Ecological Assessment of Salt Ponds on St. John, USVI

by

Alexa Gangemi

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Abstract

Salt ponds serve several valuable ecological functions in the United States Virgin Islands (USVI), although they have traditionally been undervalued and poorly understood. This thesis describes an ecological assessment performed to provide baseline information on salt ponds on St. John, U.S. Virgin Islands, to recommend a range of indicators to determine the water quality of a salt pond, and to suggest areas of further research to help maintain the value that salt ponds provide to the island. Quantitative and qualitative data were collected for fifteen ponds on the island. These data consist of a descriptive habitat assessment including pond classification, shore characteristics, water characteristics, biota characteristics, specific pond descriptions, as well as macroinvertebrates and chlorophyll a levels sampled in each of the ponds. Findings are presented by salinity, housing density, nitrate levels, dissolved oxygen, macroinvertebrates, species richness, and chlorophyll a. To determine correlation between variables measured, data are then analyzed by pair regression analysis. Multivariate regression results are presented for three independent variables: species richness, chlorophyll a, and dissolved oxygen. In the multivariate regression analysis of species richness, the most significantly correlated factors are berm height, temperature, pH, dissolved oxygen, and nitrate levels; chlorophyll is significantly related to temperature, pH, dissolved oxygen, nitrate levels, and salinity levels; and dissolved oxygen is significantly correlated with depth, berm height, temperature, and pH. The results of this study seem to contradict the original hypothesis-that salt pond health is adversely affected by human development. A series of recommendations are proposed including monitoring sentinel species and metrics, beginning an ongoing salt pond measurement program, performing a nitrogen balance for the ponds, conducting sediment studies on the ponds, and considering the implementation of buffer zones around the ponds.

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Table Of Contents

CHAPTER 1 – INTRODUCTION **11**
ST. JOHN – CLIMATE AND HYDROGEOLOGY 12
SALT POND DEFINITION 12
MANGROVES 14
HUMAN IMPACTS - DIRECT AND INDIRECT 14
PROJECT OVERVIEW 16
CHAPTER 2 – METHODS **17**
DESCRIPTIVE HABITAT ASSESSMENT 17
Methods 17
Pond Classification 17
Shore Characteristics 17
Water Characteristics 18
Biota Characteristics 18
Additional Information 18
CHLOROPHYLL 18
Overview 18
Methods 19
MACROINVERTEBRATES 20
Overview 20
Methods 21
Day Sampling 21
Night Sampling 21
Housing Density 22
Statistical Analysis 22
Ocean Water Delta Calculation 22
SAMPLE NUMBERING SCHEME 23
CHAPTER 3 – RESULTS **24**
VARIABLES 24
Habitat 24
Salinity 26
Housing Density 26
Nitrate Levels 27
Dissolved Oxygen 28
Macroinvertebrates 30
Species Richness 34
Chlorophyll A 34
PAIR REGRESSION ANALYSIS 35
All Ponds 35
Pond Subset 36

Nitrate And Salinity 37
MULTIVARIATE REGRESSION RESULTS 39
Species Richness 39
Chlorophyll A 40
Dissolved Oxygen 41
CONCLUSIONS 42
Sentinel Species 42
Nitrate Sources 43
CHAPTER 4 - RECOMMENDATIONS & AREAS FOR FURTHER RESEARCH **44**
APPENDIX A : SALT PONDS STUDIED ON ST. JOHN, USVI **47**
APPENDIX B : NATIONAL PARK SERVICE POND LIST (1998) **48**
APPENDIX C : INDIVIDUAL POND RESULTS **49**
CHOCOLATE HOLE WEST 50
DRUNK BAY 52
ELK BAY EAST 54
EUROPA BAY 56
FRANCIS BAY 58
FRANK BAY POND 60
FRIIS BAY 62
HANSON BAY 64
HART BAY 65
KIDDEL BAY 67
LAGOON POINT 69
POPILLEAU BAY 71
PRIVATEER BAY 73
SALT POND 75
SOUTHSIDE POND 77
APPENDIX D : TAXA FOUND IN SALT PONDS **79**
KINGDOM ANIMALIA 80
Artemiidae 80
Ceratopogonidae 81
Ciliatea 82
Copepoda 83
Corixidae 84
Culicidae 85
Dytiscidae 86
Ephydridae 87
Hydrobiidae 88
Hydrophilidae 89

Ocypodidae 90
Oligochaeta 91
Ostracoda 92
Rotifera 93
KINGDOM PLANTAE 94
Avicennia Germinans 95
Conocarpus Erectus 96
Laguncularia Racemosa 97
Rhizophora Mangle 98
APPENDIX E : DESCRIPTIVE HABITAT ASSESSMENT SHEET 99
APPENDIX F : SITE SKETCHES 103
APPENDIX G: CHLOROPHYLL A MEASUREMENTS 118
BIBLIOGRAPHY 119

Table Of Tables

TABLE 2.1 SALT PONDS BY IDENTIFICATION NUMBER..... 22
TABLE 3.1 INDIVIDUAL POND RESULTS – HABITAT..... 24
TABLE 3.2 MACROINVERTEBRATE INVENTORY..... 29
TABLE 3.3 CHLOROPHYLL A MEASUREMENTS..... 34
TABLE 3.4 PAIR REGRESSION RESULTS - ALL PONDS..... 35
TABLE 3.5 PAIR REGRESSION RESULTS - POND SUBSET..... 36
TABLE C.1 CHOCOLATE HOLE WEST POND MEASUREMENTS..... 49
TABLE C.2 DRUNK BAY POND MEASUREMENTS..... 51
TABLE C.3 ELK BAY EAST POND MEASUREMENTS..... 53
TABLE C.4 EUROPA BAY POND MEASUREMENTS..... 55
TABLE C.5 FRANCIS BAY POND MEASUREMENTS..... 57
TABLE C.6 FRANK BAY POND MEASUREMENTS..... 59
TABLE C.7 FRIIS BAY POND MEASUREMENTS..... 61
TABLE C.8 HANSON BAY POND MEASUREMENTS..... 63
TABLE C.9 HART BAY POND MEASUREMENTS..... 64
TABLE C.10 KIDDEL BAY POND MEASUREMENTS..... 66
TABLE C.11 LAGOON POINT POND MEASUREMENTS..... 68
TABLE C.12 POPILLEAU BAY POND MEASUREMENTS..... 70
TABLE C.13 PRIVATEER BAY POND MEASUREMENTS..... 72
TABLE C.14 SALT POND MEASUREMENTS..... 74
TABLE C.15 SOUTHSIDE POND MEASUREMENTS..... 76
TABLE D.1 ARTERMIIDAE TAXONOMY DETAIL..... 78
TABLE D.2 CERATOPOGONIDAE TAXONOMY DETAIL..... 79
TABLE D.3 CILIATEA TAXONOMY DETAIL..... 80
TABLE D.4 COPEPODA TAXONOMY DETAIL..... 81
TABLE D.5 CORIXIDAE TAXONOMY DETAIL..... 82
TABLE D.6 CULICIDAE TAXONOMY DETAIL..... 83
TABLE D.7 DYTISCIDAE TAXONOMY DETAIL..... 84
TABLE D.8 EPHYDRIDAE TAXONOMY DETAIL..... 85
TABLE D.9 HYDROBIIDAE TAXONOMY DETAIL..... 86
TABLE D.10 HYDROPHILIDAE TAXONOMY DETAIL..... 87
TABLE D.11 OCYPODIDAE TAXONOMY DETAIL..... 88
TABLE D.12 OLIGOCHAETA TAXONOMY DETAIL..... 89
TABLE D.13 OSCTRACODA TAXONOMY DETAIL..... 90
TABLE D.14 ROTIFERA TAXONOMY DETAIL..... 91
TABLE D.15 AVICENNIA GERMINANS TAXONOMY DETAIL..... 92
TABLE D.16 CONOCARPUS ERECTUS TAXONOMY DETAIL..... 93
TABLE D.17 LANGUNCULARIA RACEMOSA TAXONOMY DETAIL..... 94
TABLE D.18 RHIZOPHORA MANGLE TAXONOMY DETAIL..... 96

Table Of Figures

FIGURE 1.1 GENERAL SCHEMATIC OF A SALT POND.. 12
FIGURE 2.1 LIGHT TRAP USED FOR MACROINVERTEBRATE SAMPLING.................. 21
FIGURE 3.1 MEASURED SALT POND SALINITY LEVELS.................................. 25
FIGURE 3.2 HOUSING DENSITY PER SALT POND.. 26
FIGURE 3.3 MEASURED SALT POND NITRATE LEVELS................................... 27
FIGURE 3.4 MEASURED DISSOLVED OXYGEN LEVELS.................................. 28
FIGURE 3.5 FREQUENCY OF MACROINVERTEBRATE OBSERVATION...................... 30
FIGURE 3.6 INVERTEBRATES PRESENT BY SALINITY...................................... 31
FIGURE 3.7 INVERTEBRATES PRESENT BY CHLOROPHYLL A............................ 31
FIGURE 3.8 INVERTEBRATES PRESENT BY DISSOLVED OXYGEN......................... 32
FIGURE 3.9 INVERTEBRATES PRESENT BY NITRATE LEVELS............................ 32
FIGURE 3.10 SPECIES RICHNESS BY POND.. 33
FIGURE 3.11 NITRATE (AS N) VS. SALINITY REGRESSION CURVE....................... 36
FIGURE 3.12 NITRATE (AS N) - SALINITY CORRELATION: PREDICTED VS. OBSERVED.. 37
FIGURE 3.13 SPECIES RICHNESS VS. NITRATE (AS N) DELTA REGRESSION CURVE...... 38
FIGURE C.1 CHOCOLATE HOLE WEST.. 51
FIGURE C.2 CHOCOLATE HOLE WEST.. 51
FIGURE C.3 CHOCOLATE HOLE WEST.. 51
FIGURE C.4 DRUNK BAY POND... 52
FIGURE C.5 DRUNK BAY POND... 53
FIGURE C.6 ELK BAY EAST POND... 55
FIGURE C.7 ELK BAY EAST POND... 55
FIGURE C.8 EUROPA BAY POND... 57
FIGURE C.9 EUROPA BAY POND... 57
FIGURE C.10 EUROPA BAY POND... 57
FIGURE C.11 FRANCIS BAY POND... 59
FIGURE C.12 FRANCIS BAY POND... 59
FIGURE C.13 FRANK BAY POND... 61
FIGURE C.14 FRANK BAY POND... 61
FIGURE C.15 FRANK BAY POND... 61
FIGURE C.16 FRIIS BAY POND.. 63
FIGURE C.17 FRIIS BAY POND.. 63
FIGURE C.18 FRIIS BAY POND.. 63
FIGURE C.19 HANSON BAY POND... 64
FIGURE C.20 HART BAY POND.. 66
FIGURE C.21 HART BAY POND.. 66
FIGURE C.22 KIDDEL BAY POND.. 68
FIGURE C.23 KIDDEL BAY POND.. 68
FIGURE C.24 KIDDEL BAY POND.. 68

FIGURE C.25 LAGOON POINT POND.. 69
FIGURE C.26 LAGOON POINT POND.. 70
FIGURE C.27 LAGOON POINT POND.. 70
FIGURE C.28 POPILLEAU BAY POND.. 72
FIGURE C.29 POPILLEAU BAY POND.. 72
FIGURE C.30 PRIVATEER BAY POND.. 73
FIGURE C.31 PRIVATEER BAY POND.. 74
FIGURE C.32 SALT POND... 75
FIGURE C.33 SALT POND... 76
FIGURE C.34 SALT POND... 76
FIGURE C.35 SOUTHSIDE POND.. 77
FIGURE C.36 SOUTHSIDE POND.. 78
FIGURE C.37 SOUTHSIDE POND BACTERIAL MAT... 78
FIGURE D.1 ARTERMIIDAE... 78
FIGURE D.2 CERATOPOGONIDAE... 79
FIGURE D.3 CILIATEA.. 80
FIGURE D.4 COPEPODA.. 81
FIGURE D.5 CORIXIDAE... 82
FIGURE D.6 CULICIDAE... 83
FIGURE D.7 DYTISCIDAE.. 84
FIGURE D.8 EPHYDRIDAE.. 85
FIGURE D.9 HYDROBIIDAE... 86
FIGURE D.10 HYDROPHILIDAE.. 87
FIGURE D.11 OCYPODIDAE... 88
FIGURE D.12 OLIGOCHAETA... 89
FIGURE D.13 OSTRACODA.. 90
FIGURE D.14 ROTIFERA... 91
FIGURE D.15 AVICENNIA GERMINANS.. 92
FIGURE D.16 CONOCARPUS ERECTUS... 93
FIGURE D.17 LANGUNCULARIA RACEMOSA.. 94
FIGURE D.18 RHIZOPHORA MANGLE.. 95
FIGURE F.1 CHOCOLATE HOLE WEST... 101
FIGURE F.2 DRUNK BAY POND.. 102
FIGURE F.3 ELK BAY EAST.. 103
FIGURE F.4 EUROPA BAY POND... 104
FIGURE F.5 FRANCIS BAY... 105
FIGURE F.6 FRANK BAY POND.. 106
FIGURE F.7 FRIIS BAY.. 107
FIGURE F.8 HANSON BAY.. 108

FIGURE F.9 HART BAY.. 109
FIGURE F.10 KIDDEL BAY.. 110
FIGURE F.11 LAGOON POINT.. 111
FIGURE F.12 POPILLEAU BAY.. 112
FIGURE F.13 PRIVATEER BAY POND.. 113
FIGURE F.14 SALT POND.. 114
FIGURE F.15 SOUTHSIDE POND.. 115

Chapter 1 - INTRODUCTION

Although salt ponds may not look impressive at first glance, they are extremely active and important ecosystems providing vital food and shelter to many species that live on or migrate through the United States Virgin Islands (USVI). Due to recent rapid and drastic increases in population and tourism, concern about the impact on and the fate of these ponds has been expressed by the Island Resources Foundation, a research and conservation organization in the USVI (IRF, 2002).

Although species diversity may be lower than in other systems (Montgomery, 1966), salt ponds are some of the most biologically productive ecosystems in the world. "Riparian ecosystems generally compose a minor proportion of the landscape. Typically, however, they are more structurally diverse and more productive in plant and animal biomass than adjacent upland areas. Riparian areas supply food, cover, and water for a large diversity of animals, and serve as migration routes and connectors between habitats for a variety of wildlife" (Montgomery, 1966). So far, however, only preliminary research has been performed to document ecosystems living in and depending on USVI salt ponds.

Salt ponds serve several valuable ecological functions in the USVI. For example, salt ponds serve as a habitat for many indigenous as well as migratory species, some of which are endangered or threatened under the classifications developed in the Endangered Species Act (ESA) (Bryant, 1998). Second, they act as a buffer between areas of human development and the sensitive reef ecosystems, as sediment and pollution carried by groundwater flow and surface runoff are filtered by salt ponds before they reach the ocean reefs. This effective upland sediment trapping helps maintain water quality in adjacent marine waters, but may concentrate sediments, nutrients, and chemicals in the ponds themselves (IRF, 1977).

As human development increases in the USVI, effects of development on salt ponds are becoming a major source of concern. Due to their proximity to beaches, many have been destroyed for the construction of beachfront property or marinas. Population growth has not been accompanied by improvements in the sewage infrastructure, so salt ponds are bearing a greater nutrient load from the greater number of septic tanks in use. In addition, increases in deforestation and the use of unpaved roads are leading to heightened erosion, which results in increased sedimentation in salt ponds (UVI, 2002).

Salt ponds are considered "unfriendly" places for biota to live because ambient conditions can change drastically in short periods of time. Although they are quite important in the ecosystem, it is extremely difficult to live permanently in a salt pond because of the large range and sometimes rapid changeability of the conditions. For example, the salinity of salt ponds can change considerably due to evaporation and recharge by rainfall. Since the annual rainfall in the US Virgin Islands is typically low, the ponds often shrink in size from when they were first formed, and their overall salinity is usually greater than that of seawater (Maho, undated). Temperature is another feature that can vary between ponds as well as in a single pond over time because of the intense sun exposure that the ponds receive. Pond temperature may further vary with precipitation and weather conditions. Other factors that have been shown or are suspected to have wide variability in salt ponds include dissolved oxygen, turbidity, and hydrogen sulfide. These factors are related to external causes but are also related to each other, and fluctuations are interrelated. Because of the difficulty associated with surviving in the variability of salt ponds, only the hardiest species are able to live there. The groups of organisms that are able to survive in the ponds are various species of macroinvertebrates, bacteria, and phytoplankton (Maho, undated).

St. John – Climate and Hydrogeology

The climate of St. John is classified as subtropical with the winters being mild and dry, the summers warm and humid (Colon-Dieppa et al., 1989). Precipitation increases with altitude due to the moist air being forced up the slopes into the cooler air of the higher altitudes. February and March are the driest months and September and October are the wettest. High evapotranspiration rates reduce the quantity of surface water available (Jordan and Cosner, 1973). St John receives an average of 44 inches of rainfall a year, and usable groundwater on the islands is scarce (Ramos-Perez, 1988). The islands are composed of volcanic rock and have steep slopes and irregular coastlines. Runoff ranges from 2 to 8 percent of annual rainfall (Colon-Dieppa et al., 1986).

Both the topography of the region and the amount of rainfall contribute to the variable conditions in the ponds. "St. John is very mountainous with very little flat land...Runoff is usually slight because most rain showers are brief with moderate precipitation. However, during severe storms, runoff can be a serious problem. Eighty percent of the slopes have a 30% grade or higher." (NPS, 2002) During periods of intense rainfall, substantial runoff does occur. "Most of St. John's soils fall in the US Department of Agriculture's Hydrologic Group D, indicating that they have a high potential for runoff" (Rogers, 1988). These natural factors can be exacerbated by anthropogenic forces such as road erosion and septic system outfall that can threaten the quality or even the existence of the ponds.

Salt Pond Definition

Salt ponds typically form when coral reef or mangroves grow across an open bay. As sediment accumulates on the coral, over a period of time the pond becomes closed from the ocean. "Geologically, ponds form by the gradual closing of sheltered bays as fringing reefs grow upwards and create rubble berms over which mangroves grow, eventually closing off areas from seawater interchange" (Jarecki, 1999). While exceptions do exist in the USVI (some ponds have been opened to the ocean to allow for intertidal flushing), the hydrology of salt ponds is dominated by inflows from groundwater seepage, surface runoff, and precipitation, and outflows from evapotranspiration and groundwater seepage (Figure 1.1). Salt ponds are usually located at the base of a mountainous basin where they receive and filter runoff before it flows into the ocean.

During dry periods, salinity may be increased via evaporation. This leaves a greater concentration of salt in the pond. "After closure, the ponds can no longer be flushed, and their salinity then fluctuates with relative inputs of fresh water and sea water by precipitation and through-ground seepage, respectively, and with output by evaporation" (Jarecki, 1999). Salt-water recharge may occur slowly via seepage through the berm if porosity allows, or rapidly via overwash during high tide or storm events. Other nutrients have higher concentrations than in seawater as well due to the concentration effects that occur by evaporation (Jarecki, 1999).

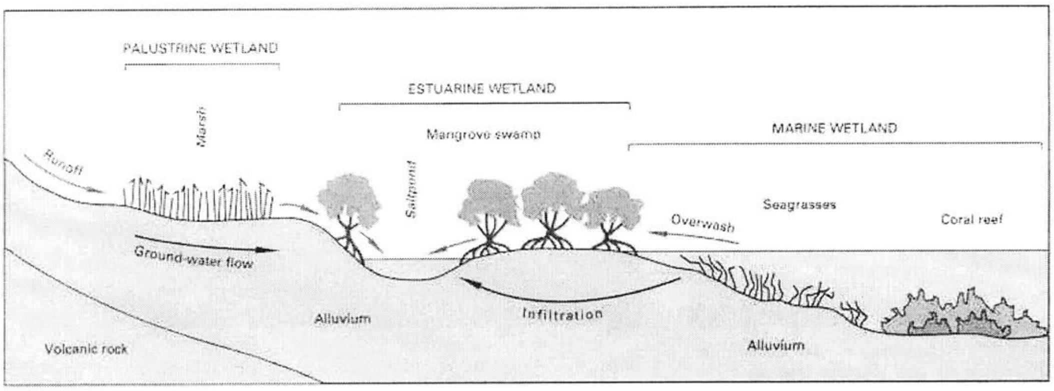


Figure 1.1 General Schematic of a Salt Pond (USGS, 1985)

Ecological value of salt ponds includes their ability to filter sediments from runoff water and to absorb nutrients from sewage and agricultural pollutants. This effective upland sediment trapping maintains water quality in adjacent marine waters. Consequently, a higher concentration of contaminants from runoff frequently ends up in salt ponds rather than the ocean (IRF, 1977). Salt ponds also balance nutrient flow between the island and the ocean. Arguably, one of the most important purposes that ponds serve is as a filter for harmful materials coming from landward areas. "Ponds are known to be particularly important in buffering the effect of land-based pollution from the shallow marine systems. They are settlement areas where runoff water collects and suspended soil and other particles settle out before the water seeps into the sea. Additionally, benthic bacterial mats in ponds absorb nitrogen from overlying waters" (Jarecki, 1999).

The filtering capacity that makes ponds so useful also makes them vulnerable to potentially serious damage. "Runoff water collects in ponds before running or seeping into the nearshore marine environments. As the runoff waters enter the lowland mangrove forests and salt ponds, they slow down and sediments carried in the water settle out...Over many years, this process leads to gradual filling of ponds. Thus, salt ponds may be at various stages of filling and of isolation from the sea" (Jarecki, 1999). Although sedimentation will eventually cause ponds to fill completely at the end of their natural life, premature filling of the pond takes away the beneficial habitat and filtering capabilities that the pond provides.

MANGROVES

Four types of mangroves exist on St. John and were identified during this study. These four types of mangroves are commonly known as red, black, white, and gray mangroves. "Mangrove" is a term used to characterize a group of water- and salt-tolerant plants typically found in warmer climates (Burke, 2001). These plants may or may not be related to each other, but they share a common set of characteristics. "All [mangroves] have evolved a competitive advantage over other woody plants by developing… physiological characteristics which allow them to thrive in seawater-moistened and often anaerobic soil. Most species develop prop roots for support in the soft environment and pneumatophores or other root structures to provide access to above-ground oxygen. The seeds of mangroves usually germinate while still attached to the tree and maintain their viability while being widely dispersed by the tides" (Nellis, 1994). Mangroves live in environments protected from waves, so they are well suited to the salt pond habitat. Mangroves with pneumatophores help to oxidize the soil rhizosphere; in fact, soil oxidation levels are directly correlated with pneumatophore density (Mitsch, 1993). Therefore, changes in mangrove community or structure would signal significant impacts on the rest of the salt pond ecosystem.

Over 50% of all mangroves in the USVI have been destroyed due to anthropogenic and natural sources (particularly hurricanes) in the last 50 years. "Red, white, and black mangroves are placed in a protected status by the Territory of the U.S. Virgin Islands due to their significant ecological role as fish and wildlife habitat, shoreline stabilization, and natural sediment reduction system…this is particularly important because other vegetation, the coastal morphology and wildlife therein are dependent upon the continued health and existence of the mangrove interface" (NPS, 2002).

Due to the thick and complex root network in these areas, mangroves are believed to provide highly effective sediment filtration for runoff that would otherwise adversely affect the marine environment. These root networks also serve to prevent bank erosion of the ponds and shore erosion where the trees are found on the seashore. Although trapping the sediment in the mangrove roots is positive for the marine environment, studies show that sedimentation at current levels will cause the end of mangrove swamps by smothering the mangrove roots (IRF, 1977). Mangroves are particularly susceptible to damage via trampling and branch breaking, as well as anchoring practices, ropes, or other gear. Therefore, mangrove population characteristics may signal magnitude and types of disturbances at the ponds.

HUMAN IMPACTS - DIRECT AND INDIRECT

Since salt ponds are generally located in conjunction with beaches, they represent valuable property to developers. Also, salt ponds have historically been regarded as unpleasant smelling areas that have been used for trash dumping. Ponds have traditionally been undervalued as a resource, and so further research of these ecosystems is vital to their understanding and preservation.

The greatest impacts of human activities on salt ponds are those that directly change the flow of water in and out of salt ponds. For example, since beaches and salt ponds typically occur in the same areas, salt ponds occupy lucrative beachfront property that may be developed. Many salt ponds have been filled, and still others have been opened to the ocean and made into marinas, fishing areas, or swimming pools for recreational use. On St. John, three of the twenty-six ponds that are accessible by land have been opened since they had been inventoried in 1998, a 12% loss in just five years. One of salt ponds' most valuable contributions to the surrounding area is their ability to filter runoff and sediment before it runs into the ocean. Opening ponds to the surrounding marine areas may release sediments and contaminants to the surrounding marine environment. Disturbing sediments at the bottom of ponds can release high levels of hydrogen sulfide that can kill organisms in the ocean due to its sudden potency (IRF, 1977). "Sedimentation from dredging and runoff probably constitutes the biggest potential source of reef degradation in the Caribbean" (Rogers, 1988). Consequent damage to the surrounding marine environment is an issue, but is beyond the scope of this project.

Indirect influences on salt ponds include development practices that do not adequately consider downstream effects. Development without proper sediment control measures can lead to rapid filling in of salt ponds and their eventual loss (Maho, undated). Runoff from roads, golf courses, agricultural areas, vessel waste, spills, and other non-point sources are the major contributors to pollution in surface waters. Various indirect human-related problems are suspected, including deforestation, careless building practices, agriculture, and accidental chemical releases. Lianna Jarecki (1999) states:

> While dredging and filling are obvious, direct impacts, activities such as deforestation, livestock grazing, and poorly designed roads in watershed areas will also impact the hydrology of salt ponds. Grazing and trampling of shores by livestock, runoff of agricultural or sewage wastes, fuel leaks, discharge of desalination plant wastewaters, and dumping of solid wastes in ponds are common activities in Caribbean salt ponds. Impacts may affect part of the biota or the entire ecosystem.

Wetlands are protected under the Territorial Indigenous and Endangered Species Act, Section 404. This act stipulates "no net loss of wetlands" and requires a permit to cut, prune, or remove mangroves. The CZM (Coastal Zone Management) Act of 1978 requires the DPNW to issue a permit before any excavation or filling is carried out in a coastal zone (United States Virgin Islands Coastal Zone Management Program, 2002). Additional measures may be required to save these important parts of the island; mitigating strategies may be proposed, however, only after detailed research on the cause and physical indications of the problem have been completed.

PROJECT OVERVIEW

The purpose of this project is to gather and analyze information on salt ponds to allow informed decisions on how to understand and treat them over time. This objective breaks down into three important pieces:

1. Provide a preliminary snapshot of the permanent ecosystem in the salt ponds

Because of the current lack of knowledge about what organisms live in the ponds, sampling was performed to determine characteristics of each pond. Quantitative measurements included (among others) macroinvertebrate identification, chlorophyll levels, housing density, salinity, nitrates, dissolved oxygen, temperature, berm characteristics, and pH. Qualitative measurements included (among others) fringing mangrove community characteristics, sediment descriptions, conversations with landowners, and items of interest specific to each pond. This information is meant to create a baseline for decision making, as well as to provide a basis for additional research and monitoring of salt ponds.

2. Recommend a range of indicators to determine the water quality of a salt pond

Although salt ponds on St. John demonstrate a wide range of conditions both compared to each other and over time, relationships between different variables are evident and are analyzed in this study. The water quality of a pond may be determined using a subset of these indicators, and management strategies can then be implemented for each individual pond by using these simplified water quality metrics.

3. Suggest areas for further research

After the establishment of baseline data on the salt ponds, additional research areas are suggested to further knowledge of the ponds. Additional field research and ongoing monitoring can refine the pond characteristics and quality indicators to improve long-term oversight strategies.

Chapter 2 – METHODS

Fifteen salt ponds were selected for sampling based on accessibility. In each salt pond on St. John sampled in January 2003, three categories of data were collected: descriptive habitat assessments, chlorophyll a samples, and macroinvertebrate sampling (using two different methodologies). The methods used to gather this data are detailed in the following sections.

DESCRIPTIVE HABITAT ASSESSMENT

A descriptive habitat assessment was performed for each of the ponds chosen for the study. Wherever accessible by boat and/or foot, the pond was studied on all sides to determine the pond environment from all perspectives.

Methods

Habitat data were transcribed onto a data sheet (Appendix E) by hand and then subsequently entered into spreadsheets for analysis. The survey consisted of five sections: pond classification, shore characteristics, water characteristics, biota characteristics, and additional information. The information gathered and recorded in each section includes:

Pond Classification

- Pond ID: The identification number of the pond, shown in Table 2.1.
- Pond name: The name assigned to the pond by the National Park Service as listed in Appendix B.
- Photograph numbers: The numbers of photographs taken of the pond.
- Sample site description: A description of each of the locations from which water and macroinvertebrate day samples were taken.

Shore Characteristics

- Mangrove species and percent within fringing forest: For each type of mangrove identified at the site, relative percentages present on the pond shores.
- Shoreline description and percent cover: Estimated percentage of the pond bank characterized by either presence of 1) mangroves or 2) dry forest species, or 3) unvegetated.
- Berm composition: Observed media comprising the berm.
- Berm height: Estimated height of the berm above the pond's water surface.
- Berm vegetation: Vegetation observed growing on the berm.
- Sediment description: Qualitative description of the sediment composition and characteristics.
- Bank land use: Description of the land use surrounding the pond.

- Boundary width: Estimate of contiguous undisturbed land use measured to the nearest 1m up to 10m.
- Bank erosion: Percentage of the bank that appears to be affected by erosion, either natural or anthropogenic.

Water Characteristics

- Depth: Water depth estimated from wading in pond.
- Salinity: Salinity levels up to about 80 parts per thousand (ppt) were measured using a YSI 600XLM multiparameter sonde. Above this range, salinity was measured using a refractometer. If the salinity was above 90-100 ppt (the upper range of the refractometer), the sample was diluted and re-measured using the refractometer.
- Temperature*: Measured using YSI 600XLM multiparameter sonde.
- Dissolved oxygen*: Measured using YSI 600XLM multiparameter sonde.
- pH*: Measured using YSI 600XLM multiparameter sonde.
- Turbidity*: Measured using a Hach 2100P Turbidimeter.

* A description of detailed methods is available in Bossi and Rose, 2003.

Biota Characteristics

- Fish: Observed presence or absence.
- Chlorophyll a level: Recorded value from laboratory analysis.
- Benthic producer community: Grass, algae, or bacterial mat.
- Benthic invertebrates: Taxonomic identification and/or qualitative description of observed invertebrates.

Additional Information

- Notes: Additional information on pond and habitat characteristics.
- Site Sketch: Sketch of the salt pond site.

CHLOROPHYLL

Overview

Phytoplankton are an integral part of a water body's ecosystem, and the levels found in a pond provide insight into the condition and history of an individual salt pond. Excessive nutrient loading in ponds may lead to excessive phytoplankton growth; these blooms can deplete dissolved oxygen levels in the pond, depriving other pond dwellers and causing a ripple effect in decreasing pond populations. As an integral part of the food chain, phytoplankton populations were also measured as part of this thesis. Chlorophyll a is a measure of the green pigment in phytoplankton commonly used to represent phytoplankton levels (Grove, 1998).

Methods

From each of the ponds, three representative sample points were chosen. Wherever possible, the three points were chosen in representative thirds (by surface area) of the pond. These points were somewhat dependent on accessibility (i.e. depth of the bacterial mat and the water, boat accessibility, and vegetation density). At each of these points, a one-liter bottle was rinsed three times with pond water before a sample was taken from 1 to 3 feet below the pond water surface. Two hundred milliliters of pond water were then measured into a beaker, and 5 drops of magnesium carbonate ($MgCO_3$) solution were added as a preservative.

The filter cup for a Millipore filter was rinsed three times with the sample water from the 1L bottle. Then a clean Whatman glass fiber filter was placed under the cup and as much of the sample pond water as possible was filtered using a syringe. The filter was folded in quarters, wrapped in aluminum foil and labeled (the numbering scheme is detailed below). The sample was then placed into a cooler with ice packs for subsequent transport to and storage in a freezer in the USVI. At the end of the field program, the frozen samples were transported to MIT by air in a cooler with ice packs.

Upon return to MIT, the frozen filters were each placed into a 15 mL tube and immersed in 5.1 mL of 90% acetone solution. The tubes were then covered from light and placed in a freezer. After 24 hours, the samples were spun in a centrifuge at 2700 rpm for 5 minutes. The supernatant was decanted into disposable glass tubes, and analyzed under a Turner 10-AU fluorometer. When the fluorometer reading had stabilized, F_o readings were taken; two drops of 1 N hydrochloric acid solution were then added to the tube. After re-stabilization the F_a readings were taken. In several cases, the chlorophyll level was too high for the fluorometer to read; in these cases 0.2mL of the supernatant was diluted with 5.1 mL of 90% acetone solution (Parsons, 1984).

The collected data was analyzed using a calculation from Jeffrey and Humphrey (Parsons, 1984) for 90% acetone extracts for leaf pigments:

$$F_d * 1.83 ((F_o - F_{0o}) - (F_a - F_{0a})) * v/V = \text{Chlorophyll a } (\mu g/L)$$

where:

F_d = Fluorometer-specific normalization factor
F_a = Fluorometer reading of the sample after the addition of HCl solution
F_o = Fluorometer reading of the sample before the addition of HCl solution
v = Extraction volume (In the case that the sample was diluted, the extraction volume was multiplied by a dilution factor of 16.5 before the addition of HCl solution)
V = Volume filtered
F_{0o} = Fluorometer reading of a blank sample before the addition of HCl solution
F_{0a} = Fluorometer reading of a blank

Duplicate samples were collected and analyzed for thirty-four percent of the samples, and the duplicate sample values were averaged with original sample values. A blank sample and a standard were used to calibrate the fluorometer.

MACROINVERTEBRATES

Overview

Macroinvertebrates are an integral part of the ecosystem in the pond, and the community composition may be used as an indicator for pond conditions. Macroinvertebrates feed on plants, detritus and other small animals in the ponds and provide food for larger invertebrates, birds, and bats. Macroinvertebrates also perform other important functions for the ponds including bioturbation and oxygenation of the sediment, and chemical cycling. "Benthic macroinvertebrates are long-term indicators of environmental quality; they integrate water, sediment, and habitat qualities...Macroinvertebrate species have sensitive life stages that respond to stress and integrate effects of both short-term and long-term environmental stressors. Classification of benthos according to their relative sensitivity to pollution and their functional feeding group level differentiates effects on ecological health in response to organic or toxic perturbations" (Barbour, 1999).

There are several measurements considered to be potential indicators of environmental stresses to a macroinvertebrate community. Some of these measurements include (Barbour, 1999):

- Reduced number of total taxa found,
- Reduced population density,
- Reduced density of species with lower tolerance,
- Elevated numbers of oligochaetes,
- Increased density of dominant taxa,
- Reduced density of crustaceans and mollusks, and
- Reduced numbers of suspension feeders or shredders.

Of course, in order to determine community fluctuations, baseline measurements for individual ponds must be taken. This study details the taxa found in each pond as a baseline measurement and makes some preliminary assessments of environmental stresses based on current macroinvertebrate communities.

Macroinvertebrates in salt ponds are able to survive in a harsh and very variable climate. The literature suggests that these organisms are therefore less rather than more specialized which enables them to deal with a wider range or environmental factors. "It is wide tolerance that sets the organisms of lagoons and estuaries apart from freshwater and marine organisms" (Carpelan, 1967). Organism resilience is positively correlated with tolerance range size. For example, organisms that are tolerant of higher levels of salinity are also more tolerant of lower levels. "In broad summary, [studies] show that species typical of only moderately saline lakes have relatively narrow absolute tolerance ranges, whereas species typical of highly saline lakes have very wide absolute tolerances" (Williams, 1998). Therefore, impact of natural or anthropogenic disturbances may affect different types of macroinvertebrates differently. "Studies of salt lakes undergoing increases in salinity following human disturbance to their hydrological balance broadly indicate two major points. First, where changes have taken place in moderately saline lakes (that is, with salinities below ~ 50 [ppt]), significant changes in the nature of their biota have occurred. Second, where changes have taken place in lakes with salinities in excess of ~ 50 [ppt], no significant changes have occurred in species composition and richness" (Williams, 1998). Therefore, the less saline ponds may be more susceptible to harm by human activities.

Some other factors favorable to salt pond animals are less competition and fewer predators as a result of overall fewer pond inhabitants. "Abundant food may help balance the physiological stresses of increased salinity. The reduced number of species in inland waters as salinities increase could mean less interspecific competition and fewer vertebrate and invertebrate predators" (Colburn, 1988). Also, lack of competition and a simple food chain may reduce stresses on individual taxa (Carpelan, 1967). In a study of species present in salt ponds in Death Valley, California, the number of taxa varies inversely with salinity measurements (Colburn, 1988). The literature generally supports the fact that "with increasing absolute salinity both species richness and diversity decrease" (Williams, 1988). Community makeup can vary widely between ponds, however, and in the research to date there seem to be few rules on the ecological composition of pond ecosystems (Jarecki, 1999). Therefore, baseline studies of pond community composition as well as information on species richness are very valuable pieces of information for ongoing pond monitoring.

Methods

In order to gather the most complete sample of macroinvertebrates, both day and night testing procedures were utilized. Macroinvertebrates were gathered and preserved in denatured alcohol. Upon return to the field laboratory, macroinvertebrate samples were identified, most often to the family level, with the assistance of field reference guides and taxonomical experts.

Day Sampling

For day sampling of macroinvertebrates, a standard D-frame dip net, 500 opening mesh was used to disturb the sediment in a back-and-forth motion 5 to 7 times. After agitation, the net was pulled out and the water drained. The nets and the collected sediments were examined for macroinvertebrates by hand. Macroinvertebrates were placed into vials containing denatured alcohol. Upon return to the field laboratory, the samples were poured into a taxa tray and examined visually and under a microscope. This process was completed for three sample sites per pond.

Night Sampling

A light trap was placed in one location in the pond for 20 minutes after sunset or before sunrise in each pond deep enough to accommodate the light trap (only Hart Bay was excluded because of insufficient depth). At the end of 20 minutes, the water within the trap was collected and transported to the field laboratory, where a group of water and macroinvertebrate samples were then examined by the naked eye and then under a microscope at 40x magnification.

The light trap was constructed using an 18-inch-long piece of 3-inch-diameter polyvinyl chloride pipe and two plastic bottles. The necks of the bottles were placed inside the pipe pointing inward and the bottles were cut radially, and folded and secured with rubber bands around the outside. A dive light was placed inside the pipe so that macroinvertebrates that were attracted to the light would swim into the trap and be unlikely to escape (Figure 2.1).

Figure 2.1 Light Trap Used for Macroinvertebrate Sampling

Housing Density

To determine housing density (number of houses per square kilometer), the area of the hydrologic basin draining to each pond was calculated using ArcView on a digital elevation model on St. John. The houses found inside each basin on a U.S. Geological Survey topographical map (1996) were counted, and then the total number of houses per square kilometer was calculated for each pond.

Statistical Analysis

In order to determine relationships between different measurements, a series of statistical analyses were performed. First, an independent variable was compared to a dependent variable by regression analysis to see which pairs were significantly correlated. Then, groups of variables were compared by multivariate regression analysis to determine relationships within groups of variables. Multivariate regression compared an independent variable to more than one dependent variable to determine whether these variables were significantly correlated to each other; relationships between different variables were quantified using this analysis in Microsoft Excel. Three of the variables measured were used as independent variables in the regression analysis since they were hypothesized to be the variables indicative of pond health: species richness, chlorophyll a, and dissolved oxygen.

Ocean Water Delta Calculation

To examine the close correlation (R^2=0.99) found between pond salinity levels and during pair regression analysis, one possible explanation was explored. This hypothesis states that if salt and nitrates are concentrated in salt ponds in the same proportion by evapotranspiration, the ratio of salinity to nitrate in ocean water would be equal to that of the salt ponds. In order to explore this hypothesis, comparison of salt pond nitrate levels to nitrates measured by the National Oceanic and Atmospheric Administration (NOAA) in the Caribbean Ocean were performed to view differences. If this hypothesis were true, a regression line constructed through the origin and the ocean water data would accurately predict nitrate levels in the ponds. This line was constructed, and a "delta" value was calculated between the nitrate levels predicted by evapotranspiration alone and actual nitrate levels measured in the ponds. Differences in nitrate levels were calculated between the value predicted by the seawater information and the actual nitrate measurements.

SAMPLE NUMBERING SCHEME

Each sample number identified the pond from which the sample was collected, the type of sample collected, and the consecutive sequence number assigned. Pond numbers are listed in Table 2.1.

Several duplicate samples were taken for chlorophyll measurements. At the beginning of the study, a duplicate was performed per sample site per pond. After the initial period, one duplicate sample was performed per pond. There was no duplicate sampling performed for macroinvertebrates

Table 2.1 Salt Ponds By Identification Number

01. Borck Creek	18. Hart Bay
02. Brown Bay	19. Kiddel Bay
03. Chocolate Hole East	20. Lagoon Point
04. Chocolate Hole North	21. Great Lameshur East
05. Chocolate Hole West	22. Great Lameshur West
06. Drunk Bay	23. Little Lameshur
07. Elk Bay East	24. Leinster
08. Elk Bay South	25. Mt Pleasant
09. Elk Bay West	26. Newfound Bay
10. Enighed Pond	27. Popilleau Bay
11. Europa Bay	28. Privateer Bay
12. Fortsberg	29. Reef Bay
13. Francis Bay	30. Salt Pond
14. Frank Bay	31. Salt Pond Bay
15. Friis Bay	32. Southside Pond
16. Grootpan Bay	33. Turner Point
17. Harbor Point	34. Hanson Bay

Chapter 3 - RESULTS

A total of fifteen ponds had a complete habitat assessment performed. A total of eight ponds had an additional water quality assessment including measurements of pH, nitrates (as N), temperature, turbidity, and dissolved oxygen (Bossi and Rose, 2003). The following chapter details the results of both the habitat and water quality assessments, in addition to determining relationships between the two. When possible, the entire data set was used, however, in many cases only those eight ponds for which complete habitat and water quality data were available were used for analysis.

Results are first presented individually by specific variable to show the full range of measured results. To determine correlation between variables, the data are then analyzed by pair regression analysis. Regression analysis was used to examine the degree of correlation between an independent and dependent variable; R^2 values are a quantitative output of the strength of that correlation. Multivariate regression analyzes the relationship between an independent variable and more than one dependent variable to determine the relationships within that group of variables. Multivariate regression results are presented for three independent variables: species richness, chlorophyll a, and dissolved oxygen. Finally, a series of conclusions about the study's findings are explored.

VARIABLES

Habitat

Mangroves were discovered at all except one pond in the study (93%) (Table 3.1). Red mangroves were observed at three ponds (20%), black mangroves at three ponds (20%), white mangroves at eight ponds (53%), and gray mangroves at nine ponds (60%). The four species were found co-existing at only one of the ponds observed (Elk Bay East Pond).

Of the fifteen ponds considered in this study, one pond (Popilleau Bay Pond) did not have any mangroves growing around it. There are several possible reasons for this. Popilleau Bay Pond is the closest pond to a road; this condition may be unfavorable for natural mangrove populations. Alternatively, mangroves may have been removed to allow line of sight into and across the pond from the landowners' homes and from the road.

Mangrove occurrences as related to pond salinity levels were consistent with the literature (Nellis, 1994). In general, red mangroves were found at lower salinity ranges (31-63 ‰), black mangroves at slightly higher ranges (59-69 ‰), and gray (45-262‰) and white (59-136 ‰) mangroves had large ranges reaching higher salinities. Neither nitrate nor dissolved oxygen levels were significantly correlated with either the presence or absence of a particular species of mangrove, or with the total number of species present.

Table 3.1 Individual Pond Results – Habitat

		Mangrove Species Percent					Percent of Cover														
Pond Number	Pond Name	Red	Black	White	Gray	Cover	Mangroves	Other Species	Unvegetated	Berm Height (m)	Land Use Value	Boundary width	Bank Erosion	Water Depth (ft)	Temperature (Degrees C)	Dissolved Oxygen (mg/L)	pH	Turbidity (NTU)	Salinity (ppt)	Chlorophyll a (ug/L)	Species Richness
14	Frank Bay Pond	0	0	85	15	75	30	45	25	1	402	>10 m	5	3	27.79	5.33	8.31	8.45	67	2300	6
5	Chocolate Hole W	0	50	10	40	95	85	10	5	2.5	215	>10 m	5	4	33.93	5.24	8.27	9.55	69	6800	3
7	Elk Bay East	50	5	30	15	70	70	0	30	1	0	>10m	0	1	29.54	4.69	7.27	14.43	59	12000	0
27	Popilleau Bay	0	0	0	0	0	0	60	40	2	35	1 m	20	0.5	30.10	6.67	8.65	13.70	37	4000	0
13	Francis Bay	0	0	100	0	100	100	0	0	1.5	21	>10m	0	0.5					136	43000	6
34	Hanson Bay	100	0	0	0	0	100	0	0	3	54	>10,	0	1	31.10	3.29	8.10	52.00	31	5800	0
19	Kiddel Point	0	0	0	100	95	90	5	5	3.5	40	>10m	20	1					120	3100	6
20	Lagoon Point	0	100	0	0	100	90	10	0		76	>10m	15	2					66	12600	5
15	Friis Bay	25	0	75	0	50	35	15	50	3.5	106	>10m	0	2	25.82	2.59	8.95	5.97	63	3600	5
30	Salt Pond	0	0	0	2	0	0	67	33	4	0	>10m	0	3	31.11	1.69	7.68	2.58	262	430	2
18	Hart Bay	0	0	50	50	100	65	35	0	5.5	40	>10m	0	0.5					192	2600	0
11	Europa Bay	0	0	100	0	100	30	70	0	2.5	0	>10m	0	4.5					90	500	0
32	Southside Pond	0	0	0	100	25	5	20	75	1	5	>10m	35	15	27.23	2.12	8.20	1.15	105	50	3
28	Privateer Bay	0	0	0	100	75	70	5	25	2.5	0	6 m	30	1					45	14000	6
6	Drunk Bay	0	0	50	50	95	70	25	5	1	0	>10m	0	1.5					60	8100	4

Salinity

Salinity ranged from more than 8 times that of seawater (262 ‰) to slightly below that of seawater (31 ‰) with an average of 93 ‰. Several factors contribute to the overall salinity of the pond: (1) ocean water may come into the pond through the ground or over the berm, thereby increasing the mass of salt in the pond; (2) precipitation and runoff periodically dilute the salinity of the pond; and (3) evaporation concentrates salt in the pond. These factors interact together to determine the salinity of a salt pond at any given time. During on-site field research not much rainfall occurred despite the month of January typically falling at the end of the wet season on St. John. In addition, because of the overall relative lack of rainfall during the "rainy season" of 2002-2003, measured salinity levels in this thesis may be slightly elevated as compared to a "normal" January. Measured salinity levels for each pond are illustrated in Figure 3.1.

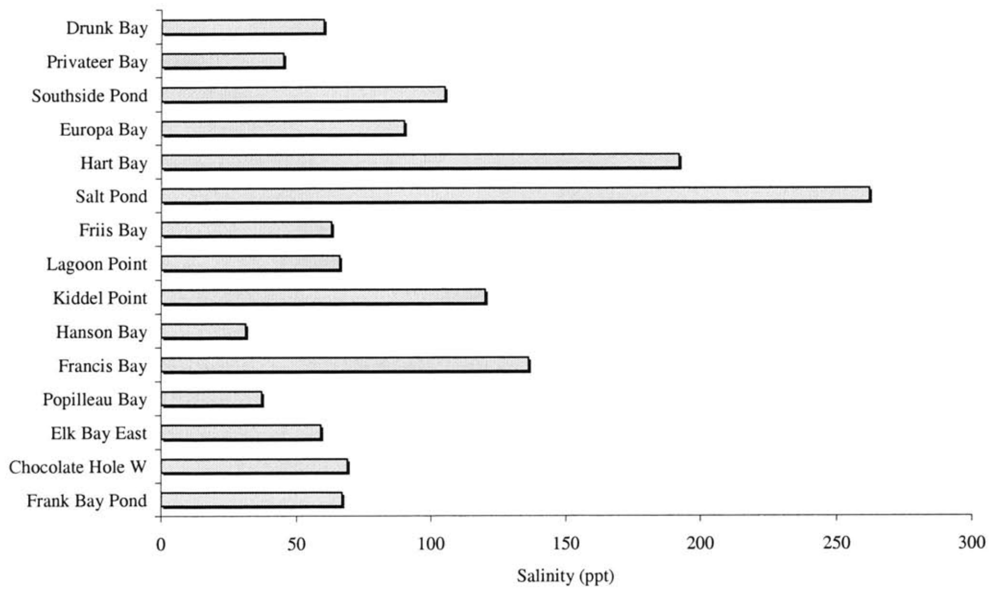


Figure 3.1 Measured Salt Pond Salinity Levels

Housing Density

Housing density data varied from zero houses per square kilometer in more remote sections of the island to just over 400 houses per square kilometer in the most densely populated areas (Figure 3.2). Housing density data measure the number of houses existing in 1996 in each pond's hydrological drainage basin. The wide range of values indicates a range of pond conditions from pristine to strongly influenced by human development. Higher housing density probably indicates more runoff into the pond due to construction and traffic, and may also indicate increased nutrient influx from residential septic systems.

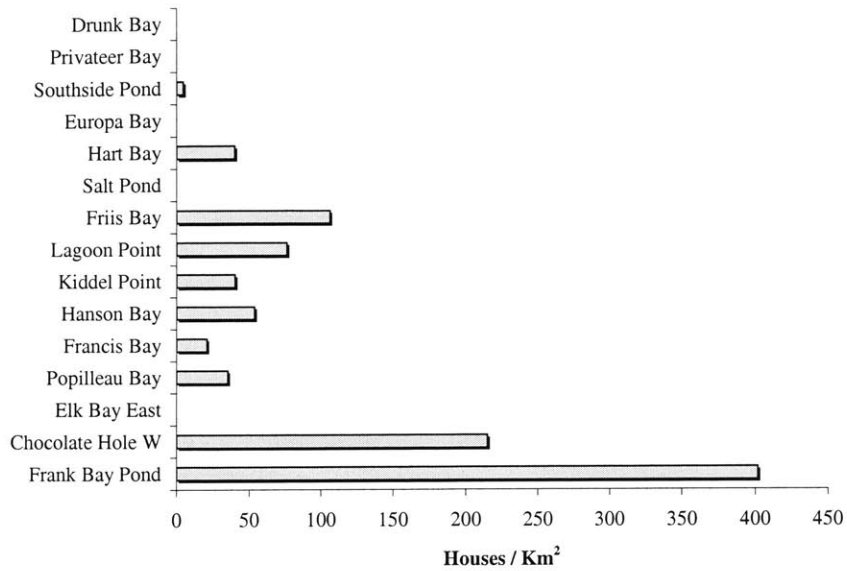


Figure 3.2 Housing Density Per Salt Pond

Nitrate Levels

In this study, nitrate as nitrogen was measured for eight ponds. "Nitrogen compounds enter the environment as nitrates or are converted to nitrates. The nitrates come from many sources including agriculture, fertilizers, sewage, and drainage from livestock" (Coulston, 1987). Elevated nitrogen levels often signal current or impending algal blooms in a body of water, which may be harmful for other pond inhabitants. High phytoplankton levels in the ponds indicate excessive nutrients originating from anthropogenic or natural sources.

Measured nitrate levels generally indicate the amounts and types of runoff that end up in the ponds (Coulston, 1987). High levels of nitrates can adversely affect ecosystem populations within the ponds and may have implications for marine water quality around the island. Although ponds filter sediments and runoff before these materials flow into the ocean, elevated nitrates may make it into the surrounding marine environments because they are highly soluble, persistent, and mobile. Measured nitrate levels are listed by pond in Figure 3.3.

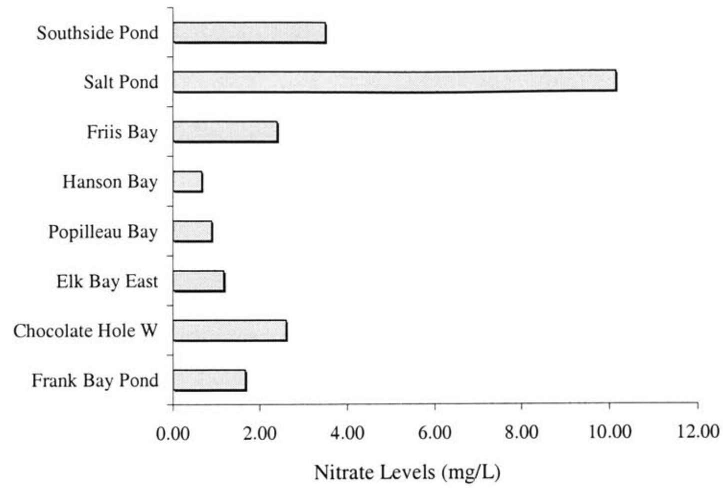


Figure 3.3 Measured Salt Pond Nitrate Levels

Dissolved Oxygen

Oxygen in the water enables oxygen-dependant organisms to live in it. EPA states "waters classified for the protection of fish and wildlife must contain sufficient dissolved oxygen to support aquatic life" (EPA, 1988). Dissolved oxygen levels fluctuate over the course of the day as well as seasonally, but very low levels of dissolved oxygen in a pond indicate ecological problems. Low levels of dissolved oxygen, also called hypoxia, can result from algal blooms in the water. The algae growth will eventually cause elevated levels of algae death, which subsequently consumes oxygen in the water column during decay. Decreases in oxygen can cause impairment or death of organisms in the water. According to EPA, invertebrates experience some production impairment at levels of 5 mg/L, and reach an acute mortality limit at 4 mg/L (EPA, 1999).

The average level of dissolved oxygen measured in the ponds is 3.95 mg/L. The levels of oxygen dissolved in the ponds (Figure 3.4) provide a reference set of data for the ecosystems currently in the salt ponds. Managing the ponds long-term will require dissolved oxygen monitoring to make sure that levels continue to be adequate to support the community living in and depending on the ponds.

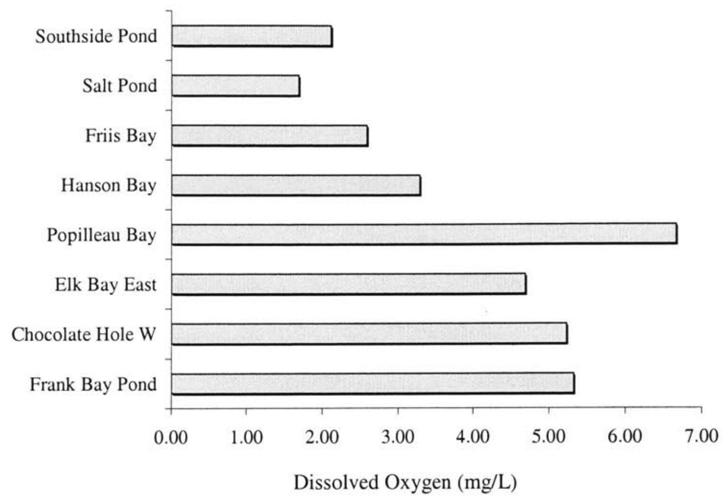


Figure 3.4 Measured Dissolved Oxygen Levels

Macroinvertebrates

In all, fourteen different types of macroinvertebrates (in bold in Table 3.2) were found in the fifteen ponds sampled. The community composition of each pond sampled was slightly different, but most macroinvertebrates were discovered in multiple ponds. The frequency of observation is described in Figure 3.5. All observed taxa are described in detail in Appendix D.

Table 3.2 Macroinvertebrate Inventory

- Animalia
  - Arthropoda
    - Hexapoda
      - Insecta
        - Pterygota
          - Neoptera
            - Coleoptera
              - Adephaga
                - **Dytiscidae**
              - Polyphaga
                - Hydrophiloidea
                  - **Hydrophilidae**
            - Diptera
              - Brachycera
                - **Ephydridae**
              - Nematocera
                - **Ceratopogonidae**
                - **Culicidae**
            - Heteroptera
              - **Corixidae**
  - Mollusca
    - Gastropoda
      - Neotaenioglossa
        - **Hydrobiidae**

- Animalia
  - Ciliophora
    - **Ciliatea**
  - **Rotifera**
  - Annelida
    - Clitellata
      - **Oligochaeta**
  - Arthropoda
    - Crustacea
      - Branchipoda
        - Sarsotraca
          - Anostraca
            - **Artemiidae**
      - Malacostraca
        - Eumalacostraca
          - Eucarida
            - Decapoda
              - Pleocyemata
                - Ocypodoidea
                  - **Ocypodidae**
      - Maxillipoda
        - **Copepoda**
      - **Ostracoda**

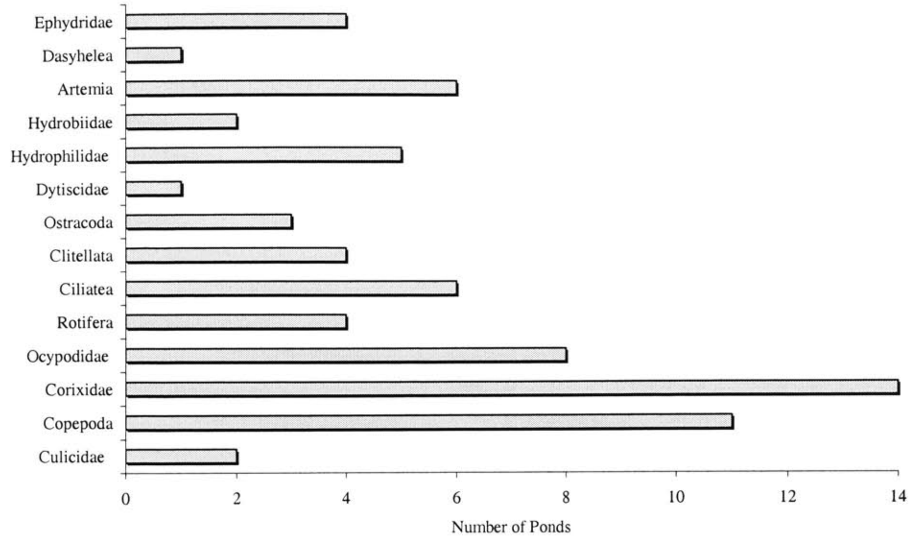


Figure 3.5 Frequency of Macroinvertebrate Observation

As illustrated in Figure 3.5, *corixidae*, or water boatman, was the most frequently observed macroinvertebrate. They were identified in fourteen of the fifteen ponds (93%) surveyed. *Copepoda* was the next most common, found in eleven ponds (73%), and *ocypodidae* were discovered in eight (53%).

Individual characteristics combined with tolerances that each group displays can delineate "sentinel" species to monitor the salt ponds on an ongoing basis. Most macroinvertebrates were found in more than one pond, which provides a range of tolerance levels that each family displays for a given characteristic. Below are the individual macroinvertebrates found by range of salinity (Figure 3.6).

Figure 3.7 shows the ranges of chlorophyll a levels in which each type of macroinvertebrate was observed. Despite the wide range of chlorophyll a levels measured in the ponds, we can see that there are six types of macroinvertebrates living in the ponds with the highest levels of chlorophyll density. Macroinvertebrates present by range of dissolved oxygen and nitrate levels are illustrated in Figures 3.8 and 3.9, respectively.

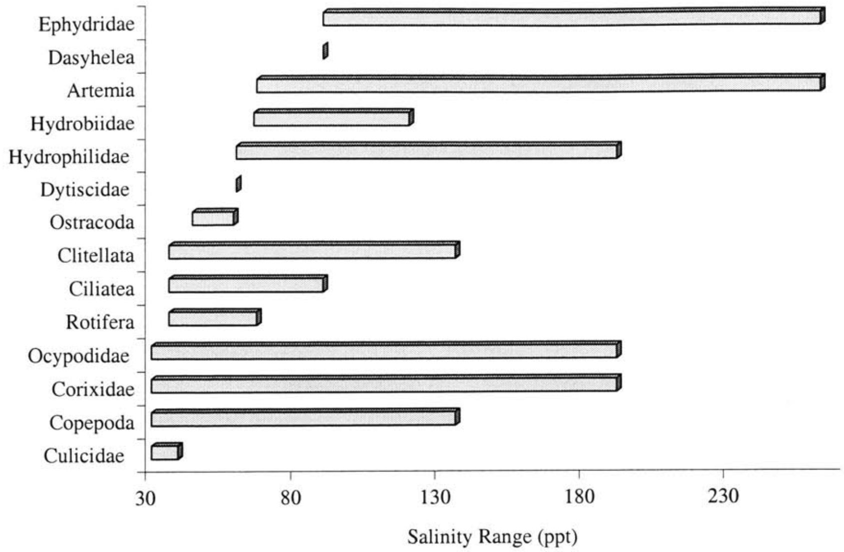


Figure 3.6 Invertebrates Present by Salinity

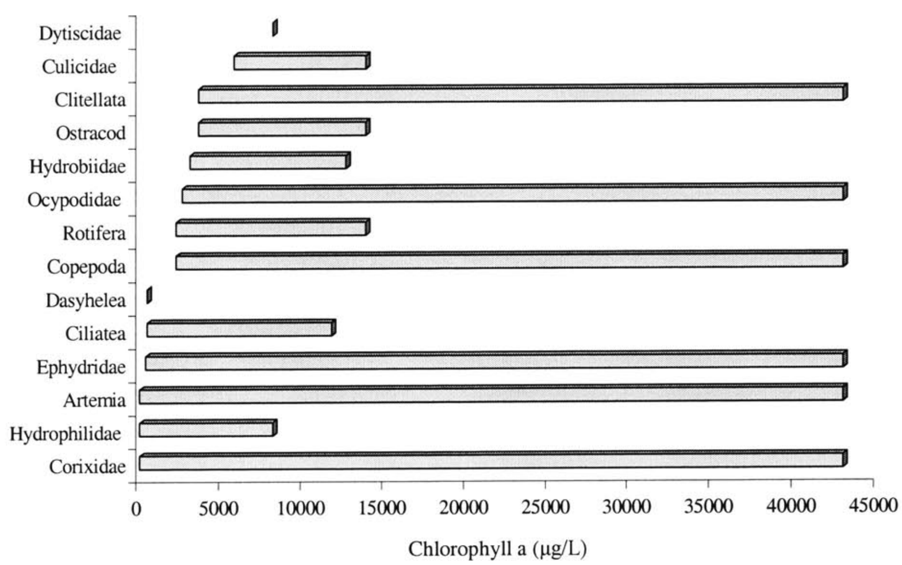


Figure 3.7 Invertebrates Present by Chlorophyll a

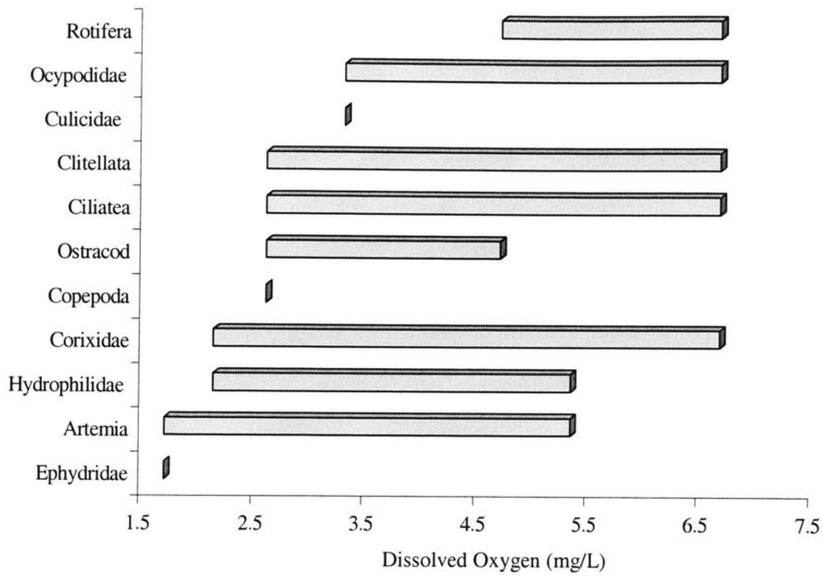


Figure 3.8 Invertebrates Present by Dissolved Oxygen

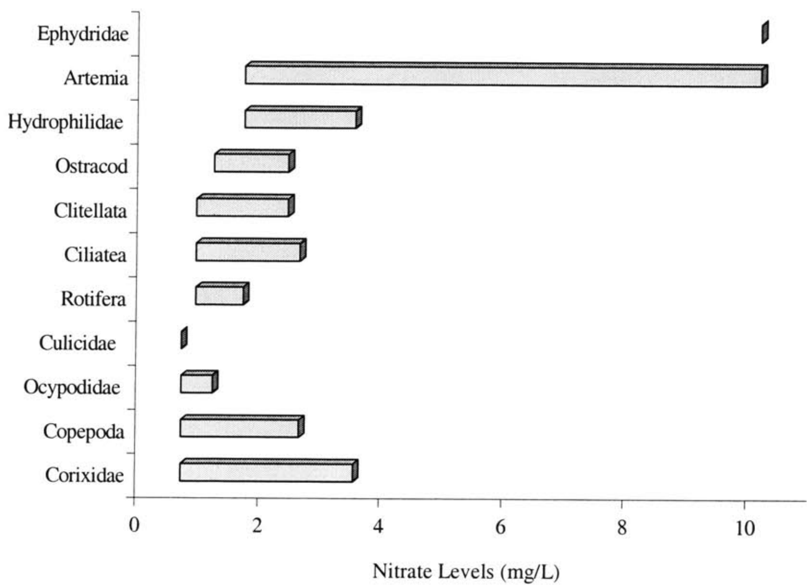


Figure 3.9 Invertebrates Present by Nitrate Levels

Species Richness

In this study, the term "species richness" is used to refer to the total number of different macroinvertebrates found in each pond. This metric is used in this study as the primary indicator of the quality of the water in the pond. The number of species per pond varied from 2 to 6 distinct family types with an average of 4.73. A higher number of species indicates that the pond conditions are favorable to a more diverse set of macroinvertebrates.

Because salt ponds are susceptible to dramatic and rapid fluctuations in conditions due to seasonal and weather factors, macroinvertebrate populations and ecosystems are in a constant state of fluctuation in order to best accommodate the set of conditions at hand. Therefore, species richness as an indicator of the ability of a pond to support macroinvertebrate populations must be considered in conjunction with seasonal and other weather variability not considered in this study. Further research on this correlation is strongly recommended.

The total number of species observed in each pond is illustrated in Figure 3.10.

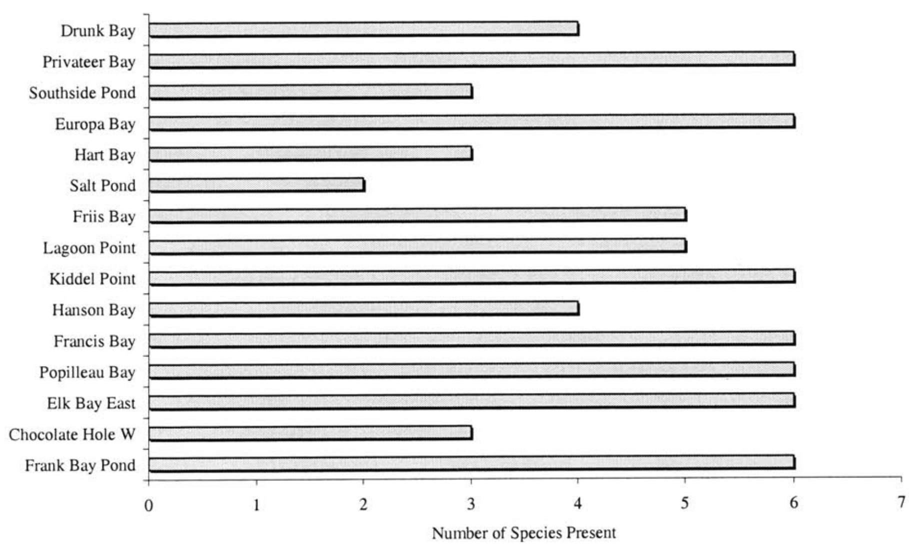


Figure 3.10 Species Richness by Pond

Chlorophyll a

Chlorophyll a is commonly used to determine the abundance of phytoplankton in a body of water (Grove, 1998). Chlorophyll a levels varied by three orders of magnitude among the ponds considered in this study, and seasonal variability may significantly impact chlorophyll levels within individual ponds. Although chlorophyll a as an indicator of pond water quality varies according to the types of water bodies in question, general indicator ranges will be proposed for the fifteen salt ponds sampled on St. John based on the data found in this study. Ongoing study to refine these ranges is recommended as an area for further research.

Chlorophyll a levels found for ponds were generally consistent among the three sample sites within each pond (Appendix G), but the range between separate ponds was extremely large due to a series of factors identified during multivariate regression analysis. Table 3.3 lists the average of the chlorophyll a measurements in each pond as determined by fluorometric analysis.

Table 3.3 Chlorophyll a Measurements

Pond Name	Chlorophyll (µg/L)
Frank Bay Pond	2,200
Chocolate Hole West	6,800
Elk Bay East	12,000
Popilleau Bay	4,000
Francis Bay	43,000
Hanson Bay	5,800
Kiddel Point	3,100
Lagoon Point	13,000
Friis Bay	3600
Salt Pond	430
Hart Bay	2,600
Europa Bay	500
Southside Pond	50
Privateer Bay	14,000
Drunk Bay	8,000

PAIR REGRESSION ANALYSIS

Regression analysis was performed for several pairs of variables collected during the study to determine relative correlation between data sets. This analysis was used as a starting point to determine which variables may be correlated in the multivariate regression analysis, detailed in subsequent sections.

All Ponds

The statistical results in Table 3.4 are a result of analysis performed on variables representing all fifteen ponds sampled. The results are sorted in Table 3.4 based on the R^2 value, which indicates the closeness of the correlation; a value of $R^2=0$ means that the values are not at all correlated, while a value of $R^2=1$ indicates that the data sets are exactly correlated. Results with R^2 values less than 0.1 have been omitted.

Table 3.4 Pair Regression Results - All Ponds

Y axis	**X axis**	**Regression**	**R^2**
Chlor-a	Mangrove Cover	y = 17296x + 278.37	0.344
Berm Height	Salinity	y = 0.0114x + 1.3751	0.300
Salinity	Species Richness	y = -23.541x + 204.9	0.290
Berm Height	Species Richness	y = -0.3515x + 4.1213	0.150
Pond Depth	Species Richness	y = -0.9747x + 7.3134	0.149
Chlor-a	Species Richness	y = 2623.2x - 4522	0.125
Pond Depth	Chlor-a	y = -0.0001x + 3.5778	0.107

As can be seen from Table 3.4, there are no significant correlations in the pair regressions performed for the full set of ponds. However, chlorophyll a is weakly correlated with the amount of mangrove cover for ponds. This result seems to indicate consistency between productive plant growth areas; more nitrogen may be available to the plants in these ponds.

Based on the R^2 value found in regression analyses of the above variables, we can conclude that several of the data types are related. Species richness appears to have some positive correlation with pond depth and chlorophyll a levels in the pond, and a negative correlation with salinity and berm height. These results make sense because each of these characteristics affects the relative ease of survival in a wetland habitat, no matter what type of macroinvertebrate.

Pond Subset

Several additional data were available for a subset of eight ponds on St. John: nitrates, dissolved oxygen, temperature, turbidity, and pH. To further explore correlation between data sets, this subset of ponds was then analyzed to determine regression relationships between the extended set of data as shown in Table 3.5. Results with R^2 values less than 0.1 have been omitted.

Table 3.5 Pair Regression Results - Pond Subset

Y axis	X axis	Regression	R^2
Nitrate	Salinity	y = 0.0412x - 0.6857	0.986
Delta	Species Richness	y = -0.3913x + 5.4556	0.540
Nitrate	Species Richness	y = -1.4057x + 9.0326	0.531
Dissolved Oxygen	Species Richness	y = 0.748x + 0.6774	0.450
Delta	Dissolved Oxygen	y = -0.9329x + 6.0566	0.394
Nitrate	Dissolved Oxygen	y = -1.0831x + 7.1607	0.392
Dissolved Oxygen	Salinity	y = -0.0146x + 5.2178	0.372
Delta	Berm Height	y = 1.2084x - 0.3476	0.297
Delta	Chlor-a	y = -0.0004x + 3.9848	0.288
Nitrate	Chlor-a	y = -0.0004x + 4.7509	0.285
Dissolved Oxygen	Berm Height	y = -0.6871x + 5.4961	0.212
Dissolved Oxygen	Chlor-a	y = 0.0002x + 3.0343	0.205
Dissolved Oxygen	Pond Depth	y = -0.1681x + 4.5698	0.199
Dissolved Oxygen	Housing Density	y = 146.99x + 2.9142	0.174
pH	Chlor-a	y = -6E-05x + 8.4237	0.170
Temperature	Species Richness	y = -0.6406x + 32.379	0.157
Dissolved Oxygen	Mangrove Cover	y = 2.3861x + 3.4401	0.156
Turbidity	Chlor-a	y = 0.0016x + 6.5209	0.142
Dissolved Oxygen	Total Cover	y = 0.0159x + 3.3236	0.117
Temperature	Chlor-a	y = 0.0002x + 28.608	0.109

Nitrate and Salinity

Based on the pair regression analysis results in Table 3.5, nitrate levels and salinity were by far the most closely correlated variables for the eight ponds measured in the study subset (R^2=0.99).

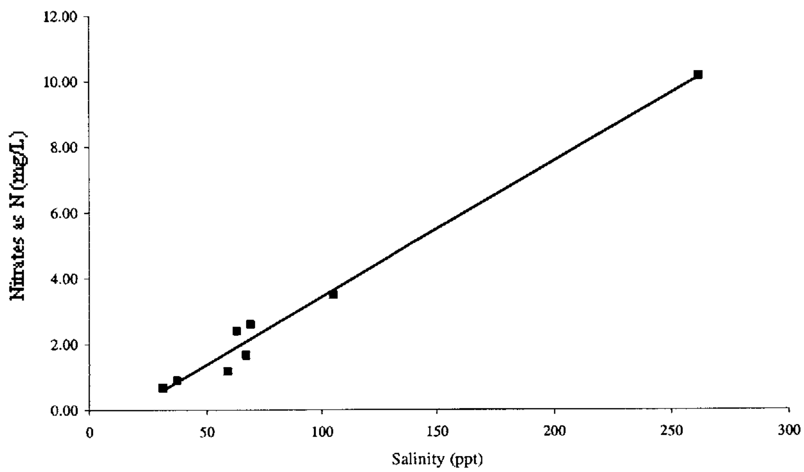


Figure 3.11 Nitrate (as N) vs. Salinity Regression Curve

The closeness of this correlation invited speculation as to the reason. One possible explanation for this linear relationship is that nitrates and salt are present in the same ratio and are concentrated to different amounts by evapotranspiration and precipitation. Since salt ponds started out as bays that eventually close, and are fed by the ocean through groundwater it follows that this ratio would be equal to that of seawater. To explore this hypothesis, data was obtained from the National Oceanic and Atmospheric Administration (NOAA) to compare seawater ratios to the ponds.

Data from latitude 18.5 and longitude 64.5 provided seawater data on nitrate (0.214 mg/L) and salinity (36.5 ppt) in the ocean near St. John (NOAA, 2001); a line was constructed through this point and the origin. If nitrate and salinity were concentrated in a common proportion, this line would predict nitrate levels based on the measured salinity of the pond. These predicted nitrate levels may be seen in Figure 3.12. Comparing predicted nitrate levels to measured nitrate levels (also in Figure 3.12) for each pond shows that the measured nitrate level is greater than the predicted nitrate level based on seawater data. Therefore, there appears to be one or more additional nitrate sources in the ponds. Further research on this topic is recommended.

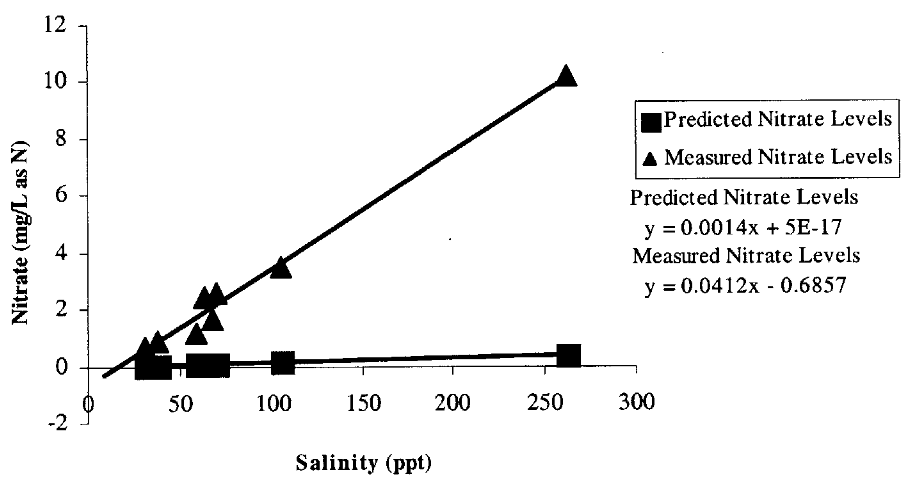


Figure 3.12 Nitrate (as N) - Salinity Correlation: Predicted vs. Observed

From the measured and predicted nitrate levels in Figure 3.12, a "delta" value was calculated to measure nitrate above values predicted by seawater. This "delta" value measures the difference between measured and predicted nitrate levels. Delta was then compared via regression analysis to species richness and to housing density. Delta was significantly and negatively correlated with species richness (R^2=0.54) as illustrated in Figure 3.13. Removal of the one extreme outlier point reduces the R^2 value to 0.4293. However, the delta value was not correlated with housing density; housing density as calculated in this study may not be an appropriate indicator value for a measure of human impact.

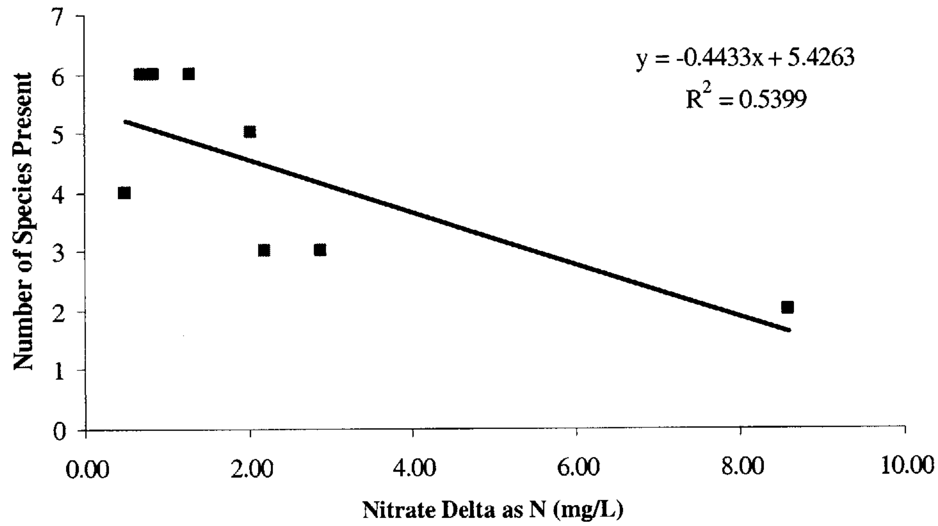


Figure 3.13 Species Richness vs. Nitrate (as N) Delta Regression Curve

MULTIVARIATE REGRESSION RESULTS

Multivariate regression analysis determines the strength of correlation among an independent variable and one or more dependent variables. This analysis is performed on an iterative basis in Microsoft Excel until all dependent variable p-values are less than 0.05, indicating a confidence level of greater than or equal to 95% that the variables are correlated. Multivariate regression results are presented for species richness, chlorophyll a, and dissolved oxygen.

Species Richness

In the multivariate regression analysis of species richness, the most significantly correlated factors were berm height, temperature, pH, dissolved oxygen, and nitrate levels.

Species Richness = 0.70*Berm Height (m) – 0.60*Temperature (°C) – 1.66*pH + 0.94*Dissolved Oxygen (mg/L) – 0.19*Nitrate (mg/L as N) + 30.98

$R^2 = 0.9944$

With p-values of:

Variable	P-value

Berm Height (m)	0.0081
Temperature (Degrees C)	0.0020
pH	0.0057
Dissolved oxygen (mg/L)	0.0021
Nitrate (mg/L as N)	0.0127

Berm height may be an indicator for the age of the pond. Since salt ponds are born as bays that close over because of coral growth, a higher berm probably indicates the maturity of a pond. Ponds that have been well established are also expected to have a well-developed ecosystem due to lessened variability of pond conditions. Newer ponds may be subject to more ocean influence and their ecosystems may be in the process of evolving from the original to a more sustainable one.

Temperature and pH are also indicators of the health of a pond, although these factors do not vary widely amongst the ponds measured. Variability of these two factors should be assessed during ongoing pond monitoring to determine whether fluctuations in temperature or pH are something to be concerned about as opposed to "normal" seasonal fluctuations.

It is no surprise that dissolved oxygen is so closely related to species richness because of the ecosystem's dependence on oxygen. The solubility of oxygen in water decreases as temperature and salinity increase, which affects DO levels in ponds on St. John. Many of the types of invertebrates found in the ponds are able to sustain periods of depleted oxygen by forming protective barriers or modifying other activities, so ponds with lower oxygen levels would likely be capable of sustaining larger communities if the DO levels were allowed to increase (Guenther, undated).

Elevated nitrates are usually considered to be indicative of current or future problems with macroinvertebrate populations. Algal blooms may be caused by an overabundance of nitrates; when this occurs, the algae eventually blocks the light and chokes the pond, subsequently dying and decaying which leads to hypoxic conditions (Thomann and Mueller, 1987). Even if the nitrates are not leading to these eutrophic conditions, they indicate an external source of nutrients in the pond that will likely result in unfavorable conditions for the pond invertebrates.

Chlorophyll a

In the multivariate regression analysis, chlorophyll was significantly related to temperature, pH, dissolved oxygen, nitrate levels, and salinity levels.

$$\text{Chlorophyll a } (\mu g/L) = -\,1318.2*\text{Temperature } (^\circ C) - 15125.5*\text{ pH} + 1889.0*\text{Dissolved Oxygen } (mg/L) + 15368.8*\text{Nitrate } (mg/L \text{ as N}) - 666.7*\text{Salinity } (‰) + 173000.69$$

$$R^2 = 0.955$$

With p-values of:

Variable	P-value
Temperature (Deg C)	0.0442
pH	0.0134
Dissolved Oxygen (mg/L)	0.0372
Nitrates (mg/L as N)	0.0236
Salinity (‰)	0.0211

Chlorophyll a levels have a measured correlation with all the elements that enhance or hinder phytoplankton growth. First, chlorophyll levels in the ponds are correlated with dissolved oxygen levels. Oxygen is generated by photosynthesis by phytoplankton at the base of the pond food chain (Grove, 1998), and this is evident in the positive correlation between the two data sets. Nitrates are positively correlated with chlorophyll levels due to the nitrogen-dependence of the plants growing in the ponds. Increased nitrate levels lead to increased phytoplankton growth, which can be detrimental to other pond biota.

Consistent with the literature, salinity is negatively correlated with chlorophyll a levels (Bayrakdar, 1994). Even if a species is highly tolerant of salinity levels, that species will generally do better in the lower part of its salinity range. This is because less energy needs to be devoted to osmoregulation of the organism and can be devoted to growth (Swanson, 1998). Also, less oxygen is able to be dissolved in ponds with higher salinity levels.

Again, correlation with temperature and pH should be further measured to determine the variability in these two factors in an average year in the ponds, and whether greater fluctuations have any significant effects.

Dissolved Oxygen

Dissolved oxygen levels were also measured for a pond subset, and these data may also be used to indicate or explore ecosystem "friendliness." In the multivariate analysis of dissolved oxygen, there was significant correlation determined with depth, berm height, temperature, and pH.

$$\text{Dissolved Oxygen (mg/L)} = -0.24*\text{Depth (ft)} - 1.4*\text{Berm height (m)} + 0.37*\text{Temperature (°C)} + 1.85*\text{pH} - 17.98$$

$$R^2 = 0.9041$$

With p-values of:

Variable	P-value

Depth (feet)	0.0151
Berm Height (m)	0.0059
Temperature (Deg C)	0.0294
pH	0.0259

Dissolved oxygen is inversely correlated with berm height. This correlation may be explained by the amount of shelter from wind that the berm provides. Higher wind speed increases the amount of oxygen that can diffuse into a water body from the atmosphere; a lower berm would provide less shelter from the wind and therefore more oxygen could dissolve into the water from the air (WOW, undated). Inverse correlation with water depth may simply be a result of the ratio changes as a result of more water volume in deeper ponds.

Temperature and pH are also related to dissolved oxygen levels although these values are fairly constant across the range of ponds sampled. Again, measurement of fluctuations in these values would help to determine the extent and significance of the correlation.

CONCLUSIONS

Sentinel Species

Several conclusions can be drawn about some of the taxa observed in the salt ponds in this study, and the range of conditions in which they were observed. For example, *ephydridae* and *corixidae* have emerged as the most tolerant macroinvertebrates over all conditions measured. Due to their widespread nature they are obviously an important part of the pond ecosystem. For the ponds measured, only *artemiidae* and *ephydridae* were found in ponds with nitrate levels above 4 mg/L; similarly, these two macroinvertebrates were found at the lowest levels of dissolved oxygen. Because of this range of tolerance, presence of these two species alone does not provide adequate information about the water quality of a pond.

Based on the data collected in this study, it is possible to identify species that can be viewed as "sentinels" for conditions in the pond. One suggested organism is *ocypodidae,* which is present in a wide range of ponds over a range of salinities (31 to 192 ‰ - see Figure 3.6) and are less tolerant of other conditions that are correlated with a decline in species richness. These macroinvertebrates, commonly known as fiddler crabs, are easy to identify because of their relatively large size and their burrows around the shallow edges of the pond. Presence of *ocypodidae* is a useful and relatively easy factor to monitor during long-term oversight of the salt ponds as a high-level indicator of other factors at work in the pond. In addition to their range of presence and tolerance to environmental factors measured in this study, crabs are viewed by the literature as a sign of ecosystem health. "Crabs are currently regarded as a key ecological element in mangrove forests" (Drude de Lacerda, 2002). Also, "fiddler crabs are perhaps the most common macrospecies in the mangrove and are an important indicator species of changes in hydrology and water quality; they are among the first organisms to leave a disturbed system" (Fifth, 1999).

Nitrate Sources

The results of this study seem to contradict the original hypothesis that salt pond health is adversely affected by human development. Since species richness, chlorophyll, nitrate, and dissolved oxygen measurements are not significantly correlated with housing density, it appears that human population density measured in houses per square kilometer does not currently cause eutrophic conditions in salt ponds, algal blooms, hypoxia, or decreased number of species. These results do not suggest that if land development continues unchecked there will be no impact on salt ponds, but rather that more research is needed to determine the extent that other human activities have on salt ponds. As the human population density increases on St. John, human contributions to nutrient loading in the ponds is an issue with which to be concerned.

It is also possible that the full extent of human development is not accurately measured by the "housing density" metric. Other factors may come into play including runoff from different types of roads and the amount of travel they receive, livestock contributions to nutrient levels, or other non-residential land uses. Typically, elevated nitrogen levels result from human activities such as waste disposal, runoff, and agriculture. On St. John, if the nitrate levels are not correlated with housing density, there could also be another unmeasured source (or group of sources) of nitrogen that should be investigated and controlled. One possible explanation for this is the migratory pattern of goats and donkeys around the island. Since livestock are seldom fenced on the island, nitrate influx may not be strictly related to human population density, and so may not be accurately represented by housing density calculations. Measuring nutrient contribution from nonhuman sources may be challenging but must be confirmed or ruled out as a factor to determine action plans to reduce or limit nitrate levels for individual ponds. Further pond study will help to resolve these and other questions.

Chapter 4 - RECOMMENDATIONS & AREAS FOR FURTHER RESEARCH

To date, few data have existed about the species living in the salt ponds, their relationships to each other and the ponds, and the external factors that affect them. In addition, the impacts of human activities on both the ponds and resident organisms have been poorly known. This study provides a baseline of information for fifteen ponds on St. John, U.S. Virgin Islands. To fully understand and preserve the ecological value of these salt ponds, several actions are recommended as next steps.

1. Monitor sentinel species and metrics

This thesis concludes that several habitat characteristics and species may be considered "sentinels" for the relative health of a salt pond. These parameters are easily monitored and may be observed on an ongoing basis by trained volunteers. For example, mangrove populations, because of their sediment filtering capabilities as well as their relative vulnerability to human activities, can be easily monitored at the ponds. Changes in mangrove community composition or distribution may signal important changes in the ponds.

Presence or absence of fiddler crabs is also easy to monitor in ponds. Disappearance of fiddler crabs in ponds indicates a "red flag" that a pond is having problems sustaining its ecosystem. It will also signal shifts in the oxygen levels and nutrient cycling of the ponds. Trash levels in salt ponds are also an obvious signal that ponds may be in danger. Additional study will suggest other sentinel metrics available for monitoring.

2. Begin an ongoing salt pond measurement program

Although fifteen ponds were sampled during this research trip, there are more than thirty ponds on the island. Accessibility issues, time constraints, and pond dryness all contributed to the choice of ponds for this study. A larger sample size of ponds will extend the data sets and increase the statistical accuracy of the results.

This study was conducted during the month of January, 2003. Although January is typically at the end of the rainy season on St. John, 2002-2003 had been a particularly dry year that contributed to excessive dryness of the ponds. These unusual conditions may have skewed the results somewhat from samples taken in January of an "average" year. Also, due to the lack of seasonal data, variations due to migratory patterns, rainfall, and other seasonal changes will not be adequately represented by this study.

For a group of water bodies, ranges of chlorophyll levels are often used to determine relative trophic states and categorize ponds for short-and long-term management strategies. For example, for estuaries in the mid-Atlantic region, EPA defines ranges as follows: good, < 15 mg/L; fair, 15-30 mg/L; poor, > 30 mg/L (EPA, 2003). These ranges appear to be salient for the group of ponds in this study as well. Although the correlation between nitrate and chlorophyll is not significant, phytoplankton must be monitored to identify eutrophic conditions in the ponds.

Because salt ponds have such an extremely high degree of variability of conditions, the biota characteristics may vary somewhat in response to factors such as weather, rainfall, and other population variations; because of this, biota composition in salt ponds may lag behind existing habitat conditions. Pond biota may be almost perpetually in the process of regulating to external conditions and so a full continuum of data should be gathered as part of an ongoing pond-monitoring project. Seasonal pond measurements will provide a more complete picture of pond conditions and responses to external factors.

3. Perform nitrogen balance for ponds

Although the nitrate levels seem to indicate that more nitrates are present in the ponds than would occur simply from seawater evaporation, there are not enough data at present to speculate about additional sources of nitrogen in the ponds. There are many nitrogen sources and sinks that are unaccounted for in this study. For example, the microbial mats common in hypersaline, evaporative environments act as a nitrogen sink for the water column (Stal, 1994), but may also block nitrogen from entering through the groundwater. Use of the pond basins by livestock and domestic and feral animals is a source of nitrogen, and phosphorus levels may impact nitrogen cycling in the salt ponds. Pond usage by birds may also affect nutrient levels in the salt ponds. Additional processes including denitrification, sorption, bacterial fixation, and atmospheric deposits should be considered. A detailed nitrogen balance would help to determine sources, sinks, and impacts of nitrogen levels on the salt ponds.

4. Conduct sediment studies for ponds

Salt ponds serve as sediment filters for runoff on St. John. Increased sedimentation rates due to construction practices and lack of erosion control pose a serious risk to macroinvertebrate communities as well as the ponds in general. "Declines in invertebrate density and taxonomic richness, accompanied by shifts in taxonomic composition, are generally associated with acute sedimentation...Direct mechanisms include loss of invertebrate habitat, burial of invertebrates, burial of major food sources...and accumulation of particles on respiratory and feeding structures of macroinvertebrates ...Indirect mechanisms include those changes that alter the productivity of algae, bacteria and fungi, as well as those that affect the decomposition of plant detritus" (Martin, 2001).

In a study conducted by Martin and Neely (2001), increased sedimentation was found to decrease invertebrate density and species richness compared with controls. Some of the macroinvertebrates in that study were also found in the salt ponds of St. John. For example, *hydrophilidae* larvae density was significantly decreased by increased sedimentation. *Dytiscidae* adult population decreased by 53%. Interestingly, in Martin and Neely's study all the invertebrates that are also common to the St. John's ponds survived both in sedimented and non-sedimented control areas even though their densities decrease. Therefore, these invertebrates demonstrate tolerance to some sedimentation (*dytiscidae*, *hydrophilidae*, *ceratopogonidae*, *culicidae*, *ephydridae*, *oligochaeta*, and *gastropoda*). Also, not all groups are affected in the same way; for example, *oligochaeta* populations remained mostly unchanged during the sedimentation study.

Sediment composition and history may provide some insight on the ecological development of the salt pond as well as the chemical makeup of each salt pond environment. Sedimentation rates and content should be studied to determine whether this is a significant source of nutrients in the ponds, as well as whether and to what extent human activities are affecting the ponds.

5. Consider implementation of buffer zones

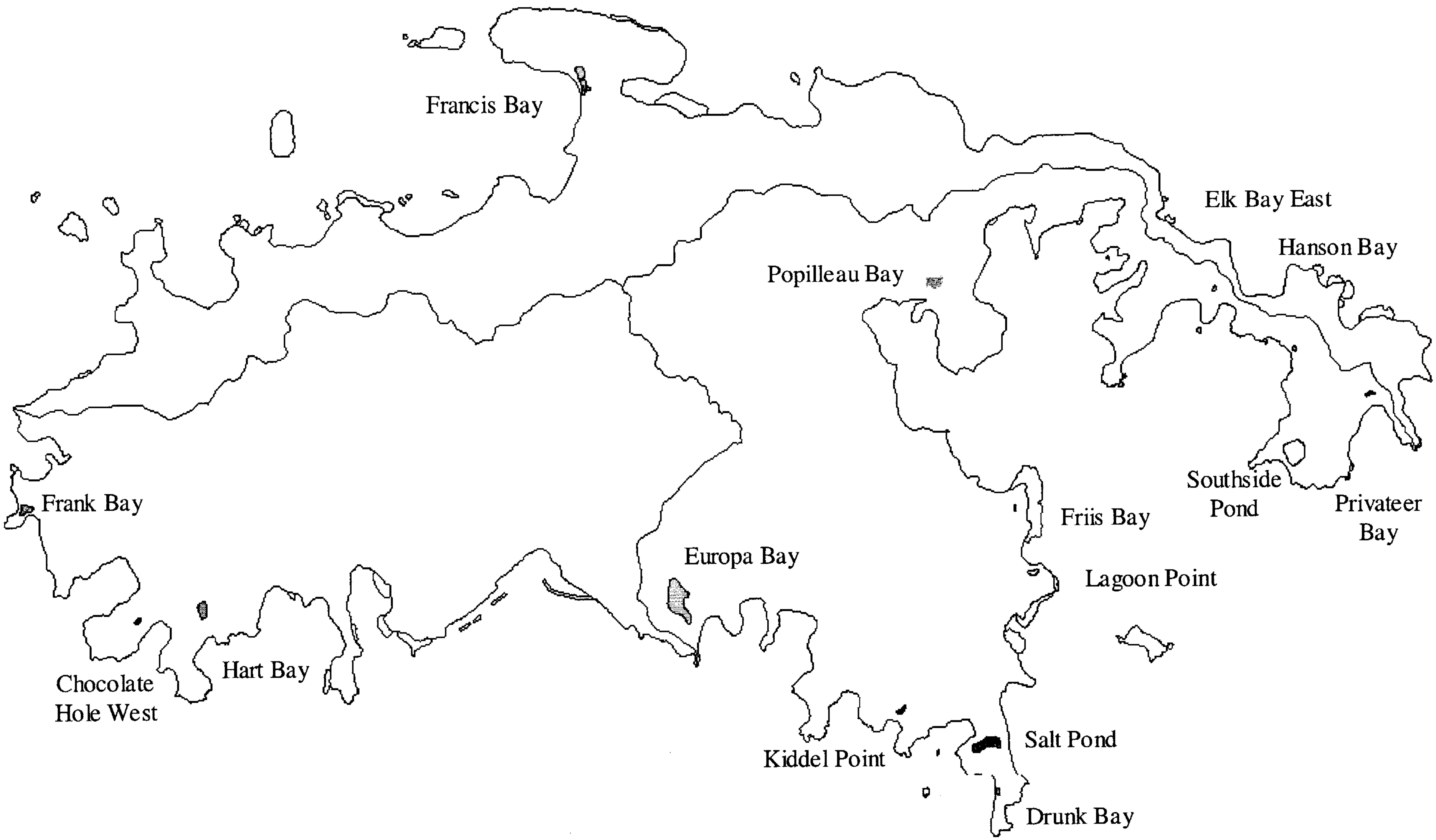
An adequate buffer is crucial to preserving salt ponds. According to <u>Applied Wetlands Science and Technology</u> (Kent, 2001):

> There are several reasons why a buffer is thought to enhance the wildlife habitat value of a coastal wetland. Many wildlife species that live in wetlands depend on the surrounding upland for cover, nesting, foraging, and migration. According to the classical ecological theory of the ecotone, wildlife will be more abundant at the wetland-buffer boundary because two habitat types coexist in close proximity. Many birds and mammals forage on the abundant invertebrates and fish of a salt marsh but require the surrounding upland for nesting or as refuge during high tides. In addition to providing an alternative source of essential resources, a buffer also insulates the animals of the wetlands from disturbance from developments located around its periphery...Human activity brings not only noise but domestic animals and those native and alien wildlife...that are well adapted to human habitation and often compete with native wildlife in transitional areas. A 90 m distance has been recommended to provide a buffer against disturbance around state and federal wildlife refuges and conservation areas.

Implementing a buffer will be easier for some ponds than others, but this practice may be best suited to pond basins where new home construction is light or has not been started. Buffered ponds may be used as controls for ongoing monitoring as well. Buffering ponds may consider more than just construction practices. Limiting foot traffic within several meters of the pond and/or installing fences to keep goats, donkeys, and domestic animals away from the ponds should also be considered.

The implementation of these five recommendations will provide a more complete view of pond conditions over time while taking initial steps to protect the ponds from damage.

APPENDIX A : SALT PONDS STUDIED ON ST. JOHN, USVI



APPENDIX B : NATIONAL PARK SERVICE POND LIST (1998)

	Pond	Ownership / Jurisdiction	Area (Hectares)[1]
1	Borck Creek		0.36
2	Brown Bay	National Park Service	2.10
3	Chocolate Hole East		0.36
4	Chocolate Hole North		3.75
5	Chocolate Hole West		0.20
6	Drunk Bay	National Park Service	0.23
7	Elk Bay Eeast	National Park Service	0.17
8	Elk Bay South	National Park Service	0.20
9	Elk Bay West	National Park Service	0.33
10	Enighed Pond		8.70
11	Europa Bay	National Park Service	5.40
12	Fortsberg		0.23
13	Francis Bay	National Park Service	1.00
14	Frank Bay		0.80
15	Friis Bay		0.32
16	Grootpan Bay	National Park Service	9.75
17	Harbor Point		0.60
18	Hart Bay		1.20
19	Kiddel Bay	National Park Service	0.40
20	Lagoon Point		0.20
21	Great Lameshur East	National Park Service	0.42
22	Great Lameshur West	National Park Service	1.80
23	Little Lameshur	National Park Service	0.75
24	Leinster	National Park Service	0.50
25	Mt Pleasant	National Park Service	0.16
26	Newfound Bay		2.90
27	Popilleau Bay	National Park Service	0.23
28	Privateer Bay		0.36
29	Reef Bay	National Park Service	3.40
30	Salt Pond	National Park Service	2.4
31	Salt Pond Bay	National Park Service	0.34
32	Southside Pond		3.9
33	Turner Point	National Park Service	0.23
34	Hanson Bay	National Park Service	

[1] Pond area was measured by Carolyn Stengel of the National Park Service in 1998. Hanson Bay was not included in the Park Service report.

Appendix C : Individual Pond Results

Pond Name	Pond Number
Chocolate Hole West	5
Drunk Bay	6
Elk Bay East	7
Europa Bay Pond	11
Francis Bay Pond	17
Frank Bay Pond	14
Friis Bay Pond	15
Hanson Bay Pond	34
Hart Bay Pond	18
Kiddel Bay Pond	19
Lagoon Point Pond	20
Popilleau Bay Pond	27
Privateer Bay Pond	28
Salt Pond	30
Southside Pond	32

CHOCOLATE HOLE WEST

Sampled January 8, 2003

Chocolate Hole West is located near Cruz Bay, which is St. John's major tourist area and most highly developed region of the island but, in contrast to Frank Bay Pond, is located some distance from the town's center. In addition, Chocolate Hole West is poorly accessible; one can only get to the pond through private property or by walking a distance along the beach. The pond is currently owned by a couple that resides on St. John about 4-6 months per year; previously, the house had functioned as a bed and breakfast. This area has a approximately four homes located upgradient of the pond on one side.

Some sandy fill appears to have been placed in the pond near the house; the other 95% of the pond's bank is covered by dense vegetation. Most of the cover around the pond is a mix of mangroves: about 50% are black mangroves, 10% are white, and 40% are gray. Black mangroves are located at the edge of the pond, and gray mangroves are found behind the black mangroves closer to the ocean on the berm side. The berm is comprised of coral and rubble, and is about 2-3 m high. In general, the pond sediment is very soft black gelatinous mud besides some rubble near the berm, and the sandy fill area. The boundary width is greater than 10 m, and the area of the bank appearing to be affected by erosion is about 5%.

Corixidae, *copepoda*, and *ciliatea* were present in this pond, although fish were not. Chocolate Hole West is one of a triad of ponds located near Chocolate Hole Bay. Since the National Park Service Report generated in 1998 (Stengel, 1998), both Chocolate Hole North and Chocolate Hole East have been opened to the ocean for flushing.

Table C.1 Chocolate Hole West Pond Measurements

Land Use	7078 houses/km^2
Depth	4 ft
Temperature	33.9°C
Dissolved O_2	5.24 mg/L
pH	8.27
Turbidity	9.55 NTU
Salinity	69 ppt
Chlorophyll a	6775 µg/L
Berm Height	2.5 m
Nitrate	2.60 mg/L

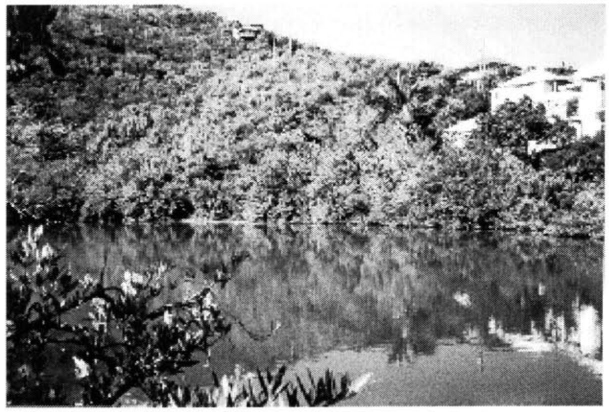


Figure C.1 Chocolate Hole West

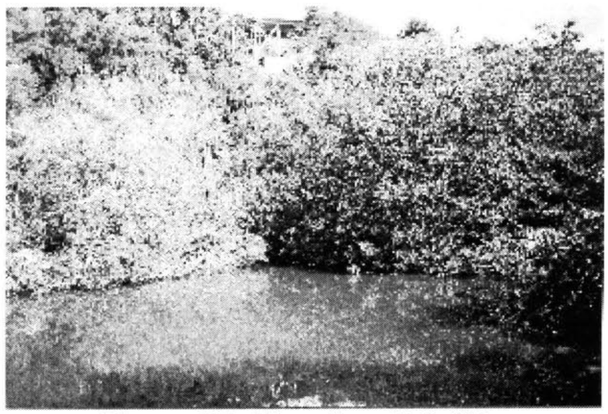


Figure C.2 Chocolate Hole West

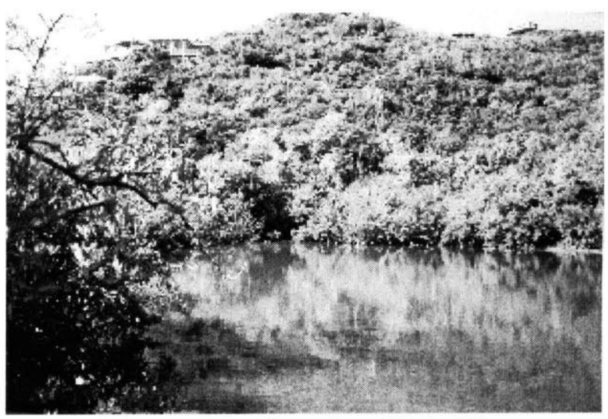


Figure C.3 Chocolate Hole West

DRUNK BAY

Sampled January 20, 2003

Drunk Bay Pond is located past Salt Pond Bay in the National Park down a walking trail. Although this trail is well maintained, the pond is somewhat difficult to access and so may be relatively undisturbed, with many Christmas plants and cacti between the trail and the pond access point. About 95% of the pond's banks have cover, and the pond's boundary is greater than 10 meters. About 70% of the vegetation around the pond is mangrove, with equal parts white and gray. The pond does not appear to be affected by erosion.

The one-meter high berm is made up of rock, coral, and rubble with mangroves, cacti, and century plants growing. The pond sediment is fine brown cover that is grainy and appears to be decaying plant material over black sulphurous sediment. The mud is fairly soft somewhat but is supported by a firmer, somewhat rocky underlayer. *Corixidae*, *copepoda*, *hydrophilidae*, and *dytiscidae* were observed in this pond.

Table C.2 Drunk Bay Pond Measurements

Land Use	0 houses/km^2
Depth	1.5 ft
Temperature	-
Dissolved O_2	-
pH	-
Turbidity	-
Salinity	60 ppt
Chlorophyll a	8,129 μg/L
Berm Height	1 m
Nitrate	-

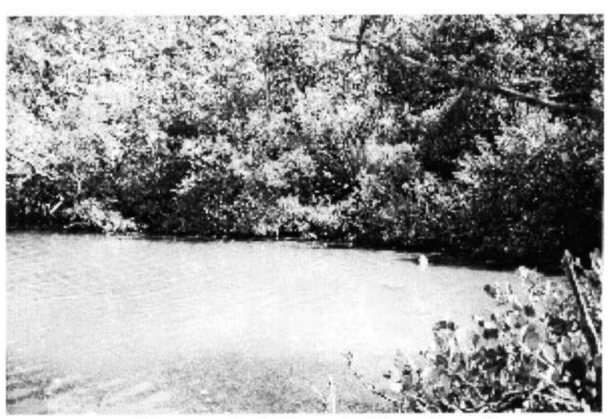


Figure C.4 Drunk Bay Pond

Figure C.5 Drunk Bay Pond

ELK BAY EAST

Sampled January 9, 2003

Elk Bay East is one of a group of three ponds that are found along Route 10 on the way to St. John's east side; these ponds are located in the National Park. Elk Bay South and Elk Bay West were both dry at the time of the study and therefore were not sampled; the water level in Elk Bay East was very low.

Elk Bay East is the only pond found in this study where all four types of mangroves coexist. Red mangroves formed a thick barrier between the pond and the ocean on the berm, and were also found along the ocean shore in Elk Bay. About 30% of the pond's bank was unvegetated; of the vegetated area, all of the plants were mangroves. Red mangroves comprised about 50% of the cover around the pond; black, white, and gray mangroves comprised 5%, 30%, and 15%, respectively. Red mangroves formed a thick barrier between the pond and the ocean on the berm, and were also found along the ocean shore in Elk Bay. The berm is composed of sand, silt, and soil, and is about 1m high. The pond's boundary is greater than 10 m, and no erosion seems to be affecting the pond.

The pond's sediment medium is a bacterial mat, mustard-green in color, over a more solid underlayer. Many twigs, leaves, and mangrove seeds were embedded in the pond sediment. *Corixidae*, *copepoda*, *rotifera*, *ciliatea*, *ostracoda*, and *ocypodidae* were found in this pond; fish were not present.

Table C.3 Elk Bay East Pond Measurements

Land Use	0 houses/km^2
Depth	1 ft
Temperature	29.5°C
Dissolved O_2	4.69 mg/L
pH	7.47
Turbidity	14.43 NTU
Salinity	59 ppt
Chlorophyll a	11,749 μg/L
Berm Height	1 m
Nitrate	1.18 mg/L


Figure C.6 Elk Bay East Pond


Figure C.7 Elk Bay East Pond

EUROPA BAY

Sampled January 17, 2003

Europa Bay Pond is located inside the domain of the National Park, and can be accessed by foot via a 0.6-mile trail beginning at Little Lameshur Bay. Europa Bay Pond is densely vegetated and does not appear to be affected by erosion anywhere; the pond's banks are completely covered. The pond's boundary is greater than 10 meters. There were some accessibility issues around the perimeter of this pond; it was one of the largest ponds studied but not accessible by boat. Although there was a very thick, well defined, cohesive bacterial mat, accessing the pond more than a few meters from shore was difficult due to sinking into the sediment.

Approximately 30% of the bank's vegetation is white mangrove; the remainder is other various herbaceous species. The berm of Europa Bay is comprised of rock, coral, and rubble, is about 2-3 meters high, and is extremely densely vegetated with trees, shrubs, vines, sea grape and century plants.

The bacterial mat is orange around the edges of the pond and gray in the middle. *Corixidae*, *ciliatea*, *hydrophilidae*, *artemiidae*, *ephydridae*, and *ceratopogonidae* were the macroinvertebrates observed in this pond.

Table C.4 Europa Bay Pond Measurements

Land Use	0 houses/km^2
Depth	4.5 ft
Temperature	-
Dissolved O_2	-
pH	-
Turbidity	-
Salinity	90 ppt
Chlorophyll a	503 μg/L
Berm Height	2.5 m
Nitrate	-

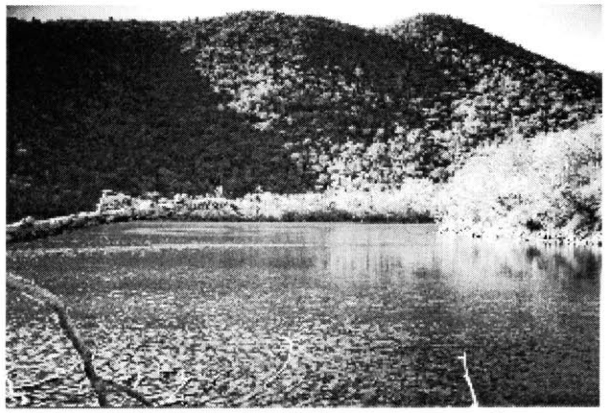


Figure C.8 Europa Bay Pond

Figure C.9 Europa Bay Pond

Figure C.10 Europa Bay Pond

FRANCIS BAY

Sampled January 10, 2003

Francis Bay is located on the north side of St. John within the National Park. From the road there is a very well maintained path to the pond, and a dock has been constructed from this path a short distance into the pond for viewing wildlife and birds. Francis Bay pond is completely surrounded by thick white mangroves, and the banks are completely covered. There is a large amount of dead mangrove debris around the edges and in the center of the pond. Of interest, and unique to this pond is the appearance of the white mangroves around the perimeter. The leaves appear to be consistently discolored, presumably as a result of disease or unfavorable conditions. Also, unlike other ponds, the water felt very oily and left a residue on the skin. There are a few houses visible a distance from the pond, and the pond boundary is greater than 10 m. There are no areas that appear to be affected by erosion.

There is a wide berm, about 1-2 m high, composed of soil and silt on which the walking path is located. The pond sediment is yellowish-green and very mucky – some sinking occurs although the pond is navigable by foot, and other footprints were also found in the pond, although the source of the prints was unclear. There were no fish observed in the pond; however, there were *corixidae*, *copepoda*, *ocypodidae*, *artemiidae*, *oligochaeta*, and *ephydridae*.

Table C.5 Francis Bay Pond Measurements

Land Use	4645 houses/km^2
Depth	0.5 ft
Temperature	-
Dissolved O_2	-
pH	-
Turbidity	-
Salinity	136 ppt
Chlorophyll a	42,968 μg/L
Berm Height	1.5 m
Nitrate	-

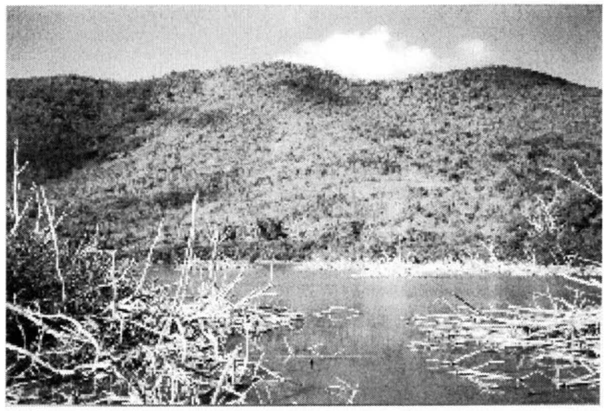


Figure C.11 Francis Bay Pond

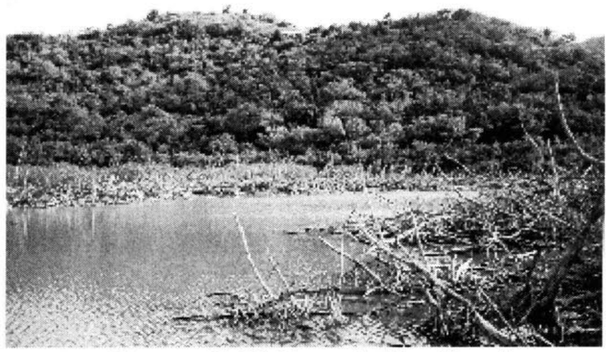


Figure C.12 Francis Bay Pond

FRANK BAY POND

Sampled January 6, 2003

Frank Bay Pond is located in Cruz Bay, and is surrounded by a dense residential area. The St. John desalination plant is directly adjacent to the pond. There is no large-scale sewage treatment facility on the island, so the homes have septic systems whose effluent likely flows into the pond. Frank Bay Pond's 1 m tall berm has a road that separates the pond from the ocean; it appears that the berm, comprised of rock, coral, and other fill, was enlarged at least partly to accommodate the road. There also appears to have been some additional sandy fill placed near homes located by the desalination plant, opposite the pond's berm. Besides the small sandy area, most of the pond sediment is black sulphurous gelatinous bacterial bottom. Chunks of algae float throughout the water.

Local landowners have been responsible for much of the pond's upkeep. After severe hurricanes, landowners have cleaned much of the residual debris from the pond. The gray mangroves found around the pond were planted by a landowner to replace those lost in hurricanes. There is a small parking area on the road as well as a constructed bench next to the pond for bird watchers. Frank Bay Pond has recently been declared a bird sanctuary; the treasurer of the local Audubon Society lives in a house adjacent to the pond. Domestic dogs in the area disturb the birds on the shores of the pond, so the landowners anchored a surfboard in the pond for the birds to use.

About 75% of the pond bank is covered with vegetation; of the mangroves found on the banks, about 85% were white mangroves and 15% were gray. The boundary width is greater than 10m, and only about 5% of the bank is estimated to be affected by erosion. Fish were absent in this pond, but present were *corixidae*, *copepoda*, *rotifera*, *ciliatea*, and *hydrophilidae* larvae. The vast majority of macroinvertebrates were found near the sandy fill by the desalination plant.

Table C.6 Frank Bay Pond Measurements

Land Use	23463 houses/km^2
Depth	3 ft
Temperature	27.8°C
Dissolved O_2	5.33 mg/L
pH	8.31
Turbidity	8.45 NTU
Salinity	67 ppt
Chlorophyll a	2271 μg/L
Berm Height	1 m
Nitrate	1.67 mg/L


Figure C.13 Frank Bay Pond


Figure C.14 Frank Bay Pond


Figure C.15 Frank Bay Pond

Friis Bay

Sampled January 11, 2003

Friis Bay Pond is located on private property on the southeastern side of the island. The landowner keeps goats, chickens and pigs in enclosed areas on one side of the pond, although the pond has a boundary on all sides of more than 10 meters. There is light residential development on the opposite side. Approximately half of the pond's banks are covered with vegetation; of this, about 70% is mangroves while the remainder is other herbaceous species. The mangroves present are about three-quarters white and one quarter red. Erosion does not appear to affect any part of the surrounding area.

The berm is about 3-4 meters in height and is composed of coral and rubble with some low shrubs and bushes growing on it. The pond sediment is reddish-brown and is extremely soft in the deeper regions of the pond. There were no fish in the pond; however, *corixidae*, *copepoda*, *ciliatea*, *ostracoda*, and *oligochaeta* were found during macroinvertebrate sampling.

Table C.7 Friis Bay Pond Measurements

Land Use	4871 houses/km^2
Depth	2 ft
Temperature	25.8°C
Dissolved O_2	2.59 mg/L
pH	8.95
Turbidity	5.97 NTU
Salinity	63 ppt
Chlorophyll a	3,611 µg/L
Berm Height	3.5 m
Nitrate	2.40 mg/L

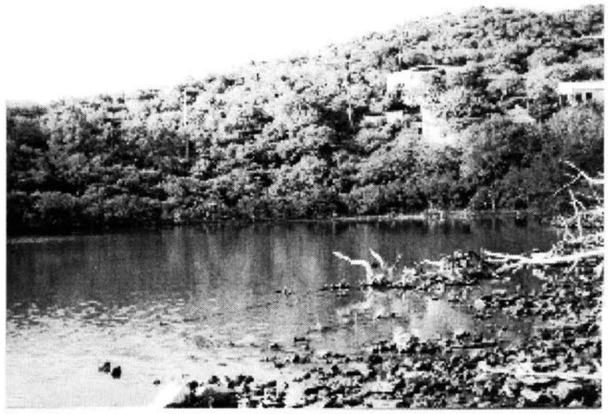


Figure C.16 Friis Bay Pond

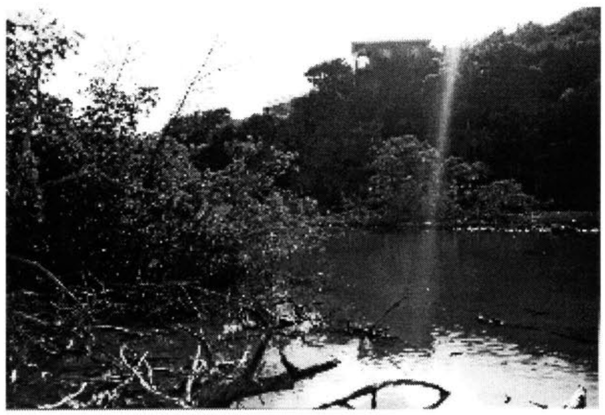


Figure C.17 Friis Bay Pond

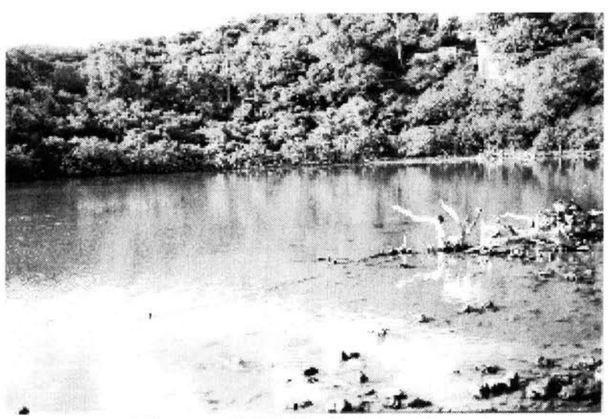


Figure C.18 Friis Bay Pond

HANSON BAY

Sampled January 10, 2003

Hanson Bay is the only pond studied that was not included in the original National Park Service Salt Pond Inventory report (Stengel, 1996), although it is present on the Park Service map. This pond is quite difficult to access due to the very thick network of exclusively red mangroves and their prop roots around the entire perimeter of the pond. Hanson Bay pond is located inside the National Park on the eastern side of the island. The pond has a boundary of greater than 10 m, and there is no visible erosion. Many new red mangroves are growing around the edges and in the center of the pond.

Because of the density of the trees, the sediment is full of twigs, branches, seeds, and leaves. The substrate is thick and gray, with limited yield underfoot. The berm is comprised of coral and rubble, and is about 3 m high. This pond had the lowest salinity of those measured, below that of seawater. For this reason, many mosquitoes were present around this pond, and there were also many spiders and caterpillars not seen near other ponds. *Copepoda*, *ocypodidae*, and *culicidae* larvae were found in the pond.

Table C.8 Hanson Bay Pond Measurements

Land Use	5646 houses/km^2
Depth	1 ft
Temperature	31.1°C
Dissolved O_2	3.29 mg/L
pH	8.10
Turbidity	52.00 NTU
Salinity	31 ppt
Chlorophyll a	5,756 μg/L
Berm Height	3 m
Nitrate	0.67 mg/L

Figure C.19 Hanson Bay Pond

HART BAY

Sampled January 13, 2003

Hart Bay is located near Cruz Bay on the western side of the island, and was almost completely dry at the time of sampling. Nighttime light trap sampling was impossible due to extremely low water levels that prohibited adequate submersion of the light trap. Because of the pond's dryness, bank parameters were estimated based on the apparent pond boundary. The bank land use is residential, and the pond's banks do not appear to be affected by erosion. The banks were completely covered by vegetation, about two thirds of which are mangroves. The mangrove population is evenly split between white and gray mangroves.

A seep from the ocean was apparent through the berm. The berm is extremely wide for this pond – one cannot hear the ocean from the pond and a walking path leads the distance from the pond to the ocean over the berm. The berm is difficult to categorize due to its large size; it appears to be composed mostly of soil and sand, as well as some rock and coral. The berm is about 5-6 m high, and is highly vegetated with white mangroves and other herbaceous species. The substrate of the pond is a slippery gray bacterial mat that varies spatially in terms of yield to body weight from being firm to allowing several feet of sinking. *Corixidae*, *hydrophilidae*, and *ocypodidae* were present in this pond.

Table C.9 Hart Bay Pond Measurements

Land Use	4154 houses/km2
Depth	0.5 ft
Temperature	-
Dissolved O_2	-
pH	-
Turbidity	-
Salinity	192 ppt
Chlorophyll a	2,632 µg/L
Berm Height	5.5 m
Nitrate	-

Figure C.20 Hart Bay Pond

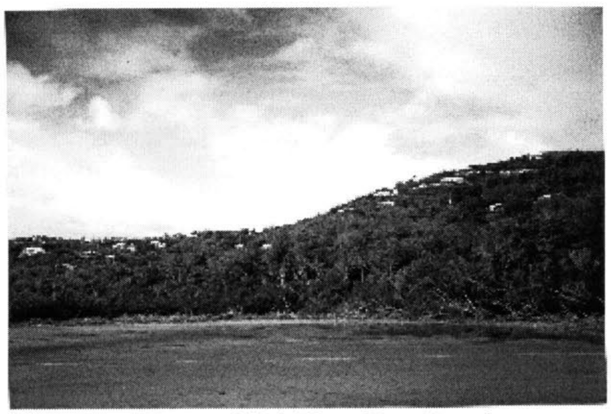


Figure C.21 Hart Bay Pond

KIDDEL BAY

Sampled January 18, 2003

Kiddel Bay Pond is located near the Virgin Island Environmental Research Station (VIERS) on the southern side of the island. Although there is currently only very light residential development around the pond at the time of sampling, many of the empty lots along the road leading to the pond are available for sale, and power lines are in place for extensive new development. At the time of the study, the water level in Kiddel Bay Pond was very low; the pond's perimeter had about 95% cover, and almost all of the surrounding vegetation was comprised of gray mangroves. The pond boundary was greater than 10m, and about 20% of the perimeter is affected by erosion.

The berm is about 3-4 m high, and is composed of rubble and coral. There is a visible seep from the ocean through a small section of the berm with no vegetation. The bacterial mat had a brownish layer on top of black thick mud with cohesive chunks of organic clay throughout. The sediment was firm enough to be navigable by foot on the far side, but did yield several feet to body weight near the berm. *Corixidae*, *artemiidae*, *copepoda*, *ocypodidae*, *ephydridae*, and *hydrobiidae* were the macroinvertebrates observed in this pond.

Table C.10 Kiddel Bay Pond Measurements

Land Use	4343 houses/km^2
Depth	1 ft
Temperature	-
Dissolved O_2	-
pH	-
Turbidity	-
Salinity	120 ppt
Chlorophyll a	3,097 µg/L
Berm Height	3.5 m
Nitrate	-


Figure C.22 Kiddel Bay Pond


Figure C.23 Kiddel Bay Pond


Figure C.24 Kiddel Bay Pond

Lagoon Point

Sampled January 18, 2003

Lagoon Point is located near VIERS on the southern side of the island. Lagoon Point is difficult to access due to thick vegetation cover and a long, very steep bank to the access road. The berm was inaccessible by foot. The pond's banks were completely covered by vegetation, about 90% of which is black mangrove. The pond's boundary is greater than 10 meters, and 15% of the banks are affected by erosion. The land use surrounding the pond is light residential.

The sediment in the pond is very soft, making access to the far side of the pond impossible. Many *hydrobiidae* were found in the mucky black sediment, as were *ocypodidae* and *oligochaeta*. *Copepoda* and *corixidae* were also collected from pond samples at Lagoon Point.

Table C.11 Lagoon Point Pond Measurements

Land Use	4929 houses/km^2
Depth	2 ft
Temperature	-
Dissolved O_2	-
pH	-
Turbidity	-
Salinity	66 ppt
Chlorophyll a	12,644 µg/L
Berm Height	-
Nitrate	-

Figure C.25 Lagoon Point Pond


Figure C.26 Lagoon Point Pond


Figure C.27 Lagoon Point Pond

POPILLEAU BAY

Sampled January 9, 2003

Popilleau Bay pond the only pond where no mangroves were found. This pond is located near the town of Coral Bay and is privately and jointly owned by several households. This pond is located right next to the main road connecting Coral Bay to the East side of St. John, the boundary width is estimated to be about 1m. There is a well-defined trail between the pond and the road that horseback riders regularly use. Several of the nearby homes have chickens and goats, and donkeys were also sighted near the pond.

The berm is comprised of sand, silt, and soil and is about 2m high. The berm is extremely wide – unlike most other ponds, one cannot hear the ocean from the pond; however, one of the landowners stated that the pond was very heavily influenced by the ocean and that it was often dry. About 20% of the bank seems to be affected by erosion. This pond was navigable by foot, for the bacterial mat caused some sinking but the substrate was relatively firm underneath. The bacterial mat was very cohesive – large, thick clumps of the mat stuck together. Many crabs were present in Popilleau Bay pond – besides *ocypodidae* (fiddler crabs), blue crabs and land crabs were also found. Although there were no fish in the pond, there were *corixidae*, *copepoda*, *rotifera*, *cilates*, and *oligochaeta*.

Table C.12 Popilleau Bay Pond Measurements

Land Use	14952 houses/km^2
Depth	0.5 ft
Temperature	30.1°C
Dissolved O_2	6.67 mg/L
pH	8.65
Turbidity	13.70 NTU
Salinity	37 ppt
Chlorophyll a	3,953 µg/L
Berm Height	2 m
Nitrate	0.90 mg/L

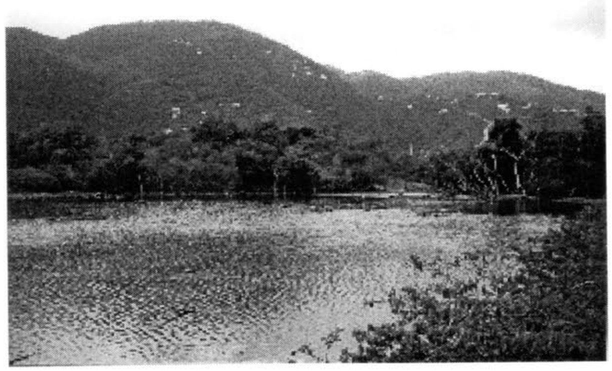


Figure C.28 Popilleau Bay Pond

Figure C.29 Popilleau Bay Pond

PRIVATEER BAY

Sampled January 15, 2003

Privateer Bay is located alongside a dirt road on the east end of St. John. Although this area was only lightly residential at the time of the study, many surrounding lots are for sale and new roads and power lines are in place to accommodate increases in population. This pond is affected by erosion on 30% of its surroundings, caused by the dirt road. About 75% of the pond's banks have cover, almost all of which is gray mangrove. This pond's berm is about 2-3 meters in height and is composed of soil, rubble, and coral. Gray mangroves and some other trees and shrubs are growing along the berm.

The sediment of this pond was gray and sticky but did not yield enough to prevent navigation on foot. This pond had long grasslike algae covering about 30% of the bottom. *Corixidae*, *copepoda*, *rotifera*, *ostracoda*, *ocypodidae*, and *culicidae* were found in this pond.

Table C.13 Privateer Bay Pond Measurements

Land Use	0 houses/km^2
Depth	1 ft
Temperature	-
Dissolved O_2	-
pH	-
Turbidity	-
Salinity	45 ppt
Chlorophyll a	13,854 μg/L
Berm Height	2.5 m
Nitrate	-

Figure C.30 Privateer Bay Pond

Figure C.31 Privateer Bay Pond

SALT POND

Sampled January 11, 2003.

Salt Pond is unique because it has two clearly defined berms; it is located at a narrow point on the island between Salt Pond Bay and Drunk Bay. Salt Pond is located within the National Park and has a well–maintained trail connecting the pond to the public beach. Erosion does not appear to be affecting Salt Pond's banks, and the pond boundary is greater than 10 meters. The vegetation around the pond is generally low shrubs because of the high winds between the two berms; about a third of the pond's banks are unvegetated and there are only very few gray mangroves present towards Salt Pond Bay. On the side nearest to Salt Pond Bay, the berm is comprised of sand and is about 3-4 m in height with low shrubs and cacti growing on it. On the side nearest to Drunk Bay, the berm is about 4-5 meters of coral, rubble, and rock, and also has some low shrubs growing.

This pond has the highest measured salinity of the fifteen ponds studied. The pond water is clear to the bottom, and there are some rocks present on the bottom of the pond as well as around the edges. The edges of the pond were sandy and there was foam around the edges of the pond; the bottom of the pond had a hard crystallized layer over extremely soft mud. This hard crust on the pond sediment provides an ideal environment for *ephydridae* larvae to which to attach. *Artemiidae* and *ephydridae* were the only macroinvertebrates observed in this pond.

Table C.14 Salt Pond Measurements

Land Use	0 houses/km^2
Depth	3 ft
Temperature	31.1°C
Dissolved O_2	1.69 mg/L
pH	7.68
Turbidity	2.58 NTU
Salinity	262 ppt
Chlorophyll a	425 μg/L
Berm Height	4 m
Nitrate	10.14 mg/L

Figure C.32 Salt Pond

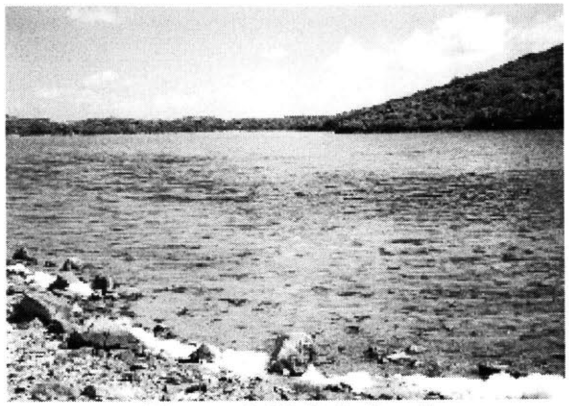


Figure C.33 Salt Pond

Figure C.34 Salt Pond

SOUTHSIDE POND

Sampled January 15, 2003

Southside Pond is located at the southeast edge of St. John, and was by far the deepest of the ponds studied. This pond is surrounded by steep inclines, about a third of which are affected by natural erosion. The surrounding land had only light development completed at the time of the study, but much construction is ongoing and many nearby lots are for sale. A local woman bathes in this pond weekly for supposed rejuvenation properties.

Only about 25% of the pond's banks are covered, and of this cover only 30% were gray mangroves. The pond's berm was about a meter high and composed of rock with some coral. On the berm were century plants, sea grape, and some relatively low trees and shrubs.

This pond has a very thick orange jellylike microbial mat that extends around the edges of the pond nearest the trail access point and covers the shallower half of the bottom of the pond. Some foam around the edges of the pond was observed. Goats and wild boar were also observed near this pond. *Corixidae*, *hydrophilidae*, and *artemiidae* were found in this pond.

Table C.15 Southside Pond Measurements

Land Use	370 houses/km^2
Depth	15 ft
Temperature	27.2°C
Dissolved O_2	2.12 mg/L
pH	8.20
Turbidity	1.15 NTU
Salinity	105 ppt
Chlorophyll a	51 μg/L
Berm Height	1 m
Nitrate	3.50 mg/L

Figure C.35 Southside Pond

Figure C.36 Southside Pond

Figure C.37 Southside Pond Bacterial Mat

Appendix D : TAXA FOUND IN SALT PONDS

Kingdom Animalia

- *Artemiidae*
- *Ceratopogonidae*
- *Ciliatea*
- *Copepoda*
- *Corixidae*
- *Culicidae*
- *Dytiscidae*
- *Ephydridae*
- *Hydrobiidae*
- *Hydrophilidae*
- *Ocypodidae*
- *Oligichaeta*
- *Ostracoda*
- *Rotifera*

Kingdom Plantae

- *Avicennia germinans*
- *Conocarpus erectus*
- *Laguncularia racemosa*
- *Rhizophora Mangle*

KINGDOM ANIMALIA
Artemiidae

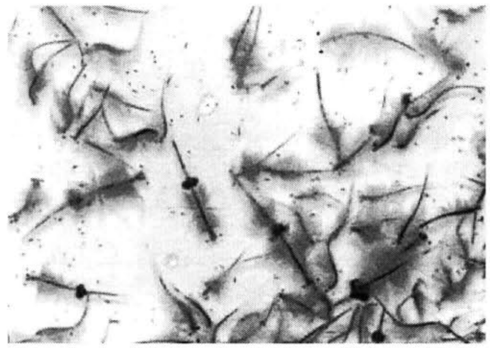


Figure D.1 Artermiidae
http://isuisse.ifrance.com/aquaetang/artemia.jpg

Artemiidae fall into the order Anostraca, and are also known as fairy shrimp. These macroinvertebrates are distinctly segmented and have 20 trunk segments. They "swim by means of complex beating movements of the legs that pass in a wavelike anterior-posterior direction...with the ventral side upward" (Pennak, 1978). These organisms feed primarily on smaller organisms and detrital material. Artemiidae are capable of tolerating extremely high salinity levels by using osmotic regulation, which "presumably occurs chiefly through the wall of the digestive tract and through the branchiae of the first 10 pairs of legs...Artemia continually swallows water, regardless of its salt concentration" (Pennak, 1978). These shrimp populations are also able to withstand periodic dry periods since their "resting eggs are capable of withstanding dessication" in the bottom mud (Pennak, 1978). In naturally occurring populations, females are typically much more abundant than males, and the normal life span of the shrimp is about 4 months.

Table D.1 Artermiidae Taxonomy Detail

Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Crustacea
Class	Branchiopoda
Subclass	Sarsostraca
Order	Anostraca
Family	Artemiidae

Ceratopogonidae

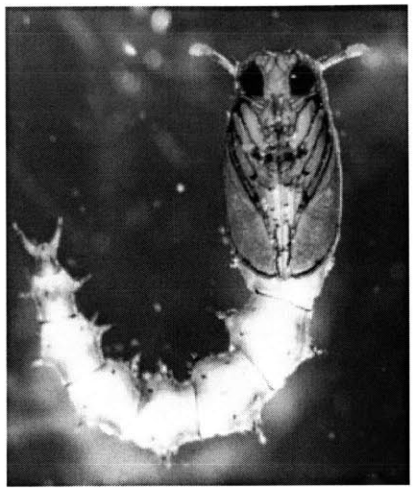


Figure D.2 Ceratopogonidae
http://www.csuchico.edu/~sacperch/FRI/images/Ceratopogonidae_pupa.jpg

The family Ceratopogonidae contains biting midges, no-see-ums, and punkies. These animals are in the same order as mosquitoes and brine flies, and so share many characteristics with those taxa. "The immature stages are chiefly aquatic…some are herbivorous, others are carnivorous, and a few are even cannibalistic" (Pennak, 1978).

Table D.2 Ceratopogonidae Taxonomy Detail

Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Hexapoda
Class	Insecta
Subclass	Pterygota
Superorder	Neoptera
Order	Diptera
Suborder	Nematocera
Infraorder	Culicomorpha
Family	Ceratopogonidae

Ciliatea

Figure D.3 Ciliatea
http://www.zoology.ubc.ca/courses/bio332/Labs/CiliateProject/ciliate1/Kentrophoros.jpg

Ciliates are single-celled organisms and so are virtually impossible to find with the naked eye. These organisms are shaped like flattened ovals, and use cilia projections for locomotion. "Cilia are shorter [than flagella], very abundant, and have only a single basal granule. They are arranged in longitudinal, diagonal, or oblique rows, and their movements are often coordinated so that waves of beats pass along the entire animal…Ciliates move more rapidly than other Protozoa, the usual speed being 200 to 1000 microns per second" (Pennak, 1978). Feeding mechanisms of these organisms is dependent upon species, but some protozoans may carry reserve food to sustain them during environmentally stressful times. Ciliates are aerobic, but can tolerate very low levels of dissolved oxygen. Formation of protective outer cysts is possible in some species to protect against dry conditions.

Table D.3 Ciliatea Taxonomy Detail

Kingdom	Animalia
Phylum	Protozoa
Subphylum	Ciliophora
Class	Ciliatea

Copepoda

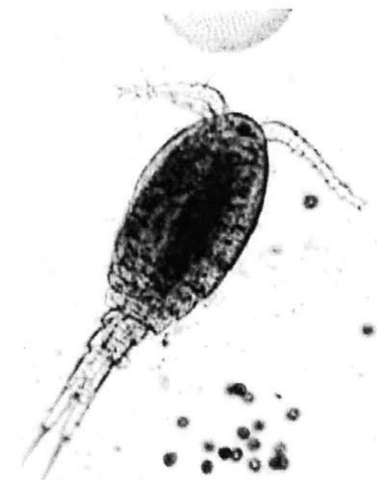


Figure D.4 Copepoda
http://home.hib.no/ansatte/asa/planktonweb/fcopep3._300.jpg

Copepods are a commonly found group of crustaceans in the salt ponds, and also the most abundant group of plankton in general (Smith and Johnson, 1996). The three most common orders of copepod are calanoid, harpactecoid, and cyclopoid; harpactecoid and cyclopoid were the two types encountered in the salt ponds of St. John. Copepods have a small central single compound eye and generally have two antennae extending laterally from the side of the head; the length of these antennae depends on the species. "Copepods are on an intermediate trophic level between bacteria, algae, and protozoans, on the one hand, and small and large plankton predators…on the other" (Pennak, 1978). They are also "intermediate hosts of parasites of higher animals" including tapeworms, flukes, and nematodes of fish, waterfowl, birds, and amphibians. "Copepods are able to tolerate low dissolved oxygen levels…some adults…may form cysts or cocoons during unfavorable environmental conditions…they may be formed as a response to anaerobic conditions" (Pennak, 1978). These cysts are designed to withstand the adversity; when conditions improve, the copepods emerge to resume their normal activity.

Table D.4 Copepoda Taxonomy Detail

Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Crustacea
Class	Maxillipoda
Subclass	Copepoda
Infraclass	Neocopepoda
Superorder	Podoplea
Order	Copepoda

Corixidae

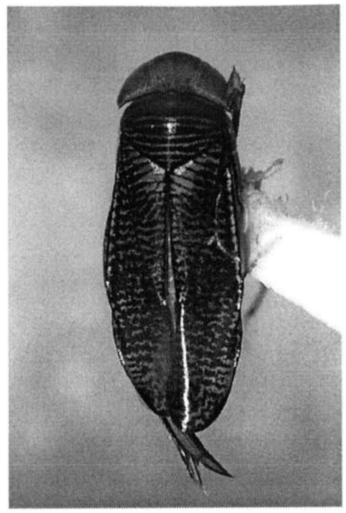


Figure D.5 Corixidae
http://www.cedarcreek.umn.edu/insects/newslides/020035019000apd.jpg

Corixidae are commonly called water boatmen, and were found in all except one salt pond on St. John. These animals have a strong tolerance for variable conditions, and are very strong osmoregulators (Colburn, 1988). According to the literature, corixidae are able to fly, although this was not observed during the study. These insects prefer to "anchor themselves to some object near the bottom with the tarsal claws of the long second legs. They swim in a quick, darting manner by oarlike movements of the hind legs… The body is almost completely enveloped in a film of air, and there is also air beneath the wings. Consequently, when not swimming or clinging to some object, they rise to the surface where the supply of oxygen is renewed" (Pennak, 1978). Corixidae are generally omnivorous, although "many genera [of corixids] are primarily collectors, feeding on detritus, and are heavily preyed upon" (Merritt and Cummins, 1996).

Table D.5 Corixidae Taxonomy Detail

Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Hexapoda
Class	Insecta
Subclass	Pterygota
Order	Heteroptera
Family	Corixidae

Culicidae

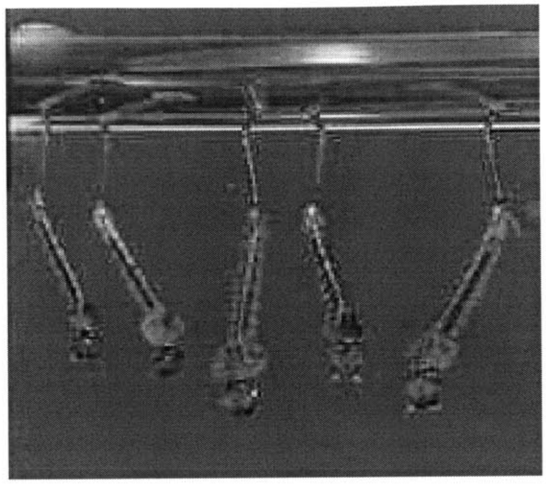


Figure D.6 Culicidae
http://www.lawestvector.org/images/larvae.jpg

Culicidae is a family of the well-known mosquito. Mosquito larvae are typically found in freshwater environments; on St. John they were found in Hanson Bay pond at a salinity of 31 ppt. These invertebrates are able to tolerate a wide range of pH, from 5 to 9. These animals are easily spotted when navigating the pond by foot. "The larvae usually lie quietly at the surface of the water, but when they are disturbed they swim downward in a characteristic rapid manner that is responsible for them being called 'wrigglers'" (Pennak, 1978). The larvae's "fused thoracic segments are wider than the rest of the body… larvae feed on algae, protozoa, or bits of organic debris by means of the filtering action of the small mouth brushes." These macros are most easily identified by the respiratory siphon at the anterior end, which can be seen in the photo as the part closest to the surface of the water.

Table D.6 Culicidae Taxonomy Detail

Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Hexapoda
Class	Insecta
Subclass	Pterygota
Superorder	Neoptera
Order	Diptera
Suborder	Nematocera
Infraorder	Culicomorpha
Family	Culicidae

Dytiscidae

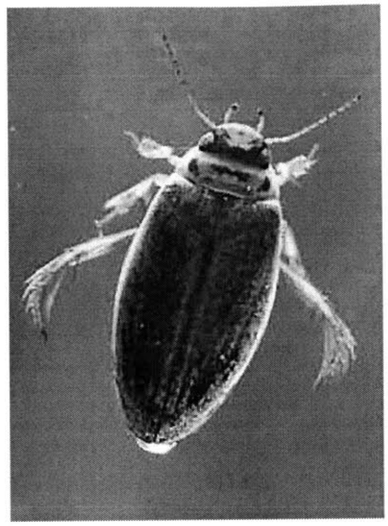


Figure D.7 Dytiscidae
http://www.toyen.uio.no/ekle_kryp/images/insekter/dytiscidae.jpg

Dytiscidae is the family commonly known as predaceous diving beetles. These beetles have flattened and hairy hind legs which "operate in an oarlike manner." These beetles exhibit rapid swimming movements. Although these beetles are excellent swimmers, "most adult aquatic beetles are fundamentally dependent on atmospheric oxygen" (Pennak, 1978). When submerged, some carry a supply of air with them under water" in the form of an air bubble (Pennak, 1978). "There are 10 pairs of spiracles…the spiracles open into the subelytral chamber so that when the beetles are submerged they utilize the oxygen of the tracheae and the subelytral chamber. It is also thought that some oxygen from the surrounding water diffuses into the subelytral chamber through the air-water interface" (Pennak, 1978). The air bubble that the dytiscidae carries with it must be renewed at the surface every few minutes. These insects are able to fly, although they cannot take off directly from the water and must crawl onto a surface first. Conversely, they are unable to land on surfaces and must land directly into the water. These beetles are "exclusively carnivorous and voracious. They feed on all kinds of aquatic metazoa…they are often called 'water tigers'" (Merritt and Cummins, 1996).

Table D.7 Dytiscidae Taxonomy Detail

Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Hexapoda
Class	Insecta
Subclass	Pterygota
Superorder	Neoptera
Order	Coleoptera
Suborder	Adephaga
Family	Dytiscidae

Ephydridae

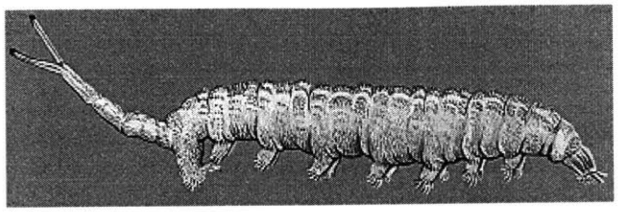


Figure D.8 Ephydridae
http://www.bioweb.lu/sapro/fliegen.htm

Ephydra is the family also known as brine flies and shore flies. The cylindrical shape of the larvae makes these easy to identify, for, once these flies pupate, the larvae shells can be found attached to rocks or crystalline bottom surfaces. The "larvae are characterized by mouth hooks that have a serrate or digitate margin" (Pennak, 1978). These larvae do not need to come to the surface for oxygen. As seen in the drawing, "there are eight pairs of short, conical, clawed, abdominal prolegs, each pair being fused at the base" (Pennak, 1978). The mature brine fly, like the rest of the order Diptera, is a two-winged fly which undergoes complete metamorphosis and has "large compound eyes, and mouth parts that are adapted for lapping or piercing and sucking" (Pennak, 1978).

Table D.8 Ephydridae Taxonomy Detail

Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Hexapoda
Class	Insecta
Subclass	Pterygota
Superorder	Neoptera
Order	Diptera
Suborder	Brachycera
Infraorder	Muscomorpha
Family	Ephydridae

Hydrobiidae

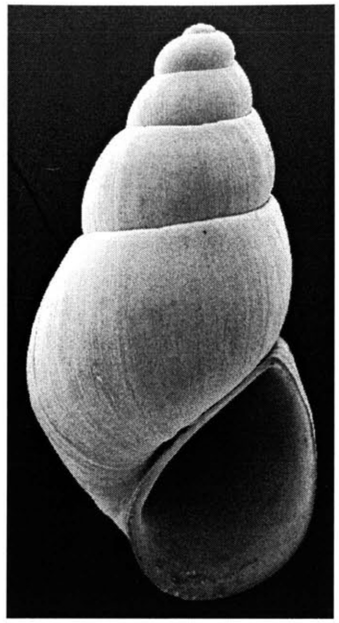


Figure D.9 Hydrobiidae
http://www.esg.montana.edu/aim/taxa/snails/eganensis.jpg

Hydrobiidae are gastropods, or snails. The muscular part of the animal that protrudes from the shell is called the foot. "The ventral portion of the foot is flat and there is a more or less prominent head at the anterior end. The head bears two tentacles...the eyes are on or near the base of the tentacles. The mouth...is at the end of a muscular probiscus, or rostrum." (Pennak, 1978). These animals are herbivorous, feeding on living and dead plant material. "Respiration is strictly aquatic and occurs through an internal gill, or ctenidium, to which the surrounding water has easy access." (Pennak, 1978). Because shell construction is dependent on the hardness of the water, these animals are more common in waters with higher levels of dissolved calcium carbonates, which are usually also above pH of 7.0. These animals also favor shallow waters, and are able to burrow into the mud to withstand unfavorable conditions including drought. "The most effective seal and protection is afforded by a mud bottom that has a high percentage of clay" (Pennak, 1978).

Table D.9 Hydrobiidae Taxonomy Detail

Kingdom	Animalia
Phylum	Mollusca
Class	Gastropoda
Order	Neotaenioglossa
Family	Hydrobiidae

Hydrophilidae

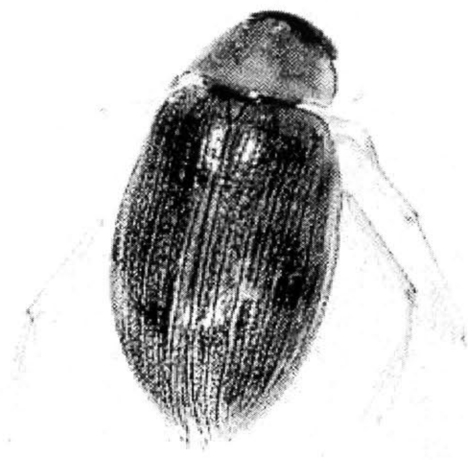


Figure D.10 Hydrophilidae
http://www.dlwc.nsw.gov.au/care/wetlands/facts/paa/invertebrates/images/berosus.jpg

Hydrophilidae are known as water scavenger beetles. These beetles are "characterized by their short, clubbed antennae, which are usually concealed beneath the head" (Pennak, 1978). When swimming, these beetles move their hind legs alternately. Similar to dytiscidae, these beetles require a supply of atmospheric oxygen. "While submerged, oxygen is obtained from air in the tracheal system, and, via the spiracles, from the subelytral chamber and from the silvery film of air (plastron) retained on the ventral side of the body by hydrofuge hairs." This air supply must also be renewed at the surface periodically. These beetles are primarily herbivorous.

Table D.10 Hydrophilidae Taxonomy Detail

Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Hexapoda
Class	Insecta
Subclass	Pterygota
Superorder	Neoptera
Order	Coleoptera
Suborder	Polyphaga
Superfamily	Hydrophiloidea
Family	Hydrophilidae

Ocypodidae

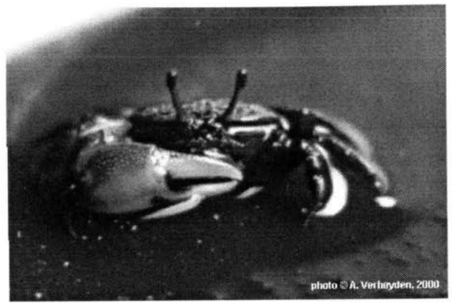


Figure D.11 Ocypodidae
http://gopher.ulb.ac.be/~dagillik/mangrove/u_chlorophthalmus.htm

Ocypodidae are commonly known as fiddler and ghost crabs. Fiddler crabs have been so named for the one enlarged cheliped (claw) of the males, used for attracting females and warding off other males. These crabs typically live in large groups, and their burrows are about half an inch wide and a foot deep. Fiddler crabs not only indicate the healthy water quality in a pond, but they also help contribute to it. "Assessment of soil properties showed that crab burrows increased soil drainage, soil oxidation, and the decomposition of below-ground debris"(Costa et al, 2001). Therefore, the species richness of the whole pond may be improved due to the environmentally beneficial actions of the fiddler crab, which increases dissolved oxygen. "During high tide, they plug the holes of their tiny homes with a ball of mud, trapping air inside the burrow. Surprisingly, all crabs have gills, but land crabs have adapted to remove oxygen from air instead of water. Their gills, however, must still stay wet" (Captain, 1999). Fiddler crabs eat detritus and plant material in the salt ponds.

Table D.11 Ocypodidae Taxonomy Detail

Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Crustacea
Class	Malacostraca
Subclass	Eumalacostraca
Superorder	Eucarida
Order	Decapoda
Suborder	Pleocyemata
Infraorder	Brachyura
Superfamily	Ocypodoidea
Family	Ocypodidae

Oligochaeta

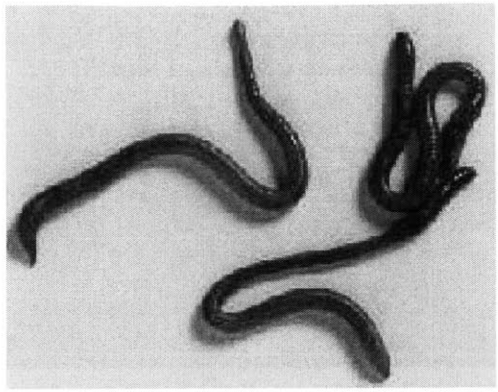


Figure D.12 Oligochaeta
http://www.howe.k12.ok.us/~jimaskew/zophyla2.htm

Oligochaeta are members of the phylum Annelida, and are more commonly known as angleworms, earthworms, night crawlers, and segmented worms. The number of segments in the body varies by species, as do locomotion methods and preferred food sources. These macroinvertebrates are found in the sediment layer of the ponds. The oligochaetes observed in the salt ponds were very small – less than 2 cm in length, and reddish in color. One particular type of oligochaeta is "usually considered an indicator of organic pollution, especially where the water is between 10 and 60 percent saturated with oxygen" (Pennak, 1978). Conveniently, this dissolved oxygen range covers almost exactly the range of ponds considered in this study. The ponds in which oligochaetes were found were Popilleau Bay, Francis Bay, Friis Bay, and Lagoon Point.

Table D.12 Oligochaeta Taxonomy Detail

Kingdom	Animalia
Phylum	Annelida
Class	Clitellata
Subclass	Oligochaeta

Ostracoda

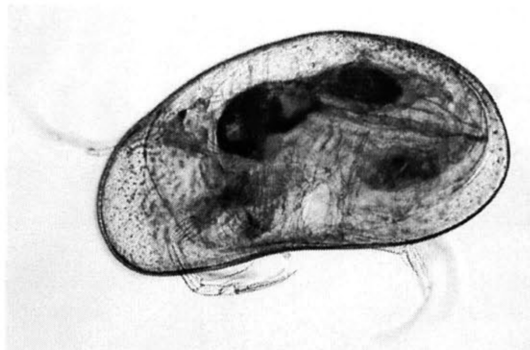


Figure D.13 Ostracoda
http://www.microscopy-uk.org.uk/micropolitan/fresh/arthropod/ostracoda.jpg

Ostracods may be found in either marine or freshwater environments. These macroinvertebrates are identifiable by their "large bivalve carapace which is bean shaped" (Smith and Johnson, 1996). The animal has a compound eye inside the carapace, and appendages that may be inside this carapace or outside if the animal is using them to propel itself. Females are much more common than males in natural populations, and reproduction is usually parthenogenic (asexual) (Pennak, 1978). Ostracods, like other invertebrates found in the salt ponds, are very resistant to adverse conditions. Ostracod eggs are capable of surviving long periods of time in dried mud, which can maintain the population over dry periods. Most species occur in very shallow water and they can "survive long periods of stagnation and oxygen exhaustion on lake bottoms." Ostracods are omnivorous scavengers, and "are also the intermediate hosts of some tapeworms of water fowl" (Pennak, 1978)

Table D.13 Osctracoda Taxonomy Detail

Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Crustacea
Class	Ostracoda

Rotifera

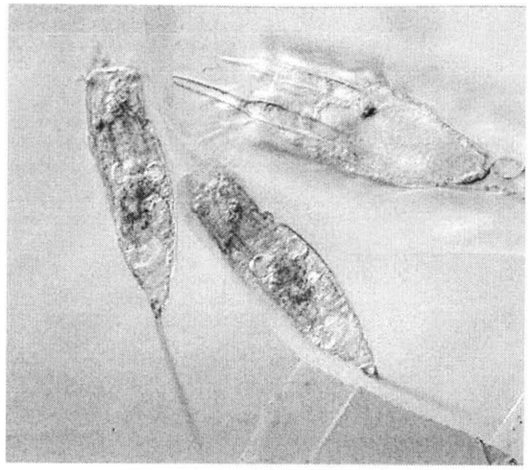


Figure D.14 Rotifera
http://protist.i.hosei.ac.jp/PDB/Images/Multicell/Rotifera/Rotifer_06.jpg

The phylum Rotifera contains rotifers and wheel animalcules. One of the most distinctive features is the "corona of cilia, found at the anterior of the animal, which appears to whirl as the cilia beat" (Smith and Johnson, 1996). This apparently rotating wheel is how rotifera were named. In rotifers "the body is usually elongated and cylindrical…usually three main body regions may be distinguished: head, trunk, and foot" (Smith and Johnson, 1996). Locomotion of rotifers occurs via the cilia as well as twisting and rotation around the body's central axis. "The cilia are attached to a short region termed the head, followed by a broader trunk. The body ends with the narrow segments of the foot. Their internal anatomy can be viewed clearly through their transparent body." (Smith and Johnson, 1996). Most rotifers are "omnivorous and ingest all organic particles of the appropriate size" (Pennak, 1978), and the cilia help propel food into the mouth.

Table D.14 Rotifera Taxonomy Detail

Kingdom	Animalia
Phylum	Rotifera

KINGDOM PLANTAE

Avicennia germinans

Figure D.15 Avicennia Germinans
Black Mangrove Pneumatophores, Elk Bay, St. John

Black mangroves have adaptive root mechanisms called pneumatophores that allow them to survive in the marshy areas around salt ponds. Pneumatophores are thin, spongy projections that grow up about six inches from the ground in the soil around the black mangrove and contain lenticels for oxygen absorption (Nellis, 1994). Both the rough black bark, the light-colored underside of the leaves, and the pneumatophores make for easy identification of these trees in the pond environment. Black mangroves can survive in salinities up to 100 ppt. Unlike red mangroves, black mangroves are able to metabolize the salt that is absorbed with the water by secreting it back into the environment. "The black mangrove secretes excess salt through specialized glands on the surface of leaves in addition to carrying out root ultrafiltration…Salt glands are microscopic and occur in epidermal depressions on the upper leaf surface. Each gland has 8-12 outer secretory cells, a lower stalk cell, and two to four other subtending, or basal cells, enclosed in a cuticle" (Schongalla, 2001). Secretions contain excess salt which dries on the undersides of the black mangrove leaves and then dissipates.

Table D.15 Avicennia Germinans Taxonomy Detail

Kingdom	Plantae
Subkingdom	Tracheobionta
Division	Magnoliophyta
Class	Magnoliopsida
Subclass	Asteridae
Order	Lamiales
Family	Verbenaceae
Genus	Avicennia
Species	Avicennia germinans

Conocarpus erectus

Figure D.16 Conocarpus Erectus
http://rps.uvi.edu/VIMAS/buttonwood.htm

Gray mangroves are often better known as buttonwood or button mangrove since they are not technically considered to be a true mangrove. "This mangrove is in the same family as the white mangrove but is often considered only an associate of mangroves… It is shrubby along the shore, but takes on a tree form further inland. The "Button" part of the name comes from the button-like appearance of the dense, rounded flower heads that grow in a branched cluster, and the purplish-green, round, cone-like fruit. The other three mangroves have leaves located opposite one another. Button mangrove leaves are alternate, leathery, pointed at the tips, have smooth edges, and two glands at the base of each leaf" (Law and Arny, undated).

The buttonwood has a high tolerance for wind and drought, which makes it particularly well adapted to the St. John shoreline. "It cannot tolerate sites as wet as those occupied by white and black mangroves, but it can survive harsh periods of drought. Thus it is usually the most shoreward of the trees in mangrove swamps and may occur at some distance from the water" (Nellis, 1994).

Table D.16 Conocarpus Erectus Taxonomy Detail

Kingdom	Plantae
Subkingdom	Tracheobionta
Division	Magnoliophyta
Class	Magnoliopsida
Subclass	Rosidae
Order	Myrtales
Family	Combretaceae
Genus	Conocarpus
Species	Conocarpus erectus

Laguncularia racemosa

Figure D.17 Languncularia Racemosa
White Mangroves, Drunk Bay, St. John

White mangroves are most easily recognized by the salt glands found on their leaves (Jarecki, personal communication). These glands show up as a border of dark spots around the edges of the leaves when they are held to the light. The white mangrove also has two raised salt glands at the base of every leaf. White mangroves can grow either a prop root system or pneumatophores in wetter soils. "The white mangrove prefers moist silty soil. It can grow in seawater-saturated soil if the site is shallow and protected from strong wave action" (Nellis, 1994). White mangroves are the most sensitive to cold and can be prone to uprooting from weather forces due to their shallow root systems.

Table D.17 Languncularia Racemosa Taxonomy Detail

Kingdom	Plantae
Subkingdom	Tracheobionta
Division	Magnoliophyta
Class	Magnoliopsida
Subclass	Rosidae
Order	Myrtales
Family	Combretaceae
Genus	Laguncularia
Species	Laguncularia racemosa

Rhizophora Mangle

Figure D.18 Rhizophora Mangle
Red Mangrove Prop Root System, Elk Bay, St. John

Red mangroves are most easily identifiable by their root networks characterized by prop roots, also sometimes called "'walking roots." This highly branching root system helps keep the red mangrove anchored in place in waterlogged soils (EPA, 1998) and also allows them to survive in saline environments. These roots may branch out from the tree's trunk or from its higher branches, and "contain numerous above-ground lenticels which provide oxygen for the roots immersed in anoxic mud. The roots are able to reject the excess salt from the environment, leaving the sap with a salinity typical of other plants" (Nellis, 1994). Unlike other mangroves, which have the ability to metabolize salt from the water, the red mangrove has a physical mechanism for blocking salt entry via the roots. "Rhizophora mangle is considered a non-secreting salt excluder because it excludes salt from entering the roots and lacks glandular secretory structures" (Schongalla, 2001). Red mangroves typically live nearer to the water than other mangroves, and are able to live in depths as great as 1 m, but they are the least tolerant of very high salinity, as observed on St. John. David Nellis states "Red mangroves can tolerate salinities from freshwater to 44 parts per thousand. The maximum height of the trees in a mature stand is inversely proportional to the soil salinity in the range of 17 to 72 ppt. Trees begin to die when soil salinities exceed 65 ppt. and all are dead if the salinity reaches 90 ppt." Red mangroves were observed at three ponds on St. John: Hanson Bay, with measured salinity of 31 ppt; Friis Bay, salinity 63 ppt; and, Elk Bay, salinity 59 ppt.

Although the prop roots of the red mangroves make it seem like an ideal mooring location, they have very thin bark which is easily damaged by the chains and rope used to anchor marine vessels. In addition, red mangroves can only produce leaves at the tips of their branches, which makes breakage especially damaging to this plant (NPS, 2002). Oil may also kill red mangroves by inhibiting the flow of oxygen via the root lenticels (Nellis, 1994). Red mangroves are also important to protect because of the habitat that they provide for local birds, bats, and waterfowl.

Table D.18 Rhizophora Mangle Taxonomy Detail

Kingdom	Plantae
Subkingdom	Tracheobionta
Division	Magnoliophyta
Class	Magnoliopsida
Subclass	Rosidae
Order	Rhizophorales
Family	Rhizophoraceae
Genus	Rhizophora
Species	Rhizophora mangle

Appendix E : DESCRIPTIVE HABITAT ASSESSMENT SHEET

CRABS SALT POND HABITAT EVALUATION

Pond ID:___________________ **Pond Name:**_____________________________________

Photograph numbers:____

Sample Site Description:

1	
2	
3	

Shore Characteristics

Mangrove species:	**Percent within fringing forest**

Cover:____

Shoreline description:	**Percent cover:**
Mangroves / salt-tolerant herbaceous plants	
Dry Forest Species	
Unvegetated	

Connection with the Sea:____

Tidal Influence:____

<u>Berm</u>

Composition:____ **Height:**_____________

Vegetation:____

Pond sediment

Description:____

____

____

____

Embeddedness:____

Bank Land Use: _______________________________________

Boundary width:____________________ **Bank erosion:**________________________

Water Characteristics

Depth:______________________________ **Dissolved oxygen:**____________________

Temperature:_________________________ **PH:**__________________________________

Salinity:______________________________ **Turbidity:**______________________________

Biota Characteristics

Fish: (Present Absent)

Chlorophyll a level:____

Benthic producer community (Grass Algae Bacterial mat)

Benthic invertebrates:

Sample ID	Taxonomy	**Number**

Notes:

Site Sketch:

Appendix F : SITE SKETCHES

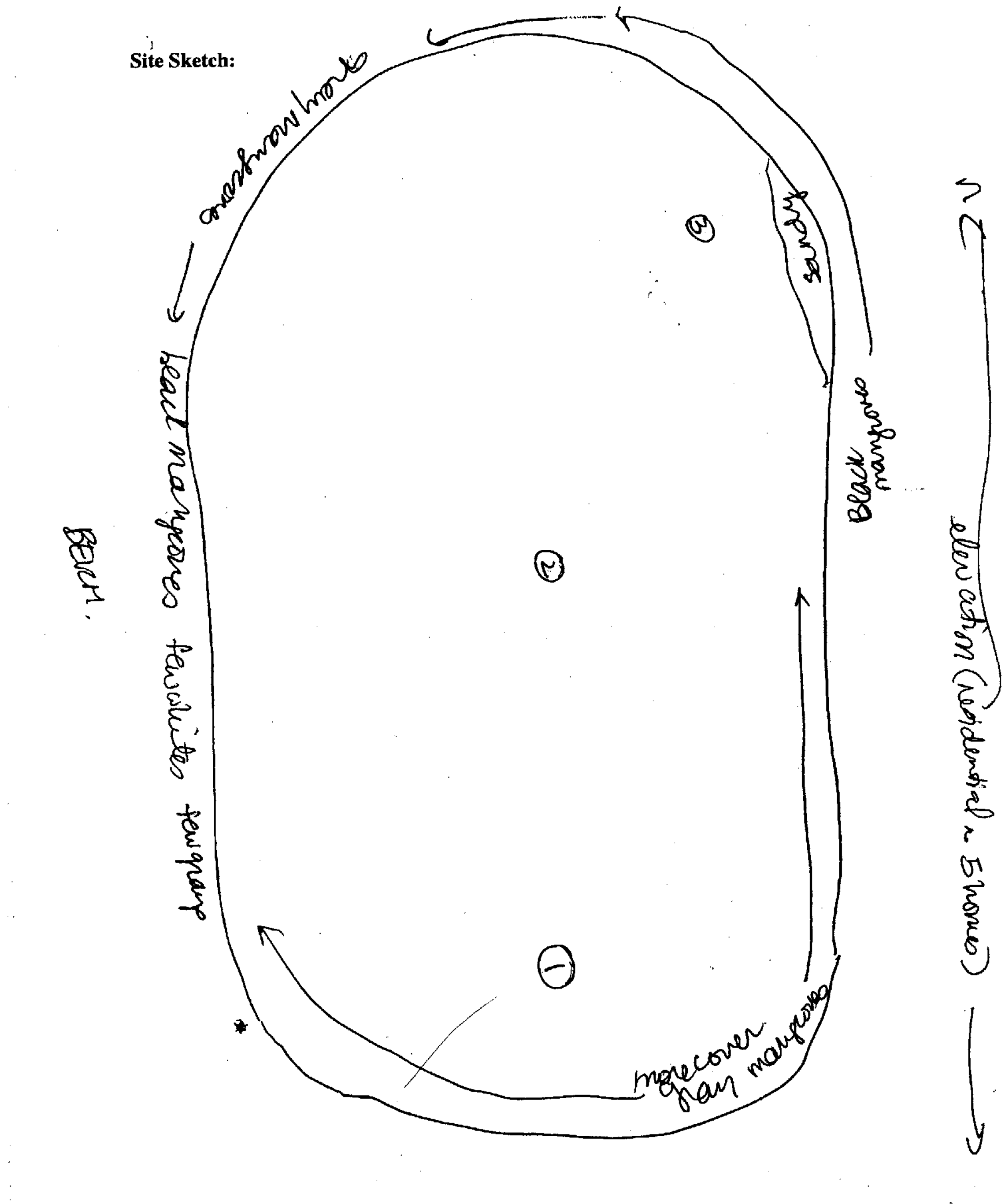


Figure F.1 Chocolate Hole West

Site Sketch:

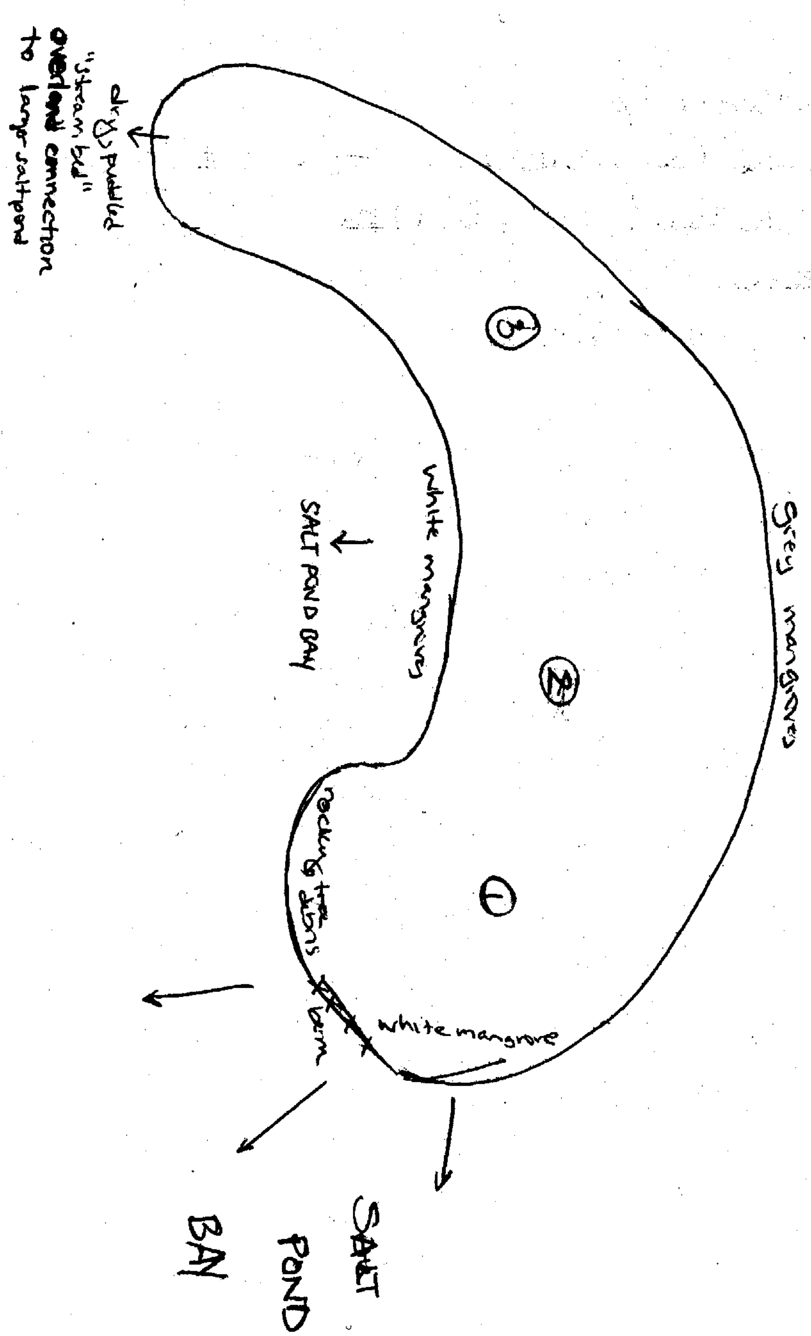


Figure F.2 Drunk Bay Pond

Site Sketch:

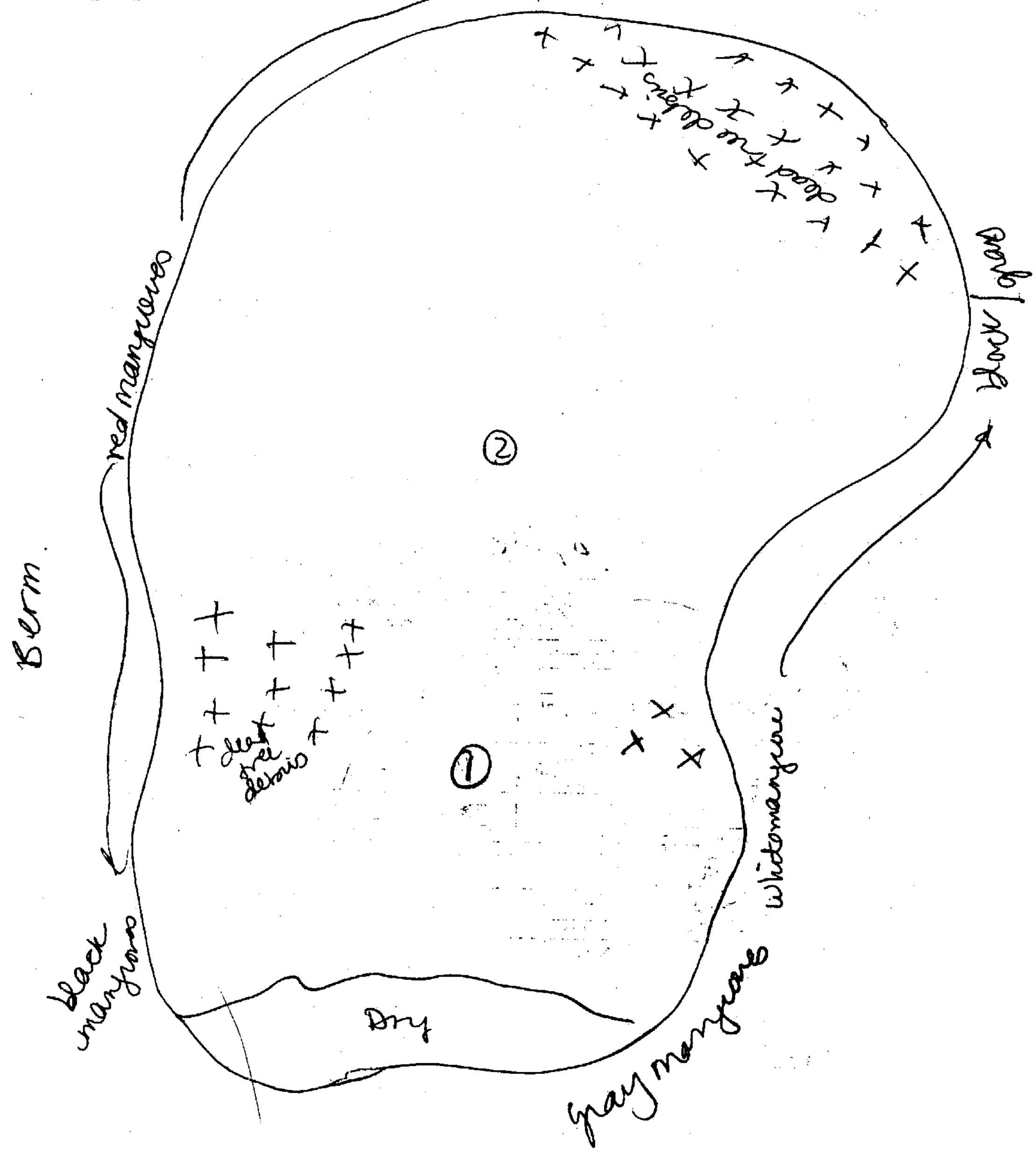


Figure F.3 Elk Bay East

Site Sketch:

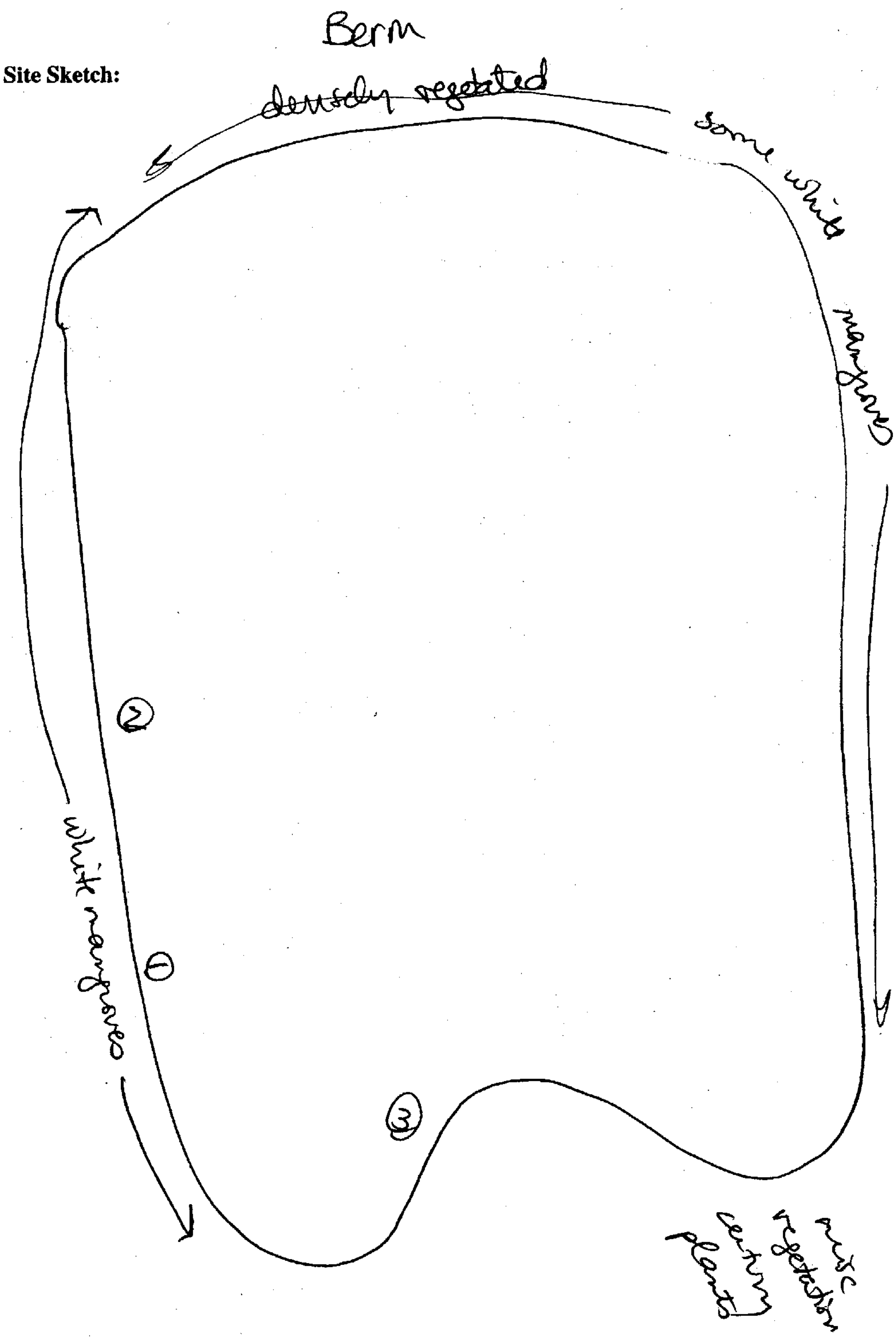


Figure F.4 Europa Bay Pond

Site Sketch:

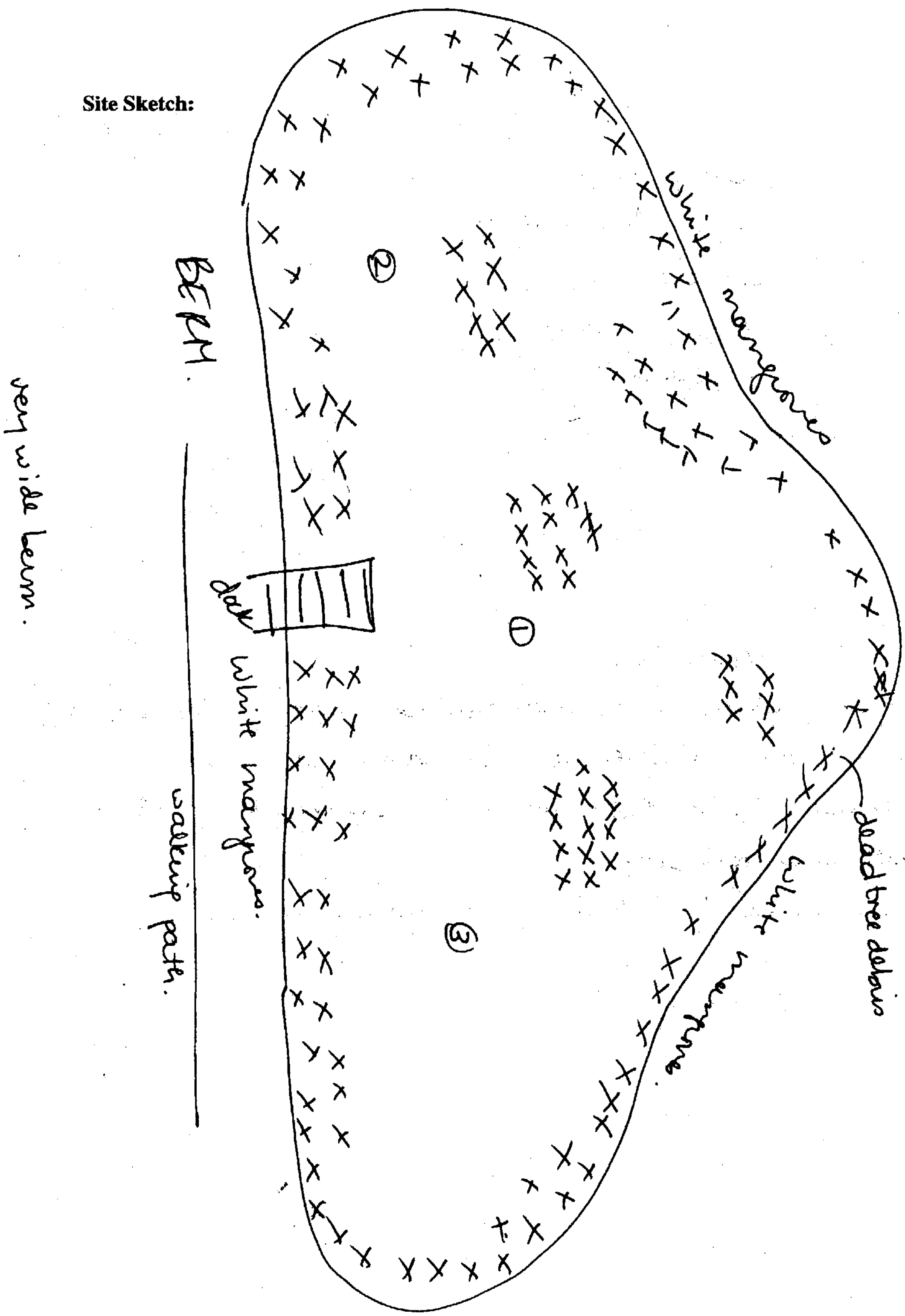


Figure F.5 Francis Bay

Site Sketch:

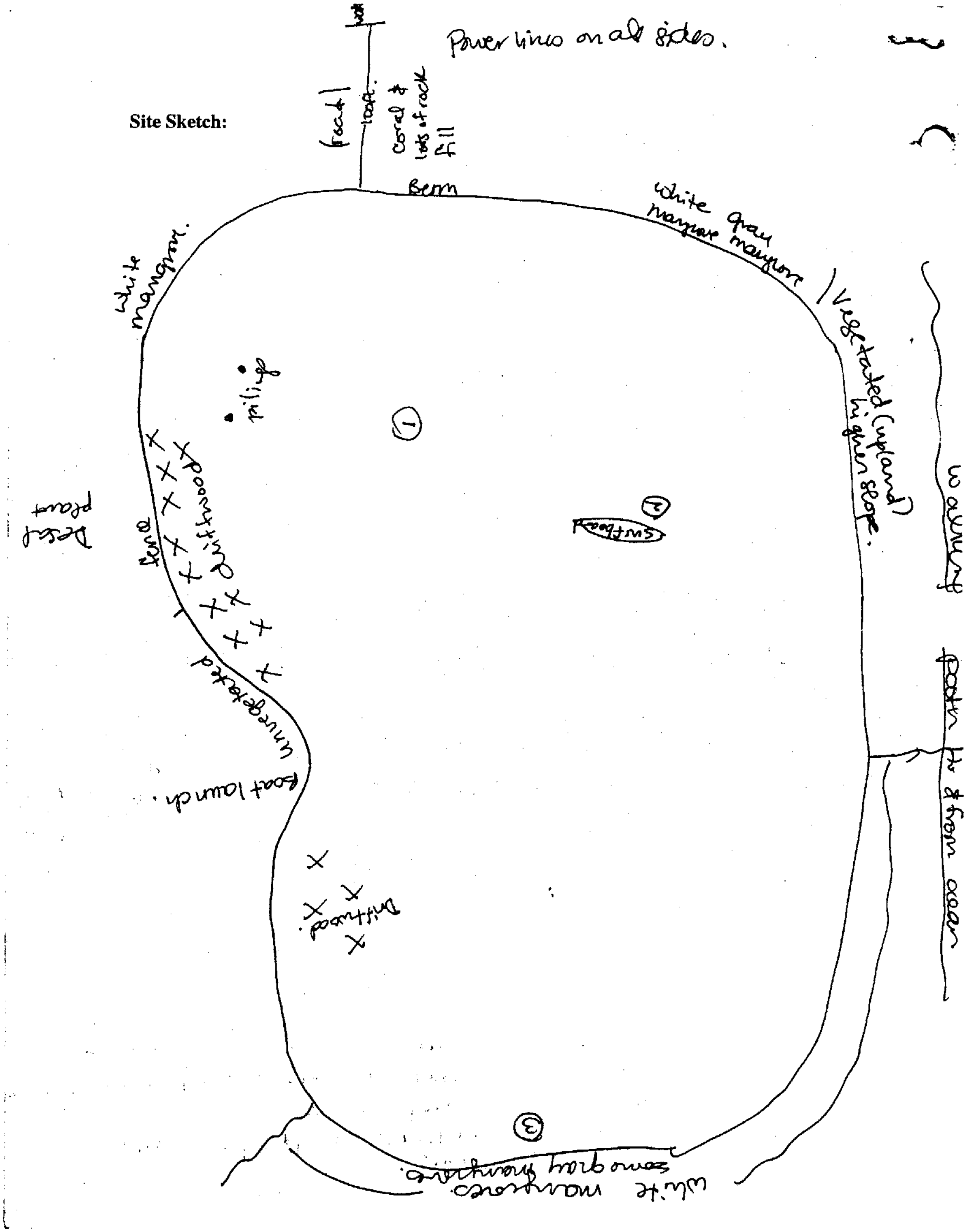


Figure F.6 Frank Bay Pond

Site Sketch:

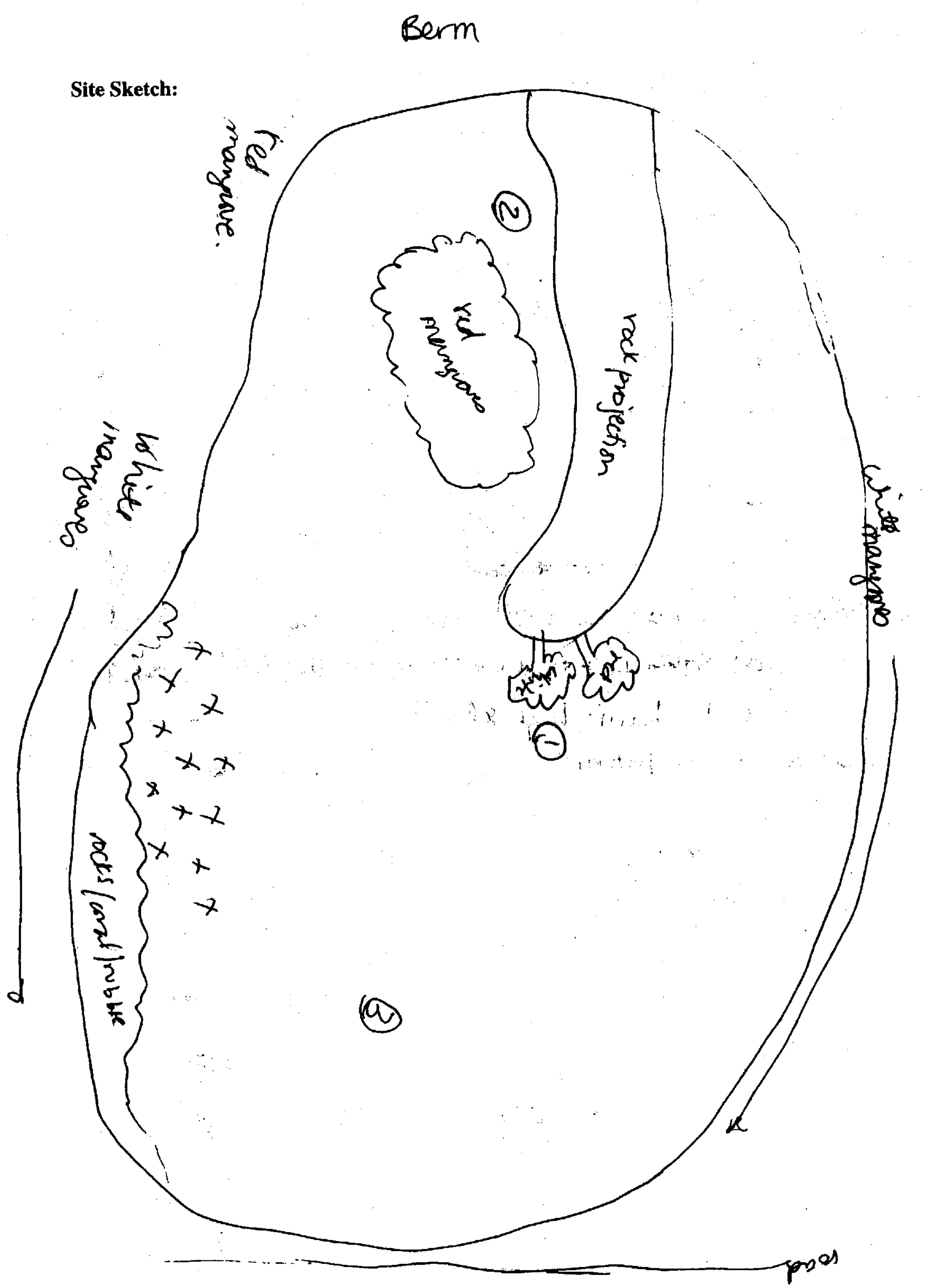


Figure F.7 Friis Bay

Site Sketch:

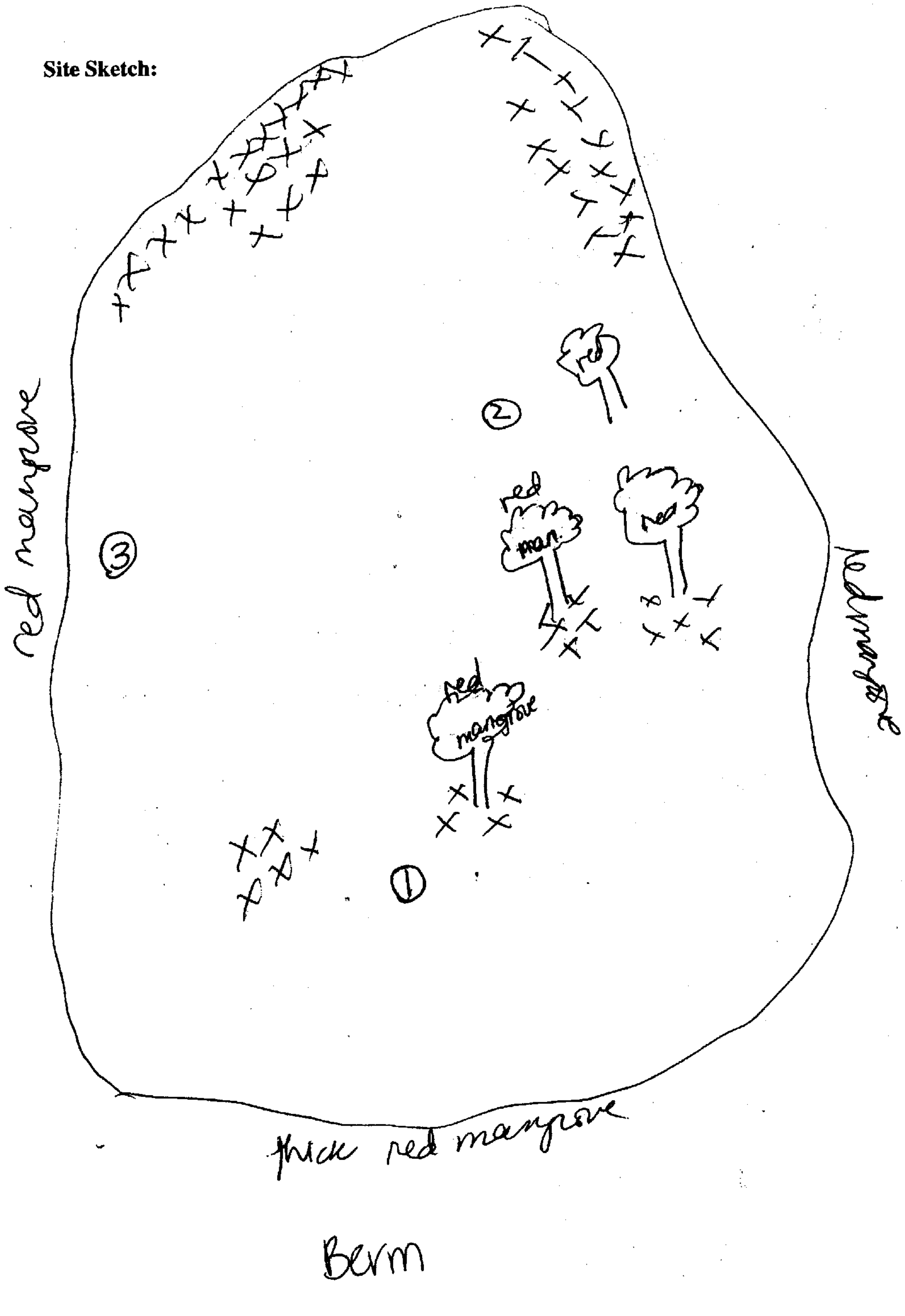


Figure F.8 Hanson Bay

Site Sketch:

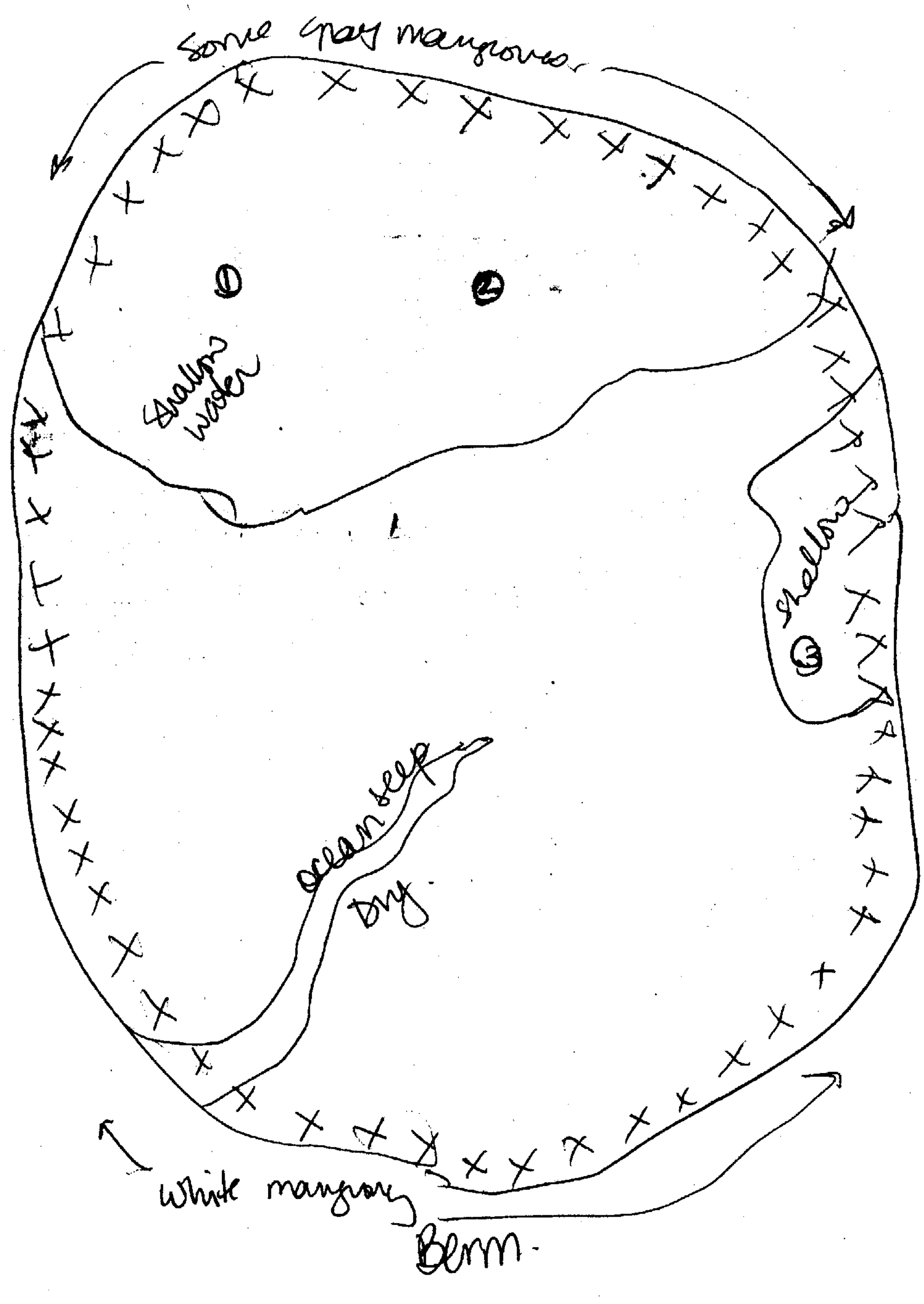


Figure F.9 Hart Bay

Site Sketch:

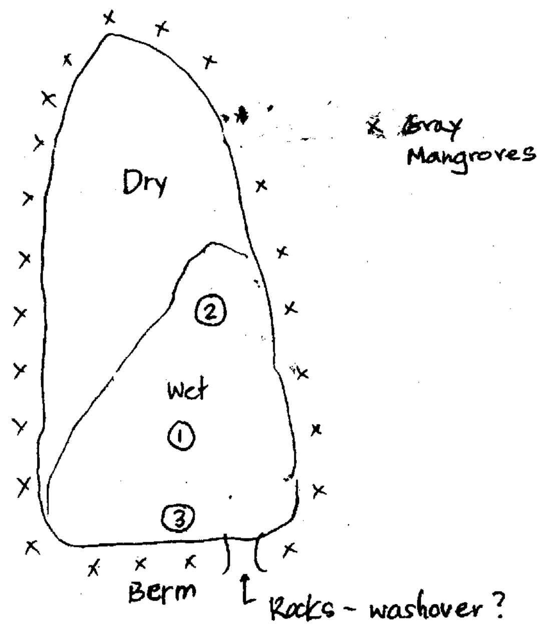


Figure F.10 Kiddel Bay

Site Sketch:

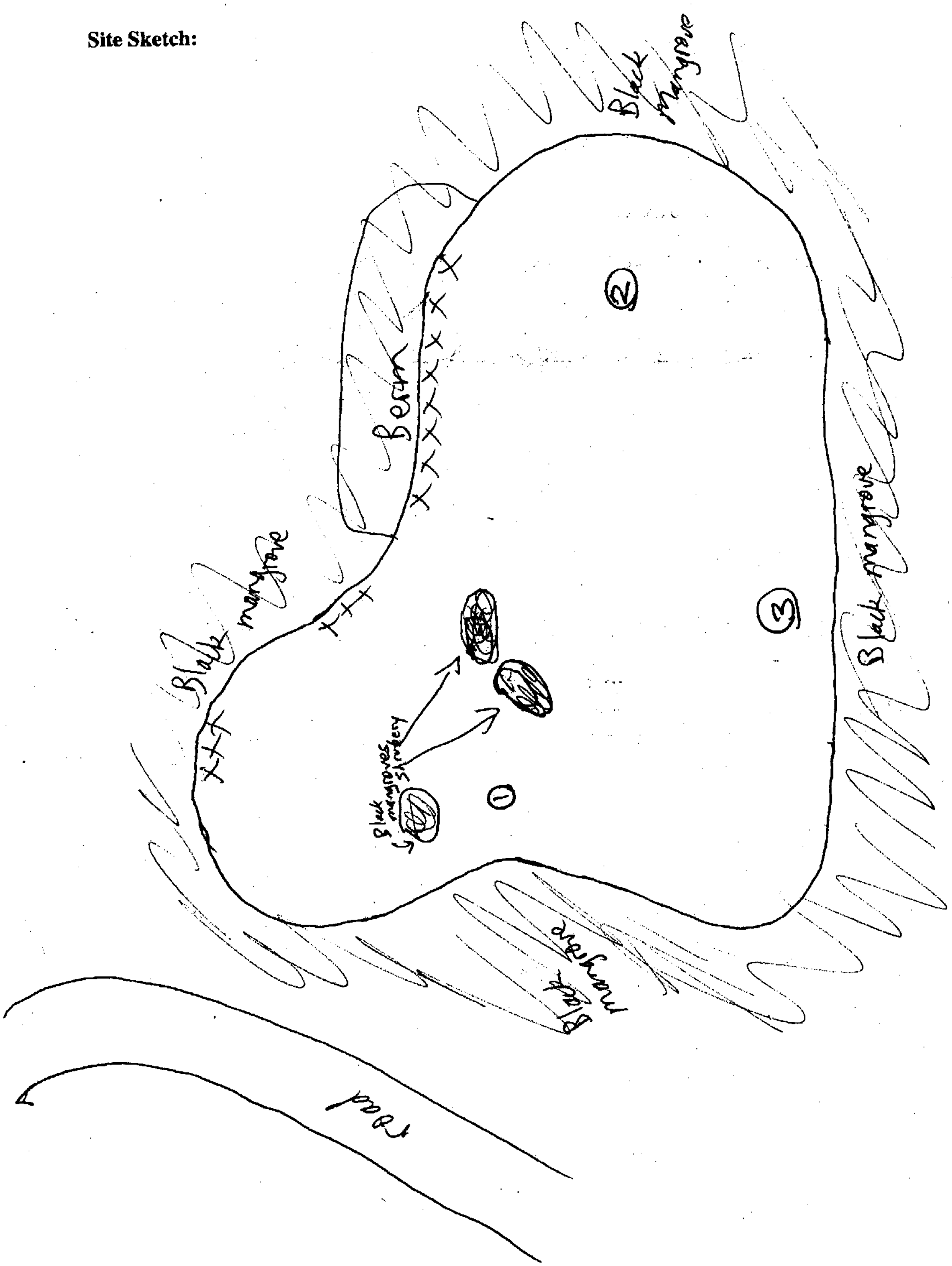


Figure F.11 Lagoon Point

Site Sketch:

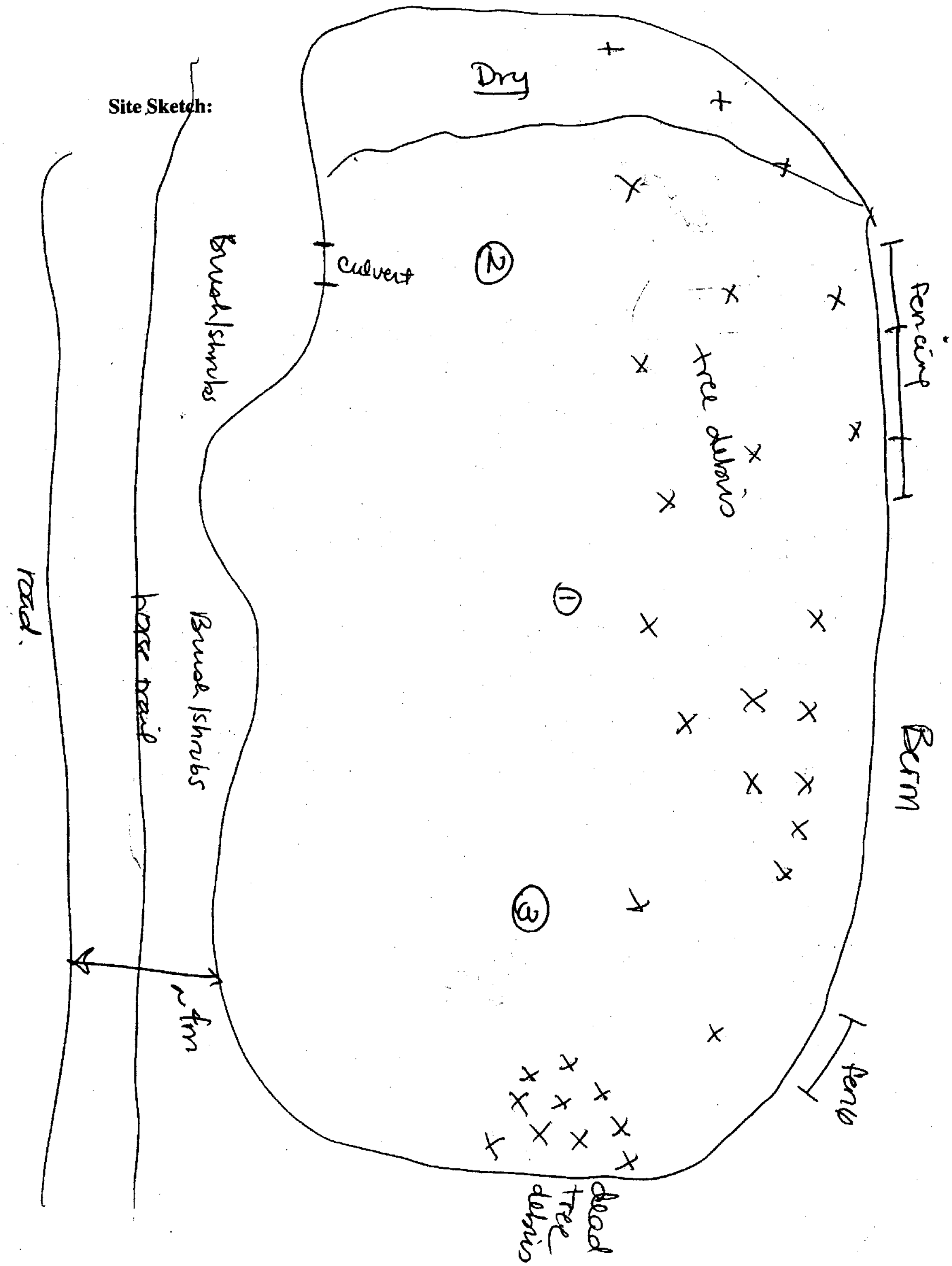


Figure F.12 Popilleau Bay

Site Sketch:

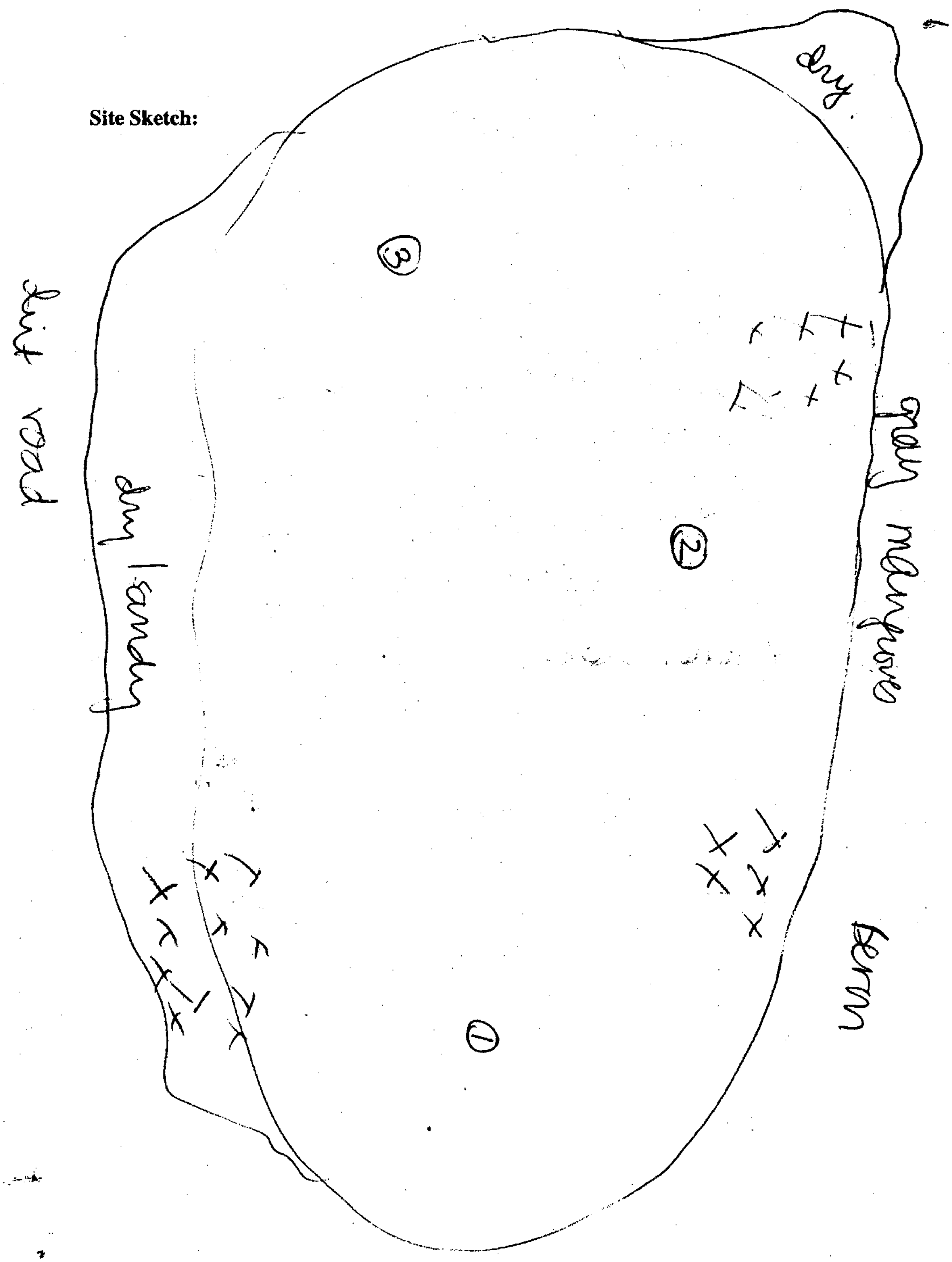


Figure F.13 Privateer Bay Pond

Site Sketch:

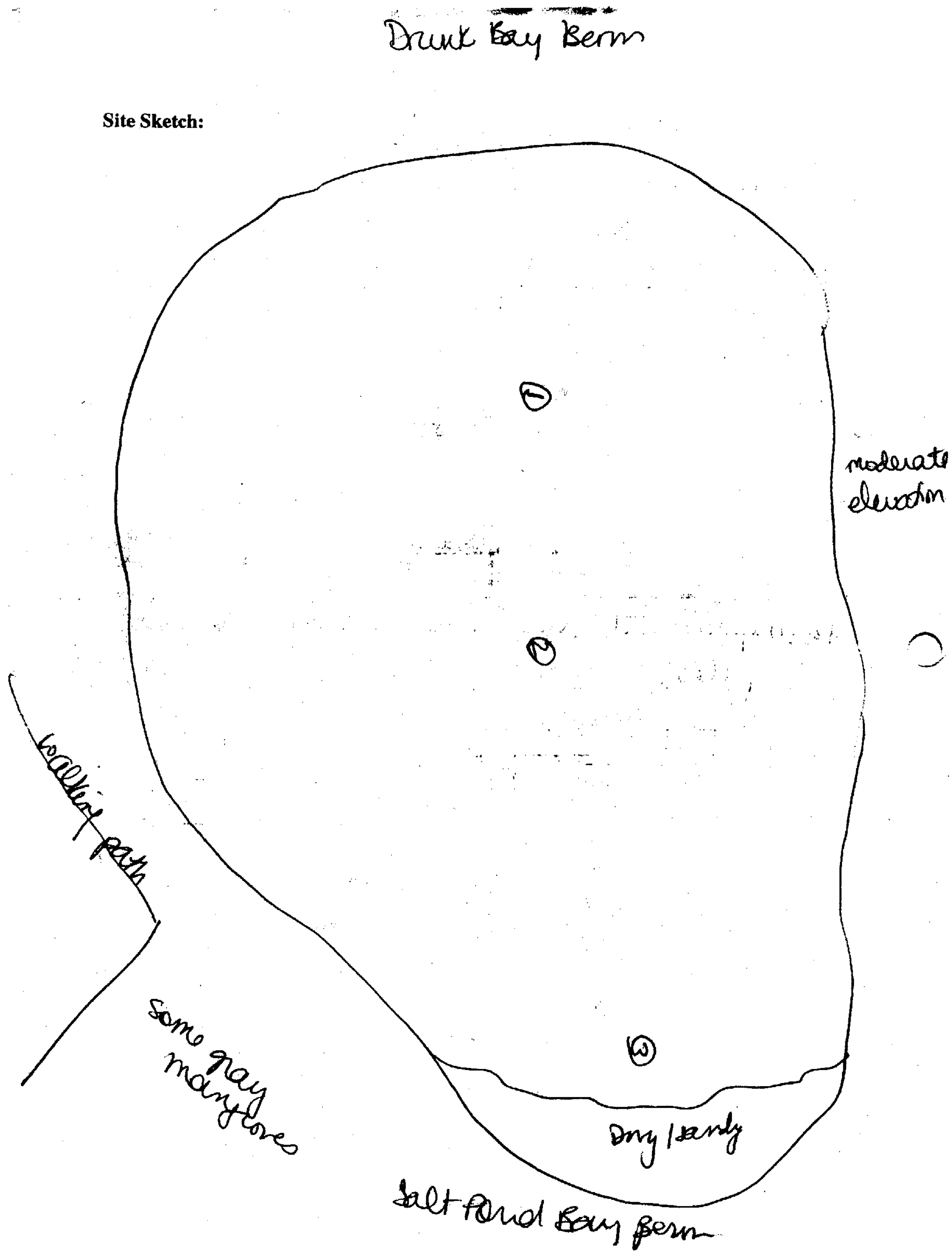


Figure F.14 Salt Pond

Site Sketch:

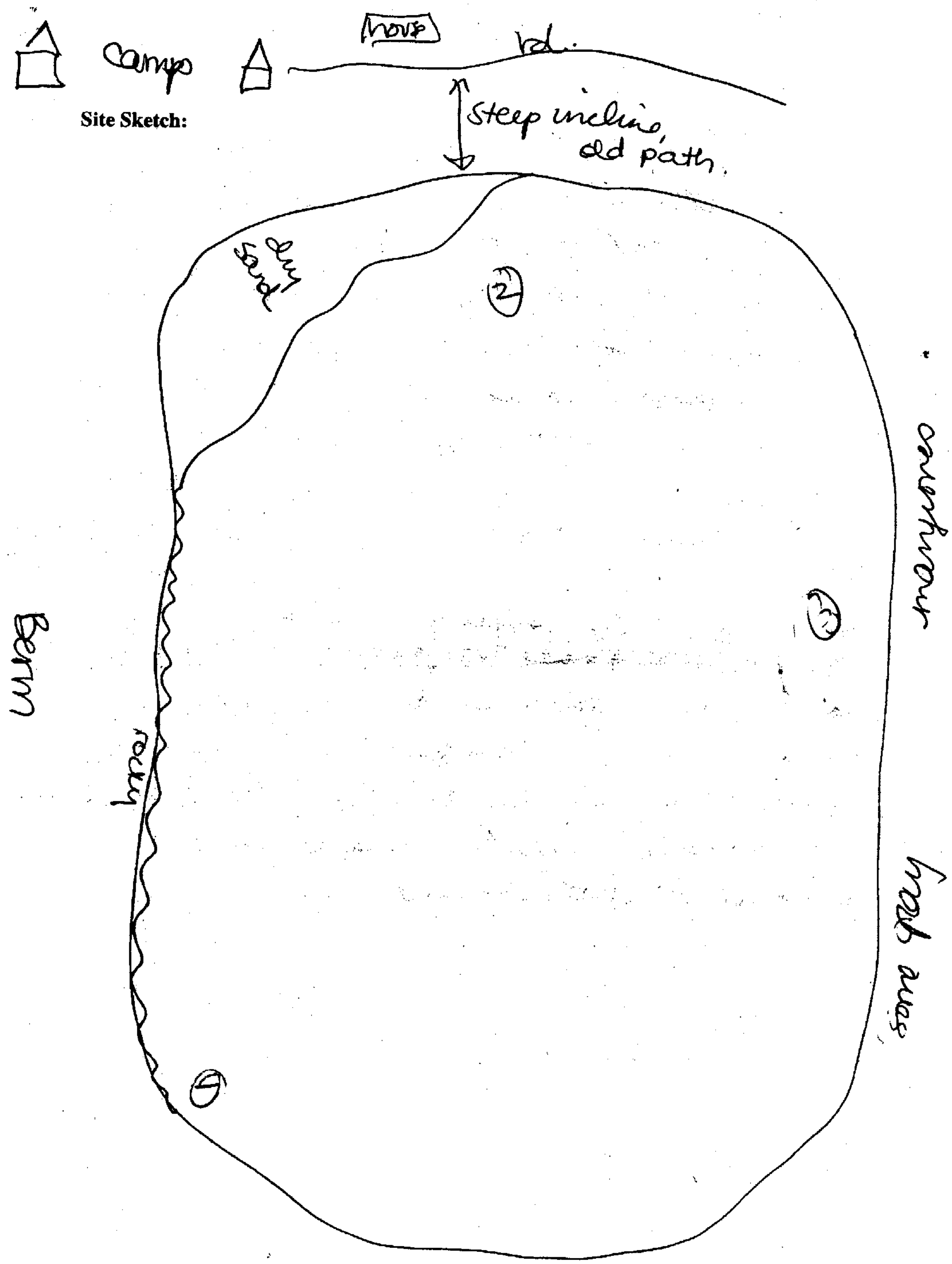


Figure F.15 Southside Pond

APPENDIX G: CHLOROPHYLL A MEASUREMENTS

Pond Number	Pond Name	Sample Number	Chlorophyll a measurement	Duplicate Averages
5	Chocolate Hole West			
		1	2200	4400
		1D	6500	
		2	5800	9400
		2D	13000	
		3	6800	
6	Drunk Bay			
		1	14000	
		2	6400	
		3	4000	
7	Elk Bay East			
		1	14000	
		2	3000	2700
		2D	2400	
		3	19000	
11	Europa Bay			
		1	190	
		2	1100	
		3	270	
13	Francis Bay			
		1	33000	
		2	39000	28000
		2D	16000	
		3	68000	
14	Frank Bay			
		1	3000	3600
		1D	4200	
		2	2400	1900
		2D	1300	
		3	1500	1400
		3D	1200	
15	Friis Bay			
		1	3600	
		2	760	2000
		2D	3200	
		3	5200	
18	Hart Bay			
		1	2300	3600
		1D	4900	
		2	3600	
		3	700	
19	Kiddel Bay			
		1	7800	
		2	760	
		3	740	
20	Lagoon Point			
		1	14000	14000
		1D	14000	
		2	14000	
		3	10000	
27	Popilleau Bay			
		1	2200	
		2	6200	4100
		2D	2000	
		3	5600	
28	Privateer Bay			
		1	23000	
		2	5000	10000
		2D	15000	
		3	8400	
30	Salt Pond			
		1	74	
		2	480	
		3	920	730
		3D	530	
32	Southside Pond			
		1	100	
		2	10	23
		2D	36	
		3	32	
34	Hanson Bay			
		1	6100	
		2	2800	5400
		2D	8000	

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