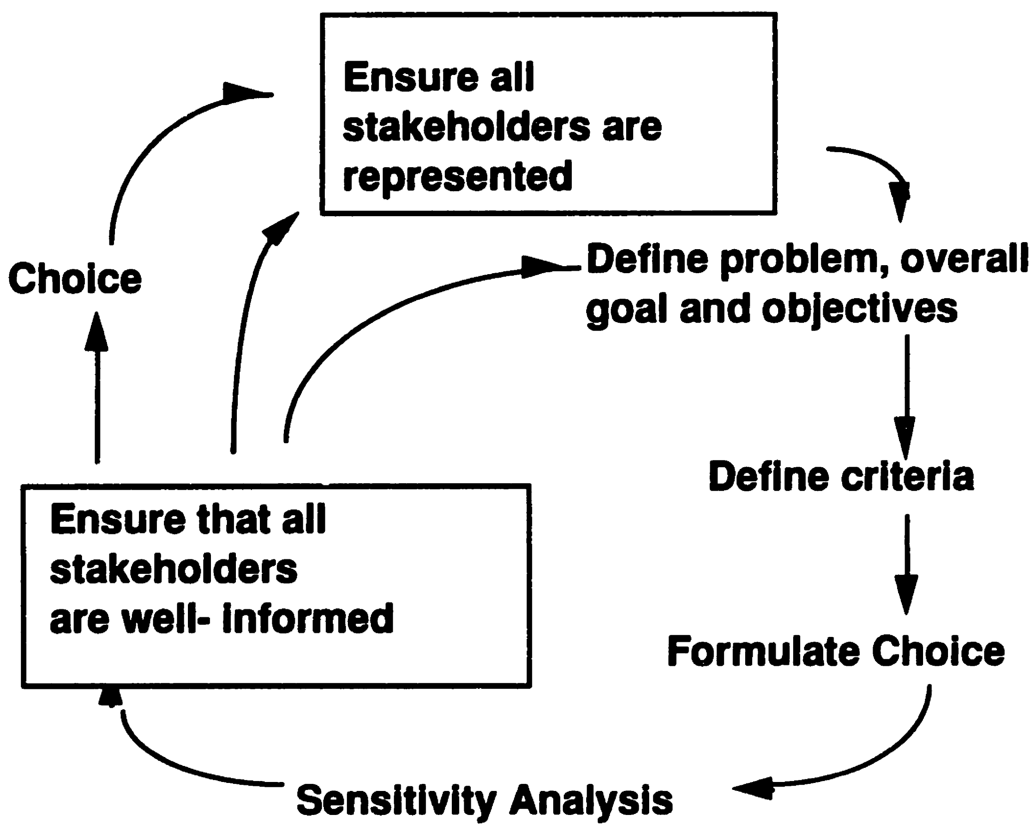
Requirement 2) Ensure stakeholders are well informed

Step 5) Choice, and

Step 6) Implementation

Again, this is best completed in many iterative steps.

Figure III - B: The recommended steps and two requirements for good decision making



1. Tools that overcome the three groups of complicating factors will enable the three necessary conditions

Consensus is often difficult to reach in environmental decisions, because i) there may be great differences in individual preferences, and methods for aggregating different preferences may not be available and ii) ensuring that the stakeholders are well-informed is not easy. The three necessary conditions can be better met if tools are sought that can overcome the complicating factors from Chapter II. There is a need to look for tools that can help overcome the three complicating factors, because they impede the necessary conditions:

Necessary Condition	is inhibited by	**Complicating Factor**
a) Well informed stakeholders:		i) Inadequate Information Management ii) Uncertainty
b) Stakeholders' preferences included		i) Many people with multiple preferences
c) Flexible and adaptable decisions		i) Inadequate Information Management ii) Many people with multiple preferences

First, the stakeholders can be better informed if tools are chosen that can better i) manage the information and ii) incorporate uncertainty. If all the known information about a subject is collected and then presented in a form that makes it easy to understand, then stakeholders will be more knowledgeable about the issue. There is a need to manage and present the information in such as way that it is easy to elicit a great deal of information, then transfer it to all the stakeholders. The tools also need to incorporate and allow for uncertainty; information with uncertainty needs to be included, and ideally, analyzed. If tools are used that can enable this, then the stakeholders will be well-informed, using the best available information.

Second, for the stakeholders' preferences to be included, tools should be chosen that allow for i) many people with multiple preferences. If a tool can elicit stakeholders' preferences, then combine multiple values and utilities, the result with be that the preferences from many stakeholders can be included. If the tools do not elicit preferences, they should at least enable the stakeholders to become well-informed, and they should allow for many people to use them at the same time.

Third, flexible and adaptable decisions will be more likely if the tools allow for i) good Information Management, and ii) ways to manage the multiple preferences from the many stakeholders. With better information management, it is more likely that the best available knowledge will be accessible and usable for judging any new information if the situation changes or a new alternative that might be suggested. Also, if tools are chosen that can elicit stakeholders' preferences, then combine their multiple values and utilities, then it is easier to assess whether a new alternative better meets the stakeholders' collective values.

Overall, the focus will be on finding tools that can overcome the three types of complicating factors, so that the three necessary conditions of good decision making can be met.

2. The recommended Steps of Good Decision-making should be followed when using the Tools

If a tool or tools are found that can overcome these three complicating factors, then the tool(s) should be used in a manner that follows the recommended steps of good decision-making, allowing for repetition and iteration when necessary. Following the recommended steps will ensure that each step is met. Using tools that can overcome the complicating factors, and following the recommended steps of good decision making will increase the probability that a decision will be made which meets the three necessary conditions.

3. A good decision is a necessary, but not sufficient condition for a good outcome

It is important to recognize that choosing a good alternative or making a good environmental decision is a necessary, but not sufficient condition for a good environmental outcome. First, because the outcome can not be known with certainty during the decision making process, it is not possible for the stakeholders to place their preferences on the outcome. To make many coastal environmental decisions, the stakeholders must place their preferences on predicted outcomes of the future result, so it is necessary to have *accurate* predictions. Everyone must agree that they have seen the best available predictions of the probable outcome for a good decision to be made. This is a more specific form of 'the stakeholders must be well informed.'

Second, for environmental decisions that are made within a political process, the political process can affect the decision's outcome regardless of the alternative chosen. (See Chapter I) The decision-making process is a subset of the political process in which coastal environmental decisions occur. The analysis of this dissertation recognizes that coastal environmental decisions happen within the political process, but this dissertation does not focus on altering the enveloping political process. It focuses on the decision-making process within the political process in order to formulate a good alternative, and focuses on the mechanics of how to find and choose the best alternative in environmental decisions.

Choosing the best alternative is a necessary, but not sufficient condition for a better outcome, though, since outcome also depends on implementation.[22] The last step of good decision-making, implementation, depends more closely and is more intertwined with the enveloping political process. This is not the focus of this work, though, so implementation does not have the same amount of attention placed on it as the other steps.

This dissertation attempts to assist the political process by formulating the chosen option in such a way that it is then easier for a government agency to know their constituents wishes, to know society's collective values. This dissertation also attempts to ensure that the decision is well-documented, so that there is less risk that the political process will divert from the stakeholders' collective values. The results of this dissertation should enable the results of the decision-making process to flow more smoothly into the political process. Altering the political process is not attempted, though.

E. CONCLUSIONS

To determine the necessary conditions of a good decision, basic microeconomics were reviewed, such as the conditions for an efficient Market System, and the definitions of Individual Choice, Preferences, Utility and Pareto Admissible. Three necessary conditions for making a good decision are i) well-informed stakeholders, ii) many stakeholders' preferences elicited and iii) a flexible and adaptable decision. Reviewing Decision Theory, one can also use the recommended steps of good decision-making. Adding two of the necessary conditions as requirements within the six recommended steps will enable a better decision to be made, a better alternative to be chosen. It will be used as the working definition for a good environmental decision.

Focus will be placed on finding tools that can overcome the three complicating factors. If the tool(s) are used within the recommended steps of good decision-making, it is more likely that:

i) the complicating factors will be overcome, so that

ii) the necessary conditions for good decision-making will be met, which enable

iii) a good environmental decision to be made. (See Figure III- B)

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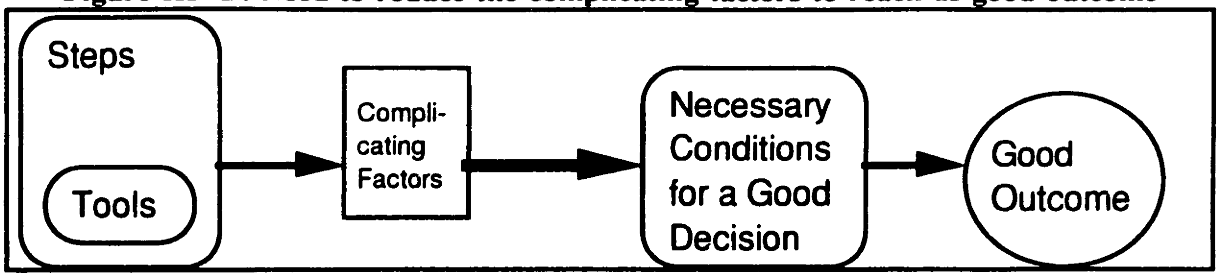
[22] For environmental decisions, it is difficult to define what constitutes a better outcome, because the outcomes may take many years to determine. Refer to **Appendix III-A for more on** the properties of good outcomes.

Figure III -B: Need to reduce the complicating factors to reach as good outcome



The next chapter begins to review some of the tools and methods often used for allocating environmental resource decisions. They will be assessed to see how well they can help overcome the complicating factors of environmental decisions.

Chapter IV. Economic and other commonly-used methods for allocating Environmental Resources - advantages and disadvantages

This chapter explores some of the economic and other commonly-used methods for making environmental decisions. When the Market System is used, environmental externalities exist, therefore the Market System does not achieve efficient allocations for many environmental amenities. As a result, other regulatory and dollar-based methods have often been used. This chapter reviews the advantages and disadvantages of many of these methods, and explains why these methods alone often do not suffice. Typically, they are best used in conjunction with other more process-oriented tools.

A. The Market System

The Market System works extremely well for maximizing the total welfare of both consumers and producers *if* all the necessary conditions for a well-functioning System are met. (See Chapter III) These necessary conditions are not met when determining how to allocate many environmental resources, because there exists:

i) Input and output factors that are not privately owned, such as common property resources, instead of privately owned input and output factors

ii) Scientific information that evolves continuously and includes a great deal of uncertainty, instead of perfect information

iii) No prices, instead of all producers and consumers which are price takers.

When Environmental Externalities do exist, they cause non-optimal allocation of many environmental resources, inefficient in the present and with concern to the future. (See Pindyck and Rubinfeld 1995, Nicholson 1985, Clark 1990, Tietenberg 1992) For these reasons there are many environmental resources that should *not* be allocated using the Market System.

There are numerous examples of when the Market System has not worked well for allocating coastal resources. Just one example of this is the Florida Everglades and Florida Bay. The clean water from the Everglades has been diverted for agricultural use, urban water consumption and flood protection. These three have left approximately one-fifth to one-tenth of the original water flow entering the Florida Bay at its mouth, with flood control alone wasting over half of the freshwater in the southern Florida watershed, diverting it into the ocean. (Ogden, Everglades National Park, 1994). Both the nutrient and salinity levels in the Bay's water have increased, not only because there is less fresh water to dilute the existing nutrients and salts, but because there are also farmers, animals and other upstream users dumping more nutrients and toxins into the reduced flow of fresh water. This has caused destruction of marine life in Florida Bay, destroying the fishing industry and negatively impacting the tourism industry. Allocation of the environmental resource, freshwater, was on a first come, first serve basis, with users upstream taking *first* with no concern for downstream users. The overall utility of the natural freshwater resource was not maximized; the Market System failed to efficiently allocate the resource. There are many other examples of poorly allocated environmental resources, public goods and common property resources that suffer from the 'Tragedy of the Commons' (Hardin, 1968), some of which are discussed in this dissertation.

B. Regulatory and Judicial Methods

Often, when the Market fails and enough people recognize the failure, the government intervenes in an effort to allocate resources more efficiently. Government's intervention can sometimes increase the total welfare of consumers and producers when an environmental resource is being ignored or mis-allocated. Regulations are often created and laws enforced in an effort to allocate the resources more equitably, to improve the overall welfare of society. It is not a given, though, that the government will find *the efficient* allocation of environmental resources, since this is extremely difficult to achieve; it is also not a given that the government intervention will provide a better allocation than the Market System did. There are, though, numerous methods that governments use to attempt *better* allocation of the resources.

1. Command and Control techniques

There are two common forms of Command and Control techniques. The first is an 'emission standard' that is set by law and to which industries must comply; for example, the legislature might dictate that no organization can emit more than a certain level of a pollutant. Another type of Command and Control is a technology standard,' when companies are required to use a certain type of equipment or a certain technology, such as double-hulled oil tankers or certain type of air pollution scrubbers. Emission standards or technology standards are typically backed up by a sufficiently large jail sentences or fines to provide the incentive for companies and organizations to comply with the mandate.

Command and control does not necessarily achieve efficient allocations of resources. The government can not always determine the total amount of pollution that should be emitted or the best technology to be used for all situations, nor can it monitor large numbers of organizations. A non-efficient level of pollution might exist if i) the fine is too low and too many pollutants are released or ii) the fine is too high and industry is over-burdened or iii) if the government can not enforce its regulations reliably. Even if the government is correct in estimating the overall total pollutant that is efficient, it is rare that the most cost-effective method for reducing pollution would entail every organization taking the same action. Also, these methods do not provide incentives for organizations to improve past what is required by the regulations ,to emit less pollution or invent better technologies. Finally, there are transaction costs; Command and Control requires that government officials examine the firms or individuals to ensure that they are within compliance, the costs of which can be expensive.

2. Financial incentives - emission fees, tradable permits, and taxes

There are regulatory mechanisms designed to use the same financial incentives as the Market System, and which attempt to extend pricing schemes so that Markets can work where they wouldn't otherwise. These mechanisms encourage industries and individuals to treat common property and public goods more like privately owned resources, attempting to incorporate Environmental Externalities into the Market structure, to internalize the externalities. This may be successful and appropriate when only one or two of the necessary conditions for a successful market outcome have been violated, or when *most* of the inputs and outputs are privately owned. (See Appendix I) The following is a list of the different methods, with their potential uses and various pros and cons.

a. Pollution charges (emission or ambient fees, deposit-refund systems, etc.)

Pollution Charges and payments take various forms; the commonalty among the methods is that the charge or payment is 'per unit of pollution.' One form of a pollution charge is an Emission Fee, which is a 'dollar per unit of pollution' charge to a firm for emitting a pollutant greater than a fixed level. An example would be when firms are charged $1.00 for every part per million of toxins they discharge to a river. Another example is the use of 'Pay-as-you-throw' garbage fees, when residents are charged $1.00 for every bag of garbage they put on the curbside. A form of a pollution payment is a Deposit Refund System, when consumers are paid for not polluting. An example might be that people receive money for returning aluminum cans, car batteries or car oil to the proper disposal sites.

There are problems with these techniques. With 'Pay-as-you-throw' charges, people may dispose of their garbage along the roadside or in public trash cans to avoid being charged. With a Deposit Refund System, people may start stealing car batteries to make money. Another problem is that these technique do not always lead to optimum levels of pollutants; it is not known what 'the efficient level' of garbage disposal is, and the correct fee to promote this level is not known. When the economy grows, new firms will enter the market and existing firms will produce more desirable goods and pollutants at the fixed pollution charges, so the total amount of pollutants emitted will grow. Also, the fixed charges must be adjusted for inflation, or the pollution charges will become relatively cheaper and more pollution will occur. There are typically high transaction costs with these methods, since governments must either measure the amount of pollutants produced, to determine the appropriate fee, or they require a collection site be set up for Deposit-Refund Systems. (See Appendix IV-A for examples.)

b. Tradable permits (Offsetting, Bubble policy, Netting, Banking)

Tradable permits occur in markets where the government assigns each firm a certain level of pollution emissions, then the various firms 'trade' their pollution rights. Firm A might buy a piece of the permit that Firm B was granted, if it is cheaper for Firm A to buy pollution permits rather than reduce its own emissions. For instance, if Firm B can reduce its phosphorous emissions for the cost of $0.10 per mg., but it costs Firm A $1.00 per mg. to reduce its phosphorous emissions, then Firm A will buy emission permits from Firm B. There will be less phosphorous in the environment at an overall *lower* cost to society. Trading permits can happen in a variety of settings such as Offsetting, Bubble Policy and Banking. (See Appendix IV-A for a more detailed discussion.)

There are problems with these techniques. If the government is to give away permits to pollute, it is not known what total quantity of pollution the government should initially permit. Again, a non-efficient level of pollution may exist if the government does not initially set the 'right' level of allowable pollution. It is also not known which firms are to receive these permits and in what quantities. It is not known what happens when new firms want to enter a market; are new permits issued and the total amount of acceptable pollution increased or must new firms purchase permits from existing firms? The permit may act as a barrier to entry. These methods do not necessarily achieve efficient allocations.

c. Market barrier reductions

Sometimes the best way to provide Market based incentives is simply to allow new markets to develop. An example is in southern California, where farmers are allowed to sell the excess of their fresh water supply to the city of Los Angeles. (See Appendix IV-A for more details). Another example is in the preservation of wetland areas. Society could give wetland owners a payment or reduce their taxes for maintaining their land as wetlands, so that wetland owners were 'paid' for the benefits wetlands provide to society, such as water filters and flood control. This would dissuade wetland owners from converting their land to other uses. These are applicable in only a small number of environmental resources, and the reduction of barriers may be complicated or impossible for political reasons.

d. Government subsidy elimination

Removing government subsidies can sometimes allow more efficient use of the Market System and enable better allocations of some environmental resources. An example where this might be helpful is in the timber industry. Timber, therefore virgin paper, would cost more if subsidies were removed. This would increase the amount of recycled paper used in paper products, decrease the amount of paper waste, and decrease the amount of virgin wood cut. Like market barrier reductions, though, this is only applicable with a few environmental resources, and the removal of a subsidy may be complicated for many reasons. (Stavins, 1993. See Appendix IV-A and Tietenberg, 1992 for more examples.)

These four general types of financial incentives are best used in different environmental allocation situations when there is an attempt to halt some type of environmental damage. Environmental economists, policy makers and others struggle with the question of "Which are better: Command and Control techniques or Market based incentives?" There is *no* simple, categorical best answer; one must use a case-by-case approach to determine which is best, or if both or neither are appropriate for the situation. The criteria to judge are:

- the ability to determine in detail the source of damage and who is responsible;
- the cost effectiveness of administering the approach;
- the steepness of the damage function;
- the degree of uncertainty.

Financial incentives may often be better than regulations, but they are not perfect and not applicable in all situations. These techniques may not be adequate when *most* of the conditions for a successful market economy do not exist.

3. Reporting mandates and Public pressure

Reporting Mandates are regulations that require organizations to submit reports about pollution emission levels and typically require that these reports be made public. For example, there are regulations for various toxic chemicals that require all users to document what quantity of the toxins are used and how they are discarded. The documentation can then be reviewed by the public, then the public can put pressure on a firm to reduce its use.

Typically, there are fines for not reporting and for exceeding the permitted amounts of toxins. Not only do the fines provide incentives such as with Command and Control techniques, but the public's demands also works as a strong incentive to change behavior., such as finding substitute products or procedures, to reduce the use of the toxins. Public pressure can also provide incentives for behavior change in situations where there are no reporting mandates. Drawback are that there is no guarantee that the Pareto Admissible level of pollution will be achieved and transaction costs may be high for companies that use the toxins, since preparing detailed documents are often time-consuming and expensive.

4. Judicial action such as Property rules and Liability laws

The court system can overcome some environmental externalities and move towards efficient allocations of environmental resources by imposing either Property Rules or Liability Laws. First, Property Rules specify the initial allocation of the entitlement. For example, an entitlement might be the right for Keys' citizens to demand that a minimum freshwater flow enter the Bay, instead of farmers taking the freshwater from the watershed. By applying property rules, the court decides whose right is pre-eminent and places an injunction against violating that right. The injunction provides a monetary incentive to the party whose right is *not* pre-eminent, so that they will not use all of the resource. (Note, in the absence of a court decision or any government action, entitlement is 'allocated' by the Market System to the party who can most easily seize ownership. The Florida Keys problems occurred, because the upstream farmers and municipal water authorities could more easily seize ownership.)

Liability laws can also serve to overcome Market System externalities. Liability laws are typically formulated and in place before any damage or mis-allocation occurs; if damage occurs, the laws require that the responsible parties pay a monetary award to the injured party corresponding to the amount of damage inflicted. The knowledge that this monetary award would need to be paid acts as an incentive to prevent damage. For example, there is a liability law for spilt oil, it provides incentives for oil companies to spend money on spill prevention. If a spill does occur, such as with the Exxon Valdez, the liability laws are used to determine the company's compensation to those who were affected by the damage, such as fishermen, tour boat guides, residents, etc. These approaches have their limitations, since they rely on a case-by-case determination, often rely on damage estimates that are carried out subjectively and have transaction costs. (See Tietenberg, 1992 for more on Judicial Methods)

5. Which Complicating Factors are overcome by the Regulatory and Judicial methods

These four types of corrective mechanisms, i) Command and Control, ii) Financial Incentives, iii)Reporting Mandates, and iv) Judicial Actions do not *ensure* that an efficient allocation of resources will be achieved.[23] These techniques are best applied to situations where there are already strong Market Systems and just a few of the input or output factors are externalities. For example, these techniques might be successful at achieving efficient allocations in the case of river pollution. An individual firm has private ownership of all of the inputs to production and most of its outputs, except one or two toxins that pollute the river. The firm does not want private ownership of this output, but the community does not want it either. If the river pollutant is the only output that the firm does not privately own, then Command and Control, Financial Incentives, Reporting Mandates or Judicial Action may provide a solution. These corrective mechanisms force the firm to take responsibility and treat the unwanted output as if it were owned by the company. These methods provide incentives so that the externality is internalized, so that the firm reduces the amount of pollution it emits.

It is difficult to use these techniques alone in cases where there are many environmental resources, or for large geographic areas in which environmental resources need to be managed for use, conservation and preservation. For situation were *most* of resources are not traded in the Market, the use of these corrective mechanisms alone can not determine efficient allocations. For example, it is nearly impossible to use bubble techniques to protect the environmental resources in San Francisco Bay or in the Florida Keys National Marine Sanctuary. Command and Control techniques were attempted for some of the farming practices in the Chesapeake Bay problem, but it is not likely they would be used for every aspect of the problem, such as the decline of riparian forests. Judicial Action has also not solved all the problems in the Exxon Valdez spill. It is difficult to determine how market based incentives or environmental economic techniques would be used, because these cases involve many complicating factors which the techniques do not help overcome such as:

1. Inadequate Information Management[24]
2. Uncertainty about cause and effect
3. Multiple groups with multiple objectives

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[23] These four corrective mechanisms are used, though, because at least they do not ignore the values of environmental resources altogether, which is often the case with Market System allocations.

[24] It is worth mentioning that these tools do not overcome any part of Inadequate Information Management:

a. so much data and information that all of it is not adequately considered
b. criteria and variables that cannot accurately be reduced to monetary values
c. criteria and variables from multiple-disciplines and areas of expertise
d. interdependencies among environmental decisions

Because these techniques can not overcome the complicating factors, they typically can not meet the three necessary conditions of good decision-making. Often, fees are created or maximum levels of emissions are set without i) the decision makers and stakeholders becoming well-informed about the physical or economic aspects of the system. Also, standards are set without ii) eliciting the prefe..nces of the general public and stakeholders; often a government department acts unilaterally to set a regulatory standard, or a judge acts unilaterally to set a judicial standard. It is also the case that fees, levels and standards are set without regard for making them iii) flexible or adaptable. It can not be assumed that using these techniques alone will find the efficient allocation of resources.

Since there is a need to incorporate the stakeholders, to have a public choice process, then one must focus on how to best prepare and transfer information to assist with public choice. It is difficult to achieve efficient allocations, for optimizing the use, conservation and preservation of many environmental resources, when these tools are used alone; often other tools must also be used to assist the allocation decision.[25] These methods alone are not likely to work for ecosystem management such as the Chesapeake Bay or the Florida Keys.

C. Dollar based methods for valuing amenities; Maximized Net Present Value

When there are many environmental externalities and it is not possible to allocate just a few externalities with regulatory or judicial methods, then more formal decisions must be made to allocate natural resources. When this is the case, often policy makers and economists attempt to base a decision using the resources' dollar equivalents; choosing the alternative with the maximum total dollar amount becomes the criteria for making the decision. If this is the criteria, then Maximized Net Present Value is the best technique for choosing an alternative.[26] Maximized NPV will be reviewed to illustrate where problems arise and why one might need to use other decision-making criteria and methods.

NPV requires placing a dollar value on all the variables or items in the decision to calculate the overall dollar value. If there are benefits or costs expected in the future, then these dollar

[25] Most of these corrective mechanisms involve Transaction costs, such as the costs of checking for compliance, court fees and such. These coats must also be included when determining if the method achieves a more efficient allocation.

[26] Note: Using monetized Benefit and Cost ratios is never advised and may lead to inadequate solutions. See any number of investment or accounting texts including Bodie, Kane & Marcus 1989, Davidscn, Stickney & Weil 1988, Brealey & Myers 1988.

amounts are discounted to their equivalent current values and then summed. The alternative with the highest dollar value is chosen. (See Brealey & Myers, 1988 or any finance text for more details.)

1. Reasons why one might use Maximized NPV: Strengths of the method

There are many situations where Maximizing the Net Present Value (NPV) is the ideal decision-making rule. When all factors in the decision have a clear monetary equivalent, Maximized NPV allows the dollar 'equivalents' of many factors to be summarized into one overall number. If all variables can accurately be reduced to their monetary equivalents, then it is easy to build consensus using Maximized NPV. Most people can agree that *all else equal*, more money is better than less money. If the decision is reduced to choosing between alternative 'A' which is worth $100, or 'B' which is worth $101, the decision is easy.

2. Problems with using Maximized NPV

Unfortunately, the maximized NPV is often used in situations where it may not provide the Pareto admissible or efficient solution.

a. Maximized NPV is not the same as Economically Efficient

Maximized NPV often focuses on summarizing the total costs (TC) and the total benefits (TB) of a project. Using TB and TC, though, is not the right criteria for determining the allocation of resources to distribute goods. In the Market System, Economic Efficiency and Pareto Optimality is defined as when Marginal Benefits (MB) equal Marginal Costs (MC). This is MB = MC, not TB = TC. (See any Micro Economics texts for a full discussion of this topic, with focus on MB + MC, such as Pindyck and Rubinfeld, 1995.) For any situation where goods are being allocated in order to reach an efficient allocation *for society*, MC should equal MB; this includes reaching an efficient allocation for environmental resources. For personal decisions or decisions where there are small groups investing or managing their own personal resources, TB = TC, or TB > TC can be used as a decision-making rule to reach the best decision. Using Total Costs and Total Benefits is not a good decision-making rule, though, when making a decision for society, when making environmental decisions. (See Tietenberg, 1992 for a more thorough discussion.)

b. Problems reducing all benefits and costs into one number

Maximizing NPV works well because most people can agree that *all else equal*, more money is better than less money, *all else* meaning criteria that are not accurately monetized. The problem with using maximized NPV for environmental decisions is that there is typically a great number of criteria that can not be accurately reduced to monetary equivalents. Often *all* *else* is not equal, and it is hard to judge the other non-monetary factors. Putting *inaccurate* dollar amounts or no dollar values on some factors or components of a decision, yet trying to compare alternatives on the basis of a single criteria, 'money,' often leads to bad decisions. This can often be more of a hindrance to good decision-making than a help.

> "It is much easier to arrive at definitive answers using cost -benefit analyses than cost-effectiveness analyses. Be careful to observe the legitimacy and the reasonableness of the transformation that condense many benefits into one number - 'total benefits,' and then condense 'total costs' and 'total benefits' into one number ... All too often, in practice, important benefits are not included in the listing, because it is not clear how a market mechanism can be conjured up to 'price out' this particular benefit. We're thinking here of such benefits as aesthetics, psychological well-being and security, among others." (Keeney and Raiffa, 1976)

For example, making decisions about environmental protection, the total *costs* of the environmental protection are easily tallied, because they are often capital projects and there is less uncertainty. A tally of the accurate total *benefits* from the environmental protection is more difficult, though, because there is more uncertainty in trying to tally the potential benefits. "How many more people will use the beach? How much will tourist income increase? How many more fish will be alive?" There is more uncertainty as to what the benefits might be, as well as uncertainty about the quantity of the benefits.

c. Problems with methods that attempt to equate worth with a dollar measure

In trying to use Maximized NPV for environmental decisions, one must get a sense of the dollar equivalents for *every* variable or item affected by the decision. Maximizing NPV may require finding the monetary equivalents to some things that are incredibly difficult or impossible to accurately monetize. Reviewing the different techniques for putting dollar equivalents on user, option and existence values,[27] one can see that each technique has its own strengths and weaknesses.

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[27] a. User Values - This is the value of a resource to those who use it now. It is the easiest type of value to measure accurately, because many user values can be measured by market behavior and seen in consumer actions.

b. Option Values - This is the value of a resource for people who want to preserve the option of using the resource in the future. It does not matter whether these people use the resources now; they place additional value in knowing they have the option of using it in the future. This option is not taken for granted; value is placed on having the option.

c. Existence Values - This comes in a variety of forms:

i) Value that people derive just from knowing the resource exists. For example, one might never travel to the Antarctic, but one is glad that it is preserved and simply exists.

ii) Value people derive just by knowing it will exist for future use by others. For example, one might be concerned that there are Rain Forests in 100 years for their children's children to enjoy.

i) **Hedonic Valuation Methods (Values imbedded in market goods)**
Many economists try to infer 'Willingness to Pay' or 'Willingness to Accept' an externality by looking at related market behavior. This is often used with wages or for property values. For example, to understand the value of a river view for an apartment, one might find out what apartments with ocean views costs and then compare the prices with apartments which have no ocean view, but otherwise have the same exact set of amenities. If there is a difference in price, it is attributed to the value of the view. (See Tietenberg, 1992 or any other environmental economic text for more examples.)

Hedonic Valuation relies heavily on econometrics for delineating the different amenities and determining each amenity's contribution to the overall value. Econometrics is an art as well as a science and uses the past to predict the future; it can not always determine accurate monetary equivalents. Hedonic Valuation can measure only user values; they cannot measure existence or option values. Finally, it is also limited to situations where the environmental resource is one feature of a good that *is* traded in the market.

ii) **Travel Cost Methods and Amenity Substitutes**
These methods are used when the externality is either a complement to or a substitute for a good that is traded in the market. First, the Travel Cost Method is most often used to determine the value of environmental goods related to recreation. To estimate the user value of a state park's recreational resources, for example, one would survey different park visitors to determine distances traveled and wages foregone in order to make the visit. These travel costs and foregone wages are complements to using the recreational amenities of the park, and would be used to estimate the park's total recreational value. Travel costs and foregone wages are used, because they can be measured in the market place and because it is believed that the consumers' travel patterns indicate their preferences.

An example of an Amenity Substitute is the purchase of water filters or bottled water, when consumers suspect that their tap water is unhealthy. The sum of the cost of buying filters and bottled water is determined as the value of having a clean water source. (See Tietenberg, 1992, or any Environmental Economics text for more details)

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iii) Value people derive just from knowing that someone else is enjoying it at the present. For example, an adult may not use a playground, but is happy that it is there for children to enjoy.

Like Hedonic Valuation, these methods i) rely heavily on econometrics which can not always determine accurate monetary equivalents, ii) can only measure user values and not measure option or existence values and iii) they can only be used in a limited number of situations. Amenity Substitutes and the Travel Cost method can only be used if there are goods in the market which are either a substitute for or a complement to the environmental good.

iii) Stated Preference Methods, such as Contingent Valuation and Experimental Markets

Contingent Valuation require using surveys, asking people what they would pay for a good or a resource in a certain situation and Contingent Ranking requires people to rank goods and resources in the order of their preferences. Many people realize that the dollar estimates or rankings may not be an accurate representation of how the respondent values the resource for a number of reasons. First, the survey question is only academic; a consumer's answer to a question is far less dependable than her behavior. Another problem with Stated Preference methods is that creating the surveys are an art; done improperly can increase the chances of inaccurate valuations. (There are many papers and books that discuss the problems with Contingent Valuation. Solow and Arrow, 1993 is generally accepted as a good summary.)

A third reason that State Preferences methods may not achieve accurate summary values of environmental resources is that often the surveys do not contain questions that address the true concerns of the public. Determining 'what to value' is an important question and should be decided by the stakeholders, not left to those who create the survey. The stakeholders' initial preferences should be elicited first to determine the parameters of the surveys, to determine what the stakeholders feel have worth. Only after this step is completed can one attempt to elicit final preferences, that is rankings or dollar estimates of the resources' worth. Inaccuracy also occur, because the surveys do not force the user to consider a limited budget and their ability to pay, nor does it make apparent the alternative choices, as would be the case in the Market System. (Again, see Solow and Arrow, 1993 for a full discussion.) Many people do use Stated Preference Methods such as Contingent Valuation, though, because it can measure option and existence values in any situation. Although "Contingent Valuation has lots of problems, it's the best we have, so we use it." (Arrow, 1994)

These three valuation methods, Hedonic Valuation, Amenity Substitutes and Contingent Valuation, try to creatively use consumer behavior and questionnaires to measure the worth of environmental amenities that are external to the market, common property resources. The problem with all these valuation techniques is that they are rarely accurate. Hedonic

Valuation and Amenity Substitutes, are more accurate than Contingent Valuation, but they can only be used in a limited number of situations. Contingent Valuation can measure user, option and existence values for any resource, but there are great inaccuracies in the estimates.

Decision makers sometimes exert great efforts trying to obtain monetary values to summarize the worth of a resource, know that it is inaccurate, use it anyway to make a decision based on maximized NPV, and yet still call the decision acceptable. "For many decision problems, especially in the public sector, the outcomes cannot be measured in monetary terms without introducing questionable value judgments." (Daellenbach, 1983) One should be wary of analysts that try to quantify the unquantifiable.

3. Which Complicating Factors are overcome using Maximized NPV

Very few of the complicating factors can be overcome by using Maximized NPV.

a. Inadequate Information Management

i. Criteria that can't easily be reduced to monetary terms

Maximized Net Present Value uses only one criterion to choose an alternative: money. With environmental decisions there are many criteria, and it is often difficult, if not impossible, to determine the monetary equivalent of many variables.

ii. Interdependencies of many variables - (Cyclical and dynamic)

Maximized NPV only considers the linear interdependence of variables. It is difficult to assess the dollar equivalents of dynamic variables or variables that have cyclical dependencies.

b. Uncertainty - (Other than probabilistic)

If one can state the probabilities of the different events occurring, then one can calculate an NPV even when there is risk. Maximized NPV can not incorporate true uncertainty, though, when accurate probabilities can not be estimated for all possible outcomes.

> "Feasibility studies in water resources are conducted under the assumption that the 'most likely' or the 'expected' values of benefits (monetary and otherwise) can provide an appropriate basis for the evaluation and comparison of alternative plans. Current methodological frameworks are not able to accommodate ranges of values for all input parameters. Even when the effort is made to consider parameter ranges, it is not clear how to proceed with the analysis of risk and uncertainty - what analytical tools should be

used and what tradeoffs to generate in order to assist in the decision-making process."(Goicoechea, 1982)

i. Ill-defined time scope

Maximizing NPV can sometimes incorporate different time frames, because future costs or benefits can be discounted back to their present value and summed. There is a problem, though, in trying to choose the proper inter-temporal discount rate. Market discount rates are different from discount rates for social goods, which may be different from the discount rates for environmental goods. Discount rates for social goods are typically lower than discount rates for market goods, because the risk for social goods is diversified among all of society, not just a small group of investors. Discount rates for environmental goods are typically lower yet, because environmental goods are important to many generations of people, so the risk is diversified among an even larger group. Lower discount rates mean that environmental goods don't lose their value over time to the same degree as private goods. There is less to be gained by consuming more environmental goods now, than in the future. (Stavins, 1993; Tietenberg, 1992, any Environmental Economics text) While Maximized NPV can discount future cash flows back to the present, there are inaccuracies, because it is not known what discount rate to use.

ii. One time, high stake decision

Maximized NPV is acceptable if the same decision is repeated many times.

> "In situations involving similar choices that are repeated many times or that have relatively low stakes, decision makers may feel that their preferences are consistent with the simple expected value of the outcomes. However, in decisions made *only once* and involving *relatively high stakes*, they may wish to avoid the possibility of an unfortunate outcome, even though the odds are actually in their favor. Most persons are risk averse in their decision-making ... although the degree of risk aversion varies greatly and is a personal matter..." (Buffa, 1981)

Many environmental decisions are one time, high stake decisions. As early as the 18th century, Daniel Bernoulli recognized that Maximized NPV monetary equivalents is not necessarily a good criterion for evaluating the payoffs in one time, high-stake decision-making situations.

> "Decisions to carry insurance or to buy lottery tickets are clearly not based on a criterion of maximizing monetary returns. Otherwise, insurance companies and lottery organizers could not cover their operating costs and make profits at the same time. Should we infer

> that such decisions are not made on a rational basis? Far from it! It simply means that there are situations where monetary terms do not measure the true worth of an outcome. The true worth reflects personal, social and financial elements." (Daellenbach, 1983)

For one time, high stake environmental decisions, maximizing the NPV is not the best decision method for allocating resources.

c. Many people with different preferences

For decision-making in the public domain, there are many stakeholders, each with his or her own subjective preferences.

> "You can go only so far without introducing subjective attitudes - no matter how hard you squeeze the available objective data, it won't come close to providing courses of action for complex problems. Indeed, a purely objective analysis might fall so far short of providing guidelines for decision-making that the output of the analysis may not pass the threshold of relevancy. We believe that complex social problems - and for that matter complex business problems - demand the consideration of subjective values and tradeoffs. It is not whether subjective elements should be considered, but whether they should be articulated and incorporated into a formal, systematic analysis. The choice is between formal analysis and informal synthesis and this meta dilemma does not have an obvious solution." (Keeney, 1976)

Eliciting and combining these subjective human values, these preferences, is necessary to determine society's collective value of a resource, in order to make good decisions concerning environmental goods. The question is how to elicit accurate preferences and subjective valuations in such a form that they can be incorporated into formal analysis.

Overall, Maximized NPV can not overcome many of the complicating factors in environmental decision-making. Maximized NPV requires that every factor that is affected by an environmental decision be represented by its monetary equivalent, but this is not always possible to accurately determine. One should quantify that which can be quantified easily and with reasonable confidence, but since every factor can't be accurately reduced to its monetary equivalent, the quantified information should be used as only part of our decision-making process. There is a need to look at other decision-making methods.

D. Conclusions -

Many methods presently used for deciding how to allocate environmental resources do not provide satisfactory outcomes for all coastal common property resources. When environmental externalities exist, the Market System should not be used to allocate environmental resources. Regulatory and Judicial methods prevent environmental amenities from being completely neglected or destroyed by the Market System, but often they do not find the socially desirable mix of use vs. protection, the economically efficient level of allocating the environmental resources. Many of incentive based methods attempt to make the environmental externality an internal part of the Market, so that the principles of the Market System can be used, but the techniques are viable in only limited circumstances. Maximized Net Present Value is sometimes used as the decision criteria when making environmental decisions. This, too, is inadequate in situations where every factor can not be accurately reduced to its monetary equivalent.

Other decision-making tools should be explored to find those that may be helpful in a wider range of circumstances for making environmental decisions, for allocating coastal resources. The above tools can be used when appropriate, but may need to be augmented in many situations. The search for tools should extend past those traditionally categorized in the economic discipline and regulations. Decision Theory should also be explored for tools that can make better decisions about how to allocate environmental resources.

Chapter V. Non-market based systems for allocating Environmental Resources - advantages and disadvantages

When trying to *decide* how to best allocate coastal resources, it helps to expand beyond economic-based methods or regulations and focus on the process for making *a decision.* Since these methods alone are usually insufficient for the purpose, the field of Decision Theory should also be explored. Operations Research, Multi-Criteria Decision-making, Multiple Objective Utility Functions and Decision Support Systems are often used to decide how to allocate environmental resources. This chapter explores these families of tools using the criteria developed in Chapters II and III. The tools need to help overcome the three major complicating factors of i) Information Management, ii) Uncertainty and iii) Group Decision-making in order to assist the environmental decision making process.

A. Operation Research tools

Operations Research, also commonly referred to as Management Science, typically refers to applying mathematical techniques to determine how to most efficiently allocate resources.

> "Since the advent of operations research as a scientific approach to decision-making...a variety of mathematical tools have been developed and applied to problems in engineering, business, government economics and the natural and social sciences... an array of systematic procedures or mathematical frameworks have been developed..." The mathematical tools of Operations Research "share a common feature: the formulation of a single criterion or objective function, and the optimization of that objective function subject to a set of prescribed constraints" (Goicoechea, 1982)

1. A review of Operations Research tools

The following is a list of some Operation Research tools used to make decisions about how to allocate resources:

i) Assignment methods (i.e. Knapsack problems)
ii) Dynamic programming
iii) Goal programming
iv) Linear programming
v) Integer Programming
vi) Network models and Critical Paths
vii) Nonlinear programming (Lagrangian Method and Kuhn-Tucker Method)
viii) Replacement (capital budgeting)

ix) Simple inventory models

x) Transportation

xi) Waiting line management, etc.

(See Turban, 1988, or any Management Science / Operations Research text for a full discussion of the many techniques.)

Many researchers recognize that there are limitations to Operations Research tools:

i) The benefits of using these tools have been mostly in generating better solutions for a narrow range or type of problems and / or

ii) The impact has been mostly on *structured* problems, where the objective, data and constraints can be pre-specified. (Turban, 1988)

Some of the tools are heuristics to be used for a narrow range or specific types of problems such as transporting goods (Network Models and Transportation Models). There are no specific heuristics for environmental problems, though, so these will not be pursued further. Other models and tools are more general and can be used for a wide range of problems, but then require a well-formed mathematical objective function and constraints. (See Goicoechea, 1982)

2. Which Complicating Factors are overcome by mathematical Operations Research tools

These methods require structured problems, but environmental decisions are rarely *structured*, so these types of Operation Research tools may not be helpful in many environmental decisions. They can help overcome some of the Complicating Factors, but can not help with others:

a. Inadequate Information Management

i) A great deal of information - These methods can help summarize a great deal of information *if* the information can be represented as a well-formed mathematical equation. If the users can not formulate equations for every part of the system, Operations Research tools offer few benefits. First, if every part can not be represented with an equations then the tools can not be run to determine predicted outcomes. Second, representing each part as only a mathematical equation does not ease the transfer of knowledge, so it is difficult for the stakeholders to understand the many parts of a complex environmental system; it is difficult for the users to become well-informed about the entire system.

ii) Multiple criteria from multiple disciplines - These tools can incorporate many disciplines, if the relevant information can be summarized as a mathematical equation. Problems arise because if every factor is represented *as only* a mathematical equation, it is difficult to generally understand the entire system. Those with expert knowledge on certain pieces would find it difficult to determine how their knowledge addresses the overall problem, making it nearly impossible to elicit the best available information.

b. Uncertainty

These tools can not accommodate uncertainty, unless it can be represented in a mathematical equation. Risk can be incorporated if accurate probabilities can be determined, but statistical uncertainty can not be included. Also, uncertainty such as one time decision with high stakes and ill-defined geographic scope can not be overcome.

c. Many people with different preferences

These tools offer no help eliciting preference from many decision makers. If the models can not be run, they offer very little help with the physical or economic aspects of environmental decisions. If the information is represented only as a mathematical equations, it is difficult for many people to understand the system and transfer knowledge.

These tools do not help overcome enough of the complicating factors, so that the necessary conditions of good decisions can be met. These tools:

- do not ensure that the stakeholders are well informed. They can not elicit the best available information from many experts and they can not assist with information transfer.
- do not include or elicit the preferences of many stakeholders.

B. Multi-criterion & multi-objective Decision-Making Tools

In some environmental and other public decisions, there are regulations requiring multiple objectives to be addressed.[28] The field of Multi-Criteria Decision Making (MCDM) began in

[28] The National Environmental Policy Act of 1969 (NEPA) among other things, directed all agencies of the federal government to "include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on -

i) the environmental impact of the proposed action

ii) any adverse environmental effects which cannot be avoided should the proposal be implemented

iii) alternatives to the proposed action the late 1960s, early 1970's, and focused on tools designed to incorporate multiple criteria and multiple objectives.

> "MCDM has emerged as a philosophy that integrates common sense with empirical, quantitative, normative, descriptive and value-judgment-based analysis. It is a philosophy supported by advanced systems concepts (e.g., data management procedures, modeling methodologies, optimization and simulation techniques, and decision-making approaches) that are grounded in both the arts and sciences for the ultimate purpose of improving the decision-making process." (Haimes, 1984)

> "In the last two decades, there has been an increased awareness of the need to identify and consider simultaneously several objectives in the analysis and solution of some problems, in particular those derived from the study of large-scale systems. (Goicoechea, 1982)

There are many reasons for the increasing interest in MCDMs.

> "First and most importantly, is the increasing recognition that most decision problems are inherently multi-objective...The reason for the multi-objective nature of these problems is simply that the outcomes associated with the decisions are multidimensional. ... A second, but related, reason for the increasing interest in MCDMs is the recognition of numerous stakeholders in many problems.... Finally, a third reason for increasing interest in MCDMs is the enormous improvement over the last 15 years in the speed, storage, and feasibility of computing facilities." (Evans, 1989)

Evans indicates that many MCDMs are aided by the computer to overcome various complicating factors, such as group decision-making and inadequate information management.

There are many MCDMs, and to better understand which families of MCDMs can be most helpful to environmental decision-making it is best to review how they are classified. Hwang and Lin, in their book Group Decision-making under Multiple Criteria, conducted critical reviews and systematic classification of MCDMs that can be used when there are multiple decision makers. A second book by Hwang, Hwang and Chen (1992) categorizes MCDM methods and tools when there is uncertainty. The different MCDM categories determined in these books will be loosely followed here.

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iv) the relationship between local short term use of man's environment and the maintenance and enhancement of long-term productivity and

v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

This is why Environmental Impact Studies (EIS) are included in many regulations.

1. Multi-objective Utility Functions

Multiple objective Utility Functions are decision-making tools that can collect many people's *values* and summarize them into one alternative. In general, this family of tools can elicit and combine many stakeholders' preferences when there is group decision-making. As defined in Chapter III, "Utility is the level of satisfaction that a person gets from consuming a good or undertaking an activity." (Pindyck and Rubinfeld, 1995) Utility Functions rank and order consumer preferences in terms of satisfaction levels; Multi-objective Utility Functions rank and order preferences when the decision involves many objectives or criteria.

Researchers categorize Multiple objective Utility Functions into three general groups depending on when in the decision process the decision makers' preferences are articulated: i)*Posterior* which is typically voting ii) *During* which is most often sequential elimination methods or interactive solution methods and c) *Prior to* which are most often weighting methods.

a. Voting

Voting is often used as the method for posterior articulation of preferences. There are different types of voting:

i) Non-ranked voting - This means that each voter states which *one* alternative he or she prefers; the voters do not rank all alternatives. Many inconsistencies occur if there are more than two alternatives, though. "The non-ranked voting system is unsuitable for any election in which there are more than two alternatives, since its use may result in the election of the least popular alternative."

ii) Preferential voting - This is when voters rank *each* alternative according to their preferences. "... preferential voting allows the voters to indicate not only which of the three or more alternatives he or she would most desire, but also in what order of preference he or she would place all the alternatives." There is a possibility that inconsistencies may occur, but in a much smaller number of situations than non ranked voting.[29] (Hwang and Lin, 1987)

At present, voting is the method used most often to elicit stakeholders' preferences in environmental decisions.

[29] See Hwang and Lin, 1987 for a more detailed description of inaccuracies that can occur with voting.

b. Multi-attribute Utility Theory and Social Welfare Functions

MAUT and Social Welfare Functions attempt to combine the *preferences* of many individuals in one 'social' utility function, as opposed to joining the *final choices* of many individuals' by methods such as voting. Some researchers define Multi-Attribute Utility Theory (MAUT) as a subset of MCDMs, while others keep them distinct. The major distinguishing feature is that MAUT developed from a more rigorous theoretical and quantitative background of Utility Theory,[30] while MCDMs typically have less theoretical background and may include heuristics. In this dissertation, MAUTs will be discussed as a subset of Multi Criteria Utility *Functions,* which will be discussed as a subset of Multi Criteria Decision Making (MCDMs).

These techniques have been applied to very few cases, though, because they are very technical in nature. For example, Multi-attribute Utility Theory, which grew out of uni-dimensional utility theory, evaluates utility functions which are designed to express the users' preferences of multiple attributes.

> "...MAUT reduces the complex problem of assessing a multi-attribute utility function into one of assessing a series of uni-dimensional utility functions. Such individually estimated 'component' functions are then glued together again; the glue is known as 'value trade-offs.' (Zeleny, 1984)

The limitations of MAUT is that it requires that the uni-dimensional indifference functions be fully transitive and the multi-attribute utility function to be additive. This requires there to be independence of attributes.

> "One of the most important tasks of MAUT is to verify the independence of attributes. It is generally quite difficult for humans to say whether attributes are independent... What if one cannot find a truly independent set of attributes and objectives? We might ultimately discover that the overall utility function is not decomposable into its components, that it must be assessed holistically, as an irreducible unity." (Zeleny, 1984)

Environmental decisions are usually complex, with criteria that have many cyclical and dynamic interdependencies. Although MAUT may be helpful on some environmental decisions, it could not be helpful in the majority of them, those involving interdependencies of variables.

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[30] See **Chapter III** for a discussion of Utility Theory.

c. Social Choice Functions

Hwang defines these as 'aggregation procedures' based on preferential voting systems. Like Social Welfare Functions, preferences are elicited and aggregated on various parts of the decision, not only on the final choices. Typically, they rely more on heuristics and are less theoretical than Social Welfare Functions, which allows them to be used in many more cases. These tools can typically incorporate many people's preferences, even when the values are subjective in nature.[31]

Hwang defines Saaty's Analytical Hierarchy Process and the Nominal Group Technique as Social Choice Functions. The KJ Method, which is typically used for group decisions in Total Quality Management, is another Social Choice Functions that is easy to use and alter. These techniques are used *during* the decision-making process, not just posterior, so they can elicit more detail than simple voting. This family of tools is promising to use for eliciting stakeholders' preferences in environmental decisions.

d. Fuzzy Set Theory

There is some overlap with Fuzzy Set Theory and Social Choice Functions. Fuzzy Set Theory is defined as "a means for modeling uncertainty (or imprecision)." Some of Fuzzy Set Theory can be used to incorporate the uncertainty of human subjectivity...

> "from mental phenomena which are neither random nor stochastic. Human beings are heavily involved in the process of decision analysis. A rational approach toward decision-making should take into account human subjectivity, rather than employing only objective probability measures. This attitude towards the uncertainty of human behavior led to the study of a new decision analysis field - Fuzzy Decision-making." (Hwang, 1992)

Some methods that can incorporate multiple preferences include: Fuzzy Simple Additive Weighting Methods, the Analytical Hierarchy Process, Fuzzy Conjunctive / Disjunctive Methods, Heuristic Multi-Attribute Utility Functions, Negi's Approach, Fuzzy Outranking Methods and Maximin Methods. (See Hwang, Hwang and Chen, 1992 and Hwang and Lai,

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[31] An example of this in the Miami beach renourishment case is that local residents do not want trucks transporting sand through the town, tying up traffic. No one knows how important this criteria is compared to the criteria of aiding central Florida's economy. These two criteria cannot be compared if the decision is made only using dollars. The subjective values of no traffic jams need to be considered. Similarly, in Manatee County, the local sponsors would not fund its portion of the renourishment until some 15 years later, because the Army Corps of Engineers failed to recognize that bart fishing and sea turtles were important to the community and had to be considered, even though they were subjective in nature.

1994 for more on Fuzzy Set Theory and descriptions of these methods.) Some methods of Fuzzy Set Theory seem appropriate for eliciting preferences for environmental decisions.

e. Game Theory

Game theory is a mathematical technique used to analyze situations where there is conflict of interest.[32] It focuses on the varied utility and conflicting preferences of different decision makers. It is the study of how to take the competitor's objectives and likely actions into account when choosing the best decision.

> "Game theory attempts to abstract the essential elements of large classes of competitive situations, put them into mathematical models, and use the scientific approach to analyze these problems. It is concerned with helping participants make the best choices and providing them with a guide for rational behavior" when faced with decisions where there is conflict and yet room for cooperation. (Hwang and Lin, 1987)

With many environmental decision, there is a great number of stakeholders, with a great variety of different preferences. Typically, it is a challenge to identify all of the preferences, and there is uncertainty about the exact causes of conflict, making it more difficult to mathematically model the preferences. Using Game Theory may not be adequate for overcoming the complicating factors in most environmental decisions.

There are some MCDMs that can elicit preferences, but also elicit information and knowledge from a large number of participants / experts. MCDMs that predominantly elicit information, but which can also elicit preferences are:

Surveys,
Delphi Method,
Conferences,
Social Participatory Allocative Network (SPAN)

2. MCDM tools that help manage and structure information

While all MCDM methods can be used with multiple criteria and multiple decision makers, not all focus on multiple preferences. Instead of focusing on human preferences, some MCDMs focus on *eliciting and recording knowledge,* that is *organizing and managing* the large amounts of information. Some of these tools are not computer based, such as:

Brainstorming,
Brainwriting,

[32] It was designed by Borel in 1921, but was brought to wide notice by Von Neumann and Morganstern in 1944.

Synetics, and
Cognitive Maps (such as Causal Loop Diagrams).

Other tools are computer based such as:
Interpretive Structure Modeling (ISM),
Decision-making Trial and Evaluation Laboratory (DEMATEL),
and Simulation models

Simulation models are one type of MCDM that can assist managers during the decision-making process. A Simulation model is used to represent a system, so that the model can be used to predict the behavior of the system and perform sensitivity analysis. Regardless of what tool or method is used for utility analysis, with environmental decisions, to analyze the implications of different alternatives, it is necessary to enable the best possible predictions, because it may require many years for the actual outcomes to evolve. Some Simulation models are purely descriptive or normative, while others can be analytical or prescriptive, where the users can change the value of variables until the desired outcome is reached. There are a number of Simulation models that can be used including:
Kane's Simulation (KSIM),
Quick Simulation (QSIM),
Cross- Impact Package (XIMP),
SPIN and
Systems Dynamics

These tools are all developed by different researchers and decision makers. (See Hwang and Lin, 1987 for more information on these tools.) Typically, Simulation models can accommodate different types of interdependencies, both pictorially and by specifying the variables and linkages as equations. Some Simulation models can help overcome different types of uncertainty as well, but these are typically classified as Uncertainty Analysis Tools.

3. MCDM Methods designed to accommodate uncertainty

There are certain MCDMs that may not be able to elicit preferences, but that are used to understand the uncertainty in physical and economic aspects of the decision. Some of these tools are also defined as part of Fuzzy Set Theory, but focus more on the uncertainty of the *physical and economic aspects* of the system than on the subjectivity and uncertainty of the *human preferences*. Within Fuzzy Set Theory, there are

"... stochastic decision methods such as statistical decision analysis ... which provide a way to model incomplete knowledge about the natural environment ..." (Hwang, 1992)

Decision Trees and Influence Diagrams can help analyze the uncertainty of the physical and economic aspects of a decision. They include a pictorial representation of the decisions and the chance happenings involved in or affecting one decision, as well as means to analyze the uncertainty. These methods allow for a graphical representation of a decision, by showing which different variables (drawn as nodes) interact with each other (the interactions drawn as arrows connecting two nodes). The graphical representation is the chronological record of a decision, starting at the initial actions or chance events, then listing the flow of all subsequent decisions and chance events which lead to the possible final outcomes. The chance events can incorporate probabilistic uncertainty or risk. Different paths or branches emanate from the different decision nodes and chance nodes, providing a tree structure. These tools enable the user to model what decisions have to be made at different branches when relevant information becomes known. By breaking down the different steps of a decision, these tools can be used to do Uncertainty Analysis for some decisions.

There are a number of computer based Uncertainty Analysis tools that can include not only probabilistic uncertainty in the variables and linkages, but also statistical uncertainty. They use Influence Diagrams and Decision Trees as their basic building block, but can do more complex analysis faster, because they are computer based. Allowing variables to be defined as statistical distributions enables the predicted outcomes to also be described as a statistical distribution. These tools can also determine which uncertain variables contribute most to the uncertainty in the outcome. Demos is one such Uncertainty Analysis tool, (Morgan and Henrion, 1990) which has analytic functions that allow sensitivity analysis to be easily performed. Demos can overcome the complicating factor of uncertainty, helps overcome some of the aspects of inadequate information management and can be used with multiple people. It can not, though, elicit preferences from the users, gathering multiple values from multiple groups.

4. Decision Support Systems

Most MCDMs which are computer-based could be classified as Decision Support Systems (DSS). The concepts involved in Decision Support Systems were first articulated in the early 1970s by Scott-Morton as "interactive computer-based systems, which help decision makers utilize data and models to solve unstructured problems." Another definition by Keen and

Scott-Morton is "DSS is a computer based support system for management and decision makers who deal with semi-structured problems." (Turban, 1988)

MCDM tools that are also DSS tools are designed so that they can overcome the complicating factor of inadequate information management with the aid of computers. They can record and utilize a great deal of information, and show the interdependencies of the information. Because a great number of criteria can be recorded and incorporated, non-monetized criteria and criteria from multiple disciplines can be included. DSS's are support tools, controlled by the decision makers; they are not Expert Systems, which attempt to automate the decision process. Decision Support Systems may be found in any of the different genres of MCDMs, such as those that focus on eliciting and combining preferences, on organizing physical and economic information or uncertainty analysis.

In general, MCDM tools are designed to be used with many people and can incorporate multiple criteria, but only some can elicit and incorporate multiple preferences from many people. All can begin to overcome the complicating factor of inadequate information management, although some are better at structuring and organizing information from many disciplines. Some can overcome the problems of uncertainty and others can only accommodate uncertainty. No one tool was found, though, that can overcome all the complicating factors of inadequate information management, uncertainty and group decision-making. Before finalizing which tool or tools will be used in a case study, the work of current environmental researchers and decision makers will be reviewed.

C. Tools Other Researchers and Practitioners Are Presently Using for Environmental Decision-Making

There are many government agencies, public interest groups and researchers who are looking at coastal environmental management. These groups are using a variety of tools to make decisions in the public sector, and more specifically decisions about how to allocate environmental resources.

1. Tools used in public sector decision-making

Many tools are used, including Monetized Cost -Benefit Analysis, Maximized Net Present Value and many Multi-Criteria Decision Making tools. Many federal agencies are required to analyze both the costs and benefits, although they need not always be monetized. Since the 1980's, there is an increasing trend towards Multi-Critieria Decision Making tools, to make decisions that can accomplish multiple tasks and to incorporate the variables that can not be easily monetized.

> "...the public sector is an increasingly interested user of Multi-Criteria Decision Making (MCDM) and Multi-Attribute Utility Theory (MAUT) models. Because most public sector problems involve multiple conflicting objectives, whether in public health care systems, *environmental policy*, *water resources*, energy or macro economic planning, the opportunities for MCDM applications are unlimited." (Dyer, 1992)

> "Multi-attribute utility analysis has been used widely to aid government decision makers. For instance, it has been used to select military systems, set *water supply* policy, site nuclear facilities, determine fire department operations, evaluate crime prevention programs and prepare international negotiators." (Ulvila and Brown, 1983)

> "The International Institute for Applied Systems Analysis (IIASA) in Luxembourg, Austria has played an important role in developing, applying and promoting MCDM and MAUT. In its commitment to complex nonpolitical problems of global concern such as in *water resources*, forestry, energy planning, population and environmental ecology, IIASA has been a major supporter of MCDM and MAUT as essential methodologies for analyzing such problems." (Dyer, 1992)

Some experts specifically pinpoint water resource management as a subset of environmental decisions that require multiple criteria tools.

> "*Water agencies*, in particular, have relied on the use of the benefit-cost ratio to select a 'recommended plan' from the list of alternative plans in a project ...but the matter of considering several other objectives with non-monetary units constitutes an entirely new ball game. A methodology is needed to address those objectives effectively, generate tradeoffs, and articulate the preferences of the various decision makers....In *water resources* development, the design of projects and programs has focused traditionally on the estimation of national benefits and costs. A more realistic analysis would include environmental, social, and regional objectives, as well." (Goicoechea, 1982)

In the late 1970's federal water agencies supported research for Multi-criteria decision making, so there has been a substantial amount of research applying one type of MCDM to a water allocation problem.

2. Researchers in environmental decision-making

Many researchers are focused on either using one tool for many purposes or applying different tools to one field, but using one tool for each different decision. It is most common to find researchers focusing on the former, applying one tool to a number of decision types, including environmental decisions.

Researchers using one type of decision-making tool for environmental decisions include:

Stermann at MIT - Using Systems Dynamics for many types of applications

Costanza at Maryland - Using Systems Dynamics in Chesapeake, Louisiana, and the Everglades

At Carnegie Mellon - Using Demos for Acid Rain and Global Climate Change

US. Department of Energy - Using Demos to prioritize chemical cleanup sites, etc.

Many researchers focus on environmental decision making, but do not focus on the use of any specific tools such as Haimes at the American Society of Civil Engineers in Virginia. Some researchers focus on environmental decisions from the discipline of Decision Theory such as Raiffa, Shaiffer, and Sebenius at Harvard and Kaufman at MIT, or from the discipline of Law, such as Nyhart at MIT, who is using a variety of tools including Systems Dynamics in environmental negotiations.[33] There are researchers from many disciplines applying great efforts towards Environmental decisions, but few have combined Economics and Decision Theory.

Conferences for Multiple Criteria Decision Making and Water Policy and Management, Risk-Based Decision Making in Water Resources, etc. There are always a few papers using a MCDM for fresh water allocation and other environmental resources. (Mashayekhi, 1989, O'Grady, 1993, Baba, 1986, Huang, 1989) In these cases, practitioners and researchers have looked at only one step or a few steps of environmental decision-making, not at the entire process, that is, all the steps and complicating factors that need to be overcome. Often a tool is applied to a given problem due to familiarity with the tools and accessibility of expertise.

To increase the potential for improving environmental decision making, there is a need to understand the entire process and then choose the methods and tools accordingly.

> "... the process has become one of direct and active public participation... Although this change has been evolving for some time, little or no serious thought has been given to how best to orchestrate direct participation into efficient and effective consensus building process." **(Basta,** 1993)

[33] See list of tools in **Appendix V- A** that Nyhart is exploring.

This author has found no comprehensive study on what families of tools can be best applied to different part of environmental decision making.

3. Combinations of tools used for decision-making

There are many tools available that can assist decision makers and managers; the question becomes which tool(s) to use. While many tools have been used by researchers and practitioners, none can achieve every step or overcome every complicating factor of environmental decision making. Any *one* tool may help overcome some complicating factors and enable some steps, but not help with others. Overcoming all the complicating factors and enabling all the steps may require a combination of tools.

Some researchers recognize the need for different tools to be used for different parts of a decision, and a few have documented which tools can be helpful for different purposes, for different parts of the decision making process, such as Hwang (1987), Warfield and Hill (1972), Sage (1977) and Robertshaw et al. (1978). These papers and books, though, do not review how the different tools can address different steps of decision making. Also, they are not specifically focused on environmental decision making, so there is no concern whether the tools can overcome the nine complicating factors. To date, there has been no research attempting to integrate many tools for *environmental decision-making*.

4. Environmental decisions designed for public participation

There are a few researchers focused on assisting public participation within environmental decisions, but typically they are vague about their recommendations or are focused on the process. For example, there have been a few papers on enabling public participation throughout the environmental decision making process. Some are theoretical cases and some document real cases, but none use specific tools to assist the process. They recommend group meetings and newsletters, for example to meet various steps in the decision making process. (Colosimo, 1994; Judd et al, 1994; Vlachos, 1994; Vearil, 1994) Some researchers use one tool to assist with public participation, to achieve one or a few of the steps of good decision making; typically a Simulation Model is used to inform many public participants and build consensus on the physical aspects of the system. (Thurin, 1994, Leib, 1994. Also work done by Stermann at MIT and Costanza at the University of Maryland.) There is also the use of Influence Diagrams for risk analysis. (Hong, 1991) These researchers used one tool is used, but there is very little attention paid to the overall process, each step.

Bower's Integrated Coastal Management used within the National Ocean and Atmospheric Agency, addresses many of the steps necessary for environmental decision making with public participants. Bower's ICM divides the decision-making process into five stages:

a) Analysis,
b) Detailed design,
c) Installation,
d) Operation and Maintenance and
e) Monitoring and Evaluation.

The first stage 'Analysis' is broken down further as:

i) estimate levels and spatial patterns of activities
ii) estimate demand for goods and services
iii) analyze activities to estimate the 'production function'
iv) analyze natural systems to estimate changes in habitat and ambient environment
v) analyze monetary changes
vi) formulate strategies
vii) evaluate strategies and
viii) present results of analysis to the decision process

While Bower's recommended process addresses some of the complicated factors addressed in Chapter II and is somewhat similar to the steps recommended in Chapter III, Bower's ICM spends much less focus on the analysis and on the 'how-to' for reaching consensus for a good alternative. Bower's ICM does mention a few tools, but is very vague. The information provided is "the second part of setting up the analysis involves the selection of the analytical techniques or models to be used"... Examples of tools to use might include models and techniques to:

- estimate future levels and spatial pattern of activities
- estimate demands
- analyze activities
- analyze natural systems
- estimate effects on natural system and
- estimate effects on existing institutions.

ICM suggests, "in many cases, simple analytical tools are sufficient, especially for 'first round' analyses or in cases where few or no empirical data exist.... A computational procedure could be simply a sequential algorithm connecting outputs to inputs or it could be a master linear program." It also mentions that "Multi-criteria Analysis could be useful." (Bower, 1992)

While these suggestions are not inconsistent with the analyze done in this dissertation, ICM does not provide details of how and when in the decision process different tools might be useful; the suggestions are vague. Also, these suggestions are not supported by research applying a variety of tools to one environmental decision.

This author has not found anyone that is exploring a range of tools that can be helpful to coastal environmental decisions, regardless of whether they focus on public participation or not. No research has been found that determines when in the decision-making process different tools could be most helpful, and no research that is exploring many tools in order to structure when each tool is best used. To date, no one that this author has found is researching how to integrate and combine many tools for environmental decision-making. There are no papers that:

i) review the necessary conditions of good decision-making,

ii) review the complicating factors of environmental decisions that inhibit the conditions from being met,

iii) search many families of tools to determine which can overcome the complicating factors and then

iv) recommend using the tools in a prescribed order to achieve better environmental decisions.

D. Tools likely to help make Good environmental decisions

There is a need to determine which tools are best for environmental decisions and therefore, which tools should be used.

> "Which model should be used in analyzing a specific problem, either formally or simply as a way of thinking about the problem? Perhaps this issue is not critical, since there is often no *one correct way* of modeling a problem. (italics existed)... However, some models do 'match' better with a particular problem than others, and thus, offer greater insights into the problem. Therefore, it is important to be able to recognize key characteristics of a problem that have implications for model selection." (Buffa and Dyer, 1984)

> "One should remember that the best technique to employ for a particular problem situation depends upon particular characteristics of that situation." (Evans, 1989)

Buffa and Evans recognize that there is no *one* best model for making decisions, but certain techniques and models do 'match' with particular types of problems better than others.

Certain techniques enable the decision makers to gain better 'insights' into the problem. Trying to find the tools and methods that provide 'better matches' for coastal environmental problems, the criteria for choosing are to:

i) Overcome the complicating factors of:

- inadequate information management,
- uncertainty, and
- group decision-making of having multiple people with multiple values, in order to

ii) Achieve the criteria of a good decisions:

- achieve well informed stakeholders
- include stakeholders' preferences

Reviewing all the tools in Chapter IV and V, no one tool was found that can overcome all the complicating factors. Different tools might overcome some factors, but there was no one tool that could overcome all factors. The focus should shift, then, to using more than one tool. It may be necessary to use a variety of tools, each which can overcome some of the complicating factors, yet still provide benefits even if the other factors still exist. This research will explore whether it is possible to use a combination of tools to overcome all the complicating factors.

Maximized NPV can help overcome a few factors, but it can not accommodate decisions where the criteria can not accurately be reduced to a monetary equivalent. Therefore, maximized NPV should not be used as the over-riding decision method. Operations Research tools can overcome some of the factors, but can not accommodate when there is a great amount of information, unless it can be accurately represented mathematically. Various Multi-Criteria Decision Making tools can overcome different factors, even if other complicating factors exist.

Many MCDMs can be used in combination with other tools. Market based methods such as monetary costs or benefits can be included within MCDM tools, since any variable or criteria that can be *accurately* reduced to its monetary equivalent can be included. MCDMs can also be used with Regulatory and Judicial tools. For example, an MCDMscan be used to decide what fee should be charged or the overall level of pollution that should be allowed.

All MCDMs are designed to help overcome the complicating factor of Inadequate information management, by incorporating multiple criteria and multiple objectives, non-monetized criteria and criteria from a broad range of disciplines. Many MCDMs also fit into the category of DSSs; DSSs are best use to help alleviate the problems of inadequate information management, when there are truly great amounts of information. Some MCDMs are better than others at managing information from a broad range of disciplines, eliciting and transferring knowledge.

All MCDMs are designed to be used with Multiple People, which overcomes half of the problem of Group decision-making. The purpose of some MCDMs, those that are Multiple Objective Utility Functions, is to incorporate preferences from many users, multiple values, the second half of the problem with Group decision-making. The purpose of Multiple objective Utility Functions is to elicit, record, then combine the preferences. Most MCDMs can accommodate uncertainty. Some MCDMs go further, and their purpose is to analyze the level of uncertainty in the system.

To see if these families of tools are helpful, examples from the different families will be applied to an important coastal decision case that is current: the creation of a Management Plan for the newly designated Florida Keys National Marine Sanctuary. Various MCDMs will be used to see if they can overcome the complicating factors, and if the conditions of good decision-making can be achieved.

The order in which the different families of tools will be used will also affect the decision. The recommended steps of good decision-making will be followed to maximize how these tools should be used together. Tools that assist with the first few steps will be used first, and the tools that assist with latter steps should be used later. Using the combination of tools within the steps of good decision-making will probably be most productive.

Table V - 1:

Process	**Tool**
Requirement 1) Ensure all stakeholders are represented	Political process
Step 1) Define problem, overall goal, objectives:	
elicit initial preferences	Utility Function
Step 2) Formulate criteria:	
elicit initial preferences	Utility Function
elicit information	Non Utility MCDM:
simple ones first,	Cognitive Map
more advanced	Simulation model
Step 3) Formulate choices:	
elicit initial preferences	Utility Function
elicit information	Non Utility MCDM:
simple ones first,	Cognitive Map
more advanced	Simulation model
	Uncertainty Analysis
Step 4) Sensitivity Analysis	
elicit advanced information	Simulation model
	Uncertainty Analysis
Requirement 2) Ensure stakeholders are well informed	Accumulation of all tools
Step 5) Choice:	
elicit final preferences	Utility Function
Step 6) Implementation	Political Process

E. CONCLUSIONS

The rest of this dissertation will review one case example, the coastal environmental decision that was made for the Florida Keys National Marine Sanctuary. Applying the different families of tools to a case will help demonstrate the usefulness of the tools. First, a number of tools will be looked at separately to determine what each one can achieve, then the tools will be reviewed together to determine if they can overcome all the complicating factors. Before the tools are applied, though, the actual case is reviewed.

Chapter VI. The Florida Keys' National Marine Sanctuary

The rest of this dissertation focuses on how the recommended tools can be applied to a difficult environmental decision, the creation of Replenishment Zones within the Florida Keys National Marine Sanctuary (FKNMS). The Replenishment Zone decision was just one decision among the many that had to be made for the FKNMS. To better understand the Replenishment Zone decision and how the recommended tools could be applied, it is first necessary to provide some background, quickly summarizing the entire FKNMS decision-making process. This chapter discusses why the Florida Keys are an important coastal area to be managed, then summarizes the circumstances under which the FKNMS Management Plan is being created.

Creating the Management Plan for the Florida Keys National Marine Sanctuary (FKNMS) required making many coastal environmental decisions which included all of the complicating factors identified in Chapter II. At the time of writing, the FKNMS decision-making process is nearing closure, so the process can be reviewed, and it is current enough to represent the 'State of the Art' for coastal environmental decision-making. Within the National Ocean and Atmospheric Agency (NOAA), it is one of their flagship projects for ecosystem management; NOAA is using it to learn and advance their own methods for Integrated Coastal Management. More effort and planning has been put into this decision-making process than most other coastal decisions.

A. FKNMS Case History and Importance as a Coastal area to Manage

> "Adjacent to the Florida Keys' land mass are located spectacular, unique and nationally significant marine environments, including seagrass meadows, mangrove islands and extensive living coral reefs. These marine environments support rich biological communities possessing extensive conservation, recreational, commercial, ecological, historical, research, educational and esthetic values which give this area special national significance." (The Florida Keys' National Marine Sanctuary Act, 1990)[34]

There is a need to manage the resources found in this area, because these rich marine biological communities are dying. The water quality is deteriorating in both Florida Bay and the Atlantic shore area near the reefs.

[34] Hereafter referred to as the FKNMS Act.

Although the entire ecosystem is important, the coral reefs off the coast of Florida are of particular significance, because they are the only barrier reefs in the continental United States and are the third largest barrier reef system in the world. The reefs also receive a great deal of attention, because they show the signs of misuse and declining health sooner than many of the other habitats, since they are 'exquisitely fragile.' What appears to be a large boulder is actually a colony of millions of living polyps.

Equally important, though, and interdependent with the reefs are the shallow waters near the shore, fringing mangroves, seagrass meadows, hard-bottom regions, patch reefs and band reefs. Jay Zieman, an ecologist at the University of Virginia doing research in the Bay, has studied the widespread death and decay and summarizes it as, "Hundreds of acres of Florida Bay look like the dark side of the moon." (Dewar, March 1994) Mr. Karl Lessard, a fisherman in the Keys, and an FKNMS Advisory Council member stated, "Florida Bay's 'Dead Zone' is now hundreds of square miles, an area devoid of any fish or seagrasses and thick with heavy algae growth." (Dewar, May 1994)

1. The importance of the Reefs and Florida Bay

The decline and destruction of the marine environments must be arrested, because the many benefits and resources they provide are dwindling. First, healthy reefs produce and provide many resources, even though reefs are rare.[35] They provide fisheries, pharmaceuticals, coastal protection, tourism and recreational uses. Healthy coral reefs are one of the most species-rich ecosystems on earth, and are often compared to rainforests; a rich population of plant and animal life depend on the reefs for shelter, food and a place to attach and grow. The reef community out-produces productive ocean fisheries by a factor of between 10-100. Reef catch worldwide is estimated at 45-48 million tons, approximately 10% of the total world fish production, even though reefs only compromise 0.17% of the seas' surface. Coastal protection can be very costly in the absence of a reef. The government of Maldives destroyed a reef for a land reclamation project making it necessary to build a seawall for coastal protection that cost $12 million per kilometer. (Weber, Worldwatch Institute, 1993)

Tourism is supported not only by healthy reefs, but also by the other habitats. The fish from Florida Bay and the reefs draw many recreational fishermen, who spend many tourist dollars trying to find trophy size fish. The beaches draw sunbathers, swimmers, campers and shell collectors. The reefs are the main attraction for the scuba diving and snorkeling industries in

[35] Coral reefs are relatively rare; although oceans cover 70% of the Earth's surface, coral reefs occupy only about 0.17% of the sea, roughly 238,000 square miles. (Ward, 1990)

the Keys. An example of the importance of recreation is that in 1990, there were only 78,000 permanent residents in the Keys; in comparison over 1.3 million people visited a single park in the Keys, John Pennekamp Coral Reef State Park in 1990. (Ehler, 1994) Florida's marine resources draw many tourists from the U.S. and abroad.

Outdoor recreation and tourism (i.e. sport fishing, diving, snorkeling and beach resorts) support about half of all employment in the Keys. (Ehler, 1994) Allowing the continued degradation and deterioration of the habitats will result in foregoing part of the Keys' $800+ million in annual tourist expenditures. (**Kearney** and Centaur Report, 1990) The continued degradation also affects the commercial fishermen, another business that generates $5 million annually in the Keys alone. (Dewar, May 1994) There are no major industries in the Keys other than tourism and commercial fisheries; without these two industries, the entire socioeconomic structure would collapse. (Ehler, 1994)

2. Causes for the decline of the marine life

The problems and causes for the collapse of the marine ecosystem are intertwined and complicated; no one understands them all. Scientists and researchers typically begin with trying to understand the conditions for maintaining a healthy ecosystem. It is not possible in this dissertation to cover all the conditions necessary for healthy Keys' ecosystems. There are many interconnections and the number of intertwined factors are large. (See Appendix VI-A for a summary of the necessary conditions for just coral reefs.)

In general, Florida Bay and the reef tract are dying, because the narrow range of necessary conditions required for a healthy ecosystem are being exceeded due to many anthropogenic and natural events. These narrow range of conditions include restricted nutrients, toxins, salinity, turbidity, temperature and physical contact. Poor water quality plays the largest role, but other factors also add to the stresses and cause the ecosystem to die. Alan Bunn, Lieutenant and Manager of Key Largo's National Marine Sanctuary, prioritized the problems as follows: water quality, increased development, physical contact and storms.

Water quality is poor because the water bodies surrounding the Keys have too many of both nutrients and toxins from agriculture and domestic runoff. This exists largely because the resource of freshwater was left to the Market System. Users upstream diverted the freshwater for uses such as farming, municipal water supply and flood control, decreasing the freshwater flow left to dilute the nutrients and toxins. High concentrations of nutrients and toxins entered surrounding water bodies. (See Appendix VI-B for a full discussion.) High levels of nutrients cause the algae to flourish, which has become the key problem. The algae decreases the amount of dissolved oxygen in water and clouds the water, blocking sunlight from corals, seagrasses and other plant life. Larger species of algae also flourish, quickly overgrowing and smothering the living coral polyps and other marine life.

The toxins also destroy the marine life. Petroleum products, heavy metals, herbicides and fertilizers used on land eventually reach the water body surrounding the Keys, since they can not go anywhere else. The toxins of pesticides, designed to kill insects, are suspected of slowing the growth, interfering with the reproduction and lowering the resistance of marine organisms. (Ward, 1990) Oil and heavy metals cause corals to be more susceptible to disease, and the corals are more likely to grow slowly. The oil and heavy metals also damage other living organisms in the Sanctuary such as zooplankton, bottom dwelling communities and fish. There are many toxins in the FKNMS waters; over a 26 month period, water samples from John Pennekamp State Park exceeded the State standards for pesticides more than 50 times and for plasticizers 65 times. (Ward, 1990) Once toxins and nutrients deteriorate the water quality, corals and other organisms in the marine environment may not have the strength to recover from the stresses of people, boats, storms and silt. It is true that "A coral reef is only as healthy as the water around it." (Ward, 1990)

Increased Coastal and Land Development can often be a problem. Coastal development such as dredge and fill activities, channeling and building of sea walls cause indirect damage from increased turbidity and silt deposits. These block sunlight from corals, seagrasses and other plant life. Coastal development also causes direct destruction of reefs and other habitats. Increased land development causes increased nutrients from sewage and lawn care, and increased toxins from mosquito spraying and pesticides.

Physical contact and boat grounding damage the reef and other marine environments. There were 100 small boat groundings in the FKNMS in 1993 alone. (Bunn, 1993) Coral reefs damaged by boats can take 50 to 100 years to repair, sometimes even longer, depending on the species of coral. In Florida Bay, boats run aground or drag their propellers, destroying hundreds of acres of seagrasses and other plants every year. Physical contact from divers and snorkelers also kills the reef. Divers and snorkelers accidentally kick the reef while swimming or stand on it when they are tired. Even a small scrape from a diver is enough to cause fatal infections. The physical contact might not be a problem if there were only a few visitors, but that is not the case. For example, four million visitors came to the National Marine Sanctuary in 1992; on average, about half the visitors make it into the water. (Causey, March 1994) The five most crowded reefs attract 3000 people on an average day and double that on warm weekends. (Ward, 1990)

Natural phenomena such as hurricanes and storms damage the reef. Strong winds and waves can break branching corals, such as elk horns, which then tumble and damage other corals. Waves can also churn up the water, causing bottom sediments to be re-suspended and turbidity to increase.

3. The effects

Many marine species are dying because the narrow range of conditions are being exceeded. There are always the natural stresses of storms and temperature fluctuations; they are now being compounded by human impacts such as increased nutrients, sediments and toxins; increased salinity due to low freshwater flow; and direct contact from divers and boats. The most delicate species are dying first, but because of the inter-relatedness of the organisms' habitats, many organisms are declining.

When water quality deteriorates, the corals and other organisms become more susceptible to diseases. For example, two coral diseases, White Band disease and Black Band disease, as well as a condition called Bleaching, are becoming common in the reef.[36] Florida Bay has been dying as well. In 1987, "the grasses of Florida Bay began to die - slowly at first, then fast as an avalanche."[37] Now hundreds of acres of Florida Bay are seemingly devoid of fish or green seagrasses The waters are turbid, full of silt from the nearly barren bottom. Olive green and rust colored algae blooms abound. "The Bays shallow banks are empty nurseries, seemingly devoid of the creatures that made Florida Bay a rich source of commercial seafood catches." says Jay Zieman, Ecologist from the University of Virginia. (Dewar, March 1994)

4. The response

Slowly people became aware of the problems. The State of Florida first recognized the reef as a valuable asset over 30 years ago, then slowly other habitats were recognized and more people and government agencies realized their importance. In 1960, the state of Florida created John Pennekamp Coral Reef State Park. In 1975, the Key Largo reef area was declared a NOAA National Marine Sanctuary, followed by the Looe Key National Marine Sanctuary in 1981.

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[36] See **Appendix VI - A** for a description of these diseases and conditions.

[37] This observation "fast as an avalanche" supports the theory that ecosystem decline is often not linear, and we can rarely predict the rate of future decline by reviewing the rate of past decline. There is often a threshold level, that once passed, irreversible episodes (such as rapid death) or total extinction of a species occur.

Over time, the neighboring habitats and the ecosystem as a whole were recognized as interdependent and all part of a valuable asset. In the 1980s, there were droughts, fish die-offs, coral bleaching and coral diseases. In 1987, Keys' residents began seeing seagrasses dying in Florida Bay, and began talking about the problems of coral reefs. In April 1989, the Exxon Valdez hit in Alaska; many people around the U.S. and world became more aware of coastal environments. In October 1989, four U.S. Congressmen went on a snorkeling tour in the Keys, including George Miller, the Head of the National Resources Committee.[38] Two weeks later, a 150' ship hit a reef in the Keys; one week later a 400' ship hit the Dry Tortugas, and the following week a ship hit the reef off Key Largo. This alarmed many people, inciting them to act and / or demand action from government agencies. The resources of the marine habitats could no longer be subject to laissez faire; they would not be allocated via the Market System. Too many externalities were affecting the natural resources.

Florida Representative Dante Fascell and Senator Bob Graham introduced federal legislation to provide comprehensive protection to the marine environment of the Florida Keys. Finally, in November 1990, the Florida Keys National Marine Sanctuary (FKNMS) and Protection Act was enacted by Congress and signed into law by President Bush. This FKNMS Act declared that an area surrounding the Florida Keys be designated as a NOAA National Marine Sanctuary. [39]

B. Review of overall context in which FKNMS decisions were made

The body of water surrounding the Florida Keys was designated as a National Marine Sanctuary by Congress in 1990 with the passage of the FKNMS Act.[40] It was the first and only National Marine Sanctuary to be declared by Congress; all others are designated internally within NOAA, typically after being nominated by the region. The FKNM Sanctuary encompasses about 2800 nautical square miles of submerged lands and waters between the southern tip of Key Biscayne and the Dry Tortugas Bank, including waters in both the Atlantic Ocean and Florida Bay. (See a map in Appendix VI - C.) Numerous state and federal parks and reserves are located within the boundaries of the Florida Keys National Marine

[38] George Miller later became instrumental in passing the FKNMS Act.
[39] In 1972, Congress passed the Marine Protection, Research and Sanctuaries Act (MPRSA) in response to a growing awareness of the intrinsic environmental and cultural value of U.S. coastal waters. Through this Act, discrete coastal areas are designated as National Marine Sanctuaries to promote comprehensive management of their special ecological, historical, recreational and esthetic resources.
[40] See **Appendix VI - D** for a copy of the FKNMS Act.

Sanctuary. Approximately 58% of the Sanctuary's waters are under the jurisdiction of the State of Florida.

National Marine Sanctuaries are administered by the Sanctuaries and Reserves Division (SRD) of NOAA, which is a division of the Department of Commerce. Because NOAA is in the Commerce Department, sanctuaries need to be managed for *use* as well as *conservation*; they can not simply be preserves. As managers, NOAA needs to "*watch, monitor and protect*" while the sanctuaries are being used, but before the natural resources decline.

1. The different parts of the decision

The FKNMS Act requires two main provisions: i) for NOAA to prepare a Comprehensive Management Plan (MP) for the Sanctuary after consulting with the public and with federal, state and local government authorities and ii) to develop a Water Quality Protection Program (WQPP) jointly with the EPA and the Florida Department of Environmental Resources and with NOAA oversight. There are also a few other pieces of work being completed to support these two major parts. The Management Plan and WQPP are currently being reviewed and will be implemented in 1995-96. (For more details, see the full Act in Appendix VI - D.)

a. The Management Plan (MP)

The Act mandates that "the Secretary of Commerce (through NOAA) in consultation with appropriate Federal, State and local government authorities and with the Advisory Council established under section 208, shall develop a Comprehensive Management Plan and implementing regulations to achieve the policy and purpose of this Act." The Management Plan has several major objectives set out for it. Among the nine objectives, three of the most relevant to this case study are:[41]

i) Facilitate those public and private uses of the Sanctuary which by their nature do not deplete or damage the integrity of the resources.

ii) Consider temporal and geographic zoning to ensure protection of sanctuary resources.

iii) Ensure coordination among the different agencies.

b. The Water Quality Protection Program (WQPP)

The Act places particular emphasis on improving water quality throughout the area. "The Administrator of the Environmental Protection Agency and the Governor of the State of Florida, in consultation with the Secretary of Commerce, shall develop a comprehensive Water Quality Protection Program for the Sanctuary. In the development and implementation

[41] See the Act for all nine objectives.

of the program appropriate state and local government officials shall be consulted." EPA was provided $1.5 M over two yeas and used a consulting firm to develop much of the WQPP.

c. Other major parts of the Management Plan

The Environmental Impact Study (EIS) was developed by the USEPA as the MP alternatives were being developed. In addition, a Socioeconomic Impact Assessment was conducted by two economists from Florida State University;[42] from the 100+ different pieces of the MP (i.e. management strategies), 24 were chosen for review because the benefits or costs of the strategies were of great concern, or there was significant variation across the different alternatives formulated. Unfortunately, the economists, Dr. Bell and Dr. Sorenson, found it difficult to quantify most of the effects. (See NOAA's FKNMS Draft Socioeconomic Impact Study for details.) The EIS and Socioeconomic Impact Study will be included in the overall Management Plan and have been used during the decision-making process.

2. The decision makers

The entire decision-making process to develop the MP and WQPP has taken over four years and included many different people. Because of the size of the Sanctuary, the variety of resources it contains, and the intensity of the land and water uses in the FKNMS, there were many meetings held with many different groups to address these non-traditional types of problems.

The groups that took part in the decision-making process for the Management Plan were many. The general public took part via numerous Public Scoping meetings and workshops, where input was received from a number of public and private interest groups. NOAA also created three distinct groups outside of NOAA and these different groups also held numerous meetings. There was considerable interaction and some overlap in membership and function among these teams, but the focus of the three teams were different; together they were created i) to ensure that contributions were provided by major stakeholders in the Sanctuary and ii) to see that a plan was produced that met the standards set forth by the Act and NOAA.

42 A socioeconomic impact assessment attempts to assemble information on the groups and / or industries likely to be impacted by various management strategies. The "qualitative nature of the kinds of impacts are discussed with respect to the connections among changes in quantity and / or quality of natural resources and their uses, and in relation to both theory and past experience. Where possible, the extent of economic values and economic impacts (sales, employment and income) associated with various uses are quantified." (Draft Socioeconomic Study, NOAA)

a) **The Interagency Core Group** was composed of managers from Federal, State and Local government agencies with direct jurisdiction in the Sanctuary. The Core Group had 28 members, including directors of National Parks, directors of six State Parks and State and County land managers. Daniel Basta, the Chief of SEA at NOAA, chaired the Core Group throughout the MP development process. The Core Group (CG) was formed to develop policies and direct the Management Plan development process. The CG helped determine the regulatory methods and laws that were in place or needed to be enacted in order to implement the recommendations. The CG held many working sessions, helping to structure the MP, flushing out the details. (See a list of the Core Group members in Appendix VI - E.)

b) **The Sanctuary Advisory Council** was mandated by the FKNMS Act to ensure public contributions to the plan and to advise and assist NOAA in the development and implementation. The Advisory Council (AC), made up of 'frequent users,' was established to act as a conduit of public opinion and to assist in developing the Plan. The Advisory Council includes representatives from commercial and recreational fisherman; the sport diving industry; realtors; hotel and motel operators; environmental groups; and representatives from the general public. (See Appendix VI- F for the complete list.) The Council members had to be approved by the Department of Commerce and even by the White House in some cases. The process by which the AC contributes to developing the MP has to follow the guidelines set out in NEPA.[43]

c) **A Strategy Identification Work Group** was composed of 45 local scientists and resource managers from various government agencies. This group generated the initial set of strategies and details on implementation requirements.[44] NOAA chose these representatives based on their knowledge of the local and regional issues related to the Sanctuary and their expertise regarding the establishment and maintenance of resource management programs. The scientists were those who had been doing research around the reefs and Florida Bay for years. The resource managers invited were "those who were the professionals out in the field, who dealt with the issues everyday." (Haskell, June, 1994)

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[43] Among other things, NEPA mandates how to set up an Advisory Council and how to take public comment.

[44] This group differed from the Core Group in that they were usually people who were closer to the field and worked in or around the Sanctuary often. Agencies included were NOAA, USEPA, the US Fish and Wildlife Service, the US Army Corps of Engineers and the US Coast Guard. State agencies included the Department of Natural Resources, the Department of Community Affairs, the Department of State and the Game and Fish Commission. Local representation consisted of Monroe County officers and officers from the South Florida Water Management District. Core Group members were usually a higher organizational level than the Strategy Identification Work Group members and further from the field.

NOAA hoped that by getting this group together, the workshop would get the many different agencies and groups to buy into the program and start working together for the future.

3. The tools

The Sanctuary and Reserves Division (SRD) was the NOAA group that had the responsibility for developing the Management Plan. The SRD had a certain method for developing Sanctuary Plans; they typically held public meetings to elicit comments, recorded the publics' opinions, then drafted the plan. In the Summer of 1991, Charles Ehler, the director of the Strategic Environmental Assessment (SEA) arm of NOAA was given temporary authority over the Sanctuary and Reserves Division. He determined that the FKNMS could benefit from SEA's information gathering and organizing methods for developing the Plan. The process actually used to develop the FKNMS Management Plan evolved as time went on and had pieces of both SEA and SRD.

SEA's involvement started in the summer of 1991, after the first Core Group meeting. Daniel Basta of SEA became involved and brought with him some of the principles of Bower's Integrated Coastal Management (ICM) process (Bower, 1992 and review Chapter V for more details). SEA's focus was on helping the best available scientific and economic information be included in the decision; they focused on the *process* of developing the Management Plan. The different Core Group members, the Advisory Council, the Strategy Identification Group and members of the public developed the *content* of the MP. SEA created a time frame designed for the FKNMS MP process, specifying when different meetings should be held, what groups should be involved, what documents needed to be published, etc. SEA also created a tool called 'Knowledge Engineering' which was used in sixteen of the Management Plan working sessions.

'Knowledge Engineering' is a process in which participants divide into various groups, each group focusing on a different part of the overall problem. To elicit and record information concerning each part, the group members i) discuss the topic, while rapporteurs record the information and ii) fill out worksheets and survey forms and later the rapporteurs organize the worksheets. The components of 'Knowledge Engineering' are:

"i) have expert knowledge available,

ii) employ an explicit process of using workshops with templates and survey forms, and

iii) use it in real time." (Goodspeed, 1994)

'Knowledge Engineering' is similar to some of the basic, written MCDM techniques such as Brainwriting and the Nominal Group Technique. Mr. Goodspeed, from NOAA's SEA department, described 'Knowledge Engineering' as "the application of organization and structure to the process of directing, acquiring and encoding what is known about a subject or problem." (Goodspeed,1994)

After an information gathering meeting was held using 'Knowledge Engineering,' NOAA's Sanctuary and Reserves Division would then use the information that was gathered - the surveys, worksheets and rapporteurs' reports, sometimes summarizing them further. Approximately 80 participants have served as the principal working knowledge base in the 'Knowledge Engineering' work sessions, although about 350 individuals have been involved to some degree. (Basta, 1994) The Core Group used 'Knowledge Engineering' most often, and the Strategy Identification Group used it the two times they met. SEA suggested these groups use 'Knowledge Engineering' to elicit information from and to help stimulate ideas for management strategies.

SEA typically ran the working sessions for the Core Group and Strategy Identification meetings after the summer of 1990. A Core Group member, most often Mr. Billy Causey, NOAA's FKNMS Manager, would suggest an agenda or problem that he or she thought should be addressed at the next meeting. SEA would develop a straw man concept of what method could be used to meet the agenda, then suggest it at the Core Group meeting. "It was a fluid process. SEA would say 'This is the way we think we should proceed - does anyone have a better idea?' At the Core Group meetings, usually no one did." (Haskell, June 1994)

In contrast, the Advisory Council often did not want to use SEA's suggested methodologies or the 'Knowledge Engineering' process. 'Knowledge Engineering' was often too much of a structured or constraining format for the Advisory Council. As Mr. Causey, NOAA's FKNMS Manager, said:

> "Sometimes it was used, but sometimes the Advisory Council did not give Dan Basta the time to use even one survey form," and
>
> "The Advisory Council rarely used 'Knowledge Engineering' or the suggestions from NOAA's SEA division. The Advisory Council preferred to control their own meetings."

Typically, the Advisory Council preferred to use their own format and methods, most often discussion and brainstorming.

There were a few other tools used by groups to make decisions related to the FKNMS, but none in the AC, CG, Strategy Identification Workshop or NOAA meetings. (For information about these other tools, see Appendix VI - G.)

4. The meetings and process[45]

NOAA SEA division generally followed a process for Integrated Coastal Management (ICM) decisions designed by Blair Bower. (Bower, 1992) This process has five major stages:

a) Analysis,

b) Detailed design,

c) Installation,

d) Operation and Maintenance and

e) Monitoring and Evaluation.

The Analysis stage is broken down further into eight stages of steps (review Chapter V). NOAA's intent was to achieve the many pieces, but Bower's ICM recommended process did not advise what tools might be helpful.[46]

In an attempt to achieve a good 'analysis,' many meetings were held. Developing the MP and WQPP has necessitated many public hearings and public workshops where the many groups have had input. A summary of the time line for the entire FKNMS MP decision-making process is:

- Keys Act signed November 1990
- 6 Public Scoping meetings held April and May 1991
- Core Group formed in June 1991
- 9 Public Technical Workshops held July 1991 - February 1993
- Technical Working Sessions held all 1991 - 92 (Core Group alone held 12+)
- Strategy Identification Work Group met and formed strategies in February 1992
- Advisory Council was formed in February 1992
- 26 Advisory Council meetings held February 1992 - August 1994
  16 two-day full committee meetings (two public comment periods at each AC meeting)
  10 subcommittee meetings
- Strategies Alternatives Meetings held all 1992, into 1993
- Zoning Alternatives developed June 1992 to February 1993

[45] **See Chapter** VII for a much more detailed analysis of the FKNMS process, with particular focus on the Replenishment Zone process.

[46] While this might have been NOAA's aim, it was not necessarily achieved as documented in NOAA's NOS report. The actual process is reviewed in detail in **Chapter VII**.

- 6 Water Quality Steering Committee Meetings (two public comment periods at each meeting)
- 2 Water Quality Technical Advisory Committee Meeting

The following is a more detailed timetable and the contents of the meetings held for the FKNMS MP decision-making process, with particular focus on the Zoning Issue.

November, 1990 - FKNMS Act is passed, which includes as one of nine objectives, "Consider temporal and geographic zoning to ensure protection of sanctuary resources."

April & May 1991 - Six initial Public Scoping meetings were held: the general public and researchers came to brainstorm the problems and identify the concerns. A survey was sent out to the Keys' residents to elicit information. The six meeting were held in various locations: three in the Keys, one in Miami, one in Tampa and one in DC.

June 1991 - The Core Group was formed and met for the first time.

July 1991 - NOAA's SEA division became involved in the FKNMS Management Planning process. The Core Group met for a two-day session and broke down the information from the Public Scoping meetings and the surveys into seven different Issues using the 'Knowledge Engineering' Process. The seven Issues were Boating, Fishing, Land Use, Recreation, Water Quality, Zoning and Education.

Fall 1991- Pubic workshops began on each of the seven Issues and a few other specific topics. Different members of the general public were invited by NOAA to participate and vote, although the meetings were open to the general public. The different Issues were brainstormed, eliciting the problems, recommended solutions and various details; surveys forms were also used. The schedule for the different workshops were as follows:

Management Issues - July 1991
Mooring buoy workshop - July 91
Education workshop - September 1991
Research workshop - October 91
Submerged Cultural Resources workshop - October 91
Zoning workshops - December 91 through February 93 (See below for more details.)
Water Quality Workshops - started in January 1992

NOAA worked to record and conclude the results from the survey forms that were used in the public workshops, the mail surveys and the Core Group meetings. NOAA sent out the results / conclusions to the different groups involved to get consensus, to determine if it was what the groups intended.

The Zoning process received special focus from the other Issues after this time, since NOAA recognized that there would a great deal of controversy and tradeoffs, where some people would lose and others would gain.

December 1991 - There was an update meeting with the Core Group. At the end of the meeting, Mr. Billy Causey, NOAA's FKNMS manager, elicited some of the CG's initial values by running a brainstorming session for the Zoning Issues. He asked "How could Zones be used and what would the Core Group like to see for Zoning?"

Calendar Year 1992 - The Nature Conservancy and the State of Florida conducted an aerial boat survey, doing 50 weekly fly overs to take photographs of the entire reef tract except for the Tortugas. This produced a survey of the density and types of boats which used various areas; the aim was to see which areas were most heavily used. This data was used to determine what areas should or should not be included in various zones.

January 1992 - NOAA ran a brainstorming meeting for Zoning with the general public broken down into five distinct user groups. The five Zoning workshops were:

Environmentalist and educators	Day 1
Commercial Fishermen	Day 2
Recreational Fishermen	Day 3
Divers	Day 4
Scientists	Day 5

NOAA sent invitations to 24 people from each of these groups and the general public was encouraged to attend these sessions. Mr. Billy Causey, NOAA's FKNMS manager, began each workshop with a presentation of how Zoning had been used in other countries such as Australia, New Zealand and in Britain's Bermuda. Mr. Causey said "These five-day meetings planted the idea of how we might use zones."

Participants were asked to talk about the objectives, criteria and rationale for zoning. The participants were asked to comment on how they believed they would be affected by the types of zones, and how they could use zoning to halt the depletion of resources. NOAA solicited ideas for how zones might be useful, how they might be beneficial. Many of the users wanted zones to i)reduce user conflicts and ii) halt resource depletion especially those from specific fishing practices such as spear-fishing or traps for shellfish. The goal was not to talk about exact locations or sizes for zones, although sometimes the users brought up the topic.

Thirty-seven types of zones were recommended in the five-day session. These thirty-seven types were very detailed, such as 'No spear-fishing,' 'No personal watercrafts,' or 'Research only.' Different focuses came from different user groups.

Early February 1992 - A four day Strategy Identification Workshop was held where the Strategy Identification Group formulated 270+ strategies for the various Issues of the FKNMS. The information solicited during the Public Scoping Meetings and Workshops was provided to the participants and the 'Knowledge Engineering' Process was used. It consisted of two parts: i)strategy identification where the participants worked in groups to identify and describe possible management strategies and ii) strategy characterization, where participants worked in groups to describe the potential impacts of the strategies.

Late February 1992 - The AC had its first meeting. The formation of the Advisory Council was relatively late in the process, since the AC members needed governmental clearance and it was a time consuming process; NOAA could not hasten the AC late starting date. In their first meeting, the AC reviewed the 270+ Strategies that the Strategy Identification Group had identified and throughout the Spring, they reviewed the other work already completed. The Zoning process differed from the other Issues after this point, because Ed Lindelof, Head of NOAA's SRD Eastern Division promised the Advisory Council that they could take charge of making the Zoning decision.

March 1992 - In their second meeting, the Advisory Council started working on the Zoning criteria and categories of use.

Spring 1992 - The AC took the list of 37 Zone types developed in the January 1992 workshops and broke it into seven major groups of Zones, then the CG broke it down further into four types. This was when the idea for Replenishment Zones was formalized. The AC listened to over 24 presentations on pros and cons of Zoning and were given many reports. The AC also held various meetings with the public and different AC members met with their different user groups to elicit information. Also, at the end of every AC meeting, members of the general public could comment, and could give the AC their opinions on the direction they were taking.

June 1992 - Advisory Council worked in small groups and created an additional 60 strategies to add to the list from the Strategy Identification Workshop. NOAA reviewed the comments made in the Public Scoping meetings and the Workshops to identify any omitted strategies; this yielded 30 strategies. Non governmental organizations contributed another 15 strategies.

In an effort to begin creating Zone boundaries, NOAA asked the AC members to consult with their constituents to find out where their activities took place and what areas they would be willing to give up. NOAA supplied each AC member with a set of maps to work with their respective user groups and descriptions of how each Zone met the users' criteria. The maps were given to mark i)where they do their work, ii) where they need to have access to or where do they traverse, iii)where do they experience the most user conflicts, and iv) which are areas of special significance. Working in coordination with their constituents, the subcommittee reviewed benthic habitat maps, information and maps on human activities and use levels, and high-resolution aerial photography covering the proposed Zones. This information was used to draw boundaries on nautical charts and the aerial photographs.

July 1992 - It was scheduled that on the second day of the meeting, the AC would review what was found after consulting with the different user groups. Some members of the public, still vehemently opposed to Zoning, staged a protest after the first day of meetings; this group was led by treasure salvagers. There was a mock hanging of stuffed dummies dressed to represent various NOAA members. Also, the public had written messages on coconuts and were going to roll them towards the AC members as they exited the building; they rolled a few, hit one of the women AC members, then placed the rest on a table.

August 1992 - Because the tension was growing, and rumors were spreading that Zones would encompass one-third of the entire sanctuary, two NOAA members penciled in the first boundary lines for different Zoning alternatives to expedite the process. Billy Causey and Rob Finegold, NOAA employees in the Keys, penciled in the first drafts of different alternatives for the five different Zone types, specifying various Zone locations and sizes. Alternative III, the moderate alternative, included three Replenishment Zones, one in Sambos, one in Dry Tortugas and one in Marquesis, in total encompassing about 5% of the sanctuary waters. The two NOAA members considered the areas of heavy used and the information provided by the user groups in an effort to create boundaries where the losses were reduced, yet the benefits of Zoning could still be reaped.

Late August 1992 - CG reviewed NOAA's initial recommendations and added some new Replenishment Zones. For Alternative III, two new locations, Key Largo and Looe Key were added. They also approximately doubled the total area of the Replenishment Zones. (Causey, January 1995)

September 1992 - NOAA showed the boundaries to the AC. The Advisory Council created a Zoning subcommittee to do some detailed work. This established the starting point for a more deliberated set of work sessions. The Advisory Council met monthly and the subcommittee met more frequently for a few months to work on Zoning. The Advisory Council also started to work on other areas, Issues other than Zoning.

September 1992 - The Core Group also met regularly, discussing different Issues, including Zoning. In one meeting, the Core Group reviewed the 370+ strategies for similarity, combining some to form a new strategy. They solidified and condensed the 370+ strategies into 100+.

> "Distillation took place. We combined overlapping strategies, cut suggestions that were not feasible and cut repetition. We checked with the Advisory Council to make sure we had captured most of their ideas." said Mr. Benjamin Haskell, NOAA SRD employee.

The Core Group created the first draft of what different strategies should be grouped in each of the seven Issues. They created the first draft of Alternatives I, II, III, IV and V for each of the seven Issues by grouping the different strategies. The five Alternatives represent a range of protection for the FKNMS Management Plan. Alternative I was the most protective and included all of the 100+ strategies, while Alternative V was the least protective and only included some of the 100+ strategies.

October 1992 - NOAA ran a second meeting for the Strategy Identification Group. The goal was to get consensus for the 100+ Strategies and to generate ideas for implementing them. To ensure that the Strategies could be implemented, SEA required detailed information on funding, lead agencies, scheduling and contingency plans for every strategy.

Winter 1992-93 - The AC reviewed the work done by the Core Group. They were asked to review Alternative III most closely, and alter the drafted Alternative III to represent their views for each of the Issues. Alternative III was then used as the backbone of the

Management Plan. A few of the strategy were added or subtracted and the language was made more or less restrictive to create the other choices, Alternatives I, II, IV and V.

December 1992 - The AC Zoning subcommittee held a workshop meeting, which ended in a field trip. NOAA members, AC members and members from the different user groups went out into the field to look at the most controversial Zones. This was done to evaluate the size of the Zones, to examine the amount of resource protection provided by the proposed Zones, and to gain insight on possible impacts on users. As a result of this process, some zone boundaries were refined. Lines were erased and new lines were draw on the maps. The Advisory Council reduced Alternative III for Replenishment Zones back to three locations and about 5% of the total sanctuary. "This was the turning point," when NOAA and the AC moved towards reaching consensus, said Billy Causey, NOAA's FKNMS manager.

January 1993 - The AC's Zoning subcommittee met with NOAA to i) develop criteria for selecting Sanctuary Preservation Areas and Replenishment Reserves, ii) apply the criteria to the proposed Zones, iii) develop a subset of Zones to be examined further.

February 1993 - The AC subcommittee met to make final adjustments to Zone boundaries, and to present their proposal to the public and the full Sanctuary Advisory Council. The Advisory Council was going to vote on each Zone one by one, but decided to vote on the entire Zoning alternative as a package. They voted on Alternative III recommending that 19 SPAs, four 'research only' SPAs, two Replenishment Reserves and one 'Special-use' Replenishment Reserve be included in the Management Plan. Finally, NOAA and the Core Group reviewed and modified the Advisory Council's proposal slightly. There are 19 SPAs, four Special Use Zones and three Replenishment Zones. The Replenishment Zone alternative finally chosen was to create Zones is three locations, the Sambos, the Dry Tortugas and Key Largo, totaling more than 5% of the FKNMS area.

Spring and Summer 1993 - The AC finished voting on all of the seven Issues. The AC voted on Alternative II for two of the Issues: Education and Research & Monitoring. They voted to accept Alternative III on the other five Issues.

November 1993 - NOAA completed the draft of the Management Plan and was finishing the other parts of the Plan, such as the DEIS and the Socioeconomic Study.

1994 and 1995 - In 1994 and early 1995, the focus in the Keys became the Water Quality Protection Plan, while the Management Plan went through due consideration.[47] In 1994, the Management Plan was circulated within NOAA and checked for consistency and to ensure that the jurisdiction of other divisions, such as the Fisheries Councils, were respected. NOAA also completed the EIS and the other pieces of the Plan. After internal checks were completed, the Plan was sent to the Office of Management and Budget for federal review.

In spring of 1995 the MP is expected to be released to the general public for comment and an external review will take place for eight months. Six public meetings will be scheduled where the public will be able to voice their views on the Plan: three in the Keys, one in DC, one in Miami and one in Tampa, or the public can write in to express their views. By NEPA law, NOAA must address every comment that is made during the public review process. NOAA, environmental groups and some members of the public are expecting some of these public meetings to become heated debates.

After the Management Plan is developed by the many decision formulators, it must be approved by the Secretary of Commerce and the Governor of Florida before it is enacted. If the Secretary of Commerce does not sign it, then NOAA has to restart the entire process. If the Governor of Florida does not sign, the Plan will not be used within Florida waters (68% of the Sanctuary).

C. CONCLUSIONS

This chapter reviewed the importance of the FKNMS Management Plan and the overall circumstances within which the FKNMS decisions were made. The most difficult decision made in the FKNMS Plan has been determining the size and location of the Replenishment Zones. The alternative finally chosen was to create Replenishment Zones is three locations, the Sambos, the Dry Tortugas and Key Largo, totaling more than 5% of the FKNMS area. This dissertation will use the Replenishment Zone decision to analyze how the different tools might have been utilized in the actual case. The next chapter will review the Replenishment Zone decision process in depth to better understand how the proposed set of tools might be used.

[47] There has been some discussions and debates within NOAA; the National Marine Fishery Agency of NOAA questioned the no-fishing zones of the Sanctuary, wondering if it infringed on their jurisdiction.

Chapter VII. The Florida Keys Replenishment Zone decision

This chapter discusses the Replenishment Zone decision made as part of the FKNMS Management Plan. This research focuses on the Replenishment Zone decision to determine if the methods and tools suggested in this thesis could have helped make a better decision. This is judged by determining if i) the steps and requirements could be more fully completed, ii)the complicating factors reduced in severity and iii) the three necessary conditions of good decision-making more thoroughly achieved. Before projecting how the tools could be used for the Replenishment Zone decision, it is important to focus on the details of how the actual decision was made, to review the actual process, so that one can understand how the different tools might be applied.

The FKNMS' Plan most difficult decision: the Replenishment Zone

The FKNMS Act written by Congress required that spatial and temporal Zones be considered, thus the Zoning Issue became one of the seven Issues in the FKNMS Management Plan.[48] Of the seven Issues, the Zoning Issue was the most controversial. "We knew the biggest challenge was going to be in the area of Zoning. Asking people to give up traditional uses caused great controversy," said Mr. Billy Causey, NOAA's FKNMS manager. (Causey, March 1994)

Within the Zoning Issue, there are five Zoning Strategies, or five Zone types:

i) Replenishment Zones

ii) Sanctuary Preservation Areas (SPAs)

iii) Special Use Zones

iv) Wildlife Management Zones and

v) recognition of all the existing Zones / management areas within the FKNMS borders.

In total, all the proposed Zones represent approximately 150 sq. nautical miles, slightly less than 6% of the total Sanctuary area. Deciding on the Replenishment Zones was the most difficult of the five Zones types, because of their shear size: slightly more than 5% of the Sanctuary.

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[48] The seven Issues are as follows:

1. Zoning
2. Boating
3. Fishing
4. Land Use
5. Recreation
6. Water Quality
7. Education

If the Replenishment Zones are created, no activity or 'No-use' could take place in these Zones in an effort to minimize human disturbances and to meet their stated purpose -"to protect the homes and foods of important commercial fisheries and to protect all of the 6000+ species that are not covered by the Fisheries Management Council."[49] Citizens in the Keys resent being prohibited from using certain areas of the Ocean and Bay, areas that have always been common property with unrestricted access. Some fishermen, divers, boaters and other users do not want to give up some of their fishing or diving spots, which they equate with giving up part of their incomes. (Causey, June 1994) It is not certain that Zoning will provide benefits, and there is more uncertainty as to what kind of benefits or the quantity.

A. ANALYSIS OF THE FKNMS DECISION-MAKING PROCESS

To review the FKNMS decision-making process, it is most informative to review each of the recommended steps and requirements of good decision-making, then review which of the complicating factors were overcome. The information for this review is derived from a number of sources, including: a NOAA internal report completed by the NOS division,[50] interviews with various AC members and NOAA employees, and personal observations.

The process used for the Zoning Issue, and in particular the Replenishment Zones, was somewhat similar to that used for the other six Issues in the Management Plan, yet there were some key differences. One reason was that Ed Lindelof, Head of the Eastern seaboard in NOAA's SRD division, had told the AC that they could be in charge of Zoning. As a result:

i) the AC largely controlled the Zoning Issue, rather than just an advisory role, and

ii) the Advisory Council spent approximately half their time with the Zoning Issue.

(Causey, January 1995)

Although the Zoning Issue, was somewhat different, it was not so different that NOAA analyzed the successfulness of the Zoning process separately from the rest of the Management Plan. The NOS report reviews all seven Issues, the entire MP decision-making process. The analysis in this dissertation will try to separate the Zoning process from the rest of the FKNMS process when there are key differences, though.

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[49] This purpose was decided within the FKNMS process. By stating the purpose of the Replenishment Zones this way, not directly stating that part of the purpose is to protect important commercial fisheries, there are fewer jurisdictional problems and less controversy from the different Fishery councils and agencies.

[50] NOAA's NOS division interviewed nearly 20 people and attended a two-day Advisory Council meeting in July 1993 to assess the actual process used. All the comments and observations in the report "came from one or more interviewees and were confirmed by others. Each represents a consensus perception of those ... interviewed." (NOS Report, 1994)

The FKNMS decision-making process has accomplished some of the steps of good decision-making, yet "NOAA, and especially employees in SEA, readily admit that it was an imperfect process," says Goodspeed from NOAA's SEA department. (Goodspeed, June, 1994)

1. Prepatory steps

In general, there was never a well-defined methodology for developing the FKNMS MP. The process evolved over time, instead of being designed from the beginning. This was because at first, NOAA's Sanctuary and Reserves Division (SRD) was using its typical decision-making process, then NOAA's SEA division became involved, which had never happened before for any of the other NOAA sanctuaries. The absence of a well formed process caused difficulties from the outset. Most Core Group and Advisory Council members felt:

> "that the 'stage' for the process was not set initially and that this led to confusion that has persisted." (NOS report, 1994)
>
> "SEA and the rest of NOAA were learning as they were going," said Goodspeed from NOAA's SEA department.
>
> "The FKNMS planning process started before the elements of Integrated Coastal Management (ICM) were codified and even today, there is debate as to what constitutes ICM. The FKNMS planning process has some elements of ICM, but a number of the most important elements are missing. ...The planning process used was not designed to produce an integrated coastal management plan for the FKNMS." (NOS report, 1994)
>
> "When the Core Group started out, there was no structure. It was a frightening process. Then SEA's Dan Basta came in with a structured process. This was critical. The most important thing is to have a structure, a timetable so we can find out where we are in the process and what comes next." said Peggy Matthews, Environmental Specialist from the Florida State EPA and Core Group member.

Requirement 1) Have all stakeholders represented and their interests included

Originally, Congress represented all stakeholders by creating the FKNMS Act, then Congress passed its power to NOAA. The Act required that NOAA, in turn, share some of its power with the State, since Florida had partial veto power in State waters, and with other government agencies, since there were multiple jurisdictions in the Sanctuary; NOAA shared the power via the Core Group. The Act also required that NOAA share some of its power with an Advisory Council, since Congress required that NEPA be followed. [See Chapter VI to review the focus and membership of the Advisory Council (AC) and the Core Group (CG).]

In the beginning of the process, there was no formal group of user representatives. All interested individuals from the general public could attend the initial Public Scoping meetings and Workshops for each of the Issues.[51] Discussion and debate were used to elicit public opinion during these meetings. In early 1992, when the appointed group of stakeholders' representatives - the Advisory Council - formed, much of the preliminary work had begun.

a. Need to define roles

Since it would have been difficult to have all members of the general public attend every meeting and to combine the preferences of all the stakeholders during the FKNMS decision-making, it is logical that a group of stakeholders' representatives would be chosen. The role of the stakeholders' representatives was somewhat confusing, though. The role of the Advisory Council was never defined, showing how it differentiated from the Strategy Identification Group and the Core Group. It was not well understood how the stakeholders would be represented and how their opinions would be included. The roles of the different groups were never formally discussed. There were many comments about the discontent that resulted, written in the NOS report:

> "The respective roles of the Advisory Council and the Core Group are obscure to many of the individuals we interviewed from both groups."
>
> "Nearly all members of the Advisory Council and the Core Group interviewed believe that there should have been a discussion in which NOAA defined the roles of the Core Group and the Advisory Council in a joint meeting."
>
> "Perhaps the most problematic set of relationships are those between the Advisory Council and the Core Group. To say that the Advisory Council resents the Core Group is not too strong."

The ill-defined roles of the different groups have caused many problems in developing trust. Although the role of the CG was somewhat ambiguous, the ill-defined role of the Advisory Council was even more problematic. Again, comments made in the NOS report included:

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[51] For the Technical Workshops for each of the Issues, NOAA specifically invited about 20 members of the general public, but any member of the general public was welcome to attend and participate in the discussion.

"There was confusion among some members of the Advisory Council we interviewed as to whom the Advisory Council is advisory to. Everyone agreed it was NOAA, but that was all they agreed upon. Some said it was the Secretary of Commerce, others Billy Causey (NOAA's FKNMS manager), still others, Ed Lindelof (NOAA's SRD, Director of Eastern United States). One member of the Core Group believed the AC was advisory to them – the Core Group."

"The roles of the AC are still ambiguous, even to NOS. This was obvious in the discussion by NOAA personnel on how the Council would be involved in the formulation of the plan, in the review of the plan, and in the revision of the plan in response to public comments. The same confusion was expressed by members of the Core Group. They pointed out, for example, that they did not know what responsibilities, if any, the Advisory Council would have after the draft plan was released."

AC members "object to the characterization that the Core Group is the 'group of experts.' They believe they (the Council) have far more expertise relevant to the FKNMS. They believe the Core Group is isolated from the users and from the real issues."

The ill-defined roles caused much tension, and it was difficult the stakeholders' representatives to contribute at their full potential or help steer pivotal decisions. In order for there to be involvement by the stakeholders' representative throughout the process, at minimum NOAA should have recognized the need to define the roles more clearly:

i) who were the decision makers (NOAA and/or the CG, AC and Strategy Identification Group)

ii) and who were merely advisors (CG and/or the AC and Strategy Identification Group).

b. Need for stakeholders' representatives to be included from the beginning

The stakeholders' representatives should partake from the *beginning* of the decision-making process, so they can influence the direction and parameters of the process and feel ownership. Because the AC first met after the Public Scoping meetings and the Technical Workshops, after the goal, sub-goals and objectives had been defined, they felt mistrust, less buy-in and less ownership. The Advisory Council felt like much of the process had already happened by the time they were part of the decision-making. Even when the AC did finally become involved, they did not feel like they could determine the direction or parameters of the decision-making. NOAA kept much control of the decision-making process, which, at times, excluded the AC. The NOS report writes:

"Early encounters of the Advisory Council with NOAA were intimidating. Most got the feeling that NOAA was big brother, that NOAA was tolerating the Council, because it had no choice because of the legislation, and in the end that NOAA would do what they wanted."[52]

"The legislation outlawing treasure salvaging early in the process without involving the Advisory Council caused major problems for them in their relationships with their constituencies. The Advisory Council felt betrayed and believes that it took many months to regain the confidence of the public that their (the Advisory Council's) opinion really did matter. It sent a signal to them and to those they represent that they were not full partners in the process."

The AC felt that often, NOAA did not listen to their interests and the interests of the stakeholders. Although the Advisory Council was included in different parts of the decision and were able to take more control in the Zoning decision, assuming a larger role, the AC did not necessarily feel ownership. The Advisory Council was not involved in the beginning, so their initial preferences could not set the direction for the decision. In general, the stakeholders were represented, but their interests were not fully incorporated into the decision.

Step 1) Define the Problem, the Overall Goal and the Objectives

The overall goal and objectives for the FKNM Sanctuary and more specifically for the Replenishment Zones, happened through a series of steps. First, Congress defined the FKNMS' overall problem, the overall goal and some objectives in the FKNMS Act. To develop more detailed objectives, the initial Public Scoping meetings were held, which were attended by many different stakeholders. The minutes of the Public Scoping meetings' were recorded, then NOAA and the CG consolidated the information using NOAA's 'Knowledge Engineering' methods in separate meetings.[53] From the information elicited and through the 'Knowledge Engineering' process, NOAA and the CG extracted and defined the seven

[52] This same feeling was shared by members of the Core Group. "Both groups said they sensed a change in NOAA attitudes when NOAA realized that they needed these two groups to succeed." Interviewees from the Advisory Council "felt this attitude changed about the third meeting of the Council: that at that point, NOAA began to realize that the Council members had good ideas and that their linkages to the local community were crucial to the success of the process." (NOS report, 1994)
[53] See Chapter VI for a description of NOAA's 'Knowledge Engineering' process.

Issues,[54] of which Zoning was one. NOAA then published a summary of the results and sent it to the public to check for accuracy.

For each of the seven Issues, objectives and suggestions were then solicited from the public during the various Technical Workshops. The Zoning workshops were different from the other Issues in that there were five workshops held, each with different user groups. Through these meetings, it was determined that various types of Zones were needed, including Zones to replenish various resources. Again, NOAA recorded the minutes of the different workshops, then the CG summarized and organized the comments using the 'Knowledge Engineering' Process after the meetings; originally, thirty-seven Zone types were identified.

The Strategy Identification Group then met to review the criteria and objectives that the CG had summarized. During this meeting, the Group created the initial 270+ Strategies for the seven Issues, the Strategies being equivalent to objectives for different parts of the FKNMS Management Plan, including the Zoning Issue. The AC did not participate in this meeting, since the AC was not formed after this preliminary work was done.

When the AC first met, they reviewed what the Strategy Identification Group had formulated, then formulated an additional 60 Strategies. In addition, NOAA reviewed the public surveys, the Public Scoping Meetings and the Workshops and found another 30 Strategies; non-government groups added another 15 Strategies. There were 370+ Strategies in total. The Zone types were also solidified after the AC met. The original 37 Zone types were reduced down to five Zone types through sequential input by the AC and the CG; Replenishment Zones was one of the five Zone types.

A few months later, NOAA and the CG reviewed all 370+ Strategies that had been identified. They looked for repetition and ways to condense the 370+, reducing them to 98 Strategies spread across the seven Issues.[55] Each Strategy focused on a different part of total FKNMS

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[54]As stated in **Chapter VI**, the seven Issues were Zoning, Boating, Fishing, Land Use, Recreation, Water Quality and Education.

[55] The Management Plan's 100+ Strategies and how they break down by the seven Issues are as follows:

- A. Zoning (5 Strategies)
    1. Replenishment Zones
    2. Sanctuary Preservation Areas
    3. Special Use Zones
    4. Wildlife Management Zones
    5. Existing Management areas
- B. Boating (15 Strategies)
- C. Fishing (13)
- D. Land Use (19)

Management Plan. One of the 98 Strategies was 'Strategy Z.2' for Replenishment Zones; another was 'Strategy Z.3' for Sanctuary Preservation Areas.

a. Need stakeholders to organize and summarize preferences in *real time*

Through the Public Scoping meetings and Workshops, the general public contributed information and initial preferences used to define the overall problem and the list of objectives for each of the seven Issues, but NOAA did not provide structure to the brainstorming and to the comments made in *real time*. These initial preferences and ideas were not organized and summarized during the meetings, with the stakeholders present. After the meetings were over, NOAA and the CG worked alone, *without* the stakeholders or their representatives, to summarize, organize and combine the objectives and criteria using the 'Knowledge Engineering' process.

The stakeholders would have learned more if the information had been organized and summarized in real time, during the meetings, as the information and preferences were suggested. This would have allowed the stakeholders to offer information, hear suggestions made by others, process the information by helping to organize each piece within the whole, and then offer additional information after better understanding the whole system and the already explicit information. The stakeholders would be more able to see how the many pieces fit together and been better able to see the gaps. For the actual FKNMS process, it was only NOAA and CG who learned when the many objectives and criteria were organized and summarized. The process should have enabled the stakeholders or their representatives to also participate, so they too could learn.

The AC had not yet formed when the goal and objectives for the Replenishment Zone were being summarized and organized. The AC had not even formed when the Strategy Identification Workshop occurred, when the 270+ Strategies were created; the AC only added to the list afterwards. The AC also was not present when the 370+ Strategies were reduced to 98 Strategies; only NOAA and the CG participated. These meetings were important, because each Strategy was typically used as the overall goal for each part of the decision; in addition, no other objectives were formally identified. For example, Strategy Z.2 for

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E. Recreation (4)
F. Water Quality (32)
G. Education (10)

(Source: the Draft Management Alternatives and Component Strategy Descriptions III, The FKNMS, March 1993)

Replenishment Zones was the *only objective formally identified* for the Replenishment Zone, so it *implicitly* became both the overall goal and the only objective.

When the Advisory Council was finally formed, much of the preliminary work was already completed; the AC reviewed this work, to understand the progress already made. In an effort to be more efficient and expedient, the AC was encouraged to accept the Strategies, the 'goals and objectives' that were not their own, which caused less buy-in. Because the Strategies were never labeled as either goals or objectives, and because the Advisory Council participated very little in this process, many participants felt they did not know what the goals, sub-goals, and objectives were. The NOS report writes,

> "Among the most important elements of the ICM process that were perceived (by the interviewees) as being *deficient or missing altogether* from the FKNMS process *was a clear identification* of *goals and objectives* at the beginning of the process. [These were specified in the Act that created the FKNMS, but members of the Advisory Council were unaware of them.]"
>
> "According to a majority of the people interviewed, the NOS process for the FKNMS had not resulted in an explicit statement of goals and objectives at the time of our interviews..."
>
> "Members of the Advisory Council and Core Group interviewed did not believe that explicit goals and objectives were formulated early on in the planning process for the FKNMS."

There is a need to summarize and organize the goals and objectives in *real time* with the stakeholders or their representatives present so that all members can learn during the process and remember the goals and objectives.

i. Need for different groups to hear each others' initial preferences

During the five Zoning workshops, NOAA did elicit objectives from the different users groups, and the separate meetings were held to reduce the controversy within each meeting. The result was that only NOAA and the CG benefited from hearing, then summarizing all the concerns, the objectives and criteria of the many user groups.[56] Neither the user groups nor the stakeholders' representatives had the opportunity to listen to or learn about the other users' concerns, until after NOAA summarized and organized all the comments.

[56] All meetings were open to the general public, but often people did not attend all the meetings.

Not only were the different user groups separated in the Zoning decision, but the Advisory Council never met with the Core Group. These two groups were never able to listen to each others' concerns and learn their initial preferences. The NOS report writes:

> "Members of the Council believe there should have been more interaction with the Core Group; there should have been a few joint meetings and one joint meeting early on to develop mutual goals and objectives ... Several members of the Core Group agreed."

The process did not promote learning across the different user groups or across the different groups of representatives.

ii. Need stakeholders' participation to insure accuracy

When NOAA sent out the summary of the meetings to determine if the groups' preferences had been accurately summarized, it was difficult for the public to judge the combined goals and objectives. Each user group had not learned about any of the other groups' initial preferences or concerns, so it was impossible to judge if the *summary* was correct. Because each group had only heard a part of the whole, they were not able to judge the whole.

Because the stakeholders were not present when the objectives were summarized, it is more likely that the stakeholders' initial preferences were not fully understood, and perhaps unintentionally misrepresented. Also, the very process of summarizing and organizing typically requires that some preferences and concerns be used; by not including the stakeholders, it is more likely that NOAA's and the CG's goals and objectives were used. The stakeholders had little recourse if they felt that the NOAA summary did not represent their views accurately.

The public could only review what NOAA and the CG had summarized; they could not work with them in real time to alter the objectives as they saw fit. When the AC finally met, they could not be sure that their user groups had been fairly represented, which caused less buy-in and ownership. To ensure more accurate summaries of the stakeholders' initial preferences, there is a need for the goals and objectives to be summarized and organized in real time.

b. Need to prioritize initial preferences

The objectives that were formulated were never prioritized.

> "The lack of priorities troubled most of the people interviewed. They cited a long list of objectives, but no attempt to rank them."(NOS Report, 1994)

These criteria give some guidance for choosing Zones, but the criteria would be more helpful if they were actually measurable qualitatively or quantitatively, so that different Zones choices could be compared to each other. The eight criteria were not measurable traits that could be used to compare the different alternatives. (See Chapter VIII and XII for examples of more detailed criteria.) It was difficult to add new criteria to the list of eight if any were identified, since they would have to be agreed to before they could be added, a danger in not separating the information elicitation process from the consensus building process. In general, defining the criteria for Zoning was better than the other six Issues, but it could have been improved.

Step 3) Choice formulation

The choice formulation process had many different groups working in sequence. The first part of the choice formulation occurred when the CG and NOAA bundled the Strategies[57] and created the five Alternatives; the choices ranged from Alternatives I which was most protective to Alternative V which was least protective. This first draft of the Replenishment Zone Alternatives were very general; the main difference among the five Alternatives was that "the areas selected for Alternative I would be slightly larger and / or more numerous than those established in Alternative II. " (Draft Management Alternatives, March 1993) Likewise, Alternative II's Zones were larger and / or more numerous than Alternatives III's, etc. The CG created the general intent and wording for each of the five Alternatives.

Using the CG's suggestion for Alternative III, the AC then worked on more of the details for the Replenishment Zone decision;[58] the AC could either strengthen or weaken Alternative III. For the Zoning decision, the Advisory Council and the AC's Zoning subcommittee spent a great deal of time discussing, debating and listening to presentations in order to help formulate the details of the different Zone locations and size. Opinions and information were

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[57] The 98 different Strategies were bundled to make up the different Alternatives. for each of the different Issues. For the mid range Alternatives, the 98 Strategies were broken down into the Seven Issues as follows:

	Alternative IV - Less Protection	Alt III - Most Balanced	Alt II - More Protection
Zoning	5 Strategies	5 Strategies	5 Strategies
Boating	15 "	15	15
Fishing	12 "	13	13
Land Use	17 "	19	19
Recreation	4 "	4	4
Water Quality	30 "	32	32
Education	8 "	9	10

Zoning had 5 Strategies for each Alternatives corresponding to the five different Zone types.

[58] In general, the same process was used for all seven Issues, for all of the 98 Strategies.

When there are long lists of objectives from many different people, there is a need to prioritize the objectives at some point in the decision. Otherwise, it is impossible to determine if the effort, time and focus is being placed on the areas of greatest concern.

Overall, the goal and objective formulation step suffered. The NOS report writes:

> "Many of those interviewed felt the process suffered from the lack of a shared vision... Nearly all felt that the process would have benefited from taking time at the outset to formulate a shared vision of what they wanted the FKNMS to be like in the future, say the year 2020. They felt that if NOAA had the vision, it was not communicated to them."

There is a need to define the goals and objectives in *real time* with the stakeholders or their representatives present to i) hear others' concerns, ii) learn and iii) check for accuracy. Then the initial preferences should be prioritized so that the decision-making process can focus on the areas of greatest concern.

Step 2) Criteria formulation

Like objectives, initial criteria for Zoning were elicited from the general public through brainstorming during the five workshops. The minutes of these meetings were summarized and organized by NOAA with the 'Knowledge Engineering' method after the workshop sessions ended. Lists of the criteria were formulated, then NOAA checked for accuracy by mailing the results to the participants. These lists of criteria were available for the Strategy Identification Group and for the Advisory Council to use in their meetings.

For the Zoning decision, the Advisory Council created a special AC Zoning subcommittee. The AC and its Zoning subcommittee reviewed the initial criteria and spent a great deal of time discussing, debating and listening to presentations in order to help refine the criteria. Opinions and information were elicited from the user groups and scientists in order to determine the different ways Zoning could be helpful, different costs Zones might incur, etc. Half of the AC's total time was spent working on the Zoning decision.

Toward the end of the Zoning decision, the AC formulated a list of criteria for two of the Strategies, Replenishment Zones and Sanctuary Preservation Areas. For the Replenishment Zone, the Zoning Subcommittee identified the following criteria:

> "Consider areas of high habitat diversity representative of the Key's biosphere
> Consider environmental and socio-economic impacts
> Consider long term impacts from establishing reserves in areas of critical economic value

Consider area with good water quality

Consider socio-economic impacts on displaced user groups

Consider ownership of nearby property

Sufficient size to include full range of habitats

Consider adjacent area regulations and restrictions" (source: NOAA's FKNMS manager)

a. Zoning did achieve iterative process of criteria formulation

In the Zoning process, the initial criteria were recorded, then the AC and the Zoning subcommittee became better informed before developing the final list of eight criteria. Criteria formulation was somewhat of an iterative, ongoing process for the Zoning Issue.

b. Need to organize and summarize criteria in real time

The same problems existed for defining the criteria as for the objectives. First, NOAA and the CG organized and summarized the initial criteria identified during the five Zoning Workshops without the stakeholders or their representatives. The stakeholders and their representatives were not able to get the benefits of processing the initial criteria in 'real time,' such as learning more within their own user group, learning from the other user groups or checking for accuracy.

Second, when the AC's Zoning subcommittee explored other criteria, attempting to refine them, they were discussed and debated, but not organized and summarized in real time. The eight criteria were only summarized and organized once at the end by making the list, not as an on-going process throughout the many meetings. It was not a process of building, adding to, and refining as more was learned. The list of criteria was made by the AC's Zoning subcommittee, and some AC members did not know how the list was developed. (Ogden, AC member, 1994)

c. Need to develop detailed list of criteria

The final eight criteria were less detailed and more general than the many criteria originally elicited from the users. The final list was somewhat helpful, but the wording is ambiguous and does not provide a clear sense of intent. For example, what is really meant by "Consider long term impacts from establishing reserves in areas of critical economic value." It might be more clear to say 'Reduce negative impacts on long term economics factors.' How should one "Consider environmental and socio-economic impacts?" What social factors need to be considered? In what ways should environmental factors be considered?

elicited from the user groups and many scientists in order to recommend different areas to be avoided, areas that were desirable, Zone locations, Zone sizes, etc. which comprised half of the AC's total efforts on the FKNMS.

After the AC had been working on the Zoning Issue for a few months, members of the general public staged the protest. NOAA members then created the first draft of the actual Replenishment Zone boundaries to diffuse any fears that the Zones would be one-third of the FKNMS. The Core Group added to these first drafts, then the Advisory Council was given the drafts to work on and review. This is when the AC created the Zoning Subcommittee, and both groups continued meeting with scientists and members of the different user groups.

The final Replenishment choices were formulated when the AC and NOAA members made a field trip onto the water and re-drew Zone boundaries on the maps. The boundaries of the Replenishment Zones for Alternative III decreased from five locations to three locations: Sambos, Key Largo and Dry Tortugas. The Replenishment Zone boundaries were then bundled with the suggestions for the other four types of Zones, and Alternative III for the entire Zoning Issue was created. After the AC had formulated Alternative III, it was used by NOAA and the CG as a strong recommendation for the Management Plan.[59] The Core Group used the AC's Alternative III to create Alternatives I, II IV and V, increasing some of the Zone locations and total area to make Alternative IV and V more protective, removing some locations and area to make Alternative II and I less protective.

a. Zoning did achieve iterative process of Choice Formulation

In general, the focus was on eliciting many suggestions and using as much scientific information as possible to formulate choices. Through the many Zoning Workshops, the Strategy Identification Workshop, and meetings held by the CG, AC, Zoning subcommittee and the user group, a great deal of information, recommendations and alternatives were elicited and brought to the process. A positive comment in the NOS report was,

> "The process has provided extensive opportunities for input by everyone. That quality should be replicated in future settings."

b. Need for stakeholders' representatives to participate in initial Choice Formulation

For the Zoning decision, the choices were first formulated without the AC. Like the objectives and criteria, the AC should have participated when the initial written drafts of the Alternatives were created, when the initial choices were formulated. Also, the AC did not

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[59] NOAA did alter two of the 98 Strategies to create the final Alternative III for all seven Issues.

participate when the first draft of the Replenishment Zone boundaries were drawn; only the two NOAA members drew the lines in an effort to expedite the process and to reduce the controversy. The CG members then reviewed and altered these choices before the AC members were shown the detailed choices, though. Including the Advisory Council earlier would have enabled a greater transfer of knowledge and a greater feeling of ownership.[60]

c. Need to achieve Choice Formulation more efficiently

Bringing great amounts of information and opinions from the public, the many groups helped develop the Zoning choices, but the many groups all worked in sequence, not together. If the AC did not understand or agree with something that the CG did, the AC might have to spend extra time retracing the CG steps and perhaps undoing some of it. This must have led to much wasted effort.

In general, the Zoning alternatives were typically formulated informally; the AC and the user groups typically brainstormed, discussed and debated. There was a large amount of choice formulation, but a criticism might be that the alternatives could have been formulated more efficiently, since the AC spent half their time on the Zoning Issue alone. It is likely that there too much repetition in the elicitation process, and therefore it took longer than needed. (See end of section A. for comments made about the long process.)

Step 4) Sensitivity Analysis

In the actual FKNMS decision-making process, sensitivity analysis was not done for the Zoning decision. There was much information about the physical and economic aspects of Replenishment Zones, but there was no agreement about the long term implications. Long term implications were hypothesized with the many users and researchers, but there was no attempt to do this in any formal way other than through discussions. Sensitivity Analysis for the human preference aspects of the decision will happen somewhat through the public review sessions, which will take about six months. NOAA, the CG, the AC and the Keys' citizens are expecting a great deal of controversy and discussion. Many are expecting these public review meetings to be heated debates.

[60] This happened not only for the Zoning decision, but also for the other Issues. The AC were not invited to participate when the Strategy Identification Group formulated 270+ of the original 370+ Strategies. They also did not participate when the initial Alternatives for all seven Issues were formulated, organized and summarized by NOAA and the CG, using the Knowledge Engineering method.

a. Need to make explicit the assumptions used to make predictions

Long term implications were hypothesized, but there was no attempt to do this in any formal way. There was no way for the decision makers to challenge or test the assumptions of those making predictions, since the assumptions were not made explicit. The members of the Advisory Council either had to either fully accept or reject any projection, since the assumptions behind the projections were not made explicit.

There was no commonly agreed to framework that could test the probable outcome of many different alternatives. If a new alternative is suggested during the Public Review process, it will be difficult to predict the alternative's impact on the physical and economic system. To assess the impacts of any new alternative, the AC, CG and NOAA would have to repeat most of its process, discussing and debating, informally assess the impacts.

b. Need to record detailed preferences to enable Sensitivity Analysis

Not only would new alternatives would be difficult to adopt because there is no easy way to obtain consensus on the physical and economic predictions, but there is also no method that would allow sensitivity analysis on the stakeholders' preferences. Their preferences were not made explicit or recorded for anything but the alternatives discussed. Also, in the Zoning process, the objectives and criteria were not prioritized. If a new alternative is suggested during the Public Review process, it will be difficult to determine if the alternative would suit the stakeholders' preferences better than any existing alternative. Again, the AC, CG and NOAA would have to repeat most of their discussion and debate to elicit the stakeholders' preferences on any new suggestion.

c. Need to complete Sensitivity Analysis before due diligence

Unfortunately, the review process or 'sensitivity analysis' will be post choice and post NOAA due diligence, so it will be very difficult to change what has already been decided, difficult to change the Plan. New suggestions would have to pass due diligence, which has taken over a year. This includes review by NOAA's National Marine Fisheries Service to see if there was conflict of interest: approval by the Federal Office of Management and Budget, which takes a few months: then printing and distribution to the public. Sensitivity Analysis on the physical and economic impacts and on the stakeholders' preference would be easier if it could occur during the decision-making process, before the alternatives are finalized. This step was not well achieved in the actual FKNMS decision making.

Requirement 2) Decision is made by a well-informed group

As stated above, to elicit and collect general information about the Zoning Issue and the other Issues, NOAA sent out survey forms and held Public Scoping meetings, Technical Workshops, Core Group meetings, Advisory Council meetings, Strategy Identification and Assessment Workshops, etc. To transfer information, NOAA held various workshops, organized presentations, distributed pamphlets, ran newspaper articles, etc. and every meeting held in Florida was open to the general public. Some meetings were even broadcast on TV. For the details of the Replenishment Zone decision, the AC and the user groups were typically informed through discussion and brainstorming. The Core Group and Strategy Identification Group supplemented their discussions with the 'Knowledge Engineering' method.

> "Many people brought their experience to bear on the Zoning decision via their involvement," said Causey, NOAA's FKNMS manager.

a. The AC, not NOAA, elicited scientific information from the users

The Advisory Council used many sources and elicited information from many people to become well-informed about the scientific knowledge and about the preferences of the stakeholders. For Zoning, the AC reviewed a great deal of information that NOAA provided, and in addition sought many of their own sources of information such as many of the user groups and various scientists, eliciting information from them.

b. Need for all groups to focus on eliciting the best available information for all aspects

Extracting information about the physical aspects of the decision was the focus of NOAA's SEA division from the beginning:

> "Much of the information required (for decisions) remains disorganized, incomplete, poorly presented for decisions or simply missing. A fundamental objective of the program has been to make maximum use of what we already know about the characteristic features of estuarine and coastal areas, especially as natural systems, to improve the information base of decision-making. Our assumption has been and continues to be, that much of what the scientific and technical community knows is never used in many levels of government and private sector decision-making. Consequently, *a major effort* has been made to collect, synthesize, structure and disseminate specific information in meaningful ways for decision makers. The data synthesis conducted is a laborious, time-consuming scientific process of data gathering, experimenting and assessment. Essentially, a bottoms up process begins with data collection from experts and institutions as close to the problem or phenomena of concern as possible." (Basta, 1993)

Reviewing the many meetings and who was involved, one can see that indeed SEA designed the process and focused on becoming well-informed about the scientific knowledge from researchers and about the stakeholders' initial preferences. The Public Scoping meetings and Zoning Workshops helped NOAA become better informed about the initial human preferences at the beginning of the process, before the stakeholders were updated. NOAA was not well-informed about the stakeholders' final preferences, though, after the stakeholders had become better-informed about Replenishment Zones.

The concern for NOAA's SEA division was to collect data and information "from experts and institutions" close to the problem. Although this statement does not exclude users from the list of experts, it does not explicitly include the users as a group from which to collect information. Many participants felt that NOAA did, in fact, spend less effort learning from the stakeholders and their representatives:

> "It became clear that 'Experts on Ecosystem' meant government officials. The process could have been better if it had captured the knowledge of the local experts." said Mr. Mark Robertson, Director of The Nature Conservancy in the Florida Keys and Advisory Council member. (Robertson, 1994)
>
> Many interviewees from the AC and the public "recommended that in the future NOAA should listen more intently to the 'locals'; don't surprise them. Exploit their expertise, their concerns and their commitment. This was not done as well as it might have been." (NOS Report, 1994)

No one was well informed about the decisions economic aspects, since the Socio-economic Impact Assessment contained very little information concerning Replenishment Zones. Also, no group knew the detailed final preferences of the stakeholders. (See next section.) In general, the stakeholders were not equally well-informed about all aspects of the decision, the physical, economics and human preference. Some of this was simply due to the information available, but some of it was due to the unequal amount of focus and effort placed on eliciting the information.

c. Need to transfer information more efficiently

Most of the information for the Zoning decision was elicited and transferred via presentations, reports and discussions, and some of the initial information was elicited and summarized by the CG and Strategy Identification Group using 'Knowledge Engineering.' The AC rarely wanted to use the 'Knowledge Engineering' process, stating that it had too much structure. (NOS Report, 1994) As Causey, NOAA's FKNMS Manager, said,

> "NOAA's 'Knowledge Engineering' was sometimes too much of a structured format for the Advisory Council. Sometimes it was used, but sometimes the Advisory Council did not give Basta (from NOAA's SEA division) the time to use even one survey form."

It is during the refining, summarizing and organizing that the most is learned, when the participants are not just listening to information, but processing it so it is internalized.[61] The absence of these steps caused less than optimal information transfer.

These methods rarely helped the AC members understand how all the information fit together, since no linkages were made explicit. The existing process did not create the linkages among all the information that was gathered from all the different sources such as the public, the scientists and different AC members. By failing to summarize and failing to show linkages, these methods did not help the users determine the relevancy of the information, determining which pieces are critical and which are merely supporting evidence. For example, Mr. Bohnsack from the Florida Marine Research Institute, spoke to the AC about many aspects of Replenishment Zones, including Cryptic Mortality. This information, though, came along with a sea of other information, so no one took particular note of Cryptic Mortality, said Mr. Haskell, a NOAA SRD employee. (Haskell, Sept. 1994)

The absence of summaries and linkages also made it difficult to efficiently transfer the best available information. Summarizing, organizing, structuring and showing linkages helps to show the users what is already known. This helps indicate the gaps in knowledge, indicates what information still needs to be elicited and makes it possible to gather more detailed information. Pictorial summaries with linkages would have enabled the scientists or experts to have some indication of what the AC members knew and what information was still needed. If there had been explicit summaries of the existing knowledge continuously updated, then the experts' information transfer would have been more time efficient.

In addition, the general public could have been better informed. NOAA made efforts to educate the public, but many felt they did not educate effectively. The NOS Report writes:

> "In future situations NOAA should have more effective mechanisms for public relations and outreach to keep the public informed. Nearly everyone expressed disappointment and concern about this failure."

[61] The old adage "I hear, I forget; I see, I remember; I do, I understand" is applicable here.

"There was general agreement that NOAA is not very skillful at dealing with the public. They cited examples of presentations at a Key Largo meeting in which the public was 'baffled' by the terminology and the complex graphics material. Too many 'buzz words'; too much jargon; too complicated flow charts."

In general, presentations, reports, discussions and the 'Knowledge Engineering' process are not necessarily the best format through which to determine what information is most relevant, enabling learning. There is a need for tools or methods that can assist the decision makers and stakeholders to organize information by just supporting the discussions and debates, not imposing the structure within which discussion happens,.

Step 5) Choice

Throughout the Zoning process, the stakeholders' preferences were elicited via a 'spot' vote, with each AC member choosing one alternative. The AC used spot votes to create the many details of Alternative III, and sometimes, AC members required that their dissenting opinions be recorded. At the end of the process, after the AC voted on the pieces of Alternative III and the Core Group created Alternatives I, II, IV and V, all the details for the Replenishment Zone were bundled with the other four Zone types.[62] Originally, the AC was going to vote zone by zone, but decided instead to vote on the packaged Alternatives for the entire Zoning Issue.

a. Need to use method to elicit detailed preferences

A spot votes often leads to inaccurate results, so a preferential vote, where the alternatives are ranked, should have been used. (See **Chapter V** or Hwang, 1987 for more details.) Also, the spot votes could not help measure the intensity of the preferences, nor could it help prioritize the many objectives. Preferential votes on all aspects of the decision would have elicited more detailed about the stakeholders' preferences.

More detail would have made the specific areas of controversy more easy to determine, therefore overcome. It would have enabled NOAA and anyone else reviewing the decision to more fully understand the stakeholders' concerns and desires, which would have probably been useful, since the AC was not the final decision maker, and their decisions were and will be reviewed by many different groups. More detail would have enabled the CG to create

[62] The four other Zone types were SPAs, Wildlife Management Zones, Special Use Zones and Existing Zones.

Alternatives II and IV to more closely reflect the stakeholders' preferences, and would increase the likelihood that their desires would be accurately reflected during implementation. Detailed preferences would have enabled NOAA, the CG, the users and even the AC to more easily determine what Alternatives most closely reflect the AC's collective values.

b. Need to elicit detailed final preferences and not use bundled Alternatives

The AC did not have a final vote on each detail within the Replenishment Zone decision; the final vote did not even differentiate among the five Zone types. The bundled Alternatives expedited the final Choice step, but it did not elicit the AC's final preferences on the many details.

Many members of the Advisory Council did *not* feel like their preferences and values were represented in the chosen Alternative. Many felt coerced into the decisions, even as late as May 1994, after the Advisory Council had given their input on the entire Management Plan and had voted on the Zoning Issue. Many members of the Advisory Council, such as Karl Lessard, Hon. Dennis Warlow, and the Advisory Council Chairman, George Barley, sometimes felt the decision had been 'engineered' and that NOAA viewed them as just a 'rubber stamp.' (FKNMS meeting, May 1994)

> "There's always been resentment. Many people feel like there's already been a decision made and the Advisory Council is being manipulated to bless the process," said Mr. Mark Robertson, Director of The Nature Conservancy in the Florida Keys and AC member. (Robertson, 1994)

> "I had the feeling like we were told 'You are in kindergarten and if you're good children you'll pick Alternative III.' I never had the feeling like they were saying 'We want to learn from you people who live down here in the Keys.'" This was the comment of Mrs. Alison Fahrer, an AC member and Chairperson of the AC's Zoning Subcommittee. (Fahrer, May 1994)

At one point during a presentations, an AC member said to Mr. Billy Causey, NOAA's FKNMS manager,

> "I know what you're trying to do - you're trying to give us information to convince us that your Alternative is right, so that we agree with you." (Causey, January, 1995)

There are many comments in the NOS report that echo these sentiments.

"Many interviewees believed that NOAA put too much attention on using them in the process and not enough attention on using them in producing the products."

"Members of the AC felt they should be 'full partners' in the process, but that they are not. They were told - literally - by NOAA 'We'll listen to you, but we don't have to do what you say.' They agreed with the conclusion (since its part of the legal guidelines), but thought the message was delivered inappropriately."

The Advisory Council had little feeling of ownership. Many of the stakeholders' representatives did not feel like their opinions or values were reflected in the chosen alternatives, even though they had participated in constructing Alternative III.

Step 6) Implement

As of Spring 1995, this step has not begun with any part of the FKNMS Management Plan, including the Replenishment Zone. In creating the original Alternatives, SEA and the Core Group put much effort into ensuring that for each Strategy seriously considered was implementable; details were defined such as lead agency, funding, scheduling and contingency plans.

a. Details of Implementation were prepared

The Strategy Identification Group and the Core Group had expertise on how the Strategies could be best implemented within each agency, and this expertise was elicited and incorporated. The users also had information about how different Strategies could be well-implemented, but this information was incorporated in a less formal manner, and sometimes not incorporated at all.

Overall review

Overall, the AC did have more control over the Replenishment Zone decision and the entire Zoning Issue, more so than the other Issues. Because it was the most controversial decision, the AC put more focus on becoming better informed and ensuring that their preferences were included. One of the few positive comments in the NOS report was:

"The process that led to Zoning was rewarding. The consensus building that resulted formed a cohesiveness among members of the Council who represent different constituencies with conflicting interest."(NOS report, 1994)

The Replenishment Zone decision was better than most of the other six Issues, but it took an un-proportionally large amount of time, about half the AC's time. Many people commented about the slow process, lacking in efficiency, stating the need to make the process less time consuming.

"I've been very frustrated with the pace. If this (the FKNMS Management Plan) were a business proposition, it would take 18 months," said Mrs. Alison Fahrer, AC member.

"There wasn't four years of public debate and discussion. The time spent on debate was time well spent. A lot of the time has been spent on NOAA internal arguments," said Mr. Mark Robertson, AC member.

"We'd like to know if there's a way to build a good management plan and get the information more efficiently, without taking so long," sail Mr. Ed Lindelof, Director of NOAA's SRD Eastern Division.

B. Did the Process Help Minimize the Complicating Factors?

The Replenishment Zone process was the most controversial decision made in the FKNMS Management Plan, and it had many complicating factors. Although the Replenishment Zone decision was better than many coastal environmental decisions, not all the steps of good decision-making were fully achieved. Reviewing the list of nine complicating factors developed in Chapter II, one also finds that not all the complicating factors were overcome:

1. Inadequate Information Management

The great number of variables concerning the physical system, the economic system and the human preferences, and the linkages among this information, make it difficult to record it all and even harder to synthesize when trying to make a good decision.

a. A great volume of information making it difficult to consider it all adequately

There was a great deal of information to consider in the Replenishment decision, such as the predicted effects on the 6000+ marine species, the economic effects on many different users, the social effects of restricting ocean access, the preferences of the many users, etc. Some of the information was summarized and categorized into lists. First, the initial human preferences, the objectives and criteria, were recorded during the Zoning workshops. Also, there was a great deal of scientific information elicited, but only some of it was summarized and prioritized. NOAA and the CG used the 'Knowledge Engineering' process to explicitly organize and summarize some of the information about the physical aspects of Zones, and some information was summarized implicitly via suggestions and choice formulation. There was much information, though, that was not organized or prioritized in any meaningful way.

Information about the economic aspects and final preferences were not well incorporated into the decision. The economists working on the Socio-Economic Impact Study could not summarize the effects of Zoning. Many of the users, AC members, scientists, etc., discussed the economic aspects of the Replenishment Zones, but there was no way to test the different hypothesis. The detailed final preferences of the stakeholders' representatives were also not elicited and recorded; the spot votes and bundled Alternatives did not enable this. Much of the information was summarized through informal processes; often it was in the memories' of the participants. Not all the information on the preference, economic and physical aspects could be summarized with the one tool, 'Knowledge Engineering' and not all participants thought it would be useful. The great amount of information necessary for just the Replenishment Zone decision stretched the capabilities of the methods used, making it difficult to include all the information.

b. Criteria and variables that cannot be accurately reduced to monetary terms

The Socio-Economic analysis could not quantify all the impacts for any Strategy; for the Zoning decisions, few of the criteria important for the Replenishment Zone decision could be quantified and little monetized information was obtainable.

> "Traditional methods such as cost-benefit analysis or cost effectiveness analysis were employed (for different Strategies), depending on the nature of the problem and the limitations of available data and methods. For Water Quality, Education and *Zoning*, (since no cost-benefit analysis could be completed) management costs and cost effectiveness were the only measure presented."

Most of the criteria important for Zoning could not be reduced to monetary terms. There were many economic repercussions to the Zoning decision, though. Hypothesis of these repercussions were discussed, but i) not everyone agreed with the hypothesis, ii) there was no way to do sensitivity analysis for the hypothesis and iii) the information could not be included into the decision in any formal way. The Replenishment Zone was good, though, in that it did not attempt to force inaccurate monetary terms on all the variables.

c. Criteria from multiple disciplines; expertise needed from many areas

To decide upon the Replenishment Zones, information was needed on i) reef biology, ii)pollution volumes and types, iii) frequency of storms, iv) the economics of tourist expenditures, v) fish life cycles, fishing income, etc. There was a need to combine many different types of information, from many fields of expertise. No one 'technical expert' could find the best alternative or solve the problem. This required that many people from many different disciplines provide information and *learn* from each other.

The Replenishment Zone decision was good in that people from many different fields of expertise and many different backgrounds participated in the Zoning decision. The decision was lacking in that information from the various groups was often not shared or transferred across the groups. For example, information from the Strategy Identification Group and the Core Group was often summarized during a meeting using the 'Knowledge Engineering' process, but it was not easy to add to this information after the meeting ended. For the Zoning decision, expertise was elicited from the actual users and stakeholders, but it was done through discussions and debate. Very little of their expertise was recorded, organized or included with other information that had been elicited. There were no methods that summarized *all* the information from the many different disciplines in one place.

d. Interdependencies among the different environmental decisions

There were many interdependencies among the different criteria and variables that affect the Replenishment Zone decision. For example, the aim of the Replenishment Zones, to protect 6000+ species, depends on many factors: the abundance and health of any one species depends on the abundance and health of many other species for food, shelter, predators, reproduction, etc.; the health of any one type of habitat depends on the health of adjacent habitats; the water quality depends on the wise use of land and the health of the entire watershed, etc. The 6000+ species, habitats and water quality are all interconnected.

There was no method to help the different groups understand the linkages among the information elicited. 'Knowledge Engineering' could organize and categorize information, but it did not show linkages among the information. There are so many interdependencies and linkages among the Zoning variables that it was difficult for any decision maker to understand and remember them all. Discussions and presentations helped illuminate different topics, but all the information needed to be recorded in a structured form to show the interdependencies. Showing linkages would have helped increase the transfer of knowledge and helped make the stakeholders better informed.

2. Uncertainty

Uncertainties, both probabilistic uncertainty and true uncertainty, made it difficult for decision makers to assess the outcomes of the different Replenishment Zone alternatives, making it difficult to choose the optimal decision. Risk or probabilistic uncertainty existed within the Replenishment Zone decision, such as with commercial and recreational fishing efforts, and with natural effects, such as rainfall, storms and hurricanes. The decision makers knew that these factors affect the Zones, but they could not predict *how*, *when* and with what *severity* these factors would happen. They could only use past trends and statistics to predict future occurrences.

There was also more general or 'true' uncertainty. For example, many of the factors that affect Replenishment Zones are known, such as physical contact by divers and snorkelers, pesticides and nutrients, salinity fluctuations, pathogens, marine life regeneration rates, etc., but the effects are not quantifiable. The biological, chemical and physical knowledge of the ecosystem is not known with enough certainty to predict what amount of physical contact will kill off what species of reef, what level of nutrients will kill what level of seagrass under what background conditions, or what level of fishing will enable long term sustainable yields. All these factors influence the habitats and affect the marine life in the Zones, but it is not known to what extent or at what levels they affect each organism. Even though many of the variables that affect the system are known, no one is able to quantify how or why. There is much uncertainty and much scientific information that needs to be learned concerning Zoning.[63]

Overall, there was a great deal of uncertainty that had to be incorporated into the Replenishment Zone decision: both risk and 'true' uncertainty. By including much information from researchers, users, government agencies, etc., the Replenishment Zone decision attempted to decrease the uncertainty, but uncertainty remained in many of the variables and in the predicted outcomes. There was no method used to quantify the level of uncertainty in the information and in the predictions made by some individuals. The uncertainty made it difficult to reduce controversy and reach consensus about a decision, and made it difficult for decision makers to become well-informed.

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[63] "Little understood phenomena such as coral bleaching and the wide spread die offs of fish and sea urchins have indicated the need for more research." (Ward) Unfortunately, though, past budgets constraints, have not permitted NOAA to support research in the Keys. The Sanctuary Managers are dependent on other groups doing research in the Keys who might share their results.

a. One time decision with high stakes

The Replenishment Zone decision will be revisited in five years, so it is possible that the decision makers can learn from some of the decisions currently made and apply the knowledge in five years. There are some aspects of the Replenishment Zone decision, though, for which the repercussions are one-time and have high stakes. For example, if the Zones are not created now, certain species may become extinct or the populations may become so small within the five years time, that it may be too late to reverse the trend later. These results may also happen if the designated Zones are not big enough. The actual Replenishment Zone decision could only discuss one-time, high stake outcomes, but could not analyze their likelihood.

b. Various ways to consider the time frame of the project

The wording in the FKNMS Act requires that the Management Plan be developed looking at a long time frame. The time frame for the Replenishment Zone decision has been set arbitrarily at five years, since the National Marine Sanctuary Act requires that each Sanctuary's Plan be reassessed every five years.

> "The Management Plan is the beginning of the Process. For example, in five years we will revisit the Zoning and Water Quality Issues. We hope to see some results from Zoning after one year. After five years, there should be scientific data available," said Causey, NOAA's FKNMS manager. (Causey, April 1994)

Specifying the time frame was easy to dictate, but caused problems in many practical situations. For example, one reason that Replenishment Zones were and are so controversial is because it requires fishermen and other users to forego income in the short term for a chance at more income in the long term.[64] How long a time frame must be considered? How long should the short term sacrifices be expected, and when can the long term benefits pay off, if ever? It is not known if results for commercially important marine species, or any of the 6000+ species, will be seen within five years. No one tried to predict the outcome over time, except by reviewing the results of Zones in other countries and places, where many of the physical, biological and chemical conditions are different. It is not known if five years is an appropriate time frame from a scientific perspective. Would a longer or shorter time frame be more appropriate for the Replenishment Zone decision?

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[64] Peggy Matthews, Florida Department of Environmental Resources and Core Group member, notes many court cases where scientific information has been brought in and the long-term focus was discussed, but if a fisherman discussed the economic hardship that would result in the short term, the judge would decide in favor of the fisherman.

In addition, all stakeholders may not be stating their preferences or offering scientific and economic information with five years in mind. Some environmental groups may be focused on decades, even centuries, while some fishermen and divers may be looking for results in less than five years. In making any environmental decision, including the Replenishment Zone decision, it is difficult to have all stakeholders consider the same time frame, and it is hard to know what time frame is 'right.'

c. Various ways to consider the geographical scope of the project

The Replenishment Zones are not only affected by what happens within their boundaries, but also depend on the health of areas outside their boundaries. The water quality of the entire region affects the water quality in the Replenishment Zone.[65] Fishing activities that happen outside the Replenishment Zone and weather patterns for the entire region also affect the Zones. Attempting to manage a small area in the FKNMS requires an understanding of much larger areas, often the entire watershed.

This complicating factor was addressed somewhat when Congress gave NOAA oversight power for many government agencies and jurisdictions. Also, a number of NOAA employees in the Keys are very involved with developing Management Plans for the rest of the watershed. The FKNMS process is focusing on the Water Quality Issue, through the Water Quality Protection Program. Still, there is nothing in the FKNMS process that helped with the uncertain geographic scope. There was no way to do sensitivity analysis to determine if a 50 mile radius or a 1000 mile radius is an appropriate area to consider for effects on the Replenishment Zone. The uncertainty in determining or defining appropriate geographical boundaries makes it difficult to make good Replenishment Zone decisions.

3. Many people (users, decision makers and implementors) with different preferences

Because the geographical area that affects the Sanctuary and each Replenishment Zone is so large, the number of stakeholders that have impact and jurisdiction on the Sanctuary is enormous. There are many i) users of the Sanctuary, ii) government officials involved in

[65] The geographical framework for managing the water quality and the resources in the Sanctuary is not confined to the Sanctuary's border, but is the entire South Florida watershed. The health of the reefs, the interconnected habitats, the marine life, the economics of the Keys', etc., are affected by the entire watershed that starts all the way up in Lake Okeechobee, far outside the Sanctuary's borders. The Everglades, Florida Bay, all of South Florida, parts of the Atlantic Ocean and parts of the Gulf of Mexico influence the FKNMS and Zone water quality. **(See Appendix VI- B** for a fuller discussion of the water quality problems in the entire watershed.)

managing the Sanctuary[66], iii) public interest groups who have certain visions for the use and care of the Sanctuary, and iv)organizations and private citizens whose water consumption habits influence the Sanctuary.[67] The greater the number of people that affect the Sanctuary, the greater the number of stakeholders that have to be considered and that should take part in the decision.

There are many user groups who often have conflicting interests and goals. Young commercial fishermen may want to see long term protection of fish stocks, while older fishermen may just want to maximize their income for a few more years until they retire. Recreational fishermen may be more interested in having more trophy sized fish, while the commercial fishermen may be more concerned with tonnage available to be fished. Treasure salvagers may want free access anywhere in the Sanctuary with little concern for renewable resources, while environmentalists may want restricted access to any ecologically sensitive area. Speed boaters may want no speed restrictions, while canoers and sailors may prefer Zones for non-motorized craft only. These were some of the criteria that were elicited in the Zoning workshops.

Not only are there conflicting goals for the users within the Sanctuary borders, but there are conflicting goals for those outside the borders. There are sugar and produce farmers, cattle herders and Municipal Water Authorities who affect the area's water quality, all with different views on how to best use the flow of freshwater. There are 365,000 newcomers to South Florida each year, each using 200 gallons of fresh water a day, double the national average, and adding nutrients and toxins to the waste streams. (Duplaix, 1990)

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[66]There are not only NOAA and state and local officials that have the job of managing the Sanctuary waters, but there are many different groups who have jurisdiction within the borders of the National Marine Sanctuary, such as the National Marine Fisheries, the Florida Marine Patrol, the US Fish and Wildlife Service, Florida's Department of Natural Resources, the Environmental Protection Agency and the US Coast Guard (USCG). Many of the Fishery Councils have a say over the Replenishment Zone decisions, because they would affect the fish stocks. Also, many of the agencies have jurisdiction over the water quality in the region, which affects the Zones. The State of Florida is the only state contributing to the fresh water flow into the Everglades and the Marine Sanctuary, so regulations protecting the Sanctuary have been somewhat easier to enact and implement compared to multi-state regions, such as the Chesapeake Bay. Still coordination has been difficult because it requires consensus of many different federal and state agencies within Florida. "The legislation is potentially very powerful, but jurisdiction is not complete" (Wingrove, 1993). The number of stakeholders is great, and there is a wide variation in their values and interest. This made it difficult to build consensus to make the Replenishment Zone decision.

[67] The management problems most difficult to control and influence are the actions of people outside the Keys," says Richard Wingrove, NOAA Lieutenant and Assistant Manager of the Looe Key National Marine Sanctuary.

For the Replenishment Zones, there have been many decision 'formulators,' groups who contributed to the Replenishment Zone decision. There was the Advisory Council, the Core Group, the Strategy Identification Group, NOAA, user groups, the state officials, local officials, etc. All worked on pieces of the decision, *but the process did not allow all to work on it together.* Even the two main groups, the CG and the AC, never had a meeting together, but worked on the same problems in sequence. With so many decision formulators and so many people who have a say in the decision, consensus building was difficult and took a long time. The consensus process will not be finished until the Public Review meetings are over. The process and tools used in the decision did not help elicit final preferences or transfer all the available information to the many groups.

C. Outcome: has decision met three Necessary Conditions?

Developing the Management Plan for the Keys is difficult, because as Causey, NOAA's FKNMS manager notes, it "is trying to do Management of the ecology - not just certain species or families like the National Marine Fishery Service and different local fishery councils." Developing any coastal management plan, managing any 100 or 1000+ square miles of coast and near shore waters is a monumental task. NOAA, the AC, the CG, the Strategy Identification Group and the public have done a better job developing the FKNMS Plan, and in particular the Replenishment Zone decision, than most groups developing Coastal Management Plans. (See Chapter II and Appendix II- A.) Although the process was relatively good, it could be improved; not all the steps of good decision-making were met and not all the complicating factors were overcome.

This section will review the three necessary conditions for creating good environmental decisions to see how well the Replenishment Zone decision met the three necessary conditions. It will review i) how well the stakeholders or their representatives were informed about all the variables that affect and are affected by Zones, and it will review ii) how their preferences were collected after they became more informed and iii) how flexible and adaptable was the decision.

1. Stakeholders well informed?

Much of this analysis has been done when reviewing the steps and requirement of good decision-making in section A. Still there is a need to focus more specifically here. There are two parts to having the stakeholders well -informed: good information elicited and the information transferred to the stakeholders.

a. Good information elicited?

In the Zoning process, the AC dedicated much time and made explicit efforts to become well-informed; they elicited relevant information from many sources via discussions with the different user groups, presentations from various researchers, review of work done by the Strategy Identification Group and the CG, etc. As, reviewed earlier, there were many ways that more and better information could have been elicited.

i. Information poorly managed

Much of the information that was elicited was not well managed. Some of the initial preferences and information about the physical system was elicited and summarized in one place, but economic information and detailed final preferences were not. A great deal of information was also elicited by the AC, but was not summarized or recorded other than informally, in the AC member's memories. There were no methods used to help the participants explicitly see the linkages and interdependencies among the information elicited, even though this would have been useful due to the great volume of information.

b. Uncertainty

There was uncertainty in many variables elicited, but the uncertainty was not formally analyzed. There was uncertainty concerning the appropriate geographic scope, the appropriate time frame and the long term implications of the Zoning alternatives. In addition, the information that was available was not summarized in any way that allowed sensitivity analysis. Predictions were only made implicitly by individuals or by 'experts,' never explicitly, so that the assumptions could be tested, the information altered or the degree of certainty in the predictions challenged. The AC members could have been better informed if the uncertainties had been quantified and the predictions tested; the participants did not possess the best available information.

c. Many people with different preferences

The criteria and initial preferences were summarized, but not in real time with the users, so there was no way to ensure accuracy. There were many groups that worked on the Zoning decision in sequence, but most of the groups never worked together. NOAA, the CG and the Strategy Identification groups never made their criteria or preferences explicit, which made it difficult for anyone outside the group to understand their rational for making the suggestions and choices they did. The AC formulated a list of eight criteria, but they were not very detailed; having fewer, less detailed criteria was probably done to achieve consensus, but it did not help elicit detailed concerns of the many people with multiple preferences.

Overall, it is likely that more information could have been elicited if:

i) all the information elicited was summarized and organized

ii) the information was structured so that linkages and interdependencies were obvious

iii) the uncertainty was analyzed and quantified

iv) predictions could be tested and sensitivity analysis could be performed

v) the many different groups could work together to elicit information

vi) more detailed final preferences were elicited from the stakeholders' representatives.

b. Knowledge transferred?

The transfer of knowledge among and across the different groups was not maximized. First, within each of the different groups, there were inadequate methods for summarizing, organizing and showing linkages among the great amounts of information, which made it difficult to maximize the information transferred. Often, the only method used for recording information was lists and written summaries, but since these are time consuming to review, information transfer was not optimized.

The second problem was that there were inadequate means to share or transfer the information *across* the many groups. Information across the groups was often transferred by reviewing lists and recommendations or through NOAA employees. An example of this was that NOAA and the CG summarized the information from the initial Public Scoping Meetings and the Zoning Workshops, without stakeholders present. The Strategy Information Group reviewed these summaries to create the initial list of Strategies. The information elicited during the Strategy Identification Workshop was shared with the other groups only through the results of their work, the list of 270+ Strategies. The other groups then built on these 270+ Strategies. NOAA was the 'glue' among the groups, typically writing the summary lists or explaining a group's results, and each group had to trust NOAA's interpretations or biases. The different groups did not work together to overcome any differences they had.

Although each group had much scientific and economic information to add, it was often difficult to assess what one group knew and what gaps existed. Because the AC, Strategy Identification Group, and CG worked separately, it was difficult for one group to use information that had been elicited and used by a different group. Again, if the information had been better summarized, and organized, if the linkages were shown and if the different groups could meet together more often, then more information would have been transferred.

Information transfer would have been more successful if:

i) the information elicited was summarized and organized and the linkages were shown

ii) the different groups could sometimes meet and work together to transfer knowledge

iii) the AC were involved in more of the critical meetings

iv) the information elicitation and transfer should be more efficient, taking less time.

2. Preferences of well-informed stakeholders included?

There are two parts to ensure that the preferences of the stakeholders are included. First, it is necessary to elicit the preferences. Second, it is necessary that these preferences be incorporated into the choices.

a. Detailed initial and final Preferences elicited?

The different user groups and the AC could not accurately *express* the intensity of their opinions, the degree of differences in their opinions, or the importance of any one decision component. Likewise, the CG, the AC and NOAA could not accurately *assess* the depth of the stakeholders' convictions or the importance of an component. The only method used to convey this was by the number of comments made, or by the amount of 'air time' taken up to discuss a component. These are not always accurate indications of preferences. Although criteria were identified, the intensity of the preferences was never elicited or recorded. Also, in the NOS report, the participants complained that the objectives were never prioritized.

The stakeholders' initial preferences were elicited via discussion, debate and surveys during the Public Scoping meetings, the five Zoning Workshops and AC sub-committee meetings, but the stakeholders did not participate when their preferences were being summarized. When NOAA sent the summaries to the participants, it was an earnest attempt to assure accuracy, but it is difficult to make corrections after the meetings, when the stakeholders could only review the information individually, instead of summarizing it together.

Initial preferences were elicited, but there was a need to elicit detailed preferences *throughout* the decision-making process, at different stages. During the decision-making process, the Advisory Council typically discussed and debated an aspect or part of the decision, often with different users, formulating different choices, then sometimes there would be a spot vote to on the suggestions. Using a more accurate ranking method after discussions would have made it easier to more measure preferences and find the areas of compromise and controversy; it would have helped focus the discussion on overcoming the largest areas of controversy.

More detailed final preferences should have been elicited at the end of the process. In the actual decision, the spot vote summaries and aggregated groups' preferences were used to create the alternatives, but detailed preferences were not elicited except through discussion. The method used to understand the final preferences of the well-informed stakeholders' representative, the final choice, was one vote. The vote was held for all types of Zones bundled into three Alternatives, so the vote did not gather detailed preferences on the different pieces of the decision. More detailed final preferences should have been elicited, because it is more likely that alternatives would be chosen that more accurately reflect how the stakeholders valued the resources.

Not having detailed preferences makes it nearly impossible to review the decision during the public review process or at some time further in the future. In five years, when the Sanctuary Management Plan is updated to see if it is still appropriate, the only record of preferences that will exist will be the final alternative chosen. If the physical, economic or social climate changes and the decision needs to be altered, there will be no record of what criteria or objectives were most important to the AC, so it will be difficult to update the decision.

Overall, to improve the initial and final preferences, there was a need to:

i) use methods that enable the intensity to the initial and final preferences to be expressed
ii) prioritize the objectives and criteria
iii) summarize the initial preferences in real time to ensure accuracy
iv) elicit detailed preferences throughout the decision to steer the focus and efforts
v) elicit detailed final preferences at the end of the process to choose alternatives that accurately reflect the stakeholders values and allow the decision to be reviewed later.

b. Preferences included in final choice?

Much work was done to elicit a great deal of information and preferences, but the physical and economic information were not linked to the initial or final preferences. If more of the information had been summarized, it would have been easier to assess it, using it at the end of the process in order to make a final decision. It would have been easier to make the linkages to the preferences aspects. Detailed criteria would have been more helpful in assessing the alternatives and placing accurate preferences. The criteria and other information were not recorded in a way that made them easy to consider and incorporate into the final votes.

Many AC members were dissatisfied with the decision, even though Replenishment Zone boundaries were changed and two of five locations were deleted. With comments about "rubber stamps" and "kindergarten," it seems that many AC members do not feel that the final alternative represents their preferences and values, yet comments were made that the "process for Zoning was rewarding" due to the consensus it built within the AC group. Either the preferences of the stakeholders were not included in the final decision to the extent they should have been, and /or there was no way to review the decision to show how the preferences of the stakeholders' representatives were combined to form the decision. Eliciting and recording the detailed preferences from the stakeholders' representatives for different aspects and at different stages of the decision would allow the decision to be reviewed in greater detail than with just one final spot vote.

Overall, to improve the degree to which final preferences were included, there was a need to:

i) summarize and organize the information, and find linkages to the initial preferences so that it is easier to incorporate into the final decision

ii) detailed preferences allow the users to understand how the many preferences were combined to reach the chosen alternative and makes the decision more defensible.

3. Flexible and Adaptable decision?

There are at least two parts to ensuring that a decision is flexible and adaptable. First, it is necessary that the existing physical and economic information should be recorded and easily accessible so that the outcome a new alternative could be predicted. Second the stakeholders' preferences and objectives should be recorded, so that a new alternative could be assessed.

NOAA recognizes that the Management Plan needs to be flexible, changing as needs change:

> "Most of the data collection and detailed analysis will occur as part of the continuous management process. The Keys are not waiting for all the information before they start action." (Basta , 1993)
>
> NOAA tried to establish a "structure and working group of different government to make decisions about the FKNMS over time, not just now." said Mr. Causey, NOAA's FKNMS manager.
>
> "Developing an integrated management approach does not take place quickly. It must evolve over time, based on incremental gains that build upon one another. The foundation

for this process will be an agreement that will formalize federal, state and local agency support for the Sanctuary. The primary purpose of the agreement will be to establish a formal commitment to the continuous management process. The agreement forms the foundation for subsequent cooperative agreements and other less formal interagency work efforts. By signing the agreement, the agencies provide their staff with incentives to extend their efforts to ensure the flow of information and assistance both within and outside their organization. The suggested participating agencies are the National Oceanic and Atmospheric Administration, the Environmental Protection Agency, the US Department of the Interior, the US Army Corps of Engineers, the US Coast Guard, the Governor and Cabinet of the State of Florida, the Monroe County Commission and the Municipalities of the Keys." (Ehler, 1994)

Although NOAA has recognized the need for a flexible Management Plan, it is not likely that the actual process will achieve this for the following reasons:

a. Well-managed information

In the actual process, long discussions would probably be needed to inform the stakeholders about the repercussions and elicit the detailed stakeholders' preferences concerning a new alternative. Ideally, the existing physical and economic information should have been recorded, so that sensitivity analysis could have been easily performed and likely outcomes predicted for any new alternatives. If the best available information had been summarized and easily assessable, it would be easier to inform the stakeholders about the repercussions of a new alternative.

b. Difficult to elicit updated final preferences from stakeholders

In the actual FKNMS process, eliciting preferences concerning a new alternative would be a time consuming process, because the stakeholders' final preferences concerning the new alternative would have to be elicited and combined. Since detailed objectives and criteria were never prioritized, it is not likely that a new alternative could be easily judged and best reflect the stakeholders' preferences. Long discussions might be needed to build consensus.

Although NOAA attempted to achieve a flexible, adaptable decision, overall it was not achieved. Although it will be reviewed in five years and pieces of it can be changed within each of the government agencies during implementation, the stakeholders' preferences may not necessarily be included when changing, altering or updating the decision. Also, there was a great deal of information that was not recorded, making it likely that a new alternative will not be assessed as thoroughly as the current decision. To change the current decision, even before it goes through the public review process and is implemented, much of the process would have to be repeated.

4. Review: How close is the decision to Pareto admissible?

Following from the previous analysis of the three necessary conditions, the chosen alternative is probably not Pareto admissible. First, the stakeholders' representatives could have been better informed. It is likely that more information could have been elicited, and more information could have been transferred among and across the different groups.

Second, the preferences of the informed stakeholders could have been more accurately included. Detailed preferences of the stakeholders' representatives were not elicited or recorded, and it was difficult to incorporate some of the preferences into the final choices, since intensities, priorities and details were not known.

Third, it would be nearly impossible to change the recommended Zone, if a new alternative was created, found or brainstormed, or if the physical or economic system changed. It would be nearly impossible to explore or adopt a new decision, since the process did not leave many records that could be easily added to or altered; it would be difficult to assess a new alternative. To build consensus, much of the process would have to be repeated.

To make the decision closer to Pareto Admissible, it should have included the following:

i) summarize and organize all the information elicited was
ii) structure the information so that linkages and interdependencies were obvious
iii) analyze and quantify the uncertainty
iv) test the predictions and perform sensitivity analysis
v) enable the many different groups to work together to elicit information
vi) enable the different groups to meet and work together to transfer knowledge
vii) involve the stakeholders' representatives, the AC, in more of the critical meetings
viii) summarize the initial preferences in real time to ensure accuracy
ix) prioritize the objectives and criteria
x) use methods that enable the intensity of initial and final preferences to be expressed
xi) elicit detailed preferences throughout the decision to steer the focus and efforts

xii) elicit detailed preferences to allow the decision to be reviewed later, allowing the users to understand how the many preferences were combined to reach the chosen alternative, making the decision more defensible.

xiii) elicit detailed final preferences at the end of the process to choose alternatives that accurately reflect the stakeholders values

5. Review: Tradeoffs and Values reflected in the decision

To understand the many tradeoffs in the Replenishment Zone decision, it can be informative to review what the Keys' citizens would give up if the three Replenishment Zones are created. Alternative III for Replenishment Zone includes about over 5% of the total Sanctuary, spread over three locations, the Sambos, the Dry Tortugas and Key Largo.

The benefits of creating the Zones are to preserve the 6000+ species and protect the homes and food, which would help to preserve the biodiversity of the area. It also might help to preserve the long term economic base of the area, by helping fisheries, scuba diving, snorkeling, beach -goers, etc. Creating the Replenishment Zones provides a lab for scientific research, which in turn may help increase the long term benefits. The possible benefits are:

i) a sustainable ecosystem

ii) preserving biodiversity

iii) more knowledge about the ecosystem, and

iv) an increase in future fishing and tourist income.

These were *potential* benefits, though, and there is uncertainty as to whether they will occur, as well as when and with what magnitude.

In contrast, the losses incurred by creating the Zones where in the near term and quite certain. First, there would be a definite 'social' losses to the users, giving up the right to use 5% of the Sanctuary. Many people had a general distaste for regulations and did not want any regulations on their common property resource, areas that had always had unrestricted access. Commercial and recreational fisherman, the sport diving industry, treasure salvagers, boaters and other users did not want to give up using parts of the Ocean or Bay.

A second probable loss would be economic, incurred to those who make a living from the marine resources; many "equated establishing the Zones with giving up part of their incomes." (Causey, 1994) In suggesting these areas, NOAA used the pictures taken during the 50 fly-overs to determine which areas would not interfere with economic activities that take place in the FKNMS. They attempted to ensure that 5% of the area would interfere with *less* than 5 % of the economic activities. NOAA tried to pick locations where there were not many users and not much boat traffic.

Although the Zones and the entire Management Plan would be reassessed in five years, the decision indicates that collectively, the decision makers are willing to forego five years of unrestricted access and endure economic losses in the uncertain hopes of preserving biodiversity and increasing the economic gains in the future. The decision makers are only willing to forego limited losses before seeing evidence that there will be gains. The decision makers are implicitly incorporating their uncertainty into the tradeoffs.

Some of the benefits may be overvalued, and some undervalued. There were no predictions made about how much future income might be lost if the Replenishment Zones are not created versus if they are created. Because no detailed preferences were elicited, it is not known whether the chosen alternative is the best representation of the stakeholders' preferences and values, or just an alternative for which consensus could be achieved. Although there were some positive comments made about Zoning, there was still dissatisfaction certainly on the part of AC, feeling that they were forced to choose Alternative III. It is possible that the chosen Alternative is a result of frustration and acceptance, instead of a consolidation of well-informed stakeholders' preferences.

D. CONCLUSIONS -

The most difficult decision made in the FKNMS Management Plan has been the Replenishment Zone decision, possessing many complicating factors and great controversies. There have been a number of decision-making tools used in the FKNMS decision-making process, yet determining when and how to use many of these tools was done in a somewhat ad hoc fashion. The process used did not accomplish all of the recommended steps for good decision-making and did not overcome all of the complicating factors to achieve the three necessary conditions of good decision-making.

If the lead agency, NOAA had been more aware of the steps and requirements for good decision-making and had chosen different tools to help the steps and meet the necessary conditions, then perhaps more of the AC, CG and general public would have been satisfied with the decision made. More information and preferences could have been extracted and incorporated to make a better decision. The rest of this dissertation will apply and discuss how different families of tools can be used. A more pre-planned process and organized set of tools will be used to explore if more information and preferences could be elicited and incorporated.

Chapter VIII: Initial Use of a Utility Function to set the decision parameters

The rest of this dissertation focuses on applying different tools to the FKNMS Replenishment Zone decision. This chapter discusses the families of tools that can accomplish the first few recommended steps of good decision-making. Referring back to Chapter V, one can see that a Multi-Criteria Utility Function should be used initially, because it elicits what aspects or components are most important to the stakeholders, helping to define the one overall goal and the many objectives. Eliciting the stakeholders' initial preferences helps set the parameters for the decision.

A. Need to Elicit stakeholders' initial preferences to structure Zoning decision: How Multiple-Objective Utility Functions Help

Following the recommended steps of good decision-making discussed in Chapter III, it is necessary to accomplish the first few steps before attempting any of the subsequent steps:

Requirement 1) Ensure all stakeholders and their preferences are represented

Step 1) - Define Problem, Overall Goal and Objectives

Step 2) - Formulate Criteria

Reviewing Chapter V, Multi-Criteria Utility Functions are the best families of tools to meet these needs, since 'including interests' and 'defining goals and objectives' denote eliciting preferences. It is necessary, then, to determine which Utility Function to use.

Requirement 1) - Ensure all stakeholders and their preferences are represented

If the number of stakeholders is very large, then it may not be feasible to have all the stakeholders participate in the decision making. If this is the case, then it is likely that stakeholders' representatives should be chosen to participate in the decision making process. Selecting the appropriate group of people is not an easy task and should not be done haphazardly. This first step is very much a part of the political process; it can be accomplished by a vote by the public, or by appointment by a federal agency as was done in the FKNMS process. None of the tools help determine who the representatives should be.

Once the Stakeholders' representatives are chosen, their preferences and interests should be elicited to direct the decision making process., which is the purpose of Utility Functions. In addition, there are many Multi-Criteria Utility Functions that can be used for multiple stakeholders, such as Voting; Social Choice Functions such as the Analytical Hierarchy

Process and the KJ Method used in Total Quality Management; Social Welfare Functions such as Multi Attribute Utility Theory; Group Participation techniques such as Surveys and the Delphi Method; etc. (See Chapter V for more on these methods) Once the stakeholders are chosen, this first requirement can be met with many tools or methods.

Step 1) - Define Problem, Overall Goal and Objectives

In the beginning of the decision-making process, each stakeholder's desires, their individual and personal *objectives*, should be known before the decision-making work begins. There may be *many objectives*, but if possible, the group should try to reach consensus on *one overall goal*, typically a generic *summary of the many individual objectives*. Since decision-making can be a long, difficult process, it can be made somewhat easier and more fruitful if all the efforts are directed toward achieving one goal and overcoming one problem that all the stakeholders agree upon. The process of identifying many objectives and agreeing to one overall problem and goal is not a simple task; it requires drawing out the stakeholders' wants, needs and preferences and can best be done by Utility Functions.

Reaching consensus and defining one overall goal can not be achieved by simply averaging the preferences of many stakeholders. In the beginning stages of decision-making, it is important to have the stakeholders' representatives not only state their preferences, but also hear and process the preferences of other stakeholders. It is necessary that the users participate in 'real time,' talking and listening, eliciting and processing. Major disagreement may surface as stakeholders suggest or demand that their individual objectives be adopted. These individual objectives should be recorded; then the overall goal can be formed by combining, the many objectives into a more general, inclusive statement. Although it is desirable to have a well-defined, specific goal to direct the decision-making, it is more important to have *all* participants agree to the overall goal, so often a very general goal must be adopted. It is important, then, to use a Utility Function that can record the many objectives identified during the preference elicitation, while searching for the overall goal.

Defining one overall goal cannot be achieved by having the views and preferences of only *some* stakeholders included. To prevent a non-inclusive goal from being accepted, all stakeholders' representatives should be present. Having many people stating multiple, widely-varying preferences can often be chaotic, but it is necessary for all stakeholders to be represented in order to build consensus. Instead of reducing the number of people and opinions so that the chaos is reduced, the aim should be toward finding and using Utility Function methods and tools that help reduce the chaos.

The tool should also allow the objectives to be updated, since decision-making is a continual process and new information may help refine the objectives or the goal. There are a number of Utility Functions that elicit preferences, but most are designed to elicit preferences only once. Although these single iteration tools can be used repeatedly, they are not designed to be used in real time, so the discussion is not facilitated to the same extent as it would be with other tools. There are a number of tools / methods that are designed to elicit values in an iterative process in real time which can also record many objectives, such as the Nominal Group Technique, the KJ method and the Analytical Hierarchy Process. (See Chapter V.)

Step 2) - Define the Criteria

After defining the goal, the next step in the decision-making process is to define criteria. Webster defines a criterion as 'a standard on which a judgment or decision may be based.' For example, for the goal of 'Choosing a good Replenishment Zone,' a criterion would probably be the 'Zone size' and the 'Zone location.' It is likely that criteria may be identified when the goal and objectives are discussed. This requires a tool which can not only assist the discussion and brainstorming during the goal definition process, but which can also record the criteria that are identified. The tool should also allow the users to add to the criteria, since this step is best done in an iterative manner. It is necessary for the tool to be able to include both subjective and objective criteria, since most environmental decisions contain both. Some Utility Functions can achieve these various needs better than others; the Analytical Hierarchy Process (AHP) is one tool which can achieve these needs.

AHP will be used

AHP will be used as the Utility Function for the Replenishment Zone decision for a number of reasons. (See Appendix VIII- A for details on how AHP is used or refer to Saaty, 1990) AHP's hierarchical structure allows many decision makers to record a large number of objectives, criteria and sub-criteria, as well as the overall goal. It also requires the users to identify and understand the inter-relationships among these different variables, breaking the decision down into large groupings or clusters.[68] Recording the elicited information in a hierarchy is an efficient way to represent many parts of a whole, helping the users organize the decision variables.[69] Organizing and showing linkages among the variables helps the

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68 Clusters become important when the hierarchy is very large. See Appendix VIII -A: Step 3 for a discussion on the benefits of clusters.

69 The hierarchical structure is argued to be a far more efficient way of looking at complex problems, since

users to analyze each element rather than treat all the elements together, which helps to elicit more preferences and information, assisting the brainstorming process. (See Appendix VIII-A for a general description of the Analytical Hierarchy Process.)

AHP allows monetary and non monetary factors, both qualitative and quantitative, to be included in the decision-making process. The hierarchy makes it possible to look at the various elements of a problem in isolation: one element compared against another with respect to each criterion. AHP was designed based on the assumption that it is much easier for humans to use their judgment and to compare two things at a time rather than assign dimensionless numbers to compare many different criteria all at once. AHP reduces the decision process to its simplest terms: pair-wise comparisons. This is why it is possible to compare quantitative variables with qualitative variables using AHP.[70] AHP also enables the users to make a final choice to choose an alternative, but this step is not yet required; it will be discussed in Chapter XII.

B. Using the Analytical Hierarchy Process for the Replenishment Zone Decision

In the remaining sections of this chapter, the Analytical Hierarchy Process is applied to the Replenishment Zone decision to see if it can improve the decision, if it can obtain more accurate initial preferences and values for the coastal resources in the FKNMS. The AHP tool was not actually used with FKNMS stakeholders; the application and results are hypothetical. for the purposes of this dissertation. The application was reviewed by the chairperson of the Advisory Council's Zoning subcommittee and Advisory Council

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Cognitive psychologists believe that humans use hierarchical structures to store and retrieve information. (From many Cognitive Psychology textbooks).

[70] Saaty saw the need to make decisions which can include both qualitative and quantitative variables because of the following three points: (Saaty, Expert Choice™ manual, 1989)

"a. Humans usually perform measurements using scales with units such as pounds, seconds, miles or dollars. These scales, developed by people slowly over many hundreds of years, limit the nature of ideas we can deal with. Social, political and other qualitative factors can in no reasonable way be assessed in terms of physical or economic measurement. There needs to be a way to incorporate these seemingly non-measurable factors into a decision.

b. Just as we can distinguish and measure physical quantities such as meters for length and seconds for time, we are able to distinguish and measure the quantities of our perceptions of qualities, such as comfort, style and political influence. We have the capacity to experience a wide range of feelings and discriminations. This permits us to develop relationships among the elements of a problem and to determine which elements have the greatest impact. These perceptions and judgments should be incorporated into decision processes.

c. Many decision makers feel more comfortable sticking with 'the facts', the 'hand-calculated numbers'. Sometimes precision is sought to ten significant digits for quantitative factors, while equally important qualitative factors are simply excluded from the decision."

member, Mrs. Alison Fahrer, to ensure that the work was representative and relative to the actual situation.

To begin applying AHP, one should first review the five steps of the tool:

1. Define the goal and objectives, and specify the decision makers
2. Develop a hierarchy specifying criteria
3. Identify alternatives
4. Use judgment to assign relative weights to the different objectives, criteria and alternatives
5. Combine weights into one overall ranking using matrix algebra

As discussed in Chapter III, Criteria Formulation, Alternative Formulation and becoming Well-Informed are best done in an iterative fashion. Since there are many tools that can assist the users with these iterative steps, it is best to use some of these tools before final alternatives are formulated and judgments are elicited to make the final decision. As a result, the first three step of the AHP can be used, but before the last two steps are finalized, other tools should be used. The last two AHP steps are discussed in Chapter XII, and the first three steps will be discussed in this chapter to show how they can assist the decision-making.

1. AHP Step 1 - Define the overall goal and objectives, and specify the decision makers

The first level of the AHP hierarchy is to define the goal and the second level is to list the decision makers who will vote. Although with AHP it is possible to define the goal first, then the decision makers, this work will follow the recommendations and steps set out in Chapter III, and will define the decision makers first. This is not a problem when using AHP.

a. Identify the decision makers

To identify the decision makers, it is necessary to define who will have voting power.[71] The names of the people in the second level of the hierarchy are a list of those people who will participate in the final choice step. In the Replenishment Zone example, the decision makers were first defined as environmental groups and user groups, because these were the two main groups with the opposing views. Learning more about the FKNMS decision-making process

[71] It is not an absolute requirement that all decision makers be defined in the beginning steps of AHP; it is possible to ignore this step or postpone it until later, because there are cases where there is only one decision maker, so this level is omitted. Defining who will vote is a formal step, though, so using AHP makes it less likely that this will be overlooked. AHP i) requires the users to consider who the decision makers are and ii) allow for many decision makers to easily participate in many steps of the decision-making process.

and the membership of the Advisory Council (AC) and the Core Group (CG), the subtleties of the different participants became more apparent. The Zoning decision was not just a conflict between environmentalists and the user groups. There were differences among the different user group members as well; commercial fishermen typically had different objectives from scuba divers, who typically had different objectives from treasure salvagers. Some user group members had objectives which were more like the objectives of the environmentalists. The many different users groups could not be put into one category, one group of decision makers with the same objectives. Since AHP requires that the decision makers be explicitly stated, it was easy for Mrs. Fahrer, an Advisory Council member and Chairperson of the Zoning Subcommittee, to see this mistake and help identify the actual decision makers: each individual member of the AC and CG, each with his or her own set of objectives. It was best not to group any of the members as having the same objectives and preferences.

If an AHP had been used in the actual Replenishment Zone decision, it would have forced the users to think about who should have voting power. The Replenishment Zone AHP would have required that those with decision-making power be explicitly defined in the beginning of the process. In the actual decision, the AC, CG and NOAA were all involved, so it will be assumed that all three groups would be assigned some voting power with AHP. Different amounts of responsibility / control could be assigned to the different groups by specifying different weights to the voting of the three groups. Since NOAA was given the authority to create the FKNMS plan and to have advisory groups, the weighting system would depend on how much power NOAA was willing to share and whether or not the AC, CG and public were willing to accept the roles 'assigned' by NOAA.

Although the actual members of the CG, AC and general public could not agree to the roles and responsibilities of the different groups even at the end of the process (see NOS report, 1994), for a good decision-making process the decision makers need to be defined. For the purposes of this dissertation, the decision makers for the Replenishment Zone will be defined as both the AC, the CG, and NOAA, since they all worked on the decision in sequence, although NOAA did have final decision-making power. The Strategy Identification Group will be not included in the group of decision makers, but will be identified as part of the technical advisory resources; they were not required by law, and they did not participate as often as the AC and CG. Those with voting power, then, will be defined as NOAA, the CG and the AC. Completing this AHP step forces the users to define who should have voting power and how much, which would have then helped define the roles of the different groups: NOAA, the CG and the AC; roles are better defined early in the decision-making process, not just at the end during the choice.

It is important to note that the initial weighting of the votes may not be appropriate. Defining the stakeholders' representatives and their voting power is necessary at the beginning of the process, but it depends on what was valued at this stage. There needs to be flexibility for learning, for realizing that new information may be uncovered that would change the stakeholders' representatives or their respective voting power. There may a need to review these decisions at the end of the process, to incorporate what was learned. AHP can accommodate a shift in voting power, assisting this to some degree. (See Chapter XII)

b. Define one Overall Goal and multiple Objectives

AHP *requires* and *assists* the decision makers in defining the overall goal. In the FKNMS Replenishment Zone decision, those who had voting power, the AC, CG and NOAA, would have had to reach consensus concerning the overall goal before creating the completed AHP hierarchy. In the actual process, defining the objectives and goal would probably be done best if the AC, the CG and NOAA together as a group brainstormed, while someone acted as a facilitator, writing down the suggestions, the individual objectives. The facilitator would ask the members where they thought each objective or sub-objective should be placed in the hierarchy.[72] The members would keep brainstorming and discussing until most or all of the individual objectives were recorded, and an overall goal would be sought.

If the AC could not participate from the beginning, then at minimum the hierarchy would provide an organized summary of the goal and all identified objectives from the Public Scoping meetings, showing the linkage among them. The AC could then update the hierarchy when they formed to include any objectives they felt were omitted and then they could have participated in refining the overall goal. This could occur for each of the issues. If AHP had been used, the overall goal would be explicitly stated at the top of the hierarchy, so that no one could forget it or claim it had never been formed.

Looking at the actual FKNMS process may provide some insight as to how the overall goal of the work *might* be defined. It seemed that Strategy Z.2., "To protect the homes and food of important commercial fisheries and to protect all of the 6000+ species that are not covered by the Fisheries Management Council." represented only part of the objectives; it was not the

[72] In an attempt to define objectives and find a common overall goal, criteria might also be identified and discussed; these too could be recorded in the AHP hierarchy. See the next step.

overall goal otherwise there would have been no opposition. All stakeholders would move towards creating a Zone that can best replenish the marine life, perhaps defining the entire Sanctuary as a Replenishment Zone. While this might have been the personal objective of some, other stakeholders wanted no zones. Strategy Z.2., the purpose for Replenishment Zones, may capture and summarize many Replenishment Zones *benefits*, but it does not capture all of the objectives, so it cannot be considered the overall goal.

The FKNMS Act, written by Congress, required zoning to be considered, so the decision makers could not dismiss zoning altogether. Some decision makers might have said their personal objectives were 'to create the largest Replenishment Zone possible,' while others might have said 'to prevent any Replenishment Zone from being created.' The Replenishment Zones could range from an area of zero to the entire Sanctuary, but by law, they had to be considered. Because there was great controversy among the different stakeholders' objectives, a general overall goal would have been needed to reach consensus. One general overall goal might be "Decide on the Zones - Where, how big and how many?" so that all the stakeholders objectives could be considered.

This would be organized in an AHP hierarchy as such:

i) overall goal agreed to by all decision makers and recorded in Level 1: 'Decide on Replenishment Zones'

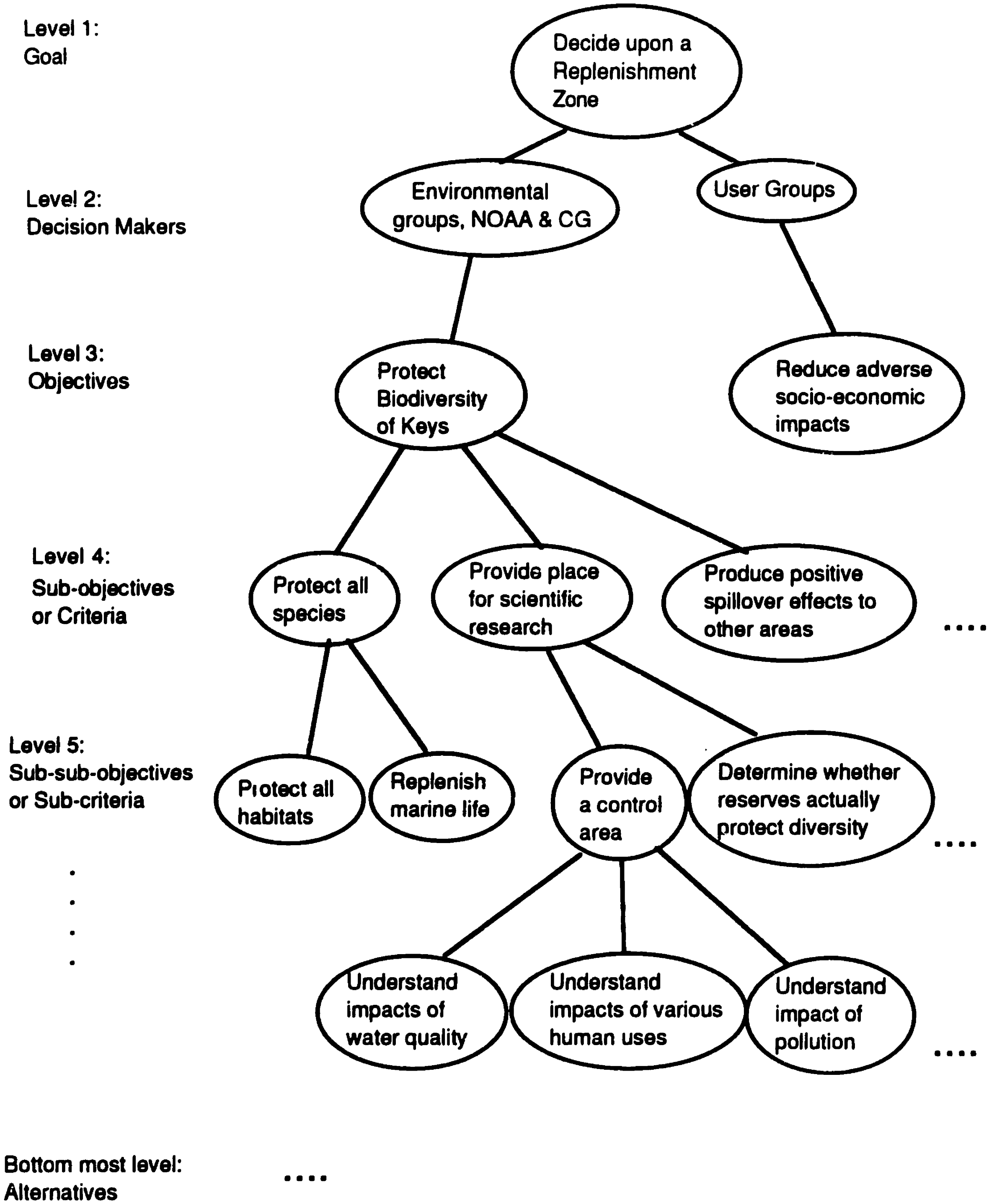
ii) different decision makers listed next in Level 2.

iii) different objectives listed next in Level 3.

The AHP might look something like **Figure VII - A** after finishing the first two steps of good decision-making.

As the hierarchy was built, the AC, CG, and NOAA might have learned new things, and the hierarchy could be altered. More objectives and sub-objectives could be added to each level as more was learned. The goal might be redefined, but always there would be only one goal stated explicitly at the top of the hierarchy for all participants to see, reducing the amount of misunderstanding that can occur when there are multiple stakeholders with different objectives. The AHP hierarchy would provide a good visual summary for the work already completed, yet it could be updated.

Figure VIII - A : First AHP hierarchy of Goal, Stakeholders and Initial Objectives



2. AHP Step 2 - Develop the hierarchy specifying the Criteria

Once the goal is defined and objectives are recorded, the next step is to continue building the hierarchy, brainstorming the sub-objectives and criteria important to the Zoning decision. Under each objective in the hierarchy, sub-objectives and criteria should be identified and recorded, to add detail. Defining these variable would probably be done best if the AC, the CG and NOAA continued discussing as a group, with someone continuing to act as a facilitator, writing down the variables and building the hierarchical structure.

Using AHP would *enable* criteria formulation in three ways. First, reviewing the existing ideas would help stimulate new ideas among the group, so the brainstorming would be enhanced. That is why it is important that the hierarchy be built in real time, with the most current hierarchy available for all to see. Second, the hierarchical structure keeps all the information organized, so people can more easily build on the existing ideas. Third, AHP does not inhibit idea generation. The AC and CG members could suggest many different ideas and criteria, without a need to argue over which are the most important criteria. The process of prioritizing and placing value judgments on the criteria and sub-criteria happens after the hierarchy is built, after the idea generation is finished.[73]

For example, someone in the Advisory Council, CG or NOAA would read the existing hierarchy, which would stimulate a new idea, a new criteria. The new criteria would be suggested and the facilitator would ask the member where it should be placed in the hierarchy. Adding a new criteria would probably incite discussion, either about its wording or its placement in the hierarchy. New ideas would develop from the discussion. The members would keep adding criteria and brainstorming, until they felt satisfied they had identified the major components and most criteria. Every member's suggestions could be written down and included in the hierarchy.

To build an example of an AHP hierarchy for this dissertation, and determine what criteria might have been included in the hierarchy if AHP had been used in the actual case, the list of eight criteria developed by the AC's Zoning subcommittee can be used. The eight criteria are:

"Consider areas of high habitat diversity representative of the Key's biosphere
Consider environmental and socio-economic impacts
Consider long term impacts from establishing reserves in areas of critical economic value
Consider area with good water quality
Consider socio-economic impacts on displaced user groups
Consider ownership of nearby property

[73] Using AHP, the idea generation and brainstorming are not inhibited, because the users would place judgment individually during the ranking or voting process, delaying the conflict. If there was disagreement during the AHP process, it might exist in trying to organize / build the hierarchy. For example, the users might disagree as to which criteria a sub-criteria should be placed under, but even in this case, AHP allows a sub-criteria to be listed under more than one criteria.

Sufficient size to include full range of habitats

Consider adjacent area regulations and restrictions"

(The source is the Zoning presentation made by Mr. Causey, the FKNMS manager, 1994)

By reviewing the subcommittee's list of eight criteria and the wording of Strategy Z.2 for Replenishment Zones, the following hierarchy of objectives and criteria was developed.

Level 1: Goal

Decide upon a Replenishment Zone[74]

Level 2: Decision Makers

A. Advisory Council Members - User Groups and Environmental Groups

B. Core Group Members

C. NOAA Members

Level 3: Objectives

Objective 1 - Protect Biodiversity

a. Area must have high biodiversity now

b. Area must have good chance for preserving biodiversity

i. Area must protect all habitats

ii. Area should not be in heavily populated areas

iii. Area must protect all marine species

- Area must protect all habitats and food
- Area must replenish marine life
- Area must protect genetic diversity of marine life
- Area must be adequately large
- Area must not be adjacent to detrimental zone

c. Produce positive spill-over effects to other areas

d. Provide place for scientific research

i. Provide a no-use control area to determine whether reserve actually protects biodiversity

- Understand impacts of water quality
- Understand impacts of various human disturbances

[74] The overall goal should be kept brief and somewhat ambiguous, so that all members of the AC and CG could agree on it. This goal "Decide upon a Replenishment Zone' would encompass i) no Replenishment Zone, ii) a Replenishment Zone the Size of the entire Sanctuary, iii) temporal as well as spatial Zones, etc.

- Understand pollution effects on marine life
- Understand salinity effects
- Understand temperature effects

ii. Do other scientific research

Objective 2: Preserve current lifestyle in the Keys

a. Zone is ideologically undesirable

b. Reduce adverse socio-economic impacts of Zone

i. Minimize NPV of economic losses (or maximize economic gains)

- Minimize long term economic losses
- Minimize short term economic losses

ii. Minimize NPV of socio-cultural losses

These are organized in the AHP hierarchy diagram for more clarity. Levels 1, 2 and 3 have already been created, so the sub-objectives and criteria will be organized in Level 4, 5, 6... The hierarchy can be continued, working downward to the level of sub-criteria, and sub-sub criteria.[75]

Mrs. Alison Fahrer, an AC member and chairperson for the AC's Zoning subcommittee, reviewed the preliminary AHP hierarchy. The preliminary AHP hierarchy was changed, adding and rearranging some of the objectives and criteria. For example, she discussed how zones were ideologically undesirable to some people in the Keys, a factor that had been omitted in the existing AHP model, so she added it. Working together, she and this author also realized that 'Reducing adverse socioeconomic impacts' was a related topic. 'Ideologically adverse' and 'reduce socioeconomic economic factors' were put together under a new heading called 'Preserve Current Lifestyle.' This made it easy to see the two main objectives within the Replenishment Zoning decision:

- 'Protect the Biodiversity of the Keys' and
- 'Preserve the Current Lifestyle.'

'Protect the Biodiversity of the Keys' was often cited as the objective and is explicitly stated in Strategy Z.2, but it was not the only objective or there would not have been so much opposition. 'Preserve the Current Lifestyle in the Keys' was never cited in the Zoning documentation, although concerns about maintaining the current lifestyle were immense.

[75] The bottom-most level is where the alternatives are listed. which will be discussed more in **Chapter XII.**

From fishing income to boating rights, from treasure salvaging to tropical fish collecting, from diving income to landowners, a great amount of time was spent discussing many of these sub-objectives and criteria.[76]

Listing various criteria under 'Preserve Current Lifestyle,' the AHP made it explicit that there are concerns about both social and economic aspects of the current lifestyle. 'Social aspects' might include 'Minimize negative impacts to landowners,' or 'Allow for subsistence fishing,' although many more would probably be identified if AHP had actually been used with the AC. Explicitly listing 'Economic aspects' allows different income sources to be identified such as fishing, diving, tourism, etc. and enables income to be further dissected into i) 'Short term Income' and ii) 'Long term future Income.' Differentiating between the short and long term income is important in the Replenishment Zone decision, so that stakeholders can see there might be a tradeoff in foregoing short term income for the chance of increasing long term income. Organizing and separating the different objectives helps elicit more criteria, more of the details. This helps the users more fully understand what qualities the subcommittee was trying to ensure in Replenishment Zones. The AHP helped elicit more information than the list of eight criteria. (See Figure VII - B for corrected AHP Hierarchy)

After working for a brief period of time, Mrs. Fahrer said the revised AHP hierarchy was a fair representation of what the AC Zoning Subcommittee's intentions were. Using the AHP diagram as a pictorial summary of the AC's initial preferences, Mrs. Fahrer was able to quickly share her insights on the Zoning Issue and convey her perspective on the overall goal, objectives and criteria. The AHP helped indicate that many of the other sub-objectives could be grouped under a new objective, 'Preserve Current Lifestyle.' Identifying this main objective would have helped in the actual Zoning decision, making it explicit that there were tradeoffs, that the Zone should not be created at all costs, but that other objectives were also important. In this way, AHP appeared to elicit information and share important ideas in a very short time period.[77]

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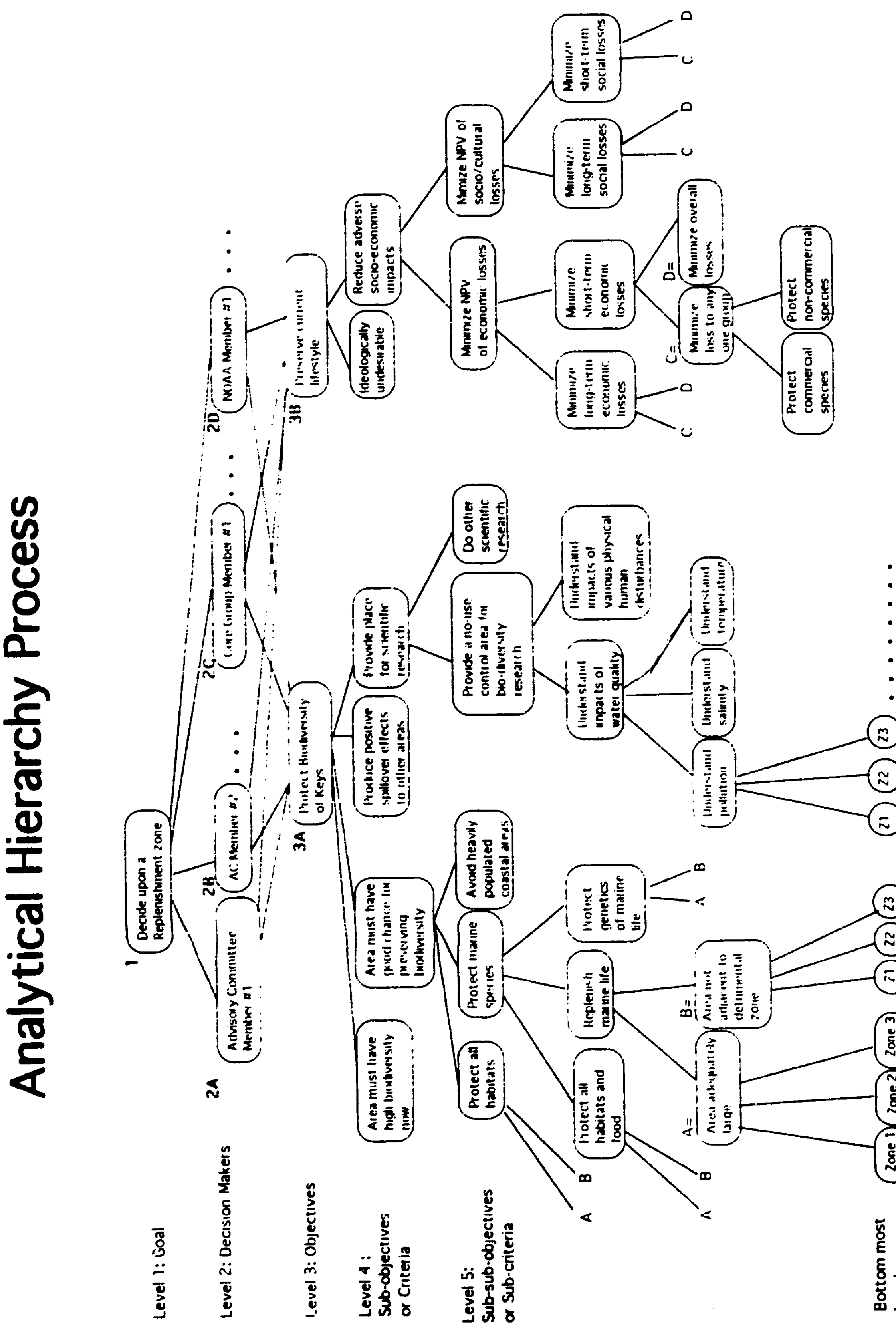
[76] The statement of Strategy Z.2 directed the decision-making, so it should have included both of the main objectives. It should have been worded similar to 'Protect Biodiversity while preserving the Current Lifestyle,' so that it was obvious there were tradeoffs and 'losses' in creating Replenishment Zones.
[77] Although this use of the Zoning AHP was only with one person, Mrs. Fahrer, the chairperson of the AC's Zoning subcommittee, it is likely that if AHP were used with many people, many concerns would be made explicit therefore enabling discussion. Consensus would take longer with more people, but these benefits of AHP could still be reaped.

Figure VIII - B: Corrected AHP hierarchy



The AHP model assisted Mrs. Fahrer because:

i) She could read it quickly; the pictorial representation helped her immediately see how all the pieces fit together.

ii) She saw *where* she did not agree with the existing model. She could easily redefine the list of decision makers, add sub-objectives, and rearrange the variables to find new objectives, as she perceived them.

These hierarchies are only examples of possible AHP's for the Replenishment Zoning decision. They are not the only hierarchies that can be used.[78] If many of the AC and CG members had participated, it is likely that i) the wording of the goal and two main objectives would have been different, ii) more detailed sub-objectives would have been identified, iii)more detailed criteria would have been identified, etc. With more detailed sub-objectives and criteria, more than two main objectives may have been identified. Overall, this example of a Zoning AHP recorded more detailed sub-objectives and criteria than the AC's list of eight criteria, but if AHP had been used in the Actual Zoning decision, it is likely that even more detail would have been elicited and recorded than what is made explicit in this example AHP.

3. AHP Step 3 - Formulate Choices

After specifying the overall goal, the decision makers, the objectives and the criteria in the hierarchy, the next step would be to define the alternatives. AHP *requires* that discrete alternatives be formulated, but it doesn't *assist* with choice formulation as much as some other tools. AHP helps the users formulate good alternatives only by making all the objectives and preferences explicit, but it does not help the users become more knowledgeable about the physical and economic aspects of the decision. Both are needed for the users to create good alternatives. Therefore, it is not likely that using AHP alone can find the best alternatives.

If some alternatives have been identified through the brainstorming process so far, they can be included in the current hierarchy and the listing can be updated later. For a more thorough exploration of alternatives, though, tools and processes other than AHP should be used. With AHP, new variables can be added as they are discovered with these other tools. As new information emerges, it can be included as new objectives, criteria or alternatives; AHP is easily altered as new information is learned.

[78] It is important to keep in mind Saaty's advice that there is no one correct hierarchy or model for a decision. "Individuals informed about a particular problem may structure it hierarchically somewhat differently, but if their judgments are similar, these overall answers tend to be similar."

C. Results of AHP Tool

This section discusses what was accomplished when AHP was used for this dissertation and projects what it could have accomplished if it had been used during the actual FKNMS process. The AHP tool could have elicited detailed initial preferences from the stakeholders and other decision makers, and could have made them better informed about each other's preferences.

1. Elicits the stakeholders' initial preferences

AHP helps elicit more of the stakeholders' initial preferences for two reasons. First, organizing the criteria that were already identified helps the users understand the information better, which helps elicit criteria and objectives that were less obvious. The objectives and criteria identified by using the AHP structure was more detailed than the AC subcommittee's eight criteria. Many criteria were elicited by the process that was used, but by attempting to organize these criteria and show linkages, a key objective was identified. Attempting to organize criteria such as 'Ideologically Opposed to Regulations'; 'Minimizing the Economic Losses'; 'Non Interference with land owners,' etc. it became apparent that one of the main objectives for many Keys' residents was to 'Preserve the Current Lifestyle.' Organizing and showing linkages in real time with the users would elicit even more criteria and objectives.

The second reason that AHP helps elicit more objectives and criteria is that AHP does not place judgments on the variables identified until the end of the process, so idea generation is not thwarted and brainstorming is not inhibited. Initial preferences can be identified and the hierarchy built, yet there is no need to attempt consensus until the end of the process, when all stakeholders share the same physical and economic knowledge, when all are well-informed with the best available relevant information. Since consensus is not attempted and a more free flow of ideas could happen, the AC would probably have listed many more measurable criteria using AHP than just their list of eight. Using AHP, the AC, CG, and NOAA could have worked together, organizing the criteria identified in the Public Scoping Meetings and Zoning workshops. In trying to organize and process those criteria, it is likely that new ideas would be stimulated and included.

2. Informs about human preference aspects

Building the AHP step by step helps the users share their initial preferences. As Mrs. Alison Fahrer said, "If you showed them a diagram in finished form, they would be turned off, but not if you let them build it." Using AHP helps record and show the linkages among the different preferences. This helps the users better understand the sources of controversy and areas of consensus.

The sources of controversy are obvious, because it is impossible to 'have a no-use Zone for scientific research' and at the same time *not* create a Zone because it is 'ideologically undesirable.' It is difficult to have an 'area to replenish marine life' and at the same time 'minimize the short term economic losses.' Another example, is that initially, one might think that Maximizing Income is one objective, but it is not; breaking it down into Long and Short Term Income allows the users to differentiate between the two, which allows one to understand the tradeoff. Long term fishing and diving income will probably be increased by creating a larger Zone, but this may hurt short term income. Older fishermen and dive operators who plan to retire soon may value short term income more than a possible increase in long term income, while younger fishermen may prefer the potential increase in long term income. AHP helps elicit enough of the details so that the users can become more knowledgeable about the trade-offs and areas of controversy or disagreement.

An AHP can also inform the users where there exists some commonalty among the objectives. The hierarchical listing shows that 'Preserve the Current Lifestyle' and 'Protect the Biodiversity' had many objectives and criteria in common, such as replenish marine species, understand pollution effects on marine life, etc. This provided a link between two separate objectives, exposing commonalty, which helps stimulate choices that might be agreeable to the two different objectives and the groups that support them. The brainstorming for choices could be guided, looking for ways to minimize the loss to short term income, while maximizing the increase of long term income and preserving the biodiversity. Using AHP helps the decision makers become more informed about opportunities for consensus.

If AHP had been used, the detailed, initial preferences of the decision makers would have been well-documented and would have allowed the AC to participate along with the CG and NOAA. The AHP could have been updated and altered so that it accurately represented the AC's initial preferences. Documenting detailed, accurate initial preferences and using them to create the decision parameters would help justify the decision, and help when people wanted to reflect on it or change it in the future. This would help during the public review process, because in defending the plan, NOAA could cite the detailed criteria and show the logic of how well each Zone meets each criteria. By recording detailed objectives and criteria, AHP would help inform the users and any interested parties, about the initial preferences of the decision makers.

D. Steps of Good Decision-Making Process achieved

If the AC, CG and NOAA members had used AHP for the preliminary steps of the actual FKNMS Zoning decision, they would have had a structured process to help them efficiently achieve the first requirement and the first three steps of good decision-making.

Requirement 1) Have all the stakeholders represented

Using AHP would have encouraged NOAA to define early in the decision-making process who was able to vote, and who was involved in all steps of the decision-making process. The voting power could be allocated in any variety of ways using AHP, for example, for CG and AC might have had equal voting power, or the AC might have voted and the results used by the CG and NOAA. Being explicit and defining voting power would have encouraged discussions about other parts of the decision-making power and roles, such as who the AC advises, how the advice is incorporated into the decision, the extent to which different users are impacted, when and how the AC and CG's work would be merged, etc. encouraging these parts of the role to be explicitly defined as well.[79] Role definition in the beginning may have caused more rivalry then, but it would have cleared up many misunderstandings concerning power and responsibility throughout the process; many problems would have had to be addressed and resolved.

Step 1) Overall Goal and Objectives defined

AHP could have been used to summarize the objectives and criteria elicited with many different stakeholders *during* the Public Scoping meetings and Zoning workshops in *real time*. Many people with widely varying opinions could have worked together, suggesting and organizing objectives and criteria, since AHP helps to minimize controversy while defining these variables; AHP would not require that the objectives or criteria be prioritized in the beginning of the process. Using AHP would have allowed large groups to participate in identifying and structuring these variables in real time.

These initial preferences recorded in the hierarchy could then be reviewed by the AC, CG and NOAA, and could have been added to, altering the AHP hierarchy. Refining the hierarchy

[79] This step can be delayed until the actual voting time, but AHP does require the users to consider it.

would have also allowed the AC, CG and NOAA to include and make explicit their own objectives and criteria.

By using AHP to record the many objectives , the users could have more easily developed one general overall goal that they all agreed upon. Having this one goal explicitly stated at the top of the hierarchy would also prevent any of the decision makers from forgetting the goal.[80] Overall, AHP would have elicited more details and a greater number of the stakeholders' and decision makers' initial preferences, enabling the decision to more closely reflect the values held by the stakeholders.

Step 2) Criteria formulation

AHP could help the users define the criteria, just as it could help define objectives. Building the AHP hierarchy is largely a process of explicitly stating these variables, and AHP *requires* the users to develop this detailed list of the objectives and criteria. Using AHP, members of the public, the AC, the CG and NOAA would have been required to state more of the objectives and criteria to a finer level of detail, so that more of their values and ideas were explicit. The AC's list of eight would not have been sufficient.

Step 3) Choice formulation

Using AHP helps only partially with choice formulation. By making the initial preferences explicit, AHP enables the users to formulate choices that will likely satisfy the stakeholders' preferences. Other tools need to be used, though, to help formulate alternatives that account for the economic and physical aspects of the system.

Requirement 2) Move towards well-informed decision makers

If AHP had been used by the AC, the CG and NOAA, it would have helped inform each member about the other participants' concerns and views; AHP does not inform about the physical or economic aspects, but it does inform about preferences.[81] Building the AHP hierarchy helps the different participants expose their preferences, which helps each user understand how his or her concerns fit into the overall goal, and helps each user understand the perspectives of others. The participants do not have to agree with each other on the priority of the different objectives and criteria, but building the hierarchy and understanding the

[80] If the CG, NOAA and / or the stakeholders had started to summarize and organize the variables, building the AHP before the AC formed, then the hierarchy would have enabled the AC to more easily review their work, adding to it and altering it. The hierarchy could have also been used if all three groups joined for an initial meeting to define the overall goal.
[81] There would have also been benefits, but to a lesser extent, if AHP hierarchies had been built in separate AC and CG meetings

other person's perspective helps build consensus. AHP would have helped the stakeholders, the AC, the CG and NOAA to work together to inform each other.

In general, the first few steps of AHP enable some of the steps and requirements of good decision-making. AHP encourages 'Requirement 1) All Stakeholders are included' since the second step of AHP requires the users to determine who will have voting power. AHP requires and assists, 'Step 1) Define Problem, Overall Goal, and Objectives;' and 'Step 2) Formulate Criteria' by facilitating the brainstorming and organizing the criteria which have already been elicited. It assists to a lesser extent with 'Step 3) Formulate Choices' and 'Requirement 2) Ensure stakeholders are well informed.' AHP can achieve or assist with the various steps in an efficient, timely fashion, because it gives the users a structured process. AHP facilitates discussion and brainstorming by providing a framework, but it does not impose an obtrusive methodology, which dictates the flow of a meeting.

E. Inadequacies of Utility Functions: Next steps for Decision-Making

Using a Multi Criteria Utility Function to elicit initial preferences helps set the parameters for the decision-making process. The Analytical Hierarchy Process accomplishes the first requirement and the first three recommended steps for decision-making, as well as partially assist with other steps. Using the Analytical Hierarchy Process for this case showed how it could be used to include the preferences of the stakeholders, their representatives - the AC, the CG and NOAA. AHP requires that an overall goal be defined, and can assist this process, by allowing objectives to be elicited in an on-going, iterative manner until consensus is reached. The many objectives and criteria can be recorded, structured and organized in the AHP hierarchy, making it so that the decision makers do not have to 'mentally juggle' the many important factors. AHP can elicit information and educate the decision makers on the human preferences aspect of environmental decision making. (See Appendix VIII-B for a brief discussion of the other FKNMS decisions where AHP could have helped.)

AHP does not help with all the steps and requirement of decision-making, though. It does not help elicit and educate people about the physical and economic aspects of the system. For example, AHP would not help educate the group on how fisheries might benefit from Replenishment Zones or the technical reasons why Zoning might be more or less beneficial than other management methods. To do this, other tools must be used.

Chapter IX. Use of Cognitive Maps to elicit and transfer general information

There is often a great deal of information concerning the physical and economic aspects of environmental decisions which require tools and models be used to extract, organize and then employ the information. There are various tools that can do this; it is best to begin with those that are easiest to use and elicit the general information first before diving into great amounts of detailed information. This chapter will explore the tools that can help elicit and transfer general information about the physical and economic aspects of the Replenishment Zone decision.

A. Need to identify, organize and Transfer general information about the system: How Cognitive Maps help

Before using this family of tools, it is best to have already completed the first two steps of decision-making and to have begun the third step, criteria formulation. This ensures that the initial preferences of the stakeholders are first understood, so that the decision-making efforts are focused on the areas that are important to the stakeholders. AHP can help elicit all the criteria and important variables that the users are aware of, but, it is likely that becoming better informed about the physical and economic aspects of the decision would help them identify more of the important variables.

1. Formulating the criteria and choices

The next two steps of decision-making, 'Formulating Criteria' and 'Formulating Choices' are best completed in an iterative, ongoing process. As the decision makers become better informed, they will probably formulate more criteria and better choices. Since the information gathering process may be ongoing, and there are many tools that can help these steps, the users should begin with the family of tools that is easiest to use and understand. This will enable a greater number of people to contribute information to it, improving the quality of the information elicited. Pictorially based tools are especially easy to use, making it quick and easy for multiple users to understand the information already gathered and see where information is still needed. If after completing the first tool, the decision makers need to learn more, then other, more complicated tools should be employed.

Cognitive maps are one of the easiest tools to use that meets the requirements of organizing information, showing linkages, pictorial-based and easy to use by many people. They are Multi-Criteria Decision Making (MCDM) tools that do not elicit preference, but that enable the users to more easily extract, organize and transfer physical and economic information. In addition, Cognitive Maps are a good first tool to use, because they are often the first step in using some of the more complicated tools for extracting the physical and economic information.

2. Cognitive Maps, Mental Mapping, and Cause and Effect Diagrams

"A cognitive map is designed to capture the structure of the causal assertions with respect to a particular policy domain, and generate the consequences that follow from this structure." (Hwang, 1987) These Cognitive Maps or Cause and Effect Diagrams can help a decision process, in two ways. First, building a Cognitive Map requires the users to identify the physical and economic variables that affect the system; these variables become nodes. Second, these diagrams require that the users identify the linkages among the variables. These linkages are drawn as arrows among the different nodes. An arrow leading from one node to another indicates that the value of the second variable depends on the value of the first variable.

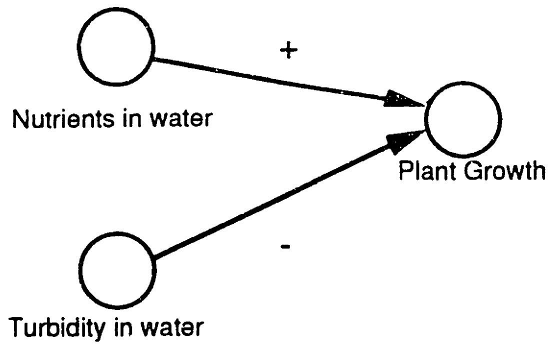
These diagrams are easy to use, both to create and read. There is no need to teach a decision-making group how to build or interpret them, so there is no time spent just trying to learn the tool. Cognitive Maps and Cause & Effect diagrams are best used to quickly elicit information and transfer knowledge about the important variables in a decision. By eliciting the relevant variables and showing their linkages, these diagrams quickly capture the users' hypothesis about cause and effect, and about the feedback in a system. They "help the process of articulating and communicating deeper insight about complex issues. They provide a language for articulating our understanding of the interconnected nature of our world and are an important tool for representing the feedback structure of systems." (Kim, 1992)

3. Causal Loop Diagrams

Causal Loop Diagrams (CLDs) are one type of Cognitive Map that many people find useful. CLDs are slightly different from other Cognitive Maps in that the linkages among the variables may be labeled as positive or negative, and immediate or delayed. If increasing the value of Variable A increases Variable C, then the two are positively linked; if increasing Variable B decreases Variable C, then they are negatively linked.[82]

[82]A linkage's sign can only be labeled if it does not change depending on quantity. For example, temperature can positively or negatively affect reef growth, depending on what is the existing

For example:



Determining the sign of some linkages may be challenging. For example, increasing the number of nutrients in a body of water increases the total mass of plant life. A problem is that the type of plant life is not specified; if nutrients increase past a certain threshold, the number of desirable plant species often decrease, and undesirable plant species increase. In addition, CLDs allow the linkages to be labeled as either immediate or delayed. If the effect happens soon after the cause, it is an immediate link; if the effect happens in the distant future, it is a delayed link.

If the sign of each linkage in the system can be determined and does not change, then the CLD can be used to determine the overall behavior of a system. If the links form a closed loop and all of the links in the loop can be labeled, then we can see if the loop is overall positive or negative.[83] If the loop is positive, then we can expect either exponential growth or exponential decline causing a crash in the system. If the feedback loop is negative, then we can expect stability, where the different linkages work to counterbalance each other, bringing the system into balance. If there are links that are delayed then one may not see the exponential growth, exponential decline, or stability; one would probably see oscillations in the system. (High Performance iThink Manual, 1992)

Considering the linkages and loops of a CLD helps the user understand the general trends that will happen as a result of the different variables interacting. If there are many closed loops in one system, as there often are in complex environmental systems, then there may be both positive and negative closed loops. In these cases, though, it may be difficult to determine which closed loop will dominate the system and how the system will behave in

---

temperature. If the water temperature is below the ideal range, then more heat will decrease the growth. Conversely, if the starting temperature is below the ideal range, then more heat will increase reef growth.

[83] Many nodes may be linked through a series of arrows. If a group of linked nodes and arrows form a closed circle, then it is called a closed loop. An odd number of negative links indicate a negative loop; an even number of negative links indicate a positive loop.

general. At this point, other more sophisticated tools may need to be used in addition to CLDs, tools that will be discussed in Chapters X and XI.

B. Using Causal Loop Diagrams for Replenishment Zone decision

A Causal Loop Diagram (CLD) is created for the FKNMS Replenishment Zone decision to see if its use could have improved the decision, to see if it is likely that a CLD could have elicited, made explicit and transferred more information than the actual FKNMS Zoning decision. This Causal Loop Diagram was not built with the help of all the AC, CG and NOAA members, so the finished diagrams and results are hypothetical. The application was reviewed by a scientist who has been involved in the FKNMS Management Plan process, and who gave presentations to the Advisory Committee to insure that the work was representative and relative to the actual situation.

To build a CLD for the Replenishment Zone requires determining which variables affect the system, and what their linkages are. This is best done with a group of people, so the members can brainstorm their ideas and build on each other's thoughts. Ideally, CLDs could have been used in the early Public Scoping meetings and Workshops to elicit some of the information from stakeholders. Then these CLDs could have been added to and refined by the AC, CG, NOAA members. Building a Zoning CLD would enable general knowledge from many disciplines, such as marine species, human activities, economic systems, ecological systems, etc. to be elicited and organized in one place. Using a CLD would allow knowledgeable participants from many disciplines to add to the information base.

For the CLD to be most effective at eliciting information, the users would first have to agree why they were building the CLD. For the Replenishment Zone decision, a reason might be to "Understand how Replenishment Zones would achieve Strategy Z.2 and the objectives recorded in the AHP hierarchy."[84] For example, the users would brainstorm what variables help "...provide natural spawning, nursery and permanent residence areas for the replenishment and genetic protection of marine life..." (FKNMS Zoning Strategy Z.2), how Zones affect 'Long term Incomes,' etc. Members of the group would brainstorm the different variables that are part of the system: physical, biological, chemical, economic, anthropogenic, etc. and they would brainstorm the linkages, or which variables relate to the other variables.

[84]Before building the CLD, there is a need to determine the reason it is being built. It is best if the objective of Replenishment Zones was defined previously by another step or tool in the process; the objective might be the wording of Strategy Z.2 - 'To protect the homes and food of important commercial fisheries and to protect all of the 6000+ species that are not covered by the Fisheries Management Council.'

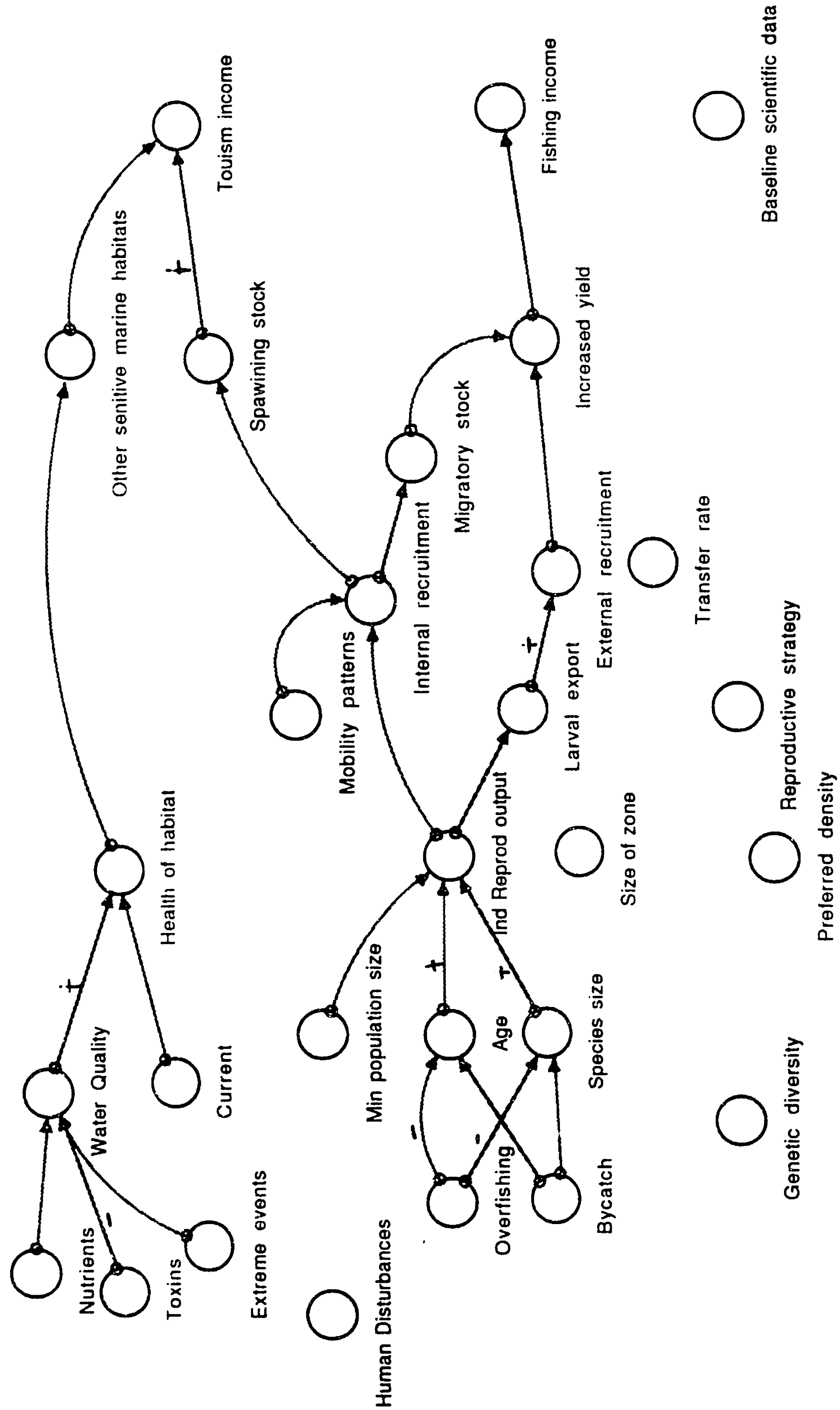
A facilitator would record the information by drawing i) nodes with the variable names and ii) arrows which link the nodes. As more variables and linkages are elicited, the Causal Loop Diagram would evolve, until the group could not think of any more relevant variables or linkages.

1. Organizing the known information and showing linkages

Instead of brainstorming with the stakeholders, AC, CG and NOAA, this CLD was built after reading a few books and articles about Replenishment Zones. (Rowley, 1992; Bohnsack, 1993; Dugan, 1992; Clark, Causey and Bohnsack, 1989; Bohnsack, 1990) and after speaking with a few scientists such as Mr. Bohnsack, Mr. Causey, Mr. Murphy and Dr. Hunt. (See Bibliography for their titles.) Like a CLD that might have been built by the actual FKNMS participants, this CLD is a collection of many information sources. It was created in an effort to organize the physical, biological and chemical information about zones as well as the economic effects and the linkages to some of the stakeholders' preferences.

The information is organized by drawing nodes for important variables such as 'Size of the Zone' and 'Stock of Harvest-able Fish;' linkages are drawn to indicate cause and effect, such as increasing the 'Individual Reproductive Rate' causes the 'Internal Recruitment' to increase. There are a number of closed loops in this preliminary Zoning CLD, and it is not possible to label some of the linkages either positive or negative, such as the link between 'Nutrients' and 'Water Quality.' The reef and other interdependent habitats in the Sanctuary flourish in a narrow nutrient range; at present, there are too many nutrients in the water, but there could also be situations where there might be too few nutrients. Another example is the link between the 'Currents' and the 'Health of Habitat.' There is a need for currents in the Sanctuary to flush out the toxins and excess nutrients, which indicates a positive link, but if currents become too great during storms, damage can be occur. (See Appendix VI-B for a fuller discussion of the physical system and see Figure IX - A for preliminary version of a Replenishment Zone CLD.)

Figure IX - A: Preliminary Causal Loop Diagram for Zoning



2. Using the CLD to elicit more information

This preliminary CLD was then shown to **Dr. Hunt,** from the Florida Marine Research Institute By just looking at the diagram, the current level of understanding was obvious to him. He could see what was already known about the system and the understanding that was missing, making it possible for him to efficiently add to the knowledge base without repeating information already known.

i) Dr. Hunt added to the existing definition of water quality, because the physical factors such as temperature and salinity had been omitted.

ii) He indicated linkages between the Health of Habitat and various other factors. For example, the Health of Habitat affects the minimum population necessary for reproduction, the reproduction rate of each adult, and the lifetime expectancy (therefore the species abundance) of the fish.

iii) He added the variable 'age structure' since the age of an individual is important to the Reproduction Rate for most species. (For example, with Red Snapper five 3-year-old individuals produce fewer larvae than one 10-year-old individual, even though 3-year-olds have reached reproductive maturity.)

iv) He indicated that species abundance affects the mobility patterns. An over abundance of fish in a Zone might increase the mobility rates of fish moving out of the Zone.

Using the CLD, it was relatively easy to elicit missing information about the physical, biological, and chemical aspects of Zone. The CLD was updated with Dr. Hunt's information, with information learned from reports and from conversations with other researchers such as Mr. Bohnsack, from the Southeast Fisheries Science Center, National Marine Fisheries Service.

Not only could the CLD incorporate the many physical and biological aspects of the system, but it can also include the economic aspects of the decision. Income was broken down into Fishing and Tourist. The CLD shows that as 'Health of Habitat' increases 'Tourist Income' increases, because more tourists would be interested in snorkeling or scuba diving to see healthy reefs. 'Health of Habitat' also increases the 'Abundance of Fish' which increases 'Fishing Income' and 'Tourist Income.' The CLD does not quantify the cause and effect, but it does show that these variables are inter-related. It may not be necessary to include in the CLD every variable that a Zone might affect, but it is necessary to include those that the decision makers believe are important.

The CLD evolved until it was a fairly good representation of how a Replenishment Zone might affect the different objectives. Creating the CLD helps the users see that there are different sections or parts of the overall decision. There is a group of variables that:

i) affect the Health of the Habitat.

ii) influence the life stages of marine species that are collected or fished. These different 'marine species' will generally be referred to as 'fish,' although there are shellfish, sponges, etc. that also fit into this category.

iii) affect the actions of fishermen

iv) affect the economics

(See Figure IX - C for updated version of CLD.)

C. Results of CLD Tool

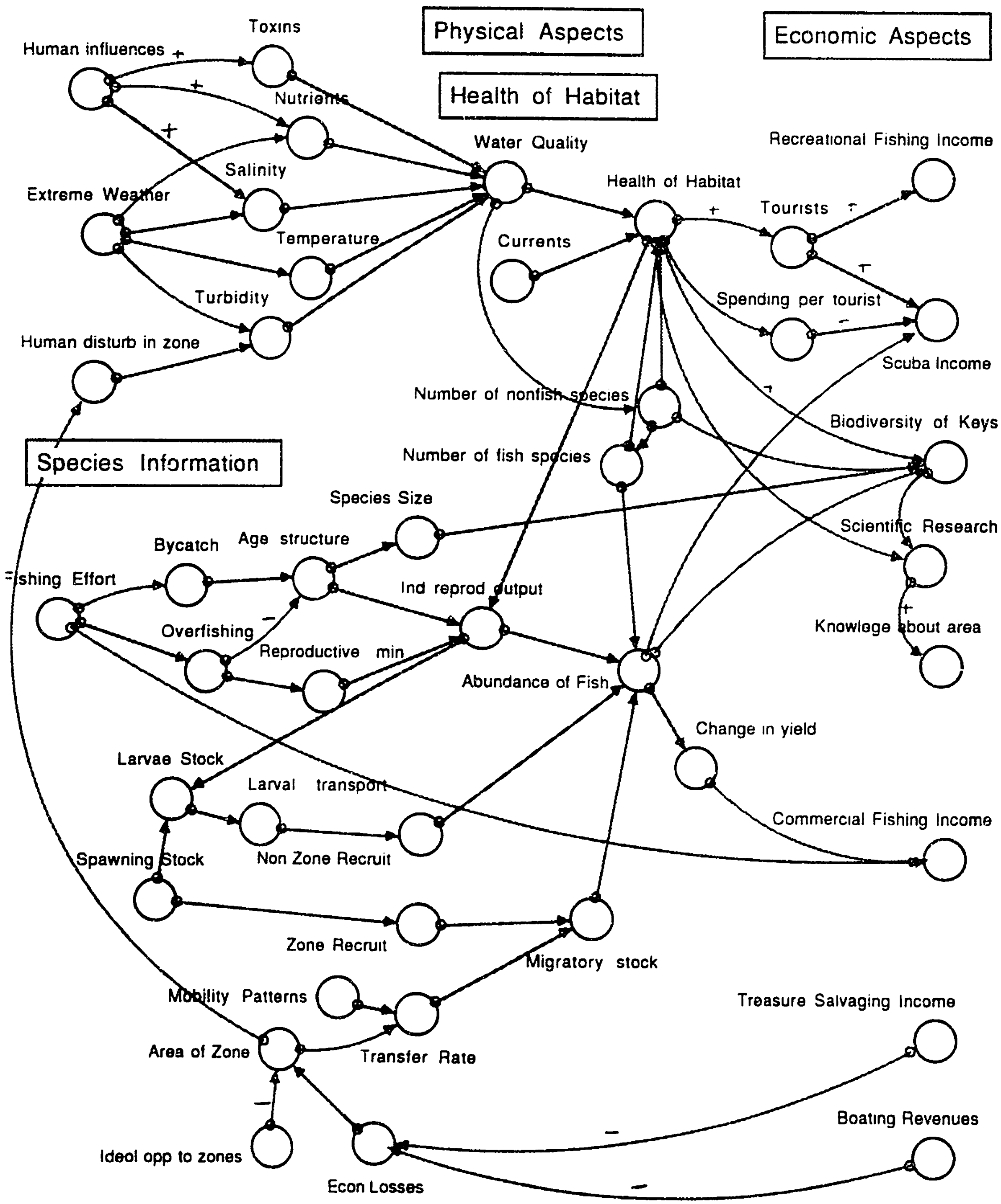
This section discusses what was accomplished when a CLD was used in this dissertation and projects what it could have accomplished if it had been used during the actual FKNMS process. Applying the CLD tool helps the users identify information about the physical and economic aspects of the decision. This enables users to better understand sources of controversy and find the areas where more effort should be spent trying to find more accurate information and preferences.

1. Organizing the information makes it easier to elicit missing information

The CLD not only provides a method for summarizing general information about the physical and economic aspects of the Replenishment Zone decision, but organizing and structuring the information that has already been elicited makes it easier to see the gaps in knowledge, therefore easier to elicit more information. Seeing the CLD made it easy for Dr. Hunt to know what areas weren't well understood. For example, factors such as Temperature, Turbidity and Salinity affect the Water Quality and influence the Health of Habitat, but they had been omitted from the CLD. The CLD pictorial summary allowed Dr. Hunt to quickly see that these physical factors had been omitted and insure that they were included.

The CLD also helped elicit information that was not already known. For example, Dr. Hunt indicated that it was 'Age Structure' not 'Age' that should be included as an important variable. Dr. Hunt spent time explaining how typically, it is an individual's age and size that determines each 'Individual's Reproductive Capability,' so rather than indicate that it is the specie's overall or average 'Age' that affects the 'Species Size' and 'Reproductive Output,' the 'Age Structure' of the species should be included as an important variable.

Figure IX - B: Updated Version of CLD



Dr. Hunt also suggested adding the variable 'Fishing Effort' to show that it is not just 'Fishing' or 'Harvest' that affects the variables, but that increased 'Fishing Effort' also increases 'Bycatch.' Very high 'Bycatch' can cause a non-sustainable 'Age Structure' which negatively affects the ' Abundance of Fish.' Increased 'Fishing Effort' can lead to high 'Fishing Incomes' in the near term, but might decrease the 'Abundance of Fish' and the 'Fishing Income' in the long term. By adding the variable 'Fishing Effort,' the CLD makes explicit to all users that there is a tradeoff between 'Fishing Efforts' and 'Fishing Income' in the short term and the long term. By using the CLD to summarize information, more can be learned and the tradeoffs can be made more explicit.

Learning more about the 'Age Structure,' 'Species Size' and the 'Abundance of Fish,' helped make explicit some of the subtle difference between the objectives of recreational fishermen and commercial fishermen. Recreational fishermen are often searching for large, trophy size fish and may be more concerned with the 'Species Size' or size structure than purely 'Abundance of Stock.' Commercial fishermen typically prefer the 'Abundance of Stock' to be high and are less concerned about the size structure; as long as the overall weight of their catch is high, they are not concerned with the size of any one fish. Difference between the Recreational and Commercial Fishermen are made explicit.

CLDs provide a quick, easy way to elicit a great amount of information from a large number of knowledgeable people. CLDs could have been used to quickly elicit information about important the variables from the user groups, the AC, the CG, NOAA and any other experts willing to help identify the factors important to the system.

2. Making the Interdependencies explicit helps inform

The CLD not only provides a method for summarizing general information from many disciplines, but CLDs can also show the inter-relatedness among the information. Even though many important variables had already been identified, the CLD helped elicit new information in the form of linkages. Attempting to label the linkages helps the users understand more about the system. For example, from reading articles about Zoning, it was known that 'Mobility Patterns' were important, but the reason was not understood. Dr. Hunt was able to see that there was a missing link and explain why 'Mobility Patterns' were important. To understand how much the Zones would help increase the stock of 'harvest-able' fish, one would need to know 'Mobility Patterns' of the adult fish. If the fish were not mobile during most of their life cycle, then it is not likely that healthy fish from inside the Zone would move outside the Zone, increasing the number of harvest-able fish. Likewise, Dr. Hunt explained how 'Larvae Export' rates were important when determining the number of recruits outside the Zone and their potential to become harvest-able fish.

Organizing the information and requiring that linkages be drawn, the CLD helps the users understand what types of future income would be improved by Replenishment Zones. For example, long term commercial 'Fishing Income,' 'Tourist Income' from scuba diving along the reefs, and 'Tourist Income' from Recreational fishing are dependent on the 'Health of Habitat' and are improved by Zones. 'Tourist Income' from boating and 'Tourist Income' from treasure salvaging are far less dependent on the 'Health of the Habitat.' The benefits of Replenishment Zones would be primarily for the long term income of *renewable resources*, not sunken treasures. Treasure salvagers have little to gain from Zoning. Building the CLD helps the users see the tradeoffs and understand the controversy among the different user groups. Those who derive their income from renewable resources are most likely to benefit from Replenishment Zones; those who do not use renewable resources will probably gain very little.

By creating the CLD and making the interdependencies explicit, the users can understand how Zones might help renewable resources, but also why the benefits are not certain. For example, scientists know that high 'Turbidity' causes death in the reef and seagrass habitats, but it is not known at what different levels of 'Turbidity' what percentage of the different seagrass species die. The linkage can not be quantified, yet the link can be included in the Causal Loop Diagram. Another example is that the Zoning CLD showed that decreasing the number of 'Human Disturbances' would improve the 'Health of Habitat,' but scientists know that many other factors influence the 'Water Quality,' which also affects the 'Health of Habitat.'[85] Since Zones decrease the number of 'Human Disturbances' but do not affect most aspects of 'Water Quality,' no one can predict how much the 'Health of Habitat' would be improved and if renewable resources would increase. By building the CLD, a great number of variables can be elicited and included, and linkages indicated, even when there is uncertainty. The areas of uncertainty are more explicit, making it more apparent why the potential benefits of Replenishment Zones are uncertain.

The CLD tool also helps show the interdependencies of Health of Habitat, Scientific Research and Future Fishing Incomes. Some users may have thought that the desire to do Scientific

[85] Zones do not help improve water quality except in the long term, through information gathering and scientific research.

Research and the desire for Income were not compatible. Instead, the CLD begins to show that more Scientific Research can increase the amount of information known about the Health of Habitat and the fish life cycles, which can help increase future Fishing Income. By helping the users become better informed, the CLD can help find areas of potential agreement.

3. Transferring Information is made easier with CLDs

Cognitive Maps and CLDs provide a means to easily transfer knowledge. CLDs can help summarize the information pictorially so that many people can learn relatively quickly. With the Replenishment Zone decision, there is an abundance of information; attempting to build the Cognitive Map helps the users organize, understand, therefore prioritize the plethora of information. The succinct representation of the physical, biological, chemical and economic aspects of the system allows many people to quickly digest the existing information. For example, the CLD enabled information about the current level of understanding to be quickly transferred to Dr. John Hunt, and then using the CLD, he was able to easily transfer knowledge about 'Age Structure,' 'Species Size' and 'Health of Habitat.' Then, changing some of the variables' names and showing the linkages made it easier to transfer more accurate knowledge about 'Fishing,' 'Bycatch,' 'Fishing Income,' and 'Mobility Patterns.' With the CLD, Dr. Hunt was able to quickly see what information was missing and was able to share his knowledge quickly with someone outside his field of expertise, to transfer his knowledge.

CLDs help organize a great deal of information into one visual summary, making the information easier to understand, transferring more of the knowledge. In the actual Replenishment Zone decision, there were over 25 presentations made to the Zoning subcommittee in two different 2-day sessions, there were many reports to read and there were many discussions. The CLD could have organized information about the systems' physical and economic aspects, so it would not just be a mass of unconnected reports or presentations. The one visual summary would enable more of the entire system to be understood.

Not only does the pictorial representation help transfer knowledge, the pictorial summary would help all decision makers understand the relevant variables and interactions in the Zoning decision in less time than it takes to listen to 25+ presentations. The succinct representation of what is already known helps reduce the amount of repetitive information. Reports and presentations can be tedious, especially when some or most of the information is already known. CLDs can enable faster, more efficient transfer of knowledge than reading reports or listening to many presentations.

CLDs help the users record and organize the relevant variables and interdependencies already known, so that there is a common knowledge base among the decision makers. This would enable the users to move closer to building consensus and help build a feeling of ownership.[86] CLDs do not help generate new analysis, though. CLDs do not help determine the effects of the interdependencies. They do not help the users understand more about how the variables affect each other as time or geographic scope changes, nor do they help the users understand the scale of the affects.

D. STEPS OF GOOD DECISION-MAKING PROCESS ACHIEVED

It is best to use the CLD after the first Requirement and first Step of good decision-making are complete. All the different decision makers could be included in the CLD building process, although not all the groups would have to meet at once to build one CLD. Various groups could work together and / or review and update each others' work. The overall goal of their work should also be determined before the CLD is attempted to focus their efforts.

The next two steps of decision-making, criteria formulation and choice formulation may begin before the CLD is built, but the CLD can be used to improve and add to these two steps. These two steps are best done in an iterative manner, in order to reach the second requirement, having well-informed decision makers.

Step 2) Criteria Formulation

Building the CLD helps formulate criteria, because organizing and structuring the variables already known helps to stimulate ideas for new variables and criteria. Some of the important physical and economic variables that are identified while creating the Replenishment Zone CLD can also be defined as criteria important in the decision-making. The users may identify criteria that were not known before or develop a better understanding why the variables are important. For example, building the CLD helped identify fish 'Mobility patterns' and 'Age Structure' as variables that affect the potential benefits of a Replenishment Zone. CLDs do not explicitly label the variables as criteria, but CLDs do help brainstorm and formulate criteria.

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[86] If collectively the decision-makers possessed all of the areas of expertise, then no other technical experts would be needed. Otherwise, technical experts could be brought in to assist the decision makers.

Requirement 2) Well informed decision makers

The Zoning CLD can help; to build a Cognitive Map, the users must identify many of the relevant variables that comprise the physical, economic and some human preference aspects of the system., and show the linkages among the variables. This helps the decision makers become better informed as to how the ecosystem works. By eliciting good information, succinctly representing it, then transferring it to the decision makers, the CLD could help inform the AC, CG and NOAA. They can also become more knowledgeable about what areas are important. yet more specific information is needed.

Step 3) Choice Formulation

Building the Replenishment Zone CLD would enable the users to formulate better choices, because it would have helped inform the users. For example, using the CLD, one can see that decreasing the number of 'Human Disturbances' can improve the 'Health of Habitat' and increase the fish 'Stock Abundance.' The Zoning CLD can help the users formulate different choices that address these important objectives, criteria and variables, such as increasing the fines for those who anchor on or touch the reefs or creating no use Zones to increase the Health of the Habitat. Other choices for improving fishing income might involve decreasing the Fishing Efforts to decrease the number of Catch and Release fishermen or ways to increase the Spawning stock. The CLD also shows that the controversy against Zoning might be reduced if there was compensation for those industries that will suffer economic losses and which have little potential for economic gains, such as Treasure Salvagers, speed boats, etc. Understanding more of the physical and economic aspects of the system helps the user understand the options available to them.

To understand the table below, the symbols can be interpreted as follows:

X: the tool assists the Step or Requirement significantly.

/: the tool assists the Step or Requirement only somewhat. It may help with only certain aspects of the item or may help, but not as much as some other tools.

0: the tool does not help at all.

~X: the tool helps only if the model can be completed and run (for Demos or SD).

a: the tool allows the item and benefits from it, but does not assist with it.

Table IX-A: Steps and Requirements that the CLD achieved

Steps and Requirements	CLDs
Stakeholders included	a
Problem, Overall Goal and Objective definition	a
Criteria Formulation	X
Choice Formulation	/
Easy sensitivity analysis	0
Well-informed decision makers	X
Choice	0
Implementation	0

E. INADEQUACIES OF COGNITIVE MAPS: NEXT STEPS FOR DECISION-MAKING

Using the Causal Loop Diagram for the Replenishment Zone decision helped elicit, summarize and organize important general information by representing the information as just variables and linkages. The pictorial representations are a quick and convenient way to ease the transfer of knowledge to many people, and specifying the negative and positive links can sometimes help the users understand the nature of the variables' interactions. Many members of the user groups, AC, CG and NOAA could easily build the CLD and become informed, therefore stimulating new and better ideas for criteria and choices. Having a large number of stakeholders present and having better choices formulated will help move the decision makers closer to a Pareto admissible outcome.

CLDs alone do not help reach the best decision, though. Although linkages are specified, no detailed insights about the interactions are illuminated. This is because CLDs can not summarize all the quantitative information that is known about each variable or the linkages between variables. CLDs can not analyze changes over time or geographic scope. It is necessary to use a Simulation model to include the next level of detail, to understand more specifically how the different variables interact and understand more fully how the overall system works.

Chapter X. Use of Simulation models to elicit more detailed information and predict repercussions

This chapter will explore the family of tools that can help elicit and transfer detailed information about the physical and economic aspects of the Replenishment Zone decision. To elicit detailed information, complex and often time-consuming tools need to be used, such as Simulation models. To create a Simulation model, detailed mathematical equations must be formulated to represent the interactions between different variables. Sometimes the model can not be completed, because there is not enough information known about some variables or linkages to write a mathematical equation. For the Replenishment Zone decision, only certain pieces of the total system can be represented using a Simulation model.

A. NEED TO ELICIT AND TRANSFER DETAILED KNOWLEDGE ABOUT VARIABLES AND LINKAGES: HOW SIMULATION MODELS HELP

Cognitive Maps such as CLDs may be helpful in pictorially representing many variables and linkages in a complex system, but they can not elicit detailed information; Cognitive Maps can not *quantify* any of the variables or the linkages. To make a well-informed decision on a complex environmental problem, the decision-makers often need more information than a Cognitive Map can elicit. CLDs do not allow users do sensitivity analysis to see how different alternatives change the predicted outcome. When a user wants to summarize more of what is known about a system by quantifying the variables and linkages, and when they want to predict the outcome, then a Simulation model should be attempted. If enough of the system is known, a Simulation model can be used as a predictive tool.

1. To predict outcomes, must represent variables and linkages as mathematical equations

Like Cognitive Maps, creating a Simulation model requires the users to explicitly state their mental models, to explicitly state their knowledge about how the system works. The decision makers are required to identify the many variables that are relevant to the system and then identify which variables are linked. Simulation models go beyond Cognitive Maps, because they require the users to mathematically represent the variables and linkages to mathematically describe how different variables interact. The variables or nodes are typically given an initial value, and the linkages are represented by mathematical equations. If the users understand the system well enough to formulate initial values and equations for every variable and linkage, then the model will be a mathematical representation of the system.

With Simulation models, there are two different sorts of systems: closed systems or open systems. A closed system compares output to some norm and attempts to modify the input, to achieve the pre-determined desired performance. An open system allows the output to be completely controlled by the inputs; no modifications are made by the system to correct its behavior to meet predetermined goals. If the Simulation model is for open systems, then it can then be used as a predictive tool, to see how the effects of a decision will evolve over time, to predict the possible future trends in the actual physical, biological, chemical and economic system.

With complex systems, determining how the value of a variable affects other variables and feed-backs to affect itself is crucial and is possible only when the decision makers consider the effects over time. Simulation models are

> "... most useful in that they allow for a long time frame, long enough to see the dynamics of a system play out. Identifying and drawing out the behavior of key variables over time is an important first step towards articulating the current understanding of the system." (Kim, 1992)

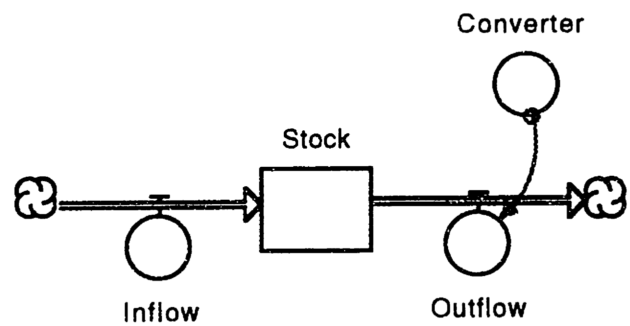
Simulation models lengthen the time horizon over which the user can see the results of a decision, which helps the users become well-informed about changes in the system over time.

Knowing *every* variable, even if it includes some degree of uncertainty, is *necessary to run* a simulation model. Many benefits of Simulation models are achievable only if the model is completed, if all the linkages are specified and the model can be run. Most Simulation models may be able to accommodate some uncertainty, but may not be able to analyze how important the uncertainty is in predicting the outcome.

2. Simulation models that are also good at eliciting information

Often a Simulation model cannot be completed and run, because there is not enough known about every variable and every linkage of the system. If there is uncertainty, but the linkages and variables can be quantified, then the model can be run and the predictions would be uncertain. If there exists even one variable that cannot be quantified, though, the Simulation model cannot be run. Still, attempting to model the system helps elicit and summarize detailed information that is known about the physical and economic aspects of a decision; some Simulation models are better than others at eliciting and summarizing the information.

Systems Dynamics is one Simulation model that can be used to model how the behavior of a complex system changes over time if the model can be run, and can be used to elicit detailed information even if the model can not be run. Like Cognitive Maps, System Dynamics is a pictorial based tool, so it is easier to see what information exists and what information is missing and still needs to be elicited. With System Dynamics (SD), the variables / nodes are classified as either stocks or converters and the linkages are categorized as either flows or connectors. Stocks, flows and converters must have equations written for them to quantify how they interact with the other variables and change over time. In addition, stocks must have initial values defined for them.



If a Systems Dynamics model can be completed, as the model runs from time=0 to time equals some future time, the values of the stocks change; the change is determined by the mathematical equations and values of the other variables defined in the system. (See **Appendix X-A** for a brief description of the Systems Dynamics tool.) Systems Dynamics could be attempted to help inform various Issues in the FKNMS Management Plan.

B. USING SYSTEMS DYNAMICS FOR THE REPLENISHMENT ZONE AND RED SNAPPER DECISION

Systems Dynamics (SD) is applied to the Replenishment Zone decision to see if it can improve the decision, to see if it can help obtain more accurate values for the coastal resources in the FKNMS. The SD model was not actually built with the AC, CG and NOAA members, but an SD model is created to show how it might have been used by the decision makers. The different steps of building an SD model will be followed and discussed as if the decision makers were using it.

1. Preparatory steps

The first step in building an SD is to decide who should take part in building it. Building a Systems Dynamics model is more complicated than building a CLD, because the more specific structure of SDs requires that the users understand the physical and economic system at a deeper level. Building an SD requires detailed information about the variables, therefore people who have expertise in the physical, biological, chemical, economic or social aspects of the system should help build the model. These people may or may not be every member of the decision-making group. If SD were being used for the actual Zoning decision, all AC, CG and NOAA members as well as Strategy Identification Group members could participate building the SD if they wanted, but some might choose not to. Some might prefer to just become informed using the predicted outcomes.

Like most Simulation models, SD requires that the users understand how SD calculates the values. The users must be trained in the 'language of Systems Dynamics,' the certain format that is required, to understand how to represent the variables. Since it can take a fair amount of time to learn how to use SD, it is probably best if an outsider with expertise in SD modeling is hired to help the decision makers build the model. Even with an expert modeler, it may be a time consuming process to build the SD. therefore, some decision makers might become frustrated. For this reason, it is not necessary that all decision makers partake in building the model, yet anyone who wants to participate can. At minimum, though, it is recommended that the AC, CG, NOAA and Technical Advisory Council members with expertise in the physical, biological, chemical or economic aspects partake in the building process.[87] It is often the case that the SD modelers do not know what information they need until they are *into* the modeling process, so it would have been ideal to have all the experts present until the model was complete; this would allow the information and best guesses to be elicited from the experts as needed.

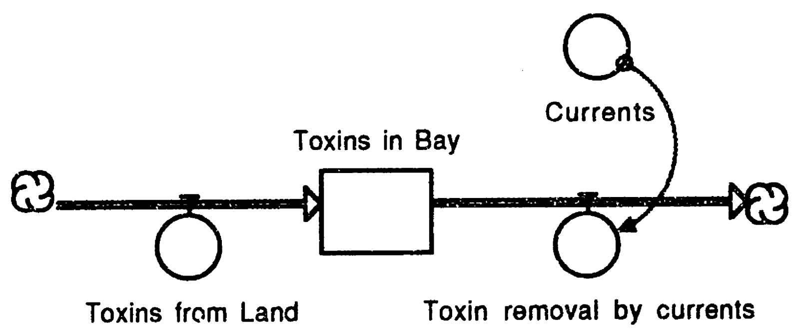
The second step to building an SD is to decide why the Zoning SD was being built. For the SD model to be most effective at eliciting detailed information, it is probably best if the decision makers agree to the purpose of the SD model before it is built. For the Replenishment Zone decision, the objective would probably be the same as that for the CLDs, to 'Inform at a greater level of detail about how Replenishment Zones would achieve Strategy Z.2 and the objectives recorded in the AHP hierarchy.'[88]

[87] If SD had been used, and the model was completed and run, then the model's predictions could have been brought back to *all* the decision makers to inform them of the possible outcomes.
[88] Strategy Z.2 is the result of the Public Scoping meetings and the Strategy Identification Workshops, and is the goal of the Replenishment Zones: "to protect the homes and food of important commercial fisheries and to protect all of the 6000+ species that are not covered in the Fisheries Management Council."

Defining the objective sets the parameters and provides the overall structure to the SD model; it is an important step. For example, with the Zoning SD, one could be given i) the *task* of modeling how Replenishment Zones work, or ii) the task of informing at a greater level of detail how the Replenishment Zones "protect the homes, food sources and 6000+ species." Although at first glance the two tasks may seem to be the same, the results may be vastly different, depending on the amount of information available.

2. Creating the structure

After determining who will participate and the purpose for building the SD model, the next step in building an SD model would be to brainstorm most of the relevant variables and linkages and build a Cognitive Map such as a CLD. Using the CLD created in the last Chapter is therefore a good place to start. The Replenishment Zone CLD can be transformed into a Systems Dynamics model, by changing the nodes of the CLD into stocks, flows and converters, and by changing the arrows into flows and connectors. The more precise structure of the SD, as compared to the CLD, requires more detailed knowledge and is also the reason why some CLD variables would be defined as flows and other times linkages are defined as flows. For example, the flow of toxins into Florida Bay and out of Florida Bay would be modeled as such:



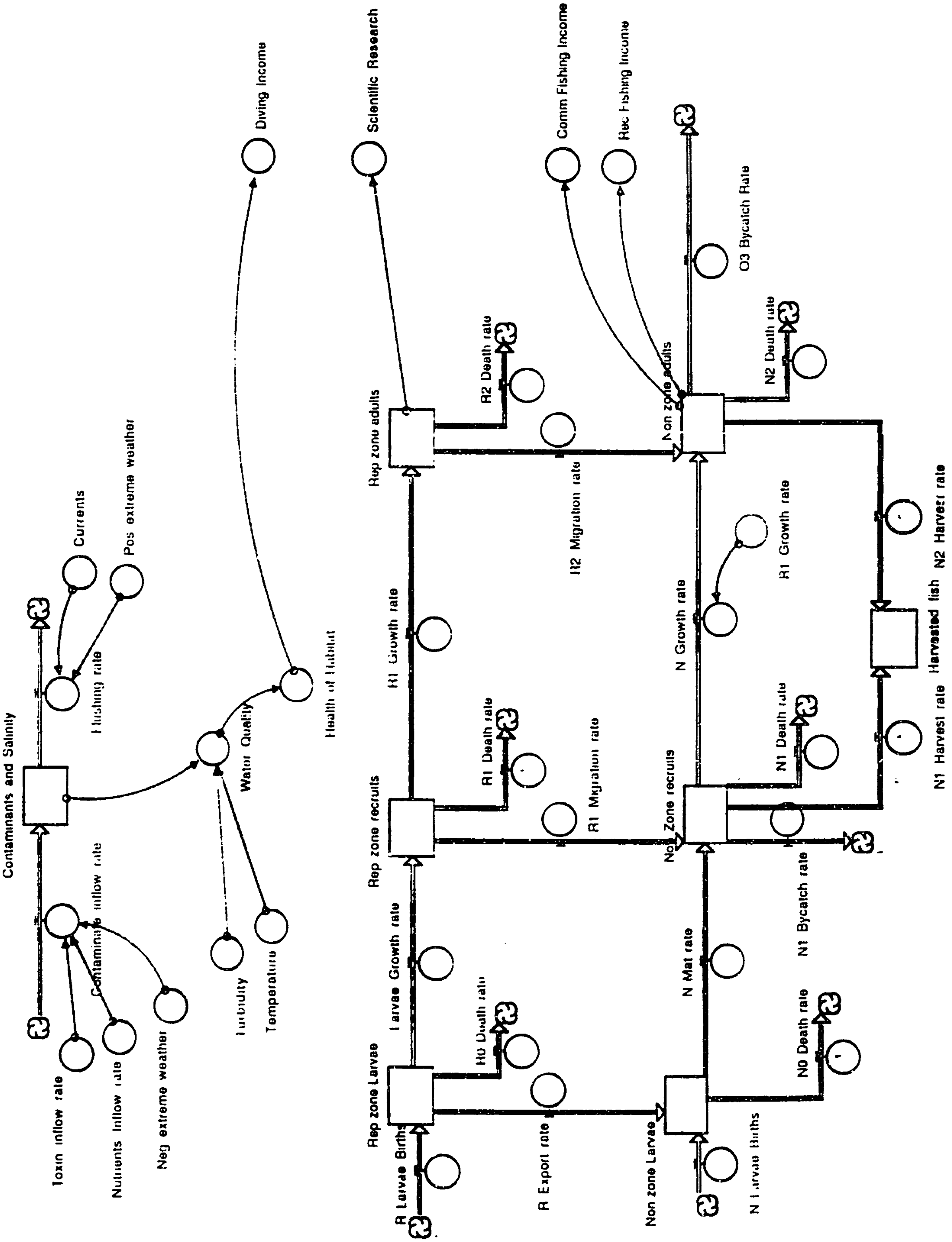
It is typical that in transforming the CLD into an SD, new variables and linkages will be identified. For example, in attempting to transform the variable 'Abundance of Stock,' one realizes that there must be many separate stocks defined, such as the Stock of larvae, the Stock of young recruits and the Stock of harvest-able fish. The Stock of harvest-able fish depends on the Stock of young recruits which depends on the Stock of larvae which is determined by the Stock of fish in their reproductive years. For the first draft of the SD, it will be assumed that the number of fish in their reproductive years is the same as the number of harvest-able fish, although it may differ depending on the species.

In modeling the Stock of harvest-able fish, one realizes that adult fish inside the Replenishment Zone are not harvest-able, so a separate variable should be defined for Zoned fish. Creating this Stock, there may be a need to separate the Stock of Zoned larvae and the Stock of Zoned recruits, depending on the Mobility Patterns of the larvae, recruits and adult fish. It is difficult to determine how to model the linkages between the larvae in the Zone and the larvae outside of the Zone, or how to best model the migration patterns. These things depend on the species of fish. In addition, defining the different Stocks of fish it becomes obvious there are different Natural Mortality rates for the larvae, versus the recruits, versus the adult fish. The Natural Mortality rates, though, again depend on the species of fish. (See Figure X - A, the first version of the SD model.)

One realizes that it becomes somewhat meaningless to create an SD as the 'average' of all 6000+ species found in the Replenishment Zone, whether commercially important or not. One could attempt to build an SD for all 6000+ species of the FKNMS, repeating the life-cycle and fishing portion of the SD for each species and determining linkages among the different species where appropriate. Not only would that SD take years to build, but it would require knowing all the details for each of the 6000+ species and details concerning how all the variables interact. There is not yet enough research or information to complete that model. Information *within* each 6000+ specie is not known with enough certainty, such as the different equations for migratory rates and reproduction rates. Even *less* is understood about the *interactions among* the species, such as what are all the predators of a specie, what are all its natural allies, what plant life does it require for spawning, etc.

For this reason, the focus of building the SD shifted away from trying to inform the users about all 6000+ species. Instead of attempting to accurately model the FKNMS ecosystem, the model was simplified and the aim became trying to understand how the Replenishment Zones might affect *one* species. To finish creating the structure of the SD model and to specify the equations to define linkages, it is necessary to choose one species of fish to model.

Figure X- A: First version of the Systems Dynamics Zoning Model



For the SD to be most informative, it is important to choose a species for which there is a need for information, a topic for which there is controversy and which is important to the stakeholders. Since Fishing Income is one sub-objective that is very important, it would probably be most informative to build the first SD model about a commercially important species. The purpose of creating the SD is redefined to "understand to a higher level of detail how Replenishment Zones would achieve Z.2 and the objectives recorded in the AHP hierarchy for one commercially important specie." More succinctly, "How do Replenishment Zones protect the homes and foods of one commercially important specie?" Ideally, by developing the SD model for just one species, if results could be drawn, then perhaps the information learned could be extrapolated to other species.

The question is, then, which species to pick. Fish biologists write in various Zoning articles that demersal, sedentary species benefit the most from Replenishment Zones. These are often the species that suffer the most from over fishing, since Sonar equipment helps fishermen find these schools of fish. To determine one extreme of how helpful Zones could be, the SD model could be focused on a commercially important demersal species which has a declining population. The Red Snapper is picked as the representative demersal specie; the Stocks have been declining throughout the Gulf. There is a fair amount of research completed about the Red Snapper life cycles, which makes it more likely that the SD model can be created and run, that all the important variables and their linkages are known. The purpose of creating the Zoning SD model is further 'redefined' as 'Understand if Replenishment Zones could protect the home and food for one important commercial fisheries: Red Snapper.'

Building the SD model for only one species has many drawbacks. The predicted outcomes and the information learned will only be directly applicable to one species instead of all 6000+ species. The users will have to judge the similarities and differences between Red Snapper and the other species to determine how much can be applied to the other species. Also, this one SD model will not enable the users to determine which characteristics help Red Snapper and which might hurt other species; the trade-offs between species will not be obvious.

3. Building the Red Snapper SD

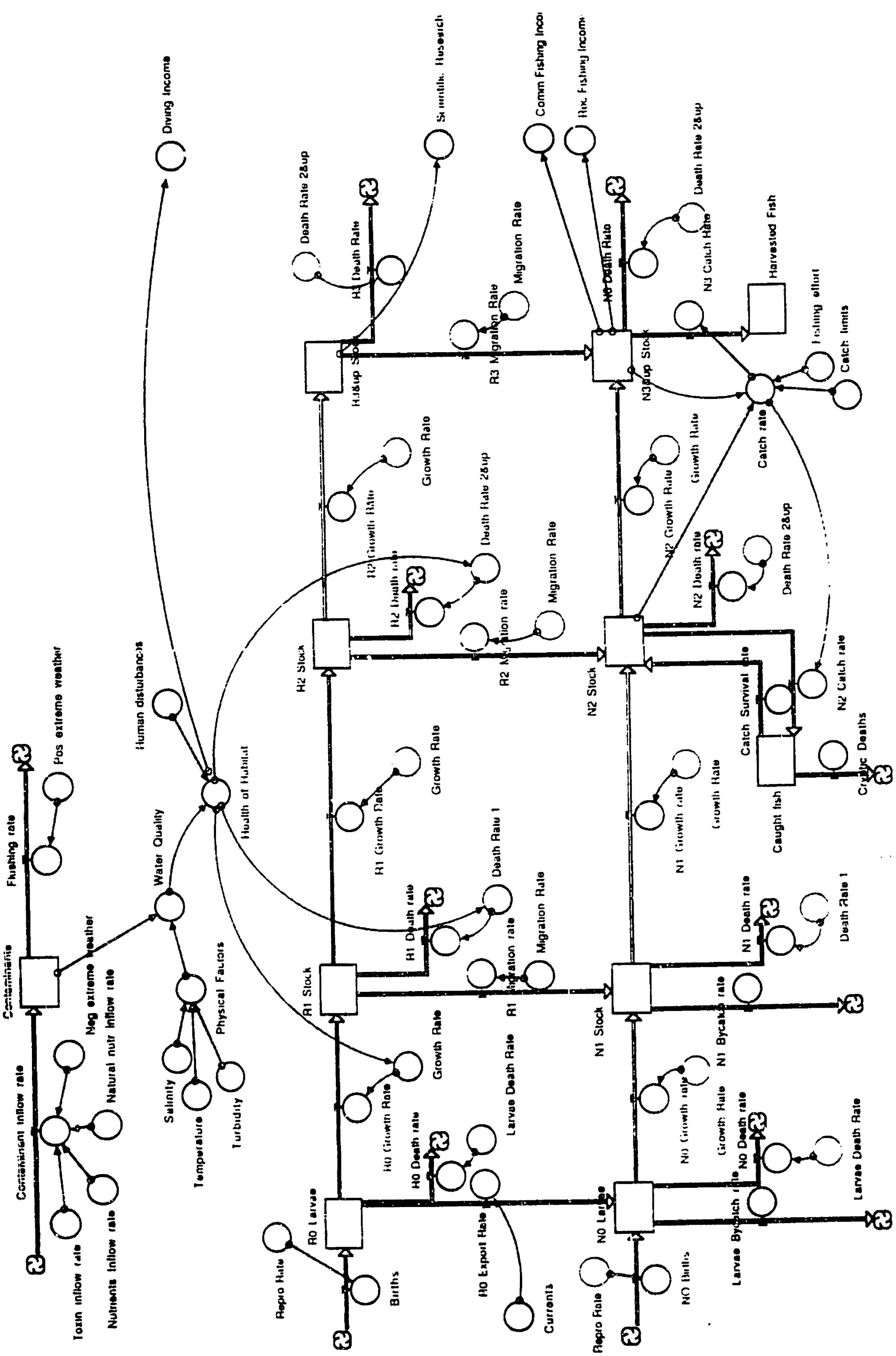
With the focus changed to one species, it is possible to continue refining the structure of the SD model. In trying to understand if it is logical to separate Red Snapper into larvae, recruits and harvest-able fish, it became apparent that Red Snapper are not re-productively mature until age three. This is also roughly the time they are 13 inches long, which was designated as the minimum length for the Catch Limit. (Goodyear, 1993) It also became apparent that two year-olds should be differentiated from one year-olds, which in turn should be differentiated from 0 year-olds, because Red Snapper researchers differentiate among each of the three groups, defining bycatch and natural mortality rates for each.

While refining just the structure of the Red Snapper SD, without yet defining any equations, it became obvious how serious a problem 'Cryptic Mortality' is to many fish Stocks.[89] For example, if the 'Fishing Efforts' of Red Snapper or any other demersal species increased, 'Cryptic Mortality' of Red Snapper would increase. If 'Fishing Efforts' were high, then a single young fish (i.e. pre- harvest age) could be caught and thrown back in numerous times before reaching the size limit. If 'Cryptic Mortality' and 'Fishing Efforts' were high, then many young fish could die just by being caught and thrown back in. The fewer two year-old fish that survive, the fewer three year-old fish there are to harvest the following year. Fewer three year-old fish would mean 'Fishing Efforts' would increase to meet the 'Catch Limits'; more two year-old fish would be caught and thrown back in, more would die...

Even if the fishermen were not searching explicitly for Red Snapper, if any type of demersal 'Fishing Effort' reached a high enough level, then 'Cryptic Mortality' could be so large that it could equal the entire Stock of two year old Red Snapper fish. Potentially, this might mean that every fish could die before being harvested. In building the structure and seeing how the variables interacted, the seriousness of the 'Cryptic Mortality' problem was made obvious. (See **Figure X- B,** the interim version of Red Snapper SD model.)

[89] Cryptic Mortality is when fish die from being caught and handled, then thrown back in.

Figure X- B: Interim version of Red Snapper SD Zoning Model



4. Defining the equations

Structuring the SD model can be informative, but the next stage in building the SD model enables the users to learn even more. For example, defining i) the linkages among the variables and ii) the initial values of the stocks, confirmed these suspicions about Cryptic Mortality. The average number for Red Snapper Cryptic Mortality is high, approximately 33%. (Goodyear, 1993) If Fishing Efforts are also high, then it is very likely that a 2 year-old could be caught, thrown back in and caught again. If a two year old fish is caught twice, the chance that it would die due to Cryptic Mortality is greater than 50%. Fewer fish would reach harvest size / age, Fishing Efforts would increase to find the fewer fish, and a downward spiral would begin. Creating the SD model helped educate the users why Cryptic Mortality alone can cause a Stock to crash.

Attempting to quantify the linkages and create equations that represent the interactions of all the variables is the most difficult part of building an SD model. Information from many sources and technical experts need to be elicited. Most equations in this Red Snapper Zoning SD were based on information from a 130+ page summary document on Gulf of Mexico Red Snapper, written by Goodyear in 1993 using the conclusions that many scientists had drawn from their research. Also used were articles about Zoning (Bohnsack, 1990;Bohnsack, 1993; Clark et al, 1989; Dugan , 1992; and Rowley, 1992) and personal communications with FKNMS researchers.

In the Goodyear document, there were some equations that the researchers had formulated describing the relationship between and among different variables. When available, these equations were used directly in the SD model to represent the different linkages. For many variables, though, there were only raw data, which had to be summarized into initial values or equations before including in the SD model. For example, there was only lists of data for the:

- Current Fishing Efforts, including Directed Commercial Fishing, Non-directed Commercial Fishing, Recreational Fishing and Shrimp Bycatch. Partial data on Fishing Efforts of Commercial and Recreational fishermen provided in the Goodyear pa[illegible] had to be extrapolated to estimate the total Fishing Efforts.

Some initial values and equations had to be formulated via discussions with marine biologists and researchers such as Dr. John Hunt, Mr. Michael Murphy, and Mr. James Bohnsack in various Florida research agencies, and Mr. Benjamin Haskell, a NOAA SRD employee. For various Florida research agencies, and Mr. Benjamin Haskell, a NOAA SRD employee. For instance, there was very little conclusive data to create equations for the following linkages:[90]

- On average, how many larvae do Red Snapper females produce each year? (Mr. Michael Murphy, from the Florida Research Center suggested this to be back calculated from the population estimates of larvae and of adult fish, 3 years old and up.)
- How much time does the average larvae spend floating in the currents before swimming? (Estimated by Dr. John Hunt and Mr. Michael Murphy and conveyed via phone conversations.)
- What are the average currents through the FKNMS? (Local circulation patterns for the region are only now being monitored by researchers, so it was estimated by Mr. Haskell, a NOAA SRD employee using partial data from the current research.)

Sometimes the answers were the result of research and sometimes the result of best guesses.

a. Attempting to incorporate the Uncertainty in the equations

In building a Replenishment SD for just one species, even when there were numbers or equations provided in the report, there was much uncertainty in specifying some of the equations. For example, the Goodyear paper read that the discard or Fishing Mortality (F)[91] from shrimp trawlers is estimated "to be about F=0.34 at age 0 and F=1.2 at age 1 for a total of 1.54 for a year class's period of exposure to the shrimp fishery. A subsequent sensitivity analysis of these estimates found the methods applied provided optimistic results and suggested that a value of F=1.64 would be more realistic for the parameter values employed." (Goodyear, 1992) Testing the predicted outcomes from their estimates, the researchers felt their original estimates were too low, so they increased the estimate.

The report also included uncertainty about how a fish's age corresponds to its length. The Goodyear paper reads, "The fishing mortality rates rise rapidly with age after the juvenile Red Snapper enter the fishery, which because of a 13 inch total length minimum size, is now at age 3." The scientists know that all 3 year olds are not 13 inches or above, that size is actually a statistical distribution dependent on age, but they use '13 inches = age 3' as a good approximation to summarize mortality rates. Another example of uncertainty was estimating the initial values or present stock of Red Snapper in the Gulf of Mexico for each age group 0, 1, 2, 3 & up year-olds. The Goodyear report had a table of annual values that were estimated by scientists combing the Gulf, the Stock sizes estimated to the closest whole number; the

[90] For detailed information on how these equations were created see **Appendix X-B.**

[91] F is a unitless measure. See Goodyear or other fish biology texts for more information.

estimates were made more exact than to the closest thousand or even hundred, but made to the first digit. These 'precise' estimates of annual Stock sizes were used throughout the Goodyear article and with different scientists to form various conclusions, just as best guesses were used to model the Red Snapper Replenishment SD.

Not only was there uncertainty in some of the variables defined in the article, but there was also such a great deal of uncertainty in some parts of the model that equations could not be formed. An area of great uncertainty existed within the sector that modeled how pollution, toxins, salinity, temperature, etc. affect the Health of the Habitat and Red Snapper. In the CLD and the original SD Replenishment model, the different sections or parts of the overall decision could all be included:

i) the Health of the Habitat.

ii) the life stages of marine species that are collected or fished.

iii) the fishermen's fishing efforts and Catch rates

iv) the populations of fished species and

v) the economics

In trying to define the equations and initial values for the Red Snapper SD model, it became obvious that there was not detailed enough information to fully include the Health of Habitat sector. Marine biologists know that the Health of the Habitat affects the growth rates, the death rates and the reproduction rates of fish, but no one has any idea what quantities of pollution affect the different life cycles and to what degree. For example, no one has formulated an equation connecting the levels of toxins, excess nutrients and sediments in the water with the death rate of Red Snapper. If a group of marine biologists and fishing experts brainstormed and attempted to define the equations for Health of Habitat, they would do a better job than this author could, but no one would know every piece of information with the certainty that is required for the SD model to be run, even for just one specie.

To see if a Replenishment Zone could affect the Red Snapper, though, not every aspect of a Replenishment Zone would have to be modeled or understood. The purpose of creating the SD model was to "inform if a Replenishment Zone could help protect the home and food of a commercially important species whose stocks are diminishing and accomplish the objectives set out in the AHP hierarchy." Creating a Replenishment Zone would affect the:

i) the life stages of marine species that are collected or fished;

ii) the fishermen's fishing efforts and catch rates ;

iii) the populations of fished species;

iv) the economics.

sooner and more directly than they would the Health of Habitat sector.

If there was a healthy habitat with no pollution and ideal levels of salinity and temperature, there could still be many deaths if over-fishing occurred. In this case, an unhealthy habitat would make a bad problem worse. As indicated by the CLD, a Replenishment Zone would decrease the human disturbances which would improve the Health of Habitat, but it is not known how much the Health of Habitat would improve since other factors typically have a strong impact on the water quality. This SD model will assume that the Health of Habitat stays constant and the Zone only affects the Fishing Efforts and fish life cycles. By assuming that the Health of Habitat is kept at a constant value, it can be approximately represented as an upper limit on the total stock of fish that the area could support.

The food and predators stocks would also be affected by the Health of Habitat. The Goodyear article includes the food and predator relationships in the Natural Mortality estimates and represents it as a percentage of the total stock. This percentage might need to be changed if the Zones were created, but it is not known by how much. The Red Snapper's SD model will assume that the predator and food stock, and therefore the Natural Mortality, equal the same percentage inside the Replenishment Zone as outside the Zone; that is, the Natural Mortality rates remain the same. It will be assumed that this percentage is correct until more is learned about how Replenishment Zones affect the one species.[92]

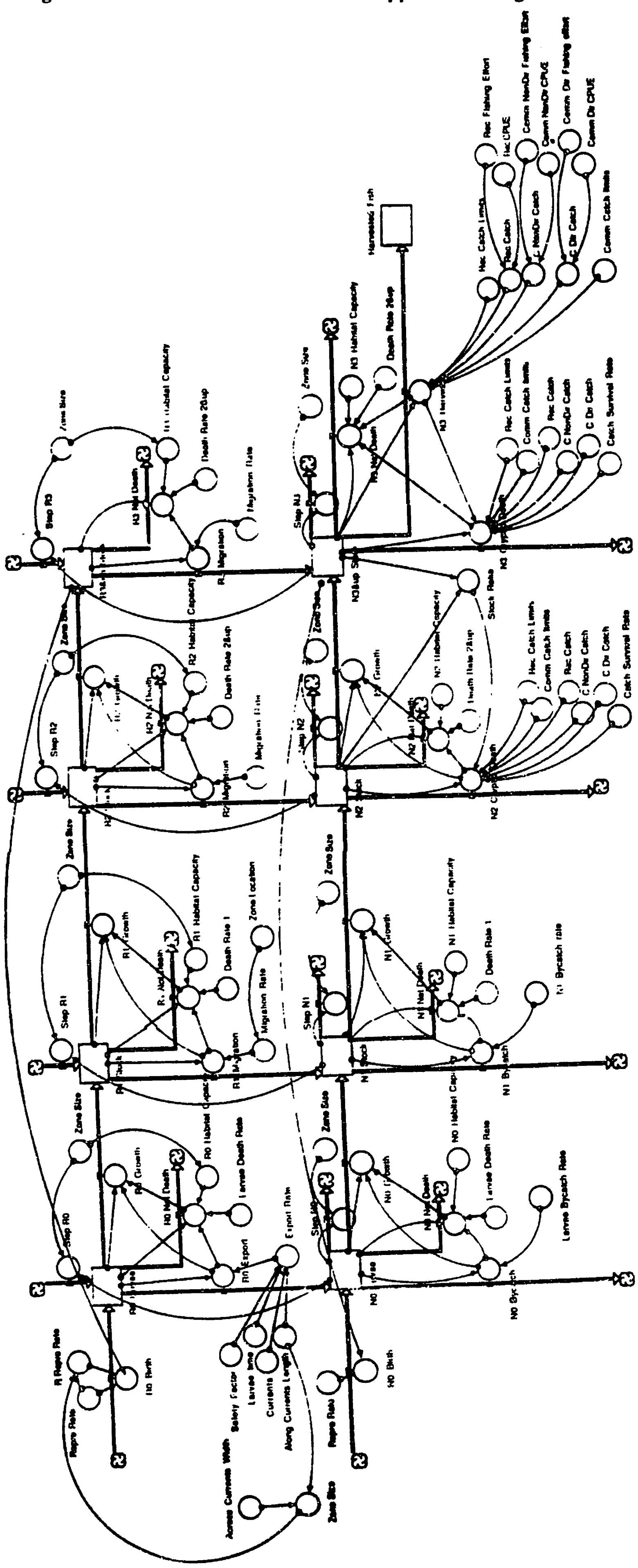
The most direct effects of Replenishment Zones, the change in Fishing Efforts and how it affects the fish life cycle, are represented in this SD and the Health of Habitat is considered to remain constant. The SD model is not 100% accurate at representing every change that a Replenishment Zone might cause, but it does focus on the aspects of fish life cycle that are most likely affected by Zones. Although it would be important to represent the changes in the food stock, predator stock, human disturbances, water quality, and general Health of Habitat are affected by Zones, this information does not yet exist; this is why scientific research in the Zones is important. These variables are important in the long run, but many questions could be answered about the Replenishment Zones with these variables represented as only a fixed number or remaining at current levels. Simplifying these sectors, the model is not 100% representative of all factors that affect Red Snapper, but it can still help inform the users on the effects of Replenishment Zones.

[92] There is a circular path of logic here, a circular need for information. It is important to recognize the inadequacies of the information and assumptions, yet push ahead for more information.

b. Including the information that is available

As with other Optimization and Simulation models, the information needed to be represented as mathematical equations so that future values can be predicted. Simulation models and Systems Dynamics are typically better at eliciting and transferring information, though, because unlike Optimization tools, the many equations can be summarized pictorially. With the Red Snapper SD model, expertise from many different fields need to be elicited; tools that can quickly communicate what information is already is already known, what information is missing, and what interactions exist among the different variables and the different areas of expertise are needed. The pictorial representation helps transfer the knowledge about the many parts more easily than a lists of variables or equations can, so each individual expert can have a general understanding of the whole model, and know where he or she can add knowledge. (See **Figure X- C** for the final version of Red Snapper SD model for stock predictions.)

Figure X- C: Final version of the Red Snapper SD Zoning Model



A summary of all the equations included in the Red Snapper SD are listed in Table X-A. (See Appendix X - B for an in-depth explanation of how the many equations were developed.)

Table X- A: Equations for Red Snapper Systems Dynamics Model

Definition of some variables used in SD model

R0 = Number of Larvae and Recruits in Replenishment Zone that are 0 years old
R1 = Number of Fish in Replenishment Zone that are 1 year old
R2 = Number of Fish in Replenishment Zone that are 2 years old
R3 = Number of Fish in Replenishment Zone that are 3 years old and up

N0 = Number of Larvae and Recruits not in Zone that are 0 years old
N1 = Number of Fish not in Zone that are 1 year old
N2 = Number of Fish not in Zone that are 2 years old
N3 = Number of Fish not in Zone that are 3 years old and up

N0 Births = The number of Births each year
N0 Growth = The number of Larvae and Recruits that survive their first year and grow into 1 year olds
N0 Nat Death = Number of Recruits and Larvae that die natural deaths
N0 Bycatch = Number of Recruits and Larvae that die from Shrimping Bycatch
etc.

Equations used in Red Snapper SD model

Stocks and Flows of Fish in Zone

R0_Larvae(t) = R0_Larvae(t - dt) + (R0_Birth + Step_R0 - R0_Export - R0_Nat_Death - R0_Growth) * dt
INIT R0_Larvae = 000
R0_Birth = R3&up_Stock*MAX(Repro_Rate*(1+0.0*(R3&up_Stock)),R_Repro_Rate)
Step_R0 = If (time >11 and time <12) then (N0_Larvae*(Zone_Size/375000)) else (0)
R0_Export = R0_Larvae*Export_Rate
R0_Nat_Death = Max ((R0_Larvae-R0_Export-R0_Habitat_Capacity) ,(R0_Larvae-R0_Export)*(1-EXP(-Larvae_Death_Rate)))
R0_Growth = (R0_Larvae-R0_Export-R0_Nat_Death)

R1_Stock(t) = R1_Stock(t - dt) + (R0_Growth + Step_R1 - R1_Growth - R1_Migration - R1_Nat_Death) * dt
INIT R1_Stock = 000
Step_R1 = If (time >11 and time <12) then (N1_Stock *(Zone_Size/375000)) else (0)
R1_Growth = (R1_Stock-R1_Migration-R1_Nat_Death)
R1_Migration = R1_Stock*Migration_Rate
R1_Nat_Death = Max((R1_Stock-R1_Migration-R1_Habitat_Capacity) ,(R1_Stock-R1_Migration)*(1-EXP(-Death_Rate_1)))

R2_Stock(t) = R2_Stock(t - dt) + (R1_Growth + Step_R2 - R2_Migration - R2_Nat_Death - R2_Growth) * dt
INIT R2_Stock = 00
Step_R2 = If (time >11 and time <12) then (N2_Stock *(Zone_Size/3750000)) else (0)
R2_Migration = R2_Stock*Migration_Rate

R2_Nat_Death = Max ((R2_Stock-R2_Migration-R2_Habitat_Capacity) ,(R2_Stock-R2_Migration)*(1-EXP(-Death_Rate_2&up)))
R2_Growth = R2_Stock-R2_Migration-R2_Nat_Death

R3&up_Stock(t) = R3&up_Stock(t - dt) + (R2_Growth + Step_R3 - R3_Nat_Death - R3_Migration) * dt
INIT R3&up_Stock = 00
Step_R3 = If (time >11 and time <12) then (N3&up_Stock *(Zone_Size/375000)) else (0)
R3_Nat_Death = Max ((R3&up_Stock-R3_Migration-R3_Habitat_Capacity) ,(R3&up_Stock-R3_Migration)*(1-EXP(-Death_Rate_2&up)))
R3_Migration = R3&up_Stock*Migration_Rate

Stocks and Flows of Fish outside Zones

N0_Larvae(t) = N0_Larvae(t - dt) + (R0_Export + N0_Birth - N0_Growth - N0_Nat_Death - N0_Bycatch - Step_N0) * dt
INIT N0_Larvae = 29000000
N0_Birth = N3&up_Stock*Repro_Rate*(1+0.0*(N3&up_Stock))
N0_Growth = N0_Larvae-N0_Bycatch-N0_Nat_Death
N0_Nat_Death = MAX((N0_Larvae-N0_Bycatch-N0_Habitat_Capacity), (N0_Larvae-N0_Bycatch)*(1-EXP(-Larvae_Death_Rate)))
N0_Bycatch = N0_Larvae*(1-EXP(-Larvae_Bycatch_Rate))Step_N0 = If (time >11 and time <12) then (N0_Larvae *(Zone_Size/375000)) else (0)

N1_Stock(t) = N1_Stock(t - dt) + (N0_Growth + R1_Migration - N1_Growth - N1_Nat_Death - N1_Bycatch - Step_N1) * dt
INIT N1_Stock = 14000000
N1_Growth = N1_Stock-N1_Bycatch-N1_Nat_Death
N1_Nat_Death = Max((N1_Stock-N1_Bycatch-N1_Habitat_Capacity), (N1_Stock-N1_Bycatch)*(1-EXP(-Death_Rate_1)))
N1_Bycatch = N1_Stock*(1-EXP(-N1_Bycatch_rate))
Step_N1 = If (time >11 and time <12) then (N1_Stock *(Zone_Size/375000)) else (0)

N2_Stock(t) = N2_Stock(t - dt) + (N1_Growth + R2_Migration - N2_Growth - N2_Nat_Death - N2_Cryptic_Death - Step_N2) * dt
INIT N2_Stock = 3500000
N2_Growth = N2_Stock-N2_Cryptic_Death-N2_Nat_Death
N2_Nat_Death = Max((N2_Stock-N2_Cryptic_Death-N2_Habitat_Capacity) ,(N2_Stock-N2_Cryptic_Death)*(1-EXP(-Death_Rate_2&up)))
N2_Cryptic_Death = MIN(N2_Stock, ((IF(Comm_Catch_limits >(C_Dir_Catch + C_NonDir_Catch)) THEN (C_Dir_Catch+C_NonDir_Catch) Else(Comm_Catch_limits)) +(IF(Rec_Catch_limits >Rec_Catch) THEN(Rec_Catch) Else(Rec_Catch_limits)))*Stock_Ratio* (1-Catch_Survival_Rate))
Step_N2 = If (time >11 and time <12) then (N2_Stock *(Zone_Size/375000)) else (0)

N3&up_Stock(t) = N3&up_Stock(t - dt) + (N2_Growth + R3_Migration - N3_Harvest - N3_Nat_Death - N3_Cryptic_Death - Step_N3) * dt
INIT N3&up_Stock = 5700000
N3_Nat_Death = MAX((N3&up_Stock-N3_Harvest-N3_Cryptic_Death-N3_Habitat_Capacity), (N3&up_Stock-N3_Harvest-N3_Cryptic_Death)* (1-EXP(-Death_Rate_2&up)))

N3_Cryptic_Death = min((N3&up_Stock-N3_Harvest),(IF (Comm_Catch_limits >(C_Dir_Catch+C_NonDir_Catch)) Then (0) ELSE(C_NonDir_Catch*(1-Catch_Survival_Rate)))+(IF(Rec_Catch_limits >+Rec_Catch) THEN(0)ELSE(Rec_Catch*(1-Catch_Survival_Rate))))
Step_N3 = If (time >11 and time <12) then (N3&up_Stock *(Zone_Size/375000)) else (0)

Harvested_Fish(t) = Harvested_Fish(t - dt) + (N3_Harvest) * dt
INIT Harvested_Fish = 0
N3_Harvest = MIN(N3&up_Stock, (IF (Comm_Catch_limits >(C_Dir_Catch+C_NonDir_Catch))Then (C_Dir_Catch+C_NonDir_Catch) ELSE(Comm_Catch_limits))+ (IF(Rec_Catch_limits >Rec_Catch) THEN (Rec_Catch) ELSE(Rec_Catch_limits)))

Converters

Across_Currents_Width = 3
Along_Currents_Length = 150
Catch_Survival_Rate = 0.67
Comm_Catch_limits = If (time<7) then(2000000000) else (if (time <8)then(1500000) else(1000000))
Comm_Dir_CPUE = 120
Comm_Dir_Fishing_effort = 23400
Comm_NonDir_CPUE = 18.6
Comm_NonDir_Fishing_Effort = If (time<7) then (24000) else (If (time<8) then (24000) else (If (time <9) then (40000) else (If (time<10) then (88000) else (88000))))
Currents = 450
C_Dir_Catch = Comm_Dir_CPUE*Comm_Dir_Fishing_effort
C_NonDir_Catch = Comm_NonDir_CPUE*Comm_NonDir_Fishing_Effort
Death_Rate_1 = 0.3
Death_Rate_2&up = 0.2
Export_Rate = min(Currents/(Along_Currents_Length/Larvae_time),1)*Safety_Factor
Larvae_Bycatch_Rate = 0.34
Larvae_Death_Rate = 0.5
Larvae_time = .167
Migration_Rate = Zone_Location + (if time >50 then 0 else 0)
N0_Habitat_Capacity = 29000000*10
N1_Bycatch_rate = 1.2
N1_Habitat_Capacity = 14000000*10
N2_Habitat_Capacity = 3500000*10
N3_Habitat_Capacity = 5700000*10
R0_Habitat_Capacity = 29000000*10*(Zone_Size/375000)
R1_Habitat_Capacity = 14000000*10*(Zone_Size/375000)
R2_Habitat_Capacity = 3500000*10*(Zone_Size/375000)
R3_Habitat_Capacity = 5700000*10*(Zone_Size/375000)
Rec_Catch = Rec_CPUE*Rec_Fishing_Effort
Rec_Catch_Limits = if (time <9)then(200000000) else(1000000)
Rec_CPUE = 0.67
Rec_Fishing_Effort = If (time<7) then(1500000) else (3000000)
Repro_Rate = 24
R_Repro_Rate = If (Zone_Size>0) then (Repro_Rate*2) else Repro_Rate
Safety_Factor = .95
Stock_Ratio = N2_Stock/(N3&up_Stock+1)
Zone_Location = 00.05

Zone_Size = Along_Currents_Length*Across_Currents_Width

C. RESULTS OF THE SD MODEL

This section discusses what was accomplished when SD was used for this dissertation and projects what it could have accomplished if it had been used during the actual FKNMS process. Systems Dynamics can build on what was learned by using Cognitive Maps, eliciting detailed information, adding to the knowledge base. Running the SD model can help the users determine how the variables mathematically interact, which can help the users understand how the system works. SD can also be used to predict possible outcomes and how different alternatives might change the outcome. SD allows more information and variables to be made explicit which allows for them to be valued later in the choice step.

1. Elicits new variables and detailed information to form equations

Building the structure and defining the equations for the Replenishment Zone SD model, it was necessary to organize and prioritize information from many sources, including the i)Goodyear document, ii) Replenishment Zone articles and iii) personal communications with a number of researchers. The structure made it easier to see the gaps of knowledge. Attempting to quantify the variables and linkages that were known to affect the system, additional information was elicited and included in the decision that would not have otherwise been elicited.

For instance, attempting to define equations for Reproduction rates and Natural Mortality rates made it obvious that one species had to be chosen. An SD could not be modeled for an 'average' over-fished species, nor could one model be built for all 6000+ species. One representative species was chosen, Red Snapper, a demersal fish that could help inform the users about one of the most important aspects of Replenishment Zones: could Zones help replenish a marine species?

Defining the equations for the Red Snapper model forces the users to attempt quantification, which elicits more information. For example, trying to define the equation for Larvae Transport Rate, it became obvious that it was really dependent on three variables that had not yet been identified. Larvae Transport Rate is dependent on i) the Zone Orientation, ii) the Time that larvae spend in their pelagic stage and iii) the Ocean and Bay Current Speeds. The 'Zone Orientation' determines the 'Along Current Length' of the Zone. This, the 'Time that a larvae spends in its pelagic stage' and the 'Current Speed' determine the number of pelagic fish larvae that are carried out of a Replenishment Zone. This affects the number of fish that grow up within the Zone, which affects how well Replenishment Zones achieve their intended purpose. Attempting to quantify the one variable, Larvae Transport Rate, identified three variables that influence the success of a Replenishment Zone.

Attempting to define the equation for adult Migration rate of Red Snapper out of a Replenishment Zone showed that Zone Location is important. To determine the number of fish that might mature in a Zone, then migrate out of the Zone and enter the harvest-able Stock, one must understand typical migration patterns of the fish species. In trying to find an equation to describe this, it was learned that Red Snapper migration depends on the seasonal weather patterns and on the spawning patterns. During certain times of year, the Red Snapper will leave its reef habitat and migrate towards the shore. Thus, if the reef and shore area are both within the Replenishment Zone, then the fish are less likely to leave the Zone. If the reef is far from shore and the Zone does not extend from the reef to the shore, then many Red Snapper are likely to temporarily leave the Zone boundaries. Trying to define Migration rate made it obvious how Zone Location may affect the success of Replenishment Zones.

Building the SD structure made it obvious what factors influenced Red Snapper fish stocks, but were not included in the Goodyear paper on Red Snapper. None of these variables, Zone Orientation, Cross current distance, or Zone Location, were mentioned in the articles written about Replenishment Zones or Red Snapper or were discovered when building the CLD, but their importance became obvious when trying to write equations for the SD model. These variables became new criteria for choosing a Replenishment Zone.

The SD made it obvious where the gaps of information were, making the users aware of what questions need to be asked and what information is necessary to understand the system. Special efforts can then be spent on filling the gaps of knowledge, on asking the questions to get the information. In trying to develop the equations, the users push the limits not only on the published information, but also on what the scientists and experts know and with what degree of certainty. Some of the initial values and equations had to be formulated via discussions with Dr. John Hunt, Mr. Michael Murphy, Mr. James Bohnsack and Mr. Ben Haskell. For instance:

- On average, how many larvae do Red Snapper females produce each year?
- How much time does the average larvae spend in its pelagic stage?
- What are the average currents through the FKNMS?

The scientists might have been hesitant to publish the information they provided via personal communications, since there was so much uncertainty, but they did have knowledge on the subjects. Building the SD helped elicit this information. Asking these questions would not have been obvious if one were to just read a report or listen to a presentation.

Building the SD also made it explicit which pieces of information were not fully developed. Attempting to define the SD equations made it clear that it was not possible to quantify the Health of Habitat variables on the fish Stocks, since the uncertainty was too great. There is no detailed information with which to write equations about how these variables interact, so the variables and linkages had to be simplified.

Building the SD also made it explicit where further research might be most insightful. There is a need for research to know more about the Reproduction rates both inside and outside the Zones; the Natural Mortality and how much they change inside a Replenishment Zone; how Health of Habitat, that is water quality and human disturbances, affects the renewable resources; more precise estimates of Catch Survival rates: more precise documentation of the Fishing Efforts; and Migration rates. (Refer back to Figure X-C)

2. Informs about how the variables interact

Using the a Simulation model not only elicits more information, but also informs the users how the variables interact, giving the users a better understanding of the system. Typically this happens when the model is run, but sometimes it can occur by just building the structure and defining the equations. For example, by attempting to quantify the Mortality rate for each age group, the users have to differentiate between the Natural Mortality and the Fishing Mortality. It was then explicit that the Health of Habitat affects Natural Mortality, but does not affect Fishing Mortality. Since the Health of Habitat is assumed constant in the Red Snapper SD, the users can realize that the SD only shows how Replenishment Zones can decrease Fishing Mortality, not Natural Mortality.

a. No Replenishment Zones or Catch limits: Predicting Stock sizes

To maximize the learning about how the system works, it is best to start with the base case scenario, which is no Replenishment Zone and no Catch Limits, then compare the results after the Catch Limits and Zones are added. The base case scenario starting at t = 0 in 1984, is:

Initial Stocks 'Not in Zone' =

N0 Stock = Stock of 0 year-olds not in Zone = 29,000,000

N1 Stock = Stock of 1 year-olds not in Zone = 14,000,000

N2 Stock = Stock of 2 year-olds not in Zone = 3,500,000

N3 Stock = Stock of 3 & up year olds not in Zone = 5,700,000

Initial Stocks in Replenishment Zone = 0 (This is an easy way to model 'no Zones')

Commercial Direct Fishing Effort = average of 1990, 1991 and 1992 = 23,400 Days

Commercial Non Direct Fishing effort = the low estimates of 1990 = 6,000 days

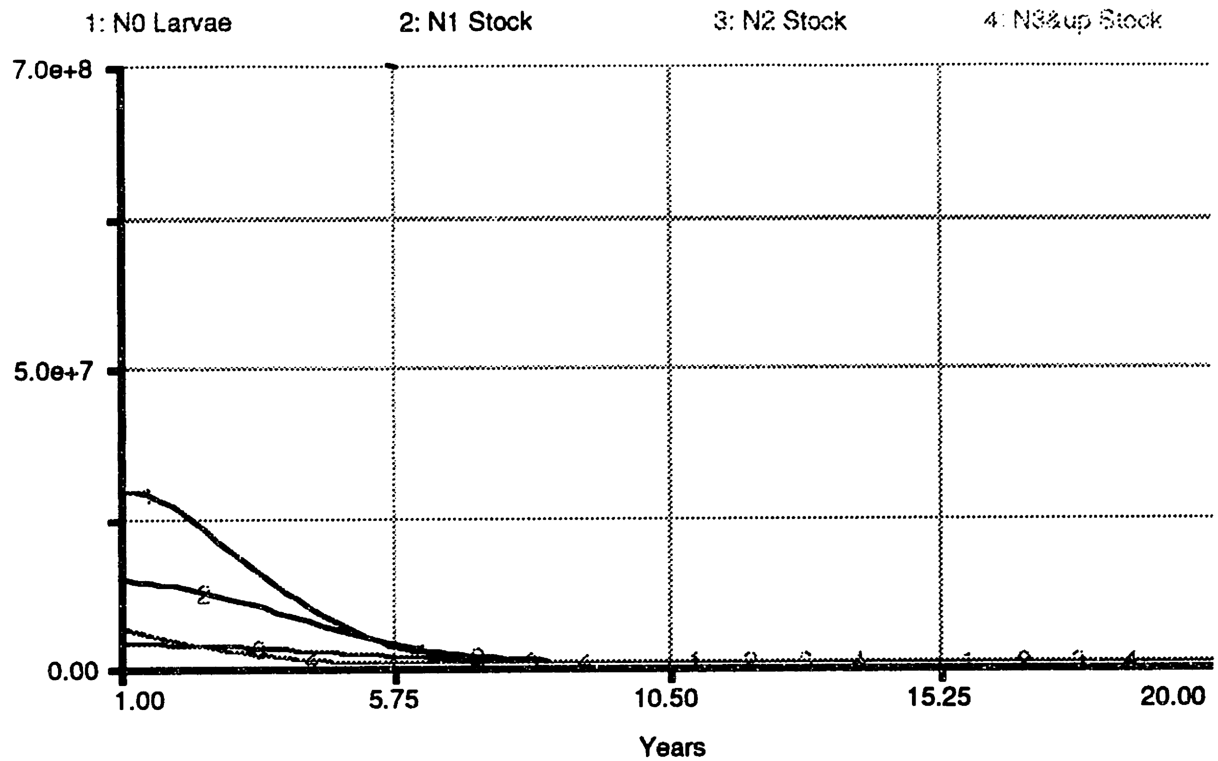
Recreational Fishing Effort = the 1990 low estimate of 1,500,000 hours / year

Catch Limit in 1984 = Infinity, since there was no Catch limit in 1984

Reproduction rate = number of 0 year olds / number of 3& up year olds = lowest rate = 5 (Numbers come from Goodyear paper, 1993. See Appendix X- C for more details on the equations and on the results.)

The Systems Dynamics model predicts that the *Stocks will crash* in the base case scenario. The Stock of three year-olds crashes first, since they are the Stock being harvested. The following year, the Stock of larvae crashes, followed by the one year olds and finally the 2 year olds. This is because if there are no N3 fish, then there are no fish available to reproduce and no larvae the next year. SD predicts that it will takes about 10 to 15 years for the Stock of N3 to totally crash if the *Reproduction rate* is as low as *5* (the *1984* Goodyear estimated rate).

Graph X - D : Stock of Non Replenishment Zone fish for 0, 1, 2, and 3& up year olds when Reproduction Rate = 5.0



Using the SD model, various graphs of the different variables can be produced; the graphs can help the users learn a great deal about the physical system by comparing different variables and how they change over time. For example, the following graph can help one understand the reason that the Stocks crash. On the graph, various variables are compared:

i) the Stock of Non-Zone 2 year olds (N2 Stock),

ii) the Stock of Non-Zone 3 & up year olds (N3 Stock)

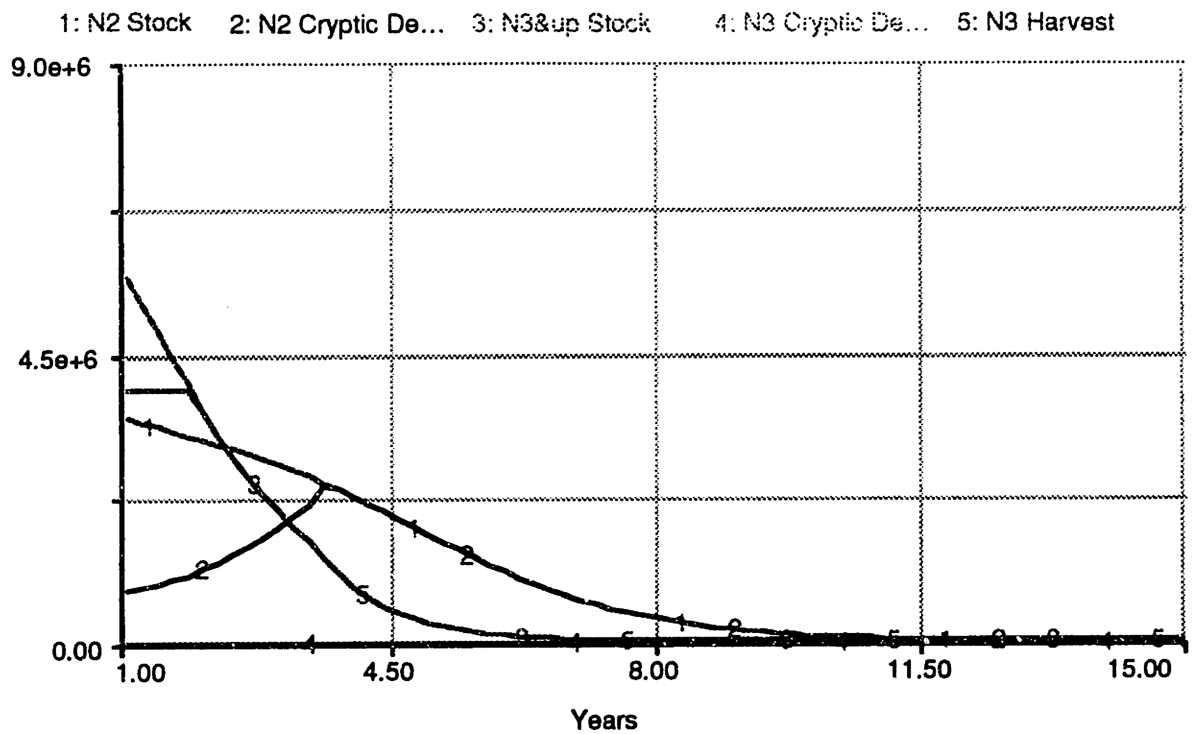
iii) the Stock of N2 fish that die due to Cryptic Deaths (N2 Cryptic Deaths),

iv) the N3 Cryptic Deaths and

v) the N3 Harvest.

Analyzing this graph, the user can see how the different variables interact and affect each other.

Graph X- E: Stock of Non Replenishment Zone fish for 2 and 3& up year olds and Stock of 2 and 3& up years olds that die from Cryptic Deaths



The SD model shows that when the Fishing Efforts are high and the fishermen are looking for 3 & up year old fish to harvest, they also catch many 2 year old fish. For every N3 fish the fishermen catch and harvest, they also catch and throw back many N2 fish many of which die from being hooked, handled etc. When the number of 2 year old fish that die from Cryptic Mortality increases, the overall Stock of N2 fish decreases as does the Stock of N3 fish the following year. The number of N2 fish that die from Cryptic Mortality (N2 Cryptic Deaths) can become so high that it equals the entire Stock of 2 year old fish. This means that all the N2 fish die, and none grow to become N3 fish; the Stock crashes.

Although an outcome can be predicted, it is necessary to ask if it is an accurate one. The most suspect piece of information is the very low *Reproduction Rate*;[93] after talking to some fish biologists, it is probable that the number is unrealistically low. Using a *Reproduction Rate = 16.5* (the *1990* Goodyear estimated rate and the highest rate from the Goodyear data) the *Stocks still crash*. Using a *Reproduction Rate of 25, the Stocks increase*, but the predicted Stocks are higher than the annual estimates of stocks from the Goodyear article. A

[93]Note: this is Replenishment rate per every adult fish. The Reproduction rate for each adult female would be approximately double this number.

Reproduction Rate of 24 causes the fish Stocks to increase for awhile, making the Stocks more like the scientist' estimates printed in the Goodyear article from 1984-1992.

When the Reproduction rate changes from 5 to 16.5 to 24 to 25, the Stock of fish experiences very different results over a 50 year period. With 5, the Stocks crash after about 5 years. With 16.5, the Stocks crash in about 10 years. With a Reproduction Rate of 24, the Stocks increase, then crash after 20 years. With a Reproduction Rate of 25, the Stocks and Larvae find their upper limit, the estimate of the Habitat's Holding Capacity after about 25 years. For the N3 Stock, this is about 90 million, a little more than 10 times the 1984 Goodyear Stock estimate.[94] By using Systems Dynamics, the users can see how important the Reproduction Rate and the Habitat's Holding Capacity is to the Stock of fish. The exact Reproduction rate and Habitat's Holding Capacity are educated guesses, but it shows that if one is to understand the future Stock levels, there is a need to better understand these two variables. More scientific knowledge and research is needed about Reproduction Rates and Habitat Holding Capacity before one can make *accurate* estimates about future Stock levels.

b. No Replenishment Zones, but Catch Limits instated: Predicting Stock sizes

The next stage of running the SD is to model the fish Stocks after the *Catch Limits* were created to see if they change the Stocks. The Commercial Catch Limits were created in 1990 and equaled 3.1 million pounds of fish per year, but were decreased in 1991 to 2.02 million pounds of fish. The Recreational Catch Limits were set in 1990 at 7 fish per recreational fishermen; in 1992 the Catch Limits were changed to 1.98 million pounds of fish per year, since the 7 fish limit would not restrict the total Recreational Catch if Recreational Fishing Efforts grew. (2 million pounds of fish per year is approximately 1 million fish per year, using Goodyear's estimates).

Once the Catch Limits were installed and using a Reproduction Rate =24, the model showed that the *Stocks did not crash*. Since the Reproduction rate of 24 is not known with certainty, it is important to know how low the Reproduction rate can be before the Catch Limits are no longer helpful. With a *Reproduction Rate of 21.9* or lower, *the Stocks crash* even though the 1990 Catch Limits were instated. This means that if the Reproduction Rates are actually lower than 22, the Catch Limits alone would not prevent the Stocks from crashing.

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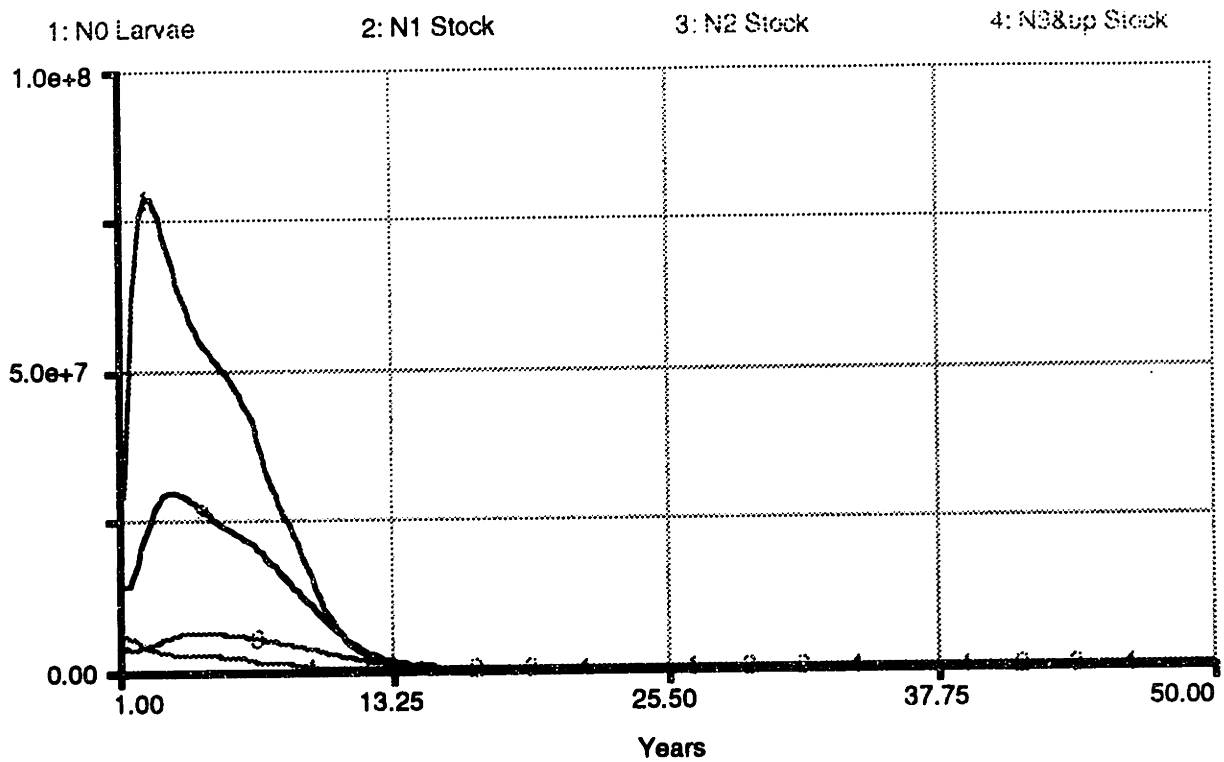
[94] The Stock levels do actually rise slightly above the fixed number set for the Habitat's Holding Capacity at the beginning of any year or any one time period, because of the way the variable is modeled; the Stocks can be as high as the (Habitat's Holding Capacity + Fishing Mortality + the Natural Mortality).

Graph X- F: Stock of Non Replenishment Zone fish for 0, 1, 2, and 3 & up year- olds when Reproduction Rate = 21.9 and Catch limits installed



The N3 Stock falls, because the Reproduction Rate of 21.9 is not high enough to replenish the stocks. Looking at graphs of other variables can help explain why. (See Appendix X -C) In year 7, the Commercial Catch Limits are installed, so the Commercial Directed Fishing Efforts decrease a little, causing the N2 Cryptic Deaths to decrease. In the beginning of the very next year, though, the Commercial Fishermen increase their Fishing Effort, so they get more of the Commercial Catch before the Limit is met, before the other Directed and Non-Directed Commercial fishermen catch all the fish. (This is confirmed in the Goodyear paper.) This causes the N2 Cryptic Mortality to increase again. This happens at the beginning of every year, until the N2 Cryptic Mortality equals the entire N2 Stock. The N2 Stock and N3 Stock continue to fall.

The N3 Stocks decrease, then the N2 Cryptic Deaths increase as the fishermen still spend the same effort trying to find the fewer N3 fish. At a Reproduction rate = 21.9 or less, it becomes a downward spiral which can cause the entire Stock to crash and become extinct. If the Reproduction rate is not known with certainty, then Catch Limits alone may not protect a species from crashing.

In attempting to understand how the variables interact, one must also vary the Fishing Efforts since there is also some uncertainty in their estimates. The Goodyear article indicates that official 'landing' reports were not mandated before the Catch Limits were installed, but that the estimates and partial reports show that the annual Recreational and Non-Directed Commercial Fishing Efforts have been increasing over the years. Also, the Goodyear paper estimated that the actual Directed Commercial Fishing Efforts were about four times greater than the reported Directed Fishing Efforts. It is also possible that the Non-Directed Fishing Efforts were under-reported by a factor of four. Running this scenario with the SD model, one can see the predicted effects on the system.

Using Non Directed Fishing Efforts in:

1984-1990 = 4 * 6000

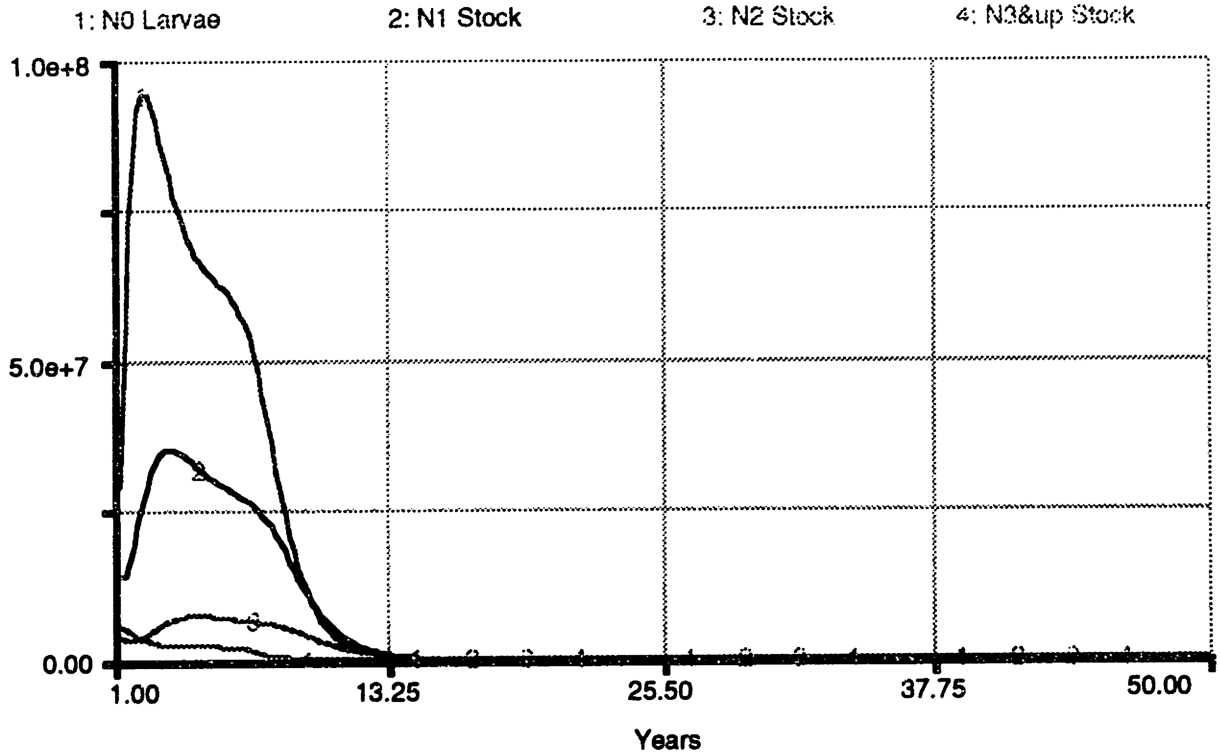
1991 = 4 * 10,000

1992 - present = 4 * 22,000,

the Reproduction rates would have to be very large to prevent the Stocks from crashing. Even if the *Reproduction Rate is as high as 27.8* and the *Catch Limits* are in place, if the Non Directed Fishing Efforts include estimates for the unreported Fishing Efforts, the *Stocks crash*. The Reproduction rate has to increase to 28.0 for the Stocks not to crash.

Not only is there imperfect information on past Non-directed Commercial Fishing Efforts, but the *Recreational Fishing Efforts* estimates are also imperfect. If *Recreational Fishing Efforts* were also *higher than the reported data* or if they *increased in the future*, again the *Stocks would crash* with Reproduction rates = 28. One can see that since there is imperfect data on past Recreational and Commercial Fishing Efforts and imperfect information about Reproduction Rates, it is very hard to set the correct level for the Catch Limits.

Graph X-G: Stock of Non Replenishment Zone fish for 0, 1, 2, and 3& up year olds when Reproduction Rate = 24.5, Catch limits, with average Non-Directed Commercial and Recreational Fishing Effort



Looking at graphs that compare different variables, one can see why the Catch Limits alone may not save a fishery. The Reproduction rate, the Non Directed Commercial Fishing Efforts and Recreational Fishing Efforts determine the N2 Cryptic Deaths, the N3 Cryptic Deaths and the Harvest. The Fishing Efforts are best estimates given the available data, but the SD model shows the need for more accurate data collection.

Even if the Fishery Management Council sees the Stocks coming back for a short period of time, as they did in 1991-1993, it is no insurance that the Stocks will not crash in the future. *Catch Limits alone may not be enough to prevent the Stock from crashing* unless one knows *future Reproduction Rates* and *all the future Fishing Efforts with certainty*. Since one can not predict future situations such as Fishing Efforts, Reproduction rates... with certainty, *Catch Limits alone may not protect a species from crashing if Reproduction rate is low and Fishing Efforts are high.*

c. Creating a Replenishment Zone: Predicting the Stock sizes

The SD can help the decision makers become better informed about how 'Can Replenishment Zones help protect the homes and food of 6000+ species.' One of the objectives was to 'Protect biodiversity' with sub-objectives 'Protect all species' and 'Replenish marine life.' Building the SD is meant to help inform if and how a Replenishment Zones can do this for a representative species, Red Snapper.

If the *Replenishment Zones were created,* the Systems Dynamics model shows that the Stocks are less likely to crash. Using:

Reproduction Rate = 28,

Commercial Catch Limits installed in 1990 = 1.5M, and 1991 = 1.0M

Recreational Catch Limits installed in 1992 = 1.0M

Commercial Non Directed fishing effort at its *highest* estimates:

1984-1990 = 4 * 6000

1991 = 4 * 10,000

1992 = 4 * 23,000

1993 = 4 * (6000 + 10,000 + 23,000) /3

Recreational fishing Effort at its *highest* estimate

pre 1990 = 1.5M and

post 1990 = 3M

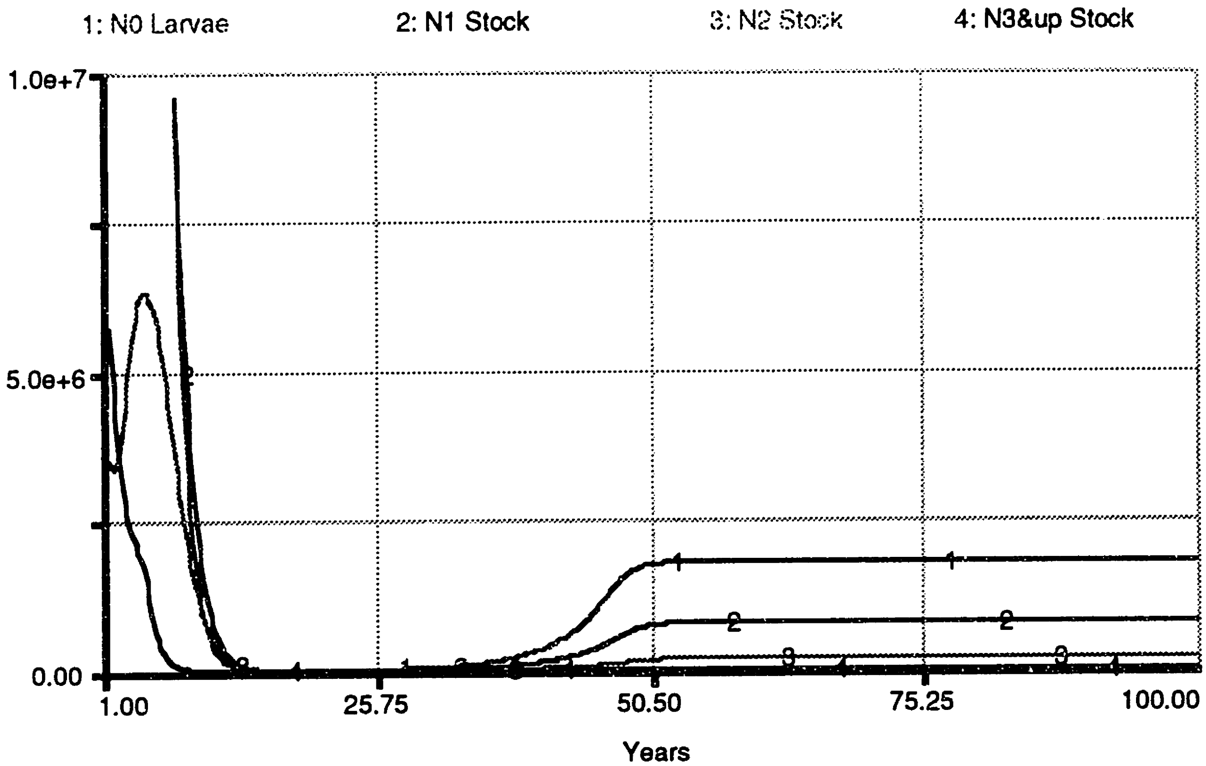
The SD model shows that with a *150 sq. mile Replenishment Zone*[95] *and the other assumptions listed above, the Stocks decline to alarmingly low levels after Year 10, but then come back after Year 45, about 30 years after the Zones are created.* Although the Stocks come back slowly, they do increase and the Harvest is estimated to be more than 4,000 pounds with the Zone. The Zones replenish the Stocks regardless of whether the Stock has crashed, as long as there are a few fish still alive, although if more fish are alive at the time the Zone is created, then the Stocks come back more quickly. Likewise, the Zones also replenish the stocks regardless of the Reproduction rate, although again with higher Reproduction rates, the Stocks come back more quickly.

If the fish's Reproduction Rate inside the Zone is greater than the Reproduction Rate outside the Zone as scientists in the Goodyear paper predict, then the results will be seen sooner. For instance, if the Reproduction rate is 10 times greater in the Zone, then the results will be seen less than 10 years after the Zone is created. If the Reproduction rate is twice as great

[95] This is the sum of the three areas suggested for the actual FKNMS Replenishment Zones

inside the Zone as outside, then the results will be seen about 25 years after the Zone is created.

Graph X-H: Stock of Non Replenishment Zone fish for 0, 1, 2, and 3& up year olds when Reproduction Rate = 48 inside the Zone and high estimates for Fishing Efforts



When the results can be seen depends on the Reproduction Rate of the fish inside the Zone. It might be about 10 years or more than 40 years. Reviewing the Systems Dynamics graphs and the interactions of the different variables, the users can understand why this occurs. Outside the Zone, the entire N2 Stock dies from N2 Cryptic Death between years, 10 and 20, because Fishing Efforts are so high. After the Zones are created, most of the fish that are being harvested are those that migrate out of the Zone and are caught. The Stock of fish inside the Zone does not grow to infinity, though, since it is limited by the Habitat's Holding Capacity, an estimated number.

A different Habitat's Holding Capacity for the Zoned area would also change the replenishment potential of the Zone. The Habitat's Holding Capacity is dependent on the number of predators, the abundance of food sources, the Zone's general Health of Habitat, the water quality, the number of human disturbances, etc. The Habitat's Holding Capacity might be five times larger than the original estimate or might increase as the Zone's Health of

Habitat improved, so that the Zone's Habitat Holding Capacity could equal 50 times Goodyear's 1984 Stock values, instead of the estimated 10 times. If the Habitat's Holding Capacity increased as such, then the R3 Stock and therefore the annual Harvest would be five times larger. Although the exact upper limit of the Habitat's Holding Capacity is just an estimate, it shows that if one is to give estimates for the 'replenishment' capabilities of the Zones, there is a need to better understand many physical factors about the Zone and their effect on the fish stocks. More scientific knowledge and research about Health of Habitat is needed before one can make *accurate* estimates about Future Stock levels. Using SD, one can explore many of the physical aspects of the Zone which have uncertainty, determining which ones most affect the replenishment capabilities of the Zone.

3. Informs about possible outcomes of choosing various alternatives

Running the SD model, the users can see that it is almost certain that "Replenishment Zones help protect the homes and food of 6000+ species." There are trade-offs, though, and it is necessary to determine how large a Zone should be created, where it should be located, how it should be oriented , etc. When there is controversy and tradeoffs to make, it is helpful to maximize the potential benefits, while minimizing the losses; there is a need to predict the possible outcomes of different Zone characteristics. Continuing to do parametric sensitivity analysis by changing the values of different Zone characteristics helps further inform the users.

a. Changing the characteristics of the Replenishment Zone: Predicting Stock sizes

By using a Simulation model such as SD, the decision makers can become better informed about the variables that they actually have control over. They can make 'dry runs' and can see the predicted results of various alternatives. This gives them more information for choosing an alternative, one that is most likely to achieve their desired outcome. Alternatives were changed and the value of different variables were altered in the Zoning SD including:

- Zone Orientation (Along Current Length and Across Current Width)
- Zone Size (from 0 to 150 to 450 square miles)
- Zone Location (changing the Migration Rate) (See Appendix X- C for more detail.)

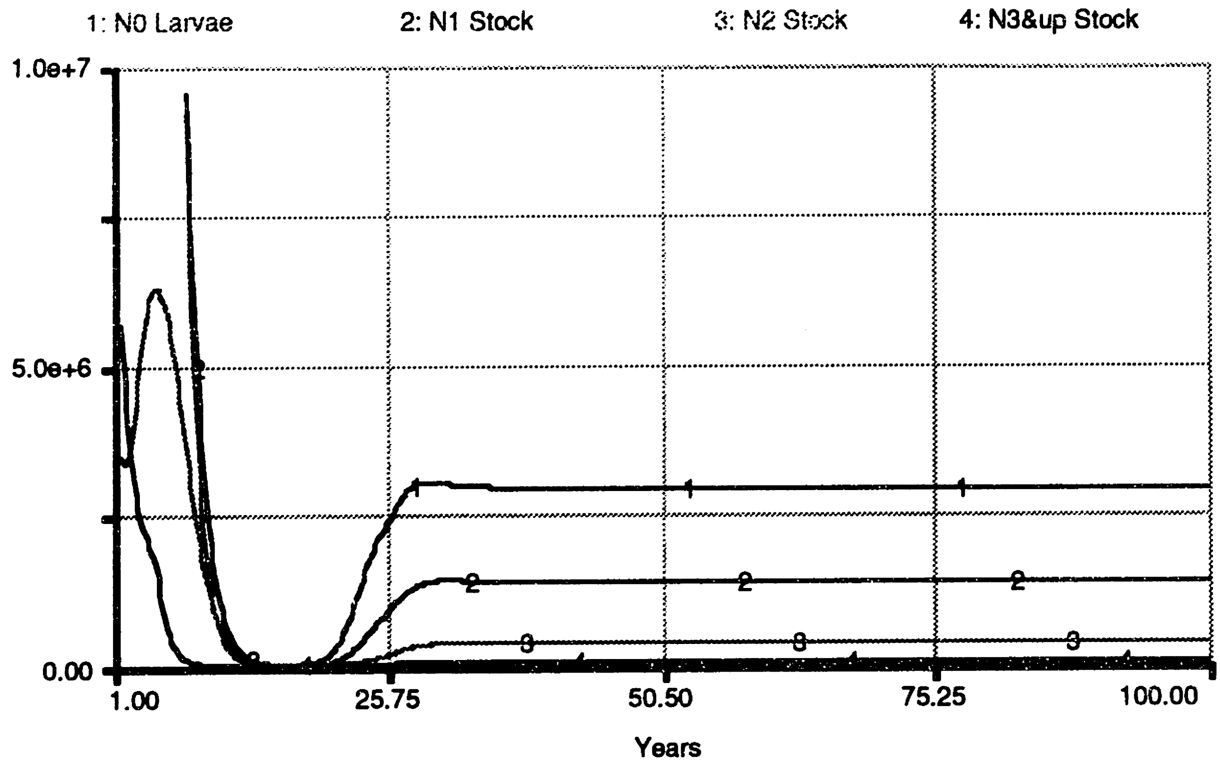
If the Replenishment Zone is re-oriented so that the Along Current Length is very large and most of the Larvae are not carried out of the Zone with the Currents, then the benefits of the Zones are seen sooner. If the Zone were oriented such that the measurements were 150 miles by 1 mile, then the results would be seen after about 12 years.

The Zone Location is also important to the replenishment capabilities of the Zone. For example, Red Snapper adults typically leave the reef and move towards shore during mating season. If the Zone is located such that the reef and shore are both within the Zone boundaries, then it is less likely that the Red Snapper will leave the Zone and Migration Rates are low. This increases the Zone's replenishment potential. If the Zone is located such that the fish have to leave the Zone to spawn, then the Migration Rate increases, which may totally destroy the replenishment capabilities of the Zone. With a Migration Rate = 30%, the Stocks were not replenished at all, since too many fish migrate out of the Zone and are caught before they can return. If the initial Migration Rate is low, but then increases as the Habitat's Holding Capacity is reached, then the Zone has an even greater potential for replenishing the Stocks outside the Zone, resulting in a larger Harvest.

Using the SD model, one can also see that if the *Replenishment Zones were bigger*, the replenishment capabilities of the Zone would change. As mentioned above, the Habitat's Holding Capacity sets an upper limit on the number of fish that the Zoned area can support. By increasing the Zone Size, one can increase the number of fish that can be supported by a Zone. For example, if the Zones were three times the area now proposed, then the annual number of Harvested fish would three times larger, or 6000 fish per year. Also, the results would be seen sooner. If Replenishment Zones were created around the entire Gulf not just within the FKNMS, so that they equaled 5% of the total Gulf fishing area, then it is likely that the Stocks would always be large enough so that the Annual Harvest could *always equal at least* the current Recreational and Commercial Catch Limits. The SD showed that the benefits of Zones could be achievable without using 33% of the entire fishing area to make Replenishment Zones, an idea that Mr. James Bohnsack from NOAA proposes.

If the Zone were larger, and the Migration increased as the Habitat's Holding Capacity approached, then it is likely that the Stocks are much bigger. The Annual Harvest could be as high as 30,000 fish / year or more than 60,000 pounds of fish per year. If Zones were created outside the Sanctuary and the total area of the Zone increased further, then the Stocks would be replenished to an even larger degree.

Graph X-I: Stock of Non Replenishment Zone fish for 0, 1, 2, and 3& up year olds when Reproduction Rate = 48 inside the Zone, Size of Zone = 150 miles x 3 mile and delayed increase in Migration Rate from 5% to 30%



Running the SD model indicates that the timing and degree to which the Zone's benefits are seen depends on many factors. It is likely that looking for conclusive results in five years, as the NOAA and Keys' citizens are attempting for the FKNMS, would be too early. The SD model helps the users understand that many factors should be considered to determine *how much and how quickly* the Stocks are replenished, including the:

i) Reproduction rate inside the Zone,

ii) Zone Size,

iii) Zone's Habitat Holding Capacity

iv) percent of larvae / offspring that remain in the Zone which depends on the Zone Orientation, the Current Speeds,

v) Zone Location, (nearness to shore), which determines the Migration rate, etc.

(See Appendix X - C for more details.)

To transpose the results of the Red Snapper SD to other species, researchers will have to determine the degree of similarity of these critical variables for the other important species.

Then the users can better understand the replenishment capabilities for many species, and the best overall Zone configuration. The Red Snapper SD informs all users how the Replenishment Zones can accomplish some of the sub-objectives: "Protect marine species" and "Protect Biodiversity" by preventing the stocks from crashing. Red Snapper is used as an example to determine the degree to which Replenishment Zones can prevent this for one demersal, over-fished specie. Even if the stock has crashed and there are just a few individuals left, the SD model indicates *that Replenishment Zones can help restock the fish.*

b. Altering the Replenishment Zone SD: Predicting the Fishing Income

The SD can also be used to inform the users about, 'How much fishing income might be lost in the short run, and how much fishing income might be gained in the long run?' The basic SD model needs to be altered slightly to do this. First, the purpose of creating the SD is redefined to be 'Inform about the annual fishing income over the next 100 years with Zones and without Zones.' Second, two new variables must be added to the SD model i)Price per fish and ii) Annual Fishing Income. The Price per fish should increase slightly each year after the Zones are created to account for the bigger, heavier fish that mature inside the Zones compared to those maturing outside the Zones. The increase does not represent inflation, since the real price, or inflation adjusted price, of fish does not increase. (Holliday, 1994; Food, 1994) Running a model with the following, the results are below.

Reproduction Rate outside the Zone =24

Reproduction Rate inside the Zone =48

Commercial Catch Limits installed in 1990 = 1.5 M and 1991= 1M

Recreational Catch Limits installed in 1992 = 1M

Commercial Non Directed Fishing Efforts at their highest estimates:

1984-1990 = 4 * 6000 = 24,000

1991 = 4 * 10,000 = 40,000

1990 = 4 * 23,000 = 92,000

1993 = 4 * (6000 + 10,000 + 23,000) /3 = 52,000

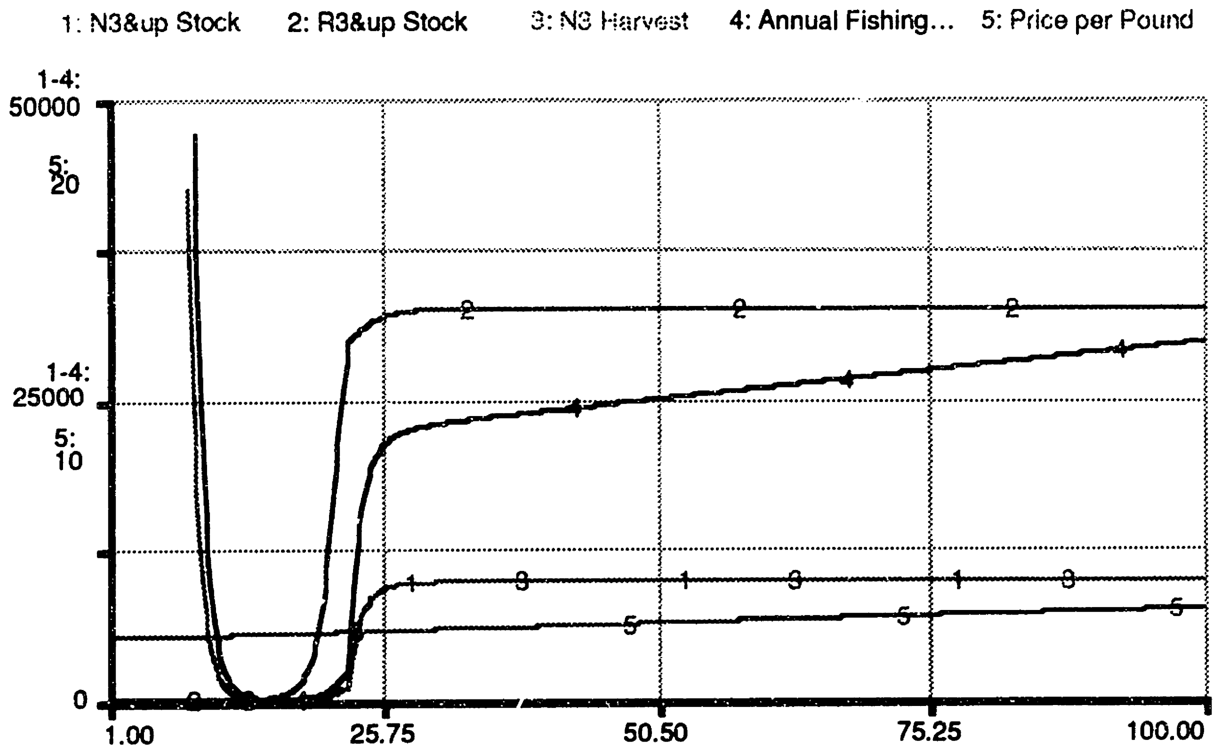
Recreational Fishing Effort = 1.5M before 1990 and 3 M after 1990.

Across Current Width = 1

Along Current Length = 150 for a total area = 150 sq. miles

Migration Rate = 5% before Habitat is crowded and 30% once the Habitat Capacity is approached, in year 22.

Graph X-F: Potential Income for Red Snapper fishermen in the Sanctuary resulting from a 150 square mile Replenishment Zone



The Fishing Income from Red Snapper alone increases from $0 per year, to over $30,000 per year about 13 years after the Zones are created. Since the Zones are close to the Florida coast, it is likely that Florida residents will be able to benefit most from the increase in income from the Zones. If Replenishment Zones were spread out along the entire Gulf fishing area and equaled 5% of this total area, then the Income would increase even more. It is likely that if Replenishment Zones could replenish Stocks so much, that the number of fish would easily exceed the Catch Limits.[96]

When trying to make predictions about fishing income, one sees that *the Income is limited by the same factors that limit the Stock of harvest-able fish with the addition of Price per pound of fish.* Just as there was uncertainty in predicting the Stock levels. there is great uncertainty in the predicted fishing income. If the users were intent on getting more accurate income estimates, the first variable to explore might be getting better estimates for the Health of Habitat upper limits, probably by contacting more experts and researchers in the field. The

[96] Creating the conditions for a massive stock is not necessarily desirable or possible. Optimal sustainable yield and avoiding a stock crash are desirable. The point is to find which option sustains the fishery stock at the least cost.

SD model also shows that the Reproduction rates inside the Zone and larvae migration out of the Zones are important, and there should be focus on getting more accurate estimates for this information. Using the SD model prioritizes the information, so that the decision makers know where to spend more effort getting the most accurate numbers possible. (Again, see Appendix X - C for more details.)

The SD model helped inform about the most important factors for preventing the extinction of the species, the replenishment capabilities of a Zone and future estimated Fishing Income. In this way, the SD model can help inform the users about many of the Zoning objectives and criteria.

<u>4. Informs somewhat about uncertainty</u>

a. SD allows Parametric Sensitivity Analysis

Even if a Simulation model can be created for a certain piece of a decision, the variables are rarely represented by values or equations that are known with 100% certainty. There are many variables with uncertain values, so the predicted outcomes have uncertainty as well. An SD model can be used to do some crude sensitivity analysis. Parametric sensitivity analysis can be completed, where one variable's value is altered at a time to do best case / worst case analysis. For example, using the SD model, parametric sensitivity analysis can be used to change the variables that one is most unsure of such as:

- Reproductive rates (from 5 to 25 per adult; which equals 10 to 50 per adult female)
- Past and Future Recreational Fishing Efforts (from 1.5 M hours per year to 3 M)
- Past and Future Non-directed Commercial Fishing Efforts (from 6K cumulative days per year to 13K)
- Habitat's Holding Capacity
- Migration Rate (uncertainty that is independent of Zone Location), etc.

(The results of the sensitivity analysis for these variables were discussed earlier.) Seeing the degree to which the outcome is changed when the different uncertain variables are altered helps the users understand which uncertain variable are most critical, and indicates where research dollars might be best spent.

The users can also use SD's parametric sensitivity analysis to alter the value of variables that are within their control in the actual decision. For example, the following variables could be altered:

- Zone's Orientation

- Zone's Size
- Zone's Location, which affects Migration rate

Performing this parametric uncertainty analysis helps inform the users about the results of different alternatives. This too was discussed previously in section 3 above. (See Appendix X - C for a full discussion of all the sensitivity analysis completed.)

b. A need for better Uncertainty Analysis for making predictions

There are many variables and linkages in the Zoning decision that are represented by a single number, but for which there is uncertainty. Best guesses and mean values are used, but the variables would be more accurately represented by statistical distributions. Using the *mean values* of best guesses only allows the SD to calculate the *mean* of a best guess for the outcome. SD cannot show a distribution of the possible outcomes.

It is possible to represent a variable using a statistical distribution using the Latin Hypercube method,[97] but with Systems Dynamics, the Latin Hypercube function generates only *one value in each time period.* A variable can be defined as a distribution of values, but since there is *only one* value generated for *each variable*, there is *only one* value calculated for the *predicted outcome* in each time period. With Simulation models such as SD, the outcome in each time period can not be calculated as a distribution using the Latin Hypercube method; the results can only be calculated as *one number*. Using Latin Hypercube uncertainty analysis in SD makes it difficult to differentiate the variations due to the uncertainty from the variations due to changes over time. This is why it is often more informative to use best case - worst case with single values, rather than using Latin Hypercube in SD.

With SD it is not possible to see the compounded effects of every variables' uncertainty at once. The SD model can not determine how the combined uncertainty of Non Directional Commercial Fishing Efforts, Commercial Fishing Efforts, Recreational Fishing Efforts, Natural Mortality, Bycatch Mortality, Reproduction Rate, etc., all affect the uncertainty of the outcome. The SD model can not give information about the range of possible outcomes while including all uncertain variables at the same time.

Using only the mean of a distribution, the users must ask themselves if the level of uncertainty in the outcome is too high to make useful decisions.[98] Also, the users must

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[97] The Latin Hypercube sampling method generates values; one value is chosen from the defined statistical distribution at 'random.'

[98] Note the level of uncertainty in the outcome will always be greater than the level of uncertainty in the individual equations.

beware of what parts of the system were simplified in an effort to complete and run the model. The users should take these simplifications into consideration when reviewing the results and the predictions. When there is a great deal of uncertainty, as there is on the Replenishment Zone decision, the users need to understand the range of uncertainty in the predictions.

5. Assists with transfer of knowledge

The SD model is a good education tool, because it i) summarizes what variables are interdependent in pictorial form and ii) summarizes the details of these interdependencies using equations and initial values. Creating the SD would enable many users, such as the AC, CG, NOAA and the Strategy Identification Group members, understand enough about the entire system to know where they should add information. The pictorial summary enables them to digest a great deal of information quickly, then know where to probe for more detail, so that better information can also be elicited. Building the Red Snapper SD helped elicit and transfer such detailed information as:

- i) Reproduction rates for the existing Stock of Red Snapper
- ii) Best estimates for past Fishing Efforts, for including the unreported data
- iii) Predictions for future Fishing Efforts
- iv) Speeds of Currents through the Zoned area, etc.

After the SD is finished, it could be reviewed and run in front of all the AC, CG and NOAA members to show the results. By changing the value of different variables and graphing the results, the user can learn how they vary as the system is run and how the variables interact. The SD model also helps prioritize the variables and criteria, so that if certain members did not participate, it would be easier to update them. As a summary, the SD model showed that:

- i) The Reproduction Rate was one of the most important factors in the system. The SD model showed that since this variable had great uncertainty and it was an important factor, that more research effort should be placed here.
- ii) Catch limits alone might not be enough to prevent the Red Snapper Stock from crashing if Non-Directed Commercial and Recreational Fishing Efforts increased beyond a certain level, or if Reproduction rates are actually below a certain level. Also, Catch Limits would probably not replenish Stocks in areas where the Stocks are presently depleted.
- iii) Cryptic Mortality caused high death rates for Red Snapper even if Fishing Efforts were focused on other species of fish.
- iv) If the Replenishment Zones were created, the Stock outside the Replenishment Zone might still decline but not crash. The SD model showed that the number of years that it

took to replenish the Stocks depended on the Reproduction rate of fish inside the Zone, the Habitat's Holding Capacity, the Migration Rate, Zone Size, etc.

v) The Zone Orientation is important if the currents through the Zone are high. It is important to choose areas where the Currents are slow to maximize the number of larvae that remain within a Zone or Zones should be created down current from spawning grounds. Good estimates of currents through the Zone should be one of the first items researched.

vi) The size of the Zone was an important factor in determining how well the Zone can replenish the Stock of fish outside the Zone. Assuming the Health of Habitat remains constant, a Zone ten times larger provided 10 times as much fish for the non-Zoned area.

The Red Snapper SD can help educate the users as to which uncertain variables were most critical to a desirable outcome. The SD graphs and pictorial representations can help convey this information to all the stakeholders, so that they are better informed. For example, Mr. Causey, NOAA's FKNMS manager, suggested that the Dry Tortugas Zone, which is the largest Zone, be re-oriented so that the replenishment potential was greater. The Advisory Council was not convinced that this would be beneficial, so they did not follow his suggestion.

Another example is that Mr. Bohnsack from NOAA's National Marine Fisheries Council, who presented information to the Advisory Council, advocates that 30% of the ocean should be designated as Replenishment Zones. Many members of the Advisory Council were vehemently opposed to such an idea. Using an SD model can help show that depending on the values of different variables, 5% of the ocean may be enough to replenish many Stocks. Using the model would have allowed all participants to review the assumptions that Mr. Bohnsack uses when he advises 30% of coastal areas.

The Red Snapper Replenishment model is a very simplistic representation of one species affected by Zoning. The equations are based on scientific data, knowledge and educated guesses. Using this information, enough of the Red Snapper life cycle is known and the links understood so that SD could be run and used *cautiously* as a predictive tool, since there is uncertainty. By focusing on the life cycle and fishing sectors of the Zoning model, the Red Snapper SD helped inform how Replenishment Zones affect i) the biodiversity and possible extinction of Red Snapper and ii) the short term and long term Fishing Income from Red Snapper.

Using this information, the users might make educated guesses as to how Replenishment Zones would affect other marine species. To find out how other demersal species are affected, the same basic SD structure might be used, and only the equations and initial values would need to be altered to represent the exact species. To understand how pelagic species are affected by the Zones, the structure might need to be changed as well; some new variables might need to be added and some linkages changed, as well as the values and equations altered. Building an SD model for a number of species would be time consuming, so the AC, CG and NOAA members would have to decide if the time and effort were worth what they might learn. It is also important to recognize that some objectives of AHP hierarchy would not be able to be informed through the use of an SD model.

D. STEPS OF GOOD DECISION-MAKING PROCESS ACHIEVED

The SD model is most helpful if the first two steps of good decision-making are already completed, since SD does not help with these two steps. SD can not help determine what stakeholders should be represented nor their roles in the decision. Many decision makers can use SD to become better informed, but every decision makers may not want to spend their time with the many details of SD, since building an SD model can be laborious and time consuming.

The SD is best used after problem definition is completed because the goal sets the parameters and provides the overall structure for the SD model. For example, in the Replenishment Zone SD, if the tasks had not been defined as 'Inform to a greater level of detail' *before* starting the SD Replenishment model,[99] the model never would not have been completed and used as a predictive tool. Defining the goal as such made it possible to assume that i) Health of Habitat was constant, so it could be represented as an upper limit on the fish Stocks and ii) predators and food would remain as the same percentage inside the Zone as outside. After the first few steps of decision-making are complete, the SD model helps most with steps 2, 3 and 4 and Requirement 2 of good decision-making.

Step 2) Criteria formulation

Systems Dynamics requires the users to identify the variables (stocks, flows and converters) that affect a system. Building the Red Snapper SD model, many important criteria for creating

[99] Before SD could have been used in the actual FKNMS decision, it would have been necessary for the stakeholders to previously agree that stocks of fish and other species were declining and that something should be done. It would have also been necessary that Replenishment Zones were recommended to ameliorate the problem, so the AC would have aim of *understanding* how "Replenishment Zones could rejuvenate fish and the other 6000+ species.'

a successful Zone were identified that had not been identified by the CLD, such as the Zone Orientation, Current Speeds and Zone Location / nearness to shore. Not only did the SD identify some new criteria, but it can also help inform the users *why all* the criteria were important.

Step 3) Choice formulation

SD does not explicitly *require* choice formulation, but it does *assist* this step. By informing the users *why all* the criteria were important, by helping them understand more of the system, the users can then be more creative with alternatives. The SD showed which variables are most important, which enable the decision makers to spend more time brainstorming ways to change these factors. For example, to increase Reproduction Rate, they might invest in larvae fish farms. To reduce Fishing Efforts they might restrict all fishing efforts to certain times of the year. To reduce the Bycatch Mortality for 0 and 1 year olds, there may be a way to preserve the recruits that get caught in shrimping nets. Understanding why the Currents through the Zone are important helps the users think of ways to configure the Zone is ensure that the Zones are stocked with larvae and recruits. Highlighting the most important variables and understanding how the variables interact, can stimulate ideas for new alternatives. If the decision makers are better informed, they are more likely to create alternatives that can achieve their objectives.

Since the Red Snapper Replenishment Zone SD model could be run, it could inform the decision makers about the likely outcomes of the alternatives chosen. The SD model showed that if no Zones were created, then the Size Limits and Catch Limits alone may not be enough to save the Red Snapper industry, depending on the Reproduction rate and Fishing Efforts. The naturally occurring high Cryptic Mortality rate would cause the Stock to decline. Doubling the area of the Zone would probably double the annual Harvest fish and double the long term Fishing Income. With SD, the decision makers can formulate the choices that can achieve their objectives by completing sensitivity analysis .

Step 4) Sensitivity Analysis

The SD model could be run, so it could do parametric sensitivity analysis. The values of different variables and the equations that describe linkages could be altered to see how they changed the outcome. The Zoning SD model could be run, so the users could have used it for 'practice runs,' giving them more information. For example, the Reproduction rates, Fishing Efforts, Habitat Holding Capacity, Zone Size, Zone Location, etc. were changed to see how they affected the Red Snapper Stock. Doing parametric sensitivity analysis also showed that the benefits of Zones may not be noticeable after five years, but depend on the actual values of uncertain physical variables and the Zone alternatives chosen. Researchers and the general public may not see replenishment of Stocks in one year; using the SD would help predict when they could see results.

Requirement 2) Decision is made by well-informed group

This is how SDs can help the decision-making process the most, whether the model can be run or not. SD is a tool that both elicits and transfers information. SD elicits information from the users while they build the model, while they try to create equations that quantify how the different variables affect each other. In building the model, the users are collecting detailed information, more detailed than the information gathered using the CLD. Although the SD modeling can be a prolonged process, it helps draw out more information than a set of technical presentations and documents, and it helps prioritize the information. The SDs pictorial summary and the graphs can help transfer what is learned to many decision makers.

Table X-B: Steps and Requirements that the SD achieve

Steps and Requirements	SD
Stakeholders included	a
Problem, Overall Goal and Objective definition	a
Criteria Formulation	X
Choice Formulation	X
Easy sensitivity analysis	~X
Well-informed decision makers	X
Choice	0
Implementation	0

E. INADEQUACIES OF SYSTEMS DYNAMICS: NEXT STEPS FOR DECISION-MAKING

Systems Dynamics can help enable many steps of good decision-making. It helps the users become well-informed about detailed information in the physical and economic aspects of the decision. It helps the decision makers formulate new criteria and new choices, as well as become informed about the possible outcomes of the choices. Simulation models do require substantial effort to create, so it is often wise to pick the most controversial parts of the decision or parts where the most confusion lies. Deciding whether or not to use a Simulation model to illuminate a decision, one should weigh the tradeoffs of i) the time needed to build the model versus ii) what can be obtained from using it.

Simulation models may not be possible to complete for all aspects of a decision, since SDs require very in-depth information about all variables in the model. SDs could not be used to model the entire FKNMS 6000+ species, since not enough of the linkages are known. Often only a small piece of the total decision can be completely modeled and run. If an SD can not be run, it would not help with sensitivity analysis. Still, even *attempting* to build a Simulation model can help elicit information and transfer knowledge, which helps formulate criteria and formulate choices.

It is important to realize that the predicted results of an SD are not known with certainty. If there is much uncertainty in many of the inputs, then it is important to understand how much uncertainty there is in the predicted results. A tool that can perform uncertainty analysis is necessary.

Chapter XI. Use of Uncertainty Analysis to determine Uncertainty in predictions

This chapter discusses the use of Uncertainty Analysis tools applied to just two pieces of the Replenishment Zone decision, the same two pieces that were explored with the Simulation model. Tools that can do Uncertainty Analysis require the users to define probabilistic or statistical distributions for each uncertain variable or linkage, requiring more detail than with Simulation models. The Uncertainty Analysis tool can be used to quantify the uncertainty in the predicted outcomes caused by the uncertainty in the variables, which is necessary if the predicted outcomes are to help inform the decision makers. These tools make available the best possible information about the likelihood of different outcomes.

A. NEED TO DETERMINE UNCERTAINTY IN PREDICTIONS: HOW UNCERTAINTY ANALYSIS TOOLS HELP

Cognitive Maps and Simulation models can elicit a great deal of information and can assist in formulating criteria and choices. Neither of these tools, though, enable the users to do detailed uncertainty analysis. With the Replenishment Zone decision, there are many variables that could not be quantified with certainty. This led to controversy, because not everyone was convinced that i) the Zones would accomplish their intended purpose or ii)what might be gained by creating Zones was greater than what would be foregone. To be well-informed and to reduce the level of controversy, the decision makers needed to understand to what degree the uncertainty in the individual variables affected the uncertainty in the predicted outcomes. For this reason, uncertainty analysis should have been completed.

1. Various tools that can incorporate uncertainty in each variables' definition

The are numerous tools for uncertainty analysis. (See Chapter V) The starting block or foundation for most of these tools is typically the Influence Diagram or Decision Tree. Influence Diagrams and Decision Trees are typically used for decision problems that involve a sequence of *chance events*, decisions, and influences. Decisions and chance events are indicated by nodes; they influence other decisions or chance events and, the influences are indicated by an arrow between the two nodes. When the influence is not known with 100% certainty and there is more than one possible chance event, then the various chance effects are listed and probability values assigned to each branch. This branching from a single node to many nodes causes the tree-like structure. Decision Trees and Influence Diagrams are a chronological record starting at the initial decision or chance events, then listing the flow of all subsequent decisions and chance events, which finally lead to all the possible final outcomes. Each branch can be traced to determine the likelihood of each end node, each possible outcome.

It is also possible to define chance events as statistical distributions, rather than only probabilities, but the calculations required typically demand that the tool be computer based There are various models and software packages that can incorporate statistical distributions as the definition for chance events, which enables the predicted outcome to be defined as a statistical distribution and enables more sophisticated uncertainty analysis. Demos is one such software package specifically designed to do uncertainty analysis; it is a Simulation model that uses the Influence Diagram as its basic building block but allows far more complex definitions of uncertain variables than practical with an Influence Diagram.

2. Define variables as statistical distributions to predict outcomes as distributions

Demos allows the variables and linkages to be defined not only as discrete probabilities, but also as statistical distributions. This allows each variable's uncertainty to be included in the predicted outcome, and allows the predicted outcome to be calculated as a statistical distribution. Defining the variables as statistical distributions also enables sensitivity analyses to determine which uncertain variables contribute most to the outcome's uncertainty.

Modeling with Demos can be somewhat like Cognitive Maps and Simulation models in that its building blocks are nodes and linkages. In fact, Uncertainty Analysis tools can be considered a special family within Simulation models, because like Simulation models, the nodes and linkages are defined as initial values and mathematical equations. With Demos, though, there is no need to use only deterministic means or mid values to represent a variable or linkage. Demos can utilize the entire statistical distribution, more of the information pertaining to the variables' uncertainty. (For a more detailed description of Demos, see Appendix XI -A or refer to Morgan & Henrion, 1990 or Demos User's Reference, 1993)

Although the building block for Demos, an Influence Diagram, can not accommodate feedback because it the values and probabilities of each node are only calculated once, Demos can incorporate feedback because the values can be calculated over multiple time frames. The probabilities for all the variables are calculated in one time period, and the results are then used as input to the next time period. There is no feedback within a time period, but there can be feedback using multiple time periods. Incorporating feedback is necessary when there are interdependent variables and in order to predict long term outcomes.

B. Using Demos for Replenishment Zone and Red Snapper Decision

Demos is applied to the Replenishment Zone decision to see if it can improve the decision, to see if it can help obtain more accurate information for the coastal resources in the FKNMS. The SD tool was not actually built with the AC, CG and NOAA members, but it is created and discussed as if it were being using by these groups.

1. Preparatory steps

For Demos to be most effective at eliciting detailed information and analyzing uncertainty, it is probably best if the first requirement and first three steps of good decision-making are already completed. To use Demos for the Replenishment Zone decision, the entire AC, CG, NOAA and the Technical Advisory Committee might be present, or it may just be a subset of this group. Not all decision makers may want to participate, spending a fair amount of time learning how to use Demos, then spend time building a model. Demos requires that the users define much detailed information, such as each variable's and each linkage's equation, initial value and parameters for any statistical distribution. Since Demos does require such detailed information, ideally all members of the AC, CG, NOAA and Strategy Identification Group who have expertise in some part of the physical, biological, chemical or economic aspects of the system should help to build the Demos model. Ideally, those with expertise in different disciplines could pool their collective knowledge in the Demos model, and then predictions would be made; no *one* person would be asked to make predictions about the entire system.

Often, a Demos model is best completed with the help of a hired facilitator and modeling expert. When building a Demos model, often the exact information needed is not known until the users are *into* the modeling process, so it would have been best to have all the experts present until the model was complete. This would enable information and best guesses to be elicited from the experts as needed. After the Demos model is built, the model and the predicted outcomes could be shared with all the decision makers to ensure that they are well -informed.

Various aspects of the Zoning decision could be modeled using Demos, but for the purpose of this dissertation, it would be most informative to use Demos for the same objective and for the same pieces of the decision that was the focus of the Systems Dynamics model, that is i)determining the future size of a Stock and ii) predicting fishing income from that Stock. In this way, one can compare the information provided by the Simulation model with the information from the Uncertainty Analysis tool. Demos will be used to inform how the Replenishment Zones 'Provide food and habitat,' 'Provide Biodiversity' and 'Prevent extinction for the Red Snapper.' It will also be used to inform how the Replenishment Zones affect the 'Long term and short term income for Red Snapper fishermen.'

It may have been possible to use Demos to model a few more parts of the Replenishment Zone decision than the Simulation model, since Demos can consider uncertainty, but *not* every aspect of a decision can be modeled with Demos. To model a system with Demos, the users must know what variables affect the system and know the parameters of uncertainty for each variable. Demos can be used with probabilistic and statistical uncertainty, but not complete uncertainty. (See Chapter II) For example, in the Zoning decision, all 6000+ species could not be modeled with Demos, because it would involve too much uncertainty; every variable that affects all 6000+ species is not known, and it is not possible to define the parameters of uncertainty for every known variable.

To build the Uncertainty Analysis model, it is best to have many of the criteria already formulated. It is recommended that most relevant variables and linkages be identified before beginning to model with an Uncertainty Analysis tool, either by building a Cognitive Map, a Decision Tree, or for complex systems, the users may want to build a structured Simulation model. Building the Simulation model will ensure that all relevant variables can be quantified, although the structure of a Demos model may differ from the structure of the Simulation model. Identifying all relevant variables and using one of these tools before beginning the Demos building process, ensures that the structure and linkages of the model are correct so that the users can then focus on accurately defining the uncertain variables with the Demos model.

2. Creating the structure

To begin building the Demos structure, the variables identified in Chapter IX's Cognitive Map and Chapter X's Simulation model can be used as the base for the Demos model. Although the one species, Red Snapper was used for the Systems Dynamic model and will be used in the Demos model, there are differences in the structure of the two models caused by differences in the software. This is why it is helpful to refer to more than the Simulation model alone.

The first step in changing the pictorial summaries of variables and linkages into a Demos model is to define each variable's type, that is either: a 'decision' node, a 'chance' node or 'the objective' node. Defining variables as either decision nodes or chance nodes helps the users discern what inputs they have control over. For example, having to define the variables' type in the Demos Zoning model made it explicit that Zone Size and Zone Orientation were *decision* variables, while Cryptic Mortality rates and Natural Mortality rates were *chance* variables. Even though the two Mortality rates have a strong effect on whether the Stocks crash, the decision makers do not have any control over these two variables, except indirectly by influencing other variables that influence them, such as Health of Habitat. For the base Zoning Demos model, the objective was first defined as 'increasing The N3 Stock' to see if the Replenishment Zones affected the Stock of adult fish, then increasing 'The Harvest.'

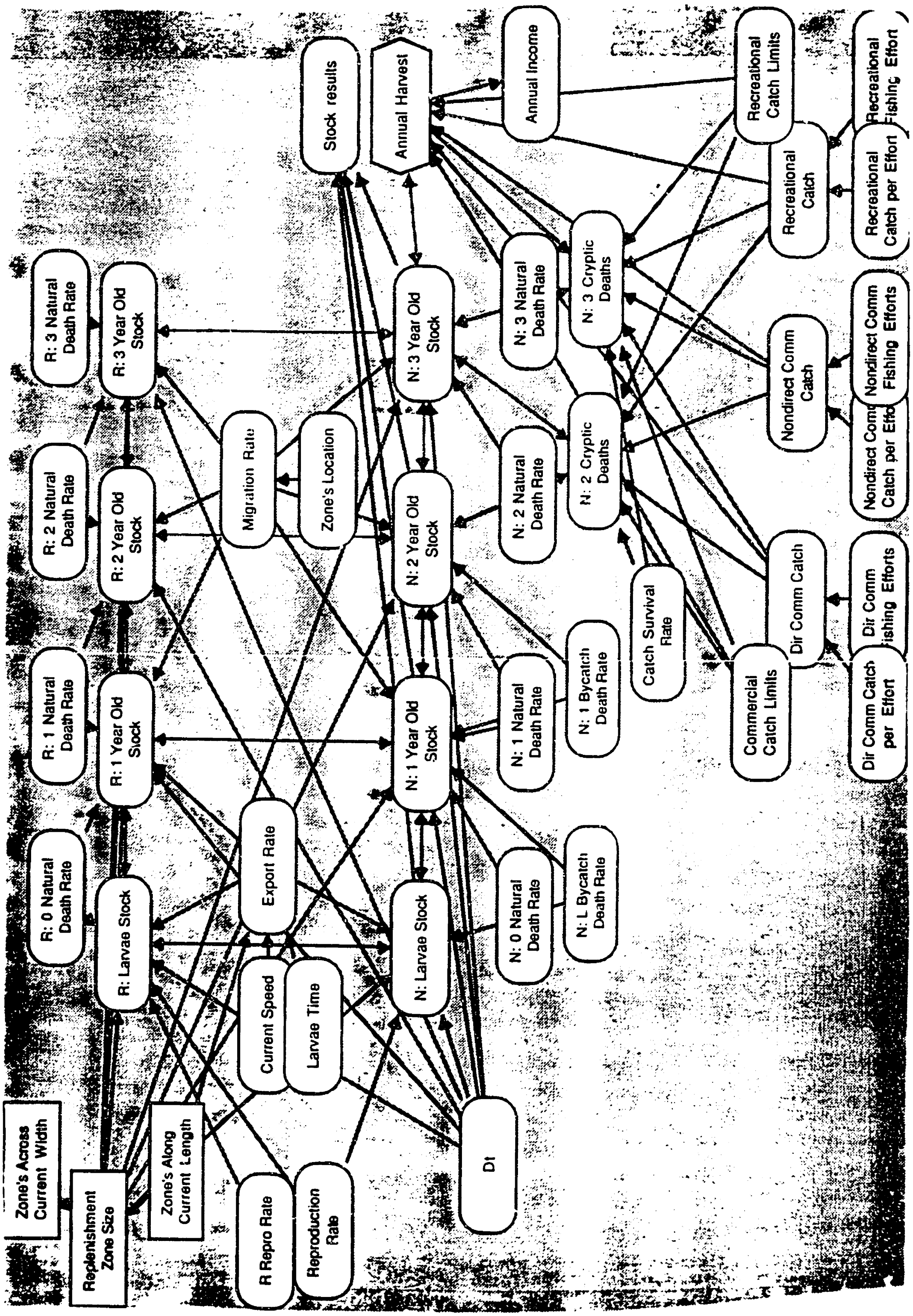
In building the Demos model for Zoning, it became apparent that the structure had to accommodate feedback to measure changes over time, since many of the variables were inter-related cyclically. For example, the Stock of larvae affects the Stock of 1 year olds, then 2 year olds, then 3&up year olds, which in turn affects the Stock of larvae via reproduction. Not only were there many cyclical interdependencies, but the results also needed to be determined over time, as they changed from year 1 and projected into the future. To enable the feedback and cyclical dependencies, the Zoning model needed to use Demos' 'Dynamic' function and structure.[100] (See Figure XI - A for the Demos Model.)

3. Defining the equations

The next step is to specify the expressions and initial values that represent the linkages and variables. Since Red Snappers were used for the Systems Dynamic model as well as the Demos model, the same sources of information could be used for most variables: the Goodyear paper, Zoning articles and personal communications.

[100] Note that although it is possible to have cyclical dependencies and variables that change value over time by using the Dynamic Function, modeling the system becomes somewhat complicated with Demos. There were times that the structure became so complicated that it was necessary to refer to the Systems Dynamic model, where cyclically and changes over time are easy to model.

Figure XI - A: Red Snapper Demos model for Zoning



a. Defining variables and linkages with statistical distributions

Creating a model to help understand if Replenishment Zones could 'Protect the home and food,' 'Protect Biodiversity' and 'Prevent Extinction' for just the Red Snapper was complex containing many uncertain variables. Although the sources of information used to define equations for the Demos model were the same as those used for the Systems Dynamics model, there were differences between the SD and Demos equations for two reasons. First, because Demos allowed equations to be defined as probabilistic and statistical distributions, and second the software and subsequent structure of the two models were different. (See Appendix X - A for the source of the equations and see Appendix XI - B for the actual Demos equations.)

There are many variables that influence the benefits of Replenishment Zones which are unpredictable and uncertain, such as the weather that influences currents and larvae movement. There are also variables where the uncertainty is due to research that has not been 100% conclusive, such as Natural Mortality or the Initial Stock values. There are also variables where there is uncertainty because the reporting has not been 100% accurate, such as the various Fishing Efforts. All these variables are best described with statistical distributions. For example, instead of defining the Natural Mortality rate for fish over two years old as a deterministic number equal to 0.2, it is more accurate to define it as a normal distribution with a mean of 0.2. With Demos, it was easy to incorporate probabilistic uncertainty (risk), and different kinds of statistical uncertainty.

Because the variables or linkages can include uncertainty, more detailed information must be extracted from the experts. For example, in trying to define the currents in the FKNMS, Mr. Benjamin Haskell, a NOAA SRD employee, was not able to give a deterministic number, but he was able to discuss his best understanding of the probable average, high and low Current Speed using the research presently being conducted. He was able to provide a reasonable estimate for the average speed of currents through FKNMS, even though the research was not finished and conclusions had not been published. This discussion provided information with which to estimate the distribution parameters.

Some of the statistical distributions used in the Demos model were defined after consulting with experts, and some were defined by summarizing empirical data in the Goodyear paper. The parameters of the distribution are often best estimates based on the available information. (See Appendix X - B for a more in-depth discussion of how the variables were defined.)

b. Redefining some variables after reviewing preliminary results

At first, the Demos model was built by using only the CLD and the pictorial summary of the Systems Dynamics model. It was found, though, that a great deal could be learned and applied to Demos by reviewing more of the SD model. After running the first draft of the Demos model, it became obvious that there were mistakes in the equations, since unrealistic results were being calculated. The Demos model was then compared to the SD model to see what could be learned.

First, Demos' 'mid-value' deterministic result was compared to the deterministic results found with the SD model. The two sets of results should have been the same, but they were not. (See Appendix XI - D) Comparing the Demos model with the SD model, it became clear that the Demos representations of Harvest, Cryptic Death and Natural Death were wrong. For example, Natural Deaths were represented as a percentage of Total Stock, instead of representing them as a percentage of the (Total Stock) - (Harvest) - (Cryptic Deaths). If Natural Death equaled a percentage of Total Stock, it might result in a situation where:

Total N3 Stock < (N3 Harvest + N3 Cryptic Deaths + N3 Natural Deaths)

It is obvious that the whole Stock, being less than the sum of its parts, would be wrong. Because some of the variables were defined incorrectly, the model calculated impossible Stocks. With Demos, there are many ways to write an equation that would logically seem to represent the variables and their interactions accurately. Unfortunately, there is only a smaller subset of these that would accurately represent the real life system; it is easy to model the system in a way that seems logically correct, but produces incorrect results. The user must understand the Demos software and understand the *order* in which variables' values are calculated, so that the system can be accurately modeled.

To generate a possible distribution for the overall outcome, Demos uses a sampling method called the Latin Hypercube method. This sampling method generates random values from each uncertain variable's distribution. With Demos, the software generates many random values *in each time frame*; typically 100 random numbers for each variable per time frame.[101]

[101] Uncertainty Analysis tools such as Demos differ from Simulation model that can not do uncertainty analysis, because the Demos software generates *many random values in each time period* Other

Demos then uses the mathematical expressions that were specified for the different variables to calculate a possible distribution of each variable's outcome, and calculates the variables in the order specified by the Influence Diagram. Each variable's value is determined in the order that the underlying Influence Diagram specifies. This is why in Demos, the order in which the variables are calculated makes a difference in accurately defining the equations.

With the Red Snapper model, the equations written for the following variables were logically correct when just the variable and its linkages are considered, but they were incorrect due to the order in which Demos calculates the value of variables :

i) Harvest

ii) N3 Cryptic Deaths

iii) N3 Natural Deaths.

When these mistakes were found, it was helpful to go back to the Systems Dynamics model and dissect each equation and each linkage to determine how each number was being calculated. Using Systems Dynamics as a complement to Demos provided a better understanding of the physical system, so that it could be modeled correctly.

With Demos, it was necessary to not only have an excellent understanding of the physical system, how it changes over time, and how the variables interact, but it was also necessary to have a clear understanding of how the Demos program executes the calculations and in what order, especially for Dynamic functions. Demos does not impose a fixed structure on the model, therefore it is easy to make mistakes, formulating equations which are physically impossible. This is in to more Structured Simulation models such as SD, which requires knowledge of the physical system, but also assists the users in developing a better understanding of the actual physical system than less structured models. The more rigid SD structure requires more knowledge concerning how to use the tool in the beginning, but makes it less likely that the user will model the system in an incorrect way. [102] This is one reason it is often beneficial to use a combination of tools.

The incorrect equations for the Demos model were changed, and the mid-value results were then checked against the SD results. Despite the fact that the two models did not have identical variables, structure or equations, the results were nearly identical. The slight difference, less than 1% difference, was due to the different order in which the two models calculated the dynamic function, i.e., values that changed over time. (See Appendix XI - D)

C. RESULTS OF DEMOS TOOL

This section discusses what was accomplished when Demos was used for this dissertation and projects what it could have accomplished if it had been used during the actual FKNMS process. This section discusses specific outputs of the Demos tool, and discusses how they results could be used in the Zoning decision. Demos' greatest contribution is that it can add to the body of detailed information elicited and transferred, and help the users understand the level of uncertainty in the predicted outcomes.

1. Elicits information about the statistical distribution of variables

There are many variables that include uncertainty in the Replenishment Zone decision. Building the SD model helps the users realize where there is uncertainty and elicits the level of uncertainty in different variables. The most obvious uncertainty was in the different variables that make up the Red Snapper's life cycle. For example, there is great uncertainty in the Reproduction rate. Not only is it difficult to estimate the mean, but it is more difficult to estimate the standard deviation. When using the SD tool, Mr. Michael **Murphy** from the Florida Marine Research Institute recommended the best way to calculate a *mean* from the available data, but did not suggest a way to estimate the standard deviation. To be conservative, it was assumed that there was a great deal of uncertainty in the mean values,

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Simulation models may use the Latin Hypercube method, but they only generate *one value in each time period.* With these other Simulation models, such as Systems Dynamics, a variable *can be defined as a statistical distribution,* but *the predicted outcome* can *not* be determined as a statistical distribution that changes over time; there is only one value generated for each variable in each time period which allows only one value for the predicted outcome to be calculated in each time period. The model can not calculate a distribution of values in each time period.

[102] It is recommended that one should complete a Simulation model first using a fixed, rigid structure such as SD, before creating a model that focuses on uncertainty analysis, such as Demos. The fixed structure of the Simulation model, SD, allows the user to focus on organizing a great amount of information without having to focus on how the software works. It is recommended that the first model, a Simulation model, be user friendly so that the user's task is more focused on the content and physical information rather than on the tool. Once the user has all the equations defined, a tool to quantify the uncertainty can then be used.

so large standard deviations were assumed. Also, various estimates of the Reproduction rate were used with Demos to do parametric sensitivity analysis.

Another example of an uncertain variable was the Catch Survival Rate. The Goodyear article sited different numbers for Catch Survival rates based on research from different scientists. Instead of just using the one deterministic value that Goodyear used in his paper's analysis, the estimates from the different researchers could be included in the Demos model. The various estimates from the different researchers could be used to calculate a mean and a standard deviation. In this way, Demos incorporates more of the information that is known.

The uncertainty in the Natural Mortality estimate was also explored by using Demos. Trying to estimate a detailed distribution for the Natural Mortality of each age group, both inside and outside the Zone, it became apparent that the mean and distribution of each age groups' Natural Mortality inside the Zone might differ from the values used for outside the Zone. In the Goodyear paper. the researchers' estimates represented the Natural Mortality of fish not in a Replenishment Zone; the Natural Mortality might be lower inside the Zone if there was a healthier habitat. Number of predators, Food availability, Health of Habitat, etc. would determine this. None of the Zoning articles discussed the possible change in Natural Mortality, though. In this way, building the Demos model requires better information. If fish biologists and researchers were present to create the model, they might know more information and make better estimates for these variables, therefore Demos would have elicited better information.

Using Demos makes it apparent that even though the Fishing Effort and Catch per Unit Effort are anthropogenic, there is great uncertainty in these variables. In attempting to define the parameters of the distribution, one must explore the raw data, because it is only the mean values, but not the standard distributions that are discussed in the Goodyear article. Exploring the data shows that the *past reported* data is probably only *a fraction* of the actual Fishing Effort and Catch, since it was not required that total landings be reported until after 1990. Goodyear estimates that the actual Directed Fishing Efforts are actually much higher than the reported data, so there is great uncertainty in using the past reported data to estimate the total *future* Fishing Effort and Catch per Unit Effort. Not only are there changes from year to year, but the inadequate reporting also makes it difficult to use trends to predict for future years.

Using the Demos and attempting to define the equations for the variables shows that there is even uncertainty in the Catch Limits and Size Limits. Although the Catch Limits and Size Limits are specified by the Fisheries Management Councils, there is uncertainty as to whether the Size Limits and Catch Limits are followed. First, it is not known with certainty that all fishermen are abiding by the Catch Limits or Size Limits. Some fish from the Stock of 2 year-olds may be harvested, although the Goodyear article assumed that it was only the Stock of 3& up year old fish that were harvested. Recreational and / or Commercial fishermen may also catch more than the 2 million pound of fish that has been set as the limit for each group. Second, although Catch Limits set a fixed number for the *pounds* of fish harvested, there is uncertainty in the number of pounds per average fish, so there is uncertainty in the *number* of fish harvested.

Using the Demos tool makes the level of uncertainty apparent for many variables and enables the system to be modeled accordingly. Demos makes it apparent that about the only thing that managers can determine with certainty is the Zone Size, the Zone Location and perhaps the Along Current Length *if* the current is steady. Defining the equations and building the structure makes it apparent that the decision makers do not know most variables with certainty and can not directly affect most variables; most variables can only be influenced indirectly if at all. Demos requires the users to define the level of uncertainty in the variables; this helps elicit more detailed information and helps the users understand what research needs to be completed so that the outcome can be predicted with more certainty.

2. Informs about statistical distribution of possible outcomes

One of the most important things Demos provides is information about the statistical distribution of the predicted outcomes. It is inaccurate to predict that any outcome will occur with 100% certainty, since there is not 100% certainty in the inputs. Demos helps aggregate the uncertainty from all the inputs at the same time, so that each uncertain variable does not have to be explored independently, one at a time. Demos quantifies the total uncertainty in the predicted outcome, so that the stakeholders can become better informed about the probable outcomes of their decisions.

With the Systems Dynamics model built for the Red Snapper Zoning problem, the outcome was predicted as a binary answer: the Stocks either definitely crashed or definitely did not crash. With Demos, the users can see the statistical distribution that Stocks might crash under various scenarios. Demos can display the results as graphs with curves representing the 5%, 25%, 50%, 75%, and 95% probabilities. (See Appendix XI - D for more details of the Demos model.)

a. No Replenishment Zones: Deterministic valuation of Stock sizes

The first scenario modeled with Demos was the base case, where all the variables in the Demos model matched those in the Systems Dynamics base case so the results from the two models could be compared. The base case scenario was:

Initial Stocks 'Not in Zone' = N0 Stock = Stock of 0 year-olds not in Zone = 29,000,000

N1 Stock = Stock of 1 year-olds not in Zone = 14,000,000

N2 Stock = Stock of 2 year-olds not in Zone = 3,500,000

N3 Stock = Stock of 3& up year olds not in Zone = 5,700,000

Initial Stocks in Replenishment Zone = 0 (An easy way to model 'no Zones')

Commercial Direct Fishing Effort = average of 1990, 1991 and 1992 = 23,400 Days

Commercial Non Direct Fishing effort = the low estimates of 1990 = 6,000 days

Recreational Fishing Effort = the low estimate of 1,500,000 hours

Catch Limit in 1984 = Infinity, since there was no Catch limit in 1984

Reproduction rate = Low 1984 rate = 5

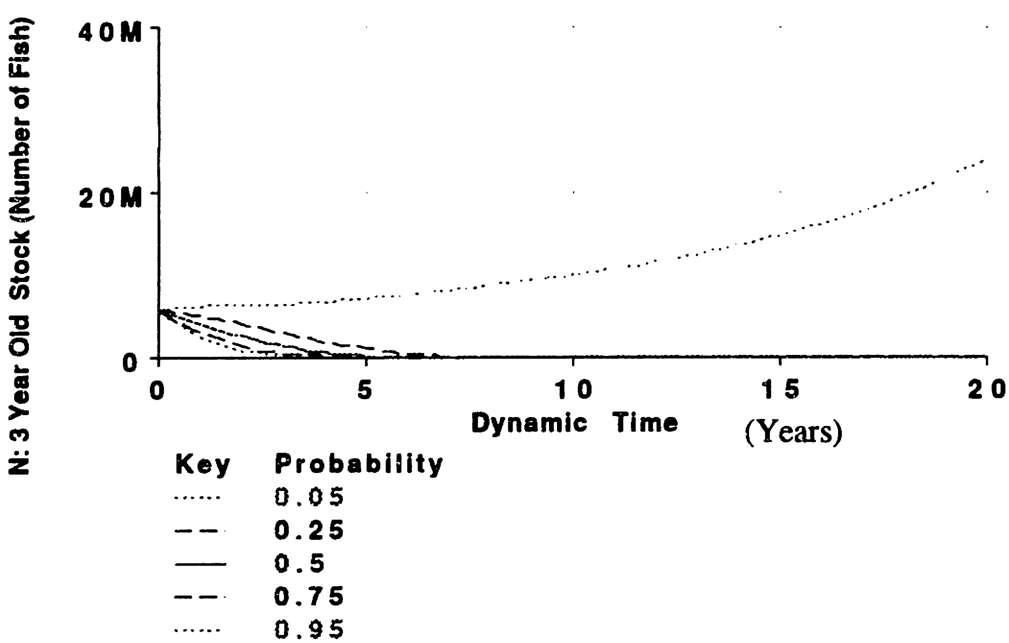
(The variables' values come from Goodyear, 1992)

As discussed earlier, the Demos model was run just using the *Mid-values Function*, where the deterministic mid-values of the variables are used to calculate a deterministic value of the predicted outcomes. After the initial run, and the Demos model was corrected, the results of the Demos model were nearly identical to the results from the Systems Dynamics model, showing year to year the same values for the Stock of each age group until each Stock crashed. The *Reproduction Rate was changed to 16.5* and Demos' Mid-value Function again showed that the Stocks will crash. With small Reproduction Rates and deterministic calculations, both the Demos and SD models predict the Stocks will crash. Listing the results in tables, one could see that the two models calculate nearly identical results.

b. No Replenishment Zones: Uncertainty Analysis of Stock sizes

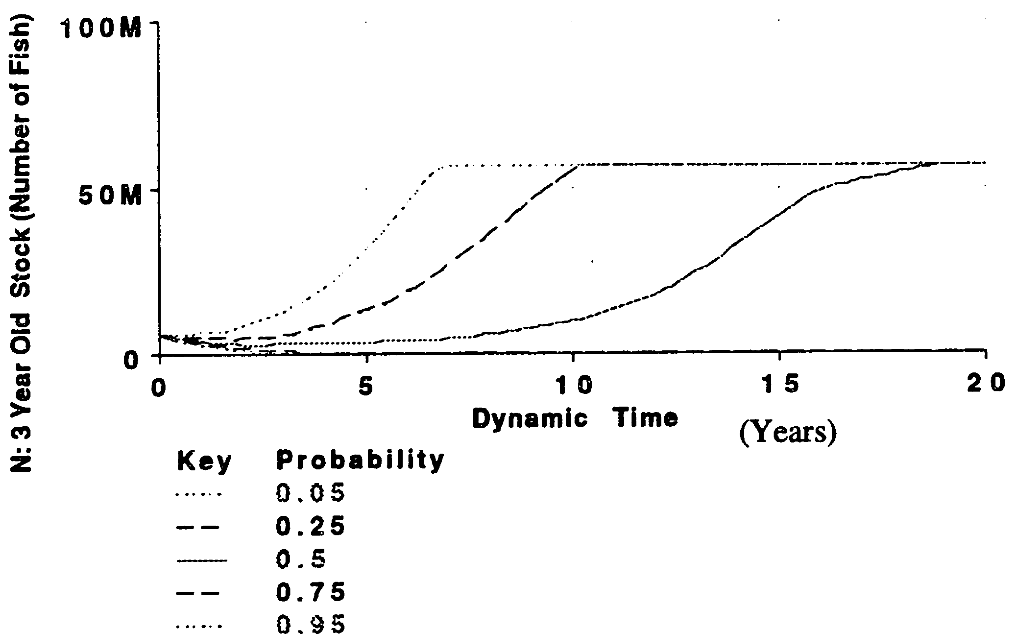
Using Demos' *Probability Distribution* function instead of the deterministic mid-value function, a Dt = 0.2, and *a Reproduction rate = 5*, Demos' uncertainty analysis calculated that there is *more than a 75%* chance that the Stock of 3& up year-olds would crash by the end of Year 10. Likewise, there is a 75% chance that the Stock of 2 year-olds would crash by Year 13. Demos shows that even with the uncertainty in the variables, one can be quite sure that the Stocks will crash if the Reproduction Rate is as low as 5 larvae per adult fish (~10 larvae per adult female fish) and there is no Catch Limits or Zones.

Figure XI-B: Probability Distribution for Stock of 3 year-olds, base case



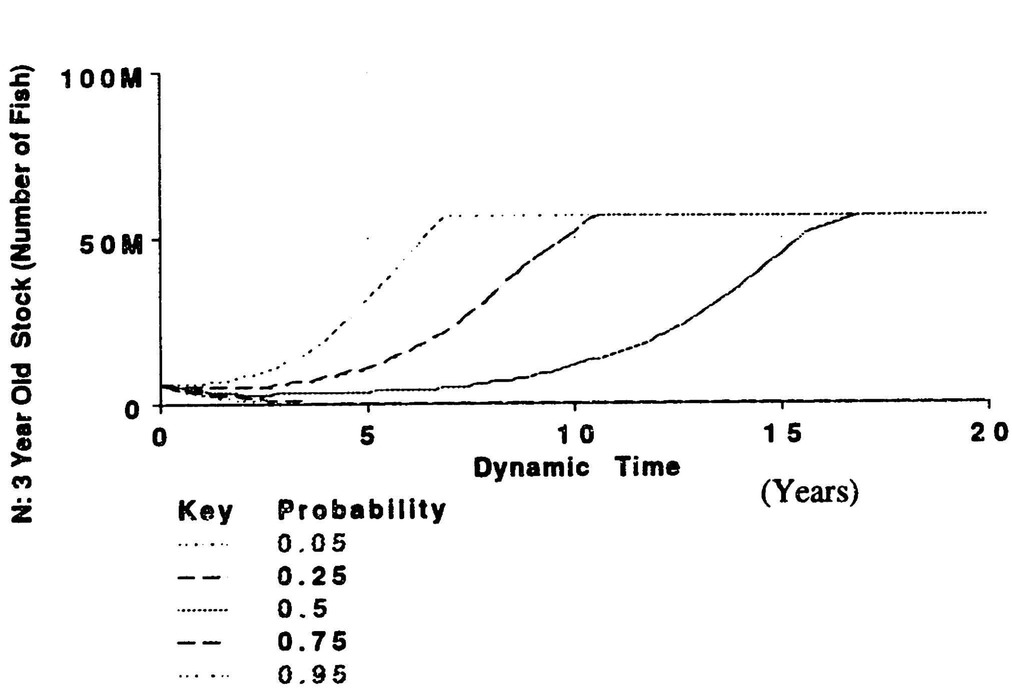
Changing the Reproduction Rate to 16.5, the probability that *the Stocks crash* is somewhere between *50% and 75%*. ˇ ₁ the *Reproduction Rate* is increased to *23* with a standard deviation of 7, finally there is slightly more than a *50% probability* that the *Stocks will not crash*.

Figure XI-C: Probability Distribution of N3 Stock, base case with Reproduction rate=23



Returning to the Reproduction Rate = 22, when the Stocks crashed with more than a 50% probability, the Catch Limits will be installed to see if they change the probability distribution. Installing the Commercial Catch Limits in 1990, and the Recreational Catch Limits in 1992, the model was run to see if the Stocks survive with Reproduction rate = 22.

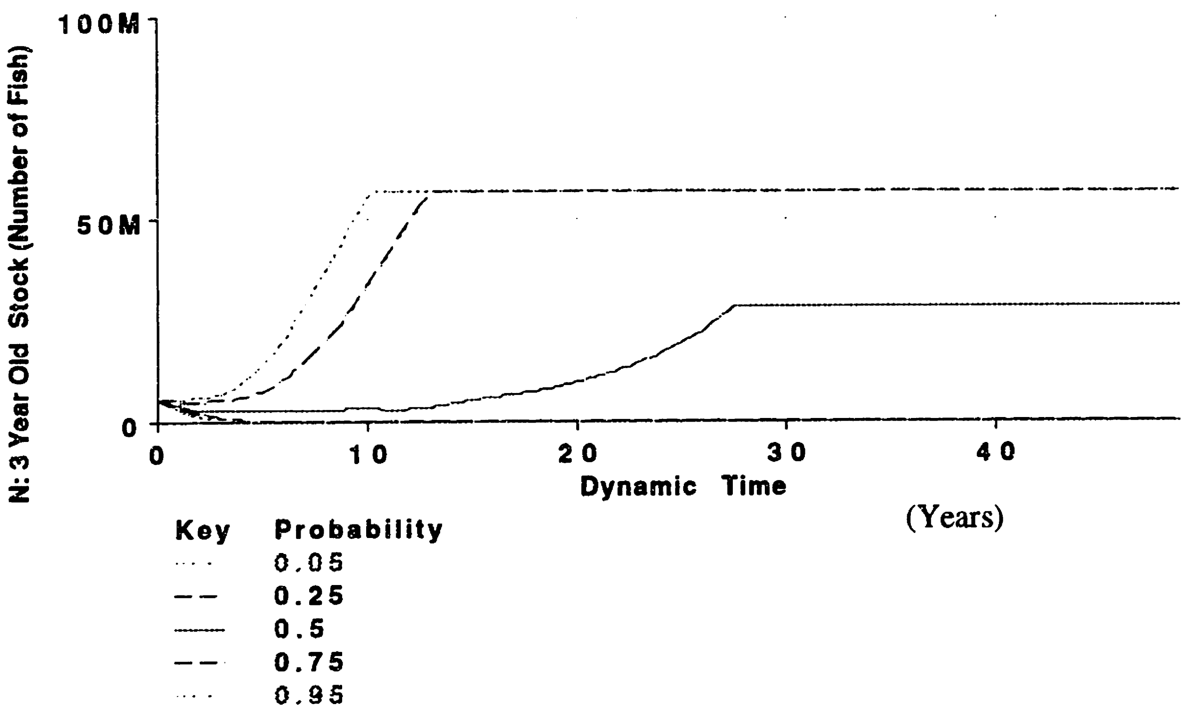
Figure XI-D: Probability Distribution of N3 Stock, Catch Limits installed and Reproduction rate=22



With the Catch Limits installed in 1990 and 1992, there is less than a 50% probability that the Stocks will crash with the Reproduction Rate = 22. The Catch Limits do help if the Reproduction rate is at least 22 larvae per fish, but the Reproduction Rate may actually be lower, or decreases due to worsening Health of Habitat, disease, etc. Running the Demos model shows that if the Reproduction rate=18 or less, then the Stocks will crash with more than a 50% probability.

It is possible to perform sensitivity analyses changing the mean of the Fishing Efforts to see if the probability of the Stock crashing would shift. If the *Non-directed Commercial Fishing Efforts* were higher, not equal to just the low 1990 reported value = 6,000 days per year, or the average 1990-1992 *reported* value = 13,000, days but also included an estimate of the *non-reported* Efforts = 52,000 day, then the probability of the Stocks crashing shifts a great deal. The Reproduction rate would have to be as high as 25 for there to be less than a 50% chance that the Stocks would crash. If either the Non-directed Commercial Fishing Efforts or the Recreational Fishing Efforts increased over time or were higher than the low 1990 reported data, then the Stocks would be more likely to crash.

Figure XI-E: **Probability Distribution of N3 Stock, Catch Limits and higher Non-Directed Commercial Fishing Efforts with Reproduction rate=25**



c. Creating a Replenishment Zone: Uncertainty Analysis of Stock sizes

Demos shows that creating a *Replenishment Zone may not substantially* change the Stock of Non-Replenishment Zone fish, depending on the size of the Zone. Using:

Reproduction Rate outside the Zone = 24

Reproduction Rate inside the Zone = 24

Recreational Catch Limits installed in 1990 =~ 1,000,000 fish

Commercial Catch Limits installed in 1990 =~ 1,000,000 fish

Non-Directed Fishing Effort at its estimated 1990-1992 average = 52,000

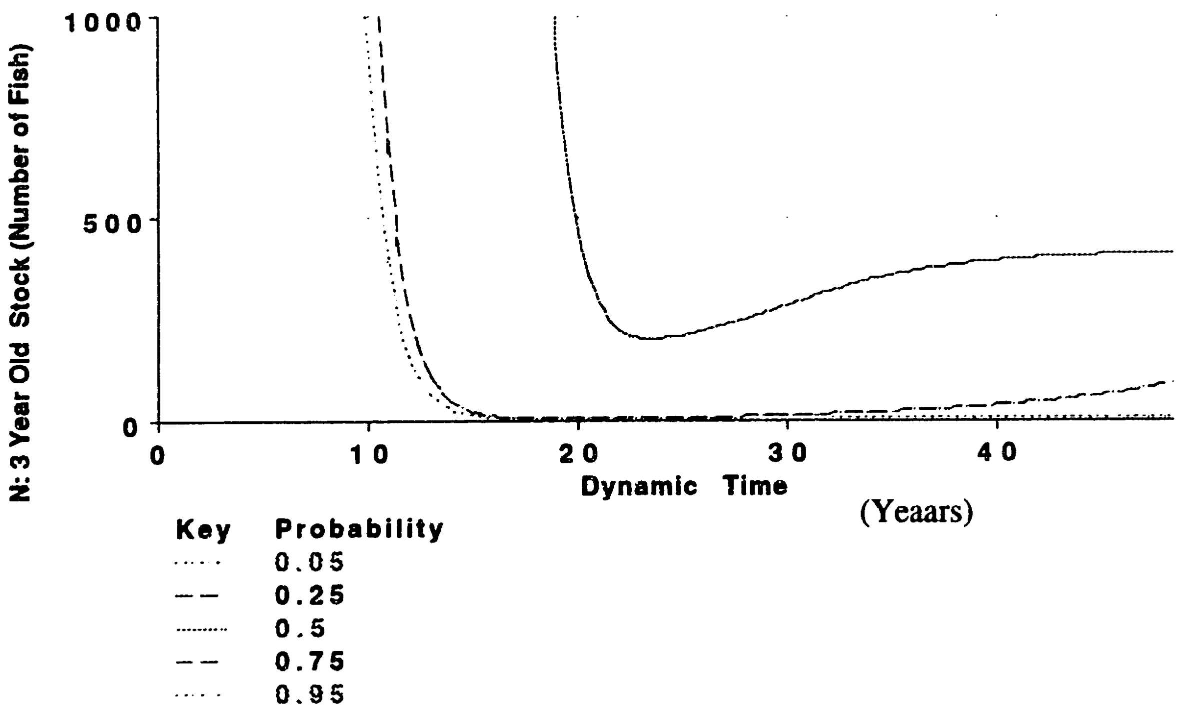
and creating the Zone so that:

Along Current Length = 12.25 miles

Across Current Width = 12.25 miles, for a total area = 150 sq. miles

If the Zone is created and the above conditions exist, the *fish Stock still crash with more than 50% probability, but then a very small comeback after the Zone is created* The comeback is so small it needs to be viewed on a different scale.

Figure XI-F: Probability Distribution of N3 Stock when Replenishment Zones are installed as well as Catch Limits, high Non-Directed Commercial Fishing Efforts = 52,000 hours and Reproduction rate=24



The Zone does help the Stock come back, but on a very small scale with the parameters above. It is more than 50% probability that the Stocks will decrease to less than 200 fish around Year 20, then start to increase in number. By Year 50, there is more than a 50% probability that the N3 Stock will reach about 500 fish.

Looking at the Stocks *inside* the Zone, the increase in fish will be noticeable sooner. With a 50% probability, one would be able to see the Zoned Stocks come back in one or two years. To ensure that the Stocks come back with more than a 75% probability, the graph shows that it may take 15 + years.

Doing sensitivity analysis on the different Reproduction rates, one can see that even if the rates decrease, Zones will replenish the Stocks with more than a 75% probability. The lower the Reproduction rate, though, the longer it takes for the results to be seen inside the Zone, and even longer for the results to be noticeable outside the Zones. Conversely, higher Reproduction rates enable the Stock levels to increase sooner.

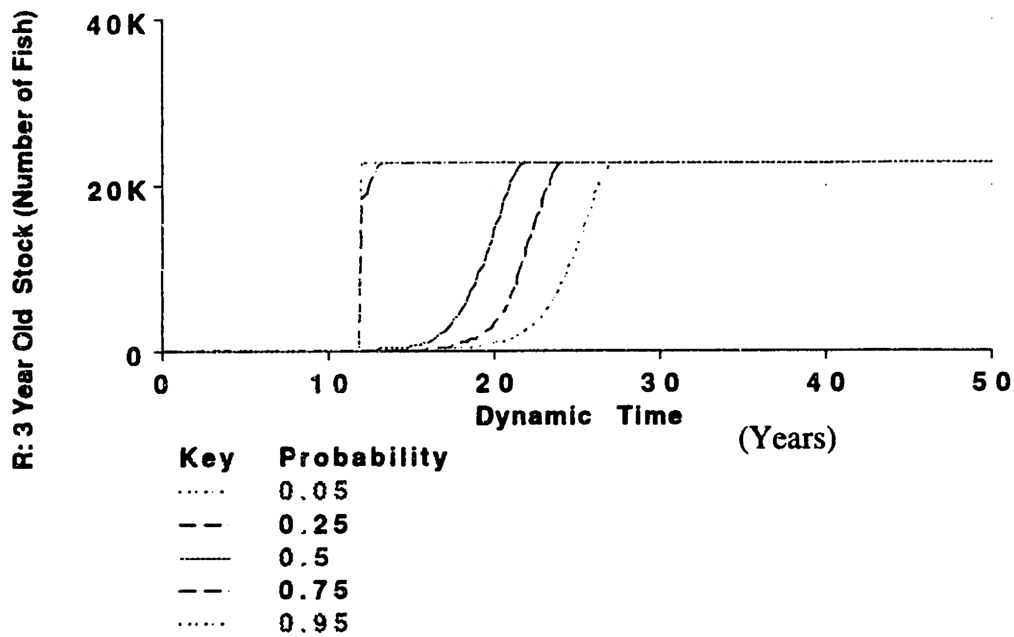
If the *Reproduction rate inside the Zone* increases and is greater than the Reproduction Rate outside the Zone as scientists predict, the Stocks would be increased in less time and the probability that the Stocks are replenished increases. For example, if the Reproduction rate outside the Zone = 24, and inside the Zone = 48, there is *more than a 95%* probability that the Stocks will increase. The R3 Stock would reach its maximum level after 30 years. With a 50% probability, the results would be seen within the first year. If the Reproduction Rate outside the Zone = 24, and the Reproduction rate inside the Zone = 240, then the results would be seen even earlier. Again with a 50% probability, the results would be seen within the first year, but with a 95% probability the R3 Stock would reach its maximum level after about 18 years.

Another variable that is important is the Habitat's Holding Capacity, an upper limit on the Stock of fish that can survive within the Zone which depends on the food stock, the predators and the Health of Habitat. If the Habitat's Holding Capacity were higher, it they were actually 50 times larger than Goodyear's 1984 Stock estimates instead of 10 times larger, then the maximum number of fish inside and outside the Zone would increase. The maximum limits would be five times larger, reflecting the change from 10 to 50.

d. Changing the characteristics of the Replenishment Zone: Uncertainty Analysis of Stock sizes

Doing sensitivity analysis with the Zone Orientation, Demos shows that if Replenishment Zones were configured 50 miles by 3 miles instead of 12.5 miles by 12.5 miles, then the Stock of fish inside and outside the Zone would be replenished somewhat earlier. If the Zone was configured 150 miles by 1 miles, then the increase in Stocks would occur much earlier. The following chart shows the Stock of 3 & up year old fish inside the Zone, when the Zone is 150 miles by 1 mile.

Figure XI-G: Probability Distribution of R3 Stock when Zone is 150 miles by 1 mile, Reproduction rate inside Zone=48 and outside Zone = 24



If the Along Current Length is very large, it is less likely that the larvae would be carried out of the Zone, so the Stocks are more likely to be replenished inside the Zone sooner, which also leads to replenishment outside the Zone sooner. The probability that the Annual Harvest would increase to more than 95% with the re-oriented Zone. The results would also be noticeable sooner.

The analysis shows that if the Zones are created, it would be important to get better estimates of the Current's Speed through the Zone. Re-orienting the Zone may or may not help, depending on the speed of the Currents through the Zone, the Along Current Length of the Zone, the time that Larvae spend in their pelagic stage drifting in the Currents, and whether or not the spawning area is within the Zone. Doing this sensitivity analysis indicated that in this model, the estimated Currents through the Zone are very fast, carrying most of the larvae out the Zone, unless the Zone is re-oriented so that the Along Current Speed is larger than the (Along Current Length / Time Larvae spend in Pelagic Stage). If the Along Current Length is less than this, then the only larvae that do not get carried out of the Zone with the Currents, are those caught in the benthic plant growth or those that float in from outside the borders; these are represented by the estimated 5% safety factor.

If the more fish moved out of the Zone rather than die as the Zone's Habitat Holding Capacity was reached, then the Migration Rate might start small, but increase over time. This would result in the fish being replenished early, as they were before, but the final upper limit on the *Annual Harvest would be higher,* increased by about the same percentage as the increase in Migration Rate. A difference in Zone Location might also change the Migration Rate. If the Zone were located, so that the reef and shore area were not within the same Zone, the Migration Rate would increase during spawning season. This would mean that more fish were caught when they moved outside the Zone, and it would *take longer for the Stocks to replenish.* In the long run, the higher Migration Rate would increase the Annual Harvest, though, and there would be a few more fish harvested in the early years.

If the Zone Total Size increased, then the number of fish inside and outside the Zone would increase. Running the Demos model, one sees that if the Zone were *three times as large,* the number of three year old fish that the Zone could produce and then 'export' across the Zone boundaries would be three times larger. Tripling the total area triples the number of fish inside the Zone and then triples the number of fish that migrate and enter the Stock of fish outside the Zone.

If the Zones were three times as large, the N3 stocks increase.

Along Current Length = 150

Across Current Width = 3, and

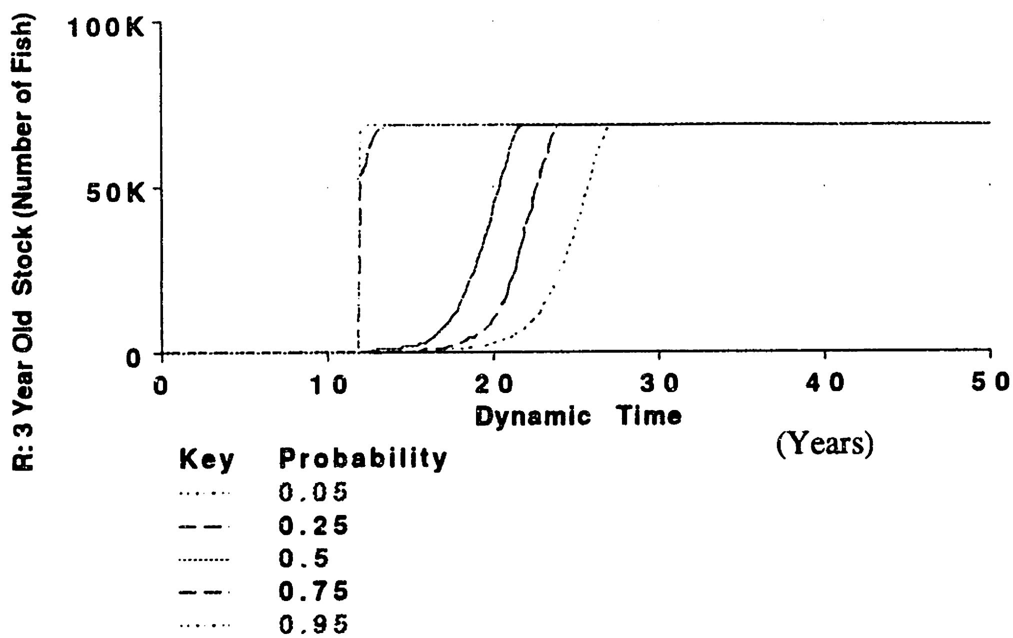
Total area is larger = 450

Migration rate = 5%

Reproduction Rate = 24 outside the Zone

Reproduction Rate = 48 inside the Zone:

Figure XI-H: Probability Distribution of R3 Stock when Zone is 150 miles by 3 miles, Reproduction rate inside Zone=48 and outside Zone = 24



The larger Zones do help. By making the total Zoned Habitat three times as large, the total holding capacity increased by a factor of 3, from 22.8K to 68.4K. This would increase the Annual Harvest by about 5% of this 68K, by more than 3K.

If 5% of the total Gulf of Mexico fishing area was designated as a Replenishment Zone instead of just 5% of the FKNM S Sanctuary, the Stocks would increase even further. Changing the total Replenishment Zone Size = 18,750 square miles, then the Annual Harvest for the total Gulf would be at least 150K with more than 95% probability. If the Migration rate increased or the Habitat's Holding Capacity were larger, this number would be higher, exceeding the total Catch Limits.

Conducting the sensitivity analysis also shows that the Zone Size is not the only limiting factor for the replenishment ability of the Zone. Changing the characteristics of the Zones helps the users to understand what variables are important and which most affect the uncertainty of the outcomes. The Demos model makes it obvious which factors contribute most to the uncertainty in the results and where the focus of future research should be if Replenishment Zones are created.

e. Changing the characteristics of the Replenishment Zone: Uncertainty Analysis of Fishing Income

Demos can be used to inform and predict results for more than just one objective. Not only is it important to understand how the Zones affect the probability of Red Snapper extinction and Biodiversity, but it is also important to understand how the Zones affect other objectives such as the short term and long term Fishing Income. It is important to know if the Zones can increase future income enough to offset foregone income in the short term?

The Red Snapper Demos model could be altered slightly to inform the users about the different objective: "Maximize Long term fishing income." For Demos to predict future Red Snapper Fishing Income, in both the short term and long term, a new variable was added, 'Annual Income.' Using:

Along Current Length = 150

Across Current Width = 1,

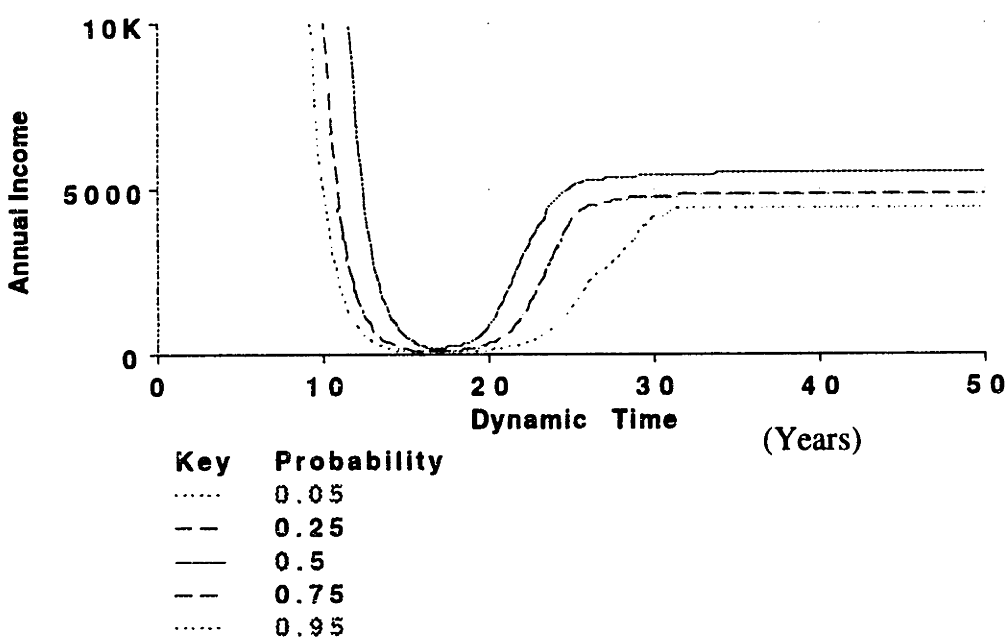
Reproduction Rate = 24 outside the Zone

Reproduction Rate = 48 inside the Zone

Migration Rate = 5%

Income = # fish * Price per pound * 2 pounds per fish

Figure XI-I: Probability Distribution of Income when Zone is 150 miles by 1 mile, Reproduction rate inside Zone=48 and outside Zone = 24



The Annual Harvest and Annual Income would decrease at first, then increase as the Stocks began to replenish due to the Zones. With the Zone configured as stated above, the Annual Harvest would be only 1,250 fish and the Income would be more than $5.000. If the Habitat's Holding Capacity were 5 times larger, the Income would be five times larger. If the total Zone Size increased by a factor of three, the income would increase by a factor of three. If the Migration rate increases by a factor of 6, the Income would increase by a factor of 6. (This would match the Systems Dynamics results of $30,000 when the Migration increases from 5% to 30%.) The timing of these increases would vary.

Focusing on other objectives in the Demos model helps the users focus on the importance of the different variables for different users. The users see which variables' uncertainty are critical to Fishing Income and what uncertainty is less critical. For example, getting better estimates Migration rates may be more important in predicting the future fishing income than obtaining updated estimates for the Natural Mortality for fish inside the Zone or even the Reproduction Rates. The stakeholders who are most concerned with Fishing Income may put more importance on locating the Zone where there are slow Currents and a Healthy Habitat, than placing a Zone right near shore, where many fish might never leave the Zone.

3. Assists with transfer of knowledge

Running the model showed that, because many variables had a wide distribution of possible values, there was a wide distribution of possible outcomes. The Demos tool enables the users to analyze the uncertainty inherent in all the variables at the same time. For example, the uncertainty in every variable such as the Natural Mortality rate, Cryptic Mortality rate, Reproduction rate, Habitat's Holding capacity, Fishing Efforts, etc. could all be included at once.

Running Demos showed that without the Replenishment Zones, it is probable that the Red Snapper fish Stocks will crash if Fishing Efforts are high, regardless of Catch or Size Limits. If the Reproduction Rate was as low as 6.5, and there were no Catch Limits and no Zones, then the Stocks would crash with more than 75% probability. Running Demos also showed that the Stocks could also crash if the Reproduction Rate was 25, the Catch Limits were in place and the Fishing Efforts were high; the probability of this was only about 50%. If the Zones were created, there would be more than a 50% chance that the Stocks would still decrease, almost crashing, but then the fish would be replenished. The number of years needed, and the number of fish that could be expected, depend on a number of variables, such as Along Current Length of Zone, Total Zone Size (area), Habitat's Holding Capacity, Zone Location and Migration Rate.

Using Demos showed that the results did not change radically if there were small changes in inputs, but the probability bands of the predicted outcomes shifted. For example, if the Reproduction Rate changed from 24 to 25, the probability of the Stocks not crashing did not change from 0% to 100% as with Systems Dynamics, but changed from slightly less than 50% to slightly more than 50% for a 12.5 by 12.5 mile Zone and high Fishing Efforts.

If the Zones are created, then the probability that the Red Snapper will crash depends on the Zone configuration and some of the biological functions within the Zone; for instance, the probability could be slightly less than 50%, less than 25%, or less than 5%, depending on the configuration. The number of fish harvested also depends on the Zone configuration and the biological functions; it could be as low as 1000 fish or higher than 2 million fish. The low of 1000 fish may not seem like much, but it would be a sharp increase from the 5-10 Red Snapper fish harvested off Florida's shore each year since the stock declined in the mid 1980's. Most Red Snapper are now caught off Louisiana's coast. (Goodyear, 1992)

Using Demo helped reinforce much of what was learned using the SD model, showing that the tools two generally arrived at similar results. For example in Demos, the probability of the Stock crashing shifted from more than 50% to less than 50% around Reproduction rate= 24 and 25, which was about the same rate for the SD model. Another example was that in Demos, doubling the Zone Size doubled the expected number of fish just as it had in the SD model. Demos showed that, in general, the SD results were somewhat accurate, and that using the SD graphs to understand why the results changed were generally correct. These type of checks give more confidence to the general information provided by both tools.

Although the uncertainty in each variable can be included at the same time, parametric sensitivity analysis was still needed for different variables when the uncertainty was great, for instance, with the Reproduction rate and the Habitat's Holding Capacity. Parametric sensitivity analysis was completed for these variables, changing the mean of the distribution. Doing parametric sensitivity analysis one of variable while still including the uncertainty from the other variables, made it easier to decipher the effects of one variable's uncertainty. For instance, using Demos made it clear why the Along Current Length of the Zone and the Current Speed affected the results as they did, more so than SD.

The ability to do parametric sensitivity analysis also helps the decision makers become informed as to what actions they can take so that the probabilities of desirable outcomes are increased. Changing the values of variables they can actually have control over, such as Zone Location showed how the Migration rate would be affected, which would affect the Annual Harvest of fish. Changing the Zone Size and Zone Orientation, the Along Current Length of the Zone, all changed the predicted outcome, which could be determined using Demos. This helps the users become better informed about the variables that will help them reach their objectives.

D. STEPS OF GOOD DECISION-MAKING ACHIEVED

Demos helps the decision-making not just by producing a distribution of the predicted outcome, but also helps more generally with some of the requirements and steps of good decision-making. It is best if the first requirement and first three steps are completed before using Demos. To build a Demos model, all the stakeholders can be present or just a subgroup can participate. When the results of the Demos model are discussed, it is best to have all decision makers present so all can become better informed. Demos is not a Utility Function, so it does not help the decision makers define the overall goal or objectives, although it is best to have a goal defined before building a Demos model.

It is best to brainstorm the variables and linkages before building a Demos tool. There are many details, equations and probabilistic distributions that need to be included in the Demos model, making the modeling process difficult; it is best to determine the general structure of the variables and their linkages before adding the extra level of complexity. Often, it is best to have the results of a Simulation model to compare with the results of the Demos tool, so the two can be used to check for accuracy. Demos is best completed after the initial use of a Utility Tool, a Cognitive Map, and a Simulation model. Demos then can focus on eliciting and summarizing detailed information from many different people, such as the uncertainty inherent in any variable.

Step 2) Formulate Criteria

There may be a few criteria that uncertainty analysis elicits that the other tools did not elicit. For example, working through the data, trying to determine the mean and standard deviation for the Natural Mortality variables, is when it first became obvious that the Natural Mortality inside the Zone might not be the same as that outside the Zone. Uncertainty Analysis can also help determine the importance of different variables, and how much each one's uncertainty adds to the uncertainty in the results. It made it obvious the importance of the Zone Location, Zone Size and Zone Orientation (the Along Current Length) to the probability and degree to which the Stocks were replenished.

Step 3) Formulate Choices

Demos helps the users formulate choices in two ways. First, it helps the users differentiate between decision variables and chance variables, making it explicit which variables the decision makers can actually change. This helps stimulate ideas for choices. For example, the Zone Size, Zone Location and Zone Orientation are defined as decision variables, since the decision makers can change these factors. Conversely, the Natural Mortality rate, Cryptic Mortality rate and Reproduction rate are 'chance' variables where humans have little opportunity to affect these chance variables directly, unless other decision variables are added, such as seasonal fishing, limited numbers of fishing licenses issued or special spawning areas.

Secondly, Demos helps formulate choices by educating the users concerning the outcome of different scenarios. The users can do sensitivity analyses, changing the different decision variables until they get their desired outcome. The decision makers can see what alternatives are available so that there is less than a 50% chance that the Stock will crash, or what alternatives are available so that there is less than a 75% chance that the Stock will crash, such as i) create Zones and ensure that Current Speeds are slow, ii) regulate every type of Fishing Effort, etc. Demos helps educate the users about the important factors so that they can brainstorm alternatives that can achieve the desired outcomes for the important factors and the overall system. Demos shows the users which variables are important, what variables could be changed to meet their objectives and what are the most important areas for future research.

Step 4) Sensitivity Analysis

Demos is designed for sensitivity analysis. If the users change the definition or value of a variable, they can see how much the outcome changes. For example, changing the mean value and distribution of the Reproduction rate from 5 to 24 was easy, and the users could see the shift in the probability distribution for the overall outcome. Running Demos helped show that the results did not change dramatically when a variable was altered a small amount, for example from Reproduction rate = 24 to 25, but showed shifts in the outcome's distribution.

Requirement 2) Decision is made by well-informed decision-makers

Demos is designed to help educate the decision makers as to how much the uncertainty in each variable affects the uncertainty in the probable outcomes. Rather than providing a deterministic prediction of the outcome, uncertainty analysis can help the users understand the probabilistic distribution of the outcome. The results are the best guesses, using the most relevant information available, just as the scientists use research and best guesses to draw conclusions in the Goodyear paper. Demos' graphical format helps to simplify what has been learned in order to communicate it easily to all the decision makers.[103]

The Zoning Demos model built helps educate the decision makers about the likely outcomes for one specie, Red Snapper. Formulating the detailed equations and identifying the uncertainty in each variable helps the users decide if the results can be used for other sedentary fish Stocks. Red Snapper is only one specie among the FKNMS' 6000+ species, but using the Demos model might have been enough to reduce the uncertainty about the potential successful of Zones for other species as well. It also enables the decision makers to judge whether building additional models for other fish and marine life species is worth the time and effort.

Table XI-A: Steps and Requirements that Demos achieved

Steps and Requirements	Demos
Stakeholders included	a
Problem, Overall Goal and Objective definition	/
Criteria Formulation	/
Choice Formulation	X
Easy sensitivity analysis	~X
Well-informed decision makers	X
Choice	0
Implementation	0

[103] The model itself is not as good as some other Simulation models, because most of the information is contained within each variable's equation instead of expressed pictorially.

E. INADEQUACIES OF UNCERTAINTY ANALYSIS TOOLS: NEXT STEPS FOR DECISION-MAKING

Uncertainty Analysis tools elicit a great deal of detailed information and enable a better use of all available information. Demos determined the probability distributions of different outcomes for a narrow piece of the Replenishment Zone decision. It was used to determine:

i) the likelihood that a representative species, the Red Snapper, will crash if Replenishment Zones are not created and

ii) the likely distribution of fishermen's income from a representative species, the Red Snapper, comparing the results of the Zones being created vs. not created.

Demos informs the stakeholders about certain pieces of the decision, exploring the probable outcomes of different alternatives. This helps the stakeholders formulate better alternatives, alternatives that are more likely to achieve the results they desire.

It is important to note that even though Demos can incorporate probabilistic uncertainty and statistical functions, it cannot incorporate complete uncertainty. For example, Demos could not model the effects of all toxins on Red Snapper growth, since there is almost no deterministic, probabilistic or statistical information on this. Also, it could not be used to model the effects of Zoning on all 6000+ species. It is probable, though, that if more experts were available to build the actual Demos model, a more complex and inclusive model could be built with Demos than what was completed for this dissertation.

Cognitive Maps, Simulation models, and Uncertainty Analysis tools help elicit the most relevant information available and enable the decision makers to become educated about the physical and economic aspects of a system by prioritizing the abundant information and by using pictorial summaries and graphs. The Simulation model and Uncertainty Analysis were applied to two of the prominent objectives in the Zoning decision. Other models could be created to inform the users about other areas of the decision. If quantifiable information is not possible to obtain, Cognitive Maps may be used, focusing on one objective or one aspect of the decision. The decision makers should jointly decide which parts of the decision need to be illuminated with these tools, if any.

After the stakeholders become informed about the physical and economic aspects of the decision, 'Requirement 2) Stakeholders are well informed' is met. It is then necessary to continue the other steps, to finish formulating alternatives and then make a choice. The opinions and preferences of the well-informed stakeholders need to be elicited and combined, which Demos does not do A Utility Function should be used for the final steps.

Chapter XII. Use of Utility Function to elicit final preferences from well-informed stakeholders

This chapter discusses how a Utility function would be used in the final steps of decision-making: Choice Formulation and Choice. It will show how a Multi-Criteria Utility Function can be used to elicit the preferences of the well-informed stakeholders. The Utility Function should be updated to include any new criteria and alternatives identified, then the stakeholders' preferences can be elicited and combined to choose an alternative. A Utility Function and other tools can be used to do sensitivity analysis to ensure that the chosen alternative is as close as possible to Pareto Admissible.

A. NEED TO ELICIT FINAL PREFERENCES FROM STAKEHOLDERS' REPRESENTATIVES

Different stakeholders may possess the same information, but due to their personal preferences and utilities, each may make different choices.

1. Well-informed stakeholders' representatives should participate in the final choice

It would be inadequate if a few decision makers made the final choice for many stakeholders. Just as monopolies or oligopolies achieve inefficient allocation of resources, it would be an inefficient allocation of private resources to have a non-representative group of decision makers make the choice for all the stakeholders. There is a need to elicit preferences from the well-informed stakeholders' representatives in order to decide how to efficiently allocate the environmental resources. These many preferences then need to be combined into one overall choice. A Utility Function that can elicit and combine preferences from multiple users needs to be employed.

It is only after the decision makers become well-informed, that their preferences should be elicited to make the final choice. After using the Cognitive Maps, Simulation models and Uncertainty Analysis to become knowledgeable about the decision's physical and economic aspects, typically the stakeholders will have identified some new criteria and alternatives. There should be a way to include this information into the final choice. If the original Utility Function is used again, it should allow the decision makers to alter it and update the information included.

As the stakeholders' preferences are elicited and combined to choose an alternative, ideally, sensitivity analysis should also be used. Seeing the predicted outcome of the chosen alternative may change some decision makers' preferences. To reach a Pareto Admissible alternative, these updated preferences should again be elicited and combined to see if a different alternative results. In this way, the final Choice step may need to be an iterative process to ensure that the decision is well-informed and as close to Pareto Admissible as possible.

2. Need to accommodate subjective and objective measures

The Utility Function used needs to combine subjective evaluations as well as objective measures. The Replenishment Zone decision is like many environmental decisions, in that there is a need to merge qualitative and quantitative factors into a single overall measure to determine which alternative is the most desirable. The 'fathers' of Multi-Attribute Utility Theory, Keeney and Raiffa, discuss the importance of combining subjective evaluations along with the objective evaluations, and having public and expert participation.

> "The quantification of these subjective factors cannot be done frivolously. They should be generated by making the best use of the accumulated experience and expertise available. And on problems of public concern, such as power plant siting, this quantification should undergo the scrutiny of independent experts as well as the concerned public." (Keeney and Raiffa, 1976)
>
> "An expert might be hard pressed to give an objective formula for ranking the quality of paintings; nevertheless, he might be able to rank order these paintings saying, in effect, that given a choice between two paintings, he would prefer one over the other... Our artist might even be willing to put a price tag on each painting, thereby quantifying *one aspect* of his subjective judgment. This sort of quantification is not done by means of an objective formula, but by subjective introspection. Is it legitimate to work with such numbers? We do it all the time. As analysts we must learn how to incorporate such soft, squishy considerations as aesthetics, psychic factors, and just plain fun into our analyses. If we don't, the hard will drive out the soft and efficiency - very narrowly interpreted - will prevail." (Keeney and Raiffa, 1976)

A Utility Function that is designed to accommodate subjective and objectives preferences, evaluation and rankings should be used. The last few steps of the Analytical Hierarchy Process is one tool that can achieve this when the alternatives are discrete choices. AHP allows the subjective, qualitative judgments to be combined with whatever objective scalar measurements exist, so it will be used.

B. USE OF AHP TO ELICIT FINAL PREFERENCES IN REPLENISHMENT ZONE DECISION

The last few steps of the Analytical Hierarchy Process are applied to the Replenishment Zone decision to see how it can achieve the recommended steps of good decision-making. The AHP tool is not actually used with FKNMS stakeholders in this dissertation. The application and results are hypothetical, since the stakeholders were not available to solicit their pair-wise comparison of the objectives, criteria and alternatives. AHP is applied to the Replenishment Zone decision and discussed as if all the stakeholders were using it, though.

To make the overall choice, the decision makers have to consider all the parts of the decision. Simulation models, Uncertainty Analysis or Cognitive Maps may be created for different parts of the decision, depending on the type and quantity of information that needs to be summarized, and the decision makers' time constraints. After these tools help the decision makers become well-informed about the physical and economic aspects of the decision, the stakeholders' preferences need to be elicited and a final choice needs to be made. To make a final choice, the first few steps of AHP can be revisited and updated, and the last few steps will be undertaken for the first time.

As a reminder, the full five steps of AHP are:

1. Define the goal and objectives, and when necessary, specify the stakeholders
2. Develop a hierarchy specifying the criteria
3. Identify alternatives
4. Use judgment to assign relative weights to the alternatives, criteria and objectives
5. Combine weights into one overall ranking using matrix algebra

In this chapter, the first three steps will be reviewed and the last two steps will be used for the first time. The first few steps are reviewed, so that the hierarchy can be updated and the new information can be included. Steps 4 and 5 will produce the final choice.

AHP Step 1 - Specify the stakeholders

This step should be reconsidered only as a check to ensure that all stakeholders are in fact represented. Although the *first* step in good decision-making is to define the stakeholders and their representatives so that they can participate throughout the decision-making process, it is possible that some stakeholder group may have been overlooked. During the information elicitation and transferring process, new information may indicate that an important stakeholder group was not acknowledged and should be included.[104] While ideally no stakeholders' group would be omitted, there is a need to a least check for this before making the final choices.

In some situations, a new stakeholders' representative may not be added, but it may be desirable to refine the decision makers' voting weights after learning about the physical and economic system. This should not be done haphazardly and the group must be careful that the voting weights are not rigged, to ensure some 'favored' alternative. Still both the group of included stakeholders and their voting power should be reviewed to ensure that the group specified at the very beginning of the decision-making process is still desirable. AHP is flexible and if necessary can accommodate the addition of new stakeholders' representative or the adjustment of voting weights.

AHP Step 2 - Build the hierarchy specifying objectives and criteria

After the decision makers are well-informed by using the Cognitive Maps, the Simulation models, and Uncertainty Analysis tools, they should review the existing AHP hierarchy to see if any important objectives, criteria or sub-criteria were omitted. As stated in Chapter VIII, the AHP hierarchy can be altered and updated as new information is learned. The AC, CG and NOAA could again brainstorm their concerns and refer back to the CLD, SD and Demos, searching for any important components of the hierarchy that may be missing; additional criteria, alternatives, and perhaps even objectives may be identified. Using AHP, the facilitator should add these new variables to the existing hierarchy, incorporating the initial preferences and knowledge with the updated preferences and information. **(See Figure XII-A** for the updated Replenishment Zone AHP model.)

AHP Step 3 - Identify alternatives

Once the decision makers agree that they are all fairly well-informed about the different variables, criteria, consequences, etc. and the AHP is updated, the next step would be to brainstorm and update the alternatives. It is likely that the decision makers would formulate

[104] Ideally, every stakeholders' group would be identified early in the process, so their representative can add to the information and help steer the decision. When a group of stakeholders has been overlooked until the end of the decision, though, it is important for the new representative to be updated, being shown what was learned from the original Utility Function, Mental Map, Simulation model and Uncertainty Analysis tool.

additional and better alternatives than were brainstormed in the beginning of the decision-making process.

With AHP, the alternatives must be discrete alternatives. For the purposes of this dissertation and to show how the AHP tool could have been used in the Zoning process, the three Zone locations that the AC voted on in the actual process will be used: one off Key Largo, one in Dry Tortugas and one in Sambos. For each of the three sites, different sized areas will be considered, and for the Key Largo site only, some different provisions such as allowing Catch and Release Fishermen will be considered.

In the actual FKNMS decision-making, each of the three Zones had three options, Alternatives II, III and IV;[105] there were three discrete options for each of the three Zones. This format, using three discrete options for each Zone, will be used for the AHP example. Using the AHP tool, the subcommittee could either i) bundle the three most restrictive options, the most lenient options and the middle options for each of the three different sites as the AC did to vote or ii) not bundle the options and vote three different times for each of the three different sites.[106] Using the latter approach, the AHP alternatives might be:

For vote #1 - Sambos:

Alternative II - 15 sq. nautical miles
Alternative III - 9 sq. nautical miles
Alternative IV - 5 sq. nautical miles

For vote #2 - Key Largo:

Alternative II - 23 sq. nautical miles and no catch and release fishing
Alternative III - 23 sq. nautical miles and catch and release fishing allowed
Alternative IV - 20 sq. nautical miles and catch and release fishing allowed

For vote #3 - Dry Tortugas:

Alternative II - 120 sq. nautical miles
Alternative III - 110 sq. nautical miles
Alternative IV - 100 sq. nautical miles

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[105] NOAA presented the original options to the AC and then the AC changed some of the boundaries, locations and sites.

[106] The former, bundling, would save time by requiring less voting, but forces the subcommittee to choose among prepackaged bundles; the bundles force on the AC a part of the decision that need not be forced. The latter would require that the AC vote three times, once for each of the three sites.

For each of the three locations, a separate vote would be taken ranking the three alternatives. For example, to complete the first vote for the Sambos location, the three alternatives would be placed at the bottom most level of the hierarchy as three distinct options. (See Figure XII-A) The stakeholders would then vote, ranking the three alternatives. To complete the vote for the Key Largo location, the three alternatives on the bottom most level of the hierarchy would be changed, but the rest of the hierarchy would remain the same.

AHP Step 4 - Using judgments to assign pair-wise comparisons (Voting)

The fourth step in the AHP process would be the voting. After developing the hierarchy and the different alternatives are identified and included, each decision-maker would then vote *independently* on all of the alternatives. To determine the overall rank of the alternatives, the decision makers could have used the AHP's method for preferential voting, that is the pair-wise comparison method. AHP requires the users to rank alternatives by pair-wise comparing at each level of the hierarchy, the different variables identified.[107] (See Appendix XII - A for a description of how to do the pair-wise comparisons.)

If there are objective measures for comparing different criteria or objectives, they can be used as the pair-wise comparisons. For example, for the criteria 'Zone Size, ' it would be easy to simply include the relative sizes 15, 9 and 5 for the Sambos Zone. Most of the criteria do not have objective, scalar measurements, though and the stakeholders' representatives would make subjective judgments. This voting step was not completed in this dissertation, since the AC, CG, and NOAA were not available for a vote. Appendix XII - A contains an example of how the pair-wise rankings would be placed and an overall ranking calculated for a miniature version of the Replenishment Zone AHP hierarchy.

[107]Preferential voting is far more accurate than non-ranked voting (spot-voting) when there are more than two alternatives. The spot vote is where each voter has one vote and no more, however many alternatives there are to choose from. The spot vote is unsuitable for any voting in which more than two alternatives compete for a single place, since its use in such a contest may result in the election of the least popular candidate. Spot voting is the simplest and perhaps most naive approach to voting, being defined as the alternative which gets the most votes wins. Many examples show that it is not a fair representation of the people's will and extraordinary injustices in voting systems have resulted What is needed in place of the spot vote is a method of voting that allows the voters to indicate not only which of the three or more alternatives he or she desires, but also in what order of preference he or she would place the alternatives. This method is called 'preferential voting." Even if preferential voting is used there may be some inconsistencies. (See Hwang 1987 a discussion of the inconsistencies that arise there.)

Figure XII - A: Updated version of the AHP model (sheet 1)

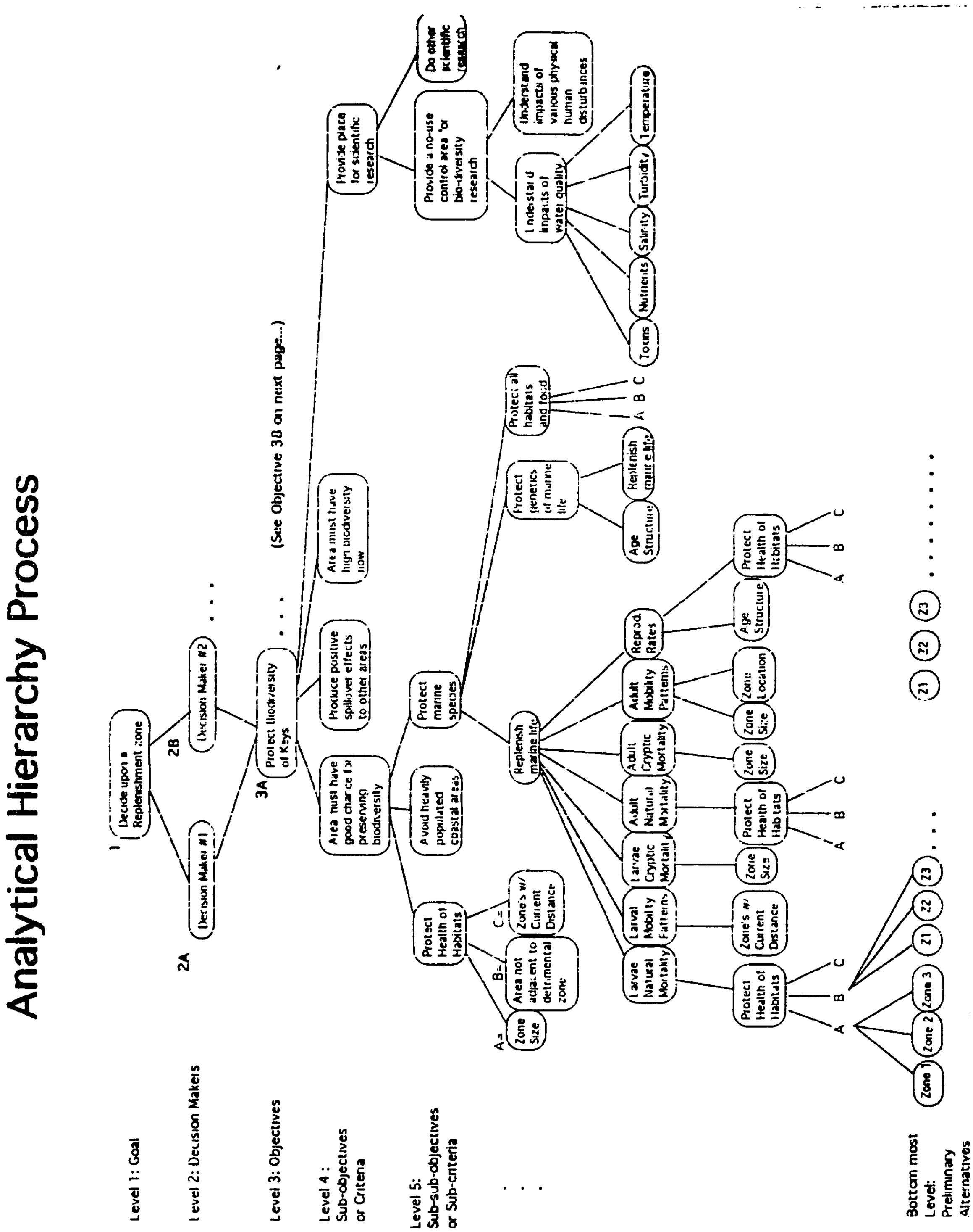
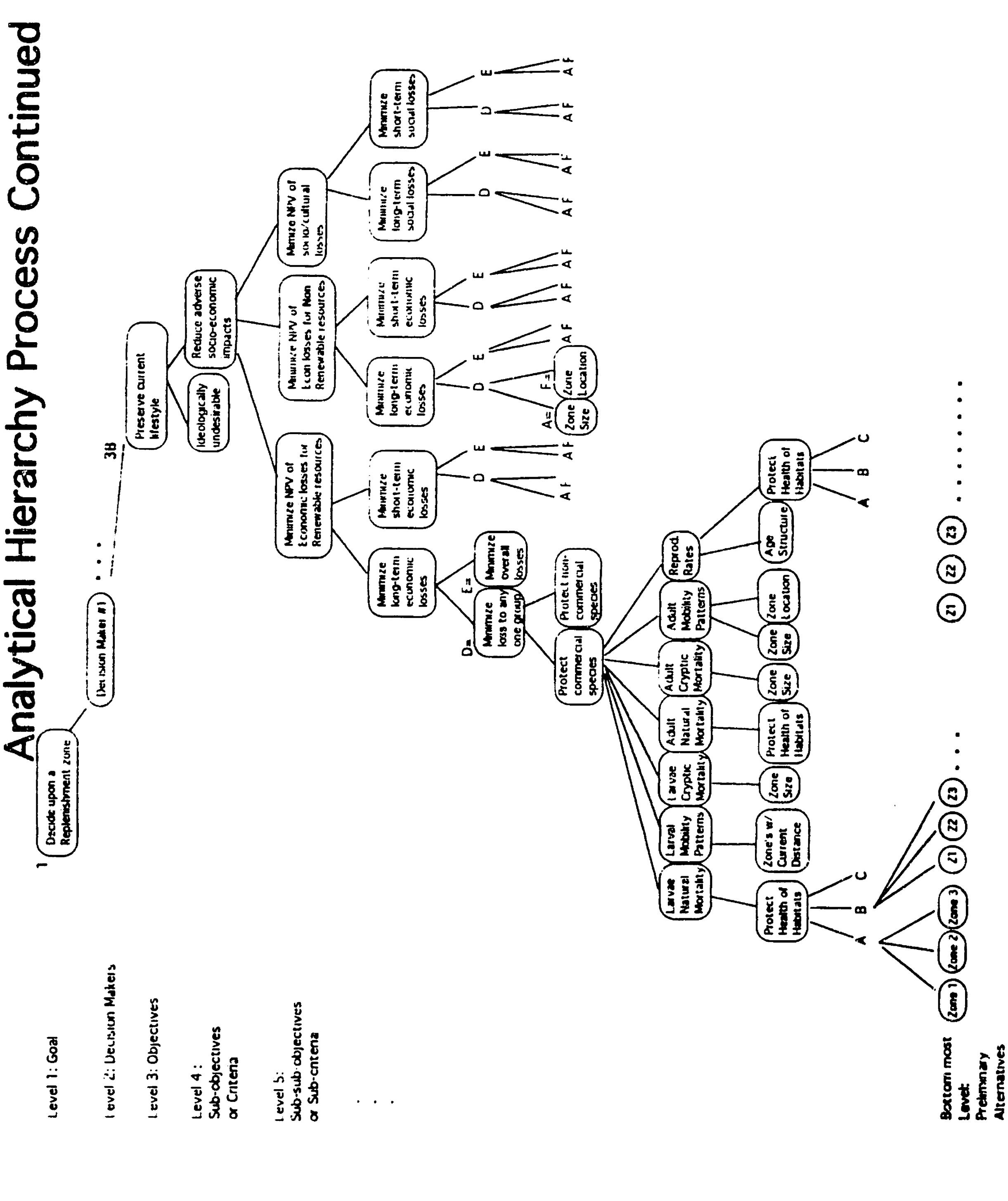


Figure XII - A: Updated version of the AHP model (sheet 2)



AHP Step 5 - Calculating the overall rank

After the pair-wise comparisons are made, the AHP tool can merge the qualitative and quantitative pair-wise comparisons into a single, overall ranking of the alternatives. AHP uses matrix algebra to combine the pair-wise comparisons of all the alternatives, criteria and objectives from all the decision makers. (See Appendix XII - A for details on the mathematics.) Combining each individual's pair-wise comparisons up to Level 2 would show how each member individually ranked the different alternatives. Continuing up to Level 1 would summarize the judgments and values of all the decision makers into one overall ranking.

The overall ranking at Level 1 would then be a summary of the preferences of all those who voted. Using the matrix algebra to summarize the overall ranking is the controversial part of AHP. When the matrix algebra is performed and then a new alternative is added, rank reversal may occur with the alternatives. Dyer's normalization process could be used, though, to prevent the rank reversal. (**See Dyer, 198_** for an explanation of the AHP normalization process.)

Although the AHP mathematical summary could be carried out by hand calculations, it would be overly burdensome. Not only is the Zoning AHP hierarchy rather large with a fair number of variables, but there would also be pair-wise comparisons for each of decision makers who voted. For hierarchies so large, it is recommended to use the computer software, Expert Choice™. A problem exists, though, in that Dyer's normalization process has not been included in the software. If new alternatives were added, it would be best for the users to create their own spreadsheet to calculate the matrix algebra, and include Dyer's normalization process.

6. Sensitivity analysis

Using AHP in this way enables an overall decision; each alternative is ranked. If the pair-wise comparisons had been completed and an overall rank had been calculated, sensitivity analysis could have been completed for the stakeholders' preferences. For example, to see how the choice would change if there were slight changes in the voters' preferences each voter could change his or her pair-wise comparisons to their most conservative, yet possible votes. To see if the overall alternative would change, the pair-wise comparisons would again be combined using matrix algebra. If the results were not different from the original ranking, then the voters would know that the rankings were firm and the overall choice reflected the collective preferences of the stakeholders with a fair margin of error. If the chosen alternative did change, then the decision makers might want to do some more information gathering to understand why the alternatives were somewhat interchangeable. This type of sensitivity analysis for the decision makers preferences could also be used for their most lenient, yet possible opinions.

When the choices are being made, the Simulation model and the Uncertainty Analysis tool can also be used to predict the probable outcome of the choice. As alternatives were voted on, the affected variables in the SD or Demos model could have been changed, and then the model could be run to see what the likely outcome might be. SD and Demos could be used as 'dry runs' to see some of the likely results of the choices. The decision makers would update their information, and perhaps decide that they should vote again. In this way, AHP, SD and Demos could be used to do sensitivity analysis.

7. Optional preliminary votes

AHP could also be used to conduct preliminary votes early in the decision-making process to determine the greatest areas of controversy. A preliminary or partial vote could be used to help inform the stakeholders about the intensity of each others' preferences. A partial voting method might be i) partial ranking of only the objectives to facilitate discussions about the different objectives or ii) pair-wise comparisons completed for the objectives and criteria without the final alternatives specified. With AHP, either the individual preferences could be summarized using matrix algebra or the individual preferences could be reviewed to determine the areas of greatest controversy.[108]

Reviewing the individual preferences, the actual pair-wise comparisons numbers, one could see which objectives, criteria or sub-criteria had the largest amount of disagreement. The level by level, variable by variable pair-wise comparisons could also indicate the intensity of each voter's preferences. During the voting process, the decision makers can become *well-informed* about the *preferences* of other stakeholders, and to the intensity of those preferences.

Used early on in the decision-making process, AHP might help determine where to focus information elicitation efforts. For example, if all the decision makers had ranked the sub-

[108] See **Appendix XII-A** for a more detailed discussion of the AHP voting method used.

criteria and criteria similarly, but half the objectives were ranked very differently, then the group would know to focus discussion and research efforts on those objectives. An AHP initial vote may be used to indicate the areas where further clarification, discussion or education is needed. It may indicate what areas of the decision need to be supplemented with further research and / or information gathering tools, such as Cognitive Maps, Simulation models and Uncertainty Analysis. Focusing these efforts would make it less likely that the stakeholders run out of time, and there being great dissatisfaction at the end of the process. The actual pair-wise votes might also be reviewed at the end of the decision-making process to i) prepare for the public hearings and ii)determine where to focus research efforts if the Zones were created.

C. RESULTS OF AHP TOOL

This section discusses what was accomplished when AHP was used for this dissertation and projects what it could have accomplished if it had been used during the actual FKNMS process.

1. Updates all criteria and objectives found through other tools

Using the AHP tool, all the important information elicited through the use of Cognitive Maps, Simulation models and Uncertainty Analysis can be summarized in the AHP hierarchy. After stimulating ideas for new criteria and new alternatives, and helping the decision makers become well-informed, the participants could again brainstorm and record the results in the AHP hierarchy. The hierarchy could updated with the best avialable information that was learned using the other tools before final preferences are elicited. AHP is a flexible and adaptable tool that can be updated as the stakeholders become better informed, so that the decision uses the best available information.

Building the AHP hierarchy gives structure to the initial preferences and the updated information, so it is not just a list of 30+ objectives and criteria that the AC, CG and NOAA members would have to mentally juggle while making a decision. The AHP can help the users become better informed about how the different preferences and criteria overlap and fit together. In the actual case, the decision makers had to remember many hundreds, maybe thousands of pieces of information at once to make their decision. Also, NOAA only has the existing list of eight criteria to help defend its choice of Replenishment Zones, and the list of eight criteria is not directly tied to the votes.

2. Elicits final preferences to choose alternative

Using AHP in the Replenishment Zone decision, all the relevant variables and information that were identified during the decision-making process could be included in the valuation process. AHP could have been used to rank the alternatives for each of the three different Zone locations. It could also be used to decide among different Zone locations. If AHP's i) pair-wise comparison ranking system was used and no additional alternatives were added or ii) Dyer's normalization process was used, AHP could have been used to rank the alternatives from best to worst. An overall alternative could have been chosen.

AHP enables the preferences of all the well-informed stakeholders' representatives to be combined. It allows the individuals' determination of value and worth to be consolidated into one overall choice, without having to put scalar measures on each variable.

3. Can elicit preferences during the decision-making process

An optional use of AHP is that it can elicit preferences at any point during the decision-making process to help steer and focus the decision making efforts. If the preferences had been broken down using the pair-wise comparisons at the objective level, the criteria level or the sub-criteria level, the users could have learned what were each others' preferences and discern the *intensity* of the preferences. In this way, the users could become well-informed about the human preference aspect of the decision.

AHP allows the users to summarize the votes on any level of the hierarchy, not just final alternatives. This can be very helpful when trying to find the areas where the most controversy lay. AHP does not help the decision makers become better informed about the physical or economic aspects, but it can help the users become better informed about the subjective human aspects of the decision.

D. STEPS IN GOOD DECISION-MAKING PROCESS ACHIEVED

A Multi-criteria Utility Tool such as AHP should be used at the end of the decision-making process to elicit final preferences from the stakeholders. After the stakeholders had determined the overall goal and elicited objectives, then criteria and alternatives need to be formulated and the decision makers need to become well-informed. Cognitive Maps, Simulation models and Uncertainty Analysis are best used to accomplish these steps.

A Utility Function for Multiple decision makers such as AHP could be used to update the list of criteria and alternatives, before the final recommended steps of good decision-making, before making the final vote. AHP could then be used to elicit and combine preferences to reach a final ranking of the alternatives.

Requirement 2) Well-informed decision makers

AHP can be used to summarize the relevant variables identified during the decision-making process. This is necessary so that the decision can explicitly include all that was learned and the decision makers do not have to attempt mental juggling, remembering many different pieces of information when trying to make the decision. Recording the updated information in the AHP hierarchy assists the decision makers in remembering the vast amounts of information.

AHP can also be used during the voting process, enabling the decision makers to become well-informed about the preferences of other stakeholders. AHP can be used not only to elicit and combine the preferences, but also to inform the decision makers about the preferences.

Step 5) Choice

AHP can be used to choose an alternative by eliciting the pair-wise comparisons from the decision makers and by combining these using matrix algebra. An overall ranking is achieved and the most preferred alternative is identified.

Step 4) revisited: Sensitivity Analysis

AHP is capable of doing sensitivity analysis on the users' preferences. The users can determine if a small change in their preferences change the overall ranking; they would do this by changing the numbers assigned to their pair-wise comparisons.

Combining AHP's capabilities from both Chapter VIII and this chapter, one can see which steps AHP can achieve.

Table XII-A: Steps and Requirements that AHP achieved

Steps and Requirements	AHP
Stakeholders included	/
Problem, Overall Goal and Objective definition	X
Criteria Formulation	/
Choice Formulation	/
Easy sensitivity analysis	X
Well-informed decision makers	X
Choice	X
Implementation	0

E. Inadequacies of Utility Functions: Next Steps for Decision-Making

The last three steps of the AHP tool help the users move closer to a Pareto Admissible option by enabling all stakeholders' opinions and values to be included in the final choice. If representatives from all the different stakeholder groups were present, then their values and concerns would be i)reflected in the criteria and objectives of the AHP hierarchy, ii) elicited by completing the pair-wise comparisons, then iii) combined using the matrix algebra. It could be expected that many good alternatives were developed after using the Utility Function to elicit initial preferences, then using Cognitive Maps, Simulation models and Uncertainty Analysis to help the decision makers become well-informed; these alternatives could be included in the final AHP hierarchy. By including the many well-informed alternatives and enabling the preferences of many stakeholders to be elicited and combined, AHP moves towards a Pareto Admissible solution.

A drawback to using AHP to rank alternatives is that it can be time consuming. It is more time consuming to elicit pair-wise comparisons for the many variables included in the AHP hierarchy than for a simple spot vote; it can be time consuming to calculate the overall ranking. Another drawback of AHP is that it can only be used for discrete choices, not a continuum of choices. With Zoning there were actually a continuum of possible choices, but they had to be reduced to a few discrete choices so that AHP could be used. A 'continuum' of choices can be achieved if the group is willing to repeat the judgment process many times.

The Analytical Hierarchy Process is an example of a Utility Function that can combine the preferences and values of many stakeholders.[109] It also enables the last few steps of the decision-making process, so that the final choice can be made. Since it can be used in conjunction will other tools and methods, all the requirements and steps of good decision-making can be met, except for implementation which is outside the focus of this work. The next chapter will review the use of the many tools together to see how well they can overcome complicating factors of Environmental decision-making.

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[109] There are at least two situations where a simple hierarchy with priority weights and alternatives as leaf nodes cannot accurately calculate the optimal choice. The first situation is when the disparity between elements in a level of the AHP hierarchy is so great that they are not of the same 'order of magnitude.' Then the elements should be put into clusters of like elements, and an extra level should be added to the tree for comparing the clusters.
The second situation is when the number of alternatives is large, but alternatives still must be compared in pairs. The consistency of pair-wise comparisons fades for more than seven alternatives. Mathematically, pair-wise comparison is more efficient (requires fewer judgments) if the number of items being compared is large, but the items are grouped into sets. Therefore, if the number of alternatives is above seven or eight, they should be arranged in separate clusters.

Chapter XIII - Comparing the actual FKNMS Replenishment Zone decision to the recommended Tools and Steps

Each tool has been applied to the same problem, the FKNMS Replenishment Zone decision, and analyzed separately to determine the degree to which each one can facilitate the various steps of good decision making. This chapter summarizes how the different families of tools can be used *together, in a prescribed manner* to achieve the many steps of good decision-making and to overcome the complicating factors inherent in environmental decisions. Using the combination of tools is compared to the actual FKNMS Zoning decision for each step and for each complicating factor.

This comparison is made, so that the benefits of using the tools and recommended steps are explicit. It is not meant to diminish in any way what has been accomplished in the actual FKNMS process, but to propose what might have been done to improve the FKNMS decisions and to improve future coastal environmental decisions.

A. REVIEWING THE STEPS: COMPARING THE ACTUAL FKNMS DECISION TO THE DECISION MADE USING THE COMBINATION OF TOOLS

To compare the actual FKNMS decision with the decision made combining the tools, it is best to follow the steps and requirements of good decision-making. First, the following chart summarizes the previous five chapters, specifying each of the steps that were accomplished using the different families of tools. One can see that combined, the four families of tools address most of the items.

As a reminder, the symbols in the table below can be interpreted as follows:

X: the tool assists the Step or Requirement significantly.

/: the tool assists the Step or Requirement only somewhat. It may help with only certain aspects of the item or may help, but not as much as some other tools.

0: the tool does not help at all.

~X: the tool helps only if the model can be completed and run (for Demos or SD).

a: the tool allows the item and benefits from it, but does not assist with it

Table XIII-A: Steps and Requirements that tools achieve

Steps and Requirements	AHP	CLDs	SD	Demos
Stakeholders included	/	a	a	a
Problem, Overall Goal and Objective definition	X	a	a	/
Criteria Formulation	/	X	X	/
Choice Formulation	/	/	X	X
Easy sensitivity analysis	X	0	~X	~X
Well-informed decision makers	X	X	X	X
Choice	X	0	0	0
Implementation	0	0	0	0

By using a combination of tools, all but Implementation are addressed, the step which did not receive focus in this dissertation. The above table shows that the four tools work well as complements. Using a specific family of tools for different steps assists the decision-making process more than any one family of tools could alone. The combinations of families should not used in any random order, though; this chapter will discuss how the tools are most helpful when they follow the recommended steps of good decision making. This process with be compared to the steps of the actual FKNMS decision.

Before reviewing each of the recommended steps, it is important to note that in the actual FKNMS decision, there was never a well-defined methodology for developing the FKNMS Management Plan, and more specifically, the Zoning Issue. The process evolved over time, instead of being designed from the beginning. The 'stage' was not set initially, which led to confusion that persisted throughout the process. If the recommended steps of good decision-making had been followed, this problem would not have existed.

Requirement 1) Have all stakeholders represented and their interests included

a. Need to define roles

As with any decision, there is a need to define the role of the decision makers. Specifying roles makes it more likely that the groups can contribute at their full potential and reduces the confusion, mistrust and tension among the different groups. In the actual FKNMS process, the roles of the different participants were never formally discussed or defined for any of the

Issues, including Zoning. It was not specified how the Advisory Council's role differed from the Core Group's, the Strategy Identification Group's, and the general public's; no one knew who the AC was supposedly advising. It was not well understood how the stakeholders' representatives would ensure that the interests of their constituents were included, which led to confusion, mistrust and even animosity between the AC and CG.

Using AHP would have helped the users define early in the decision-making process who was able to vote, and who was involved in all steps of the decision-making process. Being explicit and defining voting power would have encouraged discussions about other parts of the decision-making power, reducing the confusion over the roles of the AC, CG and NOAA.

b. Need for stakeholders' representatives to be included from the beginning

The stakeholders' representatives need to partake from the *beginning* of the process, so that their preferences and initial objectives influence the direction and parameters of the decision. In the Actual FKNMS decision, the AC could not be sure if the initial preferences of the user groups had been fairly or accurately represented, since they were not present from the beginning. In the beginning of the process, the AC felt that NOAA did not listen to their concerns and the interests of the stakeholders, especially about NOAA's decision to prohibit treasure salvaging. If the recommended steps of good decision making are followed, the decision makers are sure to include the stakeholders from the beginning. Also, the second step of building an AHP hierarchy, defining the decision makers and who has voting power, encourages this step to occur in the beginning.

Step 1) Define the Problem, the Overall Goal and the Objectives

a. Need stakeholders to organize and summarize initial preferences in *real time*

Summarizing and organizing the information during the meetings, in real time enables the stakeholders to see the gaps in knowledge and see how the many pieces fit together. This enables more relevant information to be elicited in a more timely fashion and enables the participants to learn more. In the actual FKNMS decision, information and initial preferences were elicited from the general public in order to define the overall problem and the objectives, but these initial preferences were not organized and summarized during the meetings, with the stakeholders present. They were organized afterwards with NOAA and the Core Group. NOAA did not provide structure to the brainstorming and to the comments made during the meetings, with the stakeholders present. AHP could have been used, to summarize, organize and show linkages among the goals and objectives as they were elicited, in *real time.*

i. Need for real time summaries to promote learning

Ideally, each user group should not only be well-informed about the initial preferences of their own group members, but also the concerns the other user groups, since being aware of others' preferences is a necessary step towards building consensus. To become better informed about the preferences' of others, ideally members from the various user groups should meet together, to hear and discuss their concerns. If this is not possible, then the groups would need to review accurate summaries of the other groups' preferences.

For the actual Zoning decision, NOAA elicited objectives and criteria from each of the user groups separately, due in part to the expected controversy. It was only after NOAA and the CG summarized and organized all the comments that the stakeholders could review the others' initial preferences. In addition, the Advisory Council never met with the Core Group or Strategy Identification Group to discuss their initial preferences. Only NOAA benefited from hearing and summarizing all the concerns, the objectives and criteria of the many groups. The actual FKNMS process did not enable each group to understand the other groups' initial preferences.

AHP would have assisted the stakeholders in becoming well-informed about initial preferences, because the hierarchical structure provides a visual summary, quickly communicating the initial preferences elicited. The hierarchical structure would have provided succinct summaries, that would have enabled more learning to occur within each meeting. The summaries could have also been reviewed by the other user groups if they could not all participate in the same meeting. If there had been one meeting with the different user groups, AHP would have made it easier to hear each others concerns and brainstorm in real time. AHP helps reduce controversy, since the initial preferences are elicited first, then prioritized later, so there is less judgment during the brainstorming phase. AHP's visual summaries would have promoted more learning among and across the user groups and/ or would have made it easier to have meetings with many different user groups to promote learning.

ii. Need for Stakeholders' real time participation to insure accuracy

The stakeholders or their representatives must participate when their initial preferences are summarized and organized, so that it is less likely that the stakeholders' initial preferences are unintentionally misrepresented. In addition, the summarizing and organizing process itself often requires that some preferences and judgment be used, and it should be those of the stakeholders, not those of a third party. The stakeholders or their representatives need to participate in real time to ensure that their preferences are understood and well summarized.

In the actual FKNMS decision, the many users groups met separately to discuss their initial preferences, NOAA summarized all the preferences and then asked each of the groups to review them for accuracy. Each of the different user groups had not learned about any of the other group's initial preferences, so it was impossible to judge if the *summary* of the combined goals and objectives was accurate. Each group had only heard a part of the whole, so they could not judge the whole. The AC, the stakeholders' representatives did not participate in summarizing the initial preferences either. The public and the AC could only review what NOAA and the CG had summarized; they could not work with them in real time to alter the objectives as they saw fit. They could not be sure that they had been fairly represented, which caused less buy-in and ownership.

Using the AHP would have helped promote accuracy. Within each of the five separate user groups meetings, an AHP hierarchy could have been built. The users within each meeting could have helped summarize and organize the initial preferences in real time, enabling more accurate summaries. Ideally, the AC would then summarize the various AHP hierarchies to build one hierarchy, representing the users initial preferences. Using AHP would enable the AC i) to quickly learn the preferences of the many groups due to the visual summaries, ii) identify the areas they thought should be modified and iii) combine the separate hierarchies into one overall hierarchy. If all the stakeholders had been invited to summarize and organized the various AHP hierarchies in one meeting instead of the AC, then using the AHP could reduce the controversy, making it easier for the many groups to work together to summarize the preferences. AHP could have been used to ensure that only the stakeholders and / or their representatives summarized the initial preferences, which would have ensured more accuracy.

b. Need to prioritize Objectives

When there are long lists of objectives, they should be prioritized at some point in the decision-making, otherwise, it is impossible to determine if appropriate effort is being placed on the areas of greatest concern. In the actual Replenishment Zone decision, the objectives were never prioritized. If AHP had been used, it would have enabled the users to prioritize the objectives at any point in the decision-making process. This would have enabled the users to re-focus the decision-making process, concentrating on the areas of greatest concern.

Step 2) Preliminary Criteria formulation

a. Need to organize and summarize Criteria in real time

As with objectives and the overall goal, the initial criteria should be summarized and organized in real time, so the stakeholders can learn more during the meeting. Ideally, the initial criteria should be formulated with different user and decision making groups meeting together, so that the groups could learn from each other and can check for accuracy.

In the actual FKNMS decision, the initial criteria were identified during the five Zoning Workshops, but only NOAA and the CG organized and summarized them, without the stakeholders or their representatives. Even, when the AC's Zoning subcommittee explored the Replenishment Zone criteria in-depth, attempting to refine them, they were discussed and debated during many meetings, but they were not organized and summarized along the way.

Both AHP and CLDs could be used to achieve this step. Using AHP, many of the benefits are the same for initial criteria as they were for objectives. The initial criteria would be organized and summarized in real time, as they were elicited from the stakeholders during the meetings. The users could be updated immediately with the summary of criteria, since the hierarchy provides a visual summary. The users groups could have been divided in separate groups to elicit criteria or joined in one meeting, since AHP allows many people to participate at the same time. Having one group meeting would have enabled learning among the user groups or their representatives. If separate meetings were held, the separate AHP hierarchies would provide accurate summaries of what occurred within each meeting and make it easier to transfer information across the groups.

Causal Loop Diagrams would provide additional benefits. A CLD could have been used to elicit, organize and summarize more criteria. CLDs could be used to quickly model the Zoning Issue, showing the linkages among the physical, economic and human preferences aspects of the system. CLDs can be quickly built and easily altered, which would have enabled a CLD to be started during one meeting, for example in the Zoning Workshops, and then altered and completed in another meeting, such as an AC meeting. Like the AHP, the CLD could i) summarize, organize and show linkages in the information, so gaps in knowledge could be found and more criteria elicited and ii) used as a record of the initial criteria to transfer knowledge among the different user groups. After finishing the CLD, the AHP hierarchy could be updated with any new objectives, criteria or alternatives that had been identified.

Step 3) Preliminary Choice formulation

a. Need for stakeholders' representatives to participate in initial Choice formulation

Like the objectives and criteria formulation, the stakeholders or their representatives should participate in formulating the initial choices to bring them closer to Pareto Admissible and allow for a greater feeling of ownership. In the actual Zoning decision, the choices were first formulated when the CG bundled the Strategies to make the first draft of Alternatives II, III and IV, but the AC was not present. Also, the AC did not participate when the two NOAA members drew the first draft of the Replenishment Zone boundaries.[110]

Using AHP and CLDs, the stakeholders' representatives could participate. With AHP, the group could have continued to discuss and brainstorm after the preliminary criteria were formulated, developing preliminary alternatives. This initial set of choices could be recorded in the AHP hierarchy and updated later. Initial choices could be formulated without eliciting opinions and value judgments, so that the brainstorming process would not be thwarted. If CLDs had been used, much information could have been made explicit, summarized and organized with less effort then the many presentations and reports. This would have helped formulate initial alternatives, since the users would have become more educated about the physical and economic aspects of the system.

Steps 2 &3) In-depth Criteria and Choice formulation

For some decisions, the stakeholders may be well-informed after the AHP and CLDs are used. If adequate consensus had already been reached using the previous steps, then there might be no need to continue. If not, which probably would have the case with the Replenishment Zone decision and most other complex environmental decisions, then the group could have continued, spending more time probing details, and more effort drawing out information about the physical, economic and human preference aspects of the system.

a. Actual Zoning process achieved iterative Criteria and Choice formulation

For most complex environmental decisions, formulating criteria and choices needs to be an iterative, ongoing process. In the actual FKNMS decision, detailed criteria and choices were created in an iterative manner during the AC meetings and the AC's Zoning subcommittee meetings; typically the criteria and choices were formulated informally, using brainstorming, discussion and debate. Formulating criteria, the AC and the AC's Zoning subcommittee did become better informed about the Zones before developing the final list of eight criteria.

[110] In the FKNMS Act, Congress required that Spatial and temporal Zones be considered, but did not require Zones or create the first alternatives for Zones.

Although, the criteria formulation was iterative, it was not a process of building, adding and refining as more was learned. The list of eight criteria were only summarized and organized once in one Zoning subcommittee meeting, not as an on-going process throughout the many meetings.

Formulating choices, the AC either strengthened or weakened the CG's initial choices to create Alternative III. Information, recommendations and alternatives were elicited and brought into the process through the many Zoning Workshops, CG meetings, AC meetings, the AC's Zoning subcommittee meetings, the user group meetings, and the Strategy Identification Workshop. The Zone locations and sizes of the different alternatives were formulated when AC and NOAA members made a field trip onto the water and re-drew lines on the maps. The AC took spot votes to determine what details would be included in the final Alternative III.

All four tools could be used to further assist this step. First, building models with CLDs, SD and Demos assists in both the iterative criteria and choice formulation steps, since they help inform the users about how the system works. A better understanding of the system enables the users to better judge a useful criteria and a good alternative. All three tools allow for the criteria and choices formulation to be completed in an iterative process, since they can all be added to and altered. The AHP could be used again, after CLD, SD and Demos had been completed, with the users easily altering and adding to the hierarchy. The AHP hierarchy can be updated with new criteria and the additional information learned throughout the decision-making process.

b. Need to develop detailed list of Criteria

Criteria are most helpful if they are measurable traits, either quantitatively or qualitatively, that could be used to compare the different alternatives. Also, the criteria formulation process should happen before the consensus building process, otherwise the brainstorming would stifle creativity, resulting in less detailed criteria; criteria should be elicited., then preferences or rankings should be assigned. In the actual FKNMS decision, the final eight criteria developed in the AC's Zoning Subcommittee were not detailed. The list of eight provided general intent, but did not provide qualitatively or quantitatively measurable traits with which to compare different Zone choices. Each of the eight criteria had to be agreed upon before being added to the list, which seemed to stifle the details.

SD, Demos and AHP could all be used to reach detailed criteria. Attempting to build a Simulation model such as SD requires that the users not only identify variables and linkages, but also quantify the linkages and the variables' initial values. This forces the users to probe for details and in-depth information. Building the SD model can help explain why certain variables in Zoning are important to consider, for example, the Reproduction Rate, non-directed Commercial and Recreational Fishing Efforts, Cryptic Mortality, Health of Habitat, Currents Speeds, Zone Orientation, Zone Size, as well as a reasonable time horizon to look for results. Building the Demos model helps the users understand the level of uncertainty in the best available information, so the users can be more educated about the system.

Although SD and Demos are informative and allow an in-depth analysis of the actual system, all variables must be quantified, requiring more time and effort to build. Because of this, they are often used for small pieces of the decision. The focus has to be small enough so that there is quantitative data on each of the variables in the system. For example, the Replenishment Zone SD and Demos model could only examine how the Zones would affect the Stock of one species, Red Snapper, and the corresponding fishing income.

AHP also helps formulate detailed criteria. The hierarchical structure helps the users break down the bigger pieces into more detail. In addition, since AHP separates the identification stage from the consensus building stage, creativity is not thwarted. Finally, after SD and Demos are built, the detailed criteria that were elicited could be recorded and summarized in the AHP hierarchy.

c. Need to achieve in-depth Criteria and Choice formulation more efficiently

Although these two steps need to happen in an iterative process, being repeated many times, there is always a need to be efficient with time, without sacrificing the quality of the decision. In the actual FKNMS process, the AC spent half their time on the Zoning Issue alone. First, the AC and the user groups typically formulated the criteria and alternatives through informal processes, such as brainstorming, discussion and debate. Second, many different groups worked on the Zoning Issue, typically in sequence, not together. Sometime time was spent retracing or undoing certain steps. Reducing the repetition and using a more focused process would have helped reduce the time.

The four tools could be used to more quickly formulate criteria and choices. AHP could be used to succinctly summarize the criteria and choices in one place. A CLD can be created quickly to summarize, organize and show linkages among many pieces of information, from the physical, economic and preferences aspects of a decision. Quickly summarizing what is known in a pictorial representation makes it easier for the users to learn, speeding the criteria and choice formulation.

SD and Demos take a while to build, but they can help the users differentiate among facts, uncertainty and opinions / preferences. This makes criteria and choice formulation more efficient. Running Uncertainty Analysis tools such as Demos also helps the users understand the level of uncertainty in the predicted results. This helps the users formulate the criteria and alternatives more efficiently than unsubstantiated debate and discussions.

Step 4) Sensitivity Analysis

a. Need to perform Sensitivity Analysis to utilize the most relevant information from each group and formulate good alternatives

Sensitivity analysis should be conducted using the best available information. Predicting the likely outcomes of many suggestion and assessing the physical and economic impacts of many alternatives, helps inform the users so they can formulate better alternatives. In the actual FKNMS decision, sensitivity analysis was not completed; long term implication were hypothesized and best guesses were offered by individuals, but no sensitivity analysis was done.

If SD or Demos had been used, many Zone alternatives could have been suggested and outcomes predicted. Building the SD or Demos model would bring together the best information from many sources; completing and running the models would enable the best possible predictions. By changing the value of a variable or linkage, one could determine how the system's predicted outcome would change. SD or Demos could be used i) while alternatives were being formulated, ii) when alternatives were being voted on and iii) in the public review process to show the probable outcomes. The graphical representations of the model and of the predicted outcome makes the sensitivity analysis easy to understand. Rather than just accept predictions from different individuals, all with just partial data, SD and Demos could be used to make predictions using the best available data from multiple disciplines.

b. Need to make explicit the assumptions used to make predictions

When there is uncertainty about any part of the decision, and assumptions are used to make predictions, it is necessary to make these assumptions explicit, so they can be tested. In the actual FKNMS Zoning decision, long-term implications were hypothesized, but there was no way the decision makers could test the assumptions of those making predictions. Also with SD and Demos, the models help make the assumptions explicit, therefore enabling the predictions to be tested.

<u>Requirement 2) Decision is made by well-informed stakeholders</u>

a. Actual Zoning process drew information from many sources

Information should be elicited from every good available source. For the actual Replenishment Zone decision, the AC and NOAA elicited information from many sources and from many people to become well-informed about the physical aspects of the system and about the preferences of the stakeholders. In the beginning of the process, NOAA focused on eliciting information about the physical aspects from many scientists, researchers and managers and spent great effort drawing out initial preferences from the stakeholders. Then, the AC elicited and reviewed information from the scientists, but also spent a great deal of time and effort getting information from the user groups. The AC reviewed the information that NOAA provided, and in addition sought many of their own sources of information.

The four different tools could have assisted in obtaining information from many sources. Since AHP and CLDs are easy to use, they can be used with many people, eliciting vast amounts of information from many sources. AHP can incorporate initial preferences and detailed final preferences without everyone spending time learning how to use the model. Likewise, CLDs can be used to organize, summarize and show linkages among many variables from the system's physical, economic and preference aspects with very little time spent. SD and Demos can also be used with different decision makers, but they require more time to build. To reduce the time it takes to learn how to use them, they can be used with facilitators or modeling experts.

b. Need to elicit the best available information for all aspects from all groups

There is a need for the all the groups participating in the decision to be well-informed about the physical, economic and human preference aspects of the decision. In the actual FKNMS decision, the stakeholders were not equally well-informed about all these aspects. This was due in part to the limited information available, but also due to the imbalance of focus and effort placed on obtaining some information. First, no one was well informed about the economic aspects, since the Socio-economic Impact Assessment had very little information concerning Zoning. Second, the AC's detailed final preferences were not elicited after the information gathering and summarizing finished. There was only a single spot vote on bundled alternatives, so no one was well-informed about the detailed final preferences of each stakeholder's representative. Third, NOAA's SEA division designed and focused the decision-making process so that NOAA could be well-informed about the stakeholders' initial preferences and knowledge from researchers about the physical aspects of the system. The AC then spent much time eliciting information about the physical aspects from a broader range of sources and about the preferences of the users.

If the four tools had been used, this step would have been more effectively achieved. AHP enables the stakeholders' representatives to elicit the best available information about the initial and final preferences, by recording objectives, criteria and detailed pairwise comparisons. SD and Demos can be used to elicit the best available information on the economics as well as the physical aspects of the decision. CLDs can be used to show linkages among the different aspects, which can help increase understanding and elicit more information.

c. Need to transfer information more efficiently

Information transfer is best done interactively, so that it is more efficient. The information that is already known should be made obvious, so those with the expertise know what information needs to be transferred before spending time and effort repeating information. It is desirable that the users summarize, organize, show linkages and prioritize the information already known.

In the actual Zoning decision, the AC spent about half their time on the Zoning Issue in an effort to be well-informed and make the best choice. Most of the information for the Zoning decision was gathered and transferred via presentations, reports and discussions, and some of the initial information was elicited and summarized with 'Knowledge Engineering.' To help the users become better informed, the information must be summarized and organized, but 'Knowledge Engineering' was the only method used to do this. None of the methods, though, including 'Knowledge Engineering' could prioritize the information or show important linkages and dependencies, so it was not obvious how the information fit together. There was a need for more tools to demonstrate linkages and prioritize information, as well as summarize and organize information.

If the four tools had been used, they could have helped summarize, organize, show linkages and prioritize. AHP hierarchy makes it easy to summarize, organize and show linkages among the different objectives and criteria. AHP also enables the users to easily prioritize the objectives and criteria, so that the decision makers' time and effort can be focused on the mutually agreed upon important parts of the decision.

Using Cognitive Maps such as CLDs allows qualitative information to be quickly summarized and organized in one place and makes explicit linkages among variables. They quickly show the mental models of how the physical system works and the linkages to the economic systems. The graphical representation of variables and linkages makes it more obvious what information is already known and understood. Effort and time can then be placed on the missing information and parts that are not yet well understood; the CLDs help prioritize the users' efforts to get more information.

Simulation models such as SD do take a fair amount of time to build, ranging from days to years depending on the complexity of the model, and SDs can not be completed for every decision. If an SD model is even attempted, though, creating the structure and quantifying even some variables, much information can be summarized and organized in one place. Attempting to build an SD also requires the users to structure the information and understand how the variables interact; this helps the users prioritize the information. If the model can be completed and run, it enables the users to prioritize the different criteria and aspects of the alternatives.

Demos suffers from many of the same problems as SD, such as requiring much time and effort to build and not being feasible for all decisions. Attempting to build the Demos model, though, elicits the level of uncertainty in each variable, and if the Demos model can be run, it can help the users understand the level of uncertainty in the predicted results. This helps transfer information more efficiently than unsubstantiated debate and discussions. Another advantage to using all four tools is that they have pictorial summaries, which help transfer information among large groups of people.

d. Need for tools to support learning, but not impose a rigid structure

Ideally, the tools should assist and aid the decision making without imposing too rigid a structure. The tool should support the discussions and debates, not but impose a structure within which *discussion* must occur to the degree that the structure is more important than the content.

In the actual FKNMS decision, NOAA's SEA division had planned for the Advisory Council to use the 'Knowledge Engineering' process at some of their meetings. The process was tried a few times, but the actual process rarely followed SEA's predetermined plans; sometimes the Advisory Council refused to use 'Knowledge Engineering' all together. The AC felt it imposed too much of a structure on the discussions and debates. It required that the AC split into sub-groups, but did not provide a time for all the AC members to reconvene and review all the information as one group. The AC felt that they would not be in control of their meetings and in control of the information they generated if 'Knowledge Engineering' were used.

AHP or CLDs could have been used without imposing a rigid structure on the process. These tools structure the information, not the process; they do not stifle free-flow discussion and debate, but can be used within it. SD and Demos do require an extremely rigid structure on the information, which can then affect the information elicitation process. While the focus and structure helps achieve more detailed information, it may impose such a rigid structure that the decision makers do not feel in control. In these cases, it is even more essential that CLDs are used first.

<u>Step 1) revisited - All the Stakeholders included</u>

a. Need for different groups to work together

As mentioned earlier, ideally, methods and tools should be used that enable members of different groups to work together, to learn from each other. In the actual Zoning process, many different groups participated in the Replenishment Zone decision, but they all worked in sequence. The AC and CG never had a joint meeting.

Using the four tools would have enabled the groups to more easily work together. Multiple group Utility Tools such as AHP allows many decision makers to partake in defining the goal, and formulating the objectives and criteria. AHP reduces the controversy and allows for more fluid brainstorming. CLDs are easy to use, and allow for many people to build a model together. Building the SD and Demos can help reduce the controversy, since they focus on the physical and economic aspects of the decision, separating preference elicitation from the physical and economic elicitation process. SD and Demos are somewhat complex to use, though, so all decision makers may not want to help build the models. All the tools enable multiple decision makers to participate and break up the different steps of decision making so that controversy is reduced.

b. Need to review stakeholders to ensure that none are missing

Once the group becomes well-informed, they should review the list of stakeholders to ensure that no important groups were omitted and that the voting power is appropriate. At the beginning of the decision-making process, the groups can not always anticipate who are all the stakeholders and what voting power each should have. Defining the stakeholders at the beginning of process depends on what was valued at beginning of process; this might change towards the end of the process. It is possible that during the decision process, some information will be learned which requires changes to be made. Of course, adding a new member or changing voting power at the end of the decision process is not desirable, but it may be better than altogether omitting an important stakeholder group.

In the actual Zoning decision, after the group became well-informed, they did not review who should be included in the stakeholder group. If new members had been added, it would have meant repeating most of the process.

If the four tools had been used, adding decision makers or altering the decision would have been relatively easy. CLDs, SD and Demos summarize and organize the physical and economic information elicited, making it easy to review and understand. If needed, a new member could become relatively well-informed about these aspects with less effort than reading many reports and reviewing the minutes of many meetings. With AHP the voting members or the voting weights can be easily altered. Also, if a new voter was added, he or she could use the AHP hierarchy to review the initial preferences of the other stakeholders. Using the tools, much information could be shared without repeating the whole process.

<u>**Step 5) Choice**</u>

a. Need to elicit detailed preferences

Detailed final preferences from the stakeholders' representatives enable the specific areas of controversy to be more easily found and overcome. Detailed final preferences also enable anyone reviewing the decision to more fully understand how combining the stakeholders' preferences led to the chosen alternatives. If detailed preferences are elicited, it is more likely that they will be more accurately considered and fulfilled by the government agency which have the final decision making power. For example, when the government agency is implementing the alternatives, they may need to make many small decisions that were not covered in the alternatives; the more detail the stakeholders' preferences, the more likely they will be represented in these decisions.

In the actual FKNMS decision, the AC used a series of spot votes to create the alternatives, and used a spot vote at the end of the process, when they voted on the final Alternative. The spot votes could not help measure the intensity of the preferences, nor could it help prioritize the many objectives. The bundled Alternatives did not differentiate among the five Zone types, so they did not elicit the AC's final preferences on the many details. Subsequently, many members of the Advisory Council did *not* feel like their preferences and values were represented in the chosen Alternative. Many felt coerced into the decisions. Detailed preferences would have enabled NOAA, the CG, the users and even the AC to more easily determine what Strategies and Alternatives most closely reflected the AC's *combined and collective* values for the resources.

If AHP had been used, the final preferences could have been elicited in great detail. The objectives, criteria and the final alternatives could have been ranked using AHP's pairwise comparisons and Dyer's normalization process. The decision makers detailed final preferences could have been elicited for many different levels of the decision, so that the preferences can be used in a greater variety of ways. For example, AHP's pairwise ranking and detailed preferences could have been used at earlier stages of the decision-making process to determine the areas of greatest controversy, and where more effort might be focused to better understand the physical and economic system.

Step 4) revisited - Sensitivity Analysis

a. Need to conduct Sensitivity Analysis on final preferences

To conduct sensitivity analysis on the decision makers final preferences, detailed criteria and objectives are necessary, so that each alternative can be measured against the same detailed list of objectives and criteria to see which one best meets the stakeholders' preferences. In the actual Zoning decision, the stakeholders' detailed criteria and objectives were not made explicit, so it was not possible to do sensitivity analysis concerning the final preferences. For example, the objective "To preserve the Current Lifestyle" was never made explicit, there were only a list of eight final criteria and criteria were not prioritized. No preferences were recorded for anything except the specific alternatives discussed. New alternatives would be difficult to assess, because there would be no way to judge them against the stakeholders' preferences other than by repeating most of the process.

AHP could be used to do sensitivity analysis, determining how sensitive the alternatives' rankings are to slight variations in the stakeholders' preferences. This is because the AHP hierarchy, the *objectives and criteria*, remain the same, even when different alternatives are considered. The users could re-vote to determine if the alternatives' ranking changed when preferences changed slightly.

b. Need to complete Sensitivity Analysis before Due diligence

Sensitivity Analysis on the physical, economic and stakeholders' preference aspects would be easier, if it could occur during the decision-making process, before the alternatives are finalized. For the actual Replenishment Zone decision, sensitivity analysis will be 'post choice' and 'post Due Diligence,' during the Public Review process, so it will be very difficult to change the decision. To be included, new suggestions would have to pass Due Diligence which has taken over a year.

Using AHP, SD and Demos, sensitivity analysis is relatively easy, because it can occur during the decision-making process, before the alternatives are finalized. It is easy to do sensitivity analysis with many computer-based Utility Functions, Simulation models and Uncertainty Analysis tools. SD and Demos could have been used to enable sensitivity analysis for the physical and economic aspects; AHP could be used for the human preference aspect of the decision. If someone made a suggestion in the review process, variable(s) could be changed to show the predicted outcome of that suggestion. The models could also help by documenting the decision process, which would make it more defensible.

Step 6) Implement

a. Actual Zoning process prepared Implementation details

Implementation is the important last step of good decision-making. Typically in environmental decision making, this step depends more on the political process, than on the decision making process within the political process. Still, within the decision making process, it is necessary to focus effort on formulating alternatives that can be implemented. In the actual FKNMS decision, SEA and the Core Group put much effort into ensuring that the implementation details were created, and that the alternatives could be implemented within its respective Government Agency. Implementation expertise from the Strategy Identification Group and the Core Group was well used, but expertise from the user groups was not as well utilized.

The tools do very little to directly help the implementation step, but could have indirectly helped this step. All the tools contribute to a chronicled, robust process that makes the decision making process and implementation much easier. Documenting the best available detailed information and the stakeholders' preferences makes it easier for the chosen alternatives to be well implemented.

Review

The FKNMS decision-making process has accomplished some of the steps of good decision-making, yet "it was an imperfect process." The tools would not have enabled a perfect process either, the tools would have enabled more of the steps of good decision-making. The tools used together can meet the recommended steps. In the chart below, the steps of actual FKNMS Zoning decision is compared to the recommended tools. The symbols are defined as follows:

X: the Step or Requirement was assisted a great deal.

/: the Step or Requirement was assisted only somewhat. It may help with only certain aspects of the item or may help, but not as much as some other tools.

0: the step was not helped at all.

~X: the step can be assisted only if the model can be completed and run (which is sometimes the case with Demos or SD).

r: the step was required, but assisted it only somewhat

a: the step was allowed, but not assisted

Chart XIII-B: Comparing Steps and Requirements of Actual vs. Tools

Steps and Requirements	Actual	AHP	CLDs	SD	Demos
Stakeholders included	r	r	a	a	a
Problem, Goal and Objective definition	/	X	a	a	r
Criteria Formulation	/	/	X	X	/
Choice Formulation	/	/	/	X	X
Sensitivity analysis	0	X	0	~X	~X
Well-informed decision makers	/	X	X	X	X
Choice	/	X	0	0	0
Implementation	/	0	0	0	0

For the Replenishment Zone decision, a recommended use of the tools would be:

Public and NOAA create AHP to list their initial criteria

AC add to or alter AHP hierarchy

AC, CG and NOAA have joint meeting to review AHP

AC, CG and NOAA all build CLD

All interested members of AC, CG, NOAA and Strategy Identification Group create SD

All interested members of AC, CG, NOAA and Strategy Identification Group create Demos

All AC, CG and NOAA informed about physical and economic aspects through SD and Demos

All AC and NOAA (and maybe CG) update AHP

AC (and CG) vote

NOAA use AC's vote to make final decisions

B. Reviewing the Complicating Factors: Comparing the Actual FKNMS Decision to a Decision Using the Tools & Steps

The Replenishment Zone process was the most controversial decision made in the FKNMS Management Plan with many complicating factors. Reviewing the list of complicating factors, one can understand how the recommended tools and steps overcome most of the complicating factors better than the actual FKNMS process. All nine factors developed in Chapter II will be discussed, rather than use the summary of three complicating factors, to ensure that no subtleties were overlooked. The following chart is a summary of how well each complicating factor was overcome by the actual FKNMS process versus the tools.

Chart XIII-C: Comparing Complicating Factors of Actual vs. Tools

Complicating Factors	Actual	AHP	CLDs	SD	Demos
A great volume of information	/	X	/	X	X
Criteria that are not easily monetized	/	X	X	/	/
Variables from multiple disciplines	X	X	X	X	X
Interdependencies of the variables (dynamic & cyclical)	0	/	X	X	X
Uncertainty	/	/	/	/	X
One time decision with high stakes	/	/	0	~X	~X
Appropriate time scale uncertain	0	/	0	~X	~/
Appropriate spatial scale uncertain	0	/	/	/	/
Many people w/ multiple preferences	/	X	X	/	/

One can see that together, more of complicating factors can be overcome using the different families of tools than in the actual process. The details of this chart are discussed below.

1. Inadequate Information Management

With environmental decisions, problems managing the information stem from four causes.

a. Too much information to consider it all adequately

In the Replenishment Zone decision, there was a vast amount of information to consider and the decision had a variety of aspects, such as information about the system's physical, economic and human preference aspects. In the actual FKNMS process, the initial human preferences were recorded and summarized as lists. Much information about the physical aspects was obtained, but only some of it was summarized; some implicitly via suggestions and choice formulation, and some recorded and organized explicitly using 'Knowledge Engineering.' Information about the economic aspects of the decision was not summarized in any meaningful way, and detailed final preferences were not elicited. NOAA, the CG and the AC recorded much of the information through informal processes, often in their memories.

AHP, CLDs, SD and Demos could have all been used to help overcome different aspects of this complicating factor. AHP could be used to overcome the human preference aspects part. AHP enables a great deal of initial preferences to be considered by recording and organizing many objectives and criteria. Using AHP at the end of the decision-making process, detailed information about the stakeholders' final preferences can be elicited, recorded and combined.

The Replenishment Zone CLD made it easy to collect and summarize a large amount of information about the physical, economic and some human preference aspects of the Zoning decision, showing the interconnections of many variables. The CLD was used to begin organizing the large amount of information from a number of articles, books and researchers, used to record the many variables and linkages all in one place, but it could not be used to organize as much detailed information as other tools.

Simulation models can help overcome this complicating factor for only the physical and economic aspects of the decision. Using Systems Dynamics for the Zoning decision, a great amount of detailed information was included by identifying variables and linkages, and by defining equations and initial values. SD models could not be finished and run for every part of the physical or economic system, but SD models could be *attempted* for any representative part of a decision. Even if an SD model can not be finished and run, just by *attempting* to create the model, much detailed information is organized and summarized, therefore considered.

Demos, like Systems Dynamics, can include detailed information, but can do so for only parts of the decision. Using an Uncertainty Analysis tool like Demos for the Zoning decision, it was possible to summarize extremely detailed information. By defining equations and initial values as statistical distributions, the *level* of certainty with which information is known can be included. For example, the statistical distributions of uncertain variables such as the Fishing Efforts, the Natural Mortality Rates and the Cryptic Death Rates were easily included. Using Demos, very detailed information can be considered.

b. Criteria and variables that cannot be accurately reduced to monetary terms

In the Replenishment Zone decision, there are many variables that can not be reduced to monetary terms or represented by a dollar value, but there are some monetary calculations that can and need to be completed to fully understand the Zoning decision. In the actual FKNMS Zoning decision, the Socio-Economic analysis could not accurately quantify *any* of the impacts. Hypotheses of the economic repercussions were discussed, but i) not everyone agreed to these hypotheses, yet there was no way to test these hypotheses and ii)the economic information was not included into the decision in any formal way.

The four tools can be used to overcome the different aspects of this complicating factor. Using AHP in the beginning of the process, the users can summarize and organize both the monetary and non-monetary, the quantifiable and non-quantifiable variables that are important in choosing the best Replenishment Zone. Using AHP at the end, pairwise comparisons allow any two variables to be compared, even when they are not reduced to the same scalar unit. The users' subjective evaluations and preferences can be used to compare the relative importance of any two variables, such as 'Preserving the Current Lifestyle' and 'Preserving the Biodiversity' without assigning dollar 'equivalents' to either. Any two variables can be compared, monetized or non-monetized, quantifiable or non-quantifiable, during the ranking process.

The Zoning CLD could easily include any variable or linkage whether it had a monetary equivalent or not. Variables do not need to be compared, so there is no need to define them using the same scalar unit. Linkages could be specified between two variables without reducing the variables to monetary terms. For example, the CLD reflects that the Fishing Income would increase if the pollution levels decreased, yet this linkage did not need to be specified using a dollar metric. The CLD also helps because when the users specify all the variables in chain of cause and effect, they get a sense of the uncertainty involved in any monetary estimate. For example, the CLD showed that there are many variables affecting Fishing Income, and the link between it and Pollution Levels is very complex. With CLDs, there is no need to specify the dollar equivalents, yet economic variables can be included and linkages can be drawn to the physical, biological and chemical parts of the system.

System Dynamics and Demos do not require that a dollar value be used to represent every variable in the system, but to run the model all variables and linkages do need to be defined in some scalar measure. All variables and linkages must be quantified as a mathematical equation to describe how they affect other variables. For example, to include the Health of Habitat in the Replenishment Zone SD, it had to be modeled as a number, as the Habitat's Holding Capacity, an upper limit on the number of fish that an area could support. If the users had wanted to represent a decline in the Health of Habitat, it could be represented as a decline in the maximum number of fish possible, again a quantification, but not a dollar value. All variables do not need to be reduced to a monetary term, but they do need to be defined in some scalar measure.

SD and especially Demos also *enable* monetary estimates to be made of some parts of the decision, when all the factors are known well enough to write equations. For example, the tools could be used to estimate Fishing Income. In addition, with Demos the users see all the uncertainty involved in the estimate and can better judge whether it is a worthwhile calculation. Tools that allow for both monetary and non monetary variables have the most potential for assisting environmental decisions.

c. Criteria from multiple disciplines, expertise needed from many areas

To decide upon the Replenishment Zones, there was a need to combine many different types of information, from many fields of expertise. No one 'technical expert' could find the best alternative or solve the problem. The decision requires that many people from many different disciplines provide information and *learn* from each other.

The actual Replenishment Zone decision was good, because people from many different fields of expertise and many different backgrounds participated in the Zoning decision. It was lacking, though, because the information from one group was often not shared or transferred among other groups. If information was elicited in one meeting, it was not easy to add to or build on this information after the meeting ended. There were no methods that summarized *all* the information from the many different disciplines in one place.

The four tools could be used to overcome the different aspects of this complicating factor. The Zoning AHP was able to incorporate variables from multiple disciplines within one hierarchy. For example, it could combine the *scientific* variables such as the Pollution Effects and Preserve Healthy Habitats with the *social* variables of Ideologically Opposed to Regulations and the *economic* variables Fishing Income. Other tools were needed to elicit and inform about the importance of the physical and economic aspects of many variables, but AHP could summarize all these variables in an updated hierarchy. AHP could then be used to elicit the users' preferences on variables from many disciplines, enabling their relative importance to be compared.

CLDs, too, can include variables from multiple disciplines. The Zoning CLD included the *economics* of Fishing Income, the *social aspects* of Catch Limits and the *biology* of fish life-cycles such as Natural Mortality rates and Reproduction rates. This enables the many pieces to be understood within the context of the whole system.

SD and Demos are also effective at including and linking variables and information from a wide spectrum of disciplines. Data on the physical aspects of the Zones such as Currents was combined with information on the Duration of the Larvae's Pelagic stage. Commercial Fishing Efforts and Recreational Fishing Efforts were combined with Natural Mortality Rates and Cryptic Mortality rates. SDs and Demos can incorporate, summarize and organize information from multiple disciplines, even if the models cannot be run. They do not, though, elicit or organize the human preferences.

d. Interdependencies among the different environmental decisions

In the Replenishment Zone decision, there were many dynamic and cyclical interdependencies among the variables, making it difficult for the decision makers to mentally organize the information. In the actual FKNMS Zoning decision, discussions and presentations helped illuminate different topics, but all the information was not recorded in a structured form to show the interdependencies, to help the different groups understand the linkages. 'Knowledge Engineering' was sometimes used to organize and categorize information, but it did not show linkages among the variables.

The four tools can be used to overcome the different aspects of this complicating factor. AHP can show the interdependencies of the human preference information: the overall goal, the objectives and the criteria. By showing how the variables are connected in the hierarchy, the interdependencies of the AC, CG and NOAA's preferences are made explicit.

CLDs provide a quick and easy way to show the interdependencies, by recording many variables and drawing arrows to show cause and effect. For example, the CLD showed that the Age Structure affected the Reproduction Rate, which affected the Abundance of Fish. The Abundance of Fish is one factor that determined the Fishing Efforts, which in turn affected the Age Structure. The CLDs can easily represent the linkages, but does not attempt to quantify the interdependencies.

Simulation models such as SDs are the next step past CLDs. With Simulation models, linkages need to be quantified as mathematical equations, not simply as arrows with pluses or minuses. If equations can be formulated, then the SD can be used to quantitatively determine how the different variables affect each other, enabling the users to develop a general understanding about how the variables interact. Running the SD helped quantify the interdependencies among variables such as i) Cryptic Mortality and Stock of Fish, ii)Catch Limits and Fishing Efforts and iii) the Zone Size and the time to replenish. SDs help because "although people are pretty good at understanding the structure of relationships that make a system work, they are not very good at intuiting how the dynamics generated by the relationships will play out." (High Performance iThink Manual, 1992)

Demos is good at summarizing the statistical distributions of variables' interdependencies, and in doing so can help the users quantitatively determine how the different variables affect each other. Demos is good for informing the users about the interdependencies' details, but is not as useful as Systems Dynamics for helping the users develop a general understanding about how the variables interact. This is because of Demos' loose structure, which allows the interdependencies to be defined in many ways, some of which might be incorrect. Demos' looser structure also means that most of the inter-dependencies are captured within a variable's equation rather than pictorially. For example, by looking at the Demos diagram, it is not obvious that the Stock of 0-year-olds is depleted by the Larvae Bycatch, Larvae Natural Deaths and Growth into 1-year-old fish. The tools that help show the interdependencies and linkages between and among information are needed in environmental decisions.

2. Uncertainty: Scientific information is incomplete

In the Replenishment Zone decision, there were uncertainties, both probabilistic uncertainty and true uncertainty,[111] making it difficult for decision makers to predict outcomes and choose the optimal alternative. The actual FKNMS Zoning decision attempted to decrease the level of uncertainty by eliciting a great deal of information from many sources, but still there was uncertainty in many of the variables and in the predicted outcomes. There was no method used to analyze the uncertainty, to quantify the level of uncertainty in the information or in the predictions made.

The four tools could help reduce the uncertainty. AHP allowed the Zoning hierarchy to include variables and allowed preferences to be placed, even if there was uncertainty. The CLD could be drawn including many uncertain variables and linkages, because CLDs do not require much detail. Although AHP and CLDs are both not hindered by uncertainty, they also do not help the decision makers understand or analyze the levels of uncertainty.

Systems Dynamics are hindered by uncertainty; the Zoning SD was not able to include the Health of Habitat sector, because there was great uncertainty in many of the variables and linkages. The entire Health of Habitat sector was included only as an upper limit on the maximum fish population within an area. Also, an SD model could not be realistically created for all 6000+ species, because there was too much uncertainty. SDs can analyze uncertainty in a very limited way, though, by doing parametric sensitivity analysis, where only one variable's uncertainty can be analyzed at a time.

Demos is excellent at accommodating probabilistic and statistical uncertainty in variables and linkages. In the Red Snapper Zoning model, Demos could incorporate every variables' uncertainty by easily defining the variables and linkages using statistical distributions. For example, the Natural Mortality rates of all age groups is not known with certainty, because "as with most exploited fish stocks, the level of mortality in the Gulf of Mexico Red Snapper is not well-defined," so this variable could be defined as a statistical distribution. (Goodyear, 1992) Demos can also incorporate every variables uncertainty at the same time to analyze the level of uncertainty in the predicted outcome. Like SDs, though, an accurate Demos model could not be built for all 6000+ species where there is true uncertainty and unknown variables.

[111] See **Chapter II** for the discussion concerning uncertainty.

a. One time decision with high stakes

There were some one-time, high-stakes decisions as to whether to create Replenishment Zones, because for example, it was not known if certain species will become extinct. There is also uncertainty as to what would happen to the ecosystem if some of the species crashed. These results may happen if the Zones are not created now or if the designated Zones are not big enough. In the actual Replenishment Zone decision, these types of outcomes were discussed, but could not be analyzed. The stakeholders' representatives could only implicitly consider the one-time, high stakes when final preferences were elicited.

SDs can help overcome this if the model can be run. The SD model provides 'practice runs' for the different possible alternatives, so that the decision makers can see the likely outcome of the chosen alternatives. For example, the Replenishment Zone SD model could show which alternatives would allow the species to crash and which alternatives could prevent the Red Snapper from crashing. The model provided a means for the decision to be made 'multiple times' in 'practice runs' so that the users could begin to explore the results, and the high stakes. The SD is not very good at determining the *probability* of the high stakes outcomes, though.

Demos is better than SD at overcoming this, again if the model can be run. Not only can Demos provide 'practice runs' to see the expected outcomes, but by expressing the expected outcomes as a distribution function, the users can be informed about the probability that a high-stakes event might occur. For example, if no Replenishment Zones are created and the Reproduction rates are actually 24, then the likelihood that the Stock will crash is more than 50%, but if the Zones are created, then the probability drops to less than 30%. Demos can provide information indicating what actions will most likely prevent disastrous results.

AHP could help overcome this complicating factor only somewhat. Used at the end of the decision-making process, when eliciting the final preferences, AHP enables the users to implicitly value those parts of the decision which make it a one-time, high stakes decision. CLDs can not help address this complicating factor at all.

b. Appropriate time scale unknown - various ways to consider the project's time frame

In making any environmental decision, including the Replenishment Zone decision, it is difficult to have all stakeholders consider the same time frame, and it is hard to know what time frame is 'right.' In the actual FKNMS decision, the wording in the FKNMS Act requires that the Management Plan be developed looking at a long time frame, but yet does not define 'long time frame.' The Act also requires that the entire Plan be reassessed in five years; it is not known if five years is an appropriate time frame, though. The appropriate time frame is uncertain, so all stakeholders may not be stating their preferences or offering scientific and economic information with the same number of years in mind. No one could do sensitivity analysis to predict the outcome over time, so it is not known how much the decision would change if different time frames were considered. Finally, although the decision will be revisited in five years, the actual FKNMS decision process has not created a structure enabling the decision to be easily revisited.

AHP, SD and Demos can be used to overcome the different aspects of this complicating factor. AHP can help overcome this only somewhat. Used at the end of the process, AHP elicits the users' preferences when they consider, either explicitly or implicitly, a certain time frame. If the decision makers were explicitly told an 'appropriate' time frame to consider, AHP could be used to elicit preferences for that time frame. If the time frames were dictated and varied for sensitivity analysis, i) a new set of pairwise comparisons and ranking of alternatives would have to be elicited from each voter and ii) new objectives and criteria might need to be added. It might be a rather lengthy ordeal to change the time frame, but it is possible.

SD is excellent at overcoming the problem of considering different time frames if the model can be *completed and run.* In running the model, the users specify the time frame for which they would like to see an outcome predicted, such as one year, 10 years, 100 years... by defining the time horizon. In the SD Replenishment Zone model, it was easy to change from a 20 year period to 120 just by changing one number. It was also easy to change the Dt, to have the calculations updated every one year or every one-fifth of a year, again just by changing one number.

With Demos, considering different time frames is more difficult than with SD, but it is still possible. For example, in the Replenishment Zone decision, changing the Dt from 1.0 to 0.2 required changing the definition of the N3 Stock variable and about ten other variables. It also required that the modeler explicitly understand how the Demos software performs its calculations.[112]

[112] Doing uncertainty analysis for long time frames, even for very small models, requires long computing times and large amounts of memory. Running the small Replenishment Zone model (less than 20k) for only 15 years required about 4MB of memory and took over five minutes on a high end personal computer.

A CLD can do very little to overcome this complicating factors, because it never approaches this level of detail.

c. Appropriate spatial scale unknown - various ways to consider the project's geographical scope

The geographic scope of the Replenishment Zone decision was not well-defined; the variables that affected the Zones were not just those within the Zone boundaries, but also included the surrounding areas, even the entire watershed. The water quality, fishing activities, weather patterns, etc. of areas outside the Zones affect what takes place inside the Zones. In the actual FKNMS Zoning decision, this was addressed by creating the Water Quality Protection Plan for the Sanctuary, and by various plans being developed for the entire South Florida watershed. Still, there was nothing in the FKNMS process that helped with the uncertain geographic scope. There was no way to do sensitivity analysis to determine if a 50 mile radius is an appropriate area to consider for effects on the Replenishment Zone, or if or a 1000 mile radius is more appropriate.

AHP, SD and Demos can be used to overcome only somewhat the different aspects of this complicating factor. Used at the end of the process, AHP elicits the users' preferences when they consider, either explicitly or implicitly, a certain geographic scope. If the geographical scope were dictated, and then varied for sensitivity analysis, i) a new set of pairwise comparisons and ranking of alternatives would have to be elicited from each voter and ii)new objectives and criteria might need to be added. It is possible to change the geographic scope with AHP, but it can be a lengthy process.

SDs did help some parts of this complicating factor. For example, it was relatively easy to change the geographic boundaries of the Zone form 150 square miles to 187,500 square miles. Also the SD could have been changed to review the Red Snapper model from just within the FKNMS boundaries instead of the entire Gulf of Mexico. To do this, the values for Fishing Efforts would need to change to include just FKNMS and Florida efforts. Also, the initial Stock values would need to change. A new variable would need to be added to represent the Red Snapper that migrated out of the FKNMS boundary and into other parts of the Gulf. The users might also contact the Florida Fishery Council to see if there were any new variables important to the Stock of Red Snapper in just the FKNMS. If boundaries were changed, either new variables can be added to the model or the same variables would exist and new initial values would be defined, but an entirely new and different model does not need to be created from scratch. Much of the benefits of the model, the system knowledge elicited can be transferred when the geographical framework is changed.

Like SDs, Demos can help somewhat at overcoming this complicating factor. With Demos, new variables can be added to the model or existing variables can be given new values if the geographic scope is changed. Usually, the existing model does not have to be destroyed, but just altered. The same changes would need to be made for the Demos model as the SD model.

CLDs do very little to help overcome the complicating factor of different geographic scopes.

3. Many people (users, decision makers and implementors) with different preferences

Because the geographical area that affects the Sanctuary and each Replenishment Zone is so large, the number of stakeholders that have impact on and jurisdiction over the Sanctuary is enormous. There are many user groups within the Sanctuary borders where there are conflicting interests and goals, and there are also conflicting goals outside the borders.

For the Replenishment Zones, there have been many decision 'formulators' responsible for determining the Replenishment Zones: the Advisory Council, the Core Group, the Strategy Identification Group, NOAA, user groups, the state officials, local officials, etc. All worked on pieces of the decision, *but the process did not allow all to work on it together.* With so many people involved, eliciting and transferring information was difficult. Consensus building was difficult and took a long time.

AHP can overcome one aspect of this complicating factor, because it allows many people to participate. All the AC, CG and NOAA members had different concerns and values, yet all could take part in the decision if AHP were used. Together the group could build the hierarchy, defining goals, objectives and criteria, stating their initial preferences. At the end of the decision-making process, AHP could have been used to elicit, then combine the final preferences of all the members to rank the alternatives. Having many decision makers with multiple values is not a problem with AHP.

CLDs, SD and Demos can not be used to combine the preferences of many stakeholders, but by informing the stakeholders and reducing the uncertainty in the outcomes, these tools may make it easier to reach consensus. CLDs are very easy to use with a large group of people, even if they have different values. Many decision makers can participate in building and learning from a CLD without investing a great deal of time learning how to use the tool. All the decision makers can take part in identifying the many important variables and the linkages among the variables. This helps elicit knowledge from the different decision makers, but does not explicitly address the different *values* of the users. Systems Dynamics and Demos can be used with multiple decision makers, although they are somewhat difficult to learn how to use. With the help of modeling experts or facilitators, more people can more easily participate. None of these tools are a utility functions, though, so they are not capable of reviewing and collecting values of many different decision makers; AHP is the only tool out of the four that can do this.

<u>Summary</u>

The charts below summarize how the actual FKNMS process compares with the tools and recommended steps. It summarizes how well each aspect of the nine complicating factors were overcome, the human preference aspects, the economic aspects and the physical aspects of the decision. In the tables, the lower case letters denote that the complicating factor was addressed, but to a lesser extent than where the upper case letters are used.

Chart XIII-D: Complicating Factors overcome in Actual

Complicating Factors	Init. Pref	Economics	Physical	Final Pref
A great volume of information	actual	-	actual	-
Criteria that are not easily monetized	ACTUAL	actual	ACTUAL	-
Variables from multiple disciplines	ACTUAL	-	ACTUAL	actual
Interdependencies of the variables (dynamic & cyclical)	-	-	-	-
Uncertainty	actual	-	-	-
One time decision with high stakes	actual	-	actual	-
Appropriate time scale uncertain	-	-	-	-
Appropriate spatial scale uncertain	-	-	actual	-
Many people w/ multiple preferences	ACTUAL	-	actual	actual

In the actual FKNMS decision, different aspects received different amounts of focus. The table below shows how different tools focus on the different aspects as well.

Chart XIII-E: Complicating Factors overcome with Tools

Complicating Factors	Init. Pref	Economics	Physical	Final Pref
A great volume of information	AHP, cld	cld, SD, D	cld, SD, D	AHP
Criteria that are not easily monetized	AHP	CLD, sd, d	CLD, sd, d	AHP
Variables from multiple disciplines	AHP	CLD, SD, D	CLD, SD, D	AHP
Interdependencies of the variables (dynamic & cyclical)	ahp, cld	CLD, SD, D	CLD, SD, D	ahp
Uncertainty	ahp	cld, sd, D	cld, sd, D	ahp
One time decision with high stakes	ahp	~SD, ~D	~SD, ~D	ahp
Appropriate time scale uncertain	ahp	~SD, ~d	~SD, ~d	ahp
Appropriate spatial scale uncertain	ahp	cld, sd, d	cld, sd, d	ahp
Many people w/ multiple preferences	AHP	CLD, sd, d	CLD, sd, d	AHP

One can see that together, more of complicating factors can be overcome using the different families of tools than in the actual process. The chart shows that different families of tools can together overcome or reduce the severity of most complicating factors found in coastal environmental decision-making.

Each of the tools, AHP, CLD, SD and Demos helped address the different aspects to a greater or lesser extent. One can see that AHP helps most with the human preference aspects of the complicating factor, since it is a Utility Function. CLDs, SD, and Demos help more with the economic and physical aspects of the decision, since they are not Utility Functions. They are more Multi-Criteria Decision Making tools that inform about the 'Production Function.' With SD and Demos, more of the complicating factors were overcome if the model could be run, but these tools could help overcome some factors even without completing the model.

C. CONCLUSIONS

The tools used in combination are better than any one tool used alone and are better than the actual decision making. Although the actual FKNMS process met some of the steps of good decision-making and overcame some of the complicating factors, the actual process did not meet all of them. Using the tools, more of the steps could be met and more of the complicating factors could be overcome. First, the tools can be used in an iterative manner to best fulfill the steps of good decision-making. Second, by achieving each of the steps, the tools can better overcome the complicating factors. The tools used within the recommended process[113] helped overcome more aspects of the complicating factors than the actual process did.

Using the criteria for a good decision discussed in Chapter III, these tools should then enable the three necessary conditions of good decision making more readily than the actual FKNMS process did. To see if this is a reasonable conclusion, the next chapter will compare the actual process to the proposed process and draw conclusions about this work.

[113] The different families of tools that overcome the complicating factors were discussed in **Chapter IV and V**, and the recommended steps for a 'Good' decision were discussed in **Chapter III.**

Chapter XIV. Conclusions

This chapter first compares the actual FKNMS process to the recommended tools and steps to evaluate the degree to which the three necessary conditions of good decisions were met and to determine which decision would be closer to Pareto Admissible. This chapter then reviews what has been learned through this research and projects what will be most useful for future environmental decisions concerning common property resources. A summary of the recommended families of tools and how they are best used within the recommended steps is provided. This chapter also reviews the limitations of this work and proposes areas of research for further exploration of this topic.

A. THE THREE NECESSARY CONDITIONS OF GOOD DECISION-MAKING: COMPARING THE ACTUAL FKNMS DECISION TO THE TOOLS & STEPS

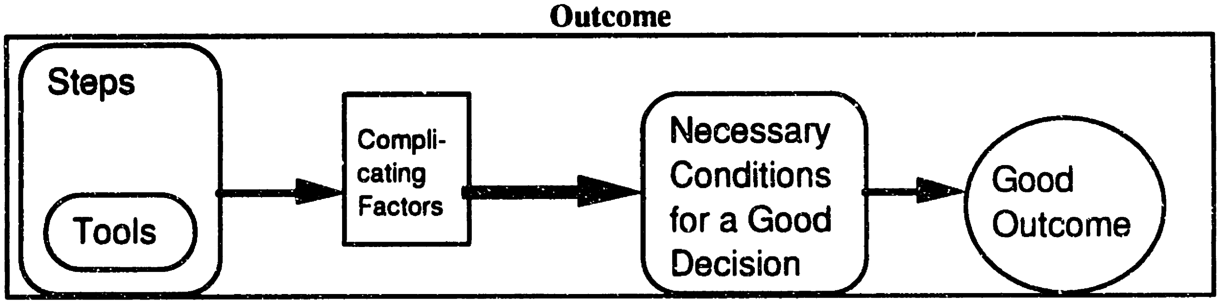
As discussed in Chapter III, the Market System can not be used to efficiently allocate environmental common property resources, because the input and output factors are not privately owned. Still, the other necessary conditions should be pursued in order for the environmental resources to be efficiently allocated, to make good environmental decisions. The previous chapter reviewed how the tools could achieve most of the steps of good decision making and reduce the complicating factors. This section will review the three necessary conditions for creating good environmental decisions, comparing the actual Replenishment Zone decision with the proposed tools:

i) All stakeholders' representatives are well-informed

ii) preferences of all well-informed stakeholders' representatives are included

iii) flexible and adaptable decision is achieved

Figure XIV - A: Tools and Steps can reduce complicating factors to reach Good Outcome



1. Stakeholders well-informed

There are two parts to having the stakeholders well-informed: all relevant information elicited and this information transferred to the all the stakeholders or their representatives. No one group should have an information advantage.

a. Good information elicited

Borrowing from the FKNMS decision analysis in Chapter VII, it is likely that the most relevant information could have been elicited if:

i) the information was well managed,

ii) the uncertainty was analyzed and quantified,

iii) information and preferences from many people could be incorporated.

These can be accomplished using the combined families of tools.

To elicit the most relevant information, it is necessary that the *information be well managed.* Summarizing, organizing, structuring and showing linkages helps to show the users what is already known and indicates the gaps in knowledge. The users can then determine what information is missing and searched for, increasing the likelihood that the best available information will be included. In the actual Zoning decision, much of the information elicited was not summarized in one place, other than informally in the memories of the AC members. Much of the physical and human preferences information was not recorded in such a way that made it easy to share among the many groups. Each group had good information to contribute, but it was difficult to assess what one group knew and what was missing. The four tools, AHP, CLDs, SD and Demos, could have been used to summarize, organize, structure and show linkages for the existing information, helping to elicit the most relevant information.

To elicit the best available information, it is also necessary that the *uncertainty* be analyzed and quantified, and long term predictions tested. In the actual Zoning decision, the uncertainty was not formally analyzed, because they did not use any methods to test the assumptions or degree of certainty in the predictions. Much of the uncertainty was simply ignored. Demos could have been used to elicit the level of uncertainty in each relevant variable and to quantify the level of uncertainty in the predicted outcomes. SD could also have been used to perform some uncertainty analysis, predicting outcomes and doing parametric sensitivity analysis. AHP and CLDs could have been used to elicit information, even if it contained uncertainty.

Finally, part of utilizing the best available information means incorporating the *final preferences* of the many stakeholders. In the actual decision, the Advisory Council's *detailed* preferences were not elicited, since all the voting was spot votes. The AC did formulate their own list of eight criteria, which helped to indicate their general preferences, but they were not detailed. Another problem was that groups other than the AC who contributed to the decision, NOAA, the CG and the Strategy Identification groups, never made their criteria or preferences explicit; this made it difficult for the stakeholders to understand why these groups made the suggestions and choices they did. Using AHP helps organize and summarize detailed preferences so that more can be elicited.

b. Knowledge transferred

A great deal of knowledge was transferred in the actual Zoning decision, but it could have been increased if the tools and recommended steps were also used. NOAA spent great efforts eliciting information through the 'Knowledge Engineering' process and the Strategy Identification Workshops, but were not always successful transferring this information to the stakeholders and their representatives. Many felt NOAA did not educate effectively. Information transfer would have been more successful if:

i) the information elicited was summarized and organized and the linkages were shown,

ii) the stakeholders' representatives were involved in more of the critical meetings,

iii) the different groups had opportunities to work together to transfer knowledge

Comparing the actual decision to the different families of tools can show how these can be more easily accomplished with the tools.

Just as it is necessary to summarize, organize and show linkages to *elicit* the best available information, it is also necessary in order for knowledge to be more easily *transferred*. Written reports can record information, but they are time consuming to review, making it difficult to transfer the best available information. Lists can summarize and organize information, but do not show linkages. In the actual Zoning decision, discussions, presentations and 'Knowledge Engineering' were used to transfer information, but only the latter can summarize and organize information. 'Knowledge Engineering' essentially only created lists, so no linkages were explicit. These methods used made it difficult to maximize the information transfer *within* a group and *across* the various groups. As said earlier, if AHP, CLDs, SD and Demos had been used, more information could have been summarized, organized and more linkages shown, so that it would have been easier to transfer information within and across the groups.

In order for the best available information to be transferred, the stakeholders or their representatives should have also been involved in more of the *meetings* where the information was *summarized and organized.* Learning is maximized when the participants are not just listening to or offering pieces of information, but summarizing, organizing and processing it so it is internalized.[114] In the actual Zoning decision, neither the stakeholders nor the AC members were asked to participate in the meetings where the information was manipulated and structured, such as the reviews after the Public Scoping meetings and the five Zoning workshops or in the Strategy Identification workshop. Using AHP and CLD would have enabled the information to be organized as it was elicited, during the meetings; all those who participated and suggested information, could also take part in organizing it. This would have enabled more information to be transferred to the stakeholders.

The third necessity for transferring the best available information is for t*he different groups to meet and work together* at various times in order to transfer knowledge. Information transfer is rarely optimized unless the different groups meet to discuss the relevant topics, to supplement the recorded information and communicate some of the subtleties. In the actual Zoning decision, the AC and user groups worked separately from the Strategy Identification Group, which worked separately from the CG; this made it difficult for information elicited by one group to be used within a different group. NOAA was the 'glue' among the groups, typically writing the summary lists or explaining one group's results to another group, so each group had to trust NOAA's interpretations or biases. Using the tools would have made it easier for the different groups to work together, within the same meeting. First, AHP separates the brainstorming stage from the judgment stage, minimizing controversy. Second, if the aim for building a CLDs, SD and Demos is pre-determined, then it is easier for members of different groups to work together, eliciting the best available physical and economic information, separating facts and substantiated information from opinions; this helps transfer the most relevant information more efficiently.

Overall, the stakeholders' representatives could have been better informed. It is likely that more information could have been elicited, and more information could have been transferred within and across the different groups if the tools had been used.

> "Tools and models help expose the mental models of each individual." (High Performance iThink Manual, 1992)

Building a model such as AHP, CLD, SD or Demos with a group provides a means for the most informed people from the many different parts of the systems to efficiently improve the

[114] As said earlier, the old adage "I hear, I forget; I see, I remember; I do, I understand." applies.

Cognitive Maps of the other participants.[115] For example, AHP helps expose the 'Maps' of each stakeholders' *value* system. CLDs, SDs and Demos act as summaries of the best Cognitive Maps of physical and basic economic resources of the system. Pictorial tools help record the information and show the linkages in abbreviated forms, making the information explicit and more accessible; the tools can be used to easily transfer information to all decision makers and many more stakeholder groups.

2. Preferences of well-informed stakeholders included

There are two parts to ensure that the preferences of the stakeholders are included. First, it is necessary to elicit detailed initial and final preferences from the stakeholders. Second, it is necessary that these preferences be combined and incorporated in the chosen alternative.

a. Detailed initial and final preferences elicited

The actual Zoning decision was good at eliciting initial preferences in the many meetings, but less successful at eliciting detailed final preferences. Overall, to improve the initial and final preferences, there was a need to:

i) summarize the initial preferences in real time to achieve a greater level of detail

ii) prioritize objectives and criteria

iii) use methods that enable the intensity of initial and final preferences to be expressed

iv) elicit detailed preferences throughout the decision to steer and focus the efforts

Multi-criteria Utility Functions such as AHP can be used to achieve this.

In order for *detailed* preferences to be elicited, it is necessary *to summarize* the initial objectives and goal during the meetings. This enables the participants to learn more, which in turn helps the participants reach a greater level of detail. Also, the stakeholders can more easily check the accuracy of the initial preferences if they are summarized during the meeting rather than after the meetings when the stakeholders can not review the information as a group. In the actual Zoning decision, discussion, debate and surveys were used to elicit the stakeholders' initial preferences during the Public Scoping meetings and the five Zoning Workshops. NOAA and the CG summarized the objectives and criteria *after* the meetings, not in real time with the stakeholders present; the stakeholders were not invited to

[115] Scientists or technical experts may argue that they often know the best technical solution without the help of models. They do not necessarily, though, know the 'best' alternative, because the stakeholders' preferences must be incorporated to find the 'best' alternative. (Refer back to the definition of Pareto admissible.) Stakeholders, therefore, need to have the best available information that is relevant to the decision, so that they can make informed decisions and their values can be included.

participate. Using AHP, the initial preferences could have been summarized *as they* were elicited, with the stakeholders learning and achieving a greater level of detail.

In order for preferences to be accurately included, it is also necessary for the *objectives and criteria to be prioritized.* In the actual Zoning decision, initial preferences were elicited during the workshops and Public Scoping meetings but the participants complained that these objectives were never prioritized. Using AHP's pairwise comparisons would have enabled the objectives to be prioritized.

Also, to include more accurate preferences, the *intensity of preferences* should be expressed. In the actual Zoning decision, the different user groups and the AC could not accurately *express* the intensity of their opinions, the degree of differences in their opinions, or the importance of any one detail. The only method used to convey this was by the number of comments made, or by the amount of 'air time' used to discuss a concern; both of these are inaccurate indications of preferences. Likewise, the CG, the AC and NOAA, could not accurately *assess* the depth of the stakeholders' convictions or the importance of an concern. Although criteria were identified and spot votes were taken, the intensity of the preferences was never elicited or recorded. Using AHP's pairwise comparisons allows the users to express the intensity of their preferences.

Lastly, it is best if these detailed preferences are elicited throughout the decision-making process, at different stages, to steer and focus the efforts. This makes it easier to find the areas of compromise and controversy, making it possible to focus the discussion so that the areas of largest controversies can be diminished. Prioritizing the objectives and criteria, and accurately expressing the preference intensities should occur at the end and throughout the decision making process. In the actual Zoning decision, the Advisory Council typically discussed and debated a concern, using 'air time' to determine the areas of greatest controversy. They formulated different choices and conducted a spot vote to either propose the alternative or not, but spot votes do not elicit detailed preferences. They used informal methods to steer and focus the discussions and the process. As a result, many members of the AC and general public do not feel like their concerns were addressed and much controversy is expected during the public review process. Using AHP's hierarchy of objectives, sub-objectives and criteria would have allowed pairwise comparisons to be elicited at any stage of the process, eliciting the priorities and intensities of the preferences.

b. Preferences included in final choice

To more easily include initial and final preferences in the final decision, there was a need to:

i) find linkages between the preferences and the physical and economic aspects so that this information is easier to incorporate

ii) combine the many final preferences accurately

Using a Multi-Criteria Utility Function tool, like AHP, supported by the other families of tools, many individuals' preferences can be included and combined to make an overall decision.

In order for preferences to be included in the final decision, it is necessary to summarize and organize all the physical and economic information, *and find the linkages to the preferences.* This makes it easier to assess the information at the end of the decision making process, so the stakeholders can use it in formulating their final preferences. The stakeholders can then judge the different alternatives using the information learned and place more accurate preferences. In the actual FKNMS decision, much work was done to elicit information and initial preferences, some of which was detailed, but the linkages from the physical and economic information to the preferences were not explicit. Although there were many criteria identified, the criteria and other information were not recorded in a way that made them easy to consider and incorporate into the final votes. Using CLDs, SD and Demos helps summarize and organize the variables, identifying new criteria. The AHP can be updated with this information extracted, and then final preferences can be elicited for these criteria, making it easier to incorporate the important information into the final preferences.

Also, in order for preferences to be included in the final decision, there must be a method for combining the many individual preferences. In the actual FKNMS decision, spot votes were used which can lead to great inaccuracy, as explained in Chapter V. AHP provides a more accurate methodology for combining the complex preferences of many decision makers.

Overall, the preferences of the informed stakeholders could have been more accurately included. Detailed final preferences of the stakeholders' representatives were not elicited or recorded. It was difficult to incorporate some of the preferences into the final choices, since connections were not explicitly made to the physical and economic information, and priorities and intensities were not known. It is likely that the preferences of the stakeholders' representatives could have been included more accurately if the tools had been used.

3. Decision is flexible and adaptable

In order for a decision to be flexible and adaptable, it must be possible to explore and assess a new alternative if one were created or found. If the new alternative is determined to be better, then the chosen alternative should be changed and the new one adopted.

In the actual FKNMS decision, if a new alternative is created, found or brainstormed now, it would be nearly impossible to explore or adopt it. Changing the recommended Zone would be difficult, since the process did not leave many records that could be easily added to or altered. It would be nearly impossible to inform the stakeholders about the repercussions of a new alternative, because much of the information was not summarized and sensitivity analysis could not be performed. To elicit the stakeholders' preferences about the new alternative and build consensus, long discussions would be needed. Objectives and criteria were never prioritized, so assessing a new alternative would require that much of the process be repeated. Although NOAA attempted to achieve a flexible, adaptable decision, some of the crucial elements were missing.

With the tools, it would be easier to change the recommended Zone, since the process would leave many records that could be easily added to or altered. New alternatives could be easily considered and assessed, since the tools can be easily modified. SD and Demos' sensitivity analysis can be used to predict the outcome. AHP's hierarchy can be used to elicit final preferences relatively easily; a new vote could be taken using the existing criteria, objectives and goals. New pairwise comparisons would be elicited, but the AHP hierarchy would not have to be rebuilt. If a few new criteria need to be added, it could be done so easily since the models do not need to be cast in bronze. Each of the tools can be altered to accommodate new criteria, new information or different values, so new alternatives could be more easily considered and the final chosen alternative could be changed.

4. Summary: A decision using the tools would be closer to Pareto Admissible

Overall, more information could have been elicited and transferred if the tools had been used; the stakeholders could have been better informed. More detailed initial and final preferences could have been elicited, then included in the decision; the preferences of the stakeholders' representatives could have been more accurately included in the decision. New alternatives could have been more easily considered and analyzed: the decision could be more flexible and adaptable. In the actual Zoning decision, reviewing the analysis of the three necessary conditions, it is likely that the chosen Zoning alternative is not Pareto admissible. It is likely that using the tools would have provided a decision closer to Pareto Admissible.

B. WHAT VALUES HAVE BEEN ELICITED AND HOW: COMPARING ACTUAL FKNMS PROCESS TO USING THE TOOLS & STEPS

1. Eliciting detailed preferences, scientific and economic information enables stakeholders' values to be more accurately represented in decision

As stated above, eliciting detailed final preferences from the stakeholders' representatives enable them to be more accurately included in the final decision. In addition, obtaining detailed predictions for each alternative makes it more likely that the stakeholders' representatives have the best available information on which to base their preferences. If detailed preferences and information is available and incorporated, it is more likely that alternatives would be chosen which accurately reflect the stakeholders' value of the resources.

a. Comparing the level of detailed preferences that could be elicited

As stated above, the final, bundled spot vote used in the actual decision-making process did little to assist NOAA in understanding the preferences of the well-informed stakeholders' representative. Bundling all options for the five Zone types into three Alternatives did not enable the vote to gather detailed preferences. The CLDs, SD and Demos make explicit more detailed information, so it can be included in the decision making process. Then, AHP could then elicit detailed final preferences, reducing the ambiguity and enabling them to be easily incorporated.

b. Comparing the level of detailed physical and economic information that could be elicited: Tradeoffs and values reflected in the decision

There are many tradeoffs in the Replenishment Zone decision, although not all of them were made explicit in the actual FKNMS decision. One of the main objectives, 'Preserving the Current Lifestyle' was never made explicit. It can be informative to review what the Keys' citizens would be foregoing if the Replenishment Zones are created. Reviewing many documents about the FKNMS decision and having many conversations with participants, the following tradeoffs became obvious:

- income from 5% of the FKNMS Zoned region for at least 5 years
- freedom to use the waters as they want

in the hopes of obtaining the benefits:

- more knowledge about the ecosystem,

• possibly increasing the chance for sustaining the ecosystem,
• possibly preserving biodiversity, and
• possibly increasing the future fishing and tourist income.

Achieving the benefits is uncertain, so the decision makers are implicitly incorporating their uncertainty into the tradeoff.

The actual process also helped answer some questions about the benefits and losses, through surveying many user groups:

• Which user groups have the greatest potential to gain?
• Which groups have the greatest potential loss and by roughly how much?
• Which Zone locations and sizes would likely result in the smallest revenue losses?

Using the tools helps make more of the trade-offs obvious. The tools help determine more specific information about the potential benefits and losses of creating the Zones. More information is made explicit, and more can be better estimated. First, using CLDs, the importance of some variables became obvious. The CLD:

• Helped differentiate between renewable vs. non-renewable ecosystem resources.
• Indicated which user groups have the greatest potential to gain. Explains why some groups are more adamantly opposed to or in favor of Replenishment Zones.
• Showed which species are most likely to be helped.
• Indicated that varying percentages of income is derived from the renewable resources that can be replenished by the Zones, for each user group. For example with scuba divers and snorkelers, what percentage of business is from reef vs. wreck dives.

With SD and Demos the importance of other variables, and new information became obvious:

• Certain Zone locations and sizes have the greatest potential for revenue gains.
  Doubling the Zone Size will likely double the replenishment capabilities of Zones.
  Zones in areas of slow currents will increase the replenishment potential of Zones for benthic or relatively sedentary species.
  Zones created down current from breeding grounds will increase the replenishment potential of Zones.
• Certain characteristics of renewable resources are most important in determining how much a Zone will replenish it, such as Reproduction rate and cryptic mortality.
• Different alternatives can change the probability that Red Snappers will be replenished.
• Different alternatives can change the future fishing income from Red Snapper.

- Determining the change in probability that other Stocks will be replenished can be estimated by discerning the degree of similarity between another demersal, commercial fish stocks and Red Snapper.
- The percentages of each user group's income derived from the proposed Zone areas varies. For example, what percentage of fishermen's income is derived from the Zoned areas now? With Red Snapper, there are almost no fish left in Florida waters.
- The user groups most likely to benefit from Zones, i.e. young fishermen.
- The worth of *some* ecosystem resources to various industries such as recreational and commercial fishermen, divers, beach-goers, etc. The tools also indicate the *uncertainty in these estimates and indicates areas where no estimates are possible.*
- The pieces of the system that need to be valued for the whole system to be preserved that probably would not be valued in market-based or by traditional methods, such as the Health of the Habitat.

Using the three tools, there is more information and better estimates about the losses incurred by creating Zones:

- Certain Zone locations and Sizes result in the greatest revenue losses.
- It is unlikely that certain non-renewable resources would ever benefit from Zones, or only in a long time frame. For example, what level of water quality or natural resources deterioration could occur before the boaters or wreck divers were affected?
- Certain groups have the greatest potential loss and by roughly how much.
- Various percentage of each user groups income that will be lost due to Zones. For example, with treasure salvagers, wreck divers, etc., it can be determined to what degree do the proposed Zone locations diminish their income streams.
- There is a need to elicit the losses for those who are ideologically opposed.

The tools also help answer some overall questions, such as:

- What were critical components for making gains outweigh losses?
- What are the short term vs. long term benefits and losses?
- Which factors do humans have control over and which can we only affect indirectly?
- Which pieces of research would be most helpful and why?
- What is the appropriate time frame in which to expect results given the Zone Size, Orientation, specie's characteristics, etc.?

Not all aspects of this information can be elicited for all parts of the Zoning decision, but eliciting some of this information can help uncover society's collective value of the resources.

Using the tools can help create new Zoning alternatives. For example, the SD showed that Currents and the Zone Orientation are important. Mr. Causey, NOAA's FKNMS manager, believed that the Zone Orientation of the Dry Tortugas Replenishment Zone should have been altered, but could not convince the Advisory Council that is was important. Using the tools, it becomes obvious that Zone Orientation may be critical and indicates why. It also indicates which pieces of information are crucial to choosing the best alternative, such as the duration of the pelagic stage for the targeted species and the local Current Speeds through the proposed Zones. If it is found that only a small percentage of the target species' larvae will stay in the Zones, then they may consider choosing a Replenishment Zone that is down current from breeding grounds, so that larvae are carried into the Zone.

Through the application of the tools, more values and information are made explicit, therefore more likely to be accurately reflected. Using the tools, one can go beyond 'seat of the pants' guesses or relying solely on the recommendations of experts. The tools enable the users to determine which characteristics of the Replenishment Zone will maximize the benefits, and indicate the items that need to be valued. Probable outcomes can be predicted with more confidence, since the predictions use the best available information from many sources.

c. Detailed preferences and information help build consensus

Breaking down the decision steps and using the tools to identify the variables important to the decision, helps the decision makers discuss the many important pieces. Often, this helps groups get to the reasons behind their opinions, instead of the decision makers just debating the overall alternatives. By exposing the 'Cognitive Maps' of both the value judgments (AHP) and physical and economic information (CLDs, SDs, Demos), the stakeholders can better understand each others' concerns, and differentiate between opinions and facts. If all stakeholders share and agree to the same information base, then consensus building can focus on the 'give and take' of finding a middle solution, where all parties feel they have made common sacrifices. The consensus building process can be more focused and directed.

Eliciting detailed information and final preferences enable better alternatives to be chosen. Using the tools may be more complicated and difficult to coordinate at the beginning of the decision-making process, but they make the final chosen alternative more robust. By the time the decision reaches the public review process, it is already been well analyzed.

2. Documenting detailed information allows the decision to be reviewed later

It is important to document the reasoning that went into a decision; the documentation may be used to justify the conclusion to others, or to reflect on the decision in the future. If decisions are well documented, one can subsequently compare the rationale and information used to arrive at the decision, enabling one to make an even better decision in the future. Using the four tools would have helped, because they elicit *and document* the information used to make the decision.

a. Recording detailed information makes the chosen alternative more defensible

Detailed individual preferences and information about the physical and economic aspects help explain how the chosen alternative was reached. Recording the detailed preferences from the stakeholders' representatives and indicating how the individual preferences were combined, enable the decision to be retraced. Likewise, recording the detailed information about the physical and economic aspects helps any interested party understand what knowledge was used and what assumptions were made, leading to the chosen alternative.

In the actual decision, many AC members were dissatisfied with the decision; there were comments about "rubber stamps" and "kindergarten." It seems that after the year long process, many AC members still do not feel that the final alternative represented their preferences and values, yet,the "process for Zoning was rewarding" due to the consensus it built within the AC group. Since there were no detailed preferences, it is difficult to explain or defend how the individual preferences were combined to form the final Alternative. Also, the lack of recorded physical and economic information makes it difficult to explain how it was included in the chosenn Alternaive to anyone who did not participate, i.e. to the public during the public review process. If the detailed preferences had been recorded using AHP, and the physical and economic information recorded with CLDs, SD and Demos, then it could be reviewed, so that many people could understand how the preferences and knowledge were combined to make the decision.

b. Documented detailed information helps to update the decision

The failure to record detailed information about the preferences, economic and physical aspects makes it nearly impossible to determine the best revisions or changes that might be needed in the future. If the physical, economic or social climate changes and the decision needs to be altered, there should be a record of what criteria or objectives were most important to the stakeholders. As stated earlier, there was very little detailed information recorded in the actual Zoning decision. In five years, when the Sanctuary Management Plan is updated to see if it is still appropriate, there will be no detailed records of the final preferences or the assumptions made about the physical and economic aspects of the decision; this breach will make it difficult to update the decision. Using AHP would have enabled final preferences to be recorded and using CLDs, SDs and Demos would have enabled the physical and economic aspects to be recorded.

3. Compare Tools & Steps with other current techniques

One can better determine the benefits of the recommended tools and steps when they are compared to existing methods of coastal environmental decision making. The National Environmental Policy Act (NEPA) of 1976 and the Blair Bower's Integrated Coastal Management (ICM) techniques used within NOAA do not specify the details of *how* one is to achieve the desired results. NEPA requires public participation and Environmental Impact Studies, but does not suggest how this could be best achieved. Typically, this took the form of public hearings or special committees. Hearings allow the most vocal citizens to speak out and have their preferences heard, but do not ensure that all stakeholder groups are represented, nor do they measure the intensity of preferences. Committees are sometimes formed in which lengthy discussions are often held, but the reports created did mot make it easy for the government agency to incorporate the information.

Bower's ICM procedures offer far more details than NEPA, but still have shortcomings. ICM defines "the second part of setting up the analysis involves the selection of the analytical techniques or models to be used"... Examples include models and techniques to:

- estimate future levels and spatial pattern of activities
- estimate demands
- analyze activities
- analyze natural systems
- estimate effects on natural systems and
- estimate effects on existing institutions.

ICM suggests, "in many cases, simple analytical tools are sufficient, especially for 'first round' analyses or in cases where few or no empirical data exist.... A computational procedure could be simply a sequential algorithm connecting outputs to inputs or it could be a master linear program." It also mentions that Multi-criteria Analysis could be useful. (Bower, 1992) While these suggestions are somewhat consistent with the tools and steps recommended in this dissertation, Bower's does not suggest any specific steps or tools to ensure that certain conditions are met. Consequently, a process following Bower's ICM suggestions can still miss many of the important steps and necessary conditions for good decision-making.[116]

4. Review why Tools & Steps may lead to better alternative chosen

This dissertation showed that by applying a series of different decision-making tools to an environmental decision, five of the six commonly recommended steps of good decision-making could be met. The tools used within the steps extract and record detailed information that is critical to more accurate predictions of the outcomes and critical to understanding the stakeholders' preferences about those outcomes. Thus, the tools enable the three necessary conditions of good decision-making: i) stakeholders are well informed, ii) stakeholders' preferences are included and iii) decision is flexible and adaptable. Therefore it is likely that a good outcome will be found, better than many outcomes of current environmental decisions.

While this work goes into much depth about *one* environmental decision, the FKNMS Replenishment Zone, it is important to understand how this research can be applied to other environmental decisions. It is necessary to understand the limitations of this work and propose areas for further research on the topic.

C. REFLECTIONS ON RELEVANCE OF THIS WORK

It is important to improve the public participation process for coastal environmental management. This dissertation determined that the best way to do this is to improve the information and preference inputs to environmental decisions, so that outcomes will more accurately reflect societal desires. The current laws and regulations mandate public participation for environmental decisions through NEPA, Coastal Zone Management programs etc. but there has very little attention paid or attempts made to determine which mode of participation would lead to good decisions. Consequently, the process for public input for environmental decisions has evolved in a haphazard way.

This dissertation analyzes many tools and reviews procedures to develop a systematic method for public participation. This work focused on improving the public participate process by determining which analytical tools and process steps would be most helpful. It is probable that these recommendations will enable better coastal environmental decisions.

[116] Bower's ICM does not review the recommended Steps of decision making from Decision Theory to ensure that all steps are completed, nor does it attempt to pare down the necessary conditions for Good decisions.

1. Recommendations for achieving Pareto Admissibility in other environmental decisions

Through the research completed, it was determined which families of tools enable the users to make good coastal environmental decisions. The tools can be used to inform the stakeholders' representatives about the decision's physical, economic and preference aspects. These tools should not be used in any random order, but within the recommended steps of good decision making. The recommendations of this work are summarized below.

In order to make coastal environmental decisions closer to Pareto Admissible, decision makers should use the recommended families of tools in the following general order:

i) Multi-Criteria Utility Functions - Elicits, then informs users about *initial* preferences

ii) Cognitive Maps - Informs users about many aspects of decision in general terms

iii) Simulation models - Informs users in detail, typically for smaller parts of a decision

iv) Uncertainty Analysis - Informs users about the levels of uncertainty in the outcome, typically for small parts of the decision

v) Multi-Criteria Utility Functions - Elicits and accurately includes stakeholders' *final* preferences in the chosen alternative.

The tools can also be used in an iterative fashion if more details are needed.

The overall decision and the use of the tools should follow the steps below. Again, these steps can be used in an iterative fashion if more details need to be elicited, especially steps 2) 3) and 4), leading to Requirement 1):

Requirement 1) Ensure all stakeholders are represented

Step 1) Define problem, overall goal and objectives

Step 2) Formulate criteria

Step 3) Formulate choices

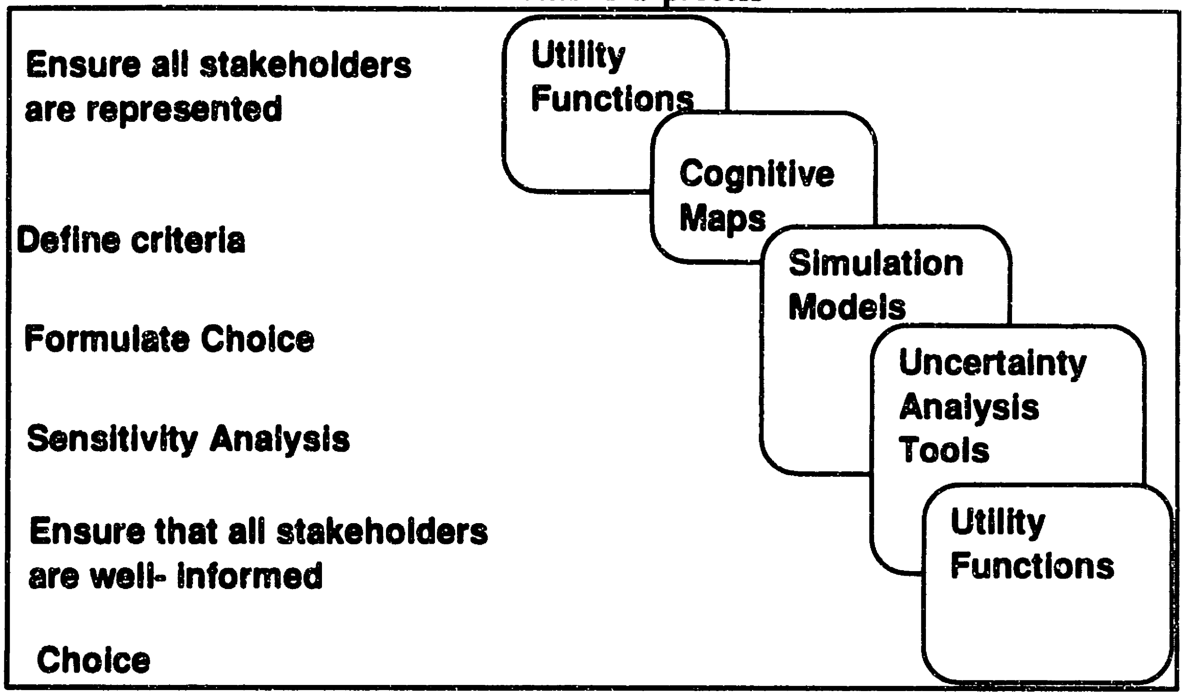
Step 4) Sensitivity Analysis

Requirement 2) Ensure stakeholders are well informed

Step 5) Choice, and

Step 6) Implementation

Figure XIV:A The recommended methodology which uses families of tools and follows a process



Using these families of tools within the recommended steps, enable the users to reach the three necessary conditions of good decision-making that were adopted from Economics, helping the decision move closer to Pareto Admissible. The three necessary conditions are:

1) Stakeholders' representatives must be well-informed about the physical, economic and preferences aspects of the decision:
   i) the best available information must be elicited from many sources, and
   ii) this information must be transferred to the stakeholders' representatives.
2) The final preferences of the stakeholders' representatives must be included in the chosen alternative:
   i) the detailed final preferences must be elicited, and
   ii) the individuals' preferences must be combined into one overall decision.
3) The decision must be flexible and adaptable.

If representatives from all the different groups were present, then their concerns would be built into the AHP hierarchy. Using CLDs, SD and Demos to become well informed would help stimulate enough good ideas and begin to stimulate some good alternatives so that a wide range of choices could be identified. Including many stakeholders and beginning to identify a wide range of alternatives would be the first steps in creating a Pareto Admissible decision. Using the tools enables new alternatives to be more easily considered. If a new alternative is suggested, SD and Demos' sensitivity analysis can be used to predict the outcome. AHP's hierarchy can be used to elicit new final preferences. All the models can be easily altered to update the decision. Using the tools, new alternatives could be more easily considered and the final chosen alternative could be changed more easily. This enables alternatives to be altered if a new one is found that is closer to Pareto Admissible.

2. Changes in research plans

Originally, the focus for this research was to find different tools that would be most applicable to different types of coastal environmental decisions. It was thought that coastal environmental decisions could be broken down into different types, and to achieve a good decision, one tool should be matched to each different type. Many tools might be needed, but it was assumed that each decision type would only require one tool.

This original focus changed for two reasons. First, reviewing many coastal environmental decisions, it became apparent that many decisions suffered from the same set of complications. If these complicating factors could be overcome, then it would be more likely that a good decision could be made for many decisions. The commonalty among these coastal environmental decisions changed the focus of this research to finding tools that could help overcome the many complicating factors, rather than assist many different types of coastal decisions. The view changed; different coastal decisions are actually comprised of different complicating factors, and if all of these complicating factors could be overcome, then one could make good coastal environmental decisions for many different problems.

Second, to create a template for how to make good environmental decisions, it was necessary to explore the *definition* of a good decision. As Dr. Shapiro, a Decision Theory professor at MIT said, "A good decision can be defined both by the process and by the outcome." Since there was no readily available definition for a good *outcome* in Decision Theory and the outcome is hard to judge for environmental decisions, the focus had to be on more than just the outcome. The definition of a good outcome from Economics was explored, as well as the definition of a good process that typically leads to a good outcome from Decision Theory. Reviewing the recommended steps of good decision making, it became obvious that all the steps needed to be met in order to make good environmental decisions. Working through a case study indicated that not all steps could be achieved with any one tool. A combination of tools was best. This assumption was reinforced after reading different authors' summaries of different tools used for different purposes within a generic decision making process.

Reviewing Economics demonstrated that the necessary conditions for a good decision occurred when i) the stakeholders' initial and final preferences are included in the decision, ii)the stakeholders' representatives are well-informed and iii) the decision is flexible and adaptable to changing conditions, information and preferences. The complicating factors would have to be overcome to achieve the three necessary conditions.

Working through the case revealed that there are many different aspects of a decision on which the stakeholders need to become well-informed, the physical, economic and human preference aspects The complicating factors typically exist for each of these. Different tools are needed to overcome each complicating factors for each of these aspects.

The product of this research differs from the original focus; after reviewing the recommended steps of good decision making, and the various families of tools that would most likely overcome some of the complicating factors, it became apparent that some families of tools could accomplish some steps and overcome some complicating factors, but there was no one tool that could assist with every step and overcome every complicating factor. Also, no one tool could help the decision makers meet the necessary conditions for every aspect of the decision. The focus changed to finding the combination of tools that together could accomplish the greatest number of steps and overcome the complicating factors, so that the three necessary conditions for a good decision could be met.

The three necessary conditions are requirements for good allocation decisions made within as well outside the Market System, such as many environmental and ecosystem management decisions. This focus on the three necessary conditions:

a) having the stakeholders' representatives well informed

b) including the initial and final preferences of the stakeholders' representatives

c) enabling a flexible and adaptable decision

helped focus this research to explore how different tools can

i) elicit the best available detailed information from many sources

ii) transfer this information to the many stakeholders

iii) elicit detailed preferences

iv) combine preferences

v) record information about the physical, economic and human preference decision aspects.

The focus was not just on finding helpful tools, but on finding tools that could be used within the recommended steps. The tools and steps together are used to meet the three conditions of good decision making.

3. Limitations of this work and work to be done in the future

a. Limitations of Tools

All users of decision-making tools and models should be warned about putting too much faith in their tools. Scientists who focus all their research efforts on modeling for different applications, such as Dr. John Stermann of MIT and Dr. Robert Costanza from the University of Maryland warn that models, by definition, are not reality and should be treated accordingly. Dr. Robert Costanza warns:

> "Don't confuse a model with reality. You build a model to move towards understanding, but don't believe the model. Expert models give you a range of possible / potential future behaviors depending on what we know now. Get a range of uncertainty, then take the precautionary action. Also, don't use models to get answer. Adaptive management doesn't consider policies as answers, but as experiments. Put the focus on monitoring policies as follow-up and regulations and use the policies more as experiments than as final answers."

These warnings are repeated in many sources of literature as well. All those who work with models should realize that most, it not all, projections of the future will be less than perfect. Few to none will be 100% correct:

> "By making (our assumptions) explicit, though, we can test our assumptions and uncover inconsistencies that may otherwise never surface." (Kim, 1992)

The different families of tools can often assist the decision-making process, but the reality of the actual process may often be far more complicated than what the models can represent. None of the tools could represent every aspect of a Replenishment Zone with 100% accuracy; many important variables had to be simplified. Also, each decision making process may vary as far as how conducive it is to using the tools.

The use of the tools in this dissertation was hypothetical, although some accuracy checks were made with the actual decision and decision makers. The recommended tools and steps were not actually used in the actual decision making, though. It is, of course, the people who make the decisions, not the tools or the process, who ultimately determine the degree to which the recommended tools and steps could facilitate their work.

b. Limits of this work

In general, this research has been very broad in scope, covering many disciplines. In the future, more work can be done to refine the recommendations. It would be desirable to explore some the disciplines in greater depth, such as Environmental Economics and Decision Theory, refining the following topics:

i) Explore more literature on the steps of good decision-making to determine if the six steps can be broken into more detail that improves the process.

ii) Review more environmental cases to see if there are any complicating factors common to many environmental cases that were omitted.

iii) If new complicating factors are found, search for families of tools to overcome them.

iv) Explore and search for more tools within each of the four families of tools already identified.

v) Apply tools other than AHP, CLD, SD and Demos from the four families of tools to environmental decisions and review their use.

vi) Search for tools that can better overcome the complicating factors that are not thoroughly overcome by these four tools, such as uncertainty in the geographic scope.

Political science research should also be conducted to better understand how political institutions can use the information and preferences elicited, to ensure that the last step of good decision making, implementation, is addressed. To refine the recommendations, it is also desirable to use the recommendations for an actual decision where many experts from the necessary multiple disciplines could participate, such as biologists, oceanographers, civil engineers, economists, etc.

Also, for each environmental decision made in the future, there may be a unique set of circumstances. While this research reviews complicating factors common in many coastal environmental cases, decision makers may find complicating factors particular to their case that were not covered in this dissertation. There may be some complicating factors that are inherent to a specific environmental problem that were not identified in this dissertation and are not overcome by any of these tools. For each individual environmental decision, the decision makers should focus on overcoming the complicating factors specific to the case.

c. Data availability

Observations of the FKNMS decision-making process occurred by this author for a one week period only once. For the Zoning decision, many written summaries were reviewed and personal interviews conducted with many of the actual FKNMS participants, but every piece of data for the one + year decision process could not be recalled with 100% accuracy. Many of the meetings occurred two to three years before the data was collected for this dissertation, and few of the necessary details were recorded during the process.

Also, many of the models were built with partial information. The models were created with the best information available *to this one researcher*, but better information would have been elicited if many researchers, users and other experts had participated. Knowledge from many experts were elicited, such as Hunt, Fahrer, Bohnsack, Sorensen, Robertson, Ogden, etc. (see Bibliography for complete list of personal communications.) It is likely that better information could be elicited if many experts *together* addressed the problems, where multiple experts from the many disciplines participated, such as biologists, oceanographers, civil engineers, economists, etc. Also, preferences could not be elicited from every member of the Advisory Council and the user groups, so the Analytical Hierarchy Process could not be used in the actual meetings. The use of the tools, while powerful, are generally hypothetical and comparative. It is necessary to test the methodology with an actual decision.

d. Assumptions made during this work

As stated above and in **Appendix** X -B, many assumptions and estimates were made using the tools and building the models. For example, the Health of Habitat was assumed to be held constant so that the effects of creating Replenishment Zones could be determined, and many of the standard deviations used in the uncertainty analysis were best guesses. The uncertainty in the information made it necessary to include uncertain variables in this analysis. See Appendix X-B for a summary of assumptions made in creating the tools. In the actual process, it was assumed that there would be nothing to prevent the decision makers from using the recommended tools and steps. It was also assumed that there would be no major opposition to using them, which might vary depending on each coastal case.

D. CONCLUSIONS

This chapter reviews what has been learned in this dissertation. It was found that if decision makers followed the recommended steps and used certain families of tools, then most of the complicating factors of coastal environmental decision making could be overcome. If the recommendations are followed, the users are more likely to become well-informed, which includes having the best possible predictions of future outcomes. It also enables the stakeholders' preferences to be included in the decision and enables the decision to be adaptable. Overall, following the recommended tools and steps should lead to environmental decisions that more closely reflect society's preferences and values for many common property resources, not just coastal resources.

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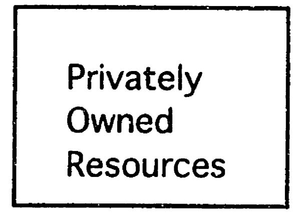
Appendix I - A: Environmental Common Property Resources

View 1:

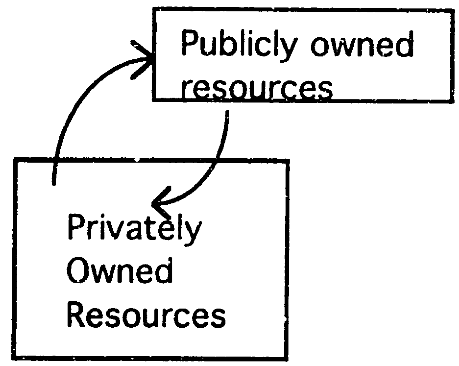
View of resource base when *all* inputs and outputs to production are privately owned.



View 2:

View of resource base when *most* inputs and outputs to production are privately owned..

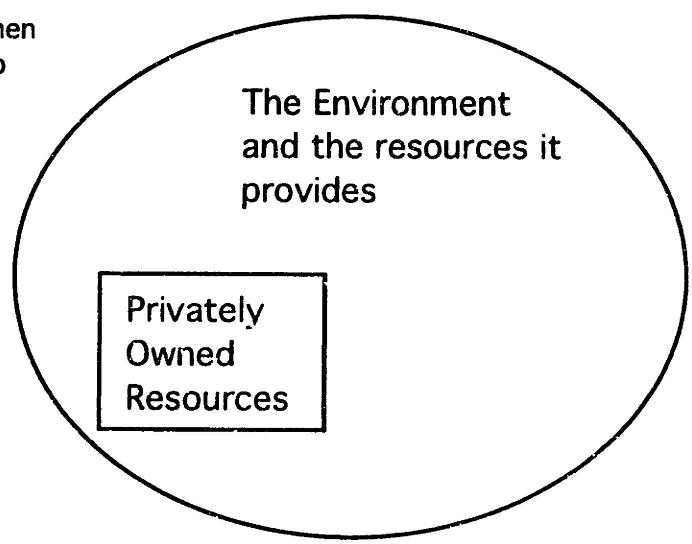
There is a need for tools and methods that attempt to place private ownership on pulbicly owned resources, such as clean air for air pollution. This occurs with such tools as Bubble Tehniques.



View 3:

View of resource base when *few* inputs and outputs to production are privately owned..

Tools and methods that attempt to place private ownership on publicly owned resources will not suffice. Environemental common property resources must be allocated via a government agency and a public decision process.



Appendix II - A: Four of the Seven Coastal Cases reviewed

1. Manatee County Florida

In 1975, the Corps of Engineers studied the Beach Erosion on Anna Maria Key and authorized 3.2 miles of shoreline restoration and periodic re-nourishment for the beach. If there were no beach nourishment, there would be negative economic effects such as storm damage to houses and hotels. The beach was *not* nourished until after 1991, at which time "the problem area had increased from 3.2 miles to 4.2 miles due to continued erosion and the negative impacts of subtropical storms." (U.S. Army Corps of Engineers, 1991) The project was delayed because the local sponsor, the Manatee County Board of Commissioners, did not provide the local part of the funding for construction during the 1970's or 1980's. This was approximately 50% of the funding as mandated by the Flood Control Act of 1965.

By delaying the project from 1975 to 1992, the problem area increased: initial fill requirements increased from 940,000 to 2.2 million cubic yards. The project's cost also increased substantially; the initial construction costs were $7.2 million in 1991 dollars. The extra 1.2 million cubic yards of fill in 1992 cost $3.6 million more. In addition, the 1992 project included $3.5 million in new items: a 0.5 miles beach fill transition Zone, removal of hazardous material from the near shore project area, and various other kinds of mitigation.

In 1972, feasibility studies for the authorized 3.2 mile project were completed and additional studies were completed in 1978. An assortment of alternatives were examined as possible solutions to the erosion and storm damage problems, but most of the suggestions came from the Corps of Engineers. The plan for beach fill with periodic nourishment and groins met the *Federal* objectives in the most "economically efficient and environmentally acceptable manner." "A plan that reasonably maximizes net national economic development benefits, consistent with the Federal objective, [1] was formulated and was identified." (U.S. Army Corps of Engineers, 1991)

Local interests, members of the public and interested private organization were contacted and their views solicited by interviews and mailing only to a limited degree during the initial decision-making process. Local citizens only contributed during the 1973 Final Environmental Impact Statement, the 1978 and 1979 FEIS supplement, the pre-construction report of 1978, and

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[1] The Flood Control Act of 1965.

the 1989 general design memorandum. Their interests and preferences did not shape the original decision.

The 1972 plan had an objective and a criteria 'economically efficient and environmentally acceptable'. In contrast, the 1992 plan included four 'accounts' that were required to be considered in the decision-making process: i) National Economic Development, ii)Environmental Quality, iii)Regional Economic Development and iv) Other Social Effects.

In the later decision, there was also more public involvement. These included eight meetings from 1988 - 1990 with various groups such as the Corps, the US Congress, Manatee County Officials, environmental and commercial fishing groups, the US Fish and Wildlife Service, the Florida Department of Natural Resources and the Department of Environmental Resources. It wasn't until the 1992 modifications that 'Acceptability,' that is, the project's acceptance by the local sponsor, became a criteria for a good decision. It also wasn't until the later plan that objectives and sub-goals other than beach protection were seriously considered.

In the 1992 project, there were concerns over the impacts of the Bart Fishing industry due to using sand from the borrow areas. As a result of the economic impact the project might have on the Bart Fishing industry, that portion of the primary offshore borrow area was to be avoided during initial construction. The local population also expressed concern over the possible adverse impacts to sea turtles in the project area. In consultation with the US. Fish and Wildlife Service, the Corps adopted a nest relocation program and other measures to protect sea turtles. It was also estimated that about 7.3 acres of near shore hard ground habitat would be negatively impacted by the project construction. The US. Fish and Wildlife Service requested mitigation: about 4.6 acres of high relief artificial habitat would be constructed by the county to replace the 7.3 acres of low relief habitat.

Complicating factors included:

a) Interdependencies of environmental decisions - Re-nourishing the beach meant some damage to bart fisheries and sea turtles. Re-nourishment would also alter some of the hard bottom habitat offshore. The public did not want the decision to be made if it ignored these interdependencies.

b) Uncertainty about cause and effect - It was unknown how long sand re-nourishment would last. Once the re-nourishment project began, the beach would probably need to be re-nourished every 5 or so years, but what would be the future costs of nourishment and sand transport? What would be the future weather and sand erosion patterns?

c) One time decision with high stakes - Even if the beach were only re-nourished one time, much of the possible environmental damage and ecological alterations would take place. The bart fishing might be destroyed, as well as the sea turtle nests. Hard-bottom habitat might be destroyed due to increased turbidity and sand sediments in the water column.

d) Multiple groups that value things differently - The Corps of Engineers tried to make the decision with very little input from the town in the 1970's. The Corps concern was physical coastal protection, and they failed to see other goals or objectives. It wasn't until the early 1990s that all the stakeholders' concerns were included. The town's tourist industry wanted the re-nourishment, the environmentalists wanted to preserve the turtles, and the fishermen were concerned with the bart fisheries.

2. Florida's Keys

The body of water that surrounds the Keys is home to the only coral reefs in the contiguous United States. They have supported a large amount of sea life, an even greater number of species than rain forests. This body of water has an abundance of natural living resources, but they are dying and being destroyed at a rapid rate.

Different people in southern Florida have different values and different uses / misuses for the water body and its living resources. First, there are many people who divert the freshwater that would otherwise flow into Florida Bay, and many people who pollute the freshwater that does reach the Bay. The numbers of residents and tourists in South Florida have climbed. Excessive nutrients in the water and less freshwater diluting the nutrients causes desirable species to die and undesirable algae to flourish. Farmers upstream from the Everglades add nutrients via their runoff[2] as lawn growers do in the Keys. As the number of residents in South Florida grows, they require more freshwater and produce more waste. Towns spray mosquito insecticides which runoff into the surrounding waters, killing desirable water species. Careless boaters, scuba divers, snorkelers, fishermen, etc. use and misuse the water by dumping waste overboard, anchoring in delicate areas or physically knocking into the reefs, killing them.

In parallel, as the water body and its resources are being destroyed, the resources become desirable to more people over time. As development increases, the need for the reefs to protect against storms increases. As tourism increases, the recreational worth of the reefs and abundant

[2] See Appendix VII-A for discussion of problem in the Everglades.

fin-fish increases. As more people populate the area, and the earth in general, there is more need for the fisheries and edible resources that the area provides. (This case is discussed in depth in Chapter VI and VII.)

This case has been complicated predominantly by the following factors:

a) Inadequate information management - For example, information about water flow, affects of pesticide use and toxic chemicals, nutrient optimization for farming, economics of South Florida, and fisheries biology should all be included in deciding how to allocate the natural resources.

b) Criteria and variables that can't be reduced to monetary terms - What is the worth of all the reefs in the area for storm protection, and what is its dollar equivalent? What is the worth of the reef for fish shelter and food? For tourism? What are the reduced benefits from a gallon of pesticides or increased nutrients from fertilizers? The dollar equivalents are very difficult to accurately measure.

c) Criteria and variables from multiple disciplines, using expertise from many fields - Marine biologist, economists, fisherman, civil engineers for urban runoff, dive shop owners are just some of the fields of experts needed.

d) Interdependencies of environmental concerns - For example, decisions made about spraying insecticides will effect health of habitats and fisheries. Both of these will also affect the number of new residents and tourists the Keys attracts. The number of new residents and tourists then affects the amount of waste water and lawn runoffs entering the water; this in turn affects the health of the habitat.

e) Uncertainty about the causes and effects - It is not known exactly what levels of different pollutants kill how much reef. Reef die off is caused by many factors, so it is not known how much any one factor causes how much death. For example, attaining zero pesticide levels in the Keys would not cause all reef die-off to halt, but how much would it help? It is only recently that researchers have linked extra nutrients with Black Band Disease which kills the reef, but exact levels have yet to be determined. More research is being done to determine the causes of marine life die-off and diseases, but exact causes and threshold levels are not known.

f) One time decisions with high stakes - Although many of the decisions within the Florida Keys National Marine Sanctuary planning process will evolve and change over time, there are certain decisions that are being made now that will be very difficult to change in the future. For instance, who will be the lead agency in charge of certain action steps? If Zones are not created now, they will probably never be created or they may be created too late, when certain species have already become extinct.

g) Various ways to consider the time frame of the project - Should the health of the reef and fishery be managed and decisions made so that they are healthy forever? Should the short term income of fisherman have higher priority? Should citizens alive now pay more to preserve the resources for future generations?

h) Various ways to consider the geographical frame of the project - For resource managers who try to protect and preserve the areas natural resources, what is an appropriate area? Should they just consider the water within the Florida Keys National Marine Sanctuary, or should they be concerned with all water usage in the Keys and in the Sanctuary? Should they be concerned with the entire Southern Florida watershed?

i) Multiple groups that value things differently - There are many conflicting needs and values placed on a fixed amount of resources. There are the vegetable farmers in Southern Florida who need water for their crops, the urban dwellers in Southern Florida who need drinking water and who want flood protection, the home owners in the Keys who want to get rid of mosquitoes, commercial fishermen who want to maximize the number of harvest-able fish, and the scuba dive shop owners who want a pretty, healthy reef.

3. Chesapeake Bay

The fin-fish, shellfish and other wildlife in the Chesapeake Bay have been declining at a rapid rate for 30 years. The Bay is filling with sediments, pollutants and nutrients which are speeding the eutrophication process; hundreds of millions of dollars have been spent to slow the process. (Schubel, 1986) Until the early 1960's, there had been a tremendous amount of diverse productivity in the Bay, including sport and commercial fin and shellfish. In the 1970's and 1980's, the stocks of marine life decreased. In 1993, oysters were at 1% of their historic levels; striped bass, herring and shad populations crashed. Crabs, perhaps the most adaptable of Bay species, seemed to be approaching a threshold as well.

These problems have many causes. One of the biggest causes is the increase in the area's human population. The population in the Bays' drainage basin increased by more than 4.2 million between 1950 and 1980, and is expected to grow an additional 1.9 million by the year 2000, resulting in more than 14.5 million people living in the Chesapeake's' watershed. The increase in population has increased the amount of runoff, sediments and nutrients in the Bay's tributaries, increasing the sediments in the Bay. (Schubel, 1986)

Another reason for the increase in sediments in the Bay is the disappearance of the watershed's riparian, or stream side forests. Riparian forests slow the overland flows of water, giving sediments time to settle out and giving water time to soak into the ground. With riparian forests, both overland and ground water that arrive at streams, rivers or bays have fewer nutrients and sediments than runoff from land without riparian forests. As the number of riparian forests declined, the amount of sediments and nutrients that entered the Chesapeake Bay and its tributaries increased, suffocating the Bay's other natural filters–its submerged aquatic vegetation and oysters. Typically riparian forests, submerged aquatic vegetation (SAV) and oysters worked as natural filters to keep the levels of sediments and nutrients in the Bay at low levels. (Horton, 1991)

Until recently, the Bay had been thought of as an infinite sink of human wastes, with few people giving thought to how much nutrients and sedimentation the Bay could tolerate and the sources of nutrients have been many. Agricultural development is the largest source of nutrients and sediments; in the early 1980's, 44% of the total nitrogen, 46% of the total phosphorous and nearly half of the total sediments entering the Bay comes from agriculture. **(US EPA, 1982)** Waste water treatment plants and industrial wastes have been the major point sources. Residential and urban development contribute point sources of nutrients and some of the non-point sources of sediments. Construction site erosion, atmospheric deposition and lawn care are the largest urban non-point sources. Until recently, there were few programs to restrict the amount of nutrients and toxins entering the Bay.

The simultaneous i) addition of huge quantities of sediment and nutrients and ii) destruction of the Bay's natural filters has led to decreased water quality. The increased nutrients and sediments cause increased algae growth and increased turbidity, which decrease light penetration, killing the submerged aquatic vegetation (SAV). With decreased SAV, there is less vegetation to stabilize the shore with the root structure or diminish the water's wave energy to prevent erosion. Because of the increased wave energy from the absence of healthy SAVs, sediments in the water take longer to settle out of the water column. Increased levels of sedimentation add to the turbidity problem, again decreasing the necessary sunlight for plant photosynthesis, making it even more difficult for SAVs to grow.

The dying SAV also increased the undesirable nitrogen and phosphorus; healthy SAVs use these nutrients taking them out of the water column, while dying, rotting SAVs add to the levels. The high levels of nitrogen and phosphorous caused increased growth of undesirable algae. Increased algae further worsens the water quality. Algae usually float near the top of the water column, blocking sunlight for the SAVs still alive. Also, when algae die, they sink to the bottom, decompose and use up valuable dissolved oxygen. Low levels of oxygen can be fatal to many species of fish and shellfish.

Not only are there problems with the plant life in the Bay, but there are also problems with animal life. Increased levels of sediments kill oyster and fin-fish; sediments eventually settle out of the water column and can cover oyster beds and fish nurseries. Fewer oysters further decreases the water quality since healthy oysters remove nutrients and sediments from the water by filtering it, removing it from the water column. (Horton, 1991)

Various private and government groups initiated efforts to slow the eutrophication process, after local attention from residents, environmental groups and a few environmentally-minded politicians. In 1976, the US Congress directed the EPA "to conduct an intensive five year study of the Bay's resources and water quality, and to develop related management strategies." (**US EPA, 1982**) Three states, Pennsylvania, Maryland and Virginia later signed the Chesapeake Bay Agreement in 1987. The goal of the agreement was "to promote increased opportunities for public appreciation of the Bay and it tributaries." The states agreed that "by the year 2000, there must be a 40% reduction of the nitrogen and phosphorous entering the Bay (based on the 1985 nutrient load)." The goal is difficult to achieve, though, because people from the entire watershed of the Chesapeake Bay, 64,000 square miles, must contribute and change their behavior. This includes over 12 million people from six States (MD, VA, PA, NY, DE, WV), from areas hundreds of miles from the Bay itself.

As a result of the efforts, the Bay has been showing some healthy signs lately.

In this case, the decision-making environment has been complicated due to:
a) A great deal of information. For example, water use information from 64,000 square miles of land must be included to try to determine how many acres of riparian forests are needed. Nutrient and toxin sources such as point sources and non-point sources, runoff from farmlands, urban centers and industrialized areas must be included. The representative preferences of over 12 million stakeholders need to be considered, at least in part.

b) Criteria and variables that can't accurately be reduced to monetary values - The value or worth of riparian forests and the SAVs can't be accurately measured. The total worth of the oysters can't be measured, either, since the market price for oysters includes only the worth for eating, and excludes filtering. Although many people want to preserve the resources of the Bay, few people realized the value of natural filters (riparian forests, sea grass and oysters) to control sediment and maintain the water quality in Chesapeake Bay.

c) Criteria and values from multiple disciplines, using expertise from many fields - For example, information of SAV biology, ideal nutrient levels for farms, rainfall predictions, the economic value of oysters, the value of water recreation to citizens... all need to be considered.

d) Interdependencies of environmental decisions - For example, allowing riparian forests to be cut for farmland reduces filters. This increases sediment runoff and the level of nutrients. This in turn overtaxes the SAVs. Turbidity increases, which causes the oysters to die off, which further decreases the filters, which further increases turbidity, etc. Increasing farmland without precautionary measures causes all the natural filters to be destroyed.

e) Uncertainty about cause and effect and changing / evolving scientific data - Scientists do not know at what exact level of turbidity or increased nutrients SAVs die, or at what levels of riparian forests the runoff causes death. There was no formula for determining how much additional sediment would cause what level of decline in desirable fin-fish and shellfish, because there are so many factors and there is uncertainty in each factor. No one understands every detail of the food web or the possible resiliency of the ecosystem. The Chesapeake is a huge, complicated ecosystem with many tributaries, pockets, etc. Research is on-going and more is being learned, but results will never be 100% conclusive.

f) Various ways to consider the geographical scope of the project - Should the Chesapeake Bay be defined only as the body of water, or should it be defined as the water body and the coastal areas in the states that border the water body, or should the Bay be defined as all the land (in the six states) that constitute the watershed?

g) Various ways to consider the time scope of the project - Should a great deal of money be spent to slow down the eutrophication process, to slow the process of the Bay filling and becoming a river, if it is going to happen anyway? If it can be slowed, should we spend enough money so that it never happens? Happens in 500 years? Happen in 100 years? What is an acceptable amount of time by which to slow it?

h) Multiple groups that value things differently - There are three states that border the Chesapeake Bay, 6 states in the Chesapeake watershed and 12 million people who affect the Bay every time they use water. There are no laws to govern farmers or urban dwellers as to legal levels of runoff and no state or county wants to restrict their farmers without restricting the farmers in other states and counties. With many decision makers, there are conflicting goals. The Bay suffers from the Tragedy of the Commons.

4. Exxon Valdez

The Exxon Valdez ran aground in March 1989 and 11 million gallons of crude oil poured into Alaska's Prince William Sound covering 1200 miles of shoreline. Experts believed that about 100,000 birds and 1000 sea otter died from the initial spill. The salmon and herring fisheries season had to be postponed. Together, these two fishing industries alone are worth $100 million a year. (Hodgson, 1990)

The Alyeska Contingency Plan required a response time of 5 hours for possible spill cleanup, but it took 12 hours to mobilize and travel the 28 miles to the site. The skimming units, boom and empty barges that were required in the plan were designed to be used for the 'most likely spill' of 1,000 - 2,000 barrels. The Valdez was 170 times bigger. The cleanup that did occur was less than efficient, because there were many people with some power and no one person with overall power; no one was willing to take responsibility and make the necessary decisions. There was no conclusive information on the long term effects of many clean up methods such as dispersants, fire and bioremediation, so no one wanted to make a decision that would increase the damage and their liability.

Another reason that the use of dispersants was delayed was because of uncertainty as to the necessary sea conditions needed to make dispersants effective and worth the possible damage. Commander McCall, the NOAA federal on-scene coordinator, decided not to use dispersants right away, since the sea was calm, lacking the energy to mix dispersants. By Sunday afternoon, preliminary test results convinced him that dispersants would be effective, but by then it was too late; 70 knot winds prevented airplanes from spraying. As a result, Exxon spent 1 billion dollars in the initial clean up / rehabilitation program and another 1 billion in longer term rehabilitation efforts.

Many more billions of dollars (6 billion dollars as of 1994) have been spent in litigation fees and compensation payments. The damage assessment and payments to the damaged parties will be determined through litigation. By congressional decree, federal and state agencies are authorized to make a damage assessment that will result in a financial claim against Exxon to cover costs of complete restoration.

Damage assessment is and will be difficult. Many experts realize that very little is known about the effects of oil in the marine environment. There will be much research done to help develop the scientific knowledge base. Kimbal Sundberg, a habitat biologist with the Alaska Department of Fish and Game said, "We will make a three-year study of the near shore coastal habitat, from Bligh Reef to as far as the oil was carried... We've established 98 oil affected sites, which we'll study. We'll compare these with 28 control sites unaffected by oil." In this way, they will study the long term effects on the food web that was affected by the oil.

The factors that complicate this case include:
a) A great amount of information - A great deal of information existed for the public, for Exxon, and for the government officials who were supposed to manage the coastal resources and regulate the oil shipping; some of it was neglected. Those with the most direct power, Alyeska and the private oil companies, wanted to ignore the risks, because ignoring it was cheaper. Because there was so much information, there was no citizen or public group that could easily check the oil companies or Alyeska.

b) Criteria that can not be accurately reduced to monetary values - The worth of a clean Prince William Sound is not known. How much should Exxon pay commercial fishermen, recreational fishermen, cruise shop owners, Native Americans for the damage?

c) Uncertainty - There was a great deal of uncertainty as to what wind conditions would be when using the dispersants. There was uncertainty when Alyeska had to predict the most probable size of a spill in order to make the Contingency Plan. There was uncertainty as to how much the oil would spread, because it was dependent on uncertain weather patterns. The greatest amount of uncertainty still lies in the effects of oil in the marine environment. "The possible long term effect on tidal and inter tidal ecosystems will take years to learn," says Dr. Jacqueline Michel, a science advisor to the National Ocean and Atmospheric Administration.

d) One time decisions with high stakes - Deciding whether or not to use dispersants, fire or bioremediation were one time decisions with high stakes. The long term effects of the methods might be negative, more negative than the oil itself. The long term effects were not known and there was no way to do tests runs or to practice. The decision of what clean-up method to use had high stakes, because it might change the ecology of the area permanently.

e) Various ways to consider the time frame of the decision - The officers in charge of clean-up were not just considering the short term impacts of oil, but also the long term impacts of the clean-up method. In trying to determine the compensation payments, how long will the oil affect the region? Even if the oil is no longer in the water, is it in the food web? How many generations of people were affected by the spill?

f) Various ways to consider the geographic scope - The oil certainly affected the water and certain shorelines in Prince William Sound. It also affected the marine and land-based food webs, people in the surrounding areas and the local economy. The appropriate geographical boundaries are hard to determine.

g) Multiple groups with different values - The oil companies wanted to reduce expenses by cutting out necessary parts of the Alyeska Contingency Plan. They also hesitated about using dispersants, because they did not want additional lawsuits from the effects of the dispersants. The local citizens wanted to protect the environment; they wanted a well stocked fleet of cleanup vessels and a conservative contingency plan, yet they did nothing to make sure it happened. They wanted a clean Sound where they could earn a living fishing. They did not want to take risks by minimizing the expenses on the Contingency Plan.

Appendix III - A: Other Components of a Good Decision Outcome

There are also some aspects of decision outcomes that many experts say are important in defining a good decision outcome. (Shapiro, Stavins, Jacoby and Kaufman, 1994 personal communication)

1. Robust decisions

These are defined as decisions that remain optimal even when some variables change a small amount. This is especially important in decisions where there is uncertainty. If every criteria or variable is not known with certainty, one would like to be sure that the chosen alternative is still very good under the different possible scenarios. This can be checked for when doing sensitivity analysis.

2. Flexible

A good outcome should also be easy to alter in the face of change. We live in a continuously changing world, a good outcome is not fixed or rigid to keeping the exact same circumstances, but is flexible and remains a good decision even when the surrounding situation changes. A good outcome will allow for changes such as technological developments, population increases, etc. to be easily incorporated into the best chosen alternative. This can be ensured by simplifying the decision process, by recording it and making it so that it can be repeated if the surrounding situations change.

3. Outcome targets original problem

Often, in trying to find the most elegant solution, or finding an alternative that allows for consensus, decision makers lose track of the original goal or problem definition. An alternative may be agreed upon, but if the alternative does not target the original goal or solve the problem, it is not a good decision outcome. To achieve this, the effort should be on ensuring that there is always a clear definition of the goal, and it is always obvious to all decision makers.

4. Decisions are made incorporating any inherent complicating factors

Since environmental decision-making can be very complicated, many decision makers attempt to simplify the decision. For instance, they do not exclude relevant items just because they do not know them with certainty. While simplification is often desirable, it should not occur at the expense of accuracy. One must specify what the complicating factors are and find methods to integrate them into the decision.

5. Implementable

The alternative must be feasible and able to be enacted. It is not just theoretically ideal, but people can go along with the decision, and put it into practice. This will be a part of the outcome, if the last step of good decision-making happens -- i.e., implementation, so it will not be repeated as one of the criteria for a good outcome.

Appendix IV - A: Examples of Environmental Economic Tools

1. Examples of Pollution Changes

An example of a Deposit-Refund system might be 'Pay-as-you-throw' charges. Instead of general property taxes paying for garbage collection and disposal, garbage disposal is paid for on a per-bag basis. This provides an incentive to reduce the amount of garbage consumers throw out and encourages recycling, composting and reduced packaging by manufacturing.

Another example where a "Deposit-Refund" system might be used is for hazardous materials or contaminants. Society would want these items to be properly disposed of, not disposed of by the least costly method. For example, to provide the incentive for proper disposal, one could use a Deposit-Refund system for motor oil and dead car batteries. Just as consumers receive money for aluminum soda cans, people would receive money back when they return a car battery to the store or a deposit center; the store would then be responsible for proper disposal.

2. Examples of Tradable Permits

a. Offsetting

This happens when pollution permits are bought from plants that are down-sizing or closing. In 1993, there were over 2000 offsets that had occurred due to the Clean Air Act Amendments of 1990. Ninety -five percent of these Offsets were internal, within the same company.

b. Bubble Policy

This is when there is a fixed area with a set total amount of pollution emission allowed. Trading can occur only within the fixed geographical area. Bubble policies are used when geographic distribution is important, because environmental and other damages increase non-linearly with the concentration of pollution. In addition to the overall total volume of allowable pollution, spatial distribution of the pollution and allowable trading areas are important.

c. Banking

This refers to the technique where a firm can, over time, acquire a certain number of pollution credits. This is usually used when a firm produces fewer pollutants than is currently allowed, but will produce more once a new set of performance standards is implemented.

3. Examples of Market Barrier Reductions

In southern California, farmers have rights to a great deal of water coming from the Colorado River. Urban areas in California, such as Los Angeles, need more water. One of the most economically efficient ways for LA to obtain more water is to buy it from the farmers. The farmers don't have excess water to spare, though, unless they start using better conservation techniques and equipment; this costs money though. If LA were allowed to 'buy' water from farmers, the farmers could use the money to invest in better water conservation equipment. Unfortunately, buying the water was illegal until the early 1990's, when Congress passed an act signed by President Bush, determining that the trade of water is allowable and desirable.

Appendix V - A: Tools being explored by Prof. Nyhart at MIT

- DATA® automates decision analysis for use in assessing the effects of risk and uncertainty on decision making. DATAs allows the user to construct a decision tree representation of the various options open to the decision maker and then have expected values calculated, probability distributions found, and sensitivity analysis conducted by the computer.

- EASI provides an accessible interface/front-end for STELLA® and DATA® and other PMNM programs on a Macintosh platform. Its initial application is for insurance underwriting negotiations.

- Indicators of Early Warning comprises a methodology by which mediators or negotiators engaged in long-protracted negotiations such as those relating to ethnic conflict or lengthy multilateral agreements may be better alerted to the possibilities of new conflicts or fundamental changes in the stability of particular parties.

- ISES - Integrated Simulation and Evaluation System provides a multiuser computer environment in which a simple simulation model is linked to a data base containing the preferences of each negotiators. ISES considers each incoming proposal one at a time, simulates its effects, and then compares those effects to the preferences of the negotiators as expressed in the data base.

- MATCH enables the user to design a "frame" to describe a particular case or problem and then uses "matching" algorithms to find similar cases or problems in a data base. The program is meant to be applicable to a variety of data types and will allow the user to specify how closely the care or problem must be matched.

- Mediator's Electronic Notebook is a computerized reference manual designed to provide a mediator with desktop access to a variety of useful resources: relevant chronological or historical events, biographical data of negotiating parties, maps or other geographical data, and a mediators own reference file.

- Mediator's Template allows facilitators to divide the mediation process into discrete phases that can work as a guide for developing an overall mediation plan, a model detailed scenario for the whole negotiation. It thus provides a standard format for systematizing and preserving successful codes of lead mediators for transfer to others.

- Mermaids is a program that enables the user to build a hierarchical costing model of an engineering system. The program can be used to perform a financial analysis of the system. For example, the program gives a graph of the expected yearly cash flow during the lifetime of the project.

ONDINE I & II - ONe Dimensional Negotiation is an unobtrusive computer environment that enables negotiators to communicate and bargain without revealing to each other basic information about their preferences. The first version, ONDINE L is used for single-issue negotiations. Version II may be applied to multi-issue negotiations.

- Preference Curves preference curves based on alternative probabilities of preferred consequences and expected values. This preference analysis tool tries to fit a curve to past offers that the negotiator has already generated or received. The tool then uses this curve to estimate a range of alternative values that fall along the efficient frontier.

- SAM is a descriptive model to simulate the negotiation process. SAM implements a library of algorithms that represent different ground rules for negotiation and group interaction.

- Smarts is an expert system shell. The shell can be programmed to give advice or instructions about either the substance or the process of negotiation. The user is asked a series of questions, and advice is provided according to the user's answers and the preprogrammed rules in the shell.

- SOLID is a program for analyzing liability insurance coverage. The program enables the user to manipulate a data base of insurance policies. The user can make changes to the data in a variety of ways, and view insurance coverage graphically.

- STELLAR is a systems dynamics program that enables the user to construct simulation models graphically. The program applies generic mathematical principles to data provided by the user in order to simulate changes of a system over time and gives output in the form of both tables and graphs.

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Project on Modeling for Negotiation Management, MIT
September, 1992

Appendix VI - A: The Health of Reef Ecosystems

Being a very fragile species, the reefs are one of the best indicators of a stressed ecosystem. Coral, a marine animal, lives within a very narrow range of conditions. For coral to thrive, water temperature should remain above 70ºF. The Florida Keys is at the cool edge of coral reef growth, since its waters dip into the 60ºs in the winter. Cold temperatures prevent extensive reef growth north of the Upper Keys.[3] In addition to a narrow temperature range, the water's salinity must remain within a narrow range for the reef to thrive.

The nutrient level within which coral reefs can thrive is also very narrow. The coral polyps survive in nutrient *deprived* waters where other organismsm, such as algae are not abundant. High level of nutrients stimulate algae growth, which will suffocate coral and cause death. Each tiny coral polyp takes in water and nutrients and exudes calcium carbonate (limestone) to form the 'boulder' or other shaped reef skeleton.[4]

The existence of the coral reef is interdependent with its mutual beneficiary the zooxanthalae algae. The coral polyps rely on the algae's byproduct, reduced carbon, to survive. In return, the zooxanthalae algae feeds on the byproducts of the individual coral polyps; carbon dioxide, nitrogen and phosphates. The algae removes the polyps wastes, detoxifying the reef for continued coral expansion. The algae require sunlight, which restricts living polyps to the photic zone[5], typically 30m deep. Excessive sedimentation and turbidity will cloud the water, decreasing the photic zone, killing the zooxanthalae algae and therefore the coral. This restricts coral reefs to a narrow range of depth and water turbidity.

The population balance between the coral and zooxanthalae algae symbiosis must be preserved. For the zooxanthalae to remain in balance with the coral, the coral must be almost the sole provider of nutrients for this algae. Elevated nutrient levels will support excess algae, which will smother the coral populations. (Johannes, 1972)

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[3] Reefs don't thrive in the Middle Keys, since there is a large gap in the land mass and nutrient rich water from the Florida Bay flows into the Atlantic, to the reef tract.

[4] There are many different species of coral, each forming a different shape of coral skeleton.

[5] The light penetration below the surface is adequate for photosynthesis and thus algae production.

The other habitats of the Sanctuary are not quite as delicate as the coral reef, but they too flourish only under limited conditions. The "secret of Florida Bay's wealth" was the warm, protected waters "prism, clear except after big storms and fluctuating in saltiness with the seasons." These small fluctuations encouraged a mix of sea grasses and variety of sea life. The Bay had "slim-bladed shoal grass, perfect for young shrimp and crabs", and "thick turtle grass", where larger bonefish and other game fish lived. Scallops lived in sandy patches, "siphoning microscopic plankton". Mullet, trout and tarpon "browsed in water ranging from mere inches to six feet deep". In the shallow water, "wading birds feasted". In the deeper waters, "dolphins pursued darting schools of fish." (Dewar, March 1994)

As the Bay water has become full of excess nutrients and high in salinity, undesirable algae are overgrowing the desirable plant life. The submerged vegetation die, as do the marine life that depend on that vegetation. The waters become turbid, form the algae and from bottom sediments. Many reefs are dying and becoming diseased; there are many reefs that have White Band Disease, Black Band Disease or are suffering from Bleaching.

White Band Disease is characterized by a bacterial pathogen that attacks the coral leaving a trailing white band, the dead coral skeleton. Black Band Disease is a deadly disease characterized by a small black band expanding outward, the boundary between the dead skeletal coral and the living polyps. Bleaching is the result of coral polyps expelling its zooxanthalae algae. What is revealed is only the white limestone, exoskeleton structure of corals, thus the descriptive term 'bleaching'. Although the diseases and condition are different, their surrounding systems frequently overlap. White Band and Black Band Diseases are linked with warm waters, elevated levels of fertilizers, heavy metals, pesticides, herbicides, storm drainage, agricultural by-products and sewage. Primary causes for bleaching are anything that reduces or clouds the photic zone. Bleaching is also linked with local warming of the area, either from Greenhouse effects or shifting currents.

Appendix VI - B: Water Quality in the Southern Florida Watershed

The water quality of the National Marine Sanctuary is poor because of the multiple problems that exist in the contributing watershed. Water has continually been diverted from the natural flow patterns, interrupting the regular flow of the watershed. The fresh water remaining has been assaulted with excessive nutrients and toxins. The Kissimee River is the headwater for the Everglades and the Florida Bay. In 1971, the US Army Corps of Engineers turned the winding 103-mile River into a 56-mile long canal. Another 1,344 miles of levees, dikes and canals were built to control the flow of water and to drain the area surrounding Lake Okeechobee, so that the marshes could be developed into farmland and pastures. In 1992, there were 45,000 dairy cows north of Lake Okeechobee that produced as much wastes as 980,000 people, that is 2295 tons of manure a day. This manure contributes 1.5 tons of phosphorous that flow into Lake Okeechobee each day. This inflow of nitrogen and phosphorous accumulate in the silty bottom of Lake Okeechobee and speed the natural aging process of eutrophication.

"Environmentalist have known for years what biologists have since confirmed - straightening the River was a colossal mistake. The wide, shallow Kissimee River that once gently flowed to Lake Okeechobee is now 30 feet deep and gushes more than it flows. The river sends water that is too dirty, too quickly to the Lake." (Duplaix, 1990) Too much pollution and inadequate freshwater flow into the Lake has caused myriad problems there, from algae blooms to an overabundance of water weeds. The Army Corp. now has a plan to straighten the 56-mile flood control canal; it will be re-flooded by weirs to regain some of its curves. (Duplaix, 1990) The 56-mile canal that took 10 years and $32 million to build will require more than $400 million to regain some of its oxbows.

South of Lake Okeechobee lies the Everglades Agriculture Area which grows mostly vegetables and sugarcane and employs more than 20,000 people. Contaminated runoff from fields in the Everglades Agricultural Areas contains abundant phosphorous and nitrogen from fertilizers and disintegrating muck, 10- 20 times the normal concentrations. (Duplaix, 1990) This runoff, high in nutrients, dumps into the Everglades National Park.

The Everglades Park and Florida Bay are last in line in the 250 mile long Everglades watershed. Water is being pumped from the Everglades Park, its natural path, to farmland and to municipal water supplies along the East Coast such as Fort Lauderdale and Miami. The Park has had little say as to how much water it receives or the timing of its deliveries. In 1983, concerned biologists drew up requests, urging water deliveries to follow seasonal rainfall; water managers cooperated somewhat. (Duplaix, 1990)

Still, the Everglades Park is the last priority. Agricultural and cities get water first whenever there is a drought, and when there is excess rains, the flood waters are dumped into the Everglades. In 1988, there were heavy rain of 12 inches in a day, which flooded farmlands. The flood waters were released to Barnes Sound, temporarily wiping out the marine breeding ground for shrimp and fish. In the 1989 drought, water went to Miami residents, and the Park saw no water for 37 weeks. These incredible fluctuations in the quantity of water have caused enormous fluctuations in the salinity and concentration of nutrients and toxins. These fluctuations make it difficult, if not impossible, for the plant and animal life to survive in the Everglades and Florida Bay.

In the Everglades Park, the original sea grasses and oxygen producing periphytic algae that were the base of the food web are dying. Less desirable species that prefer the nutrient rich waters are replacing them, cattails are replacing the sea grasses and less desirable species of algae are replacing the periphytic algae. These species are undesirable, because they support fewer organisms; the food web is being destroyed.

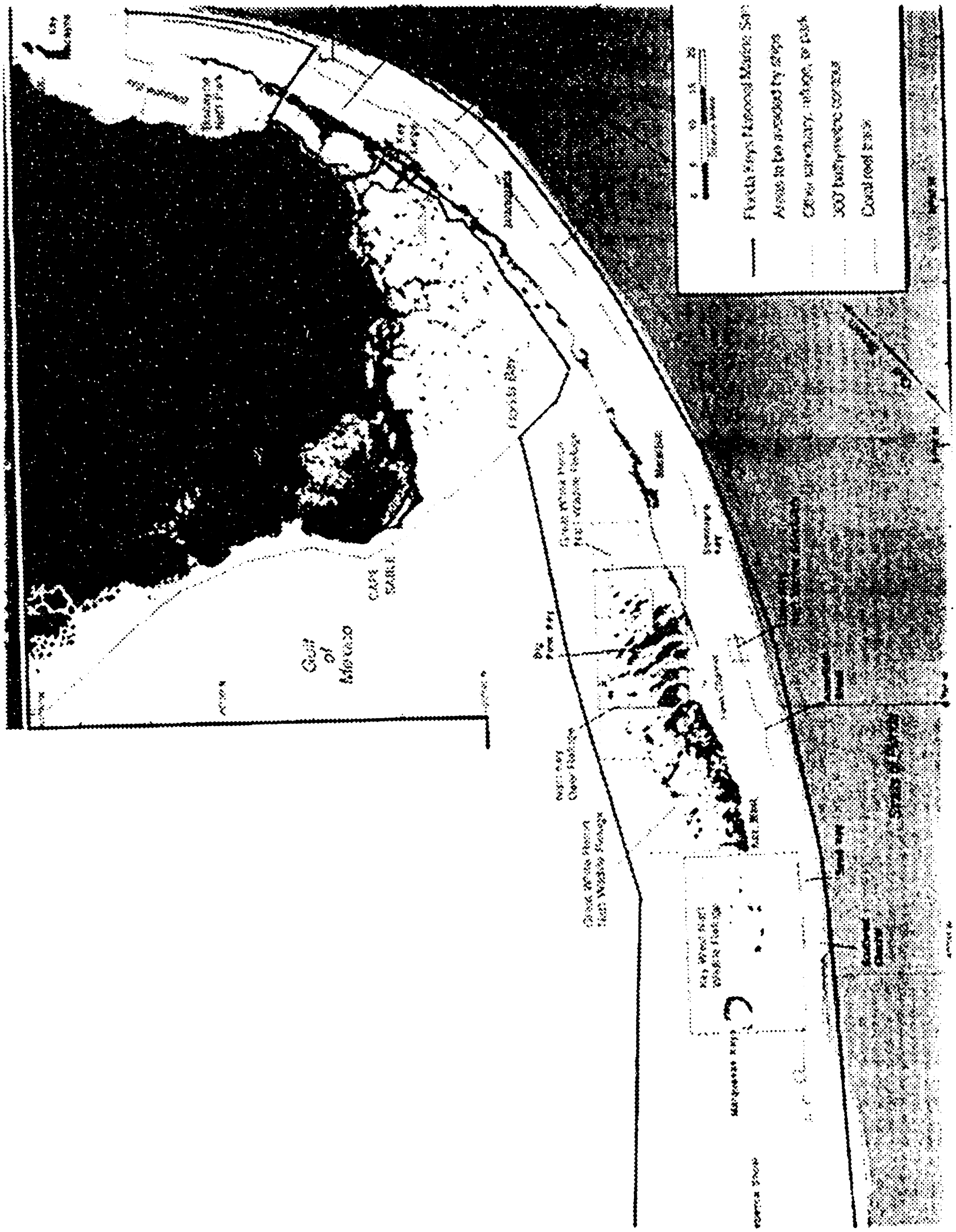
Water that passes through the Everglades finally flows out into Florida Bay, so all the problems that the Everglades see, the Bay also sees. The toxins and high levels of sedimentation causing high turbidity, which caused the sea grasses and many other species in the Bay to die. When the sea grasses die in the Bay, it reduces the natural filters of the area. Silt, nutrients and toxins do not settle out and they travel further from land, entering the reef tract. The decaying organic matter from the Kissimee watershed and the dying Bay spread into the National Marine Sanctuary, furthering its problems of high nutrients and contamination.

The water quality problems in the Everglades National Park and Florida Bay are caused by a combination of more water being taken out from the system and more nutrients and toxins being dumped into the remaining flow of water. The lack of freshwater to the Everglades and Florida is a problem because the amount of water that has been diverted is enormous.

No one is sure why there are such large areas of 'dead' matter, or why the "dead zone" exists in Florida Bay, but 'experts say at least part of the trouble stems from a mainland drainage system that reduced freshwater flow to one-fifth to one-tenth of what nature designed. In addition to the Kissimee River and the Everglades watershed, coastal currents bring runoff from Miami that pollute the Park. Some scientists say pollution from shore, from the Keys' islands, is at least partly to blame. Some scientists believe that the final push probably came from two natural insults: a late 80s drought made the Bay twice as salty as the sea, too much for the sea grasses and no hurricanes hit the Bay directly to drive out years' worth of silt and decay. (Duplaix, 1990)

The problems have been noticed, so now there are more people concerned with mitigating the damage. New regulations for agriculture have been enacted. Florida's 1987 Dairy Rule required that by 1992, pastures drain into special holding ponds to prevent nutrients from reaching Lake Okeechobee. The 1987 Surface Water Improvement and Management Act mandated that water management districts create plans for pollution reduction and environmental restoration. In 1983, 55,000 acres around the perimeter of the Everglades Park were purchased to act as a buffer zone. In 1989, the Everglades Expansion Act passed by Congress authorized another 72,000 acres of land to be converted to filtration marshes. In a 1988 poll, most of Floridians surveyed felt a need for stronger anti-pollution laws and water conservation measures. (Duplaix, 1990) There is now an Interagency Task Force looking at the best ways to mitigate the decline of Florida Bay. The National Marine Sanctuary Water Quality Protection Program is becoming more focused on efforts of upstream mitigation. This is a positive step, since defining the geographic scope of the FKNMS water quality problems recognizing the entire watershed was one of the complicating factors. Still, all the factors that contribute to the FKNMS water quality problems have not been removed nor has the water quality been restored.

Appendix VI - C: Map of Florida Keys National Marine Sanctuary



Appendix VI - D: Florida Keys National Marine Sanctuary Act

PUBLIC LAW 101-605—NOV. 16, 1990 104 STAT. 3089

Public Law 101-605
101st Congress

An Act

To Publish the Florida Keys National Marine Sanctuary, and for other purposes.

Nov.16, 1990
[H.R. 5909]

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SHORT TITLE

Florida Keys
National Marine
Sanctuary and
Protection Act

Section 1. This Act may be cited as the "Florida Keys National Marine Sanctuary and Protection Act"

FINDINGS 16 USC 1433 note

Sec. 2. The Congress finds and declares the following:

(1) The Florida Keys extend approximately 220 miles southwest from the southern tip of the Florida peninsula

(2) Adjacent to the Florida Keys land mass are located spectacular, unique, and nationally significant marine environments, including seagrass meadows, mangrove islands, and extensive living coral reefs.

(3) These marine environments support rich biological communities possessing extensive conservation, recreational, commercial, ecological, historical, research, educational, and esthetic values which give this area special national significance.

(4) These environments are the marine equivalent of tropical rain forests in that they support high levels of biological diversity, are fragile and easily susceptible to damage from human activities, and possess high value to human beings if properly conserved.

(5) These marine environments are subject to damage and loss of their ecological integrity from a variety of sources of disturbance.

(6) Vessel groundings along the reefs of the Florida Keys represent one of many serious threats to the continued vitality of the marine environments of the Florida Keys which must be addressed in order to protect their values.

(7) Action is necessary to provide comprehensive protection for these marine environments by establishing a Florida Keys National Marine Sanctuary, by restricting vessel traffic within such Sanctuary, and by requiring promulgation of a management plan and regulations to protect Sanctuary resources.

(8) The agencies of the United States must cooperate fully to achieve the necessary protection of Sanctuary resources.

(9) The Federal Government and the State of Florida should jointly develop and implement a comprehensive program to reduce pollution in the waters offshore the Florida Keys to protect and restore the water quality, coral reefs, and other living marine resources of the Florida Keys environment.

POLICY AND PURPOSE

SEC. 3.

(a) POLICY.—It is the policy of the United States to protect and preserve living and other resources of the Florida Keys marine environment.

(b) PURPOSE.—The purpose of this Act is to protect the resources of the area described in section 5(b), to educate and interpret for the public regarding the Florida Keys marine environment, and to manage such human uses of the Sanctuary consistent with this Act. Nothing in this Act is intended to restrict activities that do not cause an adverse effect to the resources or property of the Sanctuary or that do not pose harm to users of the Sanctuary.

SEC. 4. As used in this Act, the term "adverse effect" means ally factor, force, or action that would independently or cumulatively damage, diminish, degrade, impair, destroy, or otherwise Miasma 44th

(1) any Sanctuary resource, as defined in section 302(8) of the W) Marine Protection, Research, and Sanctuaries Act of 1972 (16 X d U.S.C. 1432(8)); or

(2) any of those qualities, values, or purposes for which the Sanctuary is designated.

SANCTUARY DESIGNATION

SEC. 5.

(a) DESIGNATION.—The area described in subsection (b) is designated as the Florida Keys National Marine Sanctuary (in this . Act referred to as the "Sanctuary" under title III of the Marine-Protection, Research, and Sanctuaries Act of 1972 (16 U.S.C. 1431 et seq.). The Sanctuary shall be managed and regulations enforced under all applicable provisions of such title III as if the Sanctuary had been designated under such title.

(b) AREA INCLUDED.—

(1) Subject to subsections (c) and (d), the area it referred to in subsection (a) consists of all submerged lands and waters including living marine and other resources within and on those Wands and waters, from the mean high water mark to the boundary described under paragraph (2), with the exception of areas within the Fort Jefferson National Monument. The Sanctuary shall be generally identified and depicted on National Oceanic and Atmospheric Administration charts FKNMS 1 and 2, which shall be if maintained on file and kept available for public examination during regular business hours at the Office of Ocean and Coastal Resource Management of the National Oceanic and Atmospheric Administration and which shall be updated to reflect boundary modifications under this section.

(2) The boundary referred to in paragraph (19

(A) begins at the north-easternmost point of Biscayne National Park located at approximately 25 degrees 39 minutes north latitude, 80 degrees 5 minutes west longitude, then runs eastward to the 300-foot isobath located at approximately 25 degrees 0 39 minutes north latitude, 80 degrees 4 minutes west longitude; ::

(B) then runs southward and connects in succession the points at the following coordinates:

(i) 25 degrees 34 minutes north latitude, 80 degrees 4' minutes west longitude,
(ii) 25 degrees 28 minutes north latitude, 80 degrees 5 minutes west longitude, and
(iii) 25 degrees 21 minutes north latitude, 80 degrees 7 minutes west longitude;

(C) then runs southward to the northeastern corner of the existing Key Largo National Marine Sanctuary located at 25 degrees 16 minutes north latitude, 80 degrees 8 minutes west longitude;

(D) then runs southwesterly approximating the 300-foot isobath and connects in succession the points at the following coordinates:

(i) 25 degrees 7 minutes north latitude, 80 degrees 13 minutes west longitude
(ii) 24 degrees 57 minutes north latitude, 80 degrees 21 minutes west longitude,
(iii) 24 degrees 39 minutes north latitude, 80 degrees 52 minutes west longitude,
(iv) 24 degrees 30 minutes north latitude, 81 degrees 23 minutes west longitude,
(v) 24 degrees 25 minutes north latitude, 81 degrees 50 minutes west longitude,
(vi) 24 degrees 22 minutes north latitude, 82 degrees 48 minutes west longitude
(vii) 24 degrees 37 minutes north latitude, 83 degrees 6 minutes west longitude
(vii) 24 degrees 40 minutes north latitude, 83 degrees 6 minutes west longitude,
(ix) 24 degrees 46 minutes north latitude, 82 degrees 54 minutes west longitude,
(x) 24 degrees 44 minutes north latitude, 81 degrees 55 minutes west longitude,
(xi) 24 degrees 51 minutes north latitude, 81 degrees 26 minutes west longitude, and
(xii) 24 degrees 55 minutes north latitude, 80 degrees 56 minutes west longitude

(E) then follows the boundary of Everglades National Park in a southerly then northeasterly direction through Florida Bay, Buttonwood Sound, Tarpon Basin, and Blackwater Sound;

(F) after Division Point, then departs from the boundary of Everglades National Park and follows the western shoreline of Manatee Bay, Barnes Sound, and Card Sound;

(G) then follows the southern boundary of Biscayne National Park and the northern boundary of Key Largo National Marine Sanctuary to the south-easternmost point of Biscayne National Park; and

(H) then follows the eastern boundary of the Biscayne National Park to the beginning point specified in subparagraph (A).

(c) Areas within the STATE OF FLORIDA—The designation under subsection (a) will not take effect for any area located within the waters of the State of Florida if, not later than 45 days after the date of enactment of this Act, the Governor of the State of Florida objects in writing to the Secretary of Commerce.

(d) BOUNDARY MODIFICATIONS.—No later than the issuance of the draft environmental impact statement for the Sanctuary under section 304(aXIXCXvii) of the Marine Protection, Research, and Sanctuaries Act of 1972 (16 U.S.C. 1434(a)(l)(C)(vii)), in consultation with the Governor of the State of Florida, if appropriate, the Secretary of Commerce may make minor modifications to the boundaries of the Sanctuary as necessary to properly protect Sanctuary resources. The Secretary of Commerce shall submit to the Committee on Commerce, Science, and Transportation of the Senate and the t -d Committee on Merchant Marine and Fisheries of the House of Representatives a written notification of such modifications. Any boundary modification made under this subsection shall be reflected on the charts referred to in subsection (bX1).

PROHIBITION OF CERTAIN USES

SEC. 6.

(a) VESSEL TRAFFIC.—(1) Consistent with generally recognized principles of international law, a person may not operate a tank vessel (as that term is defined in section 2101 of title 46, United States Code) or a vessel greater than 50 meters in length in the Area To Be Avoided described in the Federal Register notice of May 9, 1990 (55 Fed. Reg. 19418-19419).

(2) The prohibition in paragraph (1) shall not apply to necessary operations of public vessels. For the purposes of this paragraph, necessary operations of public vessels shall include operations essential for national defense, law enforcement, and responses to emergencies that threaten life, property, or the environment.

(3) The provisions of paragraphs (1) and (2), including the area in which vessel operations are prohibited under paragraph (1), may be modified by regulations issued jointly by the Secretary of the department in which the Coast Guard is operating and the Secretary of Commerce.

(4) This subsection shall be effective on the earliest of the following:

(A) the date that is six months after the date of enactment of

(B) the date of publication of a notice to mariners consistent with this section, or

(C) the date of publication of new nautical charts consistent with this section.

(b) MINERAL AND HYDROCARBON LEASING, EXPLORATION, DEVELOPMENT, AND PRODUCTION.—NO leasing, exploration, development, or production of minerals or hydrocarbons shall be permitted within the Sanctuary.

COMPREHENSIVE MANAGEMENT PLAN

SEC. 7.

(a) PREPARATION OF PLAN.—The Secretary of Commerce, in consultation with appropriate Federal, State, and local government authorities and with the Advisory Council established under section 208, shall develop a comprehensive management plan and implementing regulations to achieve the policy and purpose of this Act The Secretary of Commerce shall complete such comprehensive management plan and regulations for the Sanctuary not later than 30 months after the date of enactment of this Act. Ill dewing the plan and regulations, the Secretary of Commerce follow the procedures specified in sections 303 and 304 of the Marine Protection, Research, and Sanctuaries Act of 1972 (16 U.S.C. 1433 and 1434), except those procedures requiring the delineation of Sanctuary boundaries and development of a resource assessment report. Such comprehensive management plan shall—

(1) facilitate all public and private uses of the Sanctuary consistent with the primary objective of Sanctuary resource protection;

(2) consider temporal and geographical zoning, to ensure protection of Sanctuary resources;

(3) incorporate regulations necessary to enforce the elements of the comprehensive water quality protection program developed under section 8 unless the Secretary of Commerce determines that such program does not meet the purpose for which the Sanctuary is designated or is otherwise inconsistent or incompatible with the comprehensive management plan developed under this section;
(4) identify needs for research and establish a long-term ecological monitoring program;
(5) identify alternative sources of funding needed to fully implement the plan's provisions and supplement appropriations under section 9 of this Act and section 313 of the Marine Protection, Research, and Sanctuaries Act of 1972 (16 U.S.C.
(6) ensure coordination and cooperation between Sanctuary managers and other Federal, State, and local authorities with jurisdiction within or adjacent to the Sanctuary;
(7) promote education, among users of the Sanctuary, about coral reef conservation and navigational safety; and
(8) incorporate the existing Looe Key and Key Largo National Marine Sanctuaries into the Florida Keys National Marine Sanctuary except the Looe Key and Key Largo Sanctuaries shall continue to be operated until completion of the comprehensive management plan for the Florida Keys Sanctuary.

(b) PUBLIC PARTICIPATION.—The Secretary of Commerce shall provide for participation by the general public in development of the comprehensive management plan.

(c) TERMINATION OF STUDY'.—On the date of enactment of this Act, all congressionally mandated studies of existing areas in the Florida Keys for designation as National Marine Sanctuaries shall be terminated.

FLORIDA KEYS WATER QUALITY

SEC. 8.

(a) WATER QUALITY PROTECTION PROGRAM.—(1) Not later than 18 months after the date of enactment of this Act, the Administrator of the Environmental Protection Agency and the Governor of the State of Florida, in consultation with the Secretary of Commerce, shall develop a comprehensive water quality protection program for the Sanctuary. If the Secretary of Commerce determines that such comprehensive water quality protection program does not meet the purpose for which the Sanctuary is designated or is otherwise inconsistent or incompatible with the comprehensive management plan prepared under section 7, such water quality program shall not be included in the comprehensive management plan. The purposes of such water quality program shall be to—
(A) recommend priority corrective actions and compliance schedules addressing point and nonpoint sources of pollution to restore and maintain the chemical, physical, and biological integrity of the Sanctuary, including restoration and maintenance of a balanced, indigenous population of corals, shellfish, fish and wildlife, and recreational activities in and on the water; land
(B) assign responsibilities for the implementation of the program among the Governor, the Secretary of Commerce, and the Administrator in accordance with applicable Federal ant

(2) The program required by paragraph (1) shall, under Federal and State laws, provide for measures to achieve purposes described under paragraph (1), including—
(A) adoption or revision, under applicable Federal and State laws, by the State and the Administrator of applicable water quality standards for the Sanctuary, based on water quality criteria which may utilize biological monitoring or methods, to assure protection and restoration of the water quality, coral reefs, and other living marine resources of the Sanctuary
(B) adoption under applicable Federal and State laws of enforceable pollution control measures (including water quality/based effluent limitations and best management practices) and methods to eliminate or reduce pollution from point and y nonpoint sources;
(C) establishment of a comprehensive water quality monitoring program to (i) determine the sources of pollution causing or contributing to existing or anticipated pollution problems in the Sanctuary, (ii) evaluate the effectiveness of effort to reduce or eliminate those sources of pollution, and (iii) evaluate progress toward achieving and maintaining water quality standards and toward protecting and restoring the coral reefs and over living marine resources of the Sanctuary;
(D) provision of adequate opportunity for public participation in all aspects of developing and implementing the program; and

(E) identification of funding for implementation of the program, including appropriate Federal and State cost sharing ,.arrangements.

(b) Compliance Enforcement—The Administrator of the Environmental Protection Agency, the Secretary of Commerce, and the Governor of the State of Florida shall ensure compliance once the program required by this section, consistent with applicable Federal and State laws.

(c) Consultation.—In the development and implementation of the program required by paragraph (1), appropriate State and local government officials shall be consulted.

ADVISORY COUNCIL

SEC. 9.

(a) Establishment.—The Secretary of Commerce, in consultation with the Governor of the State of Florida and the Board of 3 County Commissioners of Monroe County, Florida, shall establish an ,Advisory Council to assist the Secretary in the development and implementation of the comprehensive management plan for the X Sanctuary f *

(b) Membership—Members of the Advisory Council may no be appointed from among (1) Sanctuary managers, (2) members of other - j, government agencies with overlapping management responsibilities e for the Florida Keys marine environment, and (3) representatives of g local industries, commercial users, conservation groups, the marine scientific and educational community, recreational user groups, or the general public.

(c) Expenses—Members of the Advisory Council shall not be paid .it. compensation for their service as members and shall not be reimbursed for actual and necessary traveling and subsistence expenses incurred by them in the performance of their duties as such members.

(d) ADMINISTRATION.—The Advisory Council shall elect a chairperson and may establish subcommittees, and adopt by-laws, rules, and such other administrative requirements and procedures as are necessary for the administration of its functions.

(e) STAFFING AND OTHER ASSISTANCE.—The Secretary of Commerce shall make available to the Advisory Council such staff, information, and administrative services and assistance as the Secretary of Commerce determines are reasonably required to enable the Advisory Council to carry out its functions.

AUTHORIZATION OF APPROPRIATIONS

SEC. 10.

(a) AUTHORIZATION FOR SECRETARY OF COMMERCE.—Section 313(2XC) of the Marine Protection, Research, and Sanctuaries Act of 1972 (16 U.S.C. 1444(2)(C)) is amended by striking "$3,000,000" and inserting in lieu thereof "$4,000,000".

(b) AUTHORIZATION FOR EPA ADMINISTRATOR.—There are authorized to be appropriated to the Administrator of the Environmental Protection Agency $750,000 for each of the fiscal years 1991 and 1992.

(c) RESORT.—The Secretary of Commerce shall, not later than March 1, 1991, submit to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Merchant Marine and Fisheries of the House of Representatives a report on the future requirements for funding the Sanctuary through fiscal year 1999 under title III of the Marine Protection, Research, and Sanctuaries Act of 1972 (16 U.S.C. 14321 et seq.).

Approved November 16, 1990.

Appendix VI - E: Core Group members

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Dana Bryan Phone Fax (904) 922-6215	Bureau of FL DEP
Ralph Cantral Phone (904) 488-3309 Fax	Florida Coastal Zone Management
George Garrett Phone (305) 289-2507 Fax (305) 289-2536	Monroe County Marine Resource Division
Ken Haddad Phone (813) 896-8626 Fax (813) 823-0166	Florida DEP FL Marine Research Institute
Brett Joseph Phone (301) 713-2967 Fax (301) 713-4408	NOAA General Counsel
John Klein Phone (301) 713-3000 Fax (301) 713-4384	NOAA SEA Division

Core Group, Continued

Toy Livingston Phone (904) 488-4925 Fax (904) 488-3309	Dept. of Community Affairs Bureau of State Planning
Peggy Mathew Phone (904) 488-0784 Fax (904) 922-5380	DER Coastal Management Program
Fred McManus Phone (404) 347-1740 Fax (404) 347-1797	US EPA Water Management Division
Danny Riley Phone 9904) 488-3456 Reserves Fax (904) 488-3896	Florida DEP Bur. Sanctuaries & Research
Jim Smith Phone (305) 872-1182 Fax (305) 872-1184	So. Florida Water Management Dist.
Skip Snow Phone (305) 242-7827 Fax (305) 242-7836	So. FL Research Center Everglades National Park

Appendix VI - F: Advisory Council members

List of Advisory Council Members (Cont.)

Name	Title	Address
Barley, George M. Jr.		1919 Espanola Drive Orlando, FL 32804-7019
Beall, Bonnie		**Florida Conservation Association** P.O. Box 216 Islamorada, FL 33036
Collins, Mike		**Commodore - Florida Keys Guide Association** P.O. Box 803 Islamorada, FL 33036
DeFoor, J. Allison		ATM Pharmaceutical Philadelphia, PA
Drake, Harold		**Underwater Society of America** 732 50th Street West Palm Beach, FL 33407
Etshman, Bruce A.		**Reef Relief** Key West, FL 33040
Fahrer, Alison		**Pennekamp Coral Reef Institute** P.O. Box 447 Islamorada, FL 33036
Holston, Robert W.		**Florida Association of Dive Operators** 1605 N. Roosevelt Blvd Key West, FL 33040
Hooper, Irene U.	Director	**Newfound Harbor Marine Institute at Sea Camp** Route 3, Box 170 Big Pine Key, FL 33043
Johnson, Paul		**Center for Marine Conservation** One Beach Dr., SE Suite 304 St. Petersburg, FL 33701
Laudicina, Michael		P.O. Box411 Big Pine Key, FL 33043

Sanctuary Advisory Council (Cont)

Name	Title	Address
Lessard, Karl	Captain	809 Lime Lane Marathon, FL 33050
London, Jack	Mayor	Alamo Building Rt. 2, Box 674B Summerland Key, FL 33042
Miller, James W.		Route 3, Box 295-C Big Pine Key, FL 33043
Ogden, John C.		**Florida Institute of Oceanography** 830 First Street South St. Petersburg, FL 33701
Parks, William		919 SW Twenty-Seventh Place Boynton Beach, FL 33435
Robertson, Mark L.		**The Nature Conservancy** 201FrontStreet,Suite222 Key West, FL 33041
Slate, Spencer C.		**Florida Association of Dive Operators** 51 Garden Cove Drive Key Largo, FL 33037
Sprunt, Alexander IV		**National Audobon Society** 1115 Indian Mound Trail Tavernier, FL 33070
Stewart, John F.	Regional Manager	**Professional Association of Dive** Instructors 1091 New Parkview Place West Palm Beach, FL 33417
Wickers, William Jr.	Captain	161 Key Haven Road Key West, FL 33040
Wooley, Henry		Barnett Bank 1010 Kennedy Drive Key West, FL 33040

Appendix VI - G: Tools used by groups connected to the FKNMS process

Various environmental groups and government agencies connected to the FKNMS process have used various tools that are somewhat similar to the tools explored in this research.

1. Best Guess

This was used by the Keys' Nature Conservancy in the fall of 1990 with a group of 20 people. It was used to answer the question: 'Is the Keys' waste water contributing to the water quality problems in the reefs and Florida Bay?' The Nature Conservancy needed the information for internal use, to decide whether or not "resources and funds should be used to reduce the amount of waste water generated in the Keys and entering the surrounding water bodies." said Mr. Robertson, Director of Florida's Branch of the Nature Conservancy. (Robertson, 1994)

Gregory Lowe of The Nature Conservancy (TNC) in Washington, DC. led the meeting in the Keys in the fall of 1990. The 20 people present were from different groups such as TNC in Florida, SeaKey, NOAA and the Florida Department of Environmental Protection. Mr. Lowe led a facilitated discussion, which allowed for uncertainty. He asked participants for best guesses as to what they thought were the factors contributing to poor near shore water quality. He tried to extract from the scientists their intuitive knowledge. The entire process took about half a day.

When asked why The Nature Conservancy had used such an elicitation tool and made a decision allowing for uncertainty, but NOAA had not used the tool in the FKNMS process, the president of Florida's TNC answered, "The Nature Conservancy could use the process, because we don't have to be as cautious. The (governmental) agencies want data and hard numbers before they can get money and give money." said Mr. Mark Robertson, Florida's Director of The Nature Conservancy.

2. Conflict Resolution

This was introduced by Dr. Robert Fujita of the Environmental Defense Fund. In January 1993, Dr. Fujita organized a set of meetings where researchers from Florida State University helped facilitate a community discussion on water quality in Florida Bay and the FKNMS. "Florida Bay could either be a source of cohesion or division for the Keys community." said Dr. Fujita, from the National Defense Fund. (Fujita, 1994) Fujita wanted to help make Florida Bay a source of cohesion, having many people in the Keys working together to solve the pollution problems.

Leaders from 15 to 20 constituent groups and about 25 commercial fisherman met in January 1993. Researchers from Florida State University, led by Professor Bob Jones, facilitated this Water Quality Round Table. "The three facilitated meetings went well; they helped form the Florida Keys' Water Quality Joint Action Committee." said Joyce Newman, President of Water Quality Joint Action Committee. (Newman, 1994) "It gave force to the political process; it joined environmental and economic interests in the Keys." (Fujita, 1994) The commercial fishermen realized the groups had a unified front at the first meeting, so at the second meeting, only five commercial fishermen came.

3. Systems Dynamics

Systems Dynamics is currently being used by the South Florida Water District. Dr. Robert Constanza has a contract with the SFWD to model the hydrological and ecological system in the Everglades using Systems Dynamics. Constanza uses his model with members of the public to move towards consensus on the physical aspects of the system. SFWD already has other models using different tools that simulate water flow in the Everglades, but these models capture only the hydrological system. These existing models focus almost entirely on the water needed for urban area and agricultural areas and on flood control. "Constanza's Systems Dynamics work is to be the next generation model, because it includes the ecology. The Everglades has a hydrological regime that features seasonally and annually dynamic patterns of storage and sheet flow of water. The SFWD chose to use SD, because they were looking for the next-generation tool to predict vegetation responses to altered hydrologic and nutrient regimes." said Dr. Fritz, of Maryland University. (Fritz, 1994)

The modelers are finding it more difficult to build the model than they first expected, because of missing information and great uncertainties. "The SFWD had indicated they had much more data and information than they actually have. Due to the lack of ecological data driving the water and nutrient uptake, the level of certainty in the predictions is not as accurate as originally hoped. For example, it is not known how we should alter flow-through canals and locks." (Fritz, 1994) The modelers realize the tool does not answer all questions or represent the ecosystem with high accuracy. "We have to start somewhere. These (equations used in the model) are hypothesis of how the system will work. It is better to have some information than make all ad hoc decisions." said Dr. Constanza of Maryland University.

The model will be handed over to the SFWD in early 1995, and they will continue to work on it, collecting data and specifying equations. (Constanza was contracted to finish by January 1995. In the summer of 1994, it looked more likely that it would be finished and transferred in March 1995.) "It will not be a predictive tool at that time, since there are still a lot of gaps in the knowledge. The data requirements have been horrendous." (Fritz, 1994)

"The SD model will probably be a better hydrological tool that what they (the SFWD) have now due to its better resolution. We have found already that plant transpiration is an important part in trying to understand the total water budget over time. Everything is now focused on the transpiration algorithm and flow of water through the Everglades." (Fritz, 1994) If this SFWD model can be run and be used as a predictive tool, then perhaps it could be used to determine the water and nutrient inflow into the Florida Bay.

Appendix Chapter VIII- A: General Information on how to use AHP

AHP is a multi-variable optimization technique developed by Prof. Thomas Saaty at the University of Pittsburgh. Saaty follows Herbert Simon's outline of decision making,[6] but has expanded Simon's research using decision makers and executives in organizations. Saaty developed AHP for considering problems with both qualitative (subjective) and quantitative factors. "Many decisions require qualitative as well as quantitative factors to be considered. If quantitative measurements are forced upon qualitative factors, the results may not be particularly meaningful." (Saaty, 1989)

There are five main steps to using AHP as a decision making tool:

1) Define the overall goal.

2) Develop a hierarchy by identifying all relevant variables and structuring their inter-relationships. This helps decision makers focus on the important components of the decision which became the elements of the hierarchy.

3) Identify alternatives.

4) Use judgment and assign relative weights to the different criteria.

5) So that the alternatives are clearly prioritized from best to worst, combine all judgments into one overall ranking using matrix algebra. This can be done manually or by using the computer program Expert Choice™[7].

Step 1 - Define the overall goal

In building the hierarchy, it is necessary to first identify the overall goal. The first level of the hierarchy should be the single 'goal' which is the overall purpose for the AHP model. Either the group decides together what the goal is, or if there is only one decision maker, then he or she decides the overall goal.

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[6] Simon's outline is discussed in The New Science of Management Decision, (Harper and Brothers, 1960)

[7] A computer software package, called Expert Choice™ has been developed by Saaty, Forman and others, that employs the AHP method It performs the matrix algebra, so that the users does not have to calculate the ranking by hand. After the user structures the hierarchy, enters the alternatives and enters the pairwise comparisons, the software easily calculates the rankings. Expert Choice™ is owned by and available for licensing from Expert Choice, Inc., Pittsburgh, PA 15213.

Step 2 -Develop the hierarchy and identify all the relevant variables

After the goal is agreed upon, then AHP requires the users to explicitly identify who or which groups will have decision making power. Is it an individual, or was there a group that decided on the goal? Will the group members all have equal decision making power?

Next, the users must identify the different objectives and criteria that must be considered in choosing the most desirable alternative. The criteria are the variables that are needed to meet the objectives. Saaty writes "Complex decisions require us to make judgments. In order to make judgments, standards on which these judgments can be based are required. For the Analytic Hierarchy Process, these are called criteria."[8] AHP requires that relationships among the decision variables be specified in a hierarchical structure:

- The first level in the hierarchy is the overall goal.
- The second hierarchy level is usually a listing of all the decision makers. This means that each person included has a vote in the overall decision. (If there is only one decision maker, then this level can be omitted.)
- The third hierarchy level is the level for the 'objectives' or sub-goals that support the overall goal. There can be many objectives.
- The fourth level includes the 'criteria' important to each objective.

This can be continued down to sub-criteria and sub-sub-criteria. A hierarchical structure, or tree with branches, is built.

Step 3 - Identify alternatives

The bottom-most level of the hierarchy is the alternatives. AHP requires that the different alternatives be identified and recorded in the bottom level of the hierarchy. If there are only a few alternatives that are possible, then it may be better to focus first on these few alternatives, and build the hierarchy from the bottom up as well as from the top down.

[8] Expert Choice manual, p.33

Figure VIII- A. An example of an AHP hierarchy built for only one decision maker.

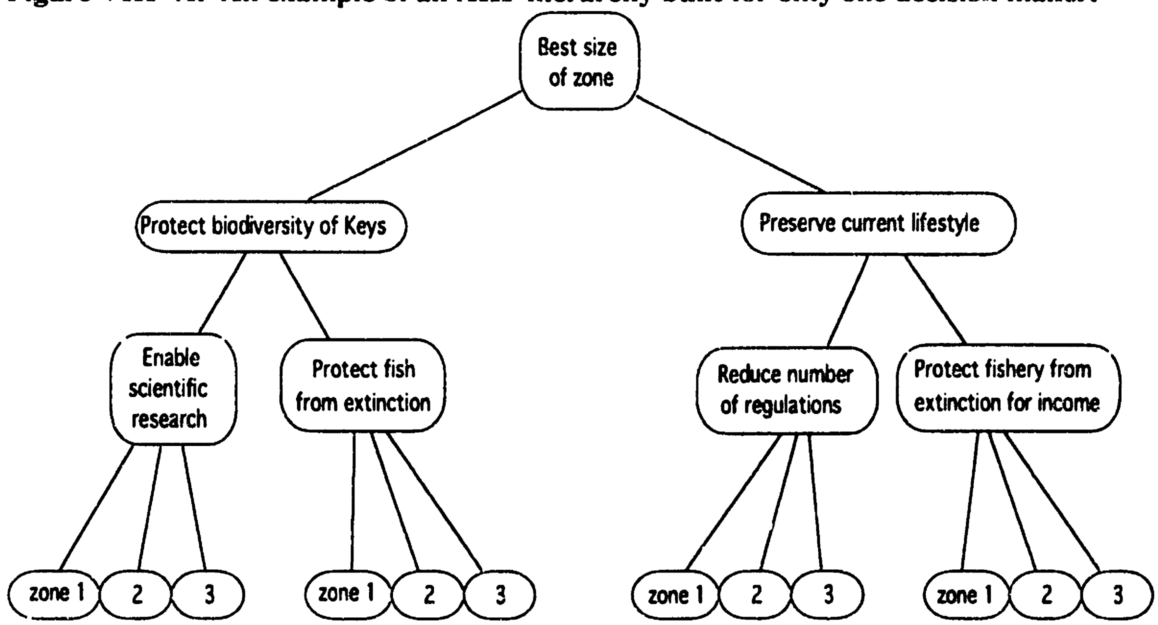

Figure VIII-A. is a simple example of an AHP hierarchy built for the FKNMS Replenishment Zone decision. Note, there is no level where multiple decision makers are defined, in this example, because this simplified version is just for one decision maker. If there are multiple decision makers, each limb and branch below the goal level will be repeated and identical for each decision maker. The same objectives and criteria would be listed under each of the different decision makers.

Building the hierarchy is completed with Steps 1, 2, and 3. Breaking down the criteria into a hierarchical structure helps to separate the issues, clarifying them for the group. If an objective or criteria is ill-defined, it can be further broken down into sub-criteria and sub/sub criteria until everyone is sure what each criteria means and what are the components of each. AHP would also help reach a more detailed list of criteria, because it doesn't need to assume that all criteria are equally important; not everyone needs to agree it is an important criteria for it to be listed. The process of valuing and judging happens later. The overall goal, objectives, criteria, sub-criteria and alternatives are identified.

One should realize that different decision makers may structure the problem very differently. Saaty advises that, "In practice, there is no set procedure for generating the objectives, criteria and alternatives to be included in a hierarchy. It is a matter of what objectives we choose to decompose a system into." To develop a hierarchical model, Saaty does recommend that one usually research the topic for enrichment of ideas and perhaps undertake a brainstorming session to list all concepts relevant to the problem.

Step 4 - Using judgment and assigning relative weights

After identifying the criteria and building the hierarchy, AHP requires the user to express the relative importance of variables. The AHP user first relates the sub-criteria to the available alternatives by pair-wise weighting the different variables at each level of the hierarchy. This is repeated with the criteria, then the objectives and ultimately the goal. The user must do pair-wise comparisons of alternatives in Level N with respect to each sub-criterion in Level N-1 to assign the weights. Then each sub-criteria in Level N-1 is pair-wise compared with respect to each criterion in Level N-2. (See Appendix XII - A for an example.) AHP uses a nine-level scale for assigning values as follows:[9]

1.0 Equal Importance of two elements with respect to a given criterion

3.0 Moderate Importance of one element over another

5.0 Strong Importance of one element

7.0 Very Strong Importance

9.0 Extreme Importance

Judgments can be made either in a top down or bottom up fashion. The bottom up approach is usually preferred, though, as the insights gained in first making judgments about alternatives will cause the judgments about the sub-criteria to be more meaningful and judgments about sub-criteria will enlighten decisions for criteria, etc.

Step 5 - Combining the judgments to achieve one overall ranking

After pair-wise comparison of variables in each level, AHP then uses matrix algebra to determine the optimal alternative. Basically, the method collapses the assigned values placed on each variable of the hierarchy into an overall ranking of alternatives using matrix algebra. (See Appendix XII- A for details on the mathematics.) Using the math to arrive at an overall ranking is the controversial part of AHP, since major inconsistencies in the form of rank order reversal may arise if new alternatives are added.[10] Even preferential voting may suffer from Condorcet's

[9] The decision to make AHP a nine-level scale is far from arbitrary. Research has shown that using a scale of pair-wise comparison from zero to infinity may not be useful at all, because it falsely assumes that human judgment is capable of comparing the relative dominance of any two objects. Our ability to discriminate is highly limited in range. When there is considerable disparity between the objectives or activities being compared, our guesses tend to be arbitrary and usually far from the actual. Results from many researchers were consulted, including Green and Miller : "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information", Psychological Rev., Vol 63, pp 81-97, March 1956.

[10] The inconsistencies that may arise are as such: Three alternatives may be pairwise compared, the matrix algebra used and an overall rank computed. (For example, Alternate A > Alternate B > Alternate C.) If a

paradox, though, and the vote may provide inconsistencies. See Hwang for discussions of inconsistencies that arise from voting. There are methods to prevent this rank order reversal using techniques that normalize the pair-wise comparisons with the new alternative; matrix algebra can still be employed for an overall ranking. (See Dyer, 1989 for more details.)

Even if an overall rank is never used, AHP can assist with the decision making process in a number of ways:
a) Complete the pair-wise comparisons for all alternatives, criteria, and objectives to assist in debates and discussions. Better understanding of the controversy and areas of disagreement can be reached when each group member only ranks each objective and criteria; the decision makers don't need to use the matrix algebra to determine overall ranking; ranking the objectives and criteria provides more information than just voting on the overall alternative; This helps break the decision down into smaller pieces, to assist the many decision makers in finding the root of their different opinions.

For example, there may be a situation where there are four objectives and six criteria. Everyone might agree on the relevant importance of the four objectives, but have very different opinions on two of the six criteria. The AHP ranking would help by indicating that future discussion and research efforts should be focused on the two criteria that people disagreed on. If only the overall alternatives had been voted on, then the group would not be any more knowledgeable as to where their disagreement lies. Ranking the criteria versus ranking just the overall alternatives can also prove very useful after the decision is made, when it has to be defended.

b) Rank the *alternatives* after reviewing the hierarchy. After reviewing the hierarchy, the decision makers would be more educated and informed about *all* the objectives and criteria important to the decision, rather than being focused on only what's important to them. It would help the stakeholders share their mental maps of important criteria, leading to a more informed decision.

c) Rank the different *objectives* after just reviewing the hierarchy. This would be helpful to the overall choice, because it would allow people to understand what are the most important objectives for each stakeholder. This is especially true in situations where a government agency

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fourth alternative is then added, it is possible that by adding the fourth, the order of the other three may be reversed. For example, the ranking is A, B, C when there is only three alternatives. When alternative D is added, instead of becoming A, D, B, C, the order of A and B might reverse so the overall rank becomes B, D, A, C.

will take the information about the stakeholders preferences and then make the final choice. It is also less time consuming than completing all the pair-wise comparisons.

Building the AHP can elicit the stakeholders' preferences for any or all levels of the hierarchy and at more detailed levels than voting on overall alternatives. Preferences at many different level of detail can be explored, not just at the final level of the alternatives. This is important since breaking down the decision often helps overcome impasses.

The AHP technique can be used for a wide variety of problems such as resource allocation, predicting future activities, conflict analysis, investment choices, cost-benefit analysis and more. What should be included in each different level of the AHP model may change slightly for each type of problem.

Appendix Chapter VIII-B: Issues other than Zoning where AHP could have been used

To quickly and easily overcome the problems of i) inadequate problem definition and ii)no iterative criteria formulation in any Issue other than Zoning, AHP could have been used to help develop many parts of the Management Plan. Since NOAA's NOS report showed that many AC and CG members felt the overall MP process suffered from not having clear goals, using AHP could have been helpful in defining some of the goals and objectives.

The first time AHP could have been used was during the Public Scoping meetings. It could have been used to help define the goals and objectives of the MP in *real time* with the public present. In these first meetings, NOAA tried to elicit the public's concerns. After eliciting the public's suggestions, the CG then narrowed many suggestions to 7 broad issues. If AHP had been used, the public would have taken the overall goals stated in the Act, then broken it down into sub goals using AHP. This would have allowed the public to define more closely the major issues.

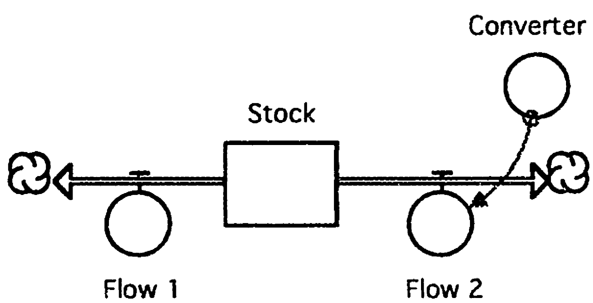
Still another place AHP could have been used is in a joint AC/Core Group meeting after the initial Public Scoping meeting. The NOS report said that the AC and CG wanted a meeting early on to set overall goals. Just as AHP would be used to elicit concerns and objectives from the public, it could have been used to elicit concerns and objectives from both the AC and CG on all of the major issues. The AHP models that were built with the public could have been shown at the joint AC/CG meeting. It could have been built upon and altered, just as the initial Zoning AHP hierarchy was built upon and altered by Allison Fahrer.

Another time AHP could have been used is within each of the issue workshop meetings in the Fall of 1991. AHP could have been used to elicit objectives and criteria and perhaps even some alternatives from the public within each of the major issues, so that each issue would have its own goals, objectives and criteria. They could have then focused on the major concerns within each of the issues, thus helping to identify alternatives or strategies. There were 278 strategies developed by the Strategy Identification Work Group. These 278 were added to by reviewing the public comments and by the AC, which created over 60 new strategies. The total number of strategies became 373. If detailed AHP hierarchies had been built with the public for each of the Seven major Issues, then the stakeholders might have felt like they contributed more to the strategies and formulation of choices. This would have allowed for a sense of ownership and more buy in from the public, and less resentment towards NOAA.

Appendix X - A: Using Systems Dynamics for Simulation

Systems Dynamics is most often used in an open system to predict the outcome of some decision alternatives. **(Hwang, 1987)** The first step in building a Systems Dynamics model is to build a Causal Loop Diagram identifying the relevant variables and linkages between the variables. To transpose a CLD into a Systems Dynamics model, it is then necessary to determine which variables are stocks, flows or converters and which linkages are flows or connectors.

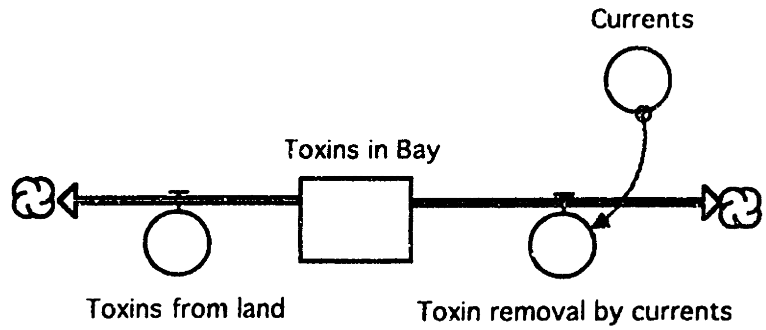
The stocks and flows are the primary building blocks that enable SDs to represent effects over time. Stocks represent accumulations and are usually variables that are nouns, or places where things can accumulate. For example, the amount of toxins in Florida Bay is a stock. It's a physical thing whose quantity can be measured. Flows are usually activities or verbs. Flows are rates, the variables that change the quantities in stocks over time. In order for there to be a Stock, an accumulation of something, there has to be an activity, a flow of something into the stock. For example, the amount of toxins that run off the land and enter the Florida Bay each year is a rate.



Converters are the variables that affect stocks or flow rates, but are not either one. They are catchalls, a variable which converts an input into an output. They can represent either information or material quantities. Unlike stocks, converters do not accumulate over time.[11] Converters can add detail to a model, used in one of the following four situations: stock related, flow related, stock/flow related or external input related. For instance, the currents which move through Florida Bay washing the toxins out, may be represented by a distribution that changes over time; currents do not, though, accumulate over time, so they are best represented as a converter. This "current" converter would *affect* the rate at which toxins flow out of the Bay, a converter which influences a flow. Lastly, connectors are simply the lines which carry

[11] Another reason for calling a 'noun' a converter instead of a stock is that the variable is not so important to the systems that the user needs to watch how it changes over the years.

information between converters and the other variables. It is the line that is drawn between the converter 'Currents' and the flow 'Toxin removal by currents.'



After transforming the variables and linkages of a CLD into stocks, flows, converters and connectors of an SD, the next step in building an SD is to try to determine the mathematical equations and initial values that represent the variables. Mathematical equations need to be defined to a) describe the stock's initial values and b) represent how the different stocks relate to each other by defining flows and c) specify the equations that represent the linkages between converters and the other variables. The user needs to go beyond what a CLD requires, simply labeling the linkages using only positive or negative signs. With SDs, the user must specify the initial *values* that define the stocks and converters and specify *equations* for flows and the connectors that link converters to the other variables.

1. Uncertainty

Trying to model a system, there are two ways to accommodate uncertainty with System Dynamics. The first way is to do a high case / low case sensitivity analysis. For example, the variable with uncertainty can be given its highest possible value and the model is run for the high case scenario. Then the value of the variable is changed to its lowest likely value and the model is run again. The user can then see if that one variable significantly changes the systems outcome.

A second more complicated method for accommodating uncertainty with SD would be to use the Latin Hyper-cube method. For the variable with uncertainty, the user could employ the graphical function. The users would determine what probability function represents the uncertainty in the variable, then specify it as a cumulative density function. Then the users could create a separate converter that would be a random number generator, a uniform distribution or some other number generator to create probabilities. (See the High Performance iThink Manual) Running the model, a range of probabilities would be created for the uncertain variable. These probabilities would be used to generate a range of possible outcomes or the distribution of events that might occur. (Kim, 1992) Note, though, that only one value or result is calculated for each variable in each time frame. Modeling uncertainty this way is possible, but it does get clumsy with Systems Dynamics. Additional converters must by inserted, and the user must draw each graphical function. As the SD diagram fills with more converters and connectors, its becomes harder for other people to follow and understand the logic. This makes it less effective as an elicitation or education tool.

2. Calculating changes over time

With Systems Dynamics, the values of the variable are calculated for future time periods. It works as such: the stocks at time = 0 are defined by the users. Then at time = 1, the values of all other variables are calculated based on the equations and the value of the stocks in time = 0. Then the stock values are updated for that period, time = 1. (This method is called a Euler Integration.) SD calculates through the value of each variable for a given time period, records every value for that time period, first converters and flows, then stocks, and then starts over and calculates the new values for the next time period.[12]

3. Mental models

The simulation tool may be easy or hard to use with many users depending on whether it is user friendly or not and whether it is pictorial based or text based. The easier it is for many people to take part in building or reviewing the model, the more helpful it becomes as an education tool. Systems Dynamics allows for many people to take part in reviewing the model because it is pictorial-based. Most of the model is created by drawing pictures, then the users go back and fill in the detail of equations and initial values. Being pictorial-based allows for many people to learn from the model. Having many people build the model may be hard to do, because it requires learning the SD language, which can be time consuming. If the decision makers are at least reviewing the model and its results after it is built, then SD can help inform the decision makers.

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[12] The equations that SD uses are differential equations, basically calculating the changes in a stock over time:

$$\frac{ds}{dt} = I_t - O_t$$

$$S_t = S_0 + \int^{t}_{t0} (I_t - O_t)dt$$

Appendix X - B: Systems Dynamics and Demos Definition of the variables

To understand whether or not replenishment Zones can help one species, red snapper, a simulation tool could be used. In this dissertation the Systems Dynamics tool is used to show the basic dynamics of the Red Snapper life cycles, death rates and harvest rates. This can be used to show why Replenishment Zones can help increase / preserve the Stock of Red Snapper and other demersal fish in the Sanctuary.

The ecology and life history of reef organisms make them vulnerable to fishing. Most reef species have a two stage life cycle; a pelagic, or open water, egg or larval stage and a demersal, bottom-dwelling, juvenile and adult stage. (Bohnsack, 1993) When they are in the sedentary demersal stage, they are vulnerable to fishermen, especially with sonar scanning devices which can detect a school of fish. Replenishment Zones can be helpful in increasing the number of reef species in their demersal life stage. Red Snapper are one reef organism that can be helped by Replenishment Zones. Red Snapper harvested by US. fishermen are primarily caught in the Gulf of Mexico, including the waters of the Florida Keys National Marine Sanctuary. In the FKNMS Red Snapper are found off the Dry Tortugas and off the deep water reefs. Red Snapper has been chosen for this dissertation as an example from the 6000+ species in the FKNMS because 1) it has faced rapid decline in recent years [13] and 2) it is well documented with more information than many other species.

Red Snapper are mostly sedentary, remaining in one reef area except during seasonal weather when they might move inshore. The Stock of Red Snapper is declining largely due to both the directed fishery and the commercial bottom trawl fishery for shrimp. Shrimp trawling causes juvenile Red Snapper ages 0 and 1 to be killed in the normal course of operation and then discarded at sea. "The present best estimate of the resulting mortality is that mean survival to the directed fishery is reduced about 83% because of the bycatch problem."

The Gulf of Mexico Fishing Marine Council has installed Catch Limits, Creel limits and minimum size limits for the Red Snappers, yet the Stocks are still not healthy. Although these

[13] Commercial landings from US waters were relatively stable at around 7 million pounds from 1964 until the mid 1970s. They subsequently declined to a minimum of 4.3 million pounds in 1980, recovered to 7.1 milllion pounds in 1983 and then declined to 2.7 million pounds in 1990. The recreational harvest declined from about 10 million pounds in the early 1980s to about 2 million pounds near the end of the decade.

fisheries' management techniques have slightly increased the Stocks in the last couple of years, it has not been enough. "Estimates of the spawning potential ratio increased from about 0.6% in 1984 to slightly above 1% by 1992. These levels compare to the 20% minimum required by the Gulf of Mexico Fishery Marine Council (GMFMC) Reef Fish Fishery Management Plan." "The conservation measures currently in place are enhancing the condition of the Stock. However, without the planned permanent reduction of 50% in the bycatch mortality rate in 1994 or an even higher reduction in 1995, it will not be possible to attain the spawning Stock goals of the Plan by the target date of 2007 and to also allow the directed fishery to operate under the current catch limit of 4 million pounds." The GMFMC is focusing on the need to reduce the shrimp bycatch so that the Stock of red snapper can increase.

The original attempt at an SD model included variables representing the "Health of Habitat", the limited food supply and predators in addition to the "Replenishment Zone" sector and "Not in the Replenishment Zone" sector. These parts, Health of Habitat, limited food supply and predators had to be altered. The stocks, flows connectors and converters that made up these parts could not be quantified in detail. They could be represented in a simplified manner, though. Realizing that the purpose of creating the SD model was to see if Replenishment Zones could help prevent a Stock from crashing, it became apparent that it was not necessary to model all these variables in detail. The most important part of the model was to look at the Stock growth and the physical dimensions of the Zone and represent the three different sectors as an upper limit of fish that could exist. (See attached graphs in Appendix X- C for more details.)

Basically, the model is broken down into the "Replenishment Zone" section and the "Not in the Replenishment Zone" section. Within each of these section, there is the "Stock of Larvae," the "Stock of 1 year old fish," the "Stock of 2 year old fish" and the "Stock of 3 year old and up." In general, these different Stocks are diminished by 1) Natural Mortality, 2) Fishing Mortality 3)Bycatch or 4) as time passes the fish matures and enters the next age group. Three-year-old and up only leave when they die, are harvested, or they exceed the maximum Stock of adult fish, that is, the fish Stock is too high to be supported by the food stock, or predators keep the fish Stock lower. Larvae are increased when the Stock of three years old and up reproduce. The reason for breaking it down into these age groups is that most of the research results and data breaks down this way.)

The original attempt at an SD model included variables representing the "Health of Habitat", the limited food supply and predators in addition to the "Replenishment Zone" sector and "Not in the Replenishment Zone" sector. These parts, Health of Habitat, limited food supply and predators

had to be altered. The variables that made up these parts could not be quantified in detail. They could be represented in a simplified manner, though. Realizing that the purpose of creating the model was to see if Replenishment Zones could help prevent a Stock from crashing if when there is a great deal of uncertainty in the values, it became apparent that it was not necessary to model all variables in detail. The most important part of the model was to look at the Stock growth and the physical dimensions of the Zone. The three sectors i)"Health of Habitat", ii) the limited food supply and iii) predators are represented as an upper limit of fish that could exist. (See attached graphs in Appendix X-D for more details.)

Both with and without the Replenishment Zone, the uncertainty analysis model basically works the same way the simulation model worked. That is:

1) There is a maximum stock of adult fish that can be sustained due to effects such as limited Health of Habitat, predators and food stock.
2) The Stock of Non-Replenishment Larvae (N0 Stock) are increased when Stock of the three year olds and up reproduce and are decreased by a) natural deaths, b) shrimp bycatch, and c) maturation into 1 year old.
3) The Stock of Non-Replenishment 1 year old (N1 Stock) are increased by the matured 0 year olds, and are decreased by a) natural deaths, b) shrimp bycatch and c) maturation into 2 year old.
4) The Stock of Non-Replenishment 2 year old (N2 Stock) are increased by the matured 1 year old and decreased by a) natural deaths, b) cryptic mortality where fish are caught and released and c) maturation into 3 year old. There has been a minimum size limit on Red Snapper since 1990 of 13 inches, which roughly translates to anything younger than 3 years old gets thrown back in. Fish that are 0 or 1 years old are probably not caught by line fishermen because they are too small. They are more often caught in shrimping nets.
5) The Stock of Non-Replenishment 3 year old and up (N3 & up Stock) are increased by the matured 2 year old and decreased by a) natural deaths, b) harvest and c) possible cryptic mortality. If the catch limits have not been met then the harvest equals the Directed Commercial Fishing Efforts, the CPUE dictate commercial catch and the non-directed commercial fishing efforts x CPUE + the Recreational Fishing and Efforts x CPUE. In this case cryptic mortality equals zero. If the catch limits have been met then the (legal) harvest equals the catch limits. Cryptic mortality, though, equal the Recreational and non-directed catch x the cryptic mortality rate. This is the reason catch limits alone may not save fisheries.

Non-directed commercial fishing and recreational fishing also exist, which either add to the harvest or causes cryptic mortality if the yearly pound limits have been met.[14]

With the Replenishment Zone, the Stocks of fish living in the Zone (R0, R1, R2, and R3 & up Stocks) are increased and decreased by the same factors as Stocks outside the Zone, except they do not decrease due to shrimp bycatch, cryptic mortality, directed or non-directed commercial fishing or recreational fishing. With the Replenishment Zones, there is also a net outflow of fish (Larvae, 1, 2 and 3 & up year olds) out of the Replenishment Zone and into the Non-Replenishment Zone, since the assumption is that the density of fish in the Zone will be higher than fish outside the Zone.

The paper, "Red Snapper in US. Water of the Gulf of Mexico, by Philip Goodyear, was used to extract most of the information to write equations and determine initial values for the model. Mr. Jim Bohnsack of NOAA's National Marine Fishery Service, Dr. John Hunt and Timothy Murphy of the Florida Marine Research Institute, and Benjamin Haskell and Billy Causey of NOAA also provided information via personal communications. (See Bibliography, under personal communications.)

None of the numbers are known with 100% certainty, but the model will be run using the best estimates of the mean values and the standard deviations as can be assumed from the Goodyear article.[15] The value of the Stocks over time without the Replenishment Zones will be graphed over time to see the *relative* change of the Stocks. Sensitivity analysis will be performed to see what variables affect the outcome. The values of the Dt's will be changed, the Reproduction rates and the Catch Limits will be varied to show how the Stocks might be effected. The Demos functions that can incorporate the uncertainty will be used.

Then the model will be run with the Replenishment Zones to see if there are any noticeable differences in the Stocks. *Relative* changes may indicate whether the Replenishment Zones will be helpful in maintaining the Stocks over time. To further describe the model, each variable will be discussed and how its value or equation was determined will be discussed.

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[14] "R' denotes Replenishment zone
"N" denotes Non-replenishment zone
"0" denotes 0 years old (or larvae)
"1" denotes 1 years old
"2" denotes 2 years old and
"3 & Up" denotes 3 year olds and up

[15] Each variable has a different amount of certainty associated with it, although no variable's uncertainty is explicitly stated by Goodyear.

1. Non-Replenishment Larvae, 1, 2 and 3& up year old Stocks

This is impossible to determine with certainty. In the Goodyear article, researchers estimate "the number of Gulf of Mexico Red Snapper alive at the beginning of the year for each age class for post-bycatch natural mortality of 0.20" and for a "post-bycatch natural mortality of 0.15." The estimates for age 2 through 11+ are derived from tuned VPA analysis. The estimates for ages 0 and 1 were derived from cohort analysis based on the VPA estimates of numbers alive at the beginning of age 2 and the dis-aggregated annual bycatch estimates with natural mortality of 0.5 for age 0 and 0.3 for age 1. The estimates for age 0 correspond to the beginning of June." Table 87 and 89 in the article gives a great deal of data including:

Stock of 0 year old range from 27,955,266 fish in the Gulf in 1984 to 70,617,208 in 1990.
Stock of 1 year old range from 12,936,286 in 1984 to 34,044,148 in 1990.
Stock of 2 year old range from 2,864,125 in 1985 to 6,150,708 in 1993.
Stock of 3 year old range from 1,857,253 in 1986 to 4,466,390 in 1992.
Stock of 4 year old range from 788,296 in 1986 to 2,315,261 in 1993, etc.
(See Table 89 in Goodyear, 1992)

The SD model will begin in 1984 using the average of the two estimates for 1984. Starting with 1984 as year 0 allows for a check: the Goodyear estimates from 1984-1990 can be compared to the estimates from the SD model. (year 0 - year 6).

Using both the 0.15 and 0.2 data from 1984-1990, Standard deviations were calculated:

Stock of 0 year: 39%.
Stock of 1 year: 40%
Stock of 2 year: 13%
Average for Stock of 3 year olds - 11 year olds: 30%

These estimates are high though, since the Stocks were steadily decreasing due to over fishing. A smaller standard deviation of 5% for all Stocks will be used.

Initial Stock of Red Snapper in Zone =

(Total number of Red Snapper in Gulf) x
(Area of Zone) / (Total area Red Snapper live in)

2. Births

The Stock of Larvae increases due to births. The number of births, the N0 Births plus R0 Births, was estimated by the number of 3 year old and up and the standard number of larvae per each adult. This equation could have been written as the number of larvae per each adult female, but this would just mean estimating that females are 1/2 the population. It would require dividing by 2 with one variable then multiplying by 2 later in another variable.) For example:

N0 Births = (N3& up Stock) x Reproduction Rate

3. Reproduction Rate

This is the rate at which the Stock of larvae increases. The number of eggs each females produces depends on the age of the adult female. Red Snapper do not reproduce at ages less than 3. "Red Snapper spawn offshore beginning in Spring or early summer and appear to move away from reef structure to spawn... " "Detailed historical studies required to characterize the actual reproductive contribution of females by age have not yet been performed. Consequently, the models used to characterize the relative reproductive importance of individual females in this report are based on the relation of mean ovarian weight during the spawning season and fish length..." "As in most long-lived species, females maturation is delayed for several years. The available data suggest some females may be mature at ages 3 and 4, but their individual contributions to the annual reproductive effort is very small compared to fish above 7 or 8 years of age." (Goodyear, 1992) General information about fish indicate that once a female fish reaches sexual maturity, then it will spawn every season, which is once a year for Red Snapper.

The Goodyear document gives a *relative* reproductive value of each age class of Red Snapper in the un-fished state. It says nothing about how many larvae are produced per adult fish. Bohnsack, Hunt and Murphy indicate that generally for every mature female fish, 10,000's to 100,000's of eggs are released. These must be fertilized, though, which depends on the number and density of mature males. Estimating the Reproduction rate as a fixed number per female fish is actually overestimating the larvae rate since reproduction rate depends on density of fish and is not fixed. It is an acceptable estimate for Red Snapper though, because they are a sedentary population; they stay relatively dense even if total population is low. The best estimate will come from extrapolating from the data on the population of 3-year-olds and up versus the population of 0-year-olds. (This method of estimating was approved by Mr. Murphy of the Florida Marine Research Institute.) That should give the general Reproduction rate for Red Snappers. The estimated the reproduction rate is:

Reproduction Rate = (Stock of 0 year old / Stock of 3 year old and up)

This gives:

4.98 larvae per adult fish in 1984

6.36 in 1985

7.80 in 1986

8.38 in 1987

8.09 in 1988

15.11 in 1989

16.46 in 1990

Note the increasing trend. Recognizing that the method for determining the Reproduction Rate is very imprecise, a large standard deviation will be used. It will be 33% of the mean.

4. Larvae Export Rate

Larvae float in the water, being moved by currents. It is assumed in the model that the number of larvae that are exported out of the Replenishment Zone are dependent on a) the size of the Replenishment Zone, b) the currents moving through the Zone, c) the amount of time a larvae spends drifting before it can swim and d) a factor of safety. The factor of safety allows for larvae to remain in the Zone either because some small percent of larvae remain in the Zone even if the currents are fast or because some larvae float into the Zone. The safety factor is assumed to be 95%. The estimate for the equation is:

Export rate = Min [(Current speed / (Size of reserve / Larvae Time),1] * 0.95

5. Current Speed

The currents of Florida Bay are presently being researched. Florida Bay's currents are presently being monitored and circulation patterns are being modeled (1994) by Ned Smith of the Harbor Beach Institute and John Wang of the University of Miami under contract of the Florida Marine Research Institute. Tom Lee of the University of Miami modeled the currents of the Atlantic and found that in near shore areas, the currents may be over 20 cm/sec. The Bay in general would be much slower than this. Ben Haskell of NOAA estimated that the Bay has a resident time on the order of months. (Haskell, 1994) Using these two different pieces of data, the currents in Florida Bay will be estimated as having an average speed of between 0.5 and 5 km/day, with an average of 2 km/day. If a specific Replenishment Zone were chosen, it would take less research to get good estimates of current speed and direction for that specific area.

Current Speed = 2 km / day = 730 km /year

The current speed was an educated guess, based on past research, but not yet measured or documented by current researchers. Therefore a large standard deviation will be used of **33%** of the mean.

6. Larvae Time

This is the amount of time Larvae spend drifting before they can swim. It is the amount of time they spend in their pelagic state, when the currents may cause them to drift out of the Replenishment Zone. "Eggs and larvae are passively transported and dispersed as plankton by ocean currents. Depending on the species and location, eggs and larvae can drift from about a week to several months before larvae settle, or 'recruit,' to bottom habitats." (Bohnsack, **1993)** Murphy gave the estimated time for Red Snapper to drift as roughly 2 months. **(Phone conversation 9/2/94)**

Larvae time = 2 months = 0.167 years

This is different for different larvae, since the growth patterns vary depending on many things, including the health of the habitat. It also depends on the speed of the currents, since it would require that the larvae be stronger and more mature to not be moved by the currents, no longer in the pelagic state. The standard deviation used will be one-sixth **(16.5%)** of the time, so that 95% of the larvae mature of the pelagic state between one and three months.

7. Size of Reserve

This would be determined by the decision makers choosing the Zone. This could be changed for sensitivity analysis, to see how the different sizes affect the Stocks of fish. In the base SD model, the average size of the three FKNMS Zones being planned was used. This is approximately an area of 100 square kilometers. The size of the reserve plays out in two places. One, it determines the cross current distance of the reserve, which affects the number of pelagic larvae that float out of the reserve. Second, the size determines the initial number of fish in the Zone, which is approximated as equal to the area of the Zone/area of the total region where Red Snapper live.

Cross current distance = 10 km

8. Bycatch Mortality Rate

Red Snapper are caught predominantly by line fishing, so the large adult population do not suffer from a bycatch mortality. If they are caught by fishermen looking for other fish, they are kept and the numbers are added to the official Commercial or Recreational catch numbers unless the yearly Catch Limits have already been met. Then Red Snapper suffer from Cryptic Mortality.

Small Red Snapper, though, do suffer from shrimp trawling bycatch. "The stock is impacted by... the commercial bottom trawl fishery for shrimp in which juvenile Red Snapper, ages 0 and 1, are killed in the normal course of operation and are discarded at sea. (Goodyear, 1992) "Unfortunately, significant data are not available to characterize either the precise magnitude of the age compositions of the annual shrimp discard mortalities by month and year. However, the monthly mean percentages of the annual bycatch were estimated by Nichols and Pellegrin in 1992 from monthly estimates of the temporal and spatial distribution of the shrimping effort, bycatch data from observer programs and resource survey data. Nichols and Pellegrin estimated the 1972-1991 annual magnitudes of the discard mortality and associated shrimping effort." (Goodyear, 1992)

"Goodyear and Phares (1990) estimated this discard mortality to be about F= 0.34 at age 0 and F=1.2 at age 1 for a total of 1.54 for a year class's period of exposure to shrimp fishery." (Goodyear, 1991) The probability of dying due to fishing = $1 - e^{(-F)}$ and the probability of dying due to natural mortality = $1 - e^{(-M)}$. Together the probability of dying = $1 - e^{(-F-M)}$. A conservative rate will be used:

F = 0.34 for 'Larvae Bycatch Rate' and

F = 1.2 for the 'N1 Bycatch Rate'

The two estimates 0.34 and 1.2 provide a combined estimate of 1.54, but "a subsequent sensitivity analysis of these estimates found the methods applied optimistic results and suggested that a value of F=1.64 would be more realistic for the parameter values employed." (Goodyear, 1992) A standard deviation should be relatively large, perhaps as large as the difference between the two estimates. A standard deviation of 1/15th **(6.7%)** of the mean will be used.

9. Cryptic Death (or Release Deaths)

Cryptic mortality is the death rate expected of a specie that occurs just by handling a live fish. When a fish is caught and thrown back in, often the fish dies due to the trauma of being caught, rapid change in depth and pressure, being out of water, being handled, etc. Gulf of Mexico Red Snapper less than 13 inches total length have been protected from harvest by a size limit since 1990. "Anecdotal comments from fishermen attest to the expected consequence of this regulation, i.e. significant numbers of undersized Red Snapper are caught and must be released. The mortality of released fish is an important consideration in evaluating the utility of minimum size regulations ... It is clear from these studies that significant mortalities of fish caught and released because of size or creel limits can be expected, but the precise extent of such mortality is not yet clear. Many of the analyses in this report assume an overall release mortality of 33%." (Goodyear, 1992)

Catch Survival Rate = 67%

"Over the range of natural mortality examined, the total fishing mortality (F) ranged from -.987 to 2.03, and the corresponding survival probability ranged from 0.37 to 0.13 respectively... Although the computed cumulative fishing mortality rates decreased with increasing natural mortality as expected, the computed fishing mortally was remarkably insensitive to natural mortality. A tenfold increase in natural mortality... yielded only a 2.4 fold increase in survival probability." If Goodyear saw 0.33 as the most likely estimate, yet other researchers calculated values such as 0, 0.01, 0.10, 0.20, 0.21, 0.26 and 0.36, then Goodyear's best guess at the distribution is probably a skewed distribution, with 0.33 as the mean.

10. N2 Cryptic Death

Although 2 year old are not supposed to be harvested, they are often caught. It is important to know the rate at which they are caught because of the high cryptic mortality. The N2 Cryptic Death is dependent on the Red Snapper commercial directed catch, the commercial non-directed catch and the recreational catch. Under-sized Red Snapper are caught in all of these situations, and have to be thrown back in. Many of these fish die due to cryptic mortality. If the yearly catch limits have been reached, then there would be no more directed commercial catch. Non-directed commercial catch and recreational catch would continue, though, and these would cause cryptic deaths.

N2 Cryptic Death = min(if catch limits < (Directed Commercial Catch + Non-directed Commercial Catch + Recreational Catch) then ((Commercial non-directed catch + recreational catch) * (Stock Ratio)* (1- Catch Survival Rate)), else ((Commercial Directed Catch + Comm Non Directed Catch + Rec Catch) * Stock Ratio* (1- Catch Survival Rate), N2 Stock)

11. N3 Cryptic Death

The Stock of the 3-year-olds and up fish can be destroyed due to cryptic mortality if the catch limits are the limiting factor for harvests. If recreational fisherman or non-directed commercial fishermen go out to fish, they might catch Red Snapper. If the catch limits have been already met for the year, the Red Snapper must be thrown back in. Some of the fish thrown back in may die due to cryptic mortality.

N3 Cryptic Death = min((N3& up Stock - N3 Harvest), If(Catch limits > Commercail Directed Catch + Comm. Non-dircetec Catch + Rec Catch)) then (0) else ((Comm Non-directed Catch + Rec Catch) * (1- Catch Survival Rate)))

12. Natural Death Rate

"As with most exploited fish Stocks, the level of natural mortality in the Gulf of Mexico Red Snapper Stock is not well-defined. This difficulty arises because the long history of the fishery does not permit an evaluation of the un-fished age distribution of the Stock." "However, in a recent study of age and growth of Red Snapper, Szedlmayer and Shepp 1992 encounter several fish from 30 to a maximum estimated age of 42 years, indicating a long life span. Overall, natural mortality (M) was assumed to be 0.5 for age 0 and 0.3 for age 1 and 0.2 for ages 2-30." (Goodyear, 1992) These numbers were used throughout the Goodyear report for many analysis, so they will be used in the SD Model:

Larvae Death Rate (M for age 0) = 0.5

Death Rate 1 (M for age 1) = 0.3 and

Death Rate 2& up (M for ages 2 and older) = 0.2

"The selection of natural mortality rates for age 0 and age 1 Red Snapper for this analysis is somewhat arbitrary. However, if the catch ability of age 1 Red Snapper is the same in the summer SEAMAP and Fall Groundfish surveys, the ratio of their relative abundance's between the two surveys would be an estimate of survival between the two periods... The resulting estimates were F=0.769 and Z=0.877. This total mortality estimate is very nearly the same as the estimate of 0.853 derived from the change in catch rates between the two surveys and provides support for the natural mortality assumption for age 1." The figures are "arbitrary" yet somewhat accurate, so the standard deviation may be average. A standard deviation of **20%** of the mean will be used.

13. Migration Rate

"Recent mark-recapture studies ...support the view that Red Snapper are relatively sedentary. Beaumariage and Bullock commented that Red Snapper definitely show specific reef residency based on their seasonal returns to summer forage areas and distinct congregation at reefs in deeper water... Recaptures of fish tagged in shallow water, 15 fathoms, or less suggest that the fish moved off the reef after being tagged, but return to the same reef a year later. Inshore-offshore movements are widely reported and are apparently related to seasonal weather patterns. Occasional individuals were observed to move considerable distances with a maximum of about 220 miles in 3 years." (Goodyear, 1992)

"Overall, the available data indicate the Red Snapper do not participate in seasonal migration as do many of the coastal pelagic species. However, they support the notion that Red Snapper do exhibit short range movements and do not discount the possibility of gradual dispersal of individuals through emigration from centers of abundance... Nonetheless, it is possible that the main mode of dispersal in the population may rely primarily on the hydrodynamic transport of the eggs or early larvae." (Goodyear, 1992)

Although the article gives much information on migration, it does not quantify how far the average fish moves off a reef. If onshore-offshore movements are common due to seasonal weather and somewhat due to reproduction patterns, and a Replenishment Zone was offshore, then fish would move outside of the Replenishment Zone. If the Zone was near shore I the migration rates might be lower. For the SD Model, the Migration rate will be simplified and equal to 5% if the Replenishment Zone extends to the shore, although this estimate is just a guess. If the Replenishment Zone were offshore as in the Dry Tortugas, the Migration Rate outside the Zone may be closer to 100% for 3 year old and up. There is no way to force the information into an equation until the users know the specific site they're building the model for. Assume the Replenishment Zone will be near shore, so:

Migration Rate = 0.05

The average used, 5% is just a guess based on researcher's observations. Therefore a large standard deviation will be assumed, **33%** of the mean.

14. Directed Commercial Catch

Since Red Snapper are caught predominantly by line, it is often the case that Red Snapper may be caught even if it is not sought. LORAN equipment, though, can make it easier for fishermen to find schools of fish, so often fishermen attempt to remember the general area where a certain specie of fish live and find the exact location with the LORAN equipment. The Goodyear article states "Trips landing 50% or more Red Snapper are considered to be directed at Red Snapper." Directed Commercial Catch would be the total number of fish caught by directed Red Snapper efforts.

Directed Comm Catch = Directed Comm Fishing Effort x Directed Comm Catch per unit effort

15. Directed Commercial Fishing Effort

It is difficult to quantify fishing effort; it is usually understood to be either the amount of time fishermen fish or the amount of money invested in fishing equipment. The commercial fishing effort has been determined by time, using "logbook data files on July 31, 1992. The data come from "commercial landings files maintained by the Fishery Dependent Data Group of the SEFSC Research Management Division (FDDG) and supporting collection programs." Examination of all data, though, indicated inconsistencies in the manner in which the fish were reported. Red

Snapper catch and effort reported by fishermen participating in the Gulf of Mexico Reef Fish Logbook Program, who landed at any Gulf port, showed that for directed fishermen the commercial effort was 1559 days in 1990, 5591 days in 1991 and 4176 days in 1992. Goodyear then took the partial data of reported catch and estimated total directed catch. "The fractions of permittees required to report by the vessel's port were estimated from the data in the permit file (Table 40). The fractions of trips and landings reported by permittees that were not required to submit logbooks were estimated by summing the trips and landings for those required and not required to submit logbooks.

Consequently, the number of days elapsed between the date of departure and the date of return (+1) was used as an estimate of days fished. The data were collated by total catch, trips, days fished, state of landing, month and year. The data were then sorted by the proportion of the total landings of fin-fish on the trip that were Red Snapper. This led to (a set of Tables) which give the catch and associated numbers of trips and effort, by state, month and year for all trips that landed Red Snapper, and those trips in which Red Snapper were more than 25%, 50% or 75% of the fin fish landed...Because of the differences in reporting recruitment by year, the number of trips and days fished are not directly comparable between years. Further complicating the problem is the fact that some participants voluntarily participated." For the SD Model, Fishing Effort was estimated from Goodyear's article Figure 38 and Table 40 commercial fishery. "Estimates of the number of days fished by week for trips where Red Snapper exceeded half the total fin-fish landings" were about 450 days per week:

Directed Commercial Effort = (450 days /week) x (52 weeks / year)

= 23,400 days / year

In Figure 38, Goodyear estimates the total Directed Commercial Effort based on t he partial reported data in Table 29-34. Using Tables 29-34, the (percentage) standard deviation will be calculated, then applied to Goodyear's total estimates. Using just April - December 1990 data before the Catch Limits effected the size of the Stocks, the monthly Standard deviation is 71% of the monthly mean. Using all the available annual totals (1990-92) the Standard deviation was 54% of the annual mean. The annual Standard deviation is probably more relevant so a SD of **55%** of the mean will be used.

16. Directed Commercial Catch per Effort

In Goodyear's article, (Figure 40) the commercial "Red Snapper Catch per day fished by week for trips where Red Snapper exceeded half the total fin fish landings" is listed. "Catch per day... (in 1992) averaged about 240 pounds and were typical for the same period the previous year."

On average, the fish caught weigh 2 pounds per fish: from Table 46 . For the SD Model, it was estimated that:

Directed Comm Catch per effort = 240 lb. per day / 2.0 lb. per fish = 120 fish /day

Again, Goodyear estimates the Directed Commercial Catch per Effort based on the partial reported data in Tables 29-34. Returning to these tables the (percentage) standard deviation will be used. Using the 1990 monthly data, a standard deviation of 49% of the mean was calculated. Using all the available annual totals, only 1990-92, a standard deviation of 30% of the mean was calculated. A standard deviation of **35%** of the mean will be used.

17. Non-directed Commercial Catch

Because Red Snapper are caught by lines, they are often caught by fishermen who may not necessarily be fishing only for them. The Goodyear article defines "Non-directed commercial catch" to be when 50% or less of a boat's fin fish catch is Red Snapper. It may be fishermen looking for many types of bottom dwelling fin fish or shrimp trawling where adult Red Snapper are caught and included in the commercial harvest catch. If the Red Snapper catch limits have been exceeded for the year, then fisherman who catch them must throw the Red Snapper back, regardless of the size. Some of these, though, may die due to cryptic mortality.

Non-directed Comm Catch = (Non-directed Comm fishing Efforts) X (ND Comm Catch per unit Effort)

18. Non-directed Commercial Catch per Effort

This was calculated using (total commercial catch - directed commercial catch) / (total commercial effort - directed commercial effort) from Table 34, 40 - 46 in the Goodyear article. It was calculated using the equation:

$$\frac{\text{(Catch: Any in catch) - (Catch: >50\% in Catch)}}{\text{(Days: Any in catch) - (Days: >50\% in Catch)}}$$

since this would be the Red Snapper catch when Red Snapper was less than 50% of the total catch. For 1990, it was 21 lb. / day, for 1991:31 lb./day and for 1992: 3.8 lb./day. Note, the dramatic drop off in 1992. Projecting back to 1984 -89 and forward past 1993, the average of these numbers will be used:

Non-directed Commercial Catch per Effort = 18.6 lb. / day ~= 9.8 fish/day

Goodyear does not estimate the total Non-directed Catch per unit Effort from the partial reported data. Using Tables 29-32, and the 1990 monthly data, the standard deviation is calculated as 94% of the mean. Using Table 34 and all the available annual data (1990-92), the standard deviation is 74% of the mean. So a large standard deviation will be used, **80%** of the mean.

19. Non-directed Commercial Fishing Effort

To get an estimate of average effort, the Table 34: "Catch and Effort Reported by fishermen participating in the Gulf of Mexico Reef Fish Logbook" was used. A conservative estimate of only the reported catch will be used, because Goodyear did not indicate the fraction of reported catch to total catch. The reported catch could be increased by a factor of four to get the approximate ratios that Goodyear calculated for Directed Commercial catch, but they would be a guess. Using only the reported catch is a conservative estimate but it is not a bad estimate because: a) it is the same order of magnitude, b) non-directed has a much smaller effect than directed, c) it may balance the Catch-per-unit effort fluctuates wildly from 3.8 to 31, but the average of 16 is being used. The Catch-per-unit Effort may be more of an error than this Effort estimate. To determine the non-directed commercial catch efforts, that is, when Red Snapper was less than 50% of the total catch. The total commercial catch efforts will be subtracted from the directed commercial catch efforts. In 1990, it was 5994 days, in 1991 it was 10,001 days, in 1992 it was 22,314 days; so the average is 12,803. Note, though, that the trend is for increasing catch in the non-directed fishery, although these people are not looking for Red Snapper. The SD Model will begin by using the low estimate, since it might have been even lower in 1984, year 1 of the SD Model.

Non-directed Comm Effort = Total Comm Efforts - Directed Comm Efforts
= 6,000 days for the low estimate

Using 1990 monthly data for the four regions in Table 29-32, the Standard deviation is 165% of the mean. Using all the available annual totals in Table 34, (1990-92) the standard deviation is 66% of the mean. So a large standard deviation of **80%** of the mean will be used.

20. Recreational Catch

Although Red Snapper recreational harvest may be "directed" using LORAN equipment, most sport fishermen go out with the hopes of catching any good game fish. The Goodyear article separates Commercial harvest from Recreational harvest, and divides Recreational harvest into Party Vessels (Head Boats), Charter Vessels and Private / Rental Vessels.

Recreational Catch = (Rec Efforts) X (Rec Catch per Effort)

21. Recreational Catch per unit Effort

Goodyear's article gives information on catch per unit effort only for "non-trolling modes by vessels participating in the Charter boat Surveys." (Tables 65 -72). For Florida Charter boats. The number range from 0.31 fish per angler hour in 1988 to 1.0 in 1991. The average for the

Charter boats will be used to estimate for Total Recreational Catch per unit Effort . Using Table 46, one can see that the Charter boat catch is similar to the Head boats and private boats, but is larger than the shore catch. Overall, this will make this Charter Boat estimate a conservative one:

Recreational Catch per unit Effort = 0.67 fish / angler hour

Using Table 69-72 to get all the available annual Charter boat Recreational Harvest (1989-1992), the standard deviation is **17%** of the mean.

22. Recreational Fishing Effort

Since Goodyear does not provide data for this directly, it will be estimated by dividing the historical Total Recreational Harvest (Table 47) by the Charter Boat Harvest per effort (Table 69-72). Total recreational Harvest ranges from a high of 1,128,000 to a low of 673,000. Using this data, the average number of angler hours per year will be estimated for recreational fishermen who spend time fishing for bottom dwelling species somewhat like Red Snapper. For reference, Red Snapper usually make up between 9% and 35% of a charter boat's catch. An estimate of the average recreational fishing effort is:

Rec Fishing Effort = Total Harvest / Harvest per Effort

= 1,474,000 angler hours / year

Note: Recreational Harvest is less than Recreational Catch from years 1979-90, because about 10% of the fish caught are not harvested.

"Recreational harvest estimates for Gulf of Mexico Red Snapper by State for the period 1979-91. The estimates are based on the 1979-91 NMRFSS, the 1986-1991 NMFS Head boat Survey and the 1981-91 length frequency samples and the 1986-1991 Catch Estimates compiled by Texas Parks and Wildlife... Where the sample size was less than 25, the state or gulf-wide annual mean was substituted... The estimates have been adjusted for missing data in January and February 1981 in all states and for 1982-84 in Texas by the average portions observed in years where these strata were sampled." Best educated guesses were used by Goodyear to estimate the data. The standard deviation will be approximated as the standard deviation of the Total Recreational Catch from 1984-1990 (Table 46), which is **30%** of the mean.

23. Catch Limit

The current catch limit for Gulf of Mexico Red Snapper is 4 million pounds per year. Since 1992, the 4 million pound limit has closed down the fishing season, so effectively, the GMFMC limit has been the controlling factor in the total harvest. The GMFMC has also implemented different conservation actions such as minimum lengths, 13 inches, and maximum recreational creel limits of 7 fish. The catch limits will be translated into an approximate number of fish by using the average fish weighing 2 pounds. Note, though, the catch limit only went into effect in 1990, so any modeling done before that should have a catch limit of infinity.

Catch limit = 4,000,000 lb. / 2 lb. per fish

= 2,000,000 fish

Although the Catch limit is set at 4 million pounds, all fish do not weigh two pounds. The (percent) standard deviation of the harvested weight will be used as an approximation for the (percent) standard deviation for the Catch Limit. Using Table 47 the standard deviation for the fish weight is **9%** of the mean.

24. N3 Harvest

This is the catch rate per year of fish 3-years-old and up. This is not the same as different commercial and recreational catch rates, since fish of any size can be caught, but many may need to be thrown back in. Red Snapper can only be harvested if a) they are greater than 13" and b) the yearly catch limits have not been met. Harvest is therefore determined by a combination of the Directed Commercial Catch, Non-directed Commercial Catch and the Recreational Catch or the Catch Limits. [16]

N3 Harvest = min [(Comm Directed Catch + Comm Non-directed Catch + Rec Catch), Catch Limits]

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[16] One would expect it to be determined by the stock of fishable fish. This is not necessarily true, for pelagic fish. "Catch per unit effort (CPUE) is sometimes a function of the abundance of the stock. This is the case when the proportion of the stock captured by an average unit of effort remains the same regardless of stock abundance. Examples would include a stock fished with a randomly applied gear and a stock distributed at random, but fished with a consistent gear. In such circumstances, CPUE is proportional to the abundance of the stock, as was assumed for the trawl data discussed previously.
However, it is well known that the characteristics of the species and/ or gear employed allow CPUE to be relatively constant over large variations in stock size. This condition is often associated with species which form aggregations that can be located reliably. It occurs where the number of fish caught from such aggregations is limited by the capacity of the industry to accommodate increased landings or the capacity of the gear (gear saturation, Rothschild, 1977) In such circumstances, the proportion of the stock captured by an average unit of effort increases as the stock declines, and cpue will to reliably reflect abundance. (Bannerot and Austin, 1983) When this condition is true, fishing mortality is density dependent and depensatory, i.e. it increases with declining stock size without concomitant increases in effort. As noted earlier, Red Snapper tend to aggregate around reefs and other structures. The locations of the aggregation points are well known. LORAN navigation has also made them easy to locate. " Gear used to catch Red Snapper " can catch a larger proportion of smaller local stock, even to the point of catching the last remaining fish on a particular structure if the conditions are favorable. These are the characteristics which lead to depensatory fishing mortality and make CPUE a poor indicator of stock size. These notions suggest that a trend of constant through time for the directed fishery is NOT a reliable indicator of constant population size. Similarly, a decline in CPUE may reflect a change in the stock is far more serious than the extent of the declines suggest."
"Data used to examine trends in CPUE in the commercial Red Snapper fishery were drawn from the logbook data files on July 1992.

25. Health of the Habitat, Limited Food Stock and Predators

Each variable in this part of the model could not be modeled quantitatively, even with a high level of uncertainty. It is not known what levels of a healthy habitat affect reproduction rates, growth rates and death rates. It is not possible to give these factors initial values or equations. The purpose of this model, though, is to see if Replenishment Zones can help "protect the 6000+ species" from crashing. For this purpose, it will probably be adequate to model these variables as constant. This will translate into using one variable called the "Habitat Limit" that represents the upper limit on the number of fish that can live in the environment. This number will have to be guessed at, but can be changed doing sensitivity analysis. The initial values for the upper limit on the Stocks will be 50 times the 1984 Stocks.

Limited food sources and natural predators would act to keep the Stocks fairly level; There would be no exponential growth to infinity as was seen in the model. There might be exponential growth to reaching the maximum Stock, but the Stock would not grow to infinity. If there were no human influences, such as fishing, boating, scuba, etc. then the Stocks would certainly be more abundant, but they would not be unlimited. A variable called Habitat Limit should be added to both models which would represent the maximum population. If scientists or fishery managers have estimates of the typical Stock sizes before people started fishing, then one could put an upper limit of the different Stock sizes. With the Habitat Limit, there would not be exponential growth that the model showed.

Habitat Limit: = 10 * Initial 1984 Stocks

The uncertainty in this variable is very large since so one has ever calculated the limit. The multiplier 10 is somewhat random; it is greater than any of the data that in the Goodyear article.

The standard deviation for the Habitat limit would be about the same as for the Initial Stocks, **5%**, if one were used.

Results of the SD Model

The SD model helped this author to understand the dynamics of the many different variables. It was easy to see how the many different variables interact and affect the outcome, that is, the size of the Stocks and the Harvest.

Even though it did not include the detailed variables of: a) Health of Habitat in model; b) food sources; and c) natural predators, SD helped educate how various human factors affected the Stock. The model helps focus on which variables' uncertainties may be most important, even though the Health of Habitat, Limited Food Stock and Predators was simplified. Attempting to model the system, the user can better understand the important variables in the system:

i) Reproduction Rate - How many larvae are created from each adult fish, that is, how many eggs do females release and how many do males fertilize?

ii) Directed Commercial Fishing Efforts - If the fish became genetically less diverse, and on average became smaller, always only 3 years old, but never larger, and Catch limits remained the same, 4,000,000 pounds per year, then directed commercial fishing efforts would need to *increase* to catch more fish before the pound limits were reached. Fewer fish, never older than 3 years old, would certainly cause the Reproduction rates to decrease and the Stocks to crash.

ii) Maximum Stock- There is already a great deal of uncertainty as to what the actual numbers would be, but scientists are quite sure that an unhealthy habitat would decrease it.

iv) Natural Mortality Rates - This rate would increase due to unhealthy habitats.

v) Migration Rates - If an area was particularly healthy, or unhealthy, it might cause a higher percentage of fish to migrate.

vi) Size of Fish - Instead of the average 3-year-old equaling an average 2 pounds, for example, an unhealthy habitat would produce 3-year-olds that were only an average of 1.5 pounds.

Even though the SD model omits the Health of Habitat and these connections, we know which variables might be most important to pursue first. The models can help many people agree as to what the most important areas of uncertainty are. This can help many people agree as to what the most important areas for research and areas to be funded are. Prioritizing research is essential when time and research budgets are limited.

Appendix X - C: Systems Dynamics Results

1. Initial Run - No Replenishment Zone

Initial Stocks Not in Zone

Stock 0 = 29,000,000 fish in the Gulf

Stock 1 = 14,000,000

Stock 2 = 3,500,000

Stock 3& up = 5,700,000

Initial Stocks in Replenishment Zone = 0 (This is an easy way to model "no Zones")

Commercial Direct Fishing Effort = average of 1990, 1991 and 1992 = 23,400 Days

Commercial Non Direct Fishing effort = the low estimates of 1990 (6,000 days)

Catch Limit in 1984 = Infinity (Since there was no Catch limit in 1984)

Dt = 1.

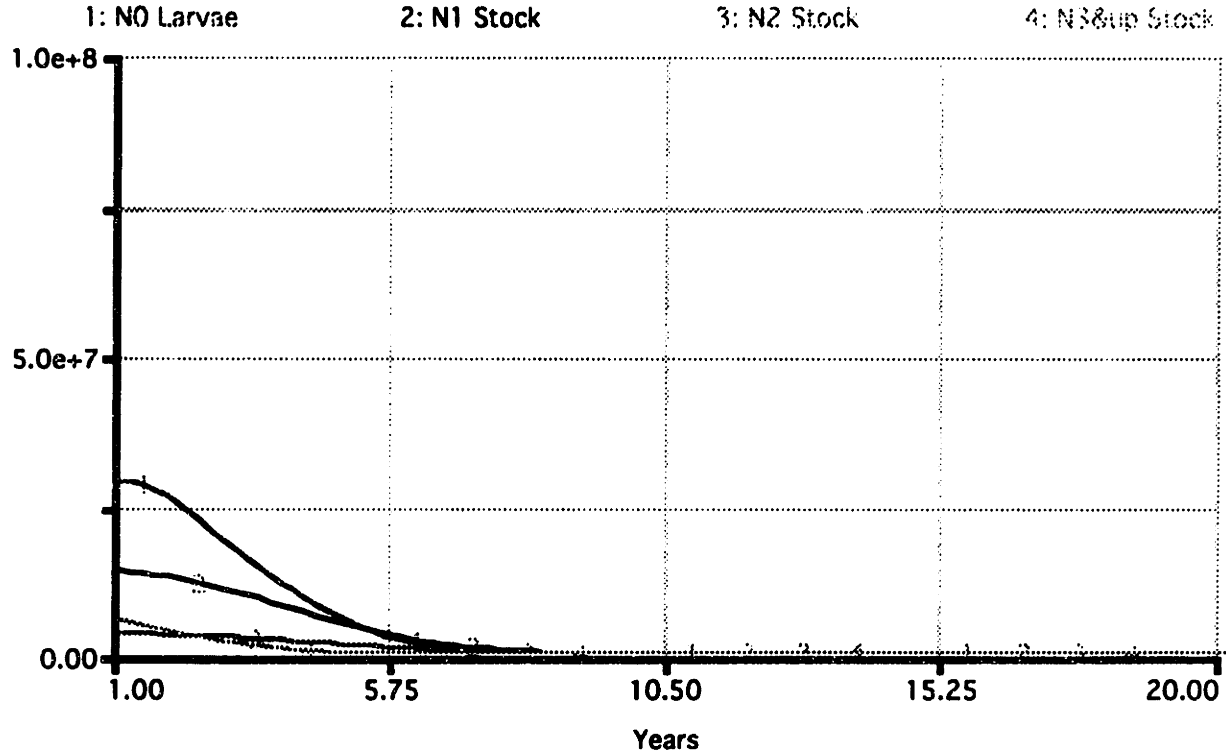
Reproduction rate = 5 (1984 rate)

The predictions are:

Year	Stock N0	Stock N1	Stock N2	Stock N3
Initial	29,000,000.00	14,000,000.00	3,500,000.00	5,700,000.00
1	28,500,000.00	12,519,605.18	3,123,822.24	3,668,038.42
2	18,340,192.11	12,303,749.92	2,793,501.51	1,654,538.12
3	8,272,690.62	7,917,653.93	2,745,337.69	496,840.02
4	2,484,200.10	3,571,407.60	1,766,667.39	0.00
5	0.00	1,072,455.33	796,888.75	0.00
6	0.00	0.00	239,297.13	0.00
7	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00

Note, the Stock of N3 year olds crashes first in year 4, since they are the Stock being harvested. The following year, the Stock of larvae crash, then the N1 year olds and finally the N2 year olds. One can understand the reason that the Stocks crash in the order they do. If there are no N3 fish, then there are no fish available to reproduce and no larvae the next year. No larvae results in no N1 fish the following year, which results in no N2 fish after that.

Using DT = 0.2, the results change slightly:



The table of values is as follows:

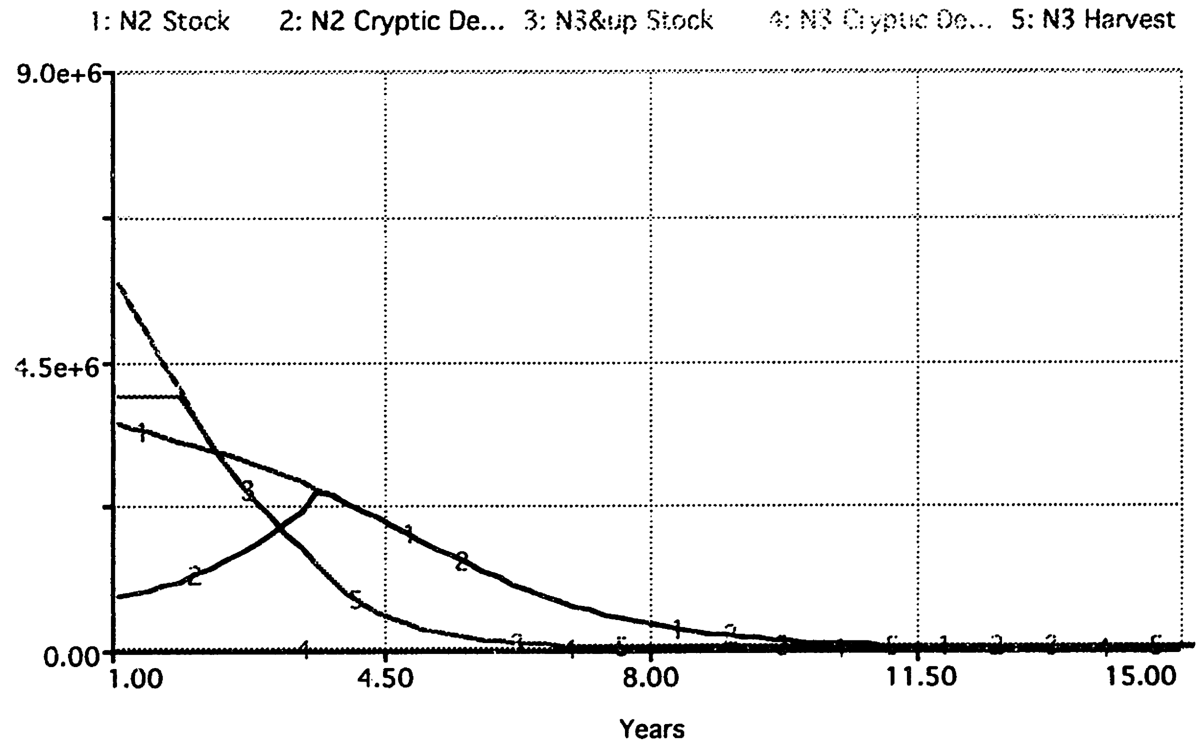
Year	Stock N0	Stock N1	Stock N2	Stock N3
Initial	29,000,000.00	14,000,000.00	3,500,000.00	5,700,000.00
1: .2	28,900,000.00	13,703,921.04	3,424,764.45	5,293,607.68
1: .4	28,413,607.68	13,458,423.65	3,351,363.18	4,882,646.24
1: .6	27,613,532.39	13,220,029.61	3,281,686.59	4,466,204.67
1: .8	26,557,030.58	12,960,234.19	3,215,306.73	4,043,187.36
2: .0	25,288,811.83	12,661,177.27	3,150,609.21	3,611,815.11
2: .2	23,842,864.57	12,312,431.05	3,085,505.47	3,220,361.76
2: .4	22,294,653.42	11,908,587.95	3,017,859.32	2,878,339.22
2: .6	20,714,061.95	11,451,837.66	2,945,720.48	2,574,484.14
2: .8	19,145,733.70	10,949,965.83	2,867,626.46	2,299,286.98
3: .0	17,615,873.94	10,413,055.61	2,782,754.70	2,044,502.14
3: .2	16,137,201.29	9,851,436.12	2,690,897.11	1,802,619.73
3: .4	14,712,380.76	9,274,468.82	2,592,348.19	1,566,147.34
3: .6	13,336,051.94	8,689,872.97	2,487,761.30	1,326,377.62
3: .8	11,995,219.17	8,103,361.17	2,378,003.59	1,070,702.95
4: .0	10,666,878.28	7,518,381.41	2,264,023.72	856,562.36
4: .2	9,390,064.98	6,935,705.85	2,146,734.51	685,249.89
4: .4	8,197,301.87	6,359,322.65	2,026,900.64	548,199.91
4: .6	7,106,041.41	5,795,230.42	1,905,311.85	438,559.93

4: .8	6,123,393.05	5,249,734.91	1,782,867.62	350,847.94
5: .0	5,249,562.39	4,728,494.57	1,660,568.93	280,678.35
5: .2	4,480,328.26	4,236,053.92	1,539,469.09	224,542.68
5: .4	3,808,805.29	3,775,684.11	1,420,613.55	179,634.15
5: .6	3,226,678.38	3,349,407.55	1,304,984.64	143,707.32
5: .8	2,725,050.02	2,958,124.24	1,193,458.48	114,965.85
6: .0	2,295,005.87	2,601,785.95	1,086,776.13	91,972.68
6: .2	1,927,977.38	2,279,584.40	985,528.29	73,578.15
6: .4	1,615,960.05	1,990,133.14	890,151.44	58,862.52
6: .6	1,351,630.56	1,731,631.91	800,932.90	47,090.01
6: .8	1,128,394.46	1,502,008.15	718,022.18	37,672.01
7: .0	940,387.58	1,299,034.47	641,446.41	30,137.61
7: .2	782,447.67	1,120,422.62	571,127.88	24,110.09
7: .4	650,068.22	963,896.28	506,902.32	19,288.07
7: .6	539,342.65	827,245.28	448,536.72	15,430.46
7: .8	446,904.57	708,364.20	395,746.05	12,344.36
8: .0	369,868.02	605,278.04	348,208.32	9,875.49
8: .2	305,769.91	516,157.62	305,577.82	7,900.39
8: .4	252,516.32	439,326.91	267,496.32	6,320.31
8: .6	208,333.37	373,264.32	233,602.47	5,056.25
8: .8	171,722.95	316,599.40	203,539.28	4,045.00
9: .0	141,423.36	268,106.44	176,960.00	3,236.00
9: .2	116,374.69	226,695.94	153,532.53	2,588.80
9: .4	95,688.55	191,404.79	132,942.56	2,071.04
9: .6	78,621.88	161,385.78	114,895.69	1,656.83
9: .8	64,554.34	135,897.01	99,118.56	1,325.47
10: .0	52,968.94	114,291.36	85,359.39	1,060.37
10: .2	43,435.52	96,006.54	73,387.88	848.30
10: .4	35,596.72	80,555.55	62,994.70	678.64
10: .6	29,156.01	67,517.93	53,990.63	542.91
10: .8	23,867.72	56,531.74	46,205.56	434.33
11: .0	19,528.50	47,286.18	39,487.24	347.46
11: .2	15,970.27	39,515.08	33,699.98	277.97
11: .4	13,054.18	32,990.97	28,723.39	222.38
11: .6	10,665.72	27,519.90	24,450.97	177.90
11: .8	8,710.48	22,936.82	20,788.88	142.32
12: .0	7,110.70	19,101.54	17,654.68	113.86
12: .2	5,802.42	15,895.18	14,976.17	91.09
12: .4	4,733.02	13,217.14	12,690.28	72.87
12: .6	3,859.29	10,982.37	10,742.05	58.29
12: .8	3,145.72	9,119.12	9,083.74	46.64
13: .0	2,563.21	7,566.90	7,673.94	37.31
13: .2	2,087.88	6,274.83	6,476.83	29.85
13: .4	1,700.15	5,200.14	5,461.49	23.88
13: .6	1,384.00	4,306.91	4,601.25	19.10
13: .8	1,126.30	3,565.02	3,873.20	15.28
14: .0	916.32	2,949.26	3,257.65	12.23
14: .2	745.28	2,438.53	2,737.74	9.78
14: .4	606.01	2,015.17	2,299.01	7.82
14: .6	492.63	1,664.46	1,929.14	6.26
14: .8	400.36	1,374.10	1,617.59	5.01
15: .0	325.30	1,133.85	1,355.39	4.01
15: .2	264.24	935.17	1,134.91	3.20
15: .4	214.60	770.95	949.66	2.56

15: .6	174.24	635.29	794.13	2.05
15: .8	141.45	523.28	663.66	1.64
16: .0	114.80	430.83	554.28	1.31
16: .2	93.15	354.58	462.65	1.05
16: .4	75.57	291.71	385.94	0.84
16: .6	61.30	239.89	321.77	0.67
16: .8	49.71	197.20	268.12	0.54
17: .0	40.31	162.06	223.30	0.43
17: .2	32.67	133.12	185.87	0.34
17: .4	26.48	109.32	154.64	0.28
17: .6	21.46	89.74	128.59	0.22
17: .8	17.39	73.65	106.88	0.18
18: .0	14.09	60.42	88.79	0.14
18: .2	11.41	49.55	73.73	0.11
18: .4	9.24	40.63	61.19	0.09
18: .6	7.48	33.30	50.77	0.07
18: .8	6.06	27.29	42.10	0.06
19: .0	4.91	22.35	34.90	0.05
19: .2	3.97	18.30	28.92	0.04
19: .4	3.21	14.99	23.95	0.03
19: .6	2.60	12.27	19.83	0.02
19: .8	2.10	10.04	16.41	0.02
20: .0	1.70	8.21	13.58	0.02
20: .2	1.38	6.72	11.23	0.01
20: .4	1.11	5.49	9.28	0.01
20: .6	0.90	4.49	7.67	0.01
20: .8	0.73	3.67	6.34	0.01
21: .0	0.59	3.00	5.23	0.00

With a smaller Dt, the decline is more gradual, the curves are smoother, there are no sharp corners. It takes until year 21 for the Stock of N3 to totally crash. One should note, though, that with Dt < 1, the model allows for fractions of fish! For all practical purposes, it is not incorrect to say that the N3 Stock crashes somewhere between year 10 and year 15.

On can understand why the Stocks of N0, N1 and N2 fish crash once the Stock of N3 fish crash. Now the problem becomes trying to understand why the N3 Stock crashes. To understand, one should compare the Stocks to the Harvest and Cryptic Deaths for 2 and 3 year olds, that is N2 Cryptic Deaths and N3 Cryptic Deaths and N3 Harvest.



Since the fishing efforts are high looking for 3 year old fish, the fishermen catch many N2 fish, some fish being caught multiple times, and thrown back in. Many of these N2 fish that are caught and thrown back in die. The number of N2 fish that die due to cryptic mortality increases, while the overall Stock of N3 fish decreases. For every N3 fish the fishermen catch and harvest, they also catch many N2 fish and throw them back in. Around year 4, the Stock of N2 fish that die due to cryptic deaths (N2 Cryptic Deaths) is so high that it equals the entire Stock of 2 year old fish (N2 Stock). This means that all the N2 fish die, and none grow to become N3 fish.

N3 Harvest is flat until year 2, because it is defined as the minimum of either a) the catch limits or b) the sum of recreational catch, directed commercial catch and non directed commercial catch. The Commercial and Recreational catches have been defined conservatively as fixed numbers in the model. From year 0 to year 2, N3 Harvest is calculated as a fixed number because the model is calculating N3 Harvest as the latter, a summation of fixed numbers.

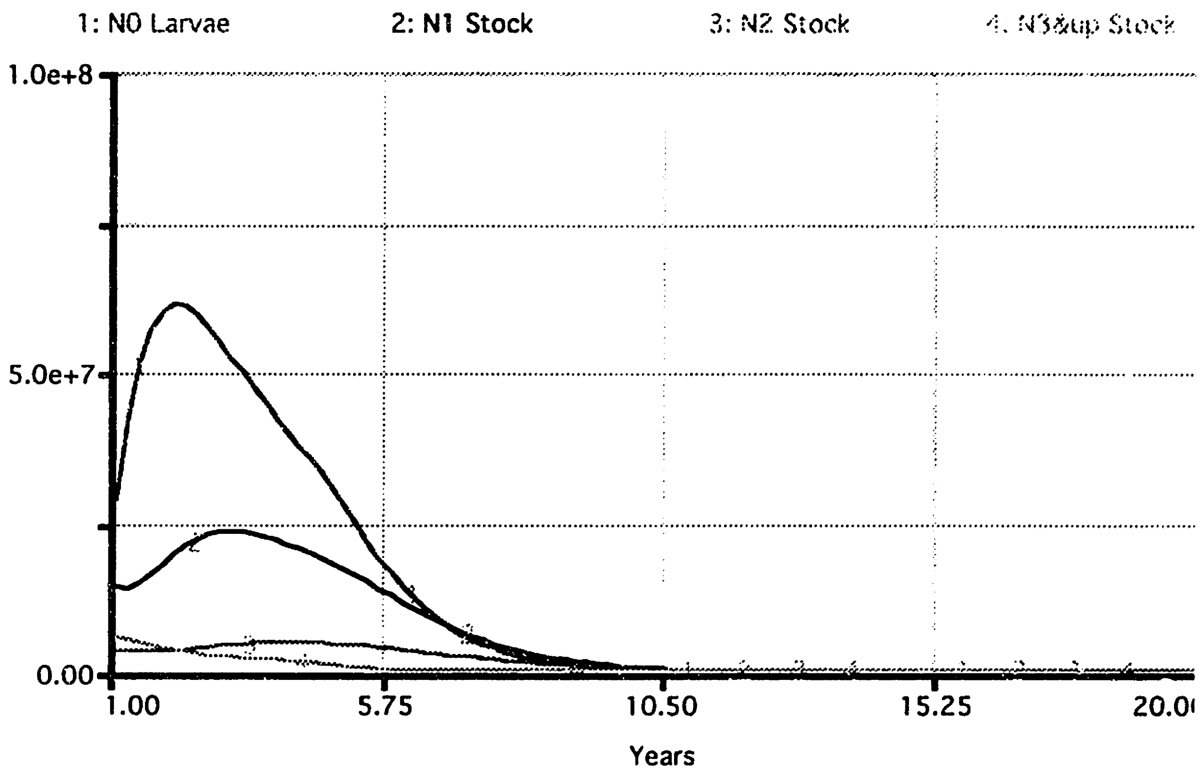
Recreational Catch, Directed Commercial Catch and Non Directed Commercial Catch are modeled as fixed over time as the actual data shows. It would be more realistic to model the fishing efforts as changing over time if all the numbers were available for each year from 1984 to the present: i) Past fishing efforts would be more accurately depicted and ii) one could look for trends and perhaps more accurately predict future fishing efforts more accurately. This is where Econometrics could help. Unfortunately, such exact numbers were not available for all years.

2. Reproduction Rate Sensitivity Analysis

It is obvious that at least some of the variables have been defined inaccurately because the model does not show the Stock of Larvae and 1 year olds increasing in the first few years as the scientific estimates in the Goodyear paper show. In order to calculate larger Larvae and N1 Stocks, either the Reproduction rate or the N3 Stock would have to increase. Sensitivity analysis should be performed.

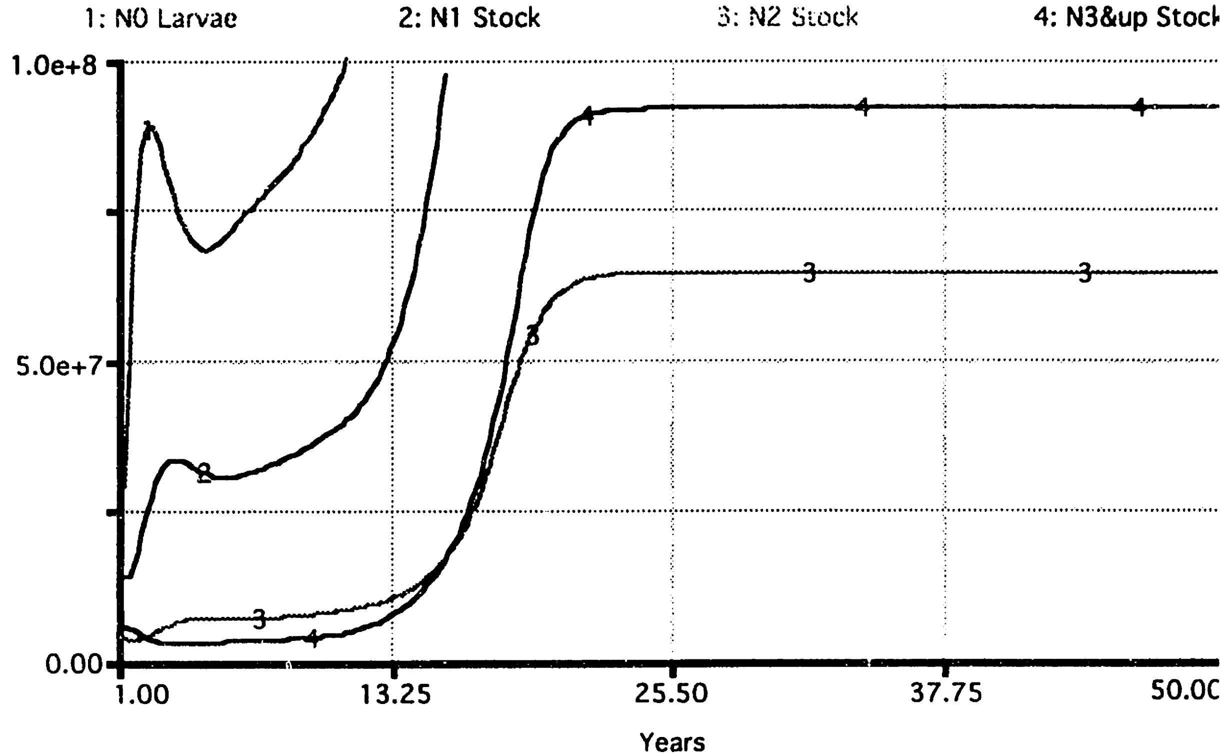
Increasing the Reproduction Rate seems most reasonable, because five Larvae per adult fish, or ~10 larvae per females adult fish, is incredibly low, making Reproduction Rate the most suspect number in the entire model. Many species of adult female fish lay 10,000's - 100,000's eggs. One should keep in mind, though, that most Red Snapper fish 3 years old do not produce as many eggs as fish 11 years old. If the species is over-fished, there may be fewer old fish. It is very possible that this number does fluctuate wildly. The Reproduction number should be explored. (Murphy, 1994) Also note that Reproduction rate is one of the variables that is most susceptible to the Health of Habitat, the part of the model that was simplified.

The Reproduction Rate will be changed to the high of 1990 instead of using the low of 1984. Using 16.5 instead of 5:



This Reproduction Rate actually causes the Stock of fish to increase for awhile, but ultimately the Stocks crash after about 10 years. The Stocks are smaller than estimated by the scientists in the Goodyear article.

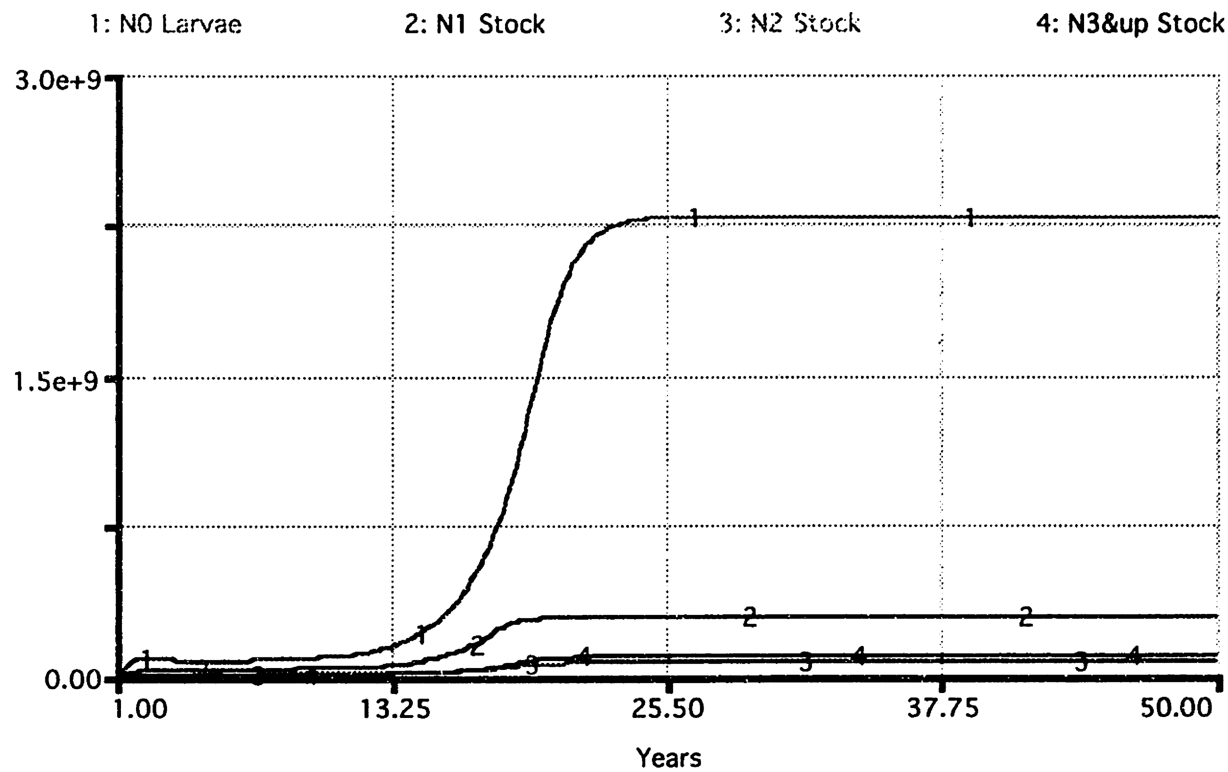
A larger Reproduction Rate of 25 will be used:



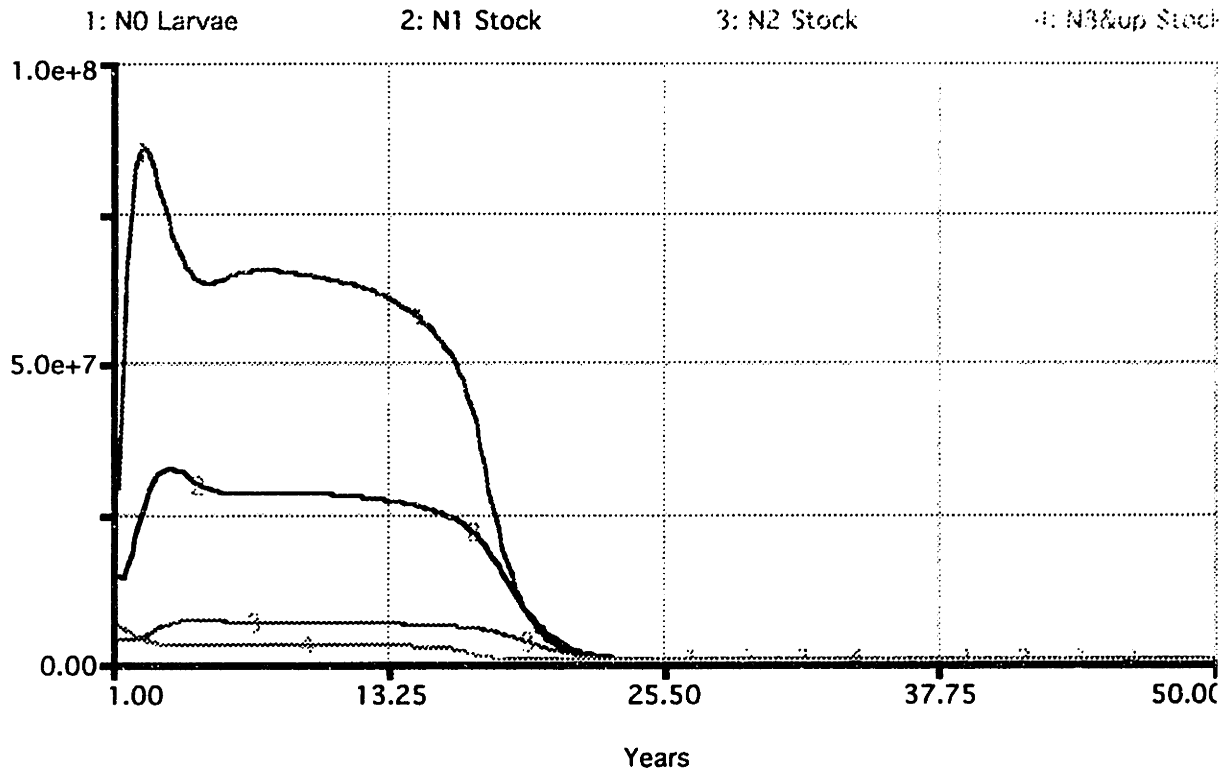
These Stocks are higher than the Goodyear estimates. The Stocks of 2 year olds and 3 year olds level off when they reach the Habitat's Holding Capacity. The Holding Capacities are set somewhat arbitrarily at about 10 times the 1984 Stock levels estimated in the Goodyear article.[17] In general, though, they represent the fact that the Stocks can not grow to infinity, that they are restricted by the number of predators, the food source and the Health of the Habitat in general.

Using the larger scale for the y-axis, one can make sure that the Stocks of Larvae and 1 year olds do not increase to infinity:

[17] The Stock levels do actually rise slightly above the fixed number set for the Habitat's Holding Capacity, because the way the variable is modeled, the Stocks can be as high as the (Fishing Mortality + the Natural Mortality + Habitat's Holding Capacity).



Now a Reproduction Rate of 24 will be used:

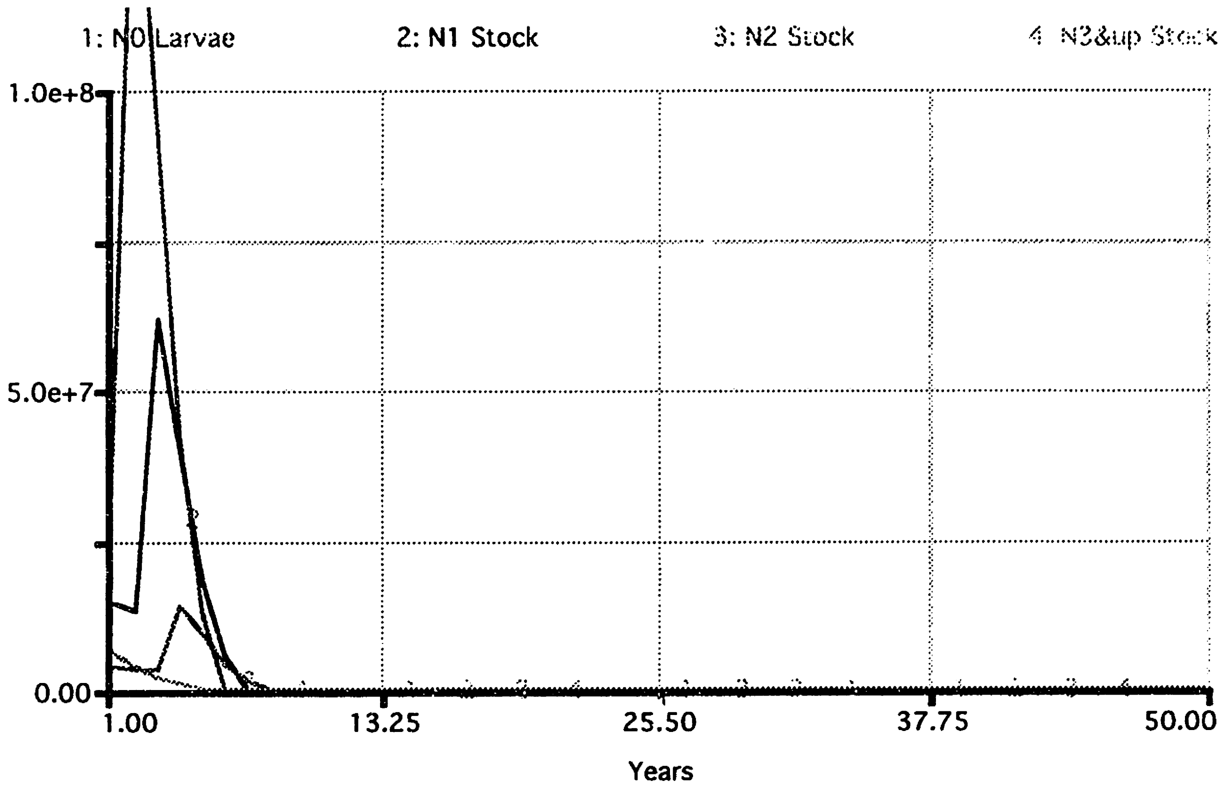


This higher Reproduction Rate does cause the fish to increase for awhile, making the Stocks more like the actual data of Stocks that the Goodyear article estimates from fishing samples.

When the Reproduction rate changes from 5 to 16.5 to 24 to 25, the Stock of fish see very different results over a 50 year period. With 5, the Stocks crash after about 5 years. With 16.5, the Stocks crash after about 10 years. With a Reproduction Rate of 24, the Stocks increase, then crash after 20 years. With a Reproduction Rate of 25, the and Larvae find their upper limit of ~11 billion after about 25 years. This shows how sensitive the Stock of fish is to its Reproduction Rate over the long term.

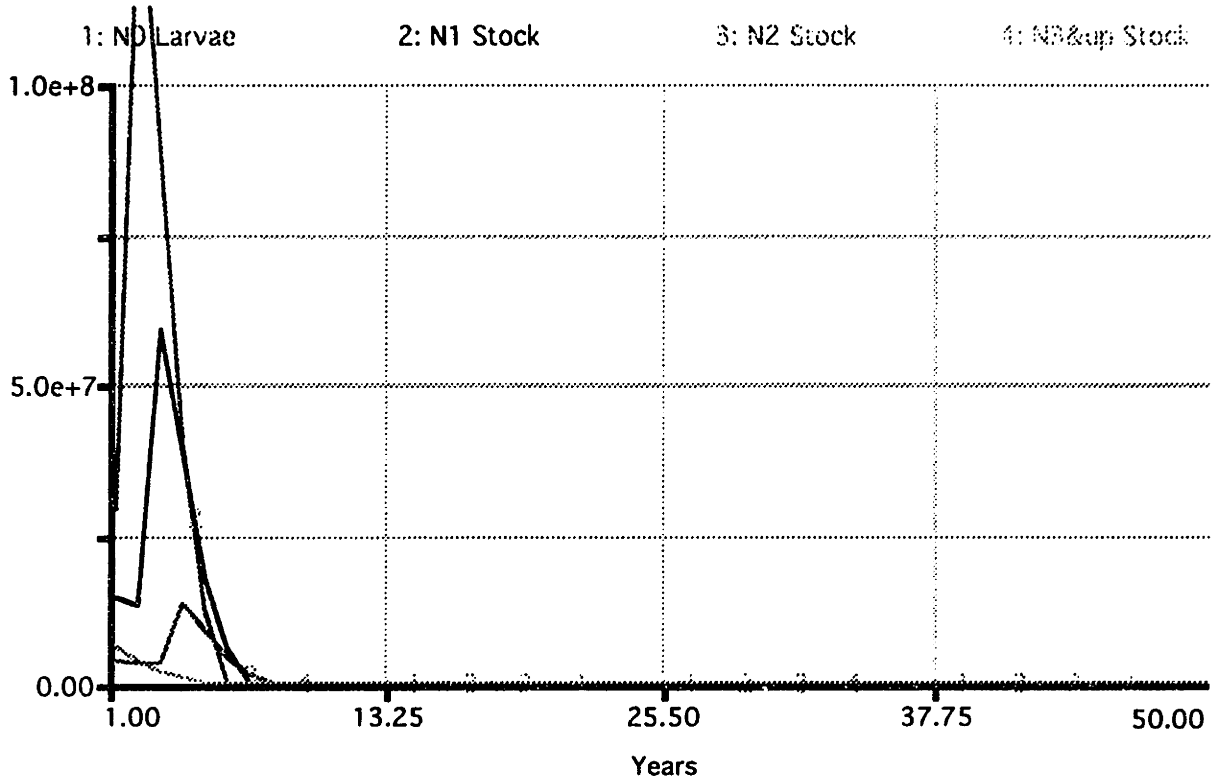
3. Does using a different Dt change the results?

It is important to determine if the Dt being used is appropriate. Sensitivity Analysis was done keeping all the inputs the same as above , including the Reproduction rate = 25. The only difference is the Dt was changed from 0.2 to 1:



The results are very different when the Stocks are not smoothed by using a small Dt. The outcome changed from a *Stock that doesn't crash to a Stock that does crash*.

Using the Reproduction Rate = 24, the results are:



Again the results change. With the Dt = 1, the Stocks crash after 7 years as opposed with a Dt= 0.2 the Stocks crash after 20 years. This shows that a Dt of 1 is too large. A Dt= 0.5 was also tried and found to be too coarse. A Dt= 0.2 will be used for the rest of the runs.

4. Catch Limits

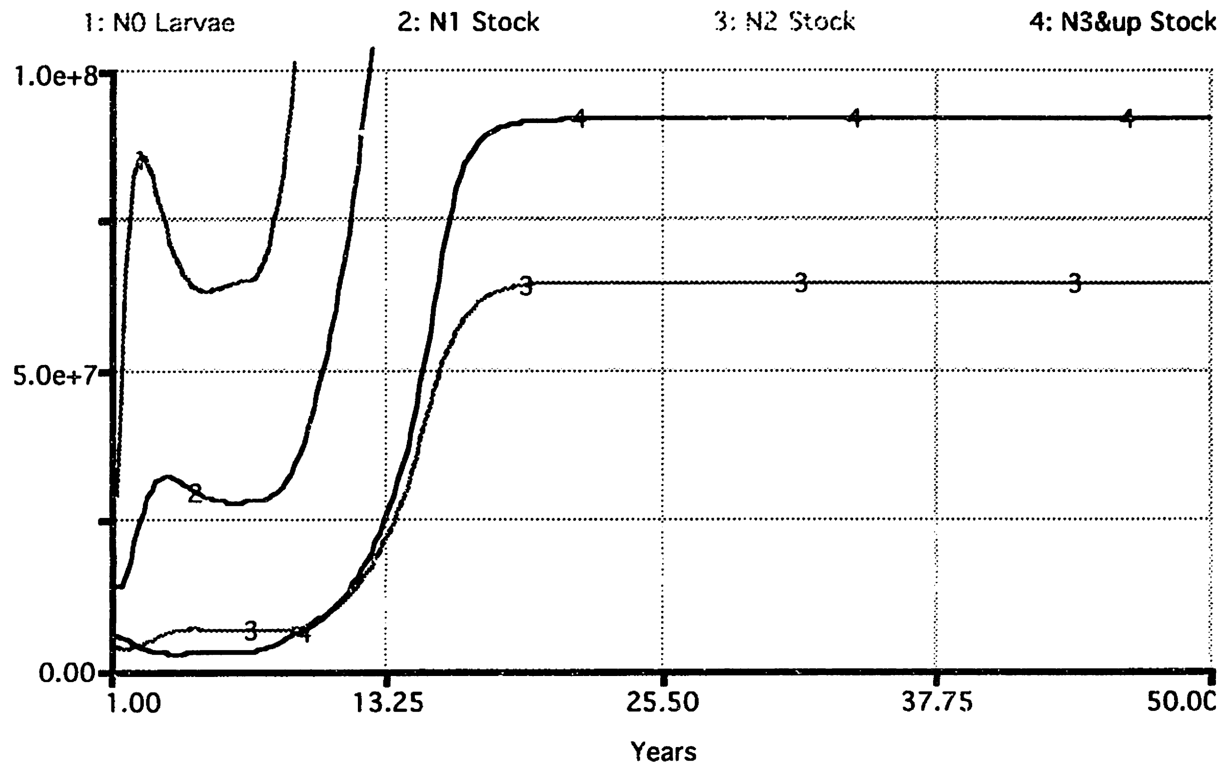
So using the Reproduction Rate = 24, a Reproduction Rate that echoes the estimates provided in the Goodyear article, the Catch Limits will be incorporated to see if they change the Stocks a great amount. In 1990, the National Fishery Council installed Catch limits for both commercial and recreational fishermen. In 1990, the Commercial Catch Limits were set at 3.02 million pounds of fish, and in 1991, this was reduced to 2,020,000 million pounds of fish. Originally in 1990, the Recreational Catch Limits were set at 7 fish per angler per day, but then in 1992, they were set at 1,980,000 million pounds of fish. This corresponds to a Commercial Catch Limit of approximately 1,000,000 fish installed in year 7, and a Recreational Catch Limit of 1,000,000 fish installed in year 9 for this model.

Using:

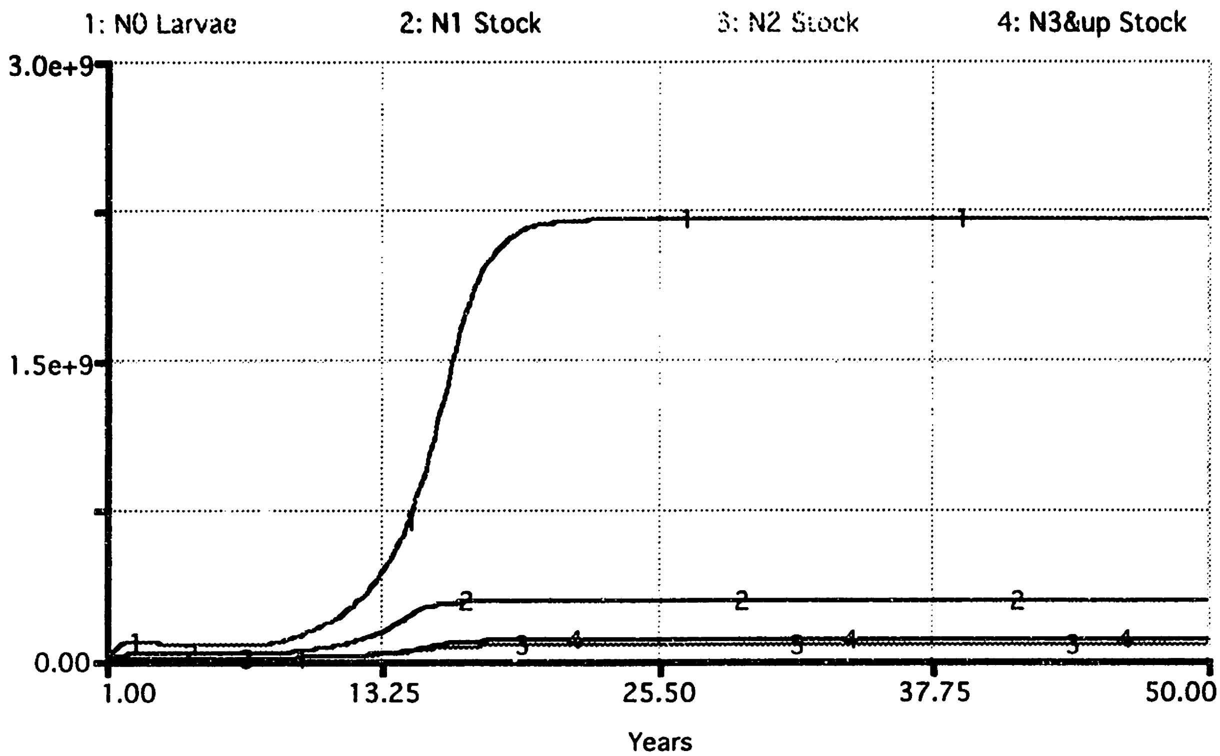
Commercial Catch limit of 1.5 million fish/year in year 7 and 1 million in year 8,

(to correspond to the Catch Limits of 3,100,000 Pounds in 1990 and 2,040,000 in 1991)

Recreational Catch Limit of 1,000,000 fish in year 9, Reproduction Rate of 24:

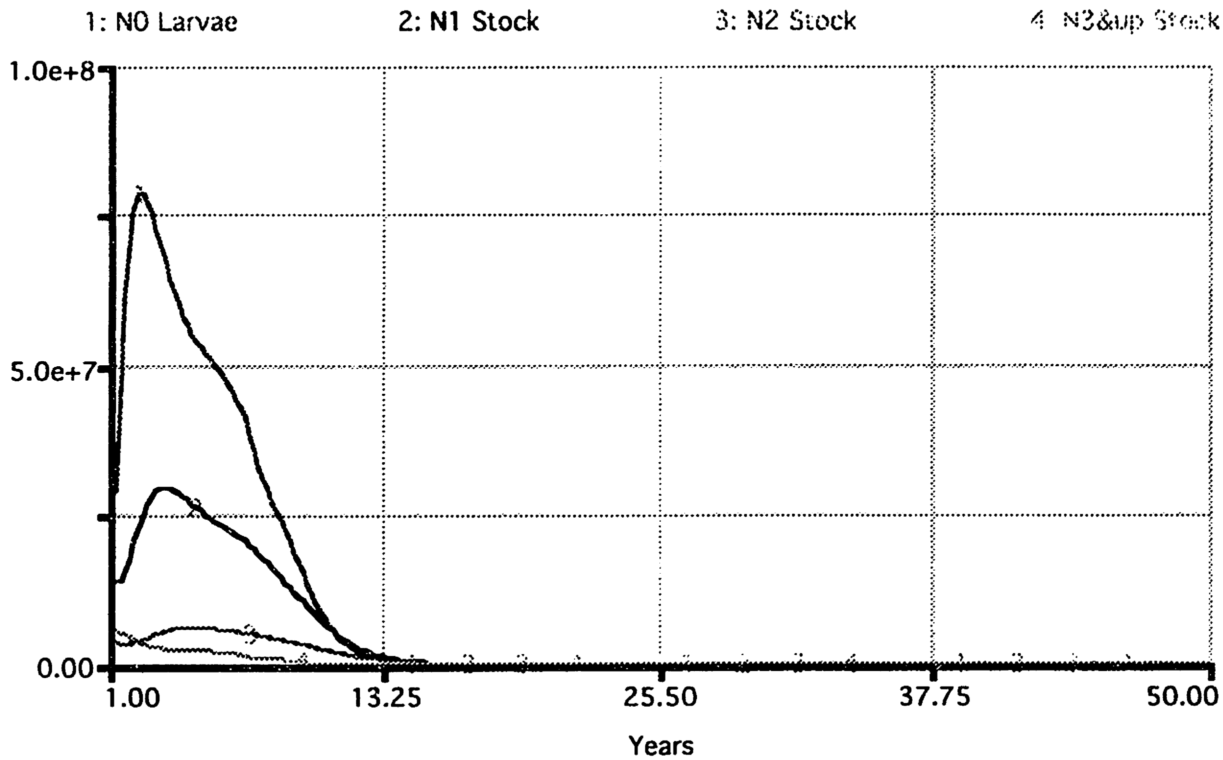


Using the larger scale to see the upper Habitat Limits:

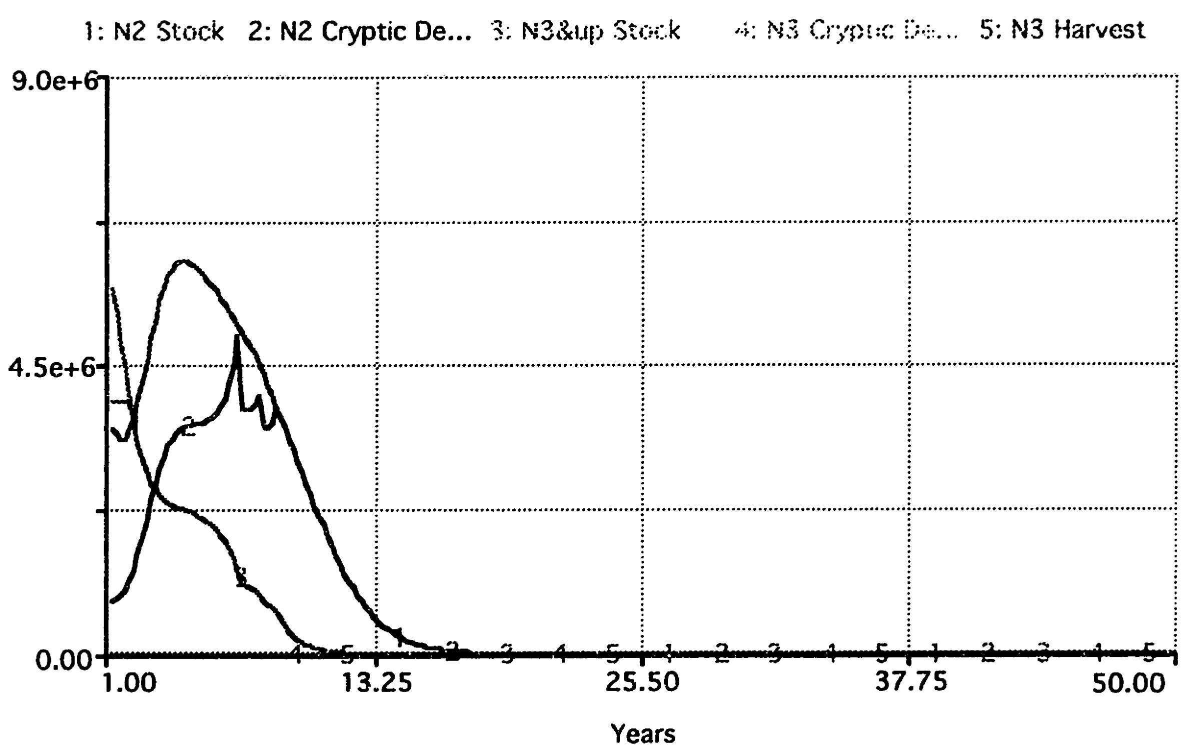


With the Catch limits instated and a Reproduction rate of 24, the Stocks do not crash. What if the Reproduction Rates were 24, but fall in the future due to health of habitat, weather, disease among the species....? Would the Catch Limits alone save the Stocks from crashing? How low can the Reproduction rate fall and still have the Catch Limits prevent the Stock from crashing?

With a Reproduction Rate of 22, the Stock does not crash, but with a Reproduction rate = 21.9 or less :



Catch Limits do not prevent the decline of fish in all circumstances , when the Reproduction Rate is 21.8 or lower. Why? Again look at the Cryptic Deaths and Harvest.



The N3 Stock is falling, because the Reproduction Rate is not high enough to replenish the Stock. The Harvest starts to decrease around year 3. In year 7, the Commercial Catch Limits are installed, so the Commercial Directed Fishing Efforts decrease some, causing the N2 Cryptic Deaths to decrease. In the beginning of the very next year, though, the Commercial Fishermen increase their Fishing Effort, so they get more of the Commercial catch before the Limit is met. (This is confirmed in the Goodyear paper.) This causes the N2 Cryptic Mortality to increase again. This happens at the beginning of every year, until the N2 Cryptic Mortality equals the entire N2 Stock. The N2 Stock and N3 Stock continue to fall.

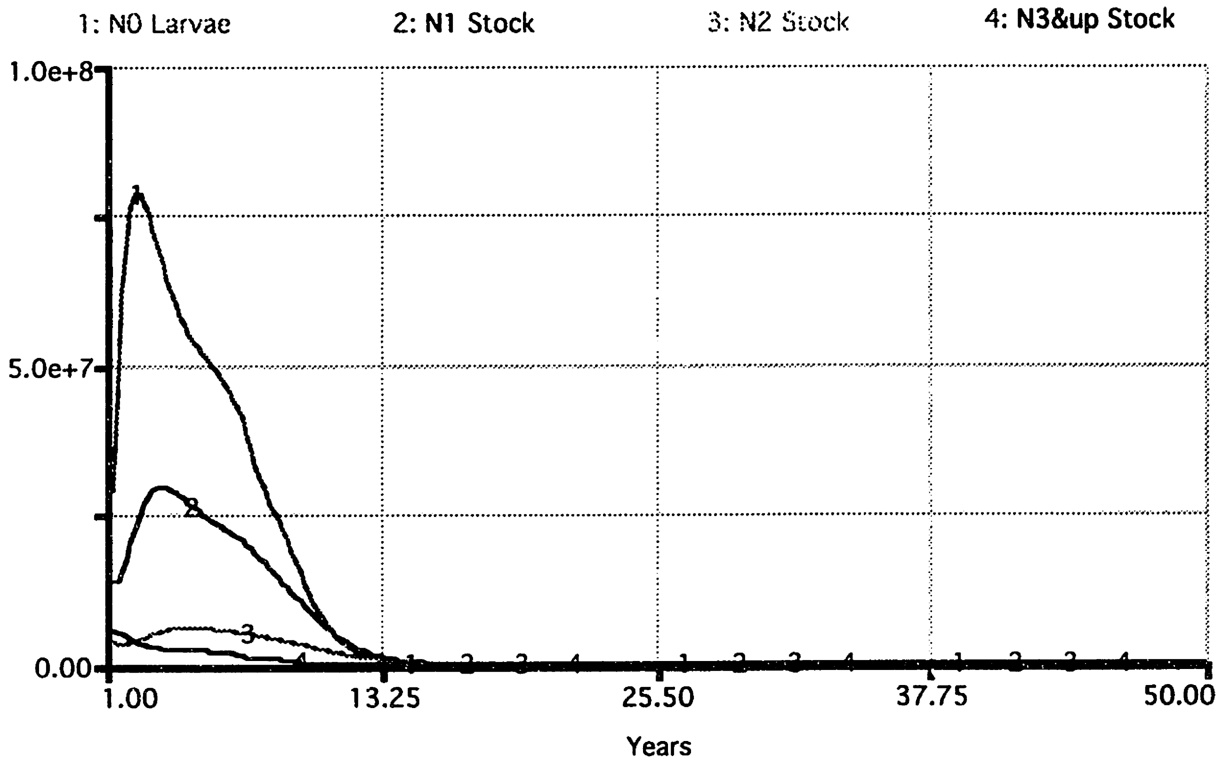
The N3 Stocks decrease, then the N2 Cryptic Deaths increase as the fishermen still spend the same effort trying to find the fewer N3 fish. At a Reproduction rate = 21.9 or less, it becomes a downward spiral which can cause the entire Stock to crash and become extinct. If the Reproduction rate is not known with certainty, then Catch Limits alone may not protect a species from crashing.

5. Increased Commercial Non Direct Fishing Efforts

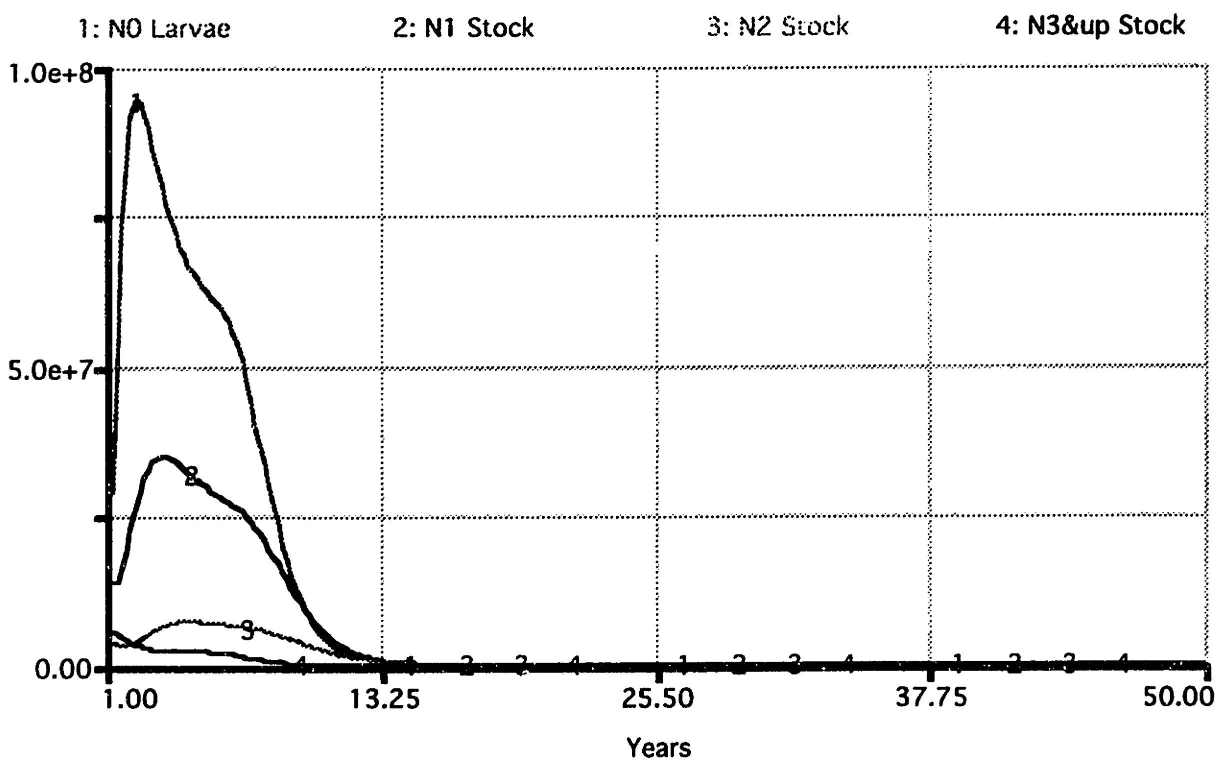
What would happen if the Fishing Efforts increase? The partial reported data for Commercial Non Direct Fishing Efforts showed that the Fishing Efforts did in fact increase in the period where data is available, from 1990 to 1992. The lowest reported data was for 5,994 days in 1990 (year 7), increased to 10,000 in 1991 (year 8) and was the highest 22,314 days in 1992 (year 9). Also, the Goodyear paper estimates that the Directed Commercial Fishing Efforts were about four times higher than the reported data. What if the actual Non-Directed Commercial Fishing Efforts were actually four times higher than the annual estimates. What would be the effects on the Stocks if the model included these increases in the Non-Directed Commercial Fishing Efforts? How does an increased Non Directed Fishing effort effect the Stock?

Using a Reproduction Rate = 21.9 larvae per adult fish,
Non Directed Fishing Efforts in:

1984-1990 = 4 * 6000
1991 = 4 * 10,000
1992 - present = 4 * 22,000, then:

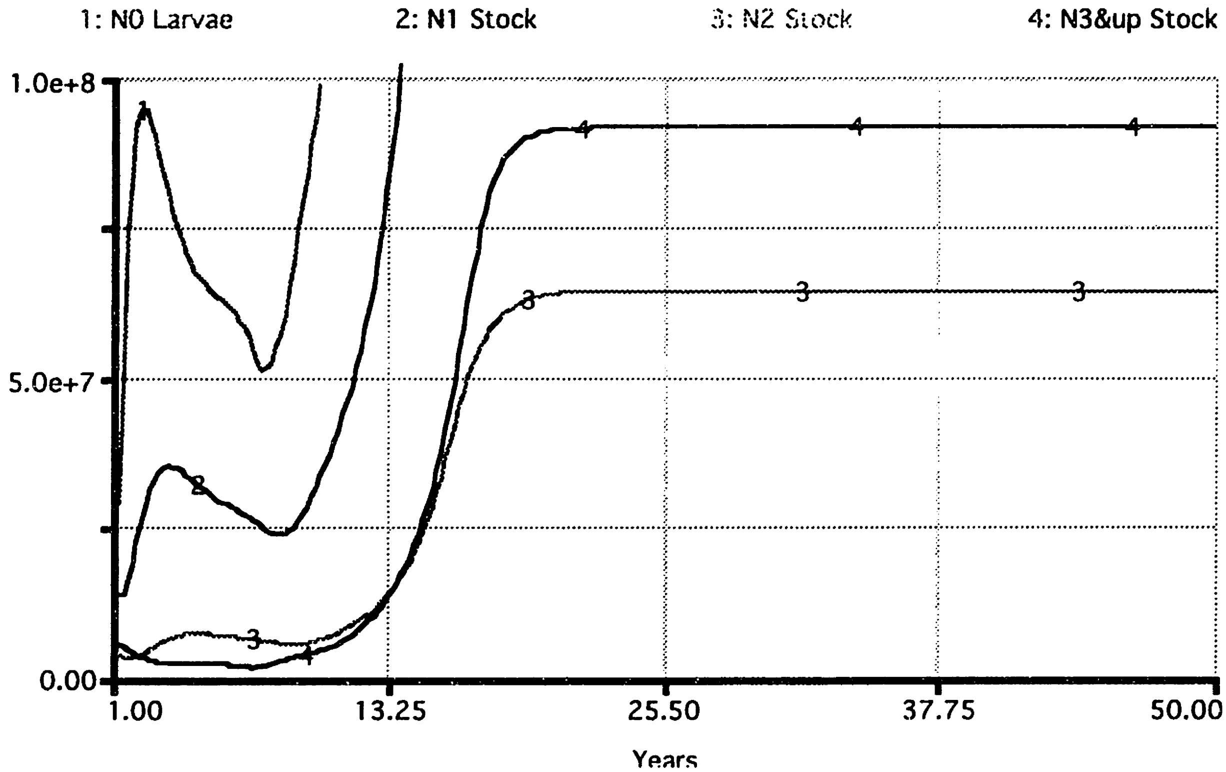


Even with a relatively high Reproduction Rate of 27.8, the Stocks still crash:

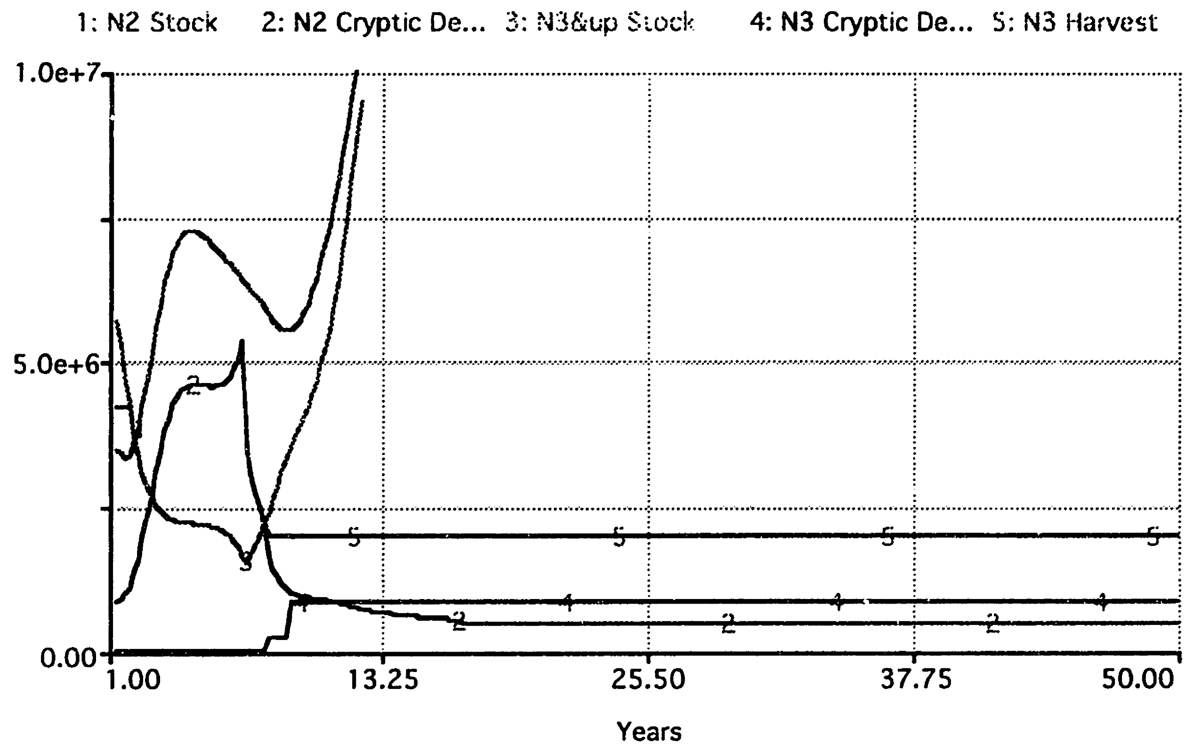


Even with the highest Reproduction Rate used yet, the N2 Stocks are not large enough to overcome the high N2 Cryptic Deaths.

It isn't until the Reproduction rate = 28 that the Stocks do not crash; instead they increase to meet the Holding Capacity of the Habitat:



Looking at the N2 and N3 Cryptic Deaths:



One can see that the Harvest equals the combined Commercial and Recreational Catch Limits of about 2 million fish per year, or 4 million pounds. The Reproduction Rate is high, so the Stocks of N3 increase after the Catch Limits are imposed. The N2 Cryptic Mortality rises for awhile after the 1990 Catch Limits are installed, but the Stocks increase enough so that the Directed Commercial fisnermen do not have to spend more effort searching for fewer fish. The N2 Cryptic Mortality then falls.

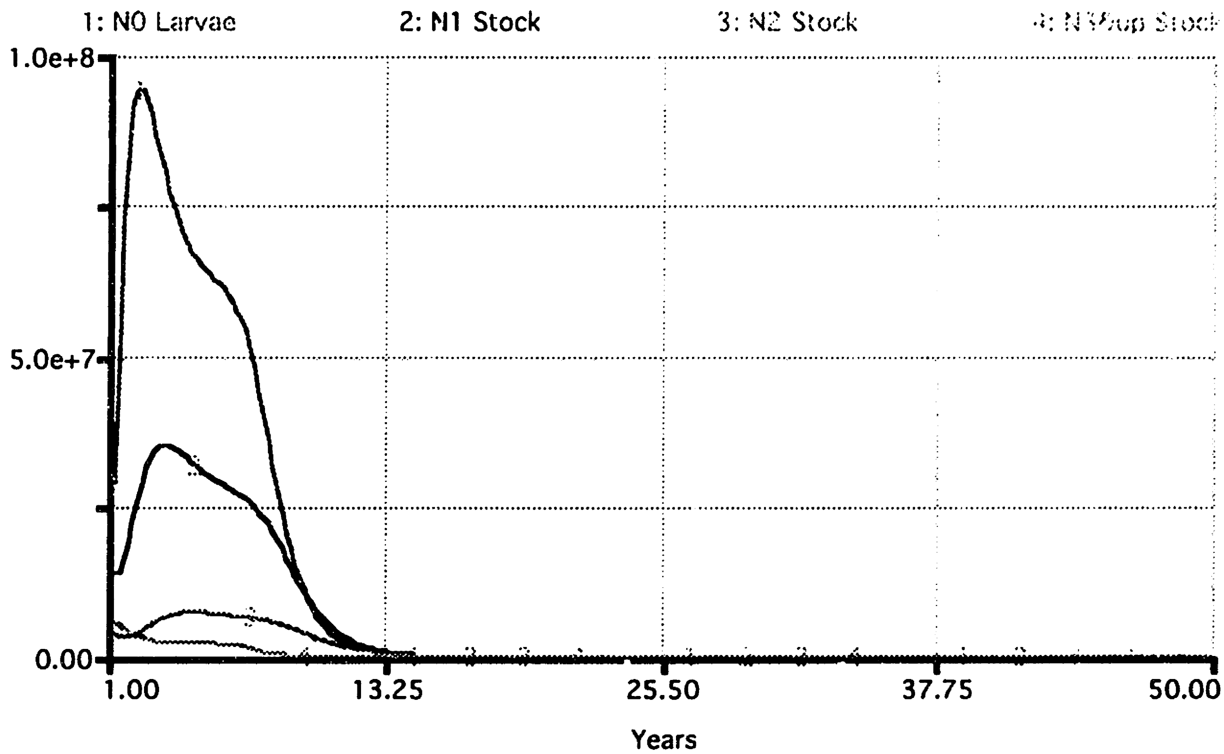
Note, though, that the N3 Cryptic Deaths have increased, due to the Catch Limits. Non-Directed Fishermen may be fishing for other types of fish, but if they catch a 3 year old Red Snapper and the Commercial Catch Limits have already been met, then the fish must be thrown back in.

Recreational Fishing Efforts:

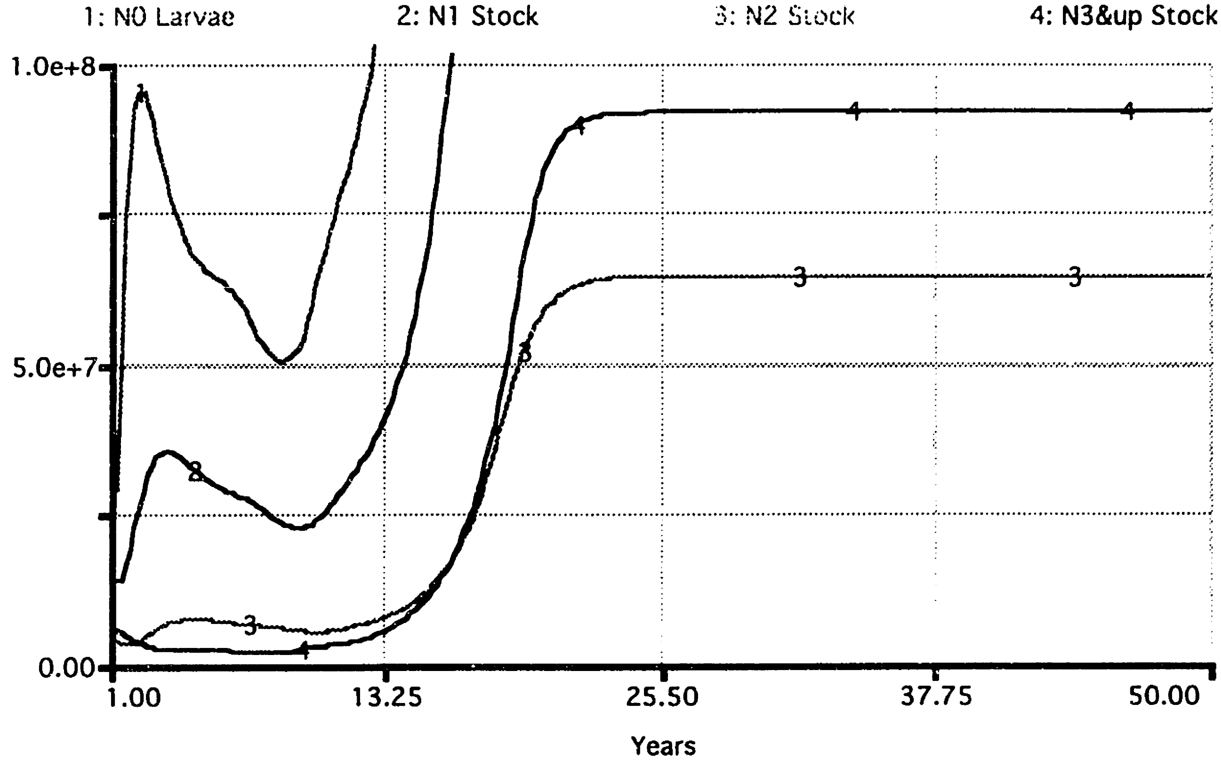
What if data for the Recreational Fishing Efforts was also not perfect. If the Recreational Fishing Effort = 1,500,000 angler hours per year and the Catch per unit effort equals 0.67 fish per hour, then the total annual recreational catch is exactly the Recreational Catch limit. The Goodyear article, though, says that since the late 1980's , half the Red Snapper that are caught are thrown back in. The Harvest would still be 1,000,0000 pounds due to the Recreational Catch Limits in 1992, but the total Recreational Catch and Cryptic Mortality might be higher, because the actual

Recreational Fishing Effort might be higher. Assume that before 1990 the Recreational Fishing Effort was 1,500,000, and increased to 3,000,000 after 1990.

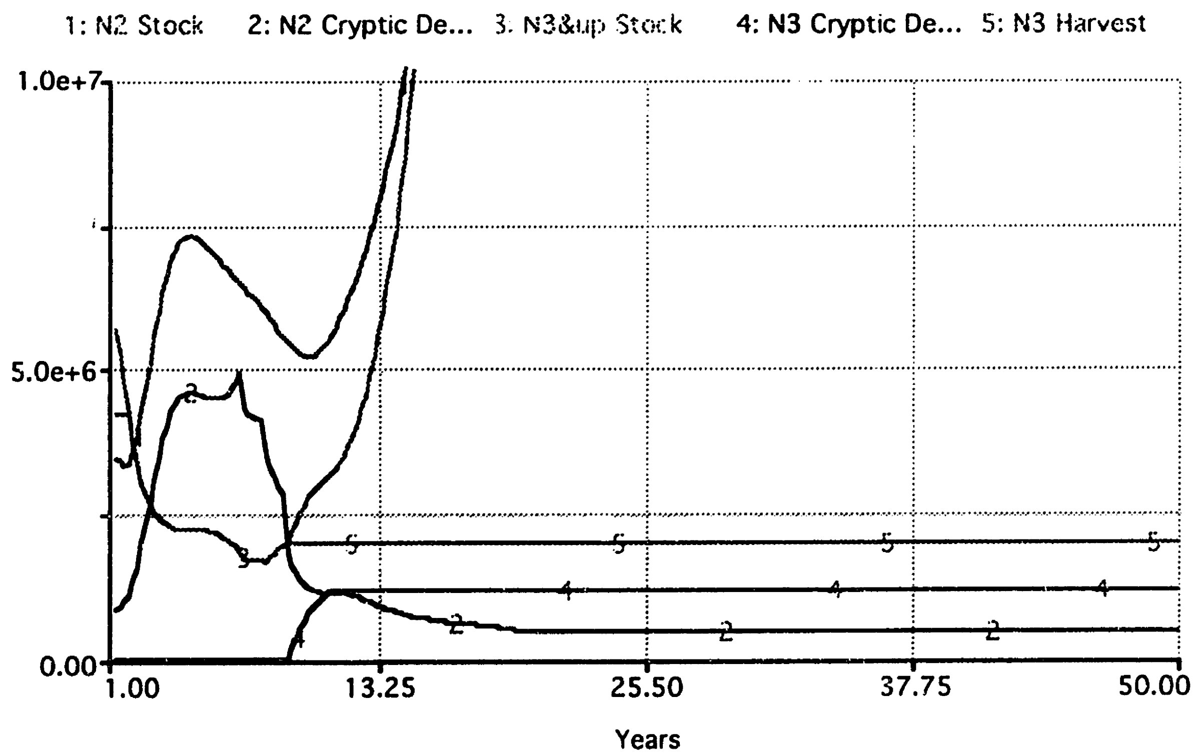
Using the Reproduction rate = 27.9, the high estimates of Non-directed Commercial Fishing Efforts from above, as well as increasing the Recreational Fishing Efforts from 1.5 million hours to 3 million hours after 1990, the Stocks now crash.



If the Recreational Fishing Efforts increase, they too affect whether or not the Stocks crash. The Reproduction rate must be at least 28.1, so that the Stocks don't crash.



To determine why the increased Recreational Fishing Effort cause the Stock to crash, it is helpful to look at N2 Cryptic Deaths, N3 Cryptic Deaths, N2 Stock N3 Stock and Harvest.



N2 Cryptic Deaths increase, decrease briefly as the Stock of N2 decreases, but then increases again when the Commercial Catch Limits are instated. They increase until around year 9 when the Recreational Catch limits are installed. This causes the N2 Stock and the N3 Stock of fish to also decrease for awhile, until the N2 Cryptic Morality decreases and levels off due to the Catch Limits and the intended decreased Fishing Efforts.

Changing the Commercial Non-directed Fishing Effort and the Recreational Fishing Effort shows that even if the Reproduction Rates are high, the Catch Limits may not be enough to prevent the Stock from crashing unless one knows *all* the Fishing Efforts with certainty. The Catch Limits can not protect the Stock for every level of Fishing Effort. If the past Fishing Efforts are not accurately reported *and the future Fishing Efforts* are not known with certainty, then one can't be sure that the Catch Limits will be enough to prevent the Stocks from crashing.

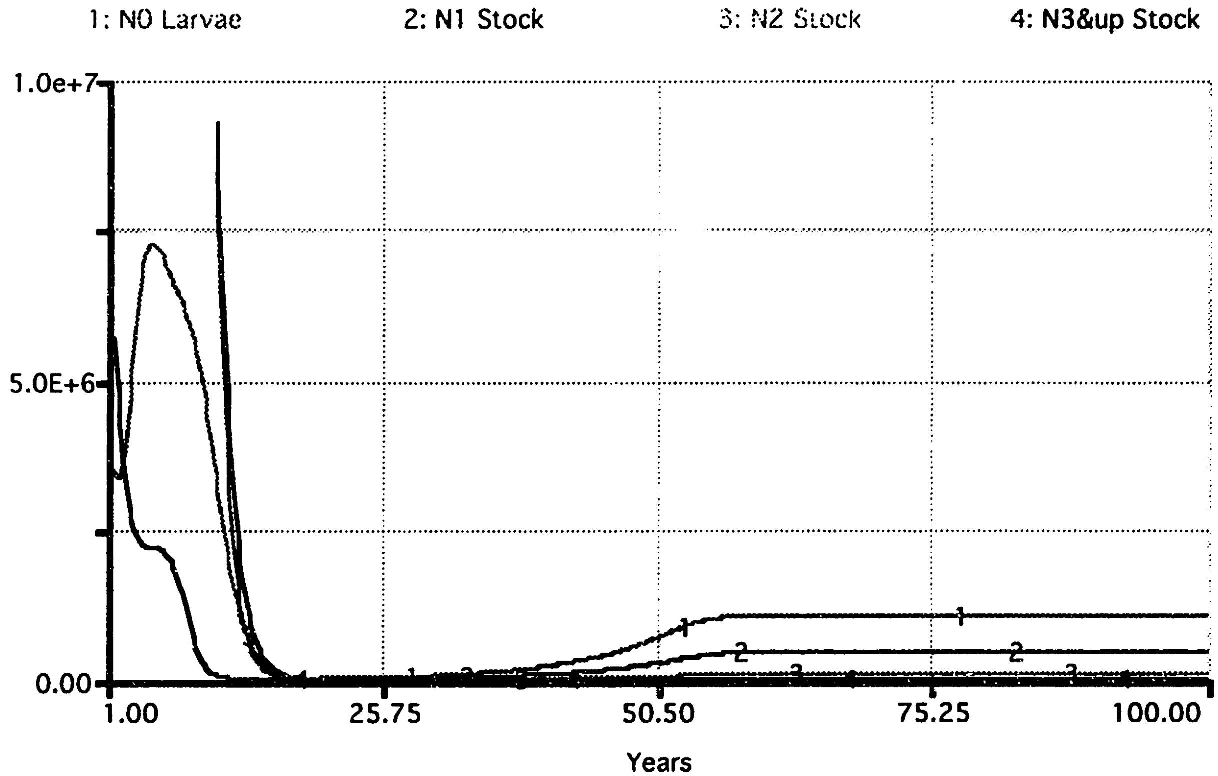
6. Creating Replenishment Zones.

Do Replenishment Zones prevent the Stock from crashing? Assume that the Replenishment Zones are 5% of the total FKNM Sanctuary, about 150 square miles. The initial Stocks in the Zone will be a about 0.04% of the Stocks in the entire National Marine Fishery Council's area for the Gulf. Red Snapper are not found in the entire Gulf of Mexico, but only in near shore waters, which is ~375,000 square miles. (Goodyear, 1992) The 0.04% estimate will be used as an approximation, since the 100,000 itself is an approximation. Also assume the Zones are created in 1996, in year 12 of the model.

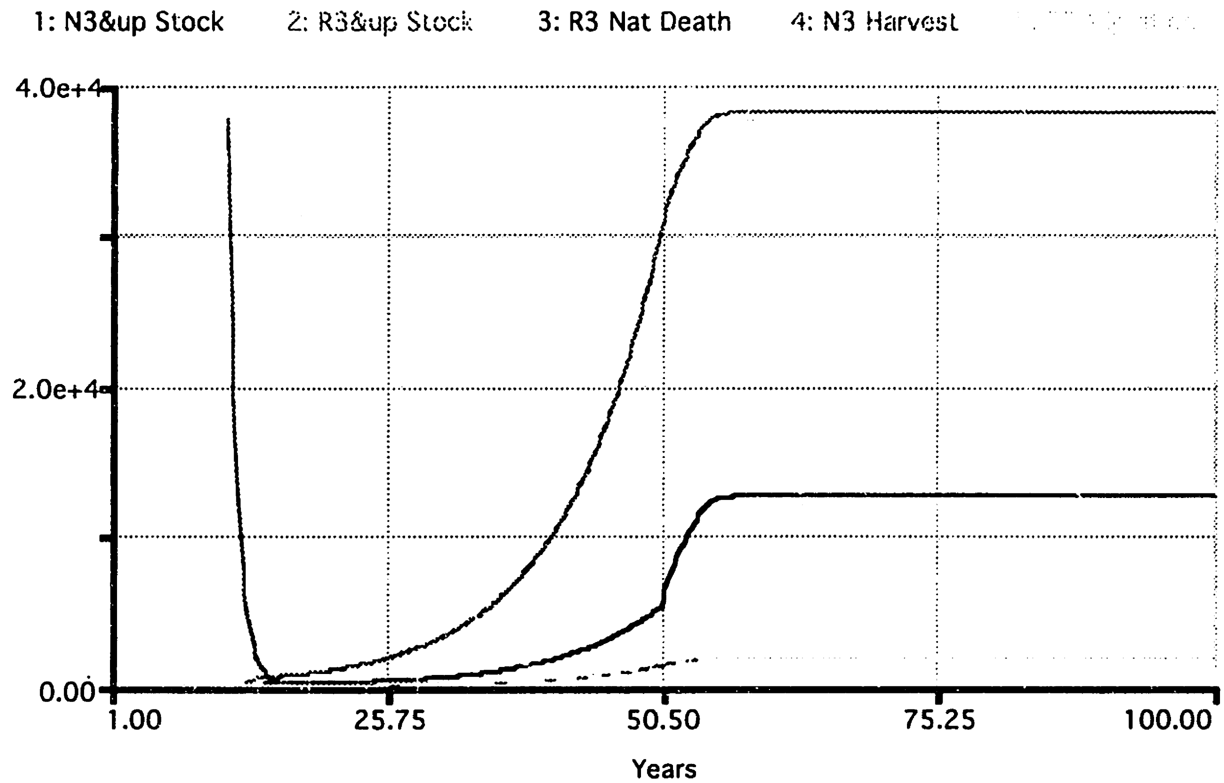
Using a:

- Zone created in 1996,
- Across -Current Width = 12.25
- Along-Current Length = 12.25 (total Size = 150)
- Commercial Catch Limits installed in 1990 = 1.5 million and 1991=1 million
- Recreational Catch Limits installed in 1992 = 1 million
- Non Directed Commercial Fishing Efforts at there highest estimates:
  - 1984-1990 = 4 * 6000 = 24,000
  - 1991 = 4 * 10,000 = 40,000
  - 1992 - future = 4 * 22,000 = 88,000
- Recreational fishing Effort = 1.5 M before 1990 and 3 M after 1990.
- Reproduction Rate = 28, (the highest Reproduction rate of which the high Fishing Efforts still caused the Stocks to crash)

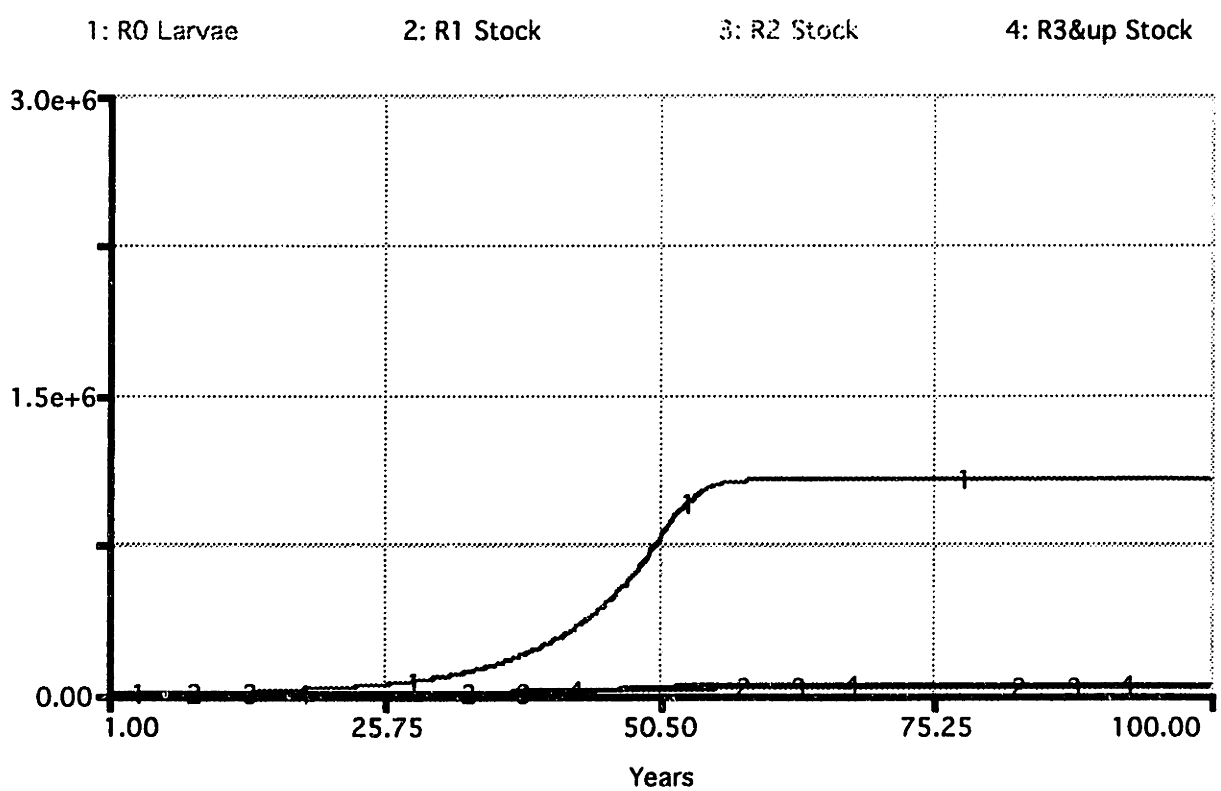
Looking at a 100 year time frame, and changing the y-axis so that the results can be seen, one can see the predicted results of creating the Zones:



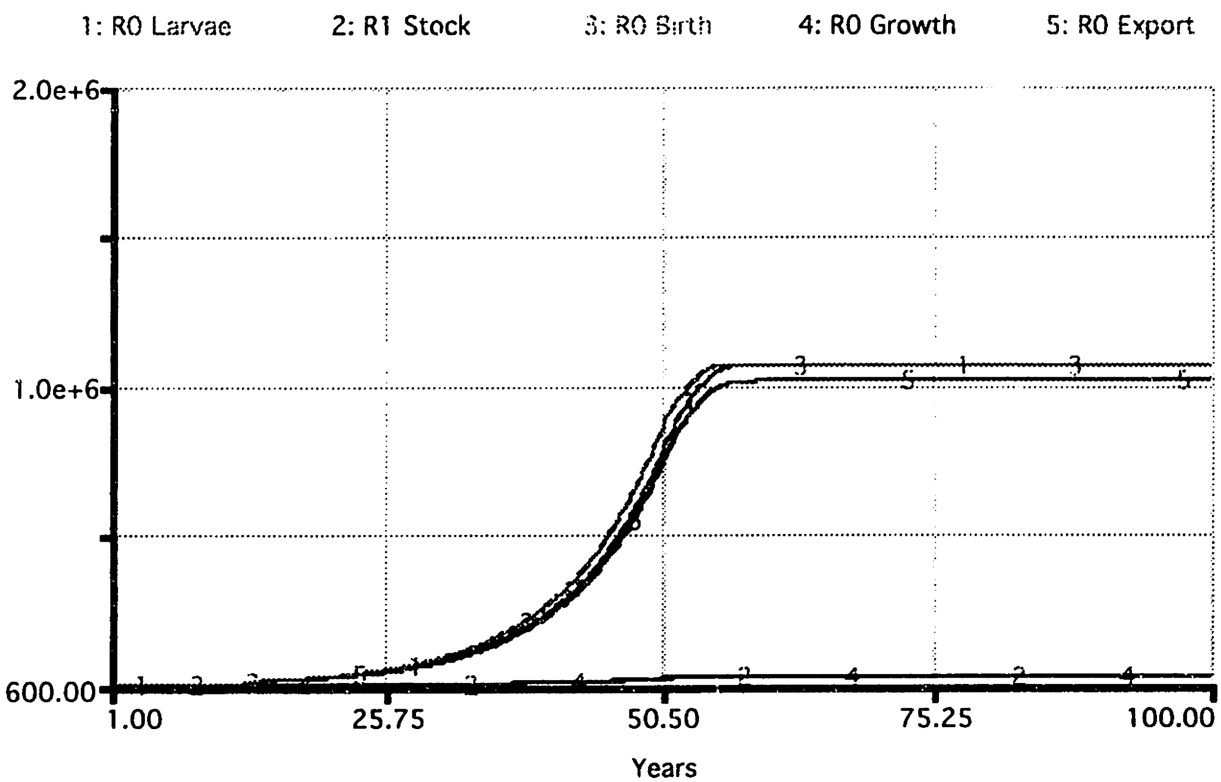
The Replenishment Zones do help replenish the Stocks after year 40, all else remaining constant. If the Zones are created in 1996, the Stocks first crash and are then replenished. Outside the Zone, the entire N2 Stock dies from N2 Cryptic Death, because the Fishing Efforts are so high outside the Zone. This causes the N3 Stock to die as well. The R3 Stocks start to increase as soon as the Zones are created, but take a while to increase, since there are so few fish left to reproduce when the Zone is created. After about year 40, the increase in the R3 Stock becomes noticeable. Some of the fish in the Replenishment Zone migrate out of the Zone and can be harvested. In fact, the only fish that are being Harvested are the R3 Stocks that migrate out of the Zone, becoming N3 harvest-able fish.



Looking at the Stock of fish *in the Replenishment Zone*:



After the Replenishment Zone is created in year 12, one can see that the Stock of Larvae increases much faster than the Stock of 1, 2 and 3 & up years olds, although all four Stocks are increasing, (R0, R1, R2, R3). The effects can be seen with the Larvae Stock much sooner, because with a Reproduction Rate = 28 there are 28 times more Larvae than 3 year old fish and because almost all the Larvae are exported out of the Zone, as shown in the graph below.



Although the R0 Births and R0 Larvae Stocks are high, the R0 Export Rate is also high. The number of Larvae exported out of the Zone is so great, that there are very few larvae left inside the Zone to grow and reproduce. This is why it takes longer for the Stocks of R1, R2 and R3 & up year olds to increase. The number of R0 Births and the Stock of R0 Larvae grow until the Larvae hit an upper limit (determined by the Reproduction Rate and the Habitat Holding Capacity of R3 fish and Larvae).

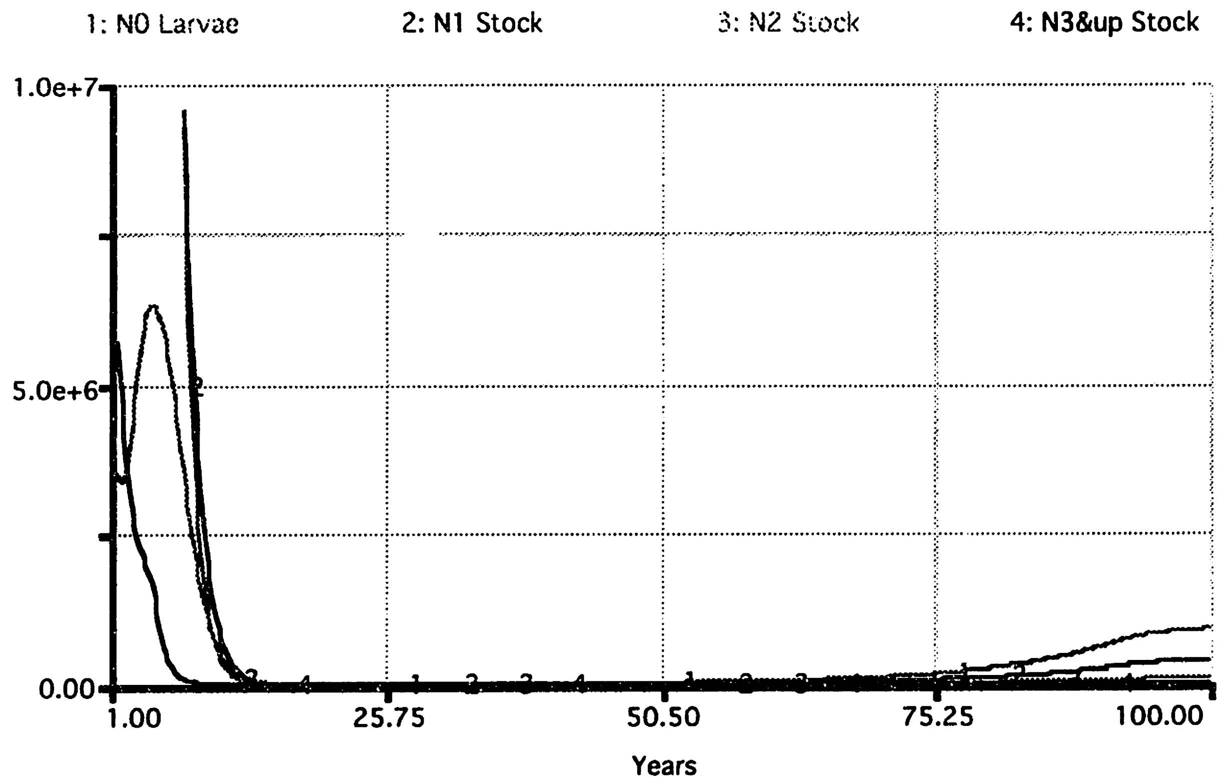
Reviewing the tables that are available with Systems Dynamics, the user can see the exact value of any variable at any time. Looking at the tables, the annual Harvest is the lowest in year 17, equal to 65 fish per year. This is because the Replenishment Zones are created in year 12, and it takes awhile for the fish to reproduce and grow. The Harvest grows to about 2000 fish per year after about year 50. The *pounds* of fish would be greater than 4000 lb. of fish or 2 lb. per fish. This is because the fish that grow up inside the Zone and migrate out will on average be heavier and larger than fish that would grow up outside the Zone. The Zone allows a greater number of older, therefore larger fish, to remain alive.

This is a relatively small Harvest, but without the Replenishment Zones, the Harvest would have been 0. Also, this Harvest estimate has many assumption in it which should be checked. For instance, it assumes that the Reproduction rate inside the Zone stays fixed at 28. It also assumes that the Migration rate stays the same for the R3 fish, even when the Replenishment Zones become densely populated and the Stock of N2 and N3 Red Snapper reach the Habitat's Holding Capacity. It assumes that the Habitat's Holding Capacity of ten times the 1984 Goodyear estimated population is correct, etc. These assumptions should be tested and varied using SD's sensitivity analysis capabilities.

7. Changing Reproduction Rate outside and inside the Zone

Researchers predict that the Reproduction rate inside the Zones would increase, because the fish would be larger. Before checking the results of a Reproduction rate increase for Zoned fish, it is informative to determine how low can the Reproduction rate for non - Zoned fish be, while still seeing the benefits of Zones .

With a Reproduction rate of 24, Zones help the fish come back, but at a much slower rate. The effects are not seen on the graph until after Year 65.



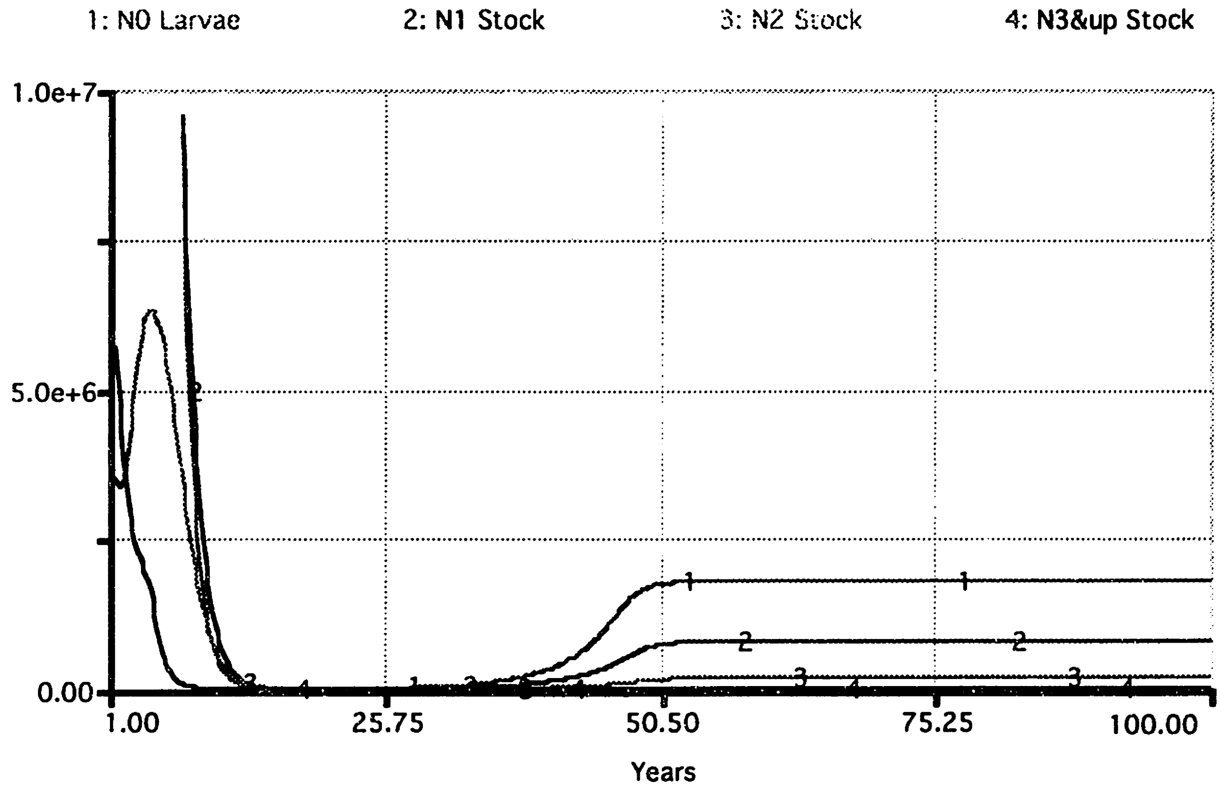
Doing sensitivity analysis with Reproduction rates that are even smaller than 24, the Zones do help the fish come back, but again at a slower rate. For example, with a Reproduction Rate = 16, the Zones help the Stocks come back only after 80 years.

Now the effects of the Zone will be determined assuming that the Reproduction Rate of fish in the Zone is higher than the Reproduction Rate of fish outside the Zone. This is what the scientist predict in the Goodyear paper, since it is expected that a greater number of older fish will be remain alive in the Zone, and the Reproduction rate of older fish are higher than young three year old fish.

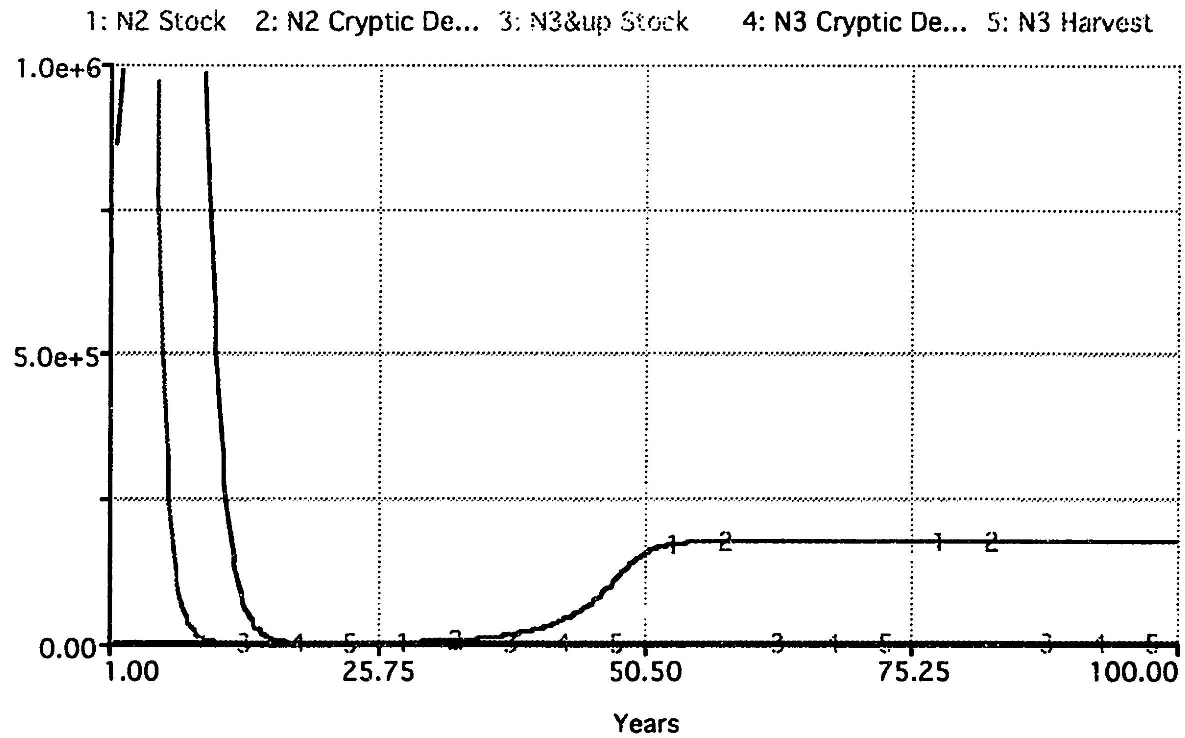
If all factors remained the same as in the previous section, except for changing only:

Reproduction rate outside the Zone = 24, (the rate found to cause pre-1990 fish Stocks closest to the Goodyear article)

Reproduction Rate inside the Zone =48, double the rate outside the Zone:

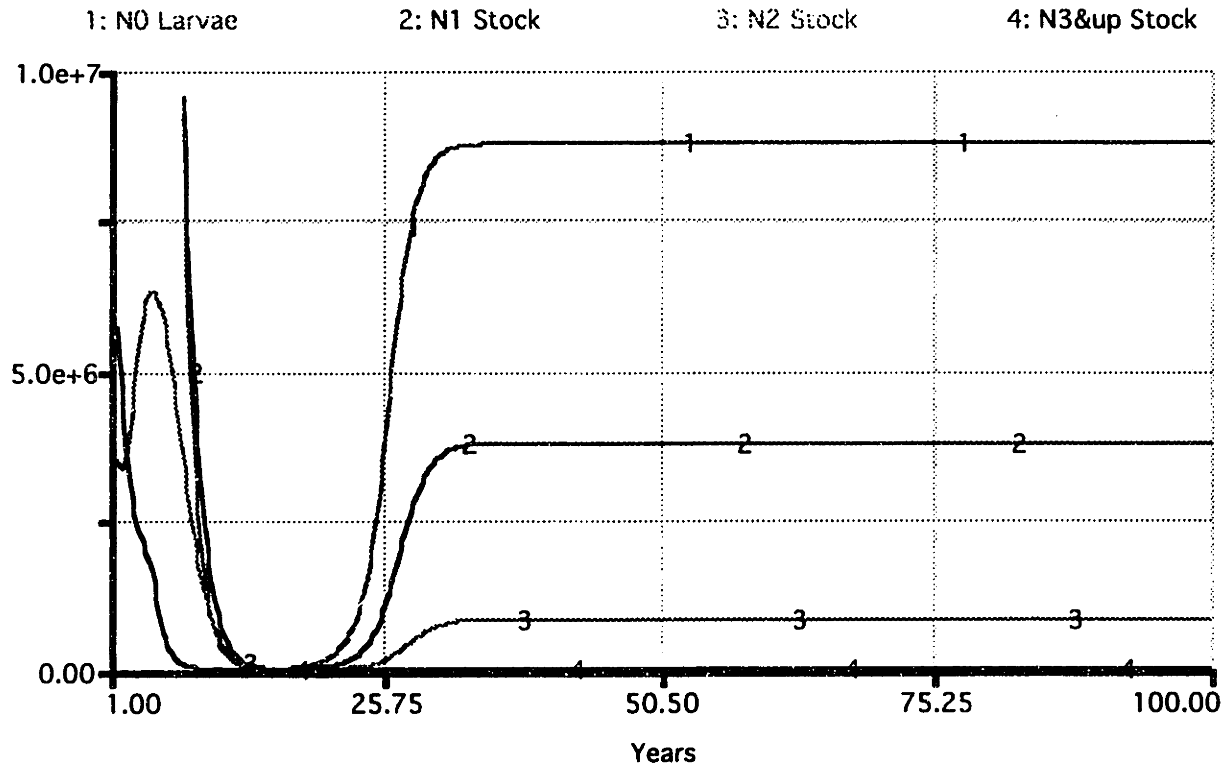


If the Reproduction Rate outside the Zone = 24, and the Reproduction Rate inside the Zone = 48, then the Stocks are helped in about half the time. Also, the total number of Larvae that are available to float out of the Zone is increased. The maximum number of adult fish outside the Zone is not any larger, though. This is because the N3 Stock is constrained by the Migration rate and the R3 Stock, which is constrained by the Habitat's Holding Capacity inside the Zoned area. Any of the R0, R1 and R2 Stock that migrate out of the Zone are killed due to Fishing and Cryptic Mortality before they can grow to become N3 fish. For example, the N2 Cryptic Mortality equals the entire N2 Stock.



The Reproduction Rate may be even more than twice the rate outside the Zone, though. It is possible that the Reproduction rate inside the Zone increases to be 10 times greater than the Reproduction rate outside the Zone. Scientist found that the Reproductive potential for Red Snapper starts at 3 years old, but increases every year until reaching the maximum at age 12; the fecundity of Red Snapper 12 years or older have approximately 100 times the Reproductive capability of 3 year old Red Snapper, so it is likely that the average increase in Reproduction rate = 10.

If the Reproduction Rate in the Zone increased by 10 times, then the results would be:



If the Reproduction rate inside the Zone increased, it would mean that the benefits of the Zone would be seen sooner, around year 20, which is less than 10 years after the Zones are created. The final maximum annual Harvest remains the same, though, at about 2000 fish. This is because the maximum number of R3 fish remains the same, since the number is still constrained by the same Habitat' s Holding Capacity, since the size of the Zone has not changed and the R0, R1 and R2 Stocks that migrate out of the Zone all die due to Fishing Mortality.

8. A Change in the Zone's Habitat Holding Capacity

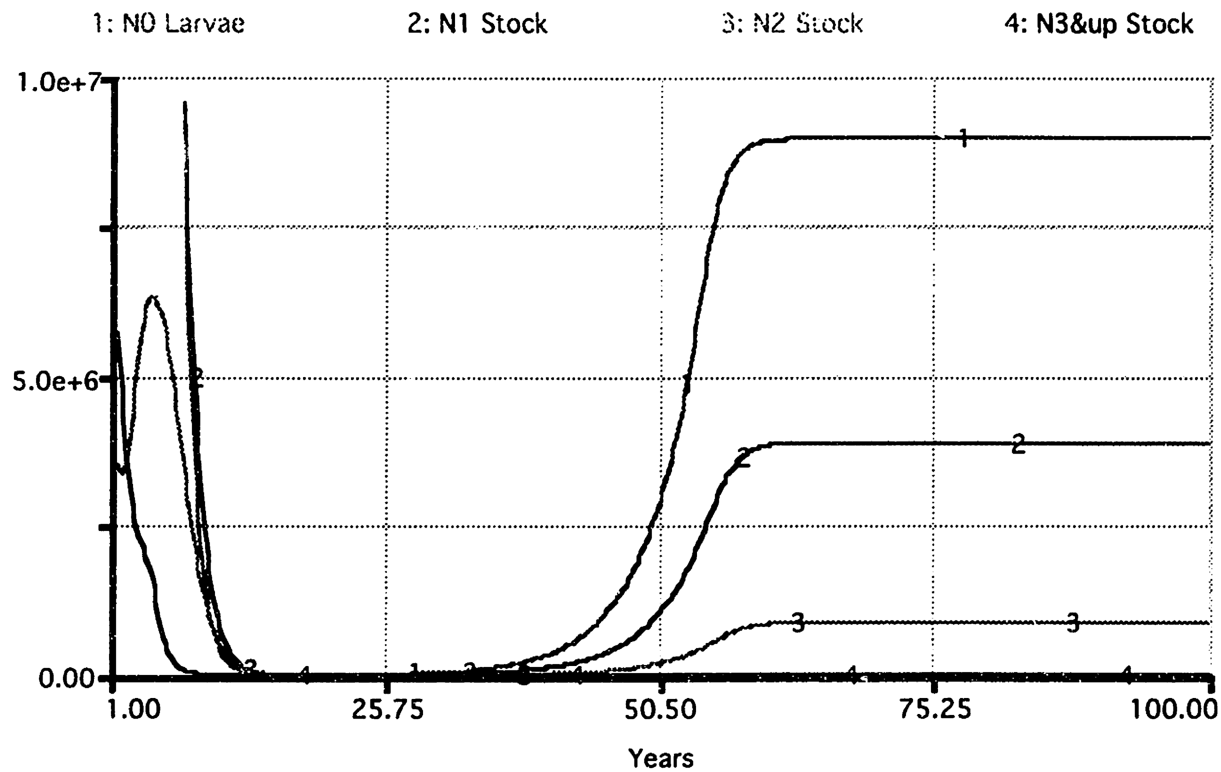
If the Zone's Habitat Holding Capacity were actually more than 10 times the estimates for the 1984 Goodyear Stock values, then again the replenishment capabilities of the Zones would be different. Using the:

Reproduction rate inside Zone = 24

Reproduction rate outside Zone = 48

Habitat's Holding Capacity = 50 * Goodyear's 1984 Stock estimates

the results are as follows:



The results can be seen after about year 45, about 30 years after the Zone is created. Also, the R3 Stock is greater, which increases the N3 Stock and the Harvest to about 9600 fish per year, more than 19,200 pounds of fish. Increasing the Habitat's Holding Capacity by a factor of five increases the total Stocks and Annual Harvest by a factor of five. This variable plays a large role in determining the final number of harvested fish.

9. Reorient Zone.

By using a Simulation model such as SD, the decision makers can become better informed about the variables that they actually have control over. They can make 'dry runs' and can see the predicted results of various alternatives. This gives them more information for choosing an alternative, one that is most likely to achieve their desired outcome.

If the Replenishment Zone were re-oriented so that the Along-Current Length was much greater than the Across Current Width, but the total area of the Zone stayed the same, the results would change. Using:

Along Current Length = 50

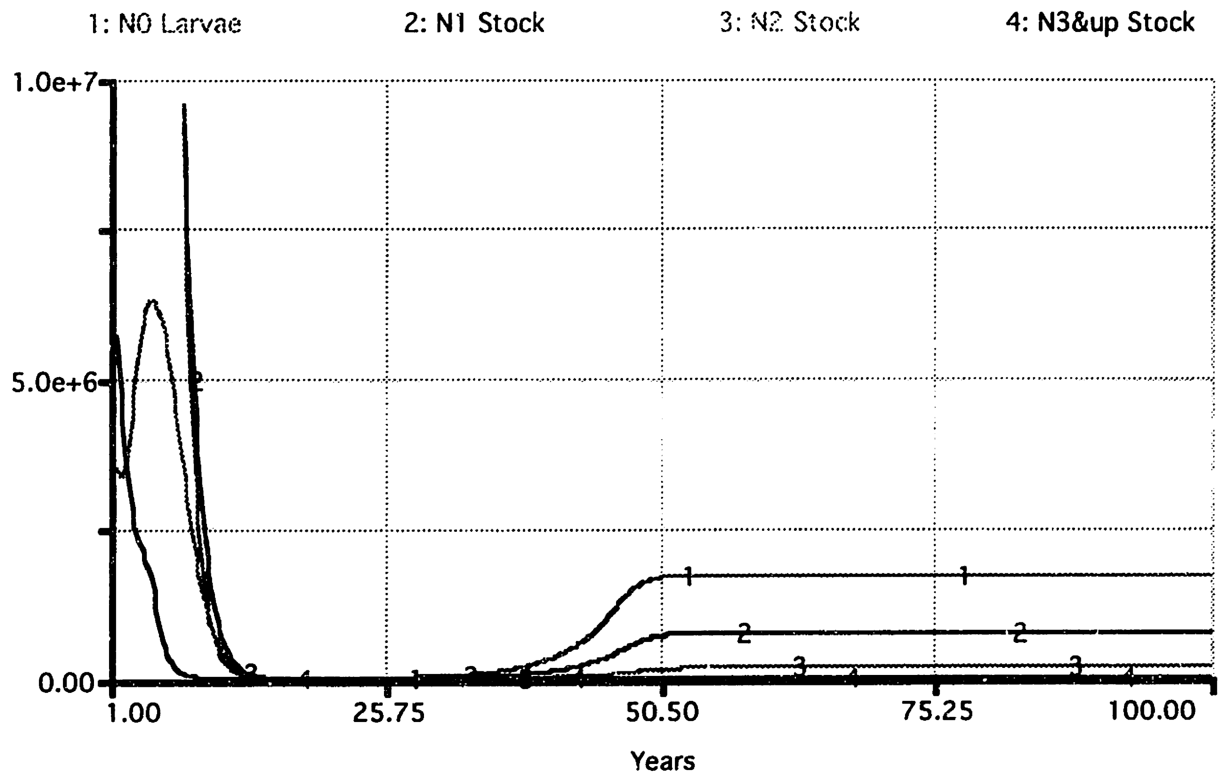
Across Current Width = 3

and the Total Area = 150, remaining the same.

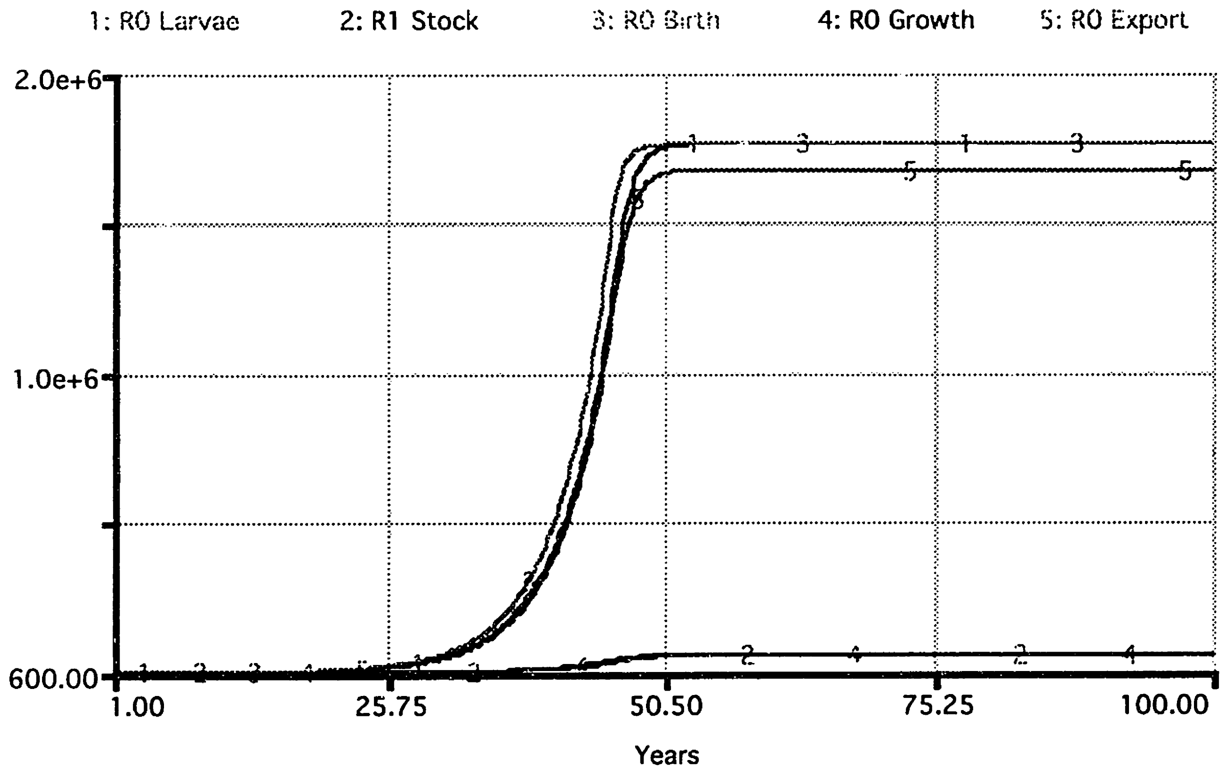
With Reproduction rate outside the Zone = 24

Reproduction inside the Zone = 48

Habitat Holding Capacity = 10 * Goodyear's 1984 Stock levels



Comparing this to the case where the Zone was square, reorienting the Zone this way does not reduce the number of Larvae exported out of the Zone enough to make a difference in this model. The Larvae Export is still very high.

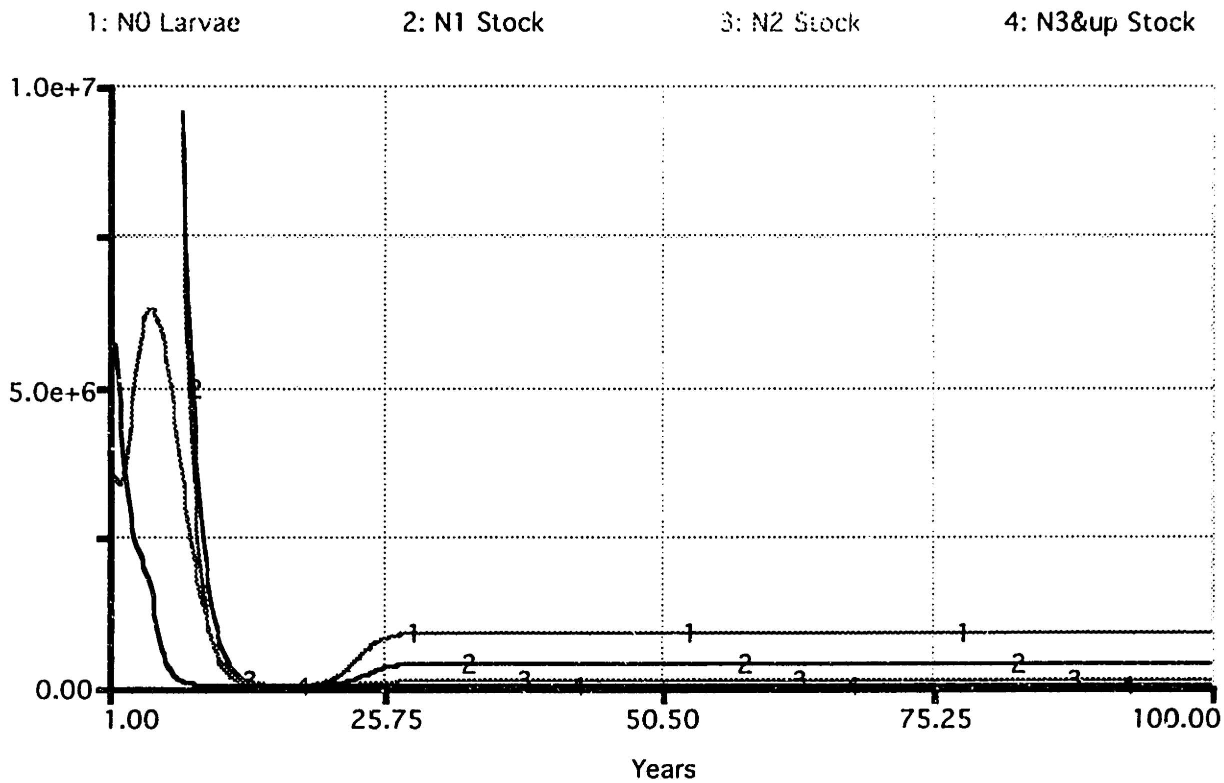


This seems strange, but when one runs reviews the equation for Larvae Export, one realizes that the estimated currents through the Zone are so great (450 miles/ year) and that even this larger Along Current Distance of 50 miles is not large enough to make much of a difference in the Larvae Export Rate. [18] The way that Larvae Export is modeled, the Along Current Length would need to be greater than the (Time larvae spend drifting) * (Annual Current Speed), or (1/6 year) * (450 miles / year) = 75 miles. If the Zone were re-oriented again, such that:

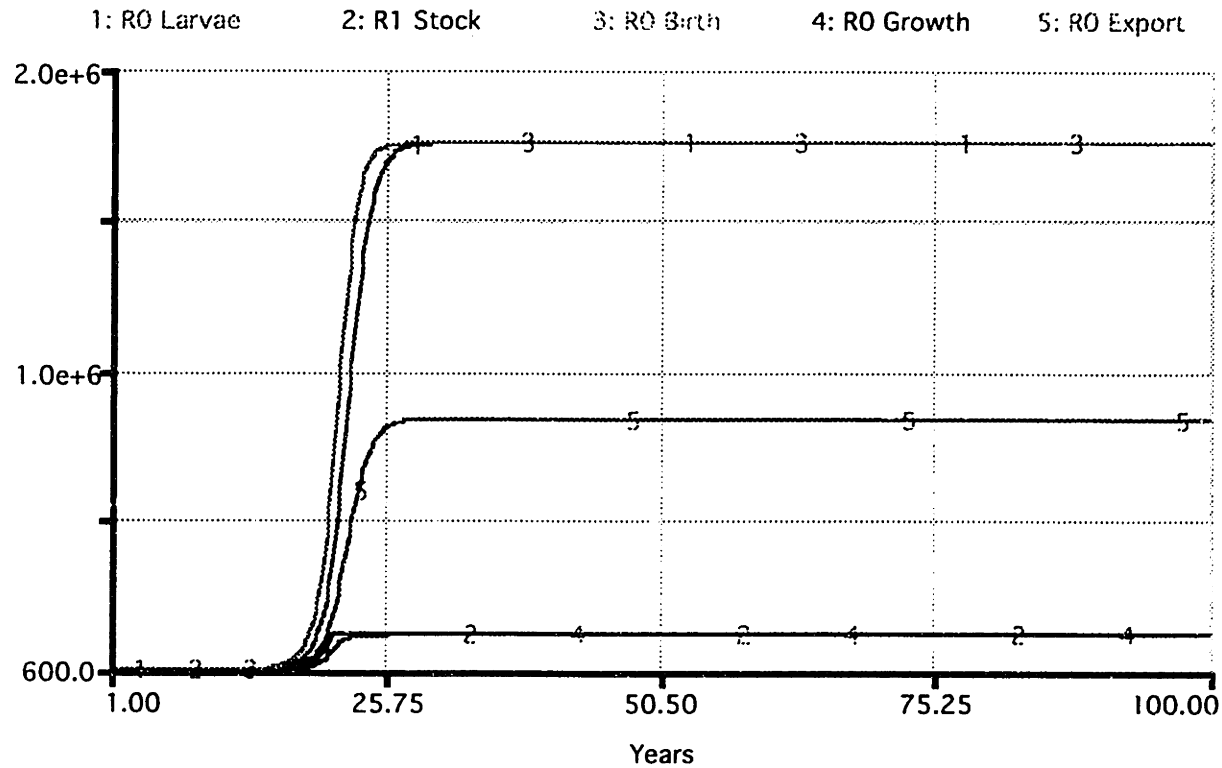
Along Current Length = 150

Across Current Width = 1

[18] Running the model indicates that the number of harvested fish would not increase and the results are not achieved noticeably sooner, all surprising results. Reviewing the Demos model, one can see this occurs because the only larvae that remain in the Zone, that do not get carried out with the Currents, are those caught in the benthic plant growth or those that float in from outside the borders; these are represented by the estimated 5% safety factor. The way the SD models the Replenishment Zone is that the Currents are so fast through the Zone that almost all the larvae are carried out, except for the estimated 5% safety factor. The 5% safety factor is still greater than the calculated number even when the Along current distance doubles; the Along Current Lenght needs to be at least one-sixth of the Currents Speed per year to ensure that the number of larvae that stay in the Zone is greater than even the small safety factor.



The Stock of all four age groups are replenished sooner and the number of larvae outside the Zone decreases. This is because of the reduced Larvae Export Rate.



The number of Larvae that are exported out of the Zone decreases, since the Zone was re-oriented. All four Stocks are replenished sooner, but the SD model predicts that the Annual Harvest will be 2000 fish /year, the same result as when the Zone was 12.5 miles by 12.5 miles and the Habitat's Holding Capacity was 10 times the 1984 Goodyear numbers.

10. Changing the Zone Location or a change in the Migration Rate

If the Zone Location were such that the reef area were not near the shore, then many adult fish would migrate out of the Zone during mating season. If the Zone were located such that most of the adult fish would have to leave the Zone for a few weeks during mating season, then the Migration Rate would change. Rather than assume that the Migration Rate is only 5%, one might assume that the Migration rate is higher, maybe 25% to account for the fish leaving than returning to the Zone within a few weeks. Using:

Reproduction rate inside the Zone = 48

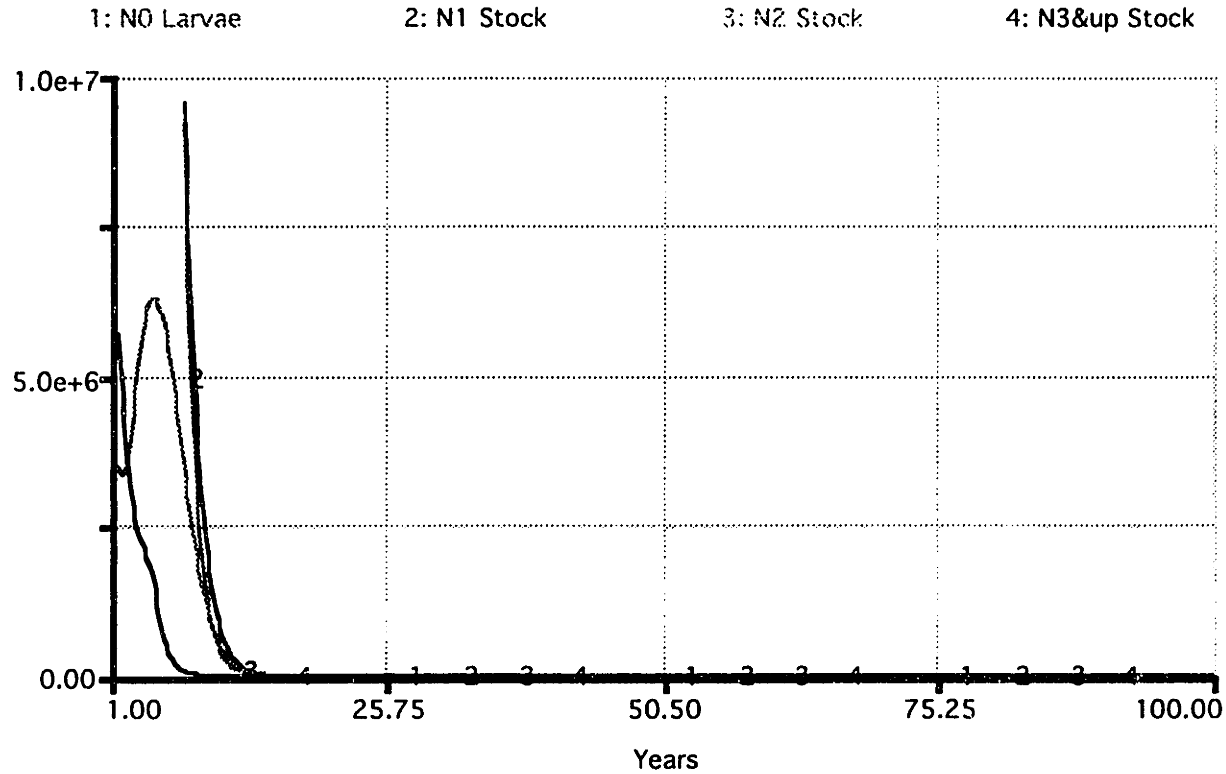
Reproduction rate outside the Zone = 24

Along Current Length = 150 miles

Across Current Width = 1 mile

Migration rate = 30%

the results are as follows:



This means that if 30% of the fish migrate out of the Zone, the Zone does not replenish the Stock. The Fishing Efforts are so high, that the few fish that do migrate out will be caught. This reduction in the number of fish in the Zone is enough though, so that there are not enough fish left in the Zone to reproduce. The Zone Location and the migration habitats of the targeted species are important in determining the replenishment potential of Zones.

The Migration rate might also change for the better, even if the Zone is located such that the reef area and shore area are both within the same Zone., even if the fish do not leave the Zone to mate. The R0, R1, R2 and R3 Stocks are limited by the Habitat's Holding Capacity, and in this SD model, the Natural Deaths increase if the Habitat's Holding Capacity is exceeded. It is probable, though, that rather than die, many R1, R2 and R3 fish from inside the Zone would probably migrate out of the Zone, seeking food sources outside the Zoned area. Red Snapper are known to be a sedentary species, but rather than die of starvation, the Migration rate would probably increase *as the Habitat's Holding Capacity approaches*. This would be different than having a consistently larger Migration Rate, from the time the Zone is first created. Using:

Across Currents Width = 1

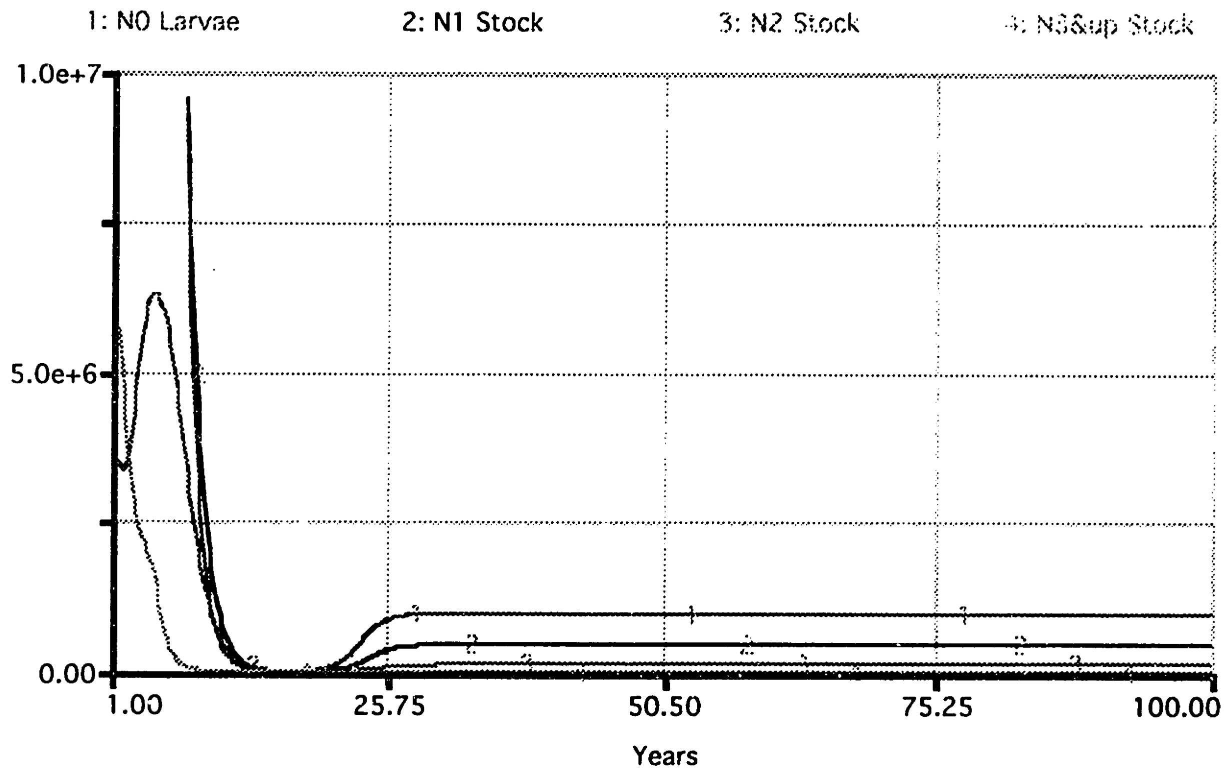
Along Currents Length = 150

Reproduction rate outside Zone = 24

Reproduction Rate inside Zone = 48 and

Migration rate starts at 5% then increases to 30% *after Year 22, as the Habitat's Holding Capacity approaches*

one can see the results:



This Migration rate increase is *delayed*. The delayed increase enables the Stocks to remain within the Zone so they can replenish rapidly in the first few years, then later as the Habitat's Holding Capacity is reached, rather than have adult fish die, they migrate out of the Zone. The actual number R1, R2 and R3 fish that migrate out of the Zone to find food increases, which increases the Harvest. With this higher delayed Migration Rate, the annual Harvest reaches about 10,000 fish per year, more than 20,000 pounds of fish.

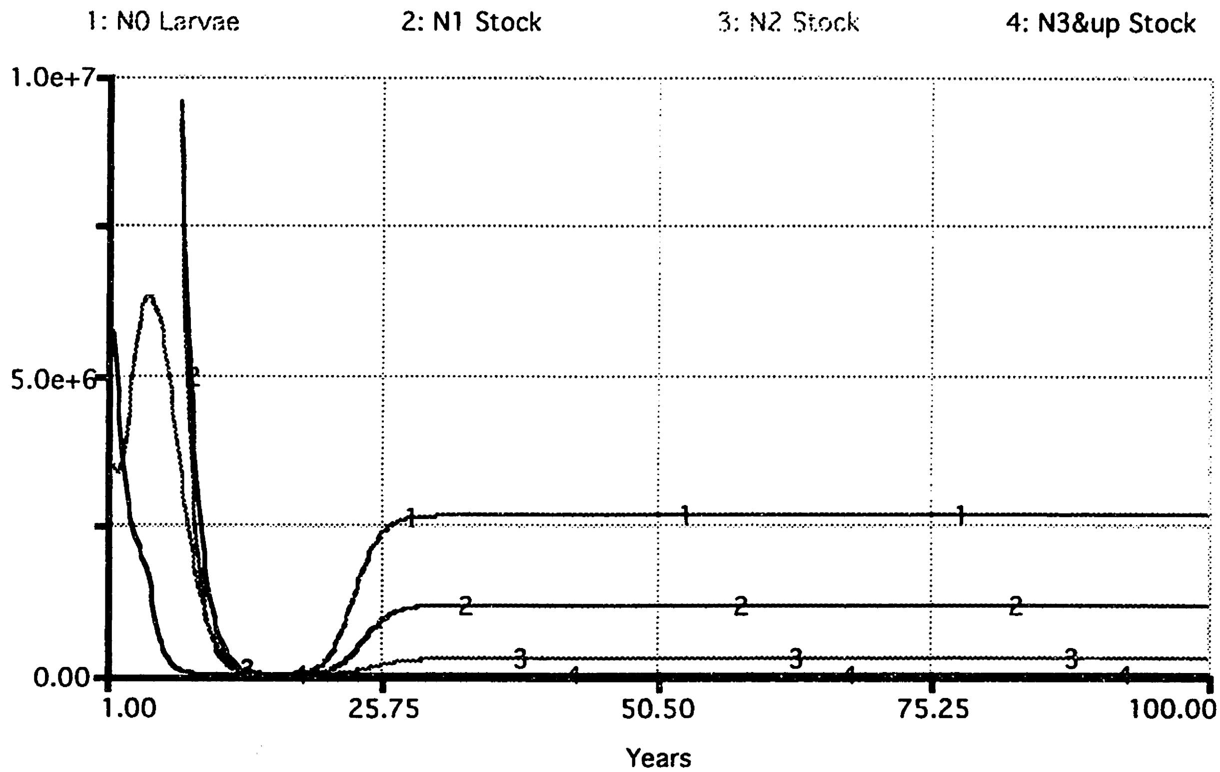
11. Changing the Zone Size

If the Replenishment Zone was larger, maybe double the area, then the results would change. Using the:

Reproduction rate outside Zone = 24

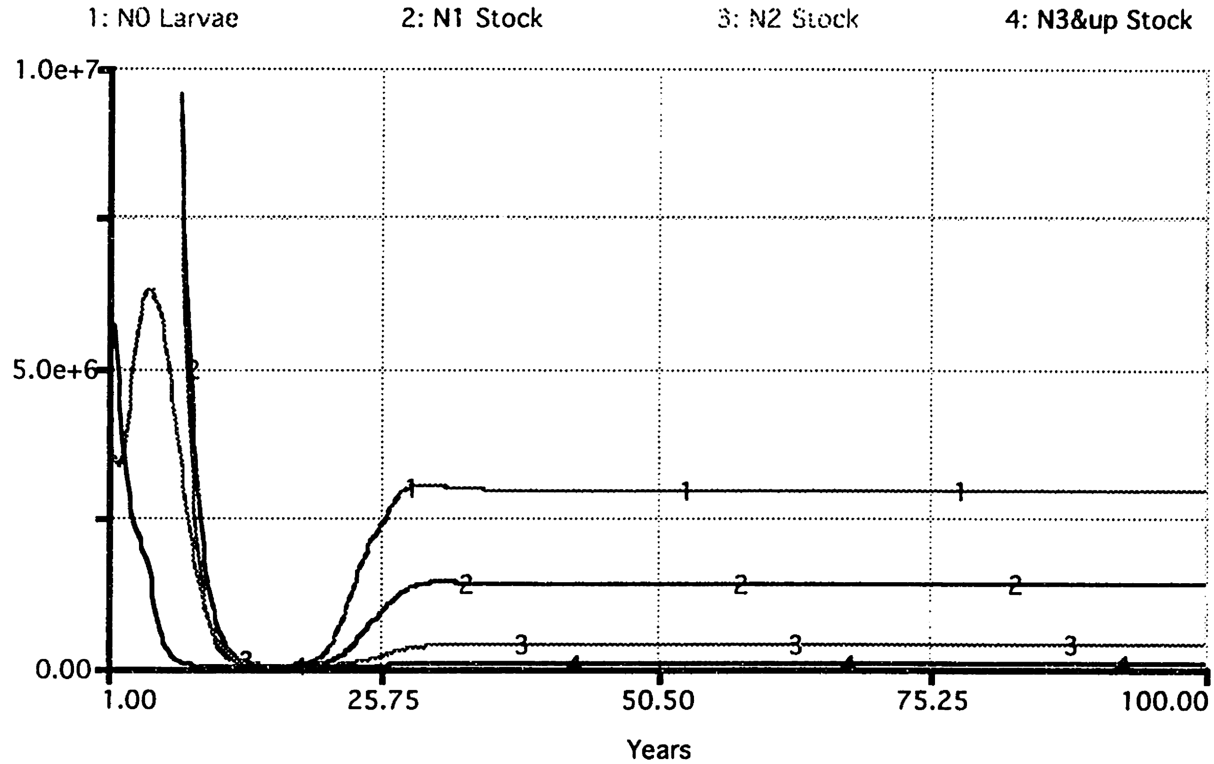
Reproduction Rate inside Zone = 48

Migration rate fixed at 5%
Across Currents Width = 3
Along Currents Length = 150
Size = 300 square miles:



Tripling the Zone Size would triple the annual Harvest rate from about 2000 fish per year to a about 6000 fish per year.

If the Migration rate increased as the Habitat's Holding Capacity approached, then the results would change dramatically.



With this higher delayed Migration Rate and larger Zone area, the annual Harvest reaches about 30,000 fish per year, more than 60,000 pounds of fish.

12. Income from Red Snapper

Without Zones, the annual Fishing Income for Red Snapper would crash. Using a:

Reproduction Rate outside the Zone =24

Commercial Catch Limits installed in 1990 = 1.5 M and 1991= 1M

Recreational Catch Limits installed in 1992 = 1M

Commercial Non Directed Fishing Efforts at their highest estimates:

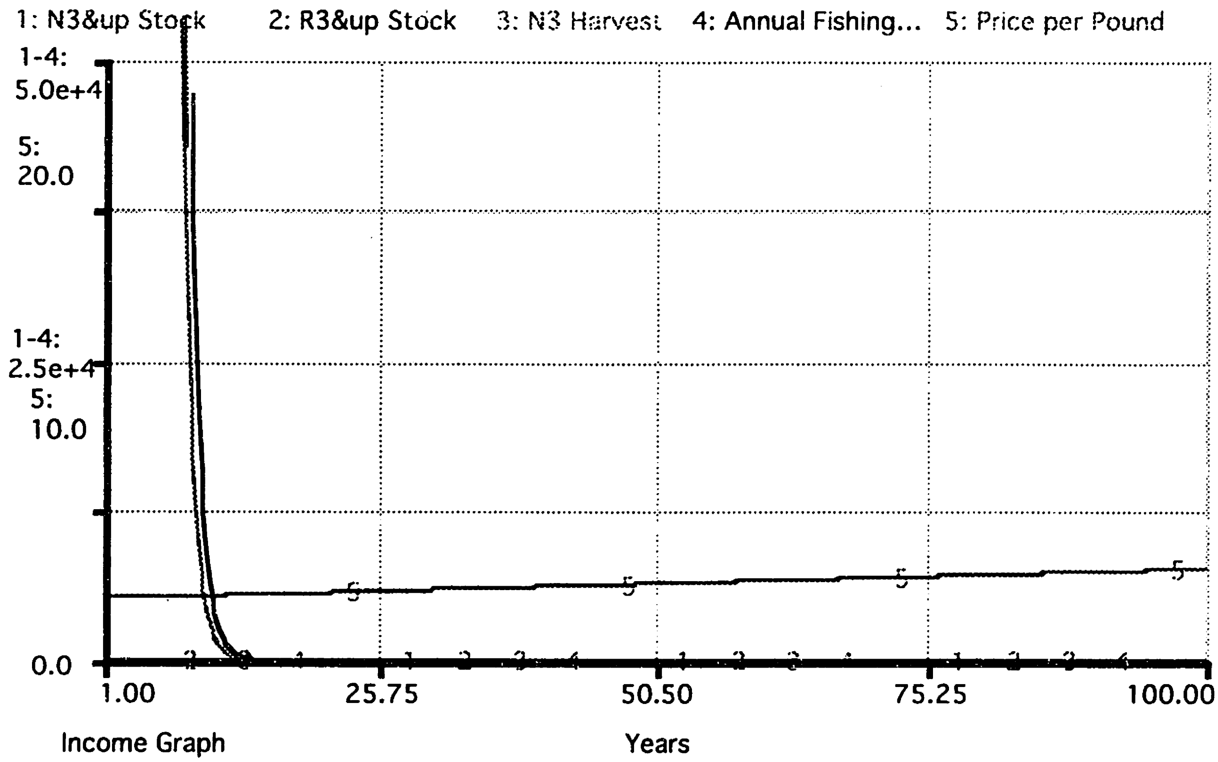
1984-1990 = 4 * 6000 = 24,000

1991 = 4 * 10,000 = 40,000

1990 = 4 * 23,000 = 92,000

1993 = 4 * (6000 + 10,000 + 23,000) /3 = 52,000

Recreational Fishing Effort = 1.5M before 1990 and 3 M after 1990.



Without the Zones, the Stocks crash around year 12, and the Fishing Income from Red Snapper is $0.

If the Zones are created in 1996, then the Red Snapper' specie is replenished and the Income increases. Using:

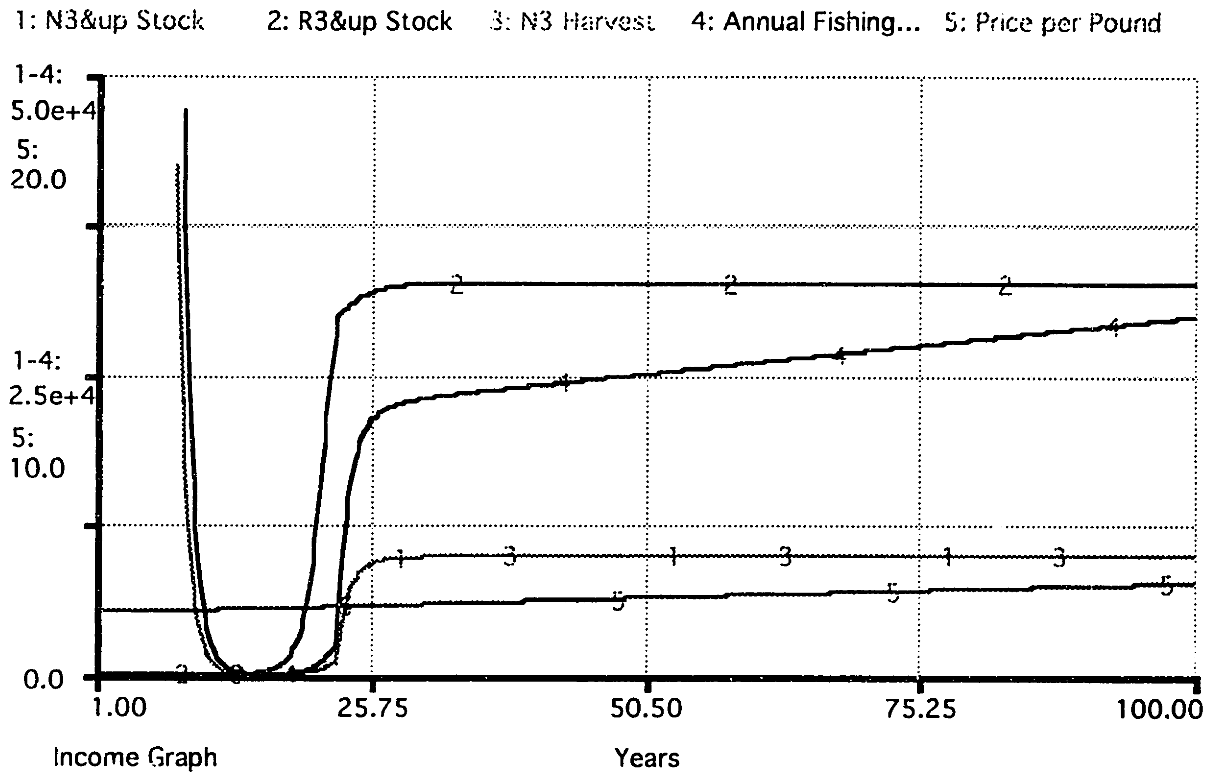
Reproduction rate outside Zone = 24

Reproduction rate inside Zone = 48

Across -Current Width = 1

Along-Current Length = 150 for a total area = 150 sq. miles

Migration Rate = 5% before Habitat is crowded and 30% once the Habitat Capacity is approached, in year 25.



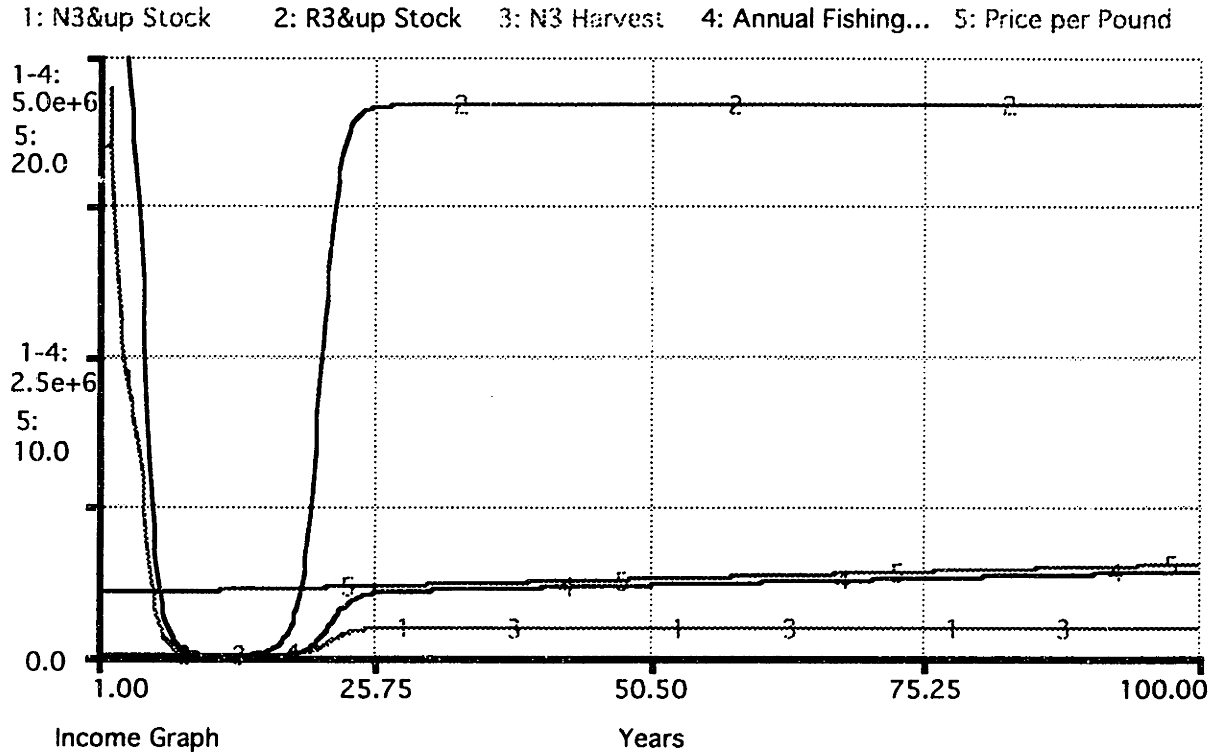
The Fishing Income from Red Snapper alone increases from $0 per year to about $25,000 per year, just 13 years after the Zones are created. Since the Zones are close to the Florida coast, it is likely that Florida residents will be able to benefit most from the increase in income from the Zones.

If Replenishment Zones were spread out along the entire Gulf fishing area and equaled 5% of this total area, then the Income would increase even more. Using the same conditions as above, except:

Across Current Width = 100 miles

Along Current Length = 188 miles

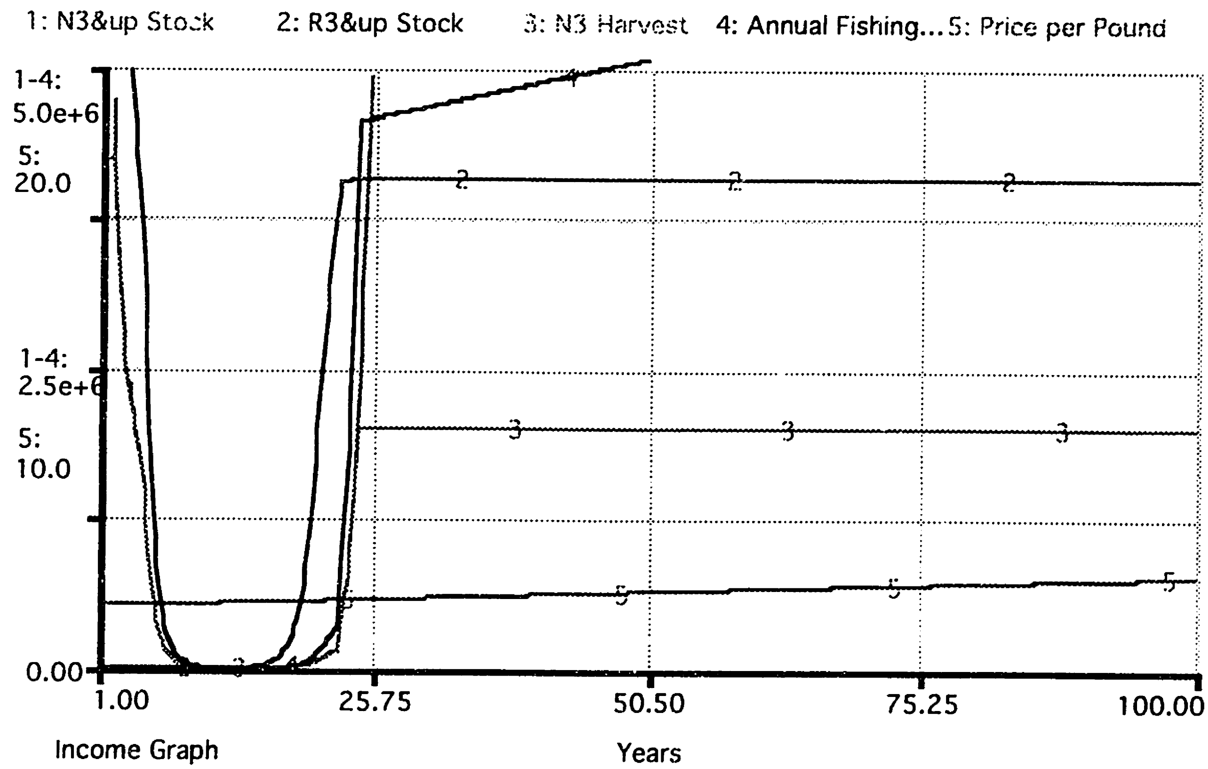
Migration Rate stays fixed = 5%



Under these conditions, the expected annual Harvest would increase to 230,000 fish /year and the Fishing Income would increase to about $500,000 per year from Red Snapper.

If the Migration rate was higher to account for the adult fish moving outside the Zone to find food rather than stay inside the Zone and die, then the income would be even higher.

Migration Rate initially 5%, and increased after year 20 to 30%
then the results would be:



The Harvest and Income would ultimately be higher. The total annual Harvest would be 2,000,000 equal to the Catch Limits and the Income would equal $4,500,000 per year, depending on the price per pound. It would equal the total Catch Limit rather than $0.

13. Other Conclusions

Using the Replenishment Zone SD model helps the users understand that there are many important variables that determine the Replenishment capabilities of the Zone. Important variables include the:

i) Reproduction rate inside the Zone,

ii) Zone's Habitat Holding Capacity

iii) Zone Size,

iv) percent of larvae / offspring that remain in the Zone which depends on the Zone Orientation, the Current Speeds,

v) Zone Location, (nearness to shore),

vi) Migration Rate, etc.

To transpose the results of Red Snapper SD to other species, researchers will have to explore the values of these critical variables for other important species. Then the users can better understand the replenishment capabilities for many species, and the best overall Zone configuration.

Appendix XI - A: Description of how to use Demos

Demos uses a diagram with nodes and linkages as the outline for representing a problem's components and interactions. It is different from many 'plumbing' diagrams or simulation tools, though, in that Demos uses Influence Diagrams as its basic building block. An Influence Diagrams is a graphical representation of a model, showing which different variables (drawn as nodes) in the model influence another variable (the influence is drawn as arrows connecting the two nodes). Influence Diagrams are different from other plumbing diagrams in that they do not represent feedback (when a variable can influence other variables, then loop back and influence itself). This circular feedback or cyclic dependency can only be represented using multiple time frames.[19]

Demos is somewhat different from Systems Dynamics because of this. SD is best at showing effects over time, but is awkward and bulky when accommodating uncertainty. Demos is best at including uncertainty on the variables and linkages, but becomes awkward and bulky when doing many calculations over time. (More on this later). Demos excels at analyzing models that have uncertain inputs and can determine which uncertain variables contribute most to the uncertainty in the outcome. Demos' analytic tools allow uncertainty to be explicitly included and sensitivity analysis easily performed. This enables Demos to identify which assumptions or predictions have the greatest influence on a decision, to identify its key sources of uncertainty. Demos allows the user to perform 'importance' analysis, such as parametric analysis and comparing alternative decisions.[20]

1. Building blocks of Demos

In the most basic sense, each node on the Influence Diagram represents a variable in the model and arrows indicate which variables affect each other. In Demos, there are different types of variables (or nodes) with different node shapes used to represent different types of variables. Demos uses the term 'variable' broadly to include any event that has a value or can be evaluated. The different types of Demos variables include:

a) The Objective variable - is the variable that evaluates the overall value or desirability of the outcomes. (There is only one per diagram and it is represented by hexagonal nodes.)

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[19]A cyclic dependency occurs when a variable depends on itself directly or indirectly so that the arrows form a directed circular path.

[20] For instance, the user can define variables such as utility, which can specify dollar values. A value can be defined for each possible outcome of the chance variables. These values describe the amount of money it would be worth to the user if the different outcomes occurred.

b) Decision variables - which are directly under the control of the decision maker (and are represented by rectangles.)

c) Chance variables - which cannot be controlled directly by the decision maker. (They are represented by nodes with rounded corners.)

d) Sub-models - contain an influence diagram, a piece of the bigger model; a sub-model can show more detail for the one piece, used in order to simplify complicated diagrams, most complex models use sub-models. (The are represented by thick-lined nodes.)

e) Constants - are variables whose value is fixed (i.e. has no inputs and is not computed). For example, the number of feet in a kilometer is a constant. (They are represented by a trapezoid shape)

f) Index - Used to define a dimension of an array. For example, a year would be an index for an array of the fishing effort in each year. (They are represented by parallelogram-shaped nodes).

g) User-Defined Functions - used to augment the functions pre-packaged in the Demos software. (Represented by an arrowhead shaped form). (Demos™ Tutorial, 1993)

Every variable (or other object) in Demos has an associated object window containing detailed information described in a list of attributes.[21] When the users create and document a variable, they must define the mathematical expression that allows Demos to compute its value. When one variable is influenced by other variables, the user must provide the mathematical expression that describes the relationship between the variables.

2. Running Demos and Predicting Outcomes

Demos can act as a simulation tool, because the user can also view the variable's value. A variable's value can be computed either using uncertain variables' distribution or using their mid-

[21] With Demos the user can add documentation about the model and its variables while creating the model. The documentation includes the following attributes:
a) definition - specifies the variable's value, or how to compute the value. The definition may be a simple number, a text string, a probability distribution or a more complicated expression. It can also be a list or table of numbers or other expression.
b) identifiers - used as a mathematical symbol in the definitions of other variables that depend on this variable. (Used to refer to the variable in definition of other variables.) It is different from the title, since it can contain up to 20 characters.
c) title - briefly describes (up to 36 characters) what the variable represents. The title is also shown in the node on the influence diagram and can help to show the logic of the model if the user selects descriptive titles.
d) description - provides a more complete description about the variable, since it allows unlimited length.
e) inputs - lists the variables (along with their identifiers) that are inputs to the value.
f) outputs - list the variable whose values depend on this variable.
g) class - specifies whether the variable is, for example, a decision variable, a chance variable or a constant.
h) units - indicates the units of measurement for the variable.

values. (Mid value is an abbreviation for deterministic value and is computed assuming all uncertain input variables are fixed at their median values.) Mid value is much quicker to compute than a full uncertain value, so its is useful for initial checks of the model, before the user performs any uncertainty analysis. Demos' greatest strength, though, is that it can calculate the distribution of possible outcomes for a variable (including the objective variable) taking into account the uncertainty of all variables in the system.

Demos uses a sampling method to determine how to generate random values from an uncertainty distribution. By default, Demos uses a sampling method called median Latin Hypercube sampling to create samples, which is a variation on Monte Carlo sampling.[22] (Other sampling methods are available in Demos.) Demos typically generates 100 random numbers from each variable's defined distribution, to estimate the statistics and probability distributions, then uses the mathematical expressions defined for linkages between the variables and calculates possible outcomes for each variable. By running through 100 random numbers for each uncertain variable, Demos generates a possible distribution for the overall outcome. For example, the mean is estimated using 100 randomly distributed numbers from each variable probabilistic distribution. This is different from the mid-value, which fixes all uncertain values at their medians.

If the users need more precise estimates, they can increase the sample size. Larger sample sizes allow Demos to produce smoother probability density graphs for example, but the results would take longer to compute. A sample size of 100 is adequate for most applications.

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[22] Median Latin Hypercube
The Median Latin Hypercube method (the default method) is simple; suppose the sample size = m and we want to generate m random values for x. In effect, we divide up the distribution into m equiprobable intervals, and then find the median of each interval. This is equivalent to generating the fractiles:

$x(i - 0.5)/m$ or $i = 1,2,m$

Then fractiles are randomly shuffled so that they are no longer in ascending order. In this way, samples from different distributions will not be positively correlated.

Random Latin Hypercube -
The random Latin Hypercube method is like the Simple Latin Hypercube, except that instead of each of the m equiprobable intervals, we sample at random from each interval

Simple Monte Carlo -
The simplest sampling method is known as Monte Carlo, named after the randomness alleged to be prevalent in games of chance. Suppose we are given a distribution for a variable x and want to generate random numbers from it. First we draw up a cumulative probability curve for x. Then we generate a random number r between 0 and 1. Then we use the cumulative probability curve to find the value of x corresponding to the cumulative probability r (i.e. the rth factile of x). This is repeated for every iteration up to the sample size.

Demos can compute and display the probability density function for any variable including the objective variables. The user can display the value of a variable in several different ways, both numerical and graphical. The Statistics' function displays the minimum, medium, mean, maximum and standard deviation numerically in a spreadsheet format.[23] The graphical displays include selected statistics, probability bands, the probability density function, the cumulative probability distribution function, or a table of random numbers from which the distribution is estimated. (Some of the graphical functions do not yet work well if the variable's value changes over time).

3. Demos' Uncertainty Analysis

It is often useful to understand how much the uncertainty of each input contributes to the overall uncertainty in the output. Using the importance analysis feature of Demos identifies these important inputs: To use the 'importance' feature, the user creates a variable that is dependent on the Objective variable or any other variable. Demos then calculates 'importance' as the rank order correlation between the sample of the chosen variable's values and the sample for each uncertain input. Each variable's importance can be calculated on a relative scale from 0 to 1.[24] Demos' 'importance' variable is a robust measure of the uncertain contribution, because it is insensitive to extreme values and skewed distribution. Unlike commonly used deterministic measures of sensitivity, it averages over the entire joint probability distribution. Therefore, it works well even for models where the sensitivity to one input depends strongly on the value of another.

Demos can do parametric analysis (also called sensitivity analysis) which involves varying the value of an input variable to examine its effect on a select output. One can easily do parametric analysis with Demos by changing a deterministic value for a variable or by changing the parameters of a variable's distribution. Another way to perform parametric analysis is to change a definition to a list. When the user does this, a cell appears in the definition space; the user replaces the first cell with a number, and add more cells to calculate the different values given the list of different inputs. Demos can then calculate and display a computed value for each parameterized value of the variable. Demos allows the user to perform sensitivity analysis on

[23] The statistic may not be exact, since they are estimated from a sample of values from the distribution. For example, in a Normal Distribution, the true minimum and maximum are minus and plus infinity. For computational efficiency, Demos truncates the distribution at +or-3 standard deviations from the mean.
[24] An importance value of 0 means that the uncertain input variable has no effect on the uncertainty in an output. A value of 1 implies total correlation, where all the uncertainty is due to a single input.

several variables simultaneously, showing the results as tables instead of lists. (Demos User's Reference, 1993)

Demos enables the user to:

- Categorize the type of uncertainty by requiring a definition from a menu of distribution types.
- Encode expert judgment in the form of probability distributions.
- Analyze whether the variables with uncertainty play a large part in the uncertainty of the outcome or a small part.

Including uncertainty is easy because Demos has many built in functions that allow uncertainty to be easily defined and analyzed. Demos has several different kinds of expressions that can be used in a variable's definition, including distributions and probability tables.[25]

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[25] a) expression - (this option lets you view any definition type including mathematical expressions, statistical, if then logic, etc.)
b) list (of expressions or numbers)
c) list of labels (text strings)
d) table - an array consisting of one or more dimensions or numbers or expressions
e) probability table - an array defining probabilities (numbers or expressions) across the domain of a discrete (chance) variable). A probability fable is similar to a regular table, except that each index of a probability table consists of its domain.
f) distribution - an uncertainty function (can chose from the distribution library including normal and chi)
g) choice - a function that lets you choose one element from an index or division variable.
Demos allows the user to edit the distribution's parameters quickly and easily.

Appendix XI - B: Definitions of the Demos variables

See Appendix X - C: Systems Dynamics Model Definitions and Documentation

Appendix XI - C: - Demos Model'sDefinition and Documentation of the Variables

Time := Sequence(0,20,0.2)

Decision Replenish
Title: Replenishment Zone Size
Units: Kilometers
Description: The size of the Replenishment Zone which equals the distance across the reserve as measured by the current flow.
Definition: 20

Chance Fishing_ef
Title: Recreational Fishing Effort
Units: Angler Hours /year
Description: Recreational Fishing Effort is the number of hours fishermen collectively spend trying to catch fin-fish somewhat like Red Snapper.
Definition: Max([0, Normal(1500000, 450000)])

Variable Catch_limi
Title: Catch Limits
Units: Fish / year
Description: The maximum number of fish that is allowed to be caught in one year. Estimated by the fixed total number of pounds divided by the distribution of fish weight.
Definition: If (Time<7)Then (999999999) Else(Normal(2000000,180000))

Chance Larvae_sto
Title: R: Larvae Stock
Units: Number of larvae
Description: The number of larvae in the Replenishment Zone
Definition: Dynamic(0, Max ([0, min([29000*2*10, ((Larvae_sto[Time-1] + ((A_year_old2[Time-1]*Dt) * (max ([Reproducti, R_repro_ra]))) + (if (time >11) and (time<12) then (29000*2*Dt) else (0)) -((Larvae_sto[Time-1]*Dt) * Export_rat) - (((Larvae_sto[Time-1]*Dt)* (1-Export_rat)) * (1-Exp(-R__death_r))) - (((Larvae_sto[Time-1]*Dt)* (1-Export_rat)) * (Exp(-R__death_r)))))])]))

Chance A_year_old
Title: R: 1 Year Old Stock
Units: Number of Fish
Description: Replenishment Stock of 1 year old fish.
Definition: Dynamic(0, max([0, min([14000*10*2, ((A_year_old[Time-1] + ((Larvae_sto[Time-1]*Dt) * (1-Export_rat) * (Exp(-R__death_r))) + (if (time >11) and (time<12) then (14000*2*Dt) else (0)) - ((A_year_old[Time-1]*Dt)*(A_migratio3)) - (((A_year_old[Time-1]*Dt)*(1-A_migratio3)) *(1-Exp(-R__1_death))) - (((A_year_old[Time-1]*Dt)*(1-A_migratio3)) *(Exp(-R__1_death)))))])]))

Chance A_year_old1
Title: R: 2 Year Old Stock
Units: Number of Fish
Description: Replenishment Stock of 2 year old fish

Definition: Dynamic(0, Max([0,min([3500*2*10, ((A_year_old1[Time-1] + (((A_year_old[Time-1]*Dt) *(1-A_migratio3)) * (Exp(-R__1_death))) + (if (time >11) and (time<12) then (3500*2*Dt) else (0)) - ((A_year_old1[Time-1]*Dt)*A_migratio) - (((A_year_old1[Time-1]*Dt)*(1-A_migratio))*(1-Exp(-R__2_death))) - (((A_year_old1[Time-1]*Dt)*(1-A_migratio))*(Exp(-R__2_death)))))])]))

Chance A_year_old2
Title: R: 3 Year Old Stock
Units: Number of Fish
Description: Replenishment Stock of 3 year old fish Definition: Dynamic(0, Max([0, min([5700*2*10 ,((A_year_old2[Time-1] + ((A_year_old1[Time-1]*Dt)* (1-A_migratio) * (Exp(- R__2_death))) + (if (time >11) and (time<12) then (5700*2*Dt) else (0)) - ((A_year_old2[Time-1]*Dt)* (A_migratio1)) - ((A_year_old2[Time-1]*Dt)* (1-A_migratio1) * (1-Exp(- R__3_death)))))])]))

Chance N_larvae_s
Title: N: Larvae Stock
Units: Number of Fish
Description: Non Replenishment Stock of Larvae and 0 year old fish. Taken from estimates in Goodyear article.
Definition: Dynamic(29000000, max([0, min ([29000000*10, (N_larvae_s[Time-1] + (N___3_year[Time-1]*Reproducti + Larvae_sto[Time-1]*Export_rat - N_larvae_s[Time-1]*(1-exp(-N__1_death- N__1_bycat)) N_larvae_s[Time-1]*(exp(-N__1_death- N__1_bycat)))*Dt)])])))

Chance N__1_year_
Title: N: 1 Year Old Stock
Units: Number of Fish
Description: Non Replenishment Zone Stock of 1 year olds.
Definition: Dynamic(14000000, max([0, min([14000000*10, (N__1_year_[Time-1] + (N_larvae_s[Time-1]*(exp(-N__1_death-N__1_bycat)) + A_year_old[Time-1]*A_migratio3 - N__1_year_[Time-1]*(1-exp(-N__1_bycat-N__1_death)) - N__1_year_[Time-1]*(exp(-N__1_bycat-N__1_death)))*Dt)])])) Location: 280,248

Chance N__2_year_
Title: N: 2 Year Old Stock
Units: Number of fish
Description: Non Replenishment Stock of 2 year olds.
Definition: Dynamic(3500000, max([0, min([3500000*10, (N__2_year_[Time-1] + (N__1_year_[Time-1]* (Exp(-N__1_death - N__1_bycat)) + A_year_old1[Time-1]* A_migratio - N2_cryptic - (N__2_year_[Time-1]-N2_cryptic)*(1-exp(-N__2_death)) - (N__2_year_[Time-1]-N2_cryptic)*(exp(-N__2_death)))*Dt)])]))

Chance N___3_year
Title: N: 3 Year Old Stock
Units: Number of Fish
Description: Non Replenishment Stock of 3 year old fish
Definition: Dynamic(5.7M,Max([0,Min([(5.7M*10),(N___3_year[Time-1]+((((((N__2_year_[Time-1]-N2_cryptic)*Exp(-(N__2_death)))+(A_year_old2[Time-1]*A_migratio1))-Anharvest)-N__3_crypt)-(((N___3_year[Time-1]-Anharvest)-N__3_crypt)*(1-Exp(-(N__3_death)))))*Dt))])]))

Chance R__death_r
Title: R: 0 Nat Deaths

Units: Number of Fish
Description: Replenishment Zone number of larvae deaths
Definition: Max([0, Normal(0.5, 0.1)])

Chance R__1_death
Title: R: 1 Nat Deaths
Units: Number of Fish
Description: Replenishment Zone deaths for fish 1 years old.
Definition: Max([0, Normal(0.3, 0.06)])

Chance R__2_death
Title: R: 2 Nat Deaths
Units: Number of Deaths
Description: Replenishment Zone natural deaths for 2 year old fish Definition: Max([0, Normal(0.2, 0.04)])

Chance R__3_death
Title: R: 3 Nat Deaths
Units: Number of Deaths
Description: Replenishment Zone Natural Deaths for fish 3 years old and up.
Definition: Max([0, Normal(0.2, 0.04)])

Chance N__1_death
Title: N: 0 Natural Deaths
Units: Number of fish (larvae)
Description: Non Replenishment Number of Larvae that die in the first year of life.
Definition: Max([0, Normal(0.5,0.1)])

Chance N__l_bycat
Title: N: L Bycatch Deaths
Units: Percentage
Description: The 'percentage' of larvae that die due to shrimp bycatch.
Definition: Max([0, Normal(0.34, 0.022)])

Chance N__1_death
Title: N: 1 Natural Deaths
Units: Number of fish
Description: Non Replenishment Zone natural deaths for fish 1 year old
Definition: Max([0, Normal(0.3,0.06)])

Chance N__1_bycat
Title: N: 1 Bycatch Deaths
Units: Percentage
Description: The 'percentage' of 1 year olds that die due to shrimp bycatch.
Definition: Max([0, Normal(1.2, 0.08)])

Chance N__2_death
Title: N: 2 Natural Deaths
Units: Number of Fish
Description: Non Replenishment Zone natural deaths for fish 2 years old.
Definition: Max([0, Normal(0.2, 0.04)])

Chance N2_cryptic
Title: N: 2 Cryptic Deaths

Units: Number of Fish
Description: Non Replenishment Zone fish 2 years old that die from cryptic deaths
Definition: Dynamic(0, Min([N__2_year_[Time-1], (If (Catch_limi < (Tndcatch + Dir_comm_c)) Then ((Tndcatch + Catch_limi) *(N__2_year_[Time-1] / (N___3_year[Time-1]+1)) * (1-Catch_surv)) Else ((Tndcatch + Dir_comm_c) * (N__2_year_[Time-1] / (N___3_year[Time-1]+1)) * (1-Catch_surv)))]))

Chance N__3_death
Title: N: 3 Natural Deaths
Units: Number of Fish
Description: Non Replenishment Zones natural deaths for fish 3 years old & up.
Definition: Max([0, Normal(0.2, 0.04)])

Objective Anharvest
Title: Annual Harvest
Units: Number of Fish
Description: The number of fish per year that are caught and HARVESTED either by commercial or recreational fishermen.
Definition: Dynamic(0, Min([Catch_limi, N___3_year[Time-1], (Dir_comm_c +Tndcatch)]))

Chance Export_rat
Title: Export Rate
Units: Number of Larvae
Description: The Number of Replenishment larvae that get carried out of the Zone due to currents.
Definition: Min([1,(Current_sp / (Replenishm / Larvae_tim))])*0.95

Chance A_migratio
Title: 2 Migration
Units: Number of Fish
Description: Replenishment 2 year old fish that migrate out of the Zone
Definition: Max([0, Normal(0.05,0.0165)])

Chance A_migratio1
Title: 3 Migration
Units: Number of Fish
Description: Replenishment 3 year old & up fish that migrate out of the Zone
Definition: Max([0, Normal(0.05,0.0165)])

Chance A_migratio3
Title: 1 Migration
Units: Number of fish
Description: Replenishment Fish 1year old that migrate out of the Zone.
Definition: Max([0, Normal(0.05,0.0165)])

Chance Reproducti
Title: Reproduction Rate
Units: Percentage
Description: Number of Larvae created each year per number of 3 & up year olds
Definition: Max([0, normal(24, 8)])

Chance Current_sp
Title: Current Speed

Units: Kilometers per day
Description: The speed of currents through the Replenishment Zone, translated from 2 km/day to 450 km/year.
Definition: Max([0,Normal(450, 150)])

Chance Larvae_tim
Title: Larvae Time
Units: Days
Description: The amount of time larvae spend drifting (in the pelagic state) before they can swim.
Definition: Max([0,Normal(0.167, 0.027)])

Chance N__3_crypt
Title: N: 3 Cryptic Deaths
Units: Number of Fish
Description: Non Replenishment Zone 3 & up year old fish that die cryptic deaths.
Definition: Dynamic(0,Min([(N___3_year[Time-1]-Anharvest), (If(Catch_limi<(Tndcatch+Dir_comm_c)) Then (Tndcatch*(1-Catch_surv)) Else 0)]))

Chance Tndcatch
Title: Total Non~Directed Catch
Units: Number of fish /year
Description: Total number of fish caught by non-directed efforts .
Definition: Indirect_c2 + Recreation1

Chance Dir_comm_c
Title: Dir Comm Catch
Units: Number of Fish
Description: Directed commercial catch is the amount of fish caught by fishermen who are specifically trying to catch Red Snapper.
Definition: Dir_comm_f * Dir_comm_c1

Chance Dir_comm_f
Title: Dir Comm Fishing Efforts
Units: Days / year
Description: Directed Commercial Fishing Efforts is the number of equivalent days per year that commercial fishermen fish for Red Snapper
Definition: Max([0, Normal(23400, 12870)])

Chance Dir_comm_c1
Title: Dir Comm Catch per Effort
Units: Fish / days
Description: Directed Commerical Catch per unit effort is the number of fish caught when commercial fishermen fish for 1 day.
Definition: Max([0, Normal(120, 40)])

Chance Indirect_c2
Title: Nondirect Comm Catch
Units: Number of Fish /year
Description: Non directed Commercial catch is the number of fish that are caught and included as part of the commercial catch, but are caught in boats where Red Snapper is less than 50% of the total finfish catch.
Definition: Indirect_c * Indirect_c1

Chance Indirect_c
Title: Nondirect Comm Catch per Effort
Units: Fish / day
Description: This is the number of fish caught by commerical fishermen who aren't specifically looking for Red Snapper.
Definition: Max([0, Normal(9.3, 7.4)])

Chance Indirect_c1
Title: Nondirect Comm Fishing Efforts
Units: Days /year
Definition: Max([0, Normal(13000, 10400)])

Chance Recreation
Title: Recreational Catch per Effort
Units: Fish / angler hour
Description: Recreational Catch per unit effort is the number of Red Snapper caught for every hour an angler (fishermen) spends fishing.
Definition: Max([0, Normal(0.67, 0.114)])

Chance Recreation1
Title: Recreational Catch
Units: Number of Fish /year
Description: Recreational Catch is the number of fish that recreational fishermen catch per year, including head boats, charter boats and private vessels.
Definition: Fishing_ef * Recreation

Chance Catch_surv
Title: Catch Survival Rate
Units: Percentage
Description: Percent of fish that survive when caught and thrown back in.
Definition: Max([0, Normal(0.67, 0.03)])

Chance Dt
Title: Dt
Description: This is the frequency of how many times the values are recalculated each year.
Definition: 0.2

Chance R_repro_ra
Title: R Repro Rate
Description: The reproduction rate of fish in the Replenishment Zone if greater than the Reproduction Rate of fish outside the Zone.
Definition: Max([24,8])

Chance Stock_resu
Title: Stock results
Definition: Table(Self)(N_larvae_s, N__1_year_, N__2_year_, N___3_year)

Appendix XI - D: Demos Results

At first, the Demos model was developed in parallel with the Systems Dynamics model, using the information directly from the Goodyear article. The results from the System Dynamics model was not referred to. This was somewhat unfortunate, because some errors in syntax and logic were made modeling in Demos, that were later overcome when Systems Dynamics was used as a check.

For example, with the Replenishment Zone first modeled with Demos, there were very strange results - triangular patterns for the N3 Stock from 0 straight up to 3 million. There was obviously an incorrect division by a very small number, then by a very large number. Although the same numbers and information from the Goodyear article were used for Demos as had been used for Systems Dynamics, the results were different.

It was determined that the N2 Cryptic Death was being calculated incorrectly; it was (N2 Stock) / (N3 Stock +1) using the Stocks in the *current* time frame. The Systems Dynamics program also calculated N2 Cryptic Death using this ratio, but it used the Stock values from the previous time period, rather than the current time period. Modeling the N2 and N3 Cryptic Deaths incorrectly caused the N2 and N3 Stocks to show impossible projections.

Checking back and forth between the two models, using the Systems Dynamics model as a reference for Demos, revealed a few other major logic 'errors' in the Demos model (and revealed a few minor mistakes in Systems Dynamics). Because Demos does not impose a structure, using Stocks and Flows as in SD, it was possible to create a Demos model with fewer variables. However, this resulted in *more* information being represented *within* the *fewer* variables. For example, there is a variable in Demos for each of the Stocks (N0, N1, N2, N3, R0, R1, R2, R3), but it was not necessary to create a separate variable for each of the *flows* out of the Stocks. Demos did not require the user to methodically create a new variable for every interaction and how every variable affected the Stock of each age group. In this Demos model, all of the correct variables were included in the equations, but it was easy to make errors in the mathematical links.

Not requiring this may be desirable for some who find a prepackaged program annoying; programming in Demos allows more flexibility on how to represent interactions and how to express linkages. While this may be a positive feature for some, it is often a negative for many others, because it allows for more errors in the programming. When trying to learn more about the interactions of a physical and system, though, not explicitly defining every variables can result in less learning and incorrect representation.

Another mistake found comparing the Demos model with the SD model was that the Demos representations of Harvest, Cryptic Death and Natural Death were wrong. For example, Natural Deaths were represented as a percentage of Total Stock, instead of representing them as a percentage of the (Total Stock) - (Harvest) - (Cryptic Deaths). If Natural Death equaled a percentage of Total Stock, it might result in a situation where:

Total N3 Stock < (N3 Harvest + N3 Cryptic Deaths + N3 Natural Deaths)

Since with Demos there is less fixed structure and one can write the equations in many ways, it is best to have a base model with which to check the Demos model. With Demos, one can run the model and calculate the outcome using the *mid value* of all variables for the case with certainty. This can be compared to the results of tools structured Simulation models that can only make deterministic predictions. Demos can then be run to determine the *median* outcome or probability bands, including the system's uncertainty. Overall, it is best to model the physical or economic part of the system first with a more structured Simulation model, and afterwards use Demos for uncertainty analysis. Building both models also helps the users understand the many pieces of a very complicated system. Building both models makes it easier to learn about the system, not just looking for mistakes in the equations or code. Doing the Replenishment Zone model, it was best when the Systems Dynamics model was developed and run first, with the Demos model, created to understand the effects of uncertainty, run afterwards .

1. No Replenishment Zone, base case

For:

No Replenishment Zone

Reproduction Rate =5 (1984 calculation; lower than other years)

Initial Stocks not in Zone

Larvae Stock =29,000,000

1 year olds Stock =14,000,000

2 year olds Stock =3,500,000

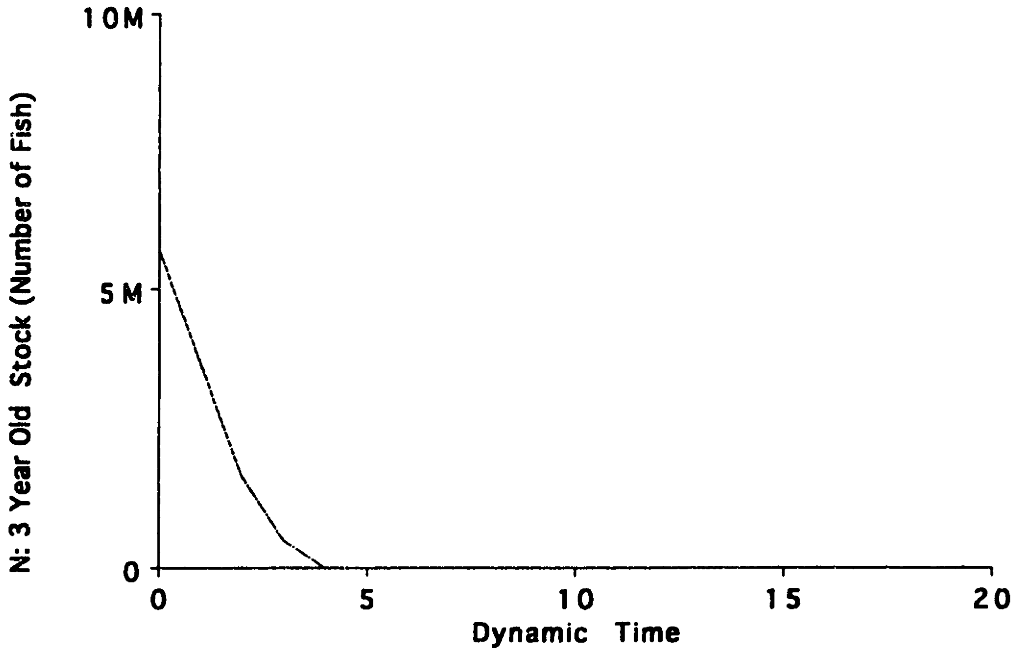
3 year olds & Up Stock = 5,700,000

Initial Stocks in Zone = 0

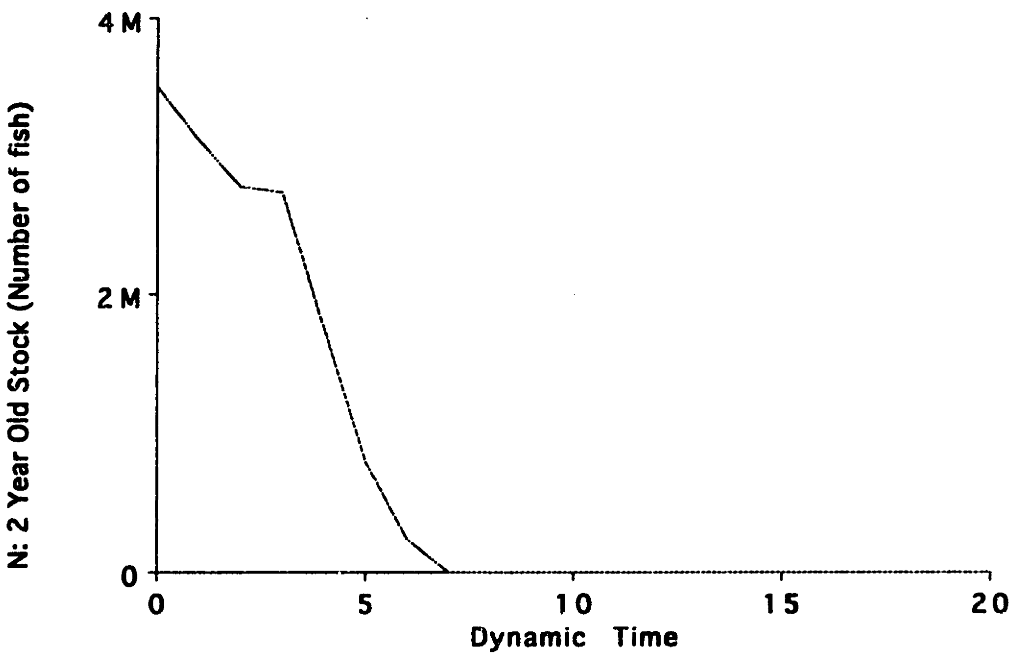
Catch Limit = infinity (since it was not imposed until 1990)

Non direct Comm Fishing Effort = 6000 (1990 low estimate using only reported data)

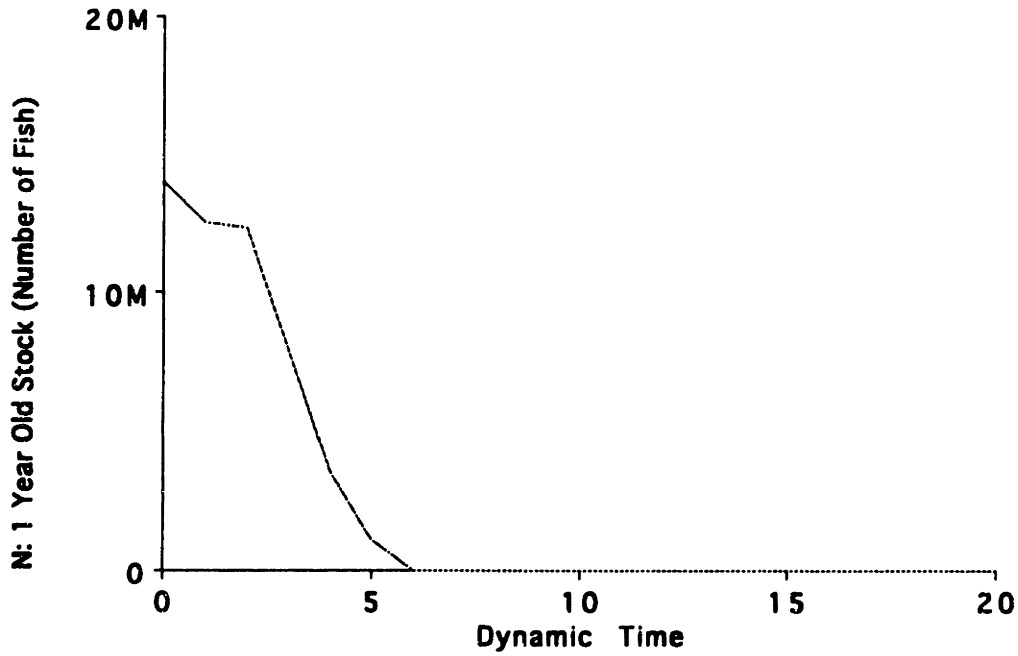
Dt =1

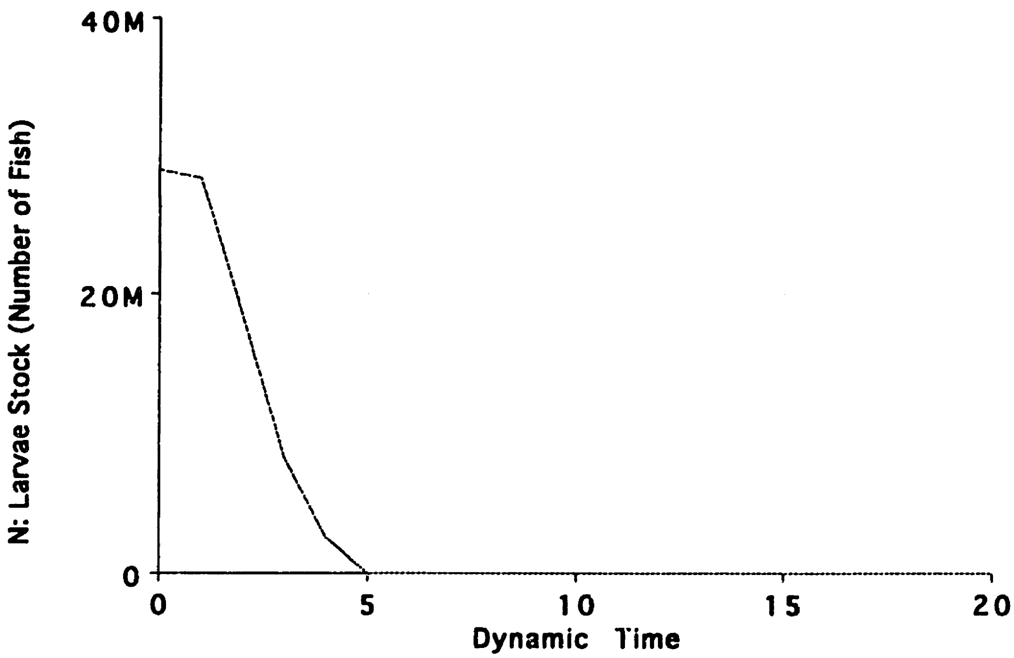


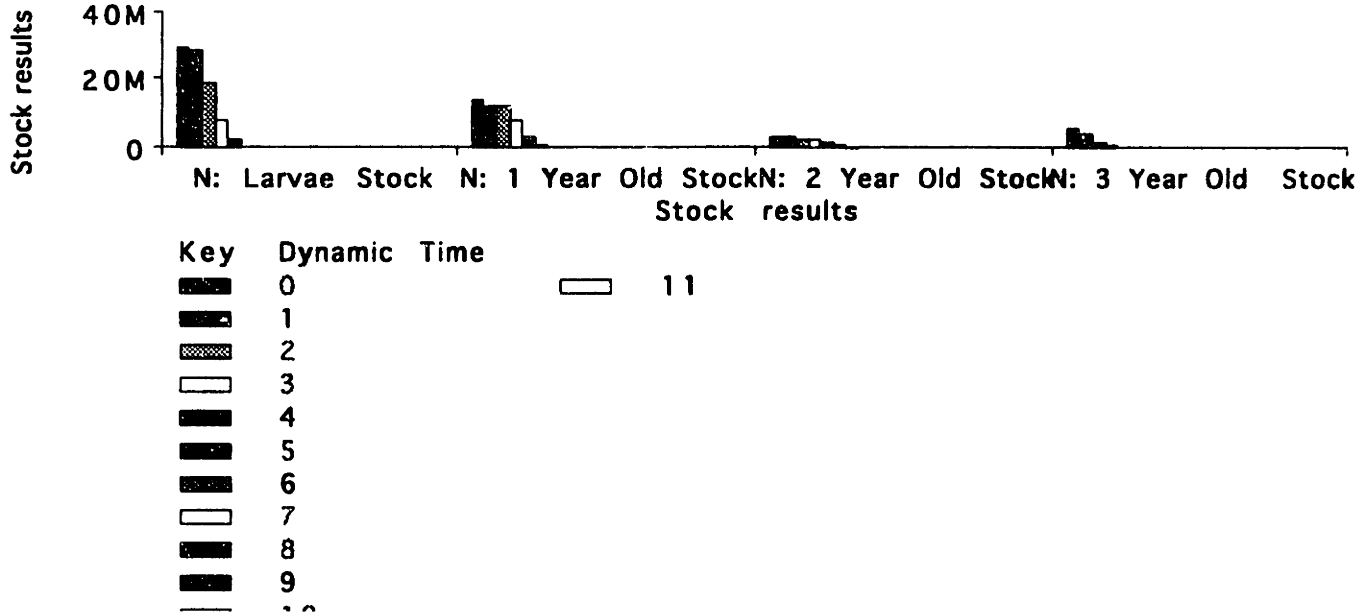
10M
5 M
0
N: 3 Year Old Stock (Number of Fish)
0
5
10
15
20
Dynamic Time



4 M
2 M
0
N: 2 Year Old Stock (Number of fish)
0
5
10
15
20
Dynamic Time


20M
10M
0
N: 1 Year Old Stock (Number of Fish)
0
5
10
15
20
Dynamic Time


40M
20M
0
N: Larvae Stock (Number of Fish)
0
5
10
15
20
Dynamic Time



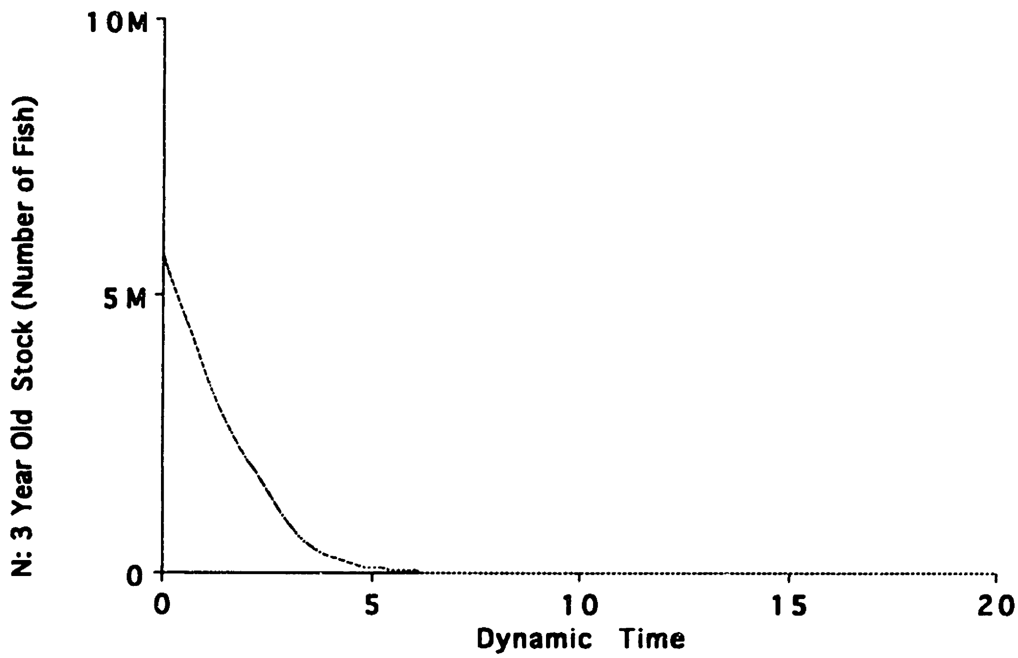
Year	N0 Stock	N1 Stock	N2 Stock	N3 Stock
0	2.9000e+7	1.4000e+7	3.5000e+6	5.7000e+6
1	2.8500e+7	1.2520e+7	3.1238e+6	3.6852e+6
2	1.8426e+7	1.2304e+7	2.7935e+6	1.6627e+6
3	8.3137e+6	7.9547e+6	2.7453e+6	5.1357e+5
4	2.5678e+6	3.5891e+6	1.7749e+6	0.0000e+0
5	0.0000e+0	1.1086e+6	8.0083e+5	0.0000e+0
6	0.0000e+0	0.0000e+0	2.4735e+5	0.0000e+0
7	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0
8	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0
9	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0
10	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0

When all the variables in Demos are defined in the same way as they are in Systems Dynamics, and Demos is run just using the mid-values, one can compare the above table to the first table in Appendix X- C to see that both models produce nearly the same results . The differences are very small; they occur because SDs and Demos calculate the variables in different orders. SD uses Euler Differentiation, while Demos calculates the value of the variables in the order that the influence diagram is drawn.

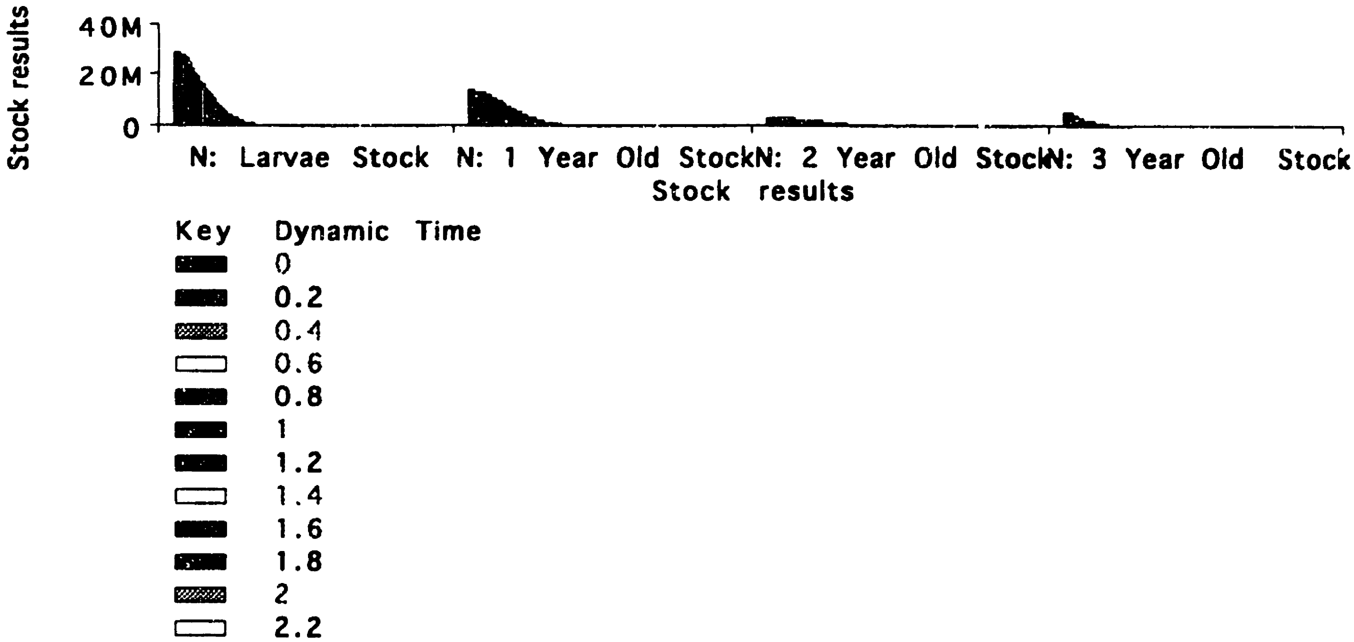
2. Changing the Dt

These examples were all completed using a Dt =1. Realizing from the SD work that a Dt= 1 is too coarse and may lead to incorrect results, the model was changed to Dt = 0.2. Demos did not change all the definitions of the variables automatically to accommodate the change in Dt. With Demos, the user has to redefine all the variables that might depend on the Dt, which requires that the user know how Demos calculates the value of the variables. To define the variables accurately with Demos requires that the user understand how the program works to a very detailed level.

Below are the projected Stock of 3 & Up year old fish when the Dt = 0.2. (Every one-fifth of a year):



The results of all the Stocks are as follows:



Year	N0 Stock	N1 Stock	N2 Stock	N3 Stock
0	2.9000e+7	1.4000e+7	3.5000e+6	5.7000e+6
0.2	2.8900e+7	1.3704e+7	3.4248e+6	5.2970e+6
0.4	2.8417e+7	1.3458e+7	3.3514e+6	4.8895e+6
0.6	2.7623e+7	1.3220e+7	3.2817e+6	4.4765e+6
0.8	2.6575e+7	1.2961e+7	3.2153e+6	4.0570e+6
1.0	2.5317e+7	1.2664e+7	3.1507e+6	3.6293e+6
1.2	2.3883e+7	1.2317e+7	3.0857e+6	3.2361e+6
1.4	2.2342e+7	1.1916e+7	3.0182e+6	2.8928e+6
1.6	2.0767e+7	1.1462e+7	2.9463e+6	2.5882e+6
1.8	1.9202e+7	1.0962e+7	2.8685e+6	2.3127e+6
2.0	1.7674e+7	1.0428e+7	2.7840e+6	2.0580e+6
	1.6197e+7	9.8682e+6	2.6926e+6	1.8166e+6
	1.4774e+7	9.2930e+6	2.5944e+6	1.5813e+6
	1.3401e+7	8.7101e+6	2.4902e+6	1.3434e+6
	1.2064e+7	8.1251e+6	2.3809e+6	1.0912e+6
3.0	1.0742e+7	7.5417e+6	2.2673e+6	8.7292e+5
	9.4668e+6	6.9609e+6	2.1504e+6	6.9834e+5
	8.2718e+6	6.3861e+6	2.0310e+6	5.5867e+5
	7.1761e+6	5.8231e+6	1.9098e+6	4.4694e+5
	6.1878e+6	5.2781e+6	1.7877e+6	3.5755e+5
4.0	5.3078e+6	4.7567e+6	1.6657e+6	2.8604e+5
	4.5323e+6	4.2637e+6	1.5448e+6	2.2883e+5
	3.8547e+6	3.8023e+6	1.4261e+6	1.8306e+5
	3.2668e+6	3.3746e+6	1.3106e+6	1.4645e+5
	2.7599e+6	2.9818e+6	1.1991e+6	1.1716e+5
5.0	2.3251e+6	2.6237e+6	1.0923e+6	9.3729e+4
	1.9538e+6	2.2997e+6	9.9093e+5	7.4983e+4
	1.6580e+6	2.0085e+6	8.9537e+5	5.9987e+4
	1.3704e+6	1.7482e+6	8.0593e+5	4.7989e+4
	1.1443e+6	1.5169e+6	7.2276e+5	3.8392e+4

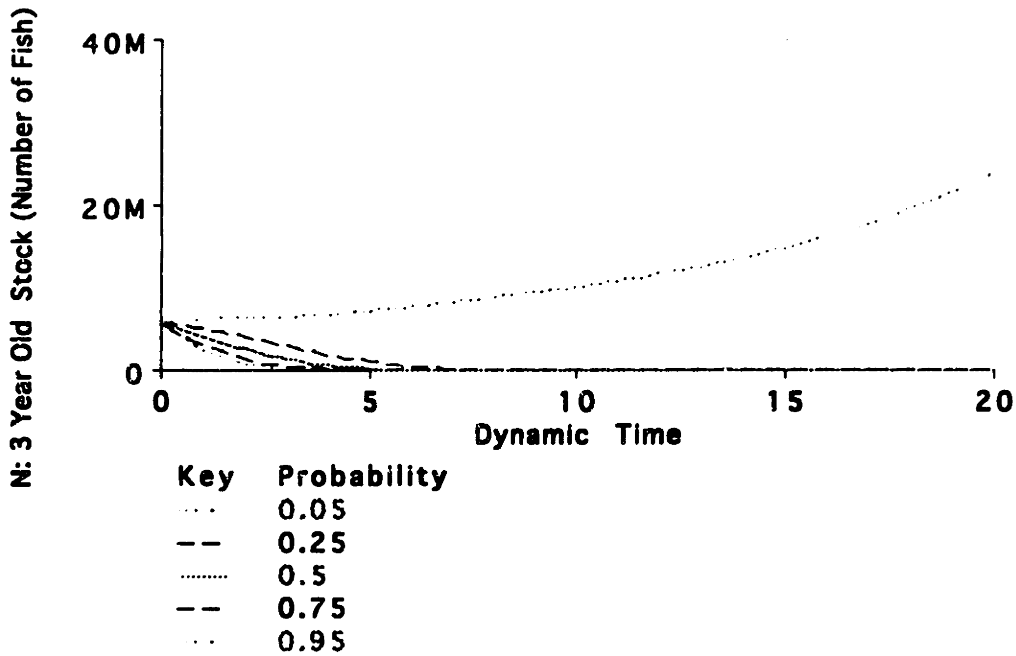
6.0	9.5384e+5	1.3123e+6	6.4590e+5	3.0713e+4
	7.9378e+5	1.1322e+6	5.7528e+5	2.4571e+4
	6.5960e+5	9.7430e+5	5.1075e+5	1.9656e+4
	5.4733e+5	8.3639e+5	4.5208e+5	1.5725e+4
	4.5359e+5	7.1637e+5	3.9899e+5	1.2580e+4
7.0	3.7545e+5	6.1226e+5	3.5116e+5	1.0064e+4
	3.1043e+5	5.2223e+5	3.0825e+5	8.0513e+3
	2.5639e+5	4.4458e+5	2.6991e+5	6.4410e+3
	2.1156e+5	3.7780e+5	2.3576e+5	5.1528e+3
	1.7440e+5	3.2051e+5	2.0547e+5	4.1223e+3
8.0	1.4364e+5	2.7147e+5	1.7868e+5	3.2978e+3
	1.1821e+5	2.2957e+5	1.5506e+5	2.6382e+3
	9.7206e+4	1.9387e+5	1.3429e+5	2.1106e+3
	7.9875e+4	1.6349e+5	1.1608e+5	1.6885e+3
	6.5589e+4	1.3769e+5	1.0016e+5	1.3508e+3
9.0	5.3822e+4	1.1581e+5	8.6275e+4	1.0806e+3
	4.4138e+4	9.7296e+4	7.4188e+4	8.6450e+2
	3.6175e+4	8.1648e+4	6.3693e+4	6.9160e+2
	2.9632e+4	6.8442e+4	5.4598e+4	5.5328e+2
	2.4259e+4	5.7312e+4	4.6732e+4	4.4262e+2
10.0	1.9849e+4	4.7944e+4	3.9944e+4	3.5410e+2
	1.6234e+4	4.0069e+4	3.4094e+4	2.8328e+2
	1.3270e+4	3.3457e+4	2.9064e+4	2.2662e+2
	1.0843e+4	2.7911e+4	2.4744e+4	1.8130e+2
	8.8555e+3	2.3265e+4	2.1041e+4	1.4504e+2
11.0	7.2295e+3	1.9377e+4	1.7871e+4	1.1603e+2
	5.8996e+3	1.6126e+4	1.5161e+4	9.2825e+1
	4.8125e+3	1.3410e+4	1.2849e+4	7.4260e+1
	3.9243e+3	1.1143e+4	1.0877e+4	5.9408e+1
	3.1988e+3	9.2536e+3	9.1992e+3	4.7526e+1
12.0	2.6066e+3	7.6790e+3	7.7723e+3	3.8021e+1
	2.1233e+3	6.3683e+3	6.5605e+3	3.0417e+1
	1.7290e+3	5.2780e+3	5.5326e+3	2.4334e+1
	1.4076e+3	4.3717e+3	4.6616e+3	1.9467e+1
	1.1455e+3	3.6189e+3	3.9244e+3	1.5573e+1
13.0	9.3199e+2	2.9940e+3	3.3010e+3	1.2459e+1
	7.5805e+2	2.4757e+3	2.7744e+3	9.9670e+0
	6.1641e+2	2.0460e+3	2.3300e+3	7.9736e+0
	5.0110e+2	1.6900e+3	1.9553e+3	6.3789e+0
	4.0726e+2	1.3953e+3	1.6397e+3	5.1031e+0
14.0	3.3091e+2	1.1514e+3	1.3740e+3	4.0825e+0
	2.6881e+2	9.4968e+2	1.1506e+3	3.2660e+0
	2.1831e+2	7.8295e+2	9.6285e+2	2.6128e+0
	1.7726e+2	6.4521e+2	8.0522e+2	2.0902e+0
	1.4390e+2	5.3147e+2	6.7297e+2	1.6722e+0
15.0	1.1679e+2	4.3760e+2	5.6209e+2	1.3377e+0
	9.4773e+1	3.6017e+2	4.6920e+2	1.0702e+0
	7.6888e+1	2.9632e+2	3.9143e+2	8.5616e-1
	6.2367e+1	2.4369e+2	3.2637e+2	6.8493e-1
	5.0578e+1	2.0034e+2	2.7197e+2	5.4794e-1
16.0	4.1011e+1	1.6464e+2	2.2652e+2	4.3835e-1
	3.3247e+1	1.3525e+2	1.8856e+2	3.5068e-1
	2.6948e+1	1.1107e+2	1.5688e+2	2.8055e-1
	2.1839e+1	9.1184e+1	1.3046e+2	2.2444e-1

	1.7696e+1	7.4833e+1	1.0844e+2	1.7955e-1
17.0	1.4336e+1	6.1394e+1	9.0092e+1	1.4364e-1
	1.1613e+1	5.0353e+1	7.4814e+1	1.1491e-1
	9.4049e+0	4.1285e+1	6.2098e+1	9.1929e-2
	7.6159e+0	3.3840e+1	5.1521e+1	7.3544e-2
	6.1663e+0	2.7730e+1	4.2727e+1	5.8835e-2
18.0	4.9918e+0	2.2716e+1	3.5419e+1	4.7068e-2
	4.0405e+0	1.8604e+1	2.9349e+1	3.7654e-2
	3.2701e+0	1.5232e+1	2.4309e+1	3.0123e-2
	2.6462e+0	1.2468e+1	2.0127e+1	2.4099e-2
	2.1411e+0	1.0203e+1	1.6658e+1	1.9279e-2
19.0	1.7321e+0	8.3472e+0	1.3782e+1	1.5423e-2
	1.4011e+0	6.8273e+0	1.1398e+1	1.2339e-2
	1.1332e+0	5.5828e+0	9.4230e+0	9.8708e-3
	9.1646e-1	4.5641e+0	7.7876e+0	7.8967e-3
	7.4106e-1	3.7304e+0	6.4337e+0	6.3173e-3
20.0	5.9917e-1	3.0483e+0	5.3135e+0	5.0539e-3

These are not the same as the Systems Dynamics predictions, but they are close. The largest difference is attributable to the first year. Systems Dynamics starts calculating the next values of Stocks, flows and converters in Year 1, while Demos calculates the next values in Year 0.2. It is helpful to compare the results from the two models to see the way the two software packages calculate the values.

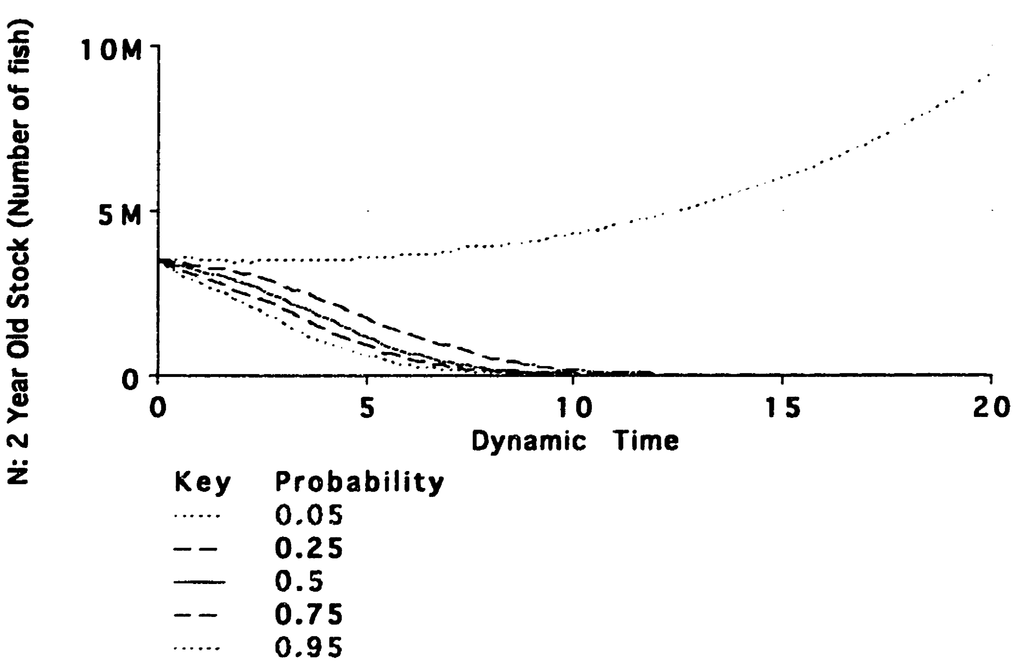
3. Modeling with Uncertainty

Rather than running many trials as with a Simulation model, it is easier to use Demos uncertainty analysis. Using Demos' Probability Distribution function, with a Dt = 0.2 and a Reproduction rate = 5, Demos' uncertainty analysis calculates:



Demos shows that there is more than a 75% chance that the Stock of 3 year olds will crash. Even with the uncertainty in the model, one can be quite sure that the Stocks will crash if the Reproduction Rate is as low as 5 larvae per adult fish (~10 larvae per adult female fish.) At a 75% level of certainty, the Stock of 3 year olds crash at about Year 7, and a 50% level of certainty that the Stock will crash earlier, by about Year 5.

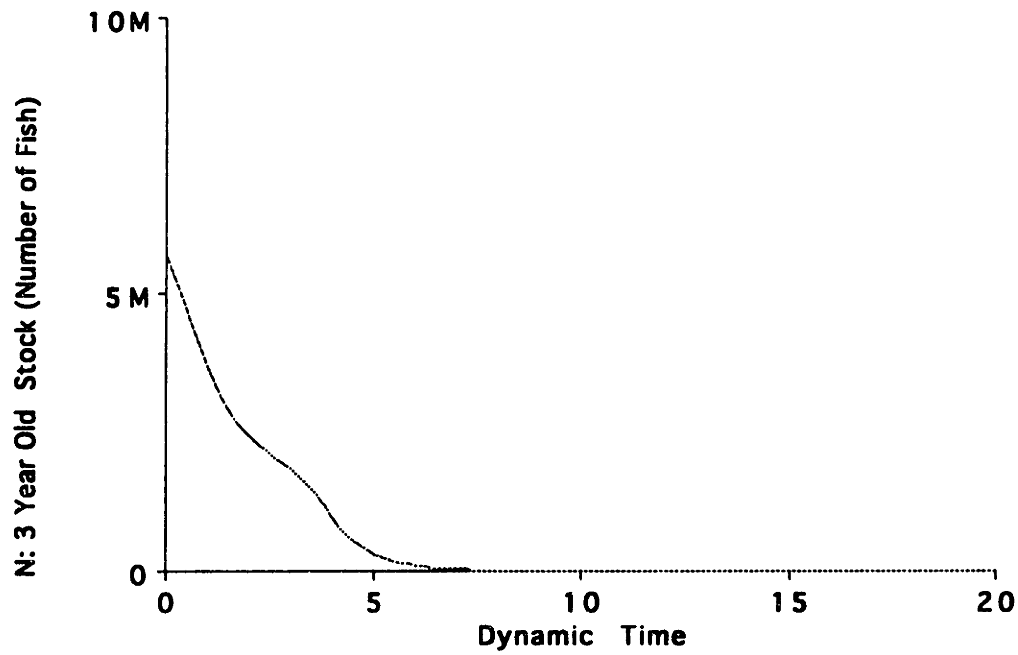
Looking at the Stock of 2 year olds:



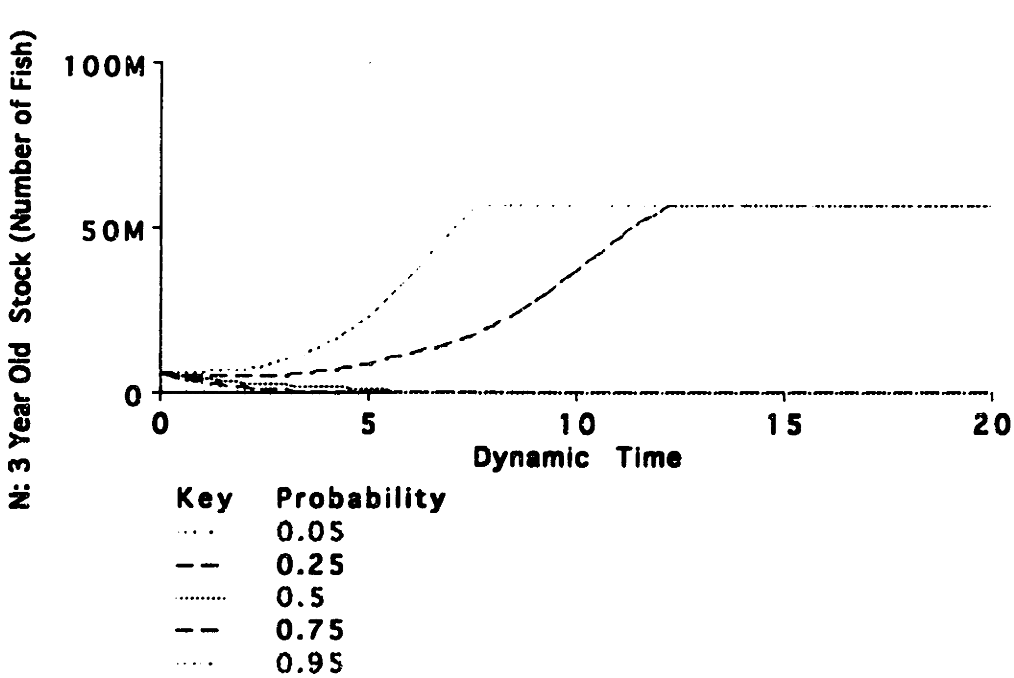
There is a 75% chance that the Stock of 2 year olds will crash by year 13 and a 50% chance that the Stock will crash before year 10.

4. Reproduction Rate

Using a Reproduction Rate of 16.5, the mid- value (deterministic) of the N3 Stock is as follows:

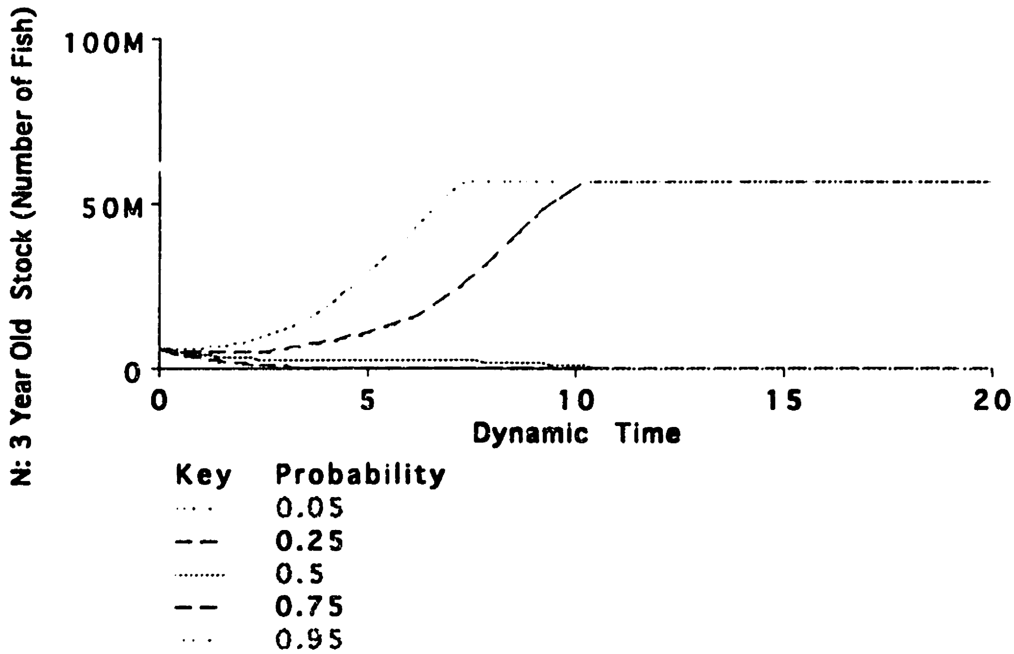


The next question is if the uncertainty of all the variables is taken into consideration, what is the likelihood that the Stock will crash?



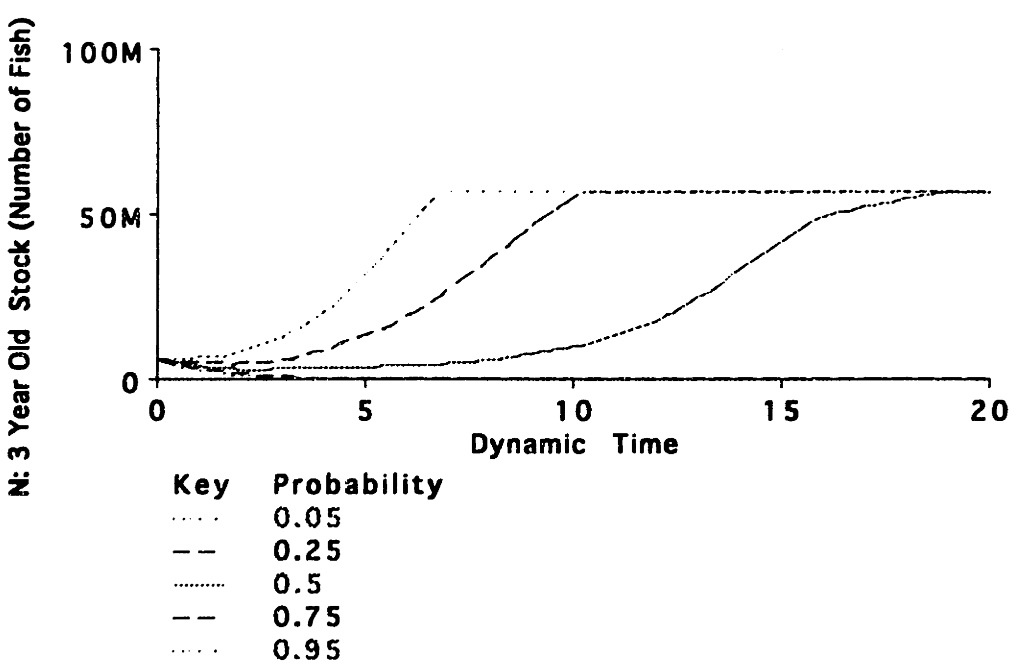
If the Reproduction Rate is 16.5, the probability that the Stocks will crash is somewhere between 50% and 75%. As one can see, the Stock of 3 year olds will reach its maximum at about 57M fish. This represents the Habitat's Holding Capacity, an upper limit on the number of fish that can exist within a fixed area. This is set, largely as an estimated guess, at ten times the 1984 estimate for the Stock of Red Snapper in the Gulf.

At what Reproduction rate do the Stocks increase with at least a 50% chance? By doing parametric sensitivity analysis with the Reproduction Rate, one can determine this. Using a Reproduction rate = 22:



With a Reproduction Rate of 22, there is a 50% chance that the Stock will crash in about 15 years. The Reproduction rate may be a little higher than 22, because the Stocks did not crash in the late 1980's or early 1990's.

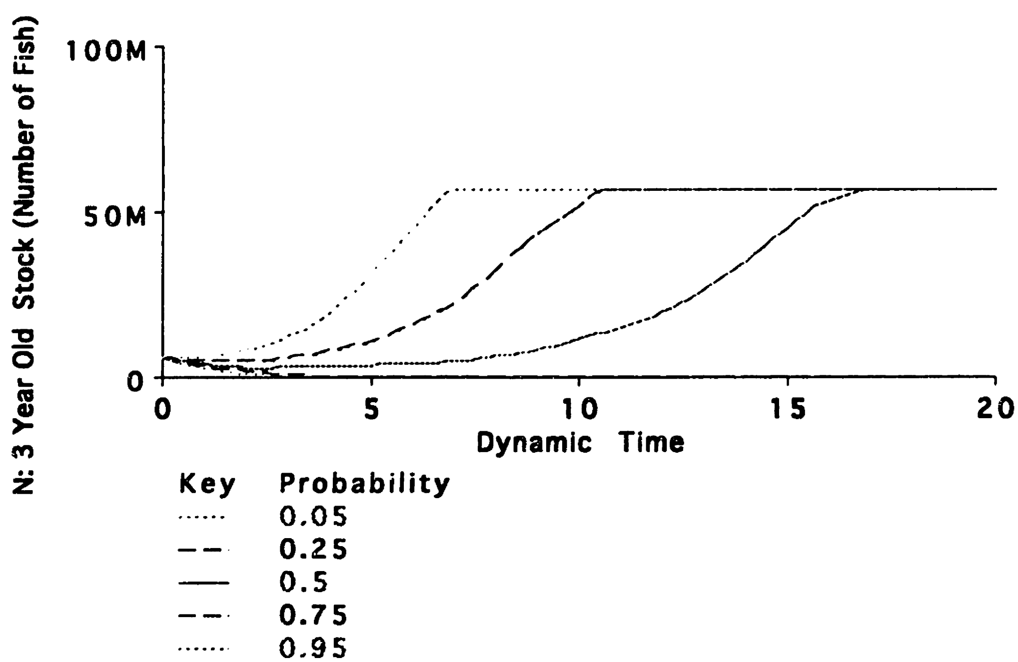
With a Reproduction Rate of 23 and a standard deviation of 7, the distribution is:



There is a little more than a 50% probability that the Stocks will *not* crash with a Reproduction Rate of 23. Note, when Reproduction rate was changed from 22 to 23 in Demos, the probability distribution shifted from more than 50% probability of crashing to less than a 50% of crashing. This change using Demos, moving from 22 to 23, is very close to the change when using Systems Dynamics, between 24 and 25. Using Demos can help validate what was learned when using the SD model.

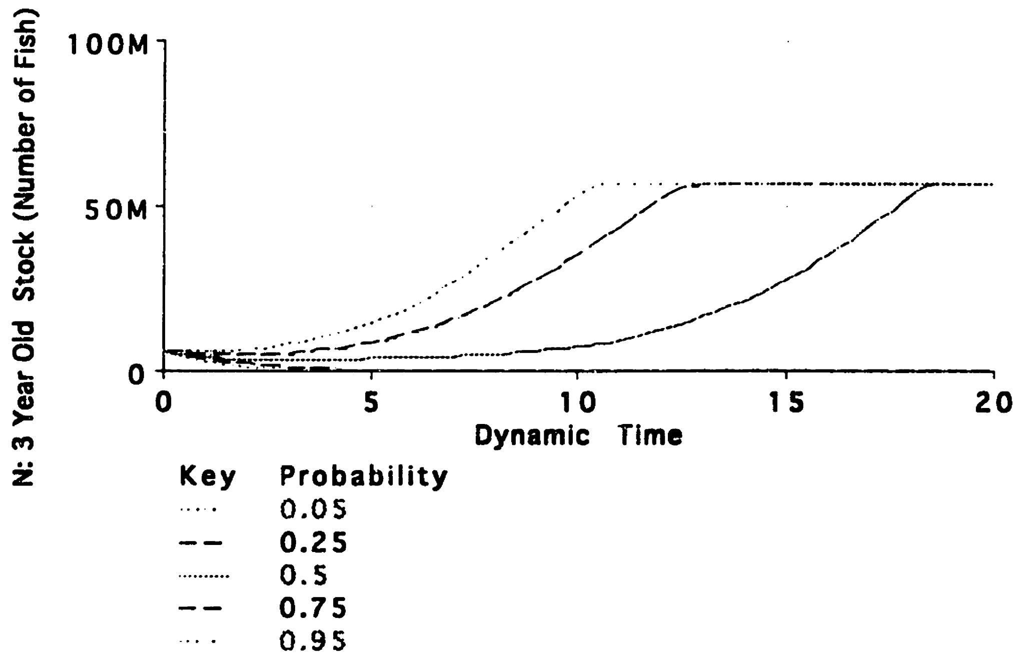
5. Catch Limits

Going back to the Reproduction Rate = 22, when the Stocks crashed with more than a 50% probability, the Catch Limits will be installed to see if they change the probability distribution. Installing the Commercial Catch Limits in 1990, and the Recreational Catch Limits in 1992, the model will be run to see if the Stocks survive with the Reproduction rate = 22.



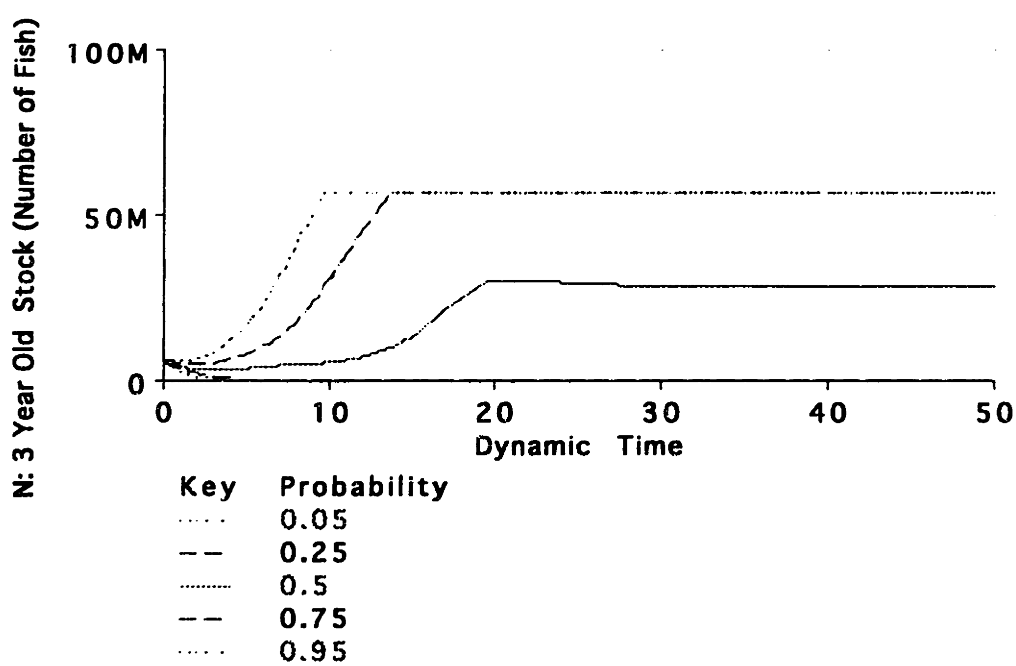
With the Catch Limits installed in 1990 and 1992, there is less than a 50% probability that the Stocks will crash. The Catch Limits do help, but it would be informative to know how low the Reproduction Rates could be and have the Catch Limits still help.

Using a Reproduction rate =20, the distribution is as follows:



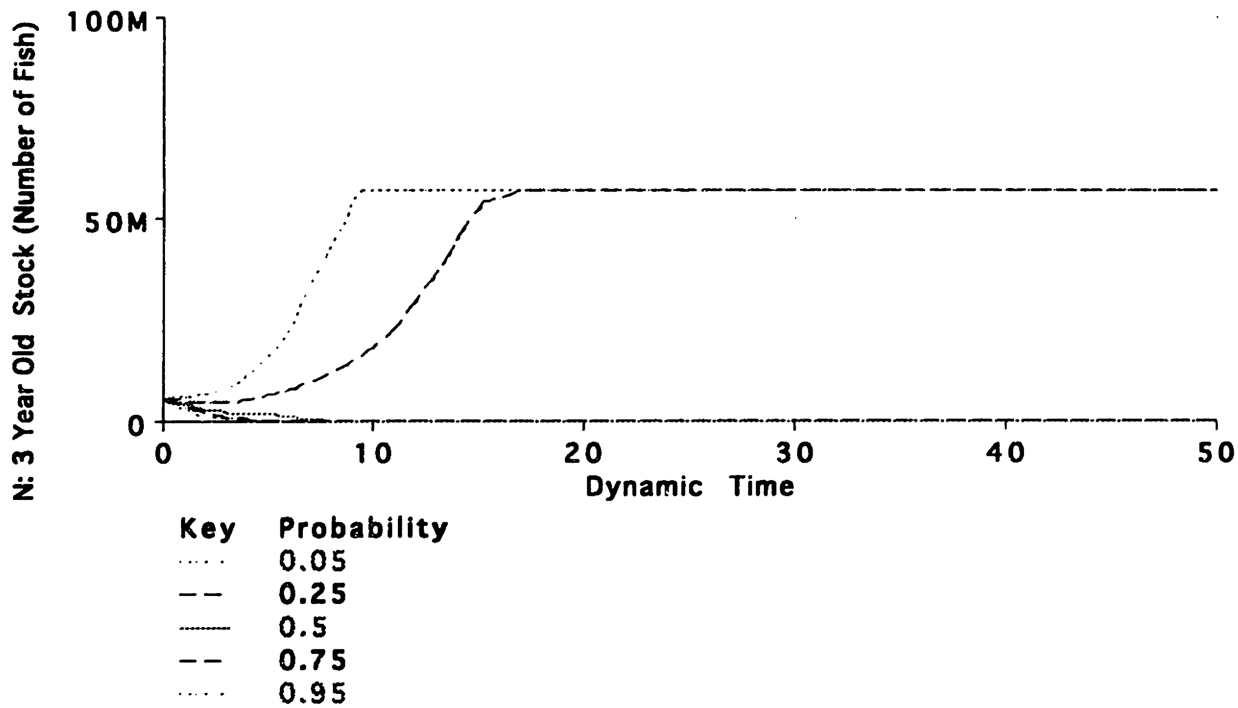
Moving to a Reproduction Rate of 20, the probability density shifts, but it is still more than 50% probable that the Stock will not crash.

Using a Reproduction rate = 19, and a 50 year time frame, one can see how Catch Limits affect the Stock.



With the low Reproduction Rate = 19, the Stocks seem to be crashing, but then rebound due to the Catch Limits. The longer 50 year time frame shows how the Stocks do come back over a longer period of time.

With a Reproduction rate = 18, the Stocks do not rebound, but crash with more than a 50% probability, even when Catch Limits exist.



6. Increased Fishing Efforts

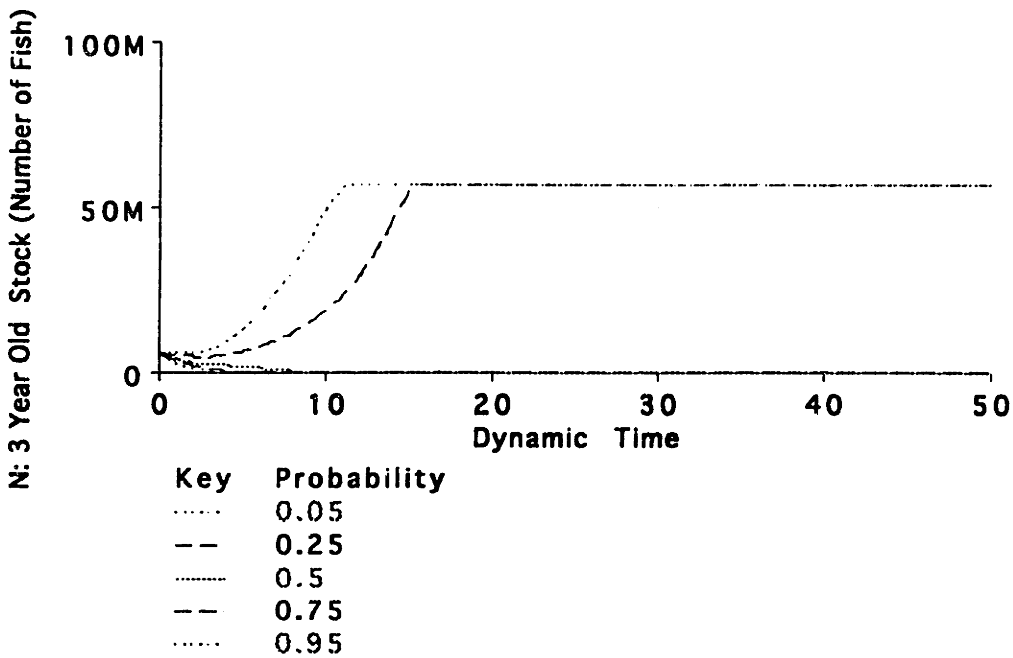
Although the Demos model accounts for variations in the Fishing Efforts because, is described as a distribution, the mean of the distribution may be very different. The Non-Directed Commercial Fishing Efforts used below were the 1990 low rates = 6000. It would be more accurate to use the average of the available data, that is the average of the 1990-1992 rate = 13,000. It is possible that the Non Directed Commercial Fishing Efforts were grossly under-reported just as the Directed Commercial Fishing Efforts were under-reported. The Non-Directed reported rates will be increased by 400% , just as the Directed rates were increased in the Goodyear paper,

Using:

the mean of the Non-Directed Commercial Fishing Effort = 52,000 and

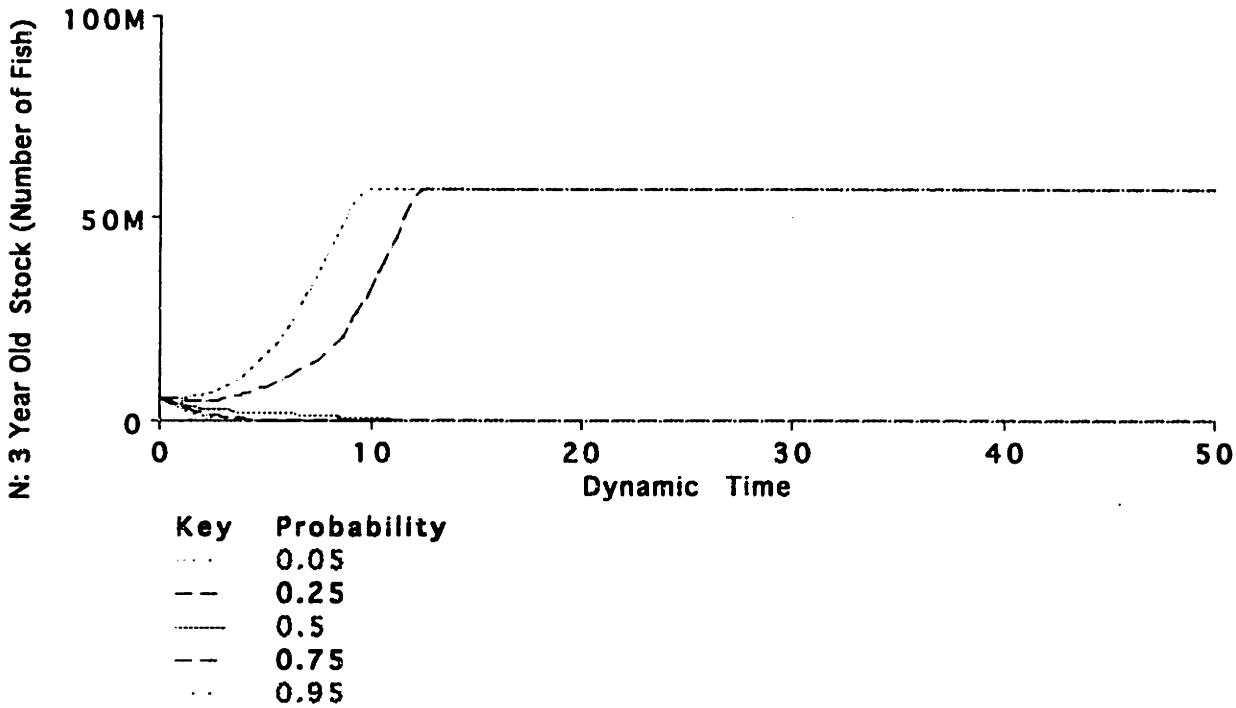
Reproduction Rate =19,

one can determine if the Catch Limits can still prevent the Stocks from crashing.

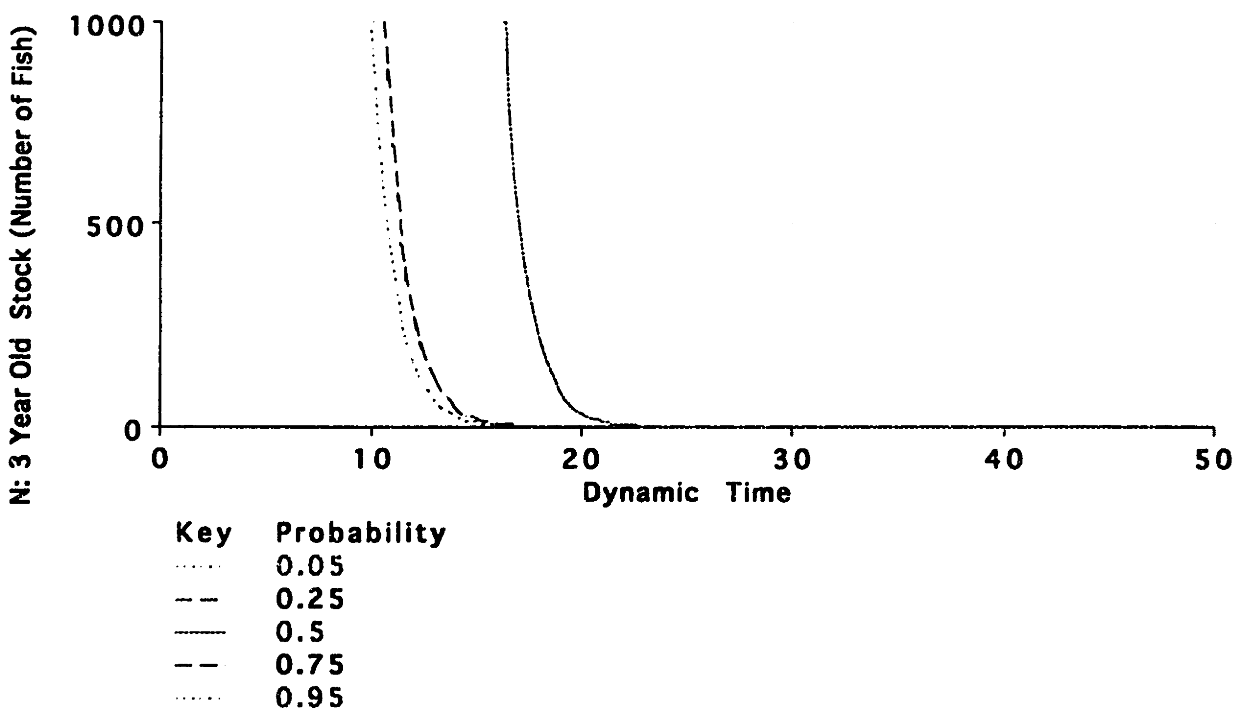


If the Commercial Fishing Efforts are higher than the low 1990 reported figure, and the Reproduction Rate = 23, then the Catch Limits may not save the Stocks with more than a 50% chance.

Changing the Reproduction Rate = 24.

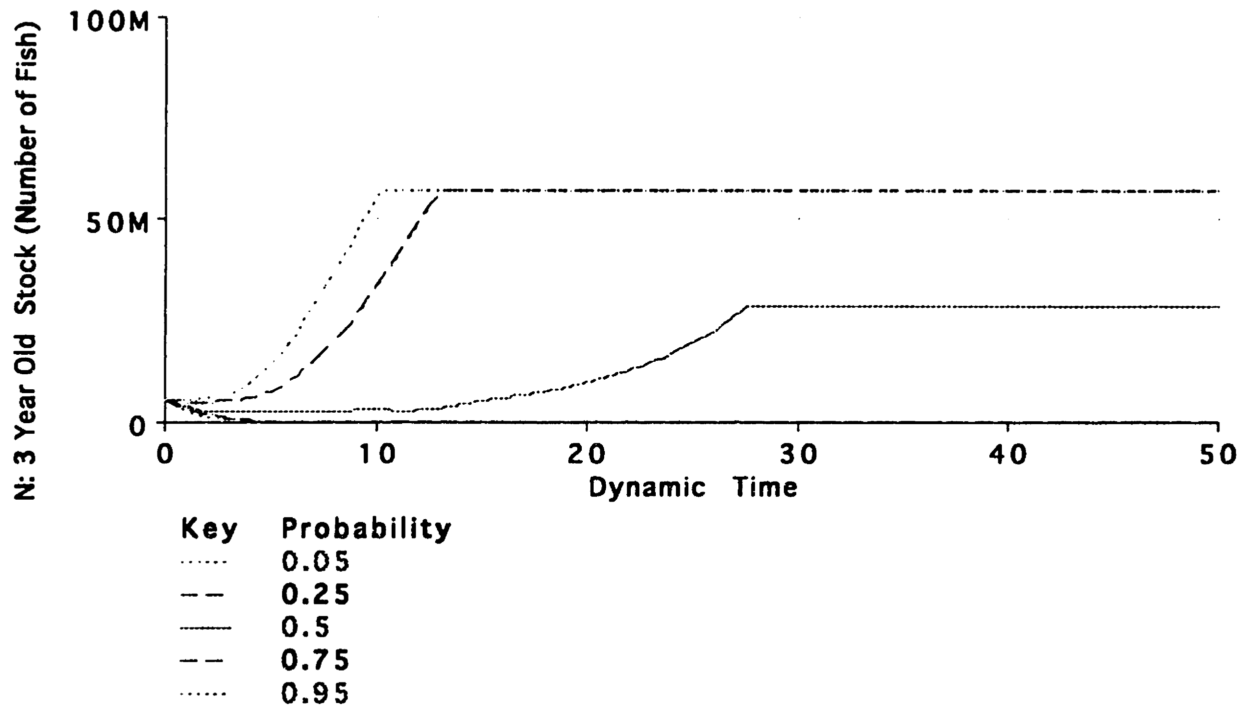


Changing the scale on the y-axis to see if the Stock increases to even a small degree, one can see:



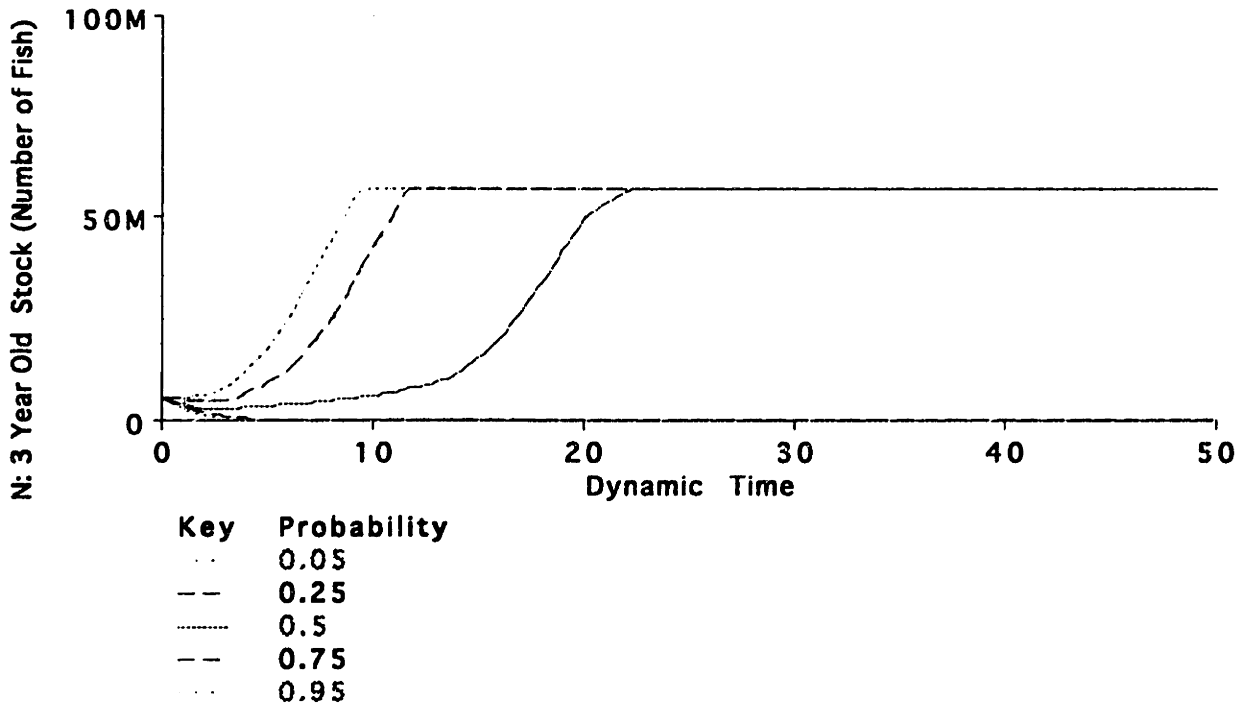
Even with a Reproduction rate = 24, the Catch Limits do not help the Stock of N3 fish enough so that the probability of a crash is less than 50%.

Using a Reproduction Rate = 25



With the higher Non-Directed Commercial Fishing Efforts, it is necessary that the Reproduction Rate = 25 before the Catch Limits can help the Stock Replenish. The Stock rebounds. The Stock of N3 fish decreased, but are replenished by the Stock of N2 fish after the Catch Limits go into affect. The Stock of 3 & up year old fish grow from two year fish, and are therefore limited by the Habitat's Holding Capacity for the N2 fish. This number is assumed to be smaller than the N3 & up Habitat Holding Capacity, since N2 is only one age group, but N3 & up are many age groups combined.

Checking the results with a Reproduction Rate = 26



If the Reproduction Rate is the high of 26, then the Stock of N3 fish never crashes with a 50% probability.

7. Replenishment Zones

Creating the Replenishment Zones , one can determine if they will make a difference.

Using the same:

Reproduction Rate outside the Zone = 24

Reproduction Rate inside the Zone = 24

Recreational Catch Limits installed in 1990 =~ 1,000,000 fish

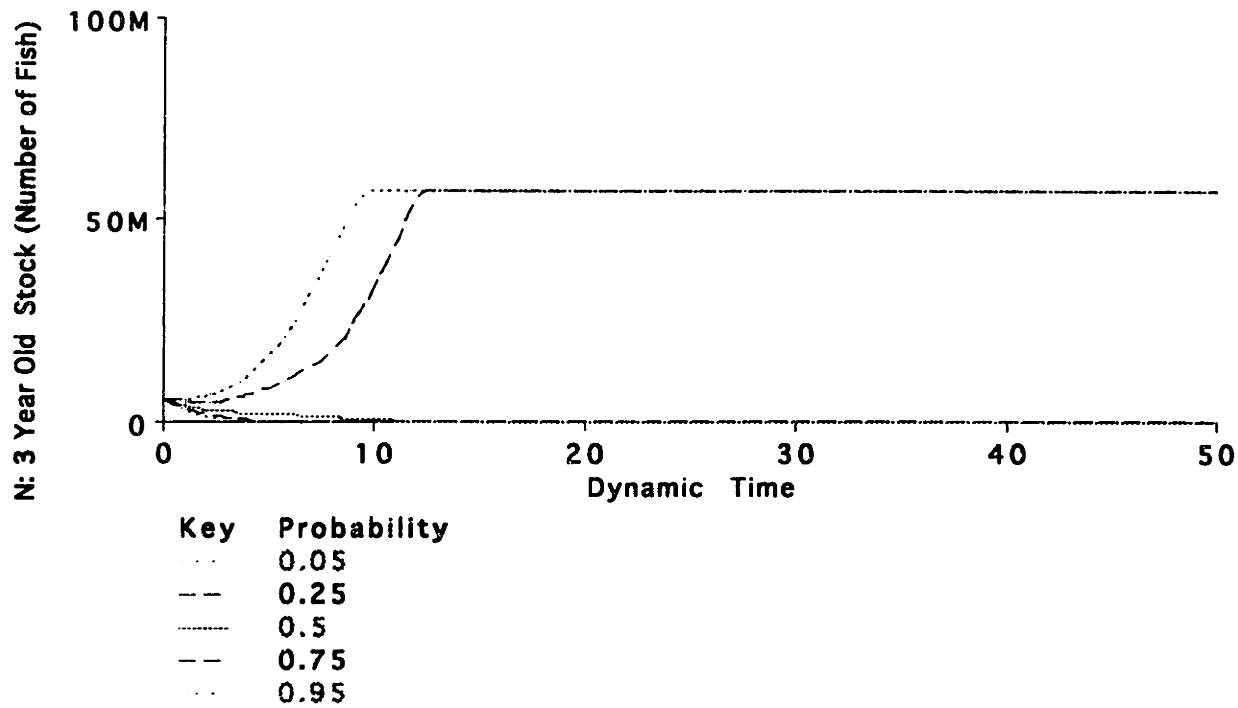
Commercial Catch Limits installed in 1990 =~ 1,000,000 fish

Non-Directed Fishing Effort at its estimated 1990-1992 average = 52,000

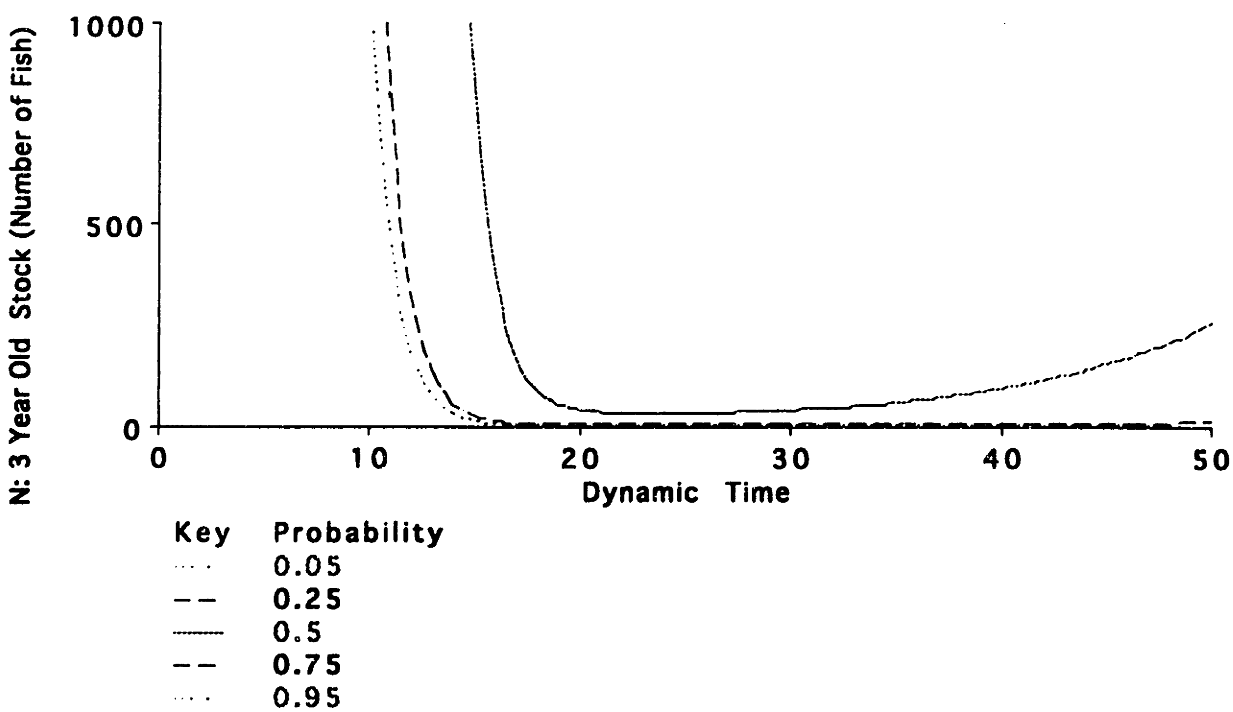
and creating the Zone so that:

Along Current Length = 12.25 miles

Across Current Width = 12.25 miles, for a total area = 150 sq. miles

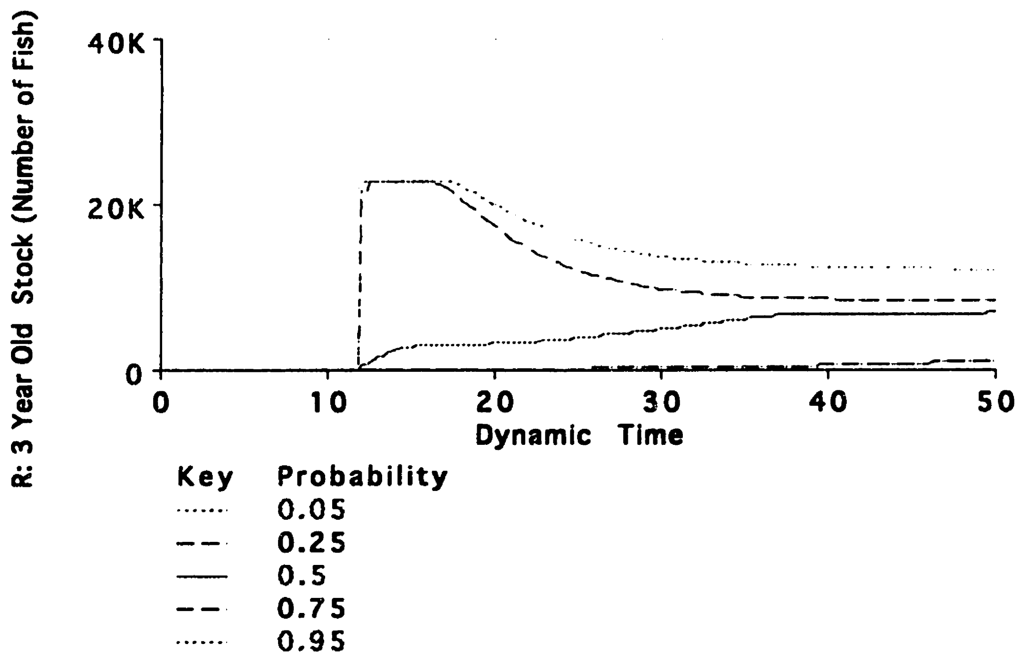


Using information learned from Systems Dynamics, it may be that Stock do come back but just on smaller scale. Using the same information above, just changing the scale of the y-axis, one can see:



The Zone does help the Stock come back, but on a very small scale with the parameters above. It is more than 50% probability that the Stocks will decrease to less than 100 fish around Year 20, then start to increase in number. By Year 50, there is more than a 50% probability that the N3 Stock will reach 250 fish.

It is also informative to look at the Stock of 3 year olds & up *inside* the Replenishment Zone to see if any fish exist after the Zone is created. Again using the same parameters as above:

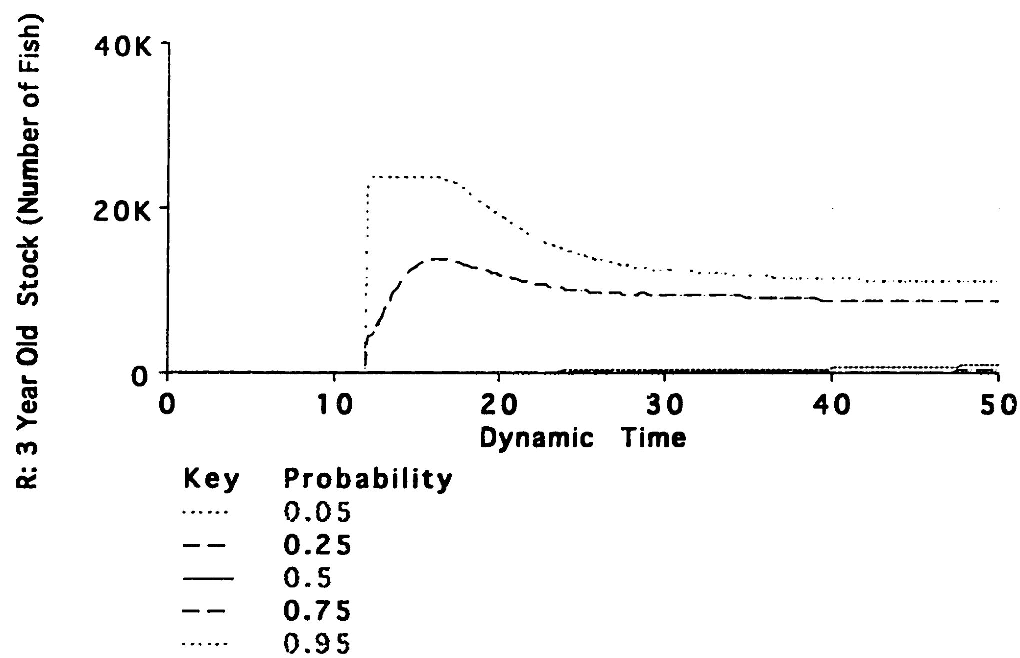


Looking at the Stock of Replenishment Zone fish 3 years old and up, one can see that the Zones do help. With a 75% probability, the fish do come back. With a 50% probability, one can see the Stocks come back in almost no time, but the graph shows that it may take 15 + years to ensure that the Stocks come back with more than a 75% probability.

The upper 5% and 25% lines are the cases where the Stocks never crashed outside the Zone. If the N3 Stock never crashed, then the Zone will start out with a healthy population. The population will only be restricted by the Zones' Habitat holding capacity for N3 & up fish, which is the (5.7M * 10 * Zone Size / 375K) = 22.8 K. If the N3 Stock outside the Zone did crash, then the R3 Stocks will have to be replenished entirely from within the Zone, growing from R2 fish, and being limited by the Zones' Habitat for R2 fish (fish from only one age group R3 as opposed to 3 & up, many age groups.) This is the (3.5M * 10 * Zone Size / 375K) = 14K limit.

The Zone is modeled such that fish will only migrate out of the Zone, because it was assumed that the density of fish inside the Zone would be higher than fish inside the Zone. Of course this is not 100% accurate, since if the fish were dense inside and outside the Zone, the 5% and 25% lines, then fish would be likely to migrate into the Zone, not just migrate out. The way the system is modeled, though, explains why the 5% and 25% probability lines merge towards the lower 14K number, because it is assumed that the R3 Stocks are only being fed from R2 fish, not from fish migrating in from outside the Zone.

Using a Reproduction Rate = 18, the rate at which the Catch Limits could not save the Stock, even with the Low Fishing Efforts, one can see if the Zones help the Stock of replenish.



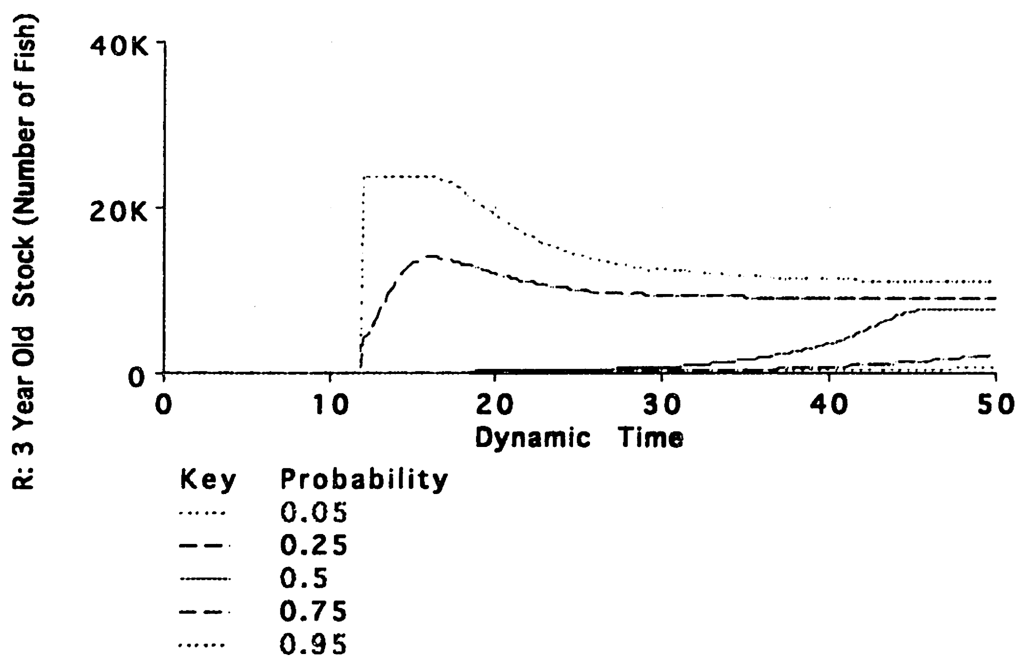
It is possible to see that around year 24, 12 years after the Zones are created, it is more than 50% probability that the R3 fish will come back. After year 47, it is more than 75% probable that the Stocks will replenish.

8. Reproduction inside the Zone increases

What if the R Reproduction rate of the fish inside the Zone actually increases, as most scientist predict, since there would be a larger number of fish over 3 years old. Using the same numbers as above, but with a

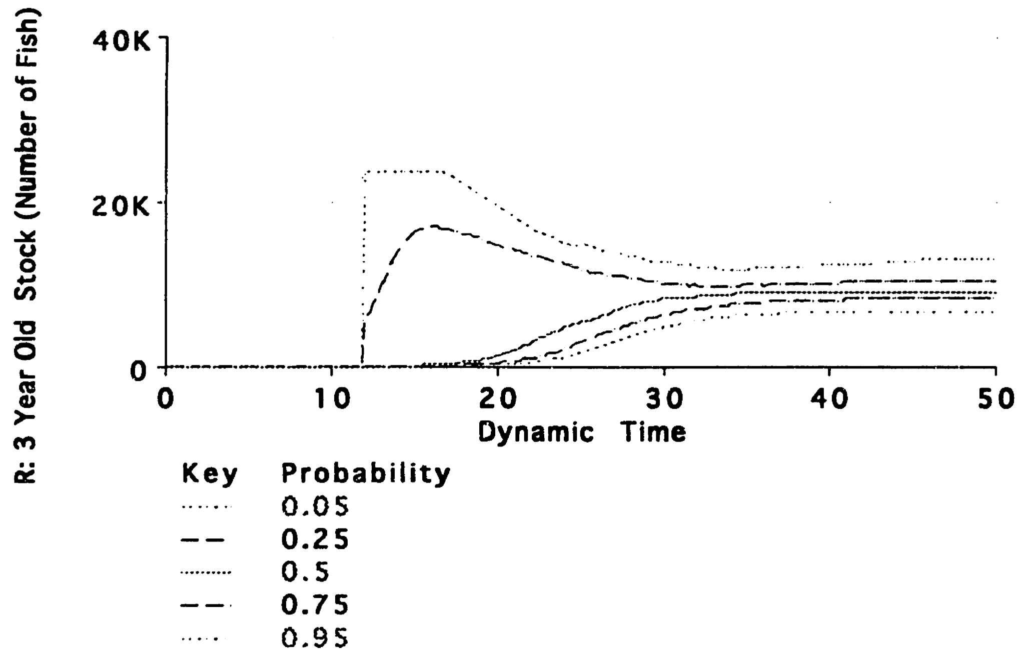
Reproduction rate outside Zone = 18

Reproduction rate inside the Zone = 36



Looking at the Stock of R3 fish inside the Zone, one can see that the Stocks are Replenished with a 95% probability, even when the Reproduction Rate is as low as 18 outside the Zone and 36 inside the Zone. This shows that the greater the Reproduction Rate inside the Zone , the Replenishment Zone does help the Stocks come back quicker and with higher probability. It is more than 95% certain that the Stocks will be replenished in Zones are created, and the Reproduction rate inside the Zone is just twice as high as outside the Zone.

If the Reproduction rate inside the Zone increased not just by two times, but by 10 times, as many scientist predict, the probability that the Zone will replenish the Stocks will only increase further. Many scientist predict that the Reproduction rate inside the Zone could easily be 10 times higher than outside the Zone, since the older fish inside the Zone have a much higher Reproduction Rate than young 3 year old fish. Using a Reproduction Rate = 18 outside the Zone and a Reproduction Rate = 180 inside the Zone, one sees:



If the Zones are created in Year 12, in 1996, and the Reproduction Rate of fish within the Zone increases by a factor of 10, then it is more than *95%* probable that the Stock of Fish in the Zones will be replenished. With a 50% probability the results will start to be seen after five years. The 75% and 95% likelihood of replenishment may take more like 10-15 years to see the results.

9. Re-orient the Zone

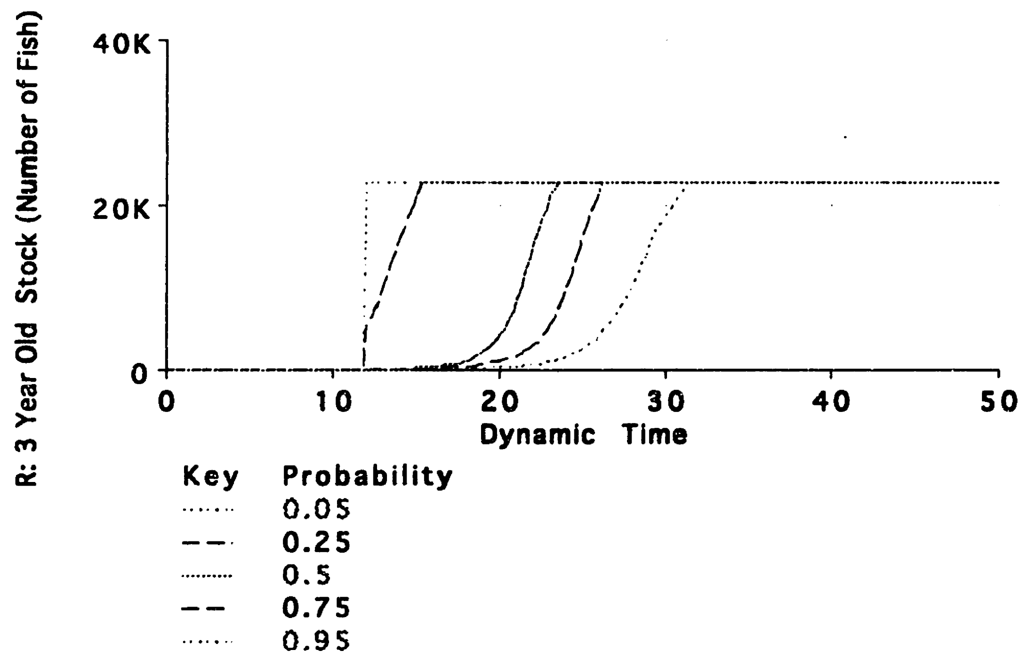
What if the Zone were re-oriented so that the cross current distance of the Zone was double, but the total area remained the same. Going back, if the

Reproduction rate = 36 outside the Zone, and the

Reproduction Rate = 18 inside the Zone, but the

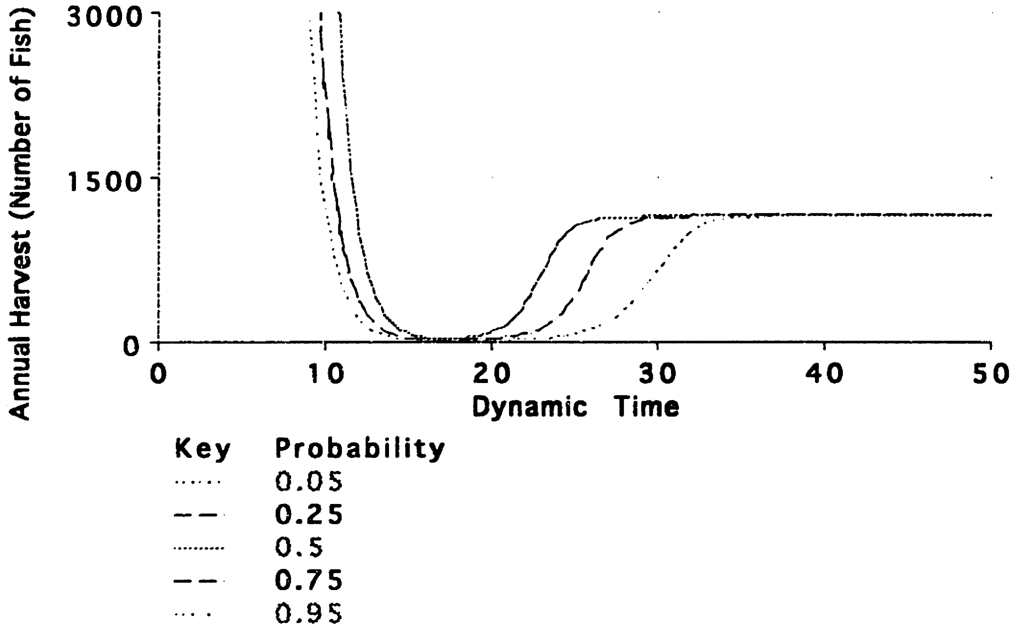
Along Current Length = 50 and the

Across Current Width = 3, then:



The Stock is replenished with more than a 95% probability and is replenished faster. More larvae are staying in the Zone, so the fish are being replenished at a faster rate. This results in the total number of R3 Stock being higher, constrained by the Habitat's Holding Capacity of R3 & up year olds, not as much by the Habitat's R2 Stock Holding Capacity. The Demos model is written such that the Stock of an age group is either constrained by its own Habitat Limits or by the Habitat Limits of the Stock that feeds it. Since replenishment is happening at a faster rate, the Stock of N3 year old & ups is constrained more by the Habitat's holding capacity for N3 fish more so than the annual recruitment of N2 year old fish. The N3 fish Stock of fish are more abundant with the Zone being re-oriented so that fewer larvae drift out.

This would result in an increased Annual Harvest. Changing the scale on the Annual Harvest to better see the results:



The Annual Harvest increases by about 5% of the R3 Stock since that is the mean of the Migration Rate. The N3 Stock is 22K and the Migration rate 5%, so there is more than a 95% chance that the Annual Harvest would increase by at least 1K.

10. Making a bigger Zone

If the Zones were twice as large, would the N3 Stocks be affected?

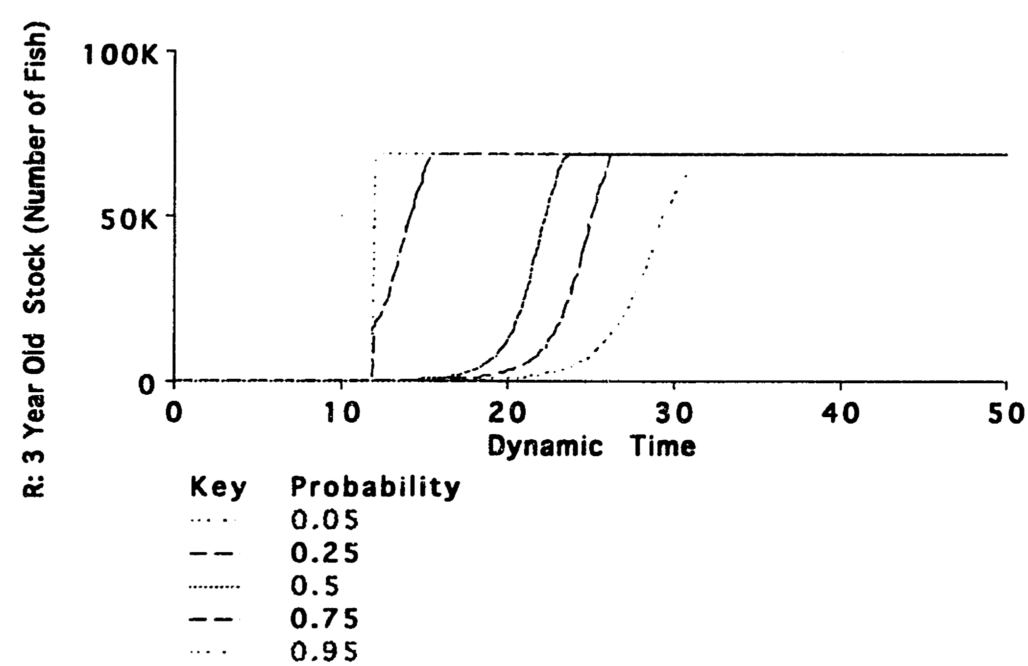
Along Current Length = 150

Across Current Width = 3, and

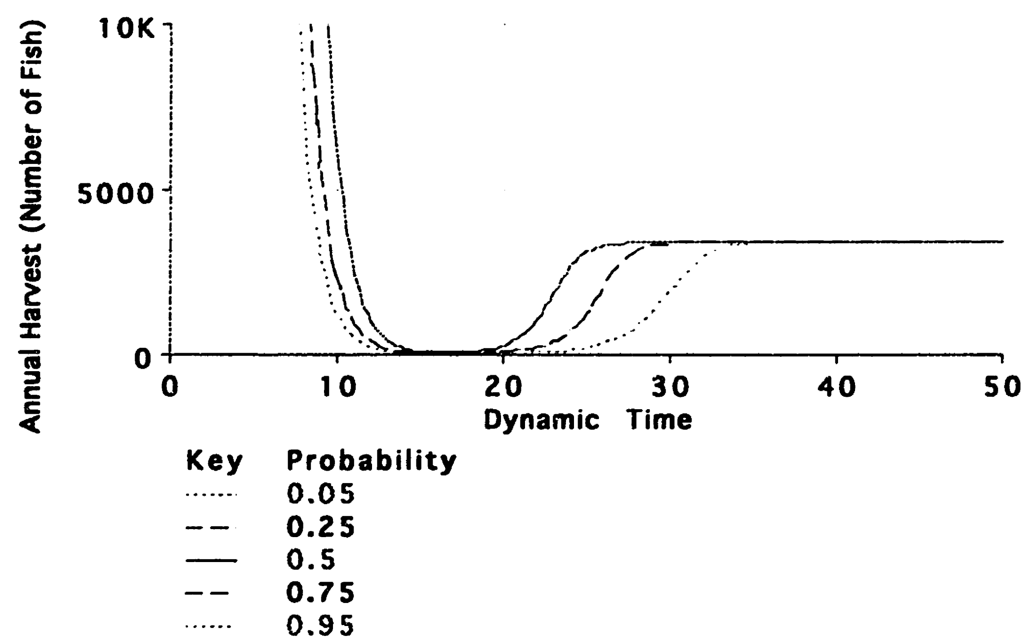
Total area is larger = 300.

Reproduction Rate = 18 outside the Zone

Reproduction Rate = 36 inside the Zone:

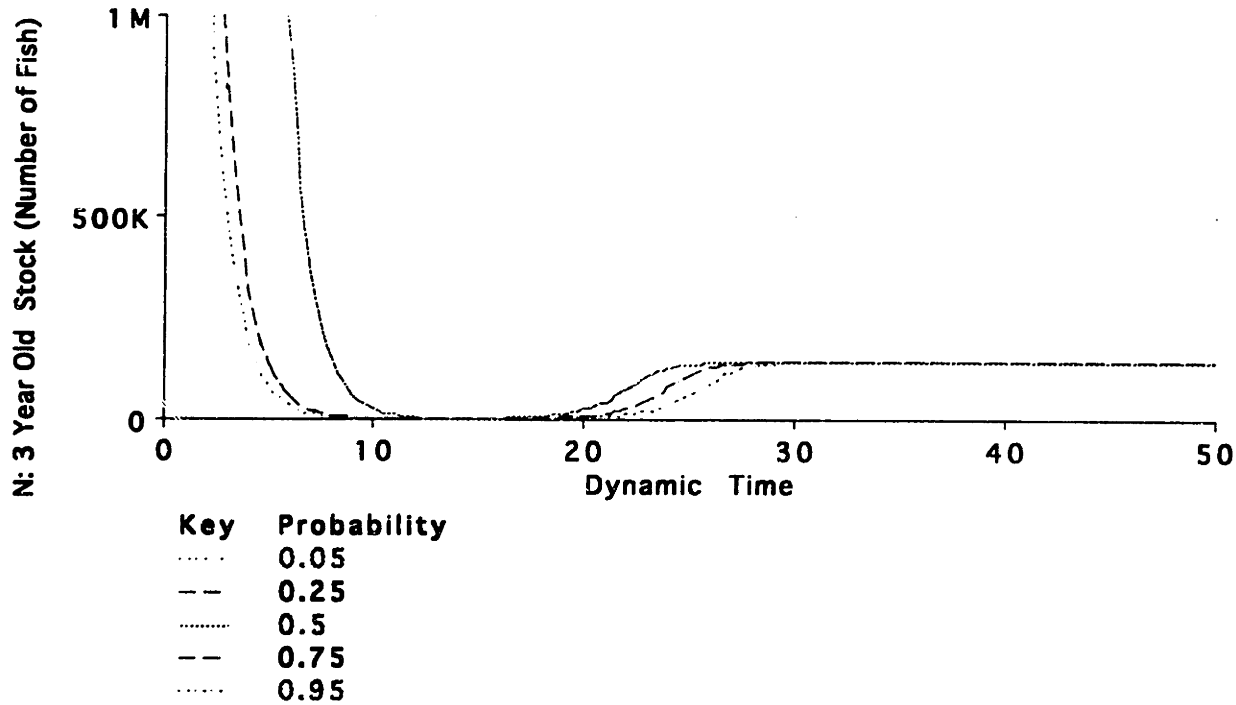


The larger Zones do help. By making the total Zoned Habitat larger, the total holding capacity increased by a factor of 3, from 22.8K to 68.4K. This would increase the Annual Harvest by about 5% of this 68K, by more than 3K.



What if instead of just the FKNM S Sanctuary designated 5% of its waters to Replenishment Zones, 5% of the total Gulf of Mexico fishing area was designated as a

Replenishment Zone? Changing the total Replenishment Zone Size = 18,750 square miles, then the Stock of Red Snapper fish would be as follows:



The Annual Harvest would for the total Gulf would be at least 150K with more than 95% probability.

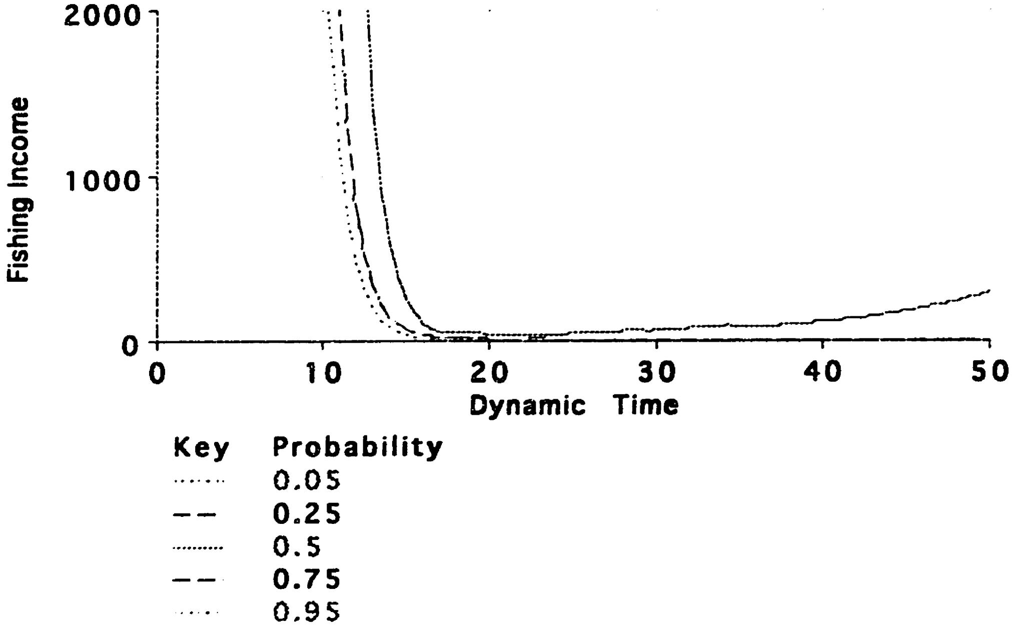
Income

Reproduction inside = 36

outside = 18

Along Current = 50

Across Current = 3


2000
1000
0
Fishing Income
0
10
20
30
40
50
Dynamic Time
Key Probability
0.05
0.25
0.5
0.75
0.95

Appendix XII- A: AHP Mathematics

To explain the mathematics of the AHP model, it is easiest to use a simplified model. In this example, the AHP model was built to decide on the best size for the Dry Tortugas Replenishment Zone in the FKNMS.

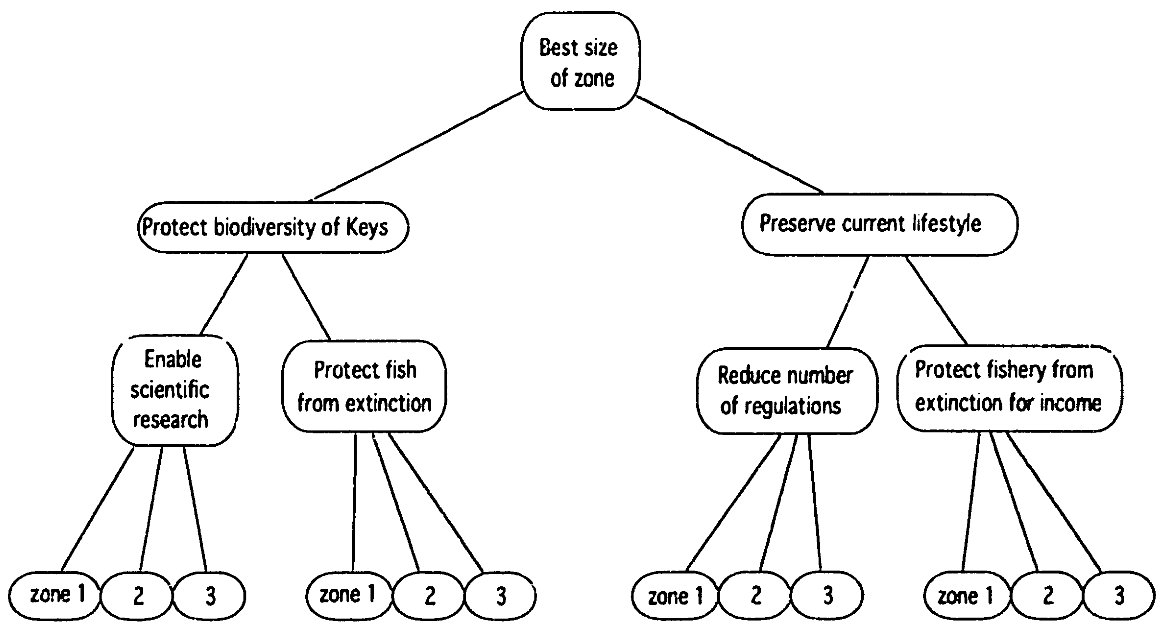


Figure 1: An Example of the Expert Choice Representation of a Hierarchy.

In Figure 1 there is a simple hierarchy including the goal at Level 1, the objectives at Level 2,[26] criteria in Level 3 and different Zone alternatives in Level 4. This simple model is far from representing an AHP model for Replenishment Zones, but will be used for illustrative purposes. Note that some variables are used more than once (such as protecting fish species from extinction and the Zone alternatives), and some variables may only be part of one branch (such as reduce number of regulations or enable scientific research). That is, not every criteria or sub-criteria affects each objective.

After the hierarchy is developed, relative weights, or priorities are entered for each variable. Starting with the alternatives in Level 4, the priorities are derived by comparing

[26] Note that Level 2 is not the list of many decision makers, since there would be only one decision maker in this example.

each alternative pair-wise to every other alternative, with respect to each criteria in Level 3. (It is usually better to keep the number of objectives in any level to eight or less, since the pair-wise comparisons are more accurate when there are fewer objectives.)

Then the user moves up to Level 3. Again, the priorities of the criteria in Level 3 are determined by pair-wise comparing each criteria with each other, with respect to each objective in Level 2. This can be continued up comparing the objectives in Level 2 with respect to the overall goal in Level 1. (One can assign the priority ratings either from the top down or the bottom up.) For example, Zone 1 is compared to Zone 2 with respect to enabling scientific research, then Zone 1 compared to Zone 3, then Zone 2 compared to Zone 3. (Each Zone is also compared to itself, but this is always unity.) The comparisons can be made using actual data, or can be subjective values or estimates. The numbers are then entered into a matrix, and this process repeats for levels 2 and 1 (See Figure 2).

Comparing of zone alternatives in level 4 with each other, with respect (w.r.t.) to criteria in level 3

w. r. t. Enabling Scientific Research (=E)

	1	2	3
1	1	$\frac{Z_1}{Z_2}$	$\frac{Z_1}{Z_3}$
2	$\frac{Z_2}{Z_1}$	1	$\frac{Z_2}{Z_3}$
3	$\frac{Z_3}{Z_1}$	$\frac{Z_3}{Z_2}$	1

w. r. t. Protecting Fish from Extinction (=P)

	1	2	3
1	1	$\frac{Z_1}{Z_2}$	$\frac{Z_1}{Z_3}$
2	$\frac{Z_2}{Z_1}$	1	$\frac{Z_2}{Z_3}$
3	$\frac{Z_3}{Z_1}$	$\frac{Z_3}{Z_2}$	1

w. r. t. Reducing Number of Regulations (=R)

	1	2	3
1	1	$\frac{Z_1}{Z_2}$	$\frac{Z_1}{Z_3}$
2	$\frac{Z_2}{Z_1}$	1	$\frac{Z_2}{Z_3}$
3	$\frac{Z_3}{Z_1}$	$\frac{Z_3}{Z_2}$	1

Comparing of criteria in level 3 w.r.t. objectives in lelvel 2

w. r. t. Protecting Biodiversity (=B)

	E	P	R
E	1	$\frac{E_B}{P_B}$	0
P	$\frac{P_B}{E_B}$	1	0
R	0	0	1

w. r. t. Preserving Lifestyle (=L)

	E	P	R
E	1	0	0
P	0	1	$\frac{P_L}{R_L}$
R	0	$\frac{R_L}{P_L}$	1

Comparison of objectives

w. r. t. Best Zone

	B	L
B	1	$\frac{B_B}{L_B}$
L	$\frac{L_B}{B_B}$	1

Figure 2: Comparisons in Matrix Form

After all the priorities weights are assigned and the matrices formed, AHP then requires the user to find maximum eigenvalues and the corresponding eigenvectors for each matrix. Starting from the bottom alternatives, (the leaf matrices) the maximum eigenvalue is found for each matrix. (See Figure 3). The user calculates the eigenvector corresponding to the maximum eigenvalue for each matrix. The eigenvector is then inserted as one of the columns in the summary matrix for level 3. Maximum eigenvalues and eigenvectors are calculated for all the matrices in level 3. One then ascends to level 2. In level 2, the maximum eigenvalue and corresponding eigenvectors are calculated and become columns in the summary matrix for level 2. This process repeats for Level 1.

To find maximum eigenvalue, solve: **det | A - II | = 0**

$$\det\left[\begin{bmatrix} 1, & \frac{Z_1}{Z_2}, & \frac{Z_1}{Z_3} \\ \frac{Z_2}{Z_1}, & 1, & \frac{Z_2}{Z_3} \\ \frac{Z_3}{Z_1}, & \frac{Z_3}{Z_2}, & 1 \end{bmatrix} - \begin{bmatrix} \lambda & 0 & 0 \\ 0 & \lambda & 0 \\ 0 & 0 & \lambda \end{bmatrix}\right] = 0 \quad \Rightarrow \quad \det\begin{bmatrix} 1-I, & \frac{Z_1}{Z_2}, & \frac{Z_1}{Z_3} \\ \frac{Z_2}{Z_1}, & 1-I, & \frac{Z_2}{Z_3} \\ \frac{Z_3}{Z_1}, & \frac{Z_3}{Z_2}, & 1-I \end{bmatrix} = 0$$

$$\Rightarrow \lambda_1 = 0 \quad \lambda_2 = 1 \quad \boxed{\lambda_3 = 2 = \lambda_{max}}$$

To find eigenvector, solve:
(w=weights)

$$[A]\begin{bmatrix} W_1 \\ W_2 \\ W_3 \end{bmatrix} = \lambda_{max}\begin{bmatrix} W_1 \\ W_2 \\ W_3 \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} 1, & \frac{Z_1}{Z_2}, & \frac{Z_1}{Z_3} \\ \frac{Z_2}{Z_1}, & 1, & \frac{Z_2}{Z_3} \\ \frac{Z_3}{Z_1}, & \frac{Z_3}{Z_2}, & 1 \end{bmatrix}\begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix} = 2\begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix}$$

$$\Rightarrow \begin{array}{l} w_1 + \frac{Z_1}{Z_2} w_2 + \frac{Z_1}{Z_3} w_3 = 2w_1 \\ \frac{Z_2}{Z_1} w_1 + w_2 + \frac{Z_2}{Z_3} w_3 = 2w_2 \\ \frac{Z_3}{Z_1} w_1 + \frac{Z_3}{Z_2} w_2 + w_3 = 2w_3 \end{array}$$

Assume values for enabling scientific research are directly proportional to the size of the zone.

Insert the values for Enabling scientific research:

Enabling Scientific Research • size of zone 1=120 sq. miles
• size of zone 2=100 sq. miles
• size of zone 3=20 sq. miles

$$\Rightarrow \begin{array}{l} -w_1 + \frac{120}{100} w_2 + \frac{120}{20} w_3 = 0 \\ \frac{100}{120} w_1 - w_2 + \frac{100}{20} w_3 = 0 \\ \frac{20}{120} w_1 + \frac{20}{100} w_2 - w_3 = 0 \end{array}$$

This results in the following eigenvector

$$\Rightarrow w_1 = \frac{3}{16}, \ w_2 = \frac{8}{16}, \text{ and } w_3 = \frac{5}{16}$$

Figure 3: Computing Eigenvalues and Eigenvectors.

Then all three summary matrices are multiplied (see Figure 4). The final matrix in the example will be of dimension (3x1), where 3 corresponds to the number of original vessel alternatives. The values in the matrix will be the overall ranking for each Zone. For example, value "a" will be the overall rank of Zone 1.

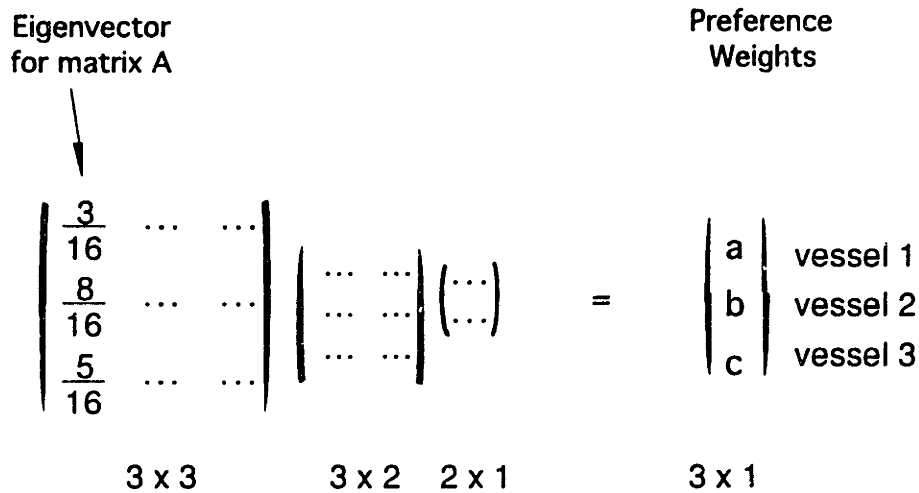


Figure 4: Matrix Multiplication for Overall Ranking.