Determining Land Use Change and Desertification in China using Remote Sensing Data

by

Leah Hutchison

Submitted to the Department of Earth, Atmosphere and Planetary Science
in partial fulfillment of the requirements for the degree of
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Abstract

Desertification, the spread of desert-like conditions in arid or semiarid areas due to human influence or to climatic change, affects most arable land in arid and semi-arid China. This project provides an analysis of desertification in northeastern arid and semi-arid China to determine its spatial distribution, severity, and causes. It locates areas of desertification and identifies and ranks in order of importance their anthropogenic and climatological causes. It especially focuses on the savanna transition zone west of Beijing to see if climate factors or increasing population density can be correlated to land cover change. GIS (Geographic Information Systems) software is used to recognize locations of rapid land cover change. Statistical tests, such as unbalanced multi-way ANOVA, determine if climatic or anthropogenic factors can predict if an area is undergoing rapid land cover change.

The climate and population data is resampled to an uniform 0.5° scale and converted into qualitative data before statistical testing. This project tests if land cover change, a more difficult indicator to measure, can be predicted by analyzing trends in vegetation, precipitation, temperature, wind and population. Desertification is more likely and more severe in climates with low precipitation. Areas with low population density tend to have less severe land degradation than areas with medium or high density; this may be due to more intense land use in high population areas.

Thesis Supervisor: Dennis McLaughlin
Title: Professor
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Chapter 1

Introduction

The most serious effect of desertification is loss of arable land—land becomes incapable of supporting at least 10% seasonal vegetation cover and has exposed soil or bedrock. Desertification is an especially severe problem in China because the country has a growing population and limited resources. An estimate of the number of people China has resources to feed, called its carrying capacity, is commonly put at 1.5 to 1.6 billion people. It is difficult to estimate a country's carrying capacity because increasing technology allows people to get more food out of less optimal resources. Some people do not accept "carrying capacity" as a valid measure, believing that a community will always develop new methods to support its population [Tomic, 1998]. However accurate a metric it is, it is worrisome that China's carrying capacity is close to current and future population estimates.

The 1990 census of Chinese population was 1.1 billion people, but this is probably an underestimate. China's population is not only very large, but also growing very quickly. There are various projections for future population growth, often depending on whether or not the government enforces its population control policies. Some estimate China's population will peak at 1.5 or 1.6 billion in 2020 with strong population controls [Anon, 1989]. China's population is large, and aging, putting an extra burden on the government to provide for its elderly citizens. The average age of China's population will also increase over the next couple of decades, meaning that there will be more people no longer working and needing social services. The strains
Figure 1-1: Context for study area in semi-arid North China
of increased growth and decreased mortality may compromise China’s ability to feed its population [Edmonds, 1994].

China’s rapidly growing population and diminishing arable land will require changes to its agricultural practices. China currently supports 22% of the world’s population on 7% of the world’s total farmland [Fullen and Mitchell, 1994]. Three quarters of its population live in rural areas, nearly all working as farmers [Fullen and Mitchell, 1994]. Since the country is so invested in farming, there is no unexploited arable land left to expand into as currently cultivated land is used up. Cropland accounts for 13.5% of China’s total area and is decreasing yearly due to erosion, pollution and depletion of soil nutrient levels [Fullen and Mitchell, 1994, Edmonds, 1994].

Desertification is the primary cause of arable land loss. Expanding urban centers, fish ponds and horticulture consume relatively little arable land [Fischer et al., 1999]. The first step in formulating changes in agricultural practices is to understand where and how quickly arable land degradation is occurring due to desertification. Then, agricultural practices that conserve and protect arable land while feeding the population can be proposed. Farming is a traditional way of life for many Chinese, so changes in the agriculture system necessary to feed the growing population will affect many people. This project has important social implications, because it helps constrain questions about China’s past and present land resources and how much food China can produce.

Land cover change in arid and semi-arid China is a function of climatic and human factors. This project looks for spatial patterns that demonstrate this relationship. Figure 1-1 shows the study area in context with the rest of China. The first consideration is how to quantify land cover over an area in Northeastern China that is 12 by 24 sq degrees, or about 2.3 million sq km. This area stretches from the Yellow Sea to the eastern front of the Gobi desert. It includes Beijing and the Yellow River and spans the provinces of Shaanxi, Gansu, Henan, Shandong, Liaoning, Shanxi, Hebei, and Inner Mongolia. Figure 2-1 shows China’s deserts and degraded lands.

Since the study area is so large, remote sensing is the only way to know land cover. How valid is it to use remote sensing-based land cover maps as a proxy for
actual land cover? The 1 km land cover data sets from 1992 and 2000 have been validated by comparison with “ground-truthing” field sites [Belward, 1999]. Their spatial resolution must be considered when making broad statements about the amount of land cover change. Relying on only remotely sensed data for land cover, no matter how sophisticated the interpretation techniques used to create and validate it, can be problematic if it does not match actual land cover. Although people creating land cover datasets from remotely sensed data are careful to ground-truth their data and attempt to make it as accurate as possible, topography, cloud cover, and spatial extent of different types of land cover confound their efforts. The topographic roughness partially determines the spatial accuracy of remote sensing land cover classification. North, northeastern and central China are very flat and with 25% of their lands used in large, purely agricultural tracts, while the hillier lands in southern and southwestern China have a more heterogeneous land cover and smaller areas of individual land cover units [Frolking et al., 1999]. This means that remote sensing classification is less likely to overestimate the dominant land cover’s extent in North China because pixels are mostly unmixed. South China’s hilly topography and frequent cloud cover makes remote sensing of land cover difficult, with many pixels including several land cover units [Frolking et al., 1999]. Those mixed pixels are classified as their dominant land cover, which leads to systematic underreporting of minority land cover units. Since the area of interest for this paper falls in North, Northeastern and Central China, remote sensing classification should be accurate.

To determine the accuracy of satellite-derived Chinese land cover datasets, researchers compare them to official agricultural censuses. There are two official Chinese agricultural censuses for China. Generally, the State and Provincial Statistical Bureaus (SSB) dataset published in the Statistical Yearbook of China is most widely used and is regarded as the “official and most authoritative” source [Fischer et al., 1999].

Frolking et al have compared 1992 1 km Advanced Very High Resolution Spectrometer (AVHRR) derived cropland estimates with the county-scale crop-specific SSB 1990 agricultural census in China to determine how different they were [Frolking et al., 1999]. He found differences of 50-100% between the census and remote sensing data when
looking on the scales of 1/2 sq degrees and several square degrees [Xiao et al., 2002]. Inaccuracies in both remote sensing and census data causes the variation. Frolking provides three reasons for the difference: (1) the official census values are under-reported, (2) the two datasets are not measuring exactly the same things (planted cropland versus arable land), and (3) overestimation of remotely-sensed cropland area because many pixels classified as cropland are a mixture of mostly cropland with other land cover. An example of the second reason is the 1990 FAO estimate of 1,236,780 km$^2$ of arable land, which includes fallow land [Frolking et al., 1999]. The 1990 FAO figure was derived from remote sensing data. The 1990 SSB Chinese agricultural census only counts planted area and estimates 975,000 km$^2$ [NBS, 2001].

Xiao et al have done an even more detailed study than Frolking (2002), looking at 30 m Landsat data to determine the cropland fraction of each 1 km pixel [Xiao et al., 2002]. This eliminates the simplification in Frolking (2002) that mixed cropland pixels were 50% cropland. Since small farms are distributed among other land cover types in China, AVHRR’s 1 km spatial resolution data cannot pick them up as well as the 30 m spatial resolution Landsat data. Xiao’s study shows the importance of considering resolution of images data in land cover classification [Xiao et al., 2002]. Looking in an area of about 1 square degree, Xiao et al determined that the AVHRR-classified cropland area was 53% greater than the unpublished 1995 digitized SSB Chinese agricultural census [Xiao et al., 2002]. The current best estimate is that the actual cropland area is underestimated in the national census by about 30% nationwide and shows variation in underreporting by region and crop type [Fischer et al., 1999]. The discrepancy between remotely sensed and census land cover areas makes discussion of land cover change difficult to measure and authenticate.

This study looked at the spatial extent of land cover change by contrasting 1992 and 2000 land cover classifications using GIS software. Then an ANOVA (statistical analysis of variance) test, of land cover change with various explanatory factors was performed. This test analyzed how much variance in the land cover data could be explained by variation in factors such as wind speed, temperature, precipitation, population density, and NDVI (a measure of amount of vegetation).
Chapter 2

Background

2.1 How Desertification Occurs

Desertification affects much of northern and interior China because those areas have generally drier climates more susceptible to soil degradation and erosion. The environment is prone to desertification because soils consist of sand and loose sediment. The windy season also coincides with the annual droughts, blowing away the soils. Land progressively degrades through a combination of factors. Wind erosion of the top fertile layers and non-sustainable agricultural practices often used by subsistence farmers remove fertile topsoil. Blowing sand that buries fertile soil and soil salinization due to increased irrigation in marginal cropland both decrease soil quality.

Desertification in arid and semiarid China often takes the form of wind erosion. Wind erosion is dependent on wind velocity, precipitation and temperature (which determines evaporation) [Zhibao et al., 2000]. The Food and Agricultural Organization (FAO) came up with a model to quantify the amount of wind erosion possible at a given location in northern China, which was ground-truthed with data from 233 meteorological stations. Semi-arid areas located to the windward side of existing deserts tend be desertified as the dominant wind direction pushes sand dunes into the semi-arid area. The ground materials most subject to wind erosion are Gobi desert, sandy desert, and loess deposits [Zhibao et al., 2000]. These materials are the dominant surfaces in northern China. Wind erosion varies not only by soil type, but
also by time of the year. The seasonal distribution and direction of wind in northern China implies a connection to the amount of wind erosion in arid northern China and the Mongolian high pressure weather systems in the spring [Zhibao et al., 2000].

Population pressure can also cause desertification. Human activities causing land degradation include overgrazing, over cultivation, and over collecting. Overgrazing occurs when too many sheep or goats eat all the grassland and compress the soil, and once compressed, it is more difficult for grass roots to penetrate the soil. Over cultivation is when people convert grassland to farmland without protective measures like tree wind-breaks, fertilizer or irrigation methods. Usually there is a sharp drop in the farm’s output after 2-3 years due to unsustainable farming practices [Edmonds, 1994]. The reclaimed grassland is abandoned and unable to regrow natural vegetation, becomes desertified. Excessive collecting of fuel wood or medicinal plants such as licorice root and Chinese ephedra often converts shrub-covered fixed or semi-fixed sand to shifting sand [Edmonds, 1994]. Many traditional Chinese herbal medicines grow as ground cover in semi-arid climates. Harvesting too much of the ground cover can destabilize a fixed sand dune into a mobile dune likely to threaten the stability of other fixed sand dunes.

In Northeast China, the encroaching deserts are not only a serious environmental concern to the region’s agriculture but are also of importance to all its inhabitants’ quality of life. Desertification has caused more frequent dust storms to blanket Beijing and other major cities in the past decades, and it disrupts transportation when shifting sand dunes cover roads and railroads [Zhibao et al., 2000]. Dust storms are concentrated in five areas in arid China. They are the Tarim Basin, Alashan Plateau (including the Tengger and Ulan Buh Deserts), the Mu Us Desert and northern Loess Plateau, southeastern Inner Mongolian, and North China Plain (to the south of Beijing). Dust storms have been documented since 205 BC and have been increasing in frequency and intensity [Zhibao et al., 2000]. It is suggested that this is the effect of human disturbance against the background of climatic fluctuation, but others claim an anthropogenic pressure cannot be attached to the increasing dust [Wu et al., 2002]. This project might help resolve the debate.
2.2 Where Desertification Occurs

An almost continuous belt of desert and degraded land stretches for 5500 km along north China and seems to be growing. Figure 2-1 shows China’s climatic zones and deserts as shaded areas. Desertification in these virtually unpopulated deserts do not have as significant impact on China’s carrying capacity as it does in those areas closer to the more-densely populated eastern coast. However, desertified land surrounds these deserts and has been trending eastward for centuries. This project focuses on the easternmost lands in Figure 2-2, especially the Horqin Sandy Lands and Mu Us Sandy Lands and the land between them near the 500mm isohyet line. These deserts and the semi-arid land surrounding them feel the pressure of increasing population
Figure 2-2: Land Cover Change map, created in GIS, with isohyets showing the transition from arid to semi-arid land and cultivation while being at a critical climate location. Figure 2-2 shows part of the land cover change map created in ArcGIS for the project, with 50 mm interval isohyets overlaid on top. Beijing is in the green area in the top right. Figure 5-8 in the Discussion section shows the land cover change for the whole study area without the isohyets.

The 500mm isohyet line, shown as a solid line in Figure 2-2, divides China’s semi-arid climate from its sub-tropical climate nearer the coast. Arid areas receive less than 250mm of precipitation a year, while semi-arid areas receive less than 500mm
[Edmonds, 1994]. Arid and semi-arid areas are most affected by desertification. It is remarkable that desertification has progressed right to the 500mm isohyet, suggesting that relatively high precipitation is necessary to stop desertification. More observation will be needed to see if desertification is limited by an annual precipitation rate and how high that precipitation rate needs to be. One topic my thesis investigates is whether precipitation rate is related to desertification. The genesis of the thesis came from Figure 2-2, from the initial GIS investigation, which suggested looking more closely at precipitation data, and other climate data, to see if there is a correlation to land cover change. See Chapter 6: Discussion and Conclusions for comments on the relationship between precipitation and desertification.

Desertification has occurred historically in China in the northwest, northeast and northern drylands. Studying soils in central China has shown that its climate changed radically during the Pleistocene as it went from warm and humid to cool and semiarid [Fullen and Mitchell, 1994]. The dominant northwest winds of the Pleistocene, which continue today, have had a significant effect on China’s landscape. Strong winds carried away finer soil material, creating gravel deserts. Further downwind were sand deserts and then finally loess formations, silty deposits that comprise the Loess Plateau. Wind speed is one of the factors this study considers because of the strong relationship between wind and desertification in the Mu Us Sand Lands, Loess Plateau and Horqin desert in Northeast China.

2.2.1 Mu Us Sand Lands and the Loess Plateau

The Loess Plateau, part of the Mu Us in Figure 2-1, formed over 2.5 million years in the Quaternary as a result of wind-deposition [Guobin, 1999]. The loess is wind-deposited sediment with a depth of 50-200m. Loess soil is very porous and uncompacted with a high infiltration rate [Guobin, 1999]. When subjected to excessive cattle grazing, the soil becomes compacted and can not infiltrate rainfall as well, leading to increased runoff and erosion.

Most of the Loess Plateau was originally covered by forests and grasses with only slight erosion, however there is currently only 13% forest and 30% grassland cover
This change of land cover has contributed to very high erosion rates in the Loess Plateau. Historically, humans have moved into the loess tablelands, turning those forests and grasses into cropland [Guobin, 1999]. The tablelands are high plains with slopes of less than 3° edged by deeply incised gullies. Once the flat tablelands were all cultivated, population pressure forced farmers to start growing crops in the gullies and steep hillsides. 15-20% of all cropland in the Loess Plateau is above a 25° slope [Guobin, 1999]. Exposed loess material in cleared farmland is easily eroded in wind or rainstorms without a protective forest or grass cover. Farmland in arid and semiarid China is usually cleared of residual crop waste after each harvest. Because of this seasonally bare land, farmland has triple the annual wind erosion of grassland [Zhibao et al., 2000]. It is unclear if erosion is getting better or worse: more people are using the land for hillside farming but there are also more conservation projects, like reservoirs, terraces and soil collection basins on steep hillsides.

Human pressures have contributed to desertification for thousands of years. There was desertification in the semiarid steppe during the Han Dynasty (202 BC - 220 AD) due to farming [Zha and Gao, 1997]. The Mu Us Sand Lands were desertified by prehistoric agriculture. The Mu Us Sand Lands is an arid, sandy area which is about 65% covered by shifting and semi-fixed sand dunes [Wu et al., 2002]. The Mu Us Desert was caused by climatic fluctuation during the Ice Age but has been progressing southward through the fragile arid grasslands since the Tang Dynasty (618-906 AD) [Zha and Gao, 1997]. Zha (1997) believes the expansion of the desert is not correlated to drought but human activities such as over-cultivation, overgrazing, and excessive gathering of fuel wood and medicinal plants. According to historical accounts, a couple of thousands of years ago the grasslands in the Mu Us Sand Lands were pasture land with clear streams. However, it was largely destroyed in a war between the Han dynasty and minority nationalities in north China [Wu et al., 2002]. Troop movement and immigrating farmers converted the soil to desert-like conditions. Population doubled between 1950 and 1990 in the Mu Us Sand Lands [Wu et al., 2002].

In the Mu Us Sandy Lands, areas that are too arid or nutrient poor for farming are used for pasture. The transition between agriculture and pasture is a convenient
marker for watching the advance of desert-like conditions [Wu et al., 2002]. The rate of desertification in the middle and northwest of the Mu Us Sandy Lands, where only pasture is possible, is much higher than that in the east and south, where land is used for both farms and pasture [Wu et al., 2002]. The agro-pastoral transition zone runs from Da Hinggan Mountains, through east and southeast Inner Mongolia, north of Hebei, Shaanxi and Shanxi and ending in the northeast of Qinghai. It is a narrow belt 100-250 km in width and 2000 km in length. The annual precipitation is 300-400 mm with most of the rain occurring June to August.

The Loess Plateau is eroding at an incredible rate, and its sediment is carried away by the Huang River. The Huang River carries 1.6 billion tons of silt annually with an average sediment density of 35 kg/m³ [Edmonds, 1994]. This river has the greatest sediment load of any river worldwide. Serious soil erosion occurs over large areas. 80% of the middle Huang Valley is affected by soil erosion of over 5000 tons per km² per year [Edmonds, 1994]. Of the total affected area, just under 1/5 is suffering from excessively high erosion rates of over 10,000 tons per km². The areas with the worst erosion rate is around 30,000 tons per km² per year. According to a remote sensing survey in 1990 from the Chinese Academy of Sciences, erosion areas cover 45% of the Plateau with an average loss of 3720 tons per km² each year [Guobin, 1999]. The worst areas of sediment yield are in northern Shaanxi and northwestern Shanxi. These areas alone produce just under 1/4 of the total annual silt load in less than 5% of the total area of the Huang River Basin [Edmonds, 1994].

Annual precipitation rates in 1992 and 1999 are variables in the project to test if precipitation rates greatly influence erosion in the Loess Plateau region.

### 2.2.2 Northeastern China

The high erosion rates of Northeastern China’s Horqin Desert are not because the soil is unconsolidated or the terrain has lots of relief. Most of the slopes are below seven degrees and the moderately thick, dark soils (chernozem and chestnut soils) are rich in hummus and carbonates, which helps slow erosion [Edmonds, 1994]. However, the lower layers of the soil are often impermeable and during the winter the ground freezes.
Therefore, soil erosion can be quite serious in the spring and summer if snow melt is accompanied by heavy rain. The Nonni River Plain and eastern Inner Mongolia have only been settled since the late 19th century, yet they still have erosion problems. In a quarter of all cultivated land in Northeast China, over half of the 70-80cm thick black soil layer has been washed away [Edmonds, 1994].

Desertification has been ongoing in China since prehistoric time; some researchers think its rate has increased over time [Zha and Gao, 1997]. Zha (1997) claims ancient cities do not show strain from desertification and that large-scale cultivation since the 1600s has led to the current rapid rate of desertification. The geologic record shows desertification is caused by both natural and human effects, but it is not possible to tell if contemporary desertification is mostly caused by human overuse or environmental fluctuation. Since desertified land covers such a large area and includes different degrees and types of degradation, sophisticated techniques are needed to determine where and how fast desertification is occurring.

2.3 How to Determine Rates of Desertification

Researchers employ a variety of techniques to discover and quantify rates and modes of desertification, ranging from field studies to aerial photography and satellite imagery. Studies have been conducted over the scales of a single farm, a small watershed, a province, and globally. While this study uses satellite imagery with some ground-based datasets, it is informative to look at other ways to determine desertification rates. Desertification occurs over all scales and can be quantified differently depending on the spatial scale and resolution of data.

The smallest study only looks at the soil in a several fields in Gansu province to quantify erosion rates [Wu and Tiessen, 2002]. The study, located in northwest China, came up with an approach that mostly solved the difficult of measuring the amount of erosion in a location when you do not know the original soil depth. It estimated the amount of soil erosion with $^{137}$Cs radioactivity and found a relationship between $^{137}$Cs levels and soil nutrient levels. When $^{137}$Cs activity is reduced, organic
C, total N, and cation-exchange capacity decline. $^{137}$Cs is a unique tracer for soil erosion because it was evenly distributed on a regional scale from known hydrogen bomb testing [Wu and Tiessen, 2002]. If the $^{137}$Cs concentration in a farm drops, it is an indication of soil erosion. New $^{137}$Cs free soil is brought up by ploughing as soil erosion removes the top soil. The assumed baseline for $^{137}$Cs activity is lightly degraded pasture (the most uneroded land in the study area). One source of error is that the initial level of $^{137}$Cs in an area depends on the amount of land cover during $^{137}$Cs deposition [Wu and Tiessen, 2002].

Remote sensing can be used to determine climatic change and its relationship to land cover and desertification. A GIS study comparing aerial photos from the 1950s to Landsat 5 Thematic Mapper (Landsat TM) images from the 1990s found that fixed sand dune areas were converting to shifting sand dunes. Wetlands and shrub land generally decreased and semi-fixed sandy land has increased. Since the 1950s, the mean annual temperature has been rising in the Mu Us Desert (about 0.1 °C per decade), yet the precipitation has remained about the same. The increase in temperature could favor and could be a result of increasing desertification.

Several studies have used aerial photography and remote sensing data (especially Landsat TM) to make historical studies of desertification. One study uses 1960 and 1987 aerial photographs of Yulin county in the Shaanxi Province of northwest China [Gao et al., 2001]. The study manually interpreted land cover as farmland, woodland, grassland and sandy areas. The eastern portion of the study area is mostly desertified. The western half is more vegetated, even though it is closer to the Mu Us Desert. Increasing desertification affects less than 2% of land and is generally shifting to the west [Gao et al., 2001]. Correlating amount of desertification with land cover, the study found that shrubs are the most effective ground cover to prevent sand dune encroachment. Grassland is the least effective land cover, especially if it is overgrazed.

Besides assessing desertification and rehabilitation of China, there have also been studies using aerial photography and Landsat TM images to create models for sustainable development. The Asian Development Bank (ADB) funded a pilot GIS study on the Northern agro-pastoral transitional zone to make decisions about economic
development and arid land management [Zhou, 1998]. The project used Landsat TM from between 1992 and color IR aerial photographs. Pressures from new coal mines, subsistence agriculture and a growing population are straining the fragile Northern transitional zone [Zhou, 1998]. The Loess Plateau, a large feature in the Northern argo-pastoral transitional zone, is mostly used for subsistence farming but the area has 60% of China’s coal reserves [Guobin, 1999]. Construction and mining help the economy but are also leading to soil erosion. Land use planning is needed to best decide how to use China’s resources in the Loess Plateau and elsewhere in northern China. The project created maps of “Land degradation by land use,” “land use planning,” and “critical risk for desertification” [Zhou, 1998]. Areas at critical risk for desertification fulfilled the following criteria: located at the margins of existing desert, located down-wind from existing desert, less than 30% vegetation cover (as indicated by Normalized Difference Vegetation Index (NDVI, discussed in Section 3.3)), and currently used as farm land [Zhou, 1998]. The project was a first attempt at modelling sustainable farming and mining practices using GIS.

Locations of coal deposits or mines are not included in the analysis because they would show up or have an appreciable effect at 1 km spatial resolution. However, the other criteria used by the ADB study are useful for thinking about causes of desertification. Wind speed and NDVI are included as factors in the ANOVA analyses that can potentially explain desertification.
Chapter 3

Sources of Data

The first step was to compare Land Cover Change between 1992 and 2000 using GIS software. The second step was to perform an ANOVA (analysis of variance) test comparing land cover change variance with the variance in explanatory variables to determine a relationship between climate factors and land cover change. Especially interesting is the transition of cropland and forest to savanna to desert. Publicly available published datasets were used in the analysis, including: land cover change (from 1992 to 2000), average precipitation in 1992, precipitation in 1999, July 1992 NDVI, annual average temperature, annual average wind speed and combined 1990 and 2000 census data. Described below are where the data was found and how it was modified for the project.

3.1 Land Cover Change

One of the two land cover maps used is derived from 1-km AVHRR (Advanced High Resolution Radiometer) data from April 1992 to March 1993 (see Figure 3-1). The dataset’s documentation is at the following link: edcdaac.usgs.gov\glcc\eadoc2.0.html. The maps came from the Eurasian Land Cover Characteristics Data Base and were projected in Lambert Azimuthal Equal Area. This data was collected and compiled by the Earth Resources Observation System (EROS) Data Center of the USGS. Amy Watson, a grad student with Prof. McLaughlin at MIT gave significant assistance in
Figure 3-1: 1992 AVHRR land cover data for land between the Gobi and eastern coast of China making the data viewable in ArcGIS.

The other land cover map comes from 2000. The most up-to-date land cover map of China available is a 1-km land cover map derived from Moderate Resolution Imaging Spectroradiometer (MODIS) data in 2000 (see Figure 3-2 – shades should be the same as in Figure 3-1 but they print lighter). MODIS is the newest technology to be used in land use change monitoring; its seven bands are chosen to optimize the unique spectral signatures from vegetation types, using knowledge gained from the AVHRR data sets. The product is called MODIS/Terra Land Cover Type 96-Day L3
Figure 3-2: 2000 MODIS land cover data for land between the Gobi and eastern coast of China
### IGBP Land Cover Units

<table>
<thead>
<tr>
<th>Land Cover Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evergreen Needleleaf Forests</td>
<td>Lands dominated by woody vegetation with a percent cover &gt;60% and height exceeding 2 meters. Almost all trees remain green all year. Canopy is never without green foliage.</td>
</tr>
<tr>
<td>Evergreen Broadleaf Forests</td>
<td>Land dominated by woody vegetation with a percent cover &gt;60% and height exceeding 2 meters. Almost all trees and shrubs remain green year round. Canopy is never without green foliage.</td>
</tr>
<tr>
<td>Deciduous Needleleaf Forests</td>
<td>Lands dominated by woody vegetation with a percent cover &gt;60% and height exceeding 2 meters. Consists of seasonal needleleaf tree communities with an annual cycle of leaf-on and leaf-off periods.</td>
</tr>
<tr>
<td>Deciduous Broadleaf Forests</td>
<td>Lands dominated by woody vegetation with a percent cover &gt;60% and height exceeding 2 meters. Consists of seasonal broadleaf tree communities with an annual cycle of leaf-on and leaf-off periods.</td>
</tr>
<tr>
<td>Mixed Forests</td>
<td>Lands dominated by woody vegetation with a percent cover &gt;60% and height exceeding 2 meters. Consists of tree communities with interspersed mixtures of other four forest types. None of forest types exceeds 60% of the landscape.</td>
</tr>
<tr>
<td>Closed Shrublands</td>
<td>Lands with woody vegetation less than 2 meters tall and with shrub canopy cover &gt;60%. The shrub foliage can be either evergreen or deciduous.</td>
</tr>
<tr>
<td>Open Shrublands</td>
<td>Lands with woody vegetation less than 2 meters tall and with shrub canopy cover between 10-60%. The shrub foliage can be either evergreen or deciduous.</td>
</tr>
<tr>
<td>Woody Savannas</td>
<td>Lands with herbaceous and other understory systems, and with forest canopy cover between 30-60%. The forest cover height exceeds 2 meters.</td>
</tr>
<tr>
<td>Savannas</td>
<td>Lands with herbaceous and other understory systems, and with forest canopy cover between 10-30%. The forest cover height exceeds 2 meters.</td>
</tr>
<tr>
<td>Grasslands</td>
<td>Lands with herbaceous types of cover. Tree and shrub cover is less than 10%.</td>
</tr>
<tr>
<td>Perennial Wetlands</td>
<td>Lands with a permanent mixture of water and herbaceous or woody vegetation. The vegetation can be present in either salt, brackish, or fresh water.</td>
</tr>
<tr>
<td>Croplands</td>
<td>Lands covered with temporary crops followed by harvest and a bare soil period (e.g. single and multiple cropping systems). Note that perennial woody crops will be classified as the appropriate forest or shrub land cover type.</td>
</tr>
<tr>
<td>Urban and Built-Up Lands</td>
<td>Lands covered by buildings and other man-made structures.</td>
</tr>
<tr>
<td>Cropland/Natural Vegetation Mosaics</td>
<td>Lands with a mosaic of croplands, forests, shrubland, and grasslands in which none one component comprises more than 60% of the landscape.</td>
</tr>
<tr>
<td>Snow and Ice</td>
<td>Lands under snow/ice cover throughout the year</td>
</tr>
<tr>
<td>Barren</td>
<td>Lands with exposed soil, sand, rock, or snow and never has more than 10% vegetated cover during any time of the year.</td>
</tr>
<tr>
<td>Water Bodies</td>
<td>Oceans, seas, lakes, reservoirs, and rivers. Either fresh or salt-water bodies.</td>
</tr>
</tbody>
</table>

Table 3.1: Table of International Geosphere-Biosphere Programme (IGBP) Land Cover Units, taken from [Anderson et al., 1976]
Global 1km ISIN Grid and is collected and compiled by the EROS Data Center of the USGS (edcdaaclusgs.gov\modic.mod12q1.html).

In both datasets, the data is classified into land cover units using the International Geosphere-Biosphere Programme (IGBP) land cover scheme (see Table 3.1). IGBP has very general classes because it is intended for use with all global modelling applications. The land cover categories were picked so they would be useful for modelling gas exchange and other atmosphere/land interactions, wetland cover and other ocean/land interactions, biosphere burning, changes in vegetation over time, biological attributes and landscape characteristics [Belward, 1999]. Because of its broad range of applications, it is not ideally suited to identify human induced land changes.

Another popular land cover classification system, the USGS scheme, is more suited than the IGBP scheme to identify changes in cropland and the human impacts on landscape. The AVHRR dataset also comes with a USGS classification scheme, but MODIS does not. The USGS categories were chosen because of their visibility in aerial and satellite photography. The purpose of the system is to identify land use and monitor environmental processes such as agricultural land degradation, loss of wetlands, loss of fish and wildlife habitat, and uncontrolled urban development [Anderson et al., 1976]. The USGS scheme is also used for determining land use for taxation purposes, by regional, state and federal governments for flood control and waste-water planning, and for monitoring how private land changes near public lands such as national parks to gauge the impact on wildlife resources. Although the USGS scheme ties in human aspects of land use change better than the IGBP scheme, this project uses the IGBP scheme because both land cover data sets use it.

### 3.2 Annual Precipitation

The precipitation data came from a global air temperature and precipitation dataset, called “Terrestrial Air Temperature and Precipitation: Monthly and Annual Time Series (1950-1999),” version 1.02 [Legates and Willmott, 1990a, Legates and Willmott, 1990b]. This interpolated dataset was available July 2001. Data from 26,858 precipitation
3.3 NDVI

NDVI is a convenient way to describe the spectral signature of vegetation; see equation 3.1 for the equation used to calculate NDVI. Red and near-infrared (NIR) reflected energy indicates the amount of vegetation present on the ground [Gitelson and Kaufman, 1998]. Reflected red energy decreases with greater vegetation because the chlorophyll in the foliage absorbs that energy. Reflected NIR energy, on the other hand, increases with greater vegetation because healthy leaves scatter the energy (through reflection and transmission) and absorb very little [Strahler et al., 1999]. Although the amount of reflected red and NIR radiation does not directly quantify type of vegetation or other plant biophysical parameters (sources of error like atmospheric conditions, what soil is below the vegetation, canopy structure and composition, and solar irradiance), the contrast between red and NIR signals is sensitive to gross vegetation amount [Strahler et al., 1999]. See Figure 3-3 for a comparison of vegetation and soil spectral reflectances.

The 1992 July monthly NDVI composite from AVHRR is used as a measure of the vegetation. The dataset’s documentation is at the following link: edcdaac.usgs.gov\glcc\tablambert.euras.as.html. The data came from the Eurasian Land Cover Characteristics Data Base and was projected in Lambert Azimuthal Equal Area. It was collected and compiled by the Earth Resources Observation System (EROS) Data Center of the USGS. The month of July was chosen because we expected to see the greatest difference between cropland and natural vegetation at that time of the year [Chen et al., 1999]. NDVI has limited sensitivity to plants with moderate to high chlorophyll content because the reflectance near 670 nm saturates at a relatively low
Figure 3-3: Spectral reflectance signature of a photosynthetically active leaf with a soil signature to show contrast, from [Strahler et al., 1999].
chlorophyll content [Gitelson and Kaufman, 1998]. However, NDVI is sensitive to low chlorophyll content and to the fraction of vegetation cover, making it ideally suited to quantify absorbed solar radiation in drier climates, like sub-humid, semi-arid and arid environments.

Both MODIS and AVHRR produce global NDVI products. See Section 6.2 for a discussion on the differences between AVHRR and MODIS land cover datasets because of differences in NDVI calculation. That section also includes Table 6.1, which lists the red and infrared bandwidths each satellite uses.

\[
NDVI = \frac{X_{NIR} - X_{RED}}{X_{NIR} + X_{RED}}
\] (3.1)

3.4 Average Temperature

The temperature data came from the “Global Air Temperature: Regridded Monthly and Annual Climatologies, version 2.02,” which is a subset of the temperature and precipitation dataset mentioned above [Legates and Willmott, 1990a, Legates and Willmott, 1990b]. This version of the temperature data was easier to obtain and view. It contains DEM-aided average monthly and annual air temperature interpolated from 24,941 temperature stations worldwide [Willmott and Matsuura, 1995]. The station air temperatures were first adjusted down to sea-level using an average environmental lapse rate (6.0° C/km). Then they were interpolated into a 0.5° latitude/longitude grid centered on the 0.25°. Finally, they were brought back up to their DEM-grid height using the same average environmental lapse rate. The dataset includes data from many years and does not represent a specific year, like the precipitation datasets do. The readme file is at: climate.geog.udel.edu\ climate\html_pages\README.lw2.html.

3.5 Average Wind Speed

Wind data came from the “CRU CL 1.0” version of the “CRU05 0.5 Degree 1961-1990 Mean Monthly Climatology” produced by the Climate Research Unit (CRU) and dis-
tributed by the Intergovernmental Panel on Climate Change (IPCC) [New et al., 2000]. This average climatology dataset includes other measures like diurnal temperature range, frost day frequencies and sunshine duration in addition to wind speed. Only the wind speed was used in the analysis. Since the data was already on a 0.5° latitude/longitude grid centered on the 0.25°, it did not need to be interpolated. Documentation is online at: www.cru.uea.ac.uk/~markn/cru05/cru05_intro.html.

3.6 Population Density

The Chinese National Population Censuses of 1990 and 2000 are my sources of population density data [NBS, 1992, NBS, 2001]. Total population is reported on the province level. The relative population density between the provinces remained the same from 1990 to 2000; all of the provinces experienced about the same amount of population growth. Scaling by the area of each province, a generalized population density map on a 1/2 square degree scale was developed.
Chapter 4

Methods

The initial results of displaying land cover change in ArcGIS suggested an interesting and informative thesis project looking at desertification and trying to identify related factors. The first section of this chapter gives a brief description of the steps in ArcGIS. The second section describes the MATLAB data analysis comparing climate and census data to land use change. More detailed discussion of various steps and possible interpretations of the figures are in Chapter 6: Results.

4.1 Initial ArcGIS analysis

Land cover change in China was determined by comparing land cover datasets from 1992 and 2000. The first step to creating a land cover change map is to reclassify the 17 IGBP land cover units into five more broad units. Land cover units were ranked according to the amount of vegetation in each; the difference between “deciduous broadleaf forest” and “mixed forest” is not as interesting to me as different between “forest” and “savanna” because only the second indicates a degradation process. See Table 4.1 to see how the IGBP land cover units map into my more general units. The five broad units are: forest, cropland, savanna, barren, and water/other.

The following are a couple of notes about reclassification decisions. It was difficult to decide where shrubland ended and grassland began because both had grassland with some percentage of tree cover, so both are reclassified as savanna. Assuming both
Figure 4-1: GIS image of 1992 1 km AVHRR Land Cover dataset for China.
Figure 4-2: GIS image of 2000 1 km MODIS Land Cover dataset for China.

<table>
<thead>
<tr>
<th>Reclassified Land Cover Units</th>
<th>Original IGBP Land Cover Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>Evergreen Needleleaf Forests</td>
</tr>
<tr>
<td></td>
<td>Evergreen Broadleaf Forests</td>
</tr>
<tr>
<td></td>
<td>Deciduous Needleleaf Forests</td>
</tr>
<tr>
<td></td>
<td>Deciduous Broadleaf Forests</td>
</tr>
<tr>
<td></td>
<td>Mixed Forests</td>
</tr>
<tr>
<td></td>
<td>Closed Shrublands</td>
</tr>
<tr>
<td>Cropland</td>
<td>Croplands</td>
</tr>
<tr>
<td></td>
<td>Cropland/Natural Vegetation Mosaics</td>
</tr>
<tr>
<td>Savanna</td>
<td>Open Shrublands</td>
</tr>
<tr>
<td></td>
<td>Woody Savannas</td>
</tr>
<tr>
<td></td>
<td>Savannas</td>
</tr>
<tr>
<td></td>
<td>Grasslands</td>
</tr>
<tr>
<td>Barren</td>
<td>Barren</td>
</tr>
<tr>
<td>Water/Other</td>
<td>Water Bodies</td>
</tr>
<tr>
<td></td>
<td>Urban and Built-Up Lands</td>
</tr>
<tr>
<td></td>
<td>Snow and Ice</td>
</tr>
</tbody>
</table>

Table 4.1: Table of more general reclassification of IGBP Land Cover Unit
shrubland and grassland can be used for pasture or cleared for farming, they represent possible sources of arable land and are grouped together. “Closed shrubland” is not grouped with the other shrubland classes in the broader “savanna” category because it has >60% canopy cover, making it more similar to forest than grassland. Hence, “closed shrubland” is reclassified as “forest.”

Land Cover Reclassification of 1992-1993 AVHRR data for all of China is shown in Figure 4-1. Land Cover Reclassification of 2000 MODIS data for all of China is shown in Figure 4-2. After calculation of land cover change, a low pass filter was implemented to eliminate noise in the data by lumping lone pixels with a different land cover than the majority of its eight surroundings pixels into the majority land cover unit. Figure 4-3 shows in black how many of the pixels changed as a result of the low pass filter. The small quantity of changed pixels means that much of the data is arranged in large groups of the same land cover unit and that there are very few lone different pixels. This suggests that the majority of land cover change shown by the ArcGIS Combine calculation really do represent changes instead of differences in the two satellites’ sensors because the land cover classification shows too much spatial correlation to all be noise.

After applying a low pass filter, all of the unique combinations for land cover change were displayed in ArcGIS using a Combine function (see Figure 4-4). The features are color-coded to emphasis the eastward gradation from desert to savanna to cropland in central China. Figure 4-4 is of central China and shows deserts (red), land that changed from savanna to desert in 2000 (dark orange), savanna that stayed savanna (light orange), and cropland that became savanna (yellow). Cropland that stayed cropland is shown as transparent, so that the DEM could be visible. The Himalayan Mountains are at the bottom of the map and Beijing is near the east coast, about the middle of the map. The next step was to look at a close up of the easternmost edge of this desertification trend to see the severity of the arable land loss and if human efforts to stop desertification are noticeable; see Figure 5-8. Analysis of Figures 4-4 and 5-8 is in Chapter 6: Results.
4.2 MATLAB analysis

First, the 1992 and 2000 land cover data was reclassified from the 17 category IGBP scheme into five categories (barren, savanna, cropland, forest, and water (which also includes urban areas), using the same reclassification scheme as in the GIS analysis, shown in Table 4.1.

The second step was to calculate the distribution of all 25 unique land cover changes (such as forest becoming barren or savanna remaining savanna). Those 25 unique land cover changes were lumped into three categories – negative, neutral, and positive land cover change. See Table 4.1 for description of which land cover change types are in each category.

Next, the number of negative land cover change pixels were counted in each 1/2 degree grid in Northeastern China. An unbalanced multi-way analysis of variance (ANOVA) compared the percent of negative land cover change with the explanatory variables of 1992 precipitation, 1999 precipitation, temperature, wind speed, 1992 NDVI, and population density. ANOVA, equation shown in 4.1, is a statistical test to determine if the differences between the means of the group is random or non-random.

\[ y_{ijklmn} = \mu + X_1 + X_2 + X_3 + X_4 + X_5 + X_6 \]  
(4.1)

where

\[ \mu = \frac{1}{N} \sum_{i,j,k,l,m,n} y_{ijklmn} \]  
(4.2)

\( \mu \) is the grand mean, the weighted average of all the samples. There are N samples in a test. The independent variables – \( X_1, X_2, X_3, X_4, X_5, \) AND \( X_6 \) – are called factors and are all divided into levels (each a degree of freedom). Then all of the possible combinations of factors are grouped together to form treatment groups. In this project, there are 6 factors (1992 precipitation, 1999 precipitation, wind speed, pop-
ulation density, 1992 NDVI, and temperature), each with three levels (low, medium and high). This test assumes that the populations from which the samples were obtained are normally distributed and that the samples must be independent. The variance within each treatment group (also called the error) and between treatment groups are calculated. The interaction effect, the effect one factor has on another, was not calculated for this project because there were not enough samples in every combination of two factors for the test to be valid. The result of an ANOVA test is an F statistic which is the variance between groups divided by the within group variance. The higher the F statistic, the less likely that factor’s explanatory power is due to random variation and the more likely that factor is significant in explaining the behavior of the dependent variable, in this case, land cover change.

The results of the negative land cover change ANOVA are shown in Figure 5-1 and indicate that temperature and wind speed may be linked to negative land cover change. To pursue that theory, histograms of the percent of negative land cover change by cells with low, medium and high wind speeds were plotted. The same histograms were plotted for low, medium and high average temperatures. See Figures 5-2 - 5-3 for the histograms. Both the ANOVA and histograms were computed using MATLAB.

A similar unbalanced multi-way ANOVA was performed for positive land cover change. The results (see Figure 5-4) suggest that 1992 precipitation, 1999 precipitation, and temperature are important factors, with population density as a secondary factor. See Figures 5-5 - 5-7 for histograms of low, medium, and high temp, precipitation, and population density. Only histograms for the 1992 precipitation data are presented because those for the 1999 precipitation data are nearly identical.
Figure 4-3: GIS image of China showing in black lone land cover pixels reassigned to the majority nearby land cover type.
Figure 4-4: GIS image of national land cover change from 1992 to 2000. Dark red stayed desert, orange stayed savanna, and dark orange is savanna that changed to desert. See text for more detailed legend.
Chapter 5

Results

The results are divided into two categories: negative land cover change and positive land cover change. First discussed are the statistical comparisons of land cover change severity with various climatic and human factors separately for each category. Then, a more qualitative interpretation of the spatial extent and geographic analysis of both types of land cover change is presented.

5.1 Negative Land Cover Change

An ANOVA test comparing the percent of negative land cover change with my explanatory variables of 1992 precipitation, 1999 precipitation, temperature, wind speed, 1992 NDVI, and population density shows that the two most significant factors are wind and temperature (see Figure 5-1). All of the other factors have an F value less than 10, denoting a stronger probability that the variation is random, so I will not consider them further.

A small fraction of areas with high wind speed saw desertification up to 75%

Temperature was the second most significant factor, however histograms of percent land degradation for 1/2 degree areas with low, medium and high average temperatures do not conclusively show a relationship between temperature and degradation. Figure 5-3 shows that most 1/2 degree areas have less than 10% degradation and a small fraction of any areas show more than 50% of their land affected by degradation.
Figure 5-1: ANOVA table of negative land cover change, showing probability that explanatory variables are random or related to land cover change. See Table 5.1 for description of explanatory variables represented in each row.

Table 5.1: Explanatory variables and how they are represented in the ANOVA tables, figures 5-1 and 5-4.

The three histograms are all similar.

### 5.2 Positive Land Cover Change

An ANOVA test comparing the percent of positive land cover change with the same explanatory variables is shown in Figure 5-4. Each factor in an multi-way ANOVA test is considered separately. The rows are not labeled on the the figure, but represent 1992 precipitation, 1999 precipitation, wind, population density, 1992 NDVI, and temperature, respectively (see Table 5.1). The ANOVA test finds that precipitation (both 1992 and 1999), temperature, and population density are important factors. Both precipitation datasets showed up as relevant, instead of just one, because they are so similar; the variation in precipitation patterns from 1992 to 1999 are not statistically significant. As a result, only histograms for low, medium and high 1992 precipitation data are shown (see Figure ??). Histograms are an easy way to look at
Figure 5-2: Histograms of negative land cover change in areas of low, medium and high wind speed. The top histogram shows relative desertification in areas of low wind speed, the middle histogram, for medium wind speed, and the bottom histogram, for high wind speed.
Figure 5-3: Histograms of negative land cover change in areas of low, medium and high average temperature.
the temperature, precipitation or census data and try to interpret links to land cover change.

**Analysis of Variance**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum Sq</th>
<th>df</th>
<th>Mean Sq</th>
<th>F</th>
<th>Prob&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>24238693</td>
<td>1</td>
<td>12119346</td>
<td>52.9</td>
<td>0</td>
</tr>
<tr>
<td>X2</td>
<td>11585164</td>
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<td>5792582</td>
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<td>0</td>
</tr>
<tr>
<td>X3</td>
<td>3082651</td>
<td>5</td>
<td>616530.2</td>
<td>7.87</td>
<td>0.0012</td>
</tr>
<tr>
<td>X4</td>
<td>4129507</td>
<td>5</td>
<td>825901.4</td>
<td>11.2</td>
<td>0.0001</td>
</tr>
<tr>
<td>X5</td>
<td>59855</td>
<td>2</td>
<td>29927.5</td>
<td>4.27</td>
<td>0.076</td>
</tr>
<tr>
<td>X6</td>
<td>6480115</td>
<td>3</td>
<td>2160038</td>
<td>3.22</td>
<td>0</td>
</tr>
<tr>
<td>Error</td>
<td>260955514</td>
<td>1139</td>
<td>229109</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>408829123</td>
<td>1151</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5-4: ANOVA table of positive land cover change, showing probability that explanatory variables are random or related to land cover change. See Table 5.1 for description of explanatory variables represented in each row.

Figure 5-5 shows the correlation of positive land cover change with population density. It is interesting to see that human factors, in addition to climate factors, are linked to land cover change. Areas with high population density tend to have more improvement – both in quantity of 1/2 square degree areas and amount that each area improved. Areas with medium population density also showed a similar marked improvement. Low population density areas showed the least amount of improvement, but it is important to note that even sparsely populated areas saw some positive land cover change.

Figures 5-6 show histograms of percent land improvement for 1/2 degree areas with low, medium and high average temperatures. Unlike the histograms of negative land cover change in different temperature regimes, these histograms allow inference about the relationship between temperature and land cover change. Areas with low and medium temperatures are more likely to experience positive land cover change than high temperature areas.

The precipitation histograms (Figure ??) also show a clear trend in land improvement with precipitation amount. Land cover in areas with low and medium precipitation is much more likely to improve than high precipitation areas. This seems counter-intuitive, but it is possible that high precipitation areas are generally forest or cropland, and so cannot show significant land cover improvement. Low and
Positive land use change in areas of Low Population Density

n=507

Positive land use change in areas of Medium Population Density

n=318

Positive land use change in areas of High Population Density

n=327

Figure 5-5: Histograms of positive land cover change in low, medium and high population density areas.
medium precipitation areas, which have a greater percentage of their land cover as savanna or desert, has the capability of showing a stronger land cover improvement.

5.3 Spatial extent of Land Cover Change

Considering the change of cropland or forest into savanna as the early stages of desertification (the land cannot support the more nutrient and water-intensive vegetation of cropland or forest), we can see that China has a serious land degradation problem. Figure 4-4 shows that desert area is expanding in all directions. A close-up view of
Figure 5-7: Histograms of positive land cover change in low, medium and high precipitation areas.
the same map (Figure 5-8) shows more clearly the savanna transition zone.

The color scheme for the close-up map is the same as for Figure 4-4; for clarity it is also described in words: barren land is red, savanna that became desert is dark orange, savanna that remains savanna is light orange, cropland that because savanna is yellow and continual cropland is shown transparently. Forest that was converted into cropland is light yellow, savanna that became forest is light green and savanna that became cropland is dark green. The last two changes represent reversals of desertification. There is a large patch of greens surrounding Beijing, probably the result of intense anti-desertification measures. See Chapter 6 for a discussion of current large-scale rehabilitation measures in China. For the most part, however, savanna has expanded coastward, degrading cropland (yellow) and forest (purple). The transition zone of savanna that was once cropland and forest is between 100 and 200 km wide.
Figure 5-8: Land Cover change in Northeastern China from 1992 to 2000.
Chapter 6

Discussion and Conclusion

The results of spatial and statistical analysis suggest some of the factors (precipitation, wind speed, temperature, NDVI and population density) are related to desertification. Taking individual areas into consideration, such as the savanna transition zone and the area around Beijing, the results imply potential causes of desertification. Section 6.1 infers possible causes of desertification and improvement for several regions. Section 6.2 points out that differences between satellites and data reduction methods may account for some of the land cover change detected. However, differences between the AVHRR and MODIS satellites do not explain all of the land cover change. Section 6.3 outlines various rehabilitation and prevention methods currently popular in China and recommends which methods to use in the previously identified degraded areas. Summarizing conclusions are presented in Section 6.4.

6.1 Discussion

Figure 5-8 shows an ArcGIS representation of land cover change from 1992-1993 to 2000. The most noticeable feature on the map is the wide swath of degraded land in the Gobi Desert. Desert is shown in dark red, savanna which changed to desert in dark orange, savanna in light orange, and desert which changed to savanna in coral. This area is mostly arid with some semi-arid regions, a factor which contributes to desertification. It was not discernable if population pressure contributed to desertifi-
cation in this area, but that is still a possibility. There is also a band of desertification (where cropland that changed to savanna is shown in yellow and forest which changed to savanna is shown in dark purple) between the savanna and the eastern cropland. The cropland is shown transparently in Figure 5-8 to reveal the topography underneath. This band means that the deserts are progressing east; it is not clear how far this desertification will advance before it is stopped by climate (more rainfall near the coast) or human effort. Currently, the degraded land extends up to the 250 mm isohyet (see Figure 2-2 for isohyets plotted on top of land cover change in area of interest). This project defines desertification as a land cover change from savanna to barren, and from cropland or forest to savanna or barren; improvement is defined as savanna changing to cropland or forest, or barren changing to savanna, cropland or forest. Since semi-arid land also exhibits degradation reaching 90% (but biased toward less than 10% degradation), desertification doesn’t seem likely to stop at its current extent because of precipitation amount. The desertified boundary can move another 250-300 km to the east before the precipitation is high enough (sub-humid climates) to make degradation unlikely. The degradation is too widespread and rapid to be merely the result of short-term climatic variation – tens of thousands of square kilometers of land have degraded in a decade.

While a general trend of decreasing vegetation is visible, there are some positive land cover changes. Some may be human-induced, while others are natural. Conversion of savanna to forest or cropland (shown in medium green and dark green, respectively), especially around Beijing, may be the result of land reclamation measures. Since the land cover change does not show a strong relationship to climatic variables, it may be due to either unexamined climatic variables (such as wind direction, humidity, water table levels, or number of sunny days) or human efforts to control their environment. Since the area experiencing positive land cover change near the highly populated east coast and where the “Three North” reforestation project is very active, it is probable that positive change is human-induced.

There is a large patch of positive land cover change in the northeast of my image, which is around Shenyang, China. It is possible that the forests of the “Three North”
reforestation project are visible in the 1 km land cover data. The reforestation will eventually cover 4 billion km² and individual planted forests may cover tens of square kilometers. Figure /reffig:poscen shows that areas with large populations, such as the land surrounding Shenyang, Beijing, and Tianjin, all large eastern cities, are more likely to have improvement their land cover between 1992 and 2000. The mandatory tree planting under the “Three North” project would naturally have a greater affect on land surrounding urban areas, as city residents don’t travel far to plant their trees.

Another type of positive land cover conversion may be the effect of land reclamation and stabilization efforts, but it is in such a remote area that the “Three North” project is probably not responsible for its improvement. In the middle of the Mu Us and other deserts, there are pixels which represent desert that became savanna (shown in coral). While those pixels occur in clumps, possibly suggesting locations of massive tree-planting projects, they are also very well intermixed with the desert and the savanna-turned-desert pixels and may represent natural vegetation variation. A third option must be considered: the change could also be the result of insensitivity in the satellites to low vegetation levels. Both MODIS and AVHRR use NDVI values as well as other data sources such as albedo, snow cover and surface temperature to derive their land cover products. It has been shown that since NDVI is a nonlinear ‘stretch’ of the NIR/red ratio, it enhances vegetation index values under low biomass conditions and compresses vegetation index values under high biomass conditions [Strahler et al., 1999]. Since small changes in vegetation levels in a sparsely vegetated area will show up as large changes in its NDVI, possibly causing some ambiguity in the classification of barren land and some of the less vegetated types of savanna. Even if true, however, this ambiguity cannot explain all of the savanna-desert land cover change because of the large land area affected by this land cover change and because only a subset of the “Savanna” reclassed land cover is sparsely enough vegetated to possibly be confused with barren land reclassified as “Desert.” Not all changes in NDVI between 1992 and 2000 reflect changes in vegetation; the next section discusses how the change in NDVI might be partially an effect of different satellites and how they measure NDVI.
6.2 Difference between AVHRR and MODIS land cover datasets

The differences between the AVHRR and MODIS land cover datasets may not only be due to land cover changes in the intervening 8 years. Differences in the remote sensing platforms and data compilation methods mean that the two satellites could differently characterize some percentage of an area. I believe the amount of difference between the two datasets is too great to be explained entirely by satellite differences, but considering how the AVHRR and MODIS datasets are created can give insight into how comparable their classifications should be.

AVHRR and MODIS land cover classification are both done with neural nets that combine a multitude of input data, such as albedo, precipitation, seasonal NDVI variability, temperature, etc, to produce a set of unique classifications for the data. Field work is needed to ground truth those classifications to unique land cover types. An important factor in creating a land cover classification is NDVI data, which is a convenient way to describe the spectral signature of vegetation. MODIS and the older AVHRR satellites both measured NDVI, which was used in their respective land cover products, but they did not measure the same value. Equation 3.1 shows how to calculate NDVI; since the two satellites have different red and infrared bandwidths, their NDVI calculations differ slightly.

Comparing MODIS NDVI data to historical AVHRR NDVI data is tricky because their calculations use different wavelengths. Table 6.1 shows the various wavelengths used for NDVI calculations by the AVHRR and MODIS satellites. A year-long comparison of MODIS and AVHRR NDVI values show that they match very well during the dry season in arid and semiarid areas (Figure 6-1) but that the MODIS NDVI is

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Red Bandwidth</th>
<th>Infrared Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVHRR</td>
<td>570 - 700 nm</td>
<td>710 - 980 nm</td>
</tr>
<tr>
<td>MODIS</td>
<td>620 - 670 nm</td>
<td>841 - 876 nm</td>
</tr>
</tbody>
</table>

Table 6.1: Wavelength bandwidths of AVHRR and MODIS satellites
Figure 6-1: A year-long comparison of AVHRR and MODIS NDVI profiles in semiarid areas. They are very consistent most of the year and only differ by ~10% during the summer.
higher during the wet season for every climate type, with greater discrepancy in the more humid sites [Huete et al., 2002]. Water vapor content in the atmosphere strongly affects the AVHRR near infrared band, causing it to report NDVI values corresponding to lower-than-actual vegetation levels. The MODIS NIR band is narrower and does not include water absorption bands so it is unaffected by seasonal variations in atmospheric humidity. The work of Dr. Huete et al established that there are some other reasons for differences between the two systems [Huete et al., 2002]:

I The red band in MODIS is more sensitive to chlorophyll, creating higher NDVI values.

II MODIS is composited over 16 days while AVHRR is composited over 14 days, and MODIS is more selective about acceptable view angles for measurements because it corrects for the atmosphere before compositing. The MODIS dataset, therefore, tends to be more accurate than the AVHRR dataset.

III Both methods use Rayleigh scattering and ozone absorption but MODIS also has aerosol correction.

IV MODIS has better spectral and radiometric measurements.

This section is a caution against mixing slightly incompatible datasets. A small part of the difference between the 1992 and 2000 NDVI data is due to different bandwidths and accuracies of the AVHRR and MODIS satellites. However, the spatial pattern of land cover change suggests that most of the variation should be a reflection of vegetation changes.

6.3 Rehabilitation

There are many and varied methods of controlling desertification, depending on its causes – wind or water erosion of topsoil, salinization of topsoil, compaction by livestock, etc. Rehabilitation of desertified areas must include both biological and techno-
logical solutions to be effective [Zha and Gao, 1997]. In areas with lots of mobile sand dunes, planting artificial or restoring natural vegetation anchors those sand dunes in place and prevents the spread of dunes. Planting shrubs can also have economic benefits if they bear fruit or are used as an herb. In places that are so arid and have such high wind speeds that plants won’t grow, China must implement more technological, rather than biological, solutions, such as establishing artificial sand fences and spraying chemical binder to stabilize shifting sands [Shengyue and Lihua, 2001]. That method stabilizes the sand surfaces so vegetation can be planted. However, chemical stabilization is a very expensive process so it is only used over small areas [Zhibao et al., 2000]. Straw checkerboards are another rehabilitation measure in remote areas and are commonly used to prevent sand movement across roads and railroad tracks. They work by slowing down wind velocity at ground level and by providing a surface for plant growth [Zha and Gao, 1997].

Areas with steep slopes, such as the Loess Plateau require different rehabilitation strategies. The most common-sense idea is to plant vegetation where it is best suited to grow and on slopes gentle enough that soil erosion rates won’t outweigh potential crop production. Grain crops should be grown on the plains and terraced tablelands, while wood and fruit trees should be planted in gullies and grasses and shrubs should be planted in nutrient-poor eroded hillsides [Guobin, 1999]. All rainfall needs to be retained and infiltrated on site [Guobin, 1999]. Engineering solutions include building catchments and ditches in mountainsides to catch water during torrential rainstorms and dams to catch silt [Edmonds, 1994].

Another suggestion for erosion control in the Loess Plateau is similar but requires more financial input in the form of terraces and fertilizers. Some of those solutions include: building sturdy terraces, choosing crops that grow well in dry conditions and will help keep soil in place, using more chemical and organic fertilizers to raise yields, reducing ploughing, and adjusting the planting cycle to reduce soil erosion and evapotranspiration [Edmonds, 1994].

Soil conservation doesn’t just rely on solutions to fix damage already done to soil; it is also necessary to reduce the area of cropland if its cultivation is conducive to
eolian erosion [Zha and Gao, 1997]. Reducing production now conserves land from erosion later. Techniques that limit the amount of cattle grazing should also be explored. Reduction of herd size, using animal breeds better suited to low-water environments (sheep and goats instead of cattle), and raising stall-kept animals will lessen the impact of animal grazing in northern China [Murphy, 2001]. The best suggestion so far is to grow alfalfa as fodder for stall-fed animals. Gansu province has begun experimental alfalfa farming as a way to feed their livestock and improve the land [Murphy, 2001]. Alfalfa has deep roots which helps hold the soil together and is also nitrogen fixing, so it increases the organic content of the soil over time, perhaps to the extent that the land could be used to grow other crops too.

Drought tolerant crops or crops that thrive in sandy soil are ideally suited to grow in arid and semiarid northern China. However, to best manage the soil, the planting method is as important as the crop type. Studies have been undertaken to determine the best method of planting crops to limit erosion. One study of soil conservation techniques and their effectiveness compared how straw mulching, polyethene mulching and no mulching of crops, which were planted along or perpendicular to the slope affected soil erosion [Fullen and Mitchell, 1994]. Generally, contour cultivation decreased erosion rates. Straw mulching was best at reducing runoff for all kinds of farmland – for any hill slope or for crops planted along contour or perpendicular to contour [Fullen and Mitchell, 1994]. Although straw mulching is generally the superior method, sometimes plastic film mulching is appropriate on flatter farmland. This new agricultural technique uses strips of plastic laid between crop rows. Plastic film mulching increases yields by six-fold [Shengyue and Lihua, 2001], but also increases erosion rates on sloped farmland [Fullen and Mitchell, 1994]. Crops with plastic film mulch produce more above ground biomass, probably by retaining moisture and increasing soil temperatures [Fullen and Mitchell, 1994]. It does not allow infiltration of rainwater and can lead to increased runoff on the non-plastic (planted) regions. This effect is amplified on steeper slopes. While it temporarily increases crop yields, it is not a good solution for long term soil conservation on slopes [Fullen and Mitchell, 1994]. While agricultural methods may retard land degradation
on the scale of a farm, not all efforts need to be small scale to be effective. China’s best publicized land conservation effort is its massive tree planting effort, called the “Three North” project.

The “Three North” project was approved by the State Council in 1978 and is known as China’s Green Great Wall [Zha and Gao, 1997]. It is a massive tree planting effort to stabilize sand dunes and protect farmland, roads and residential areas from wind erosion [Shengyue and Lihua, 2001]. The project expects to plant trees over 4 billion km² to create a forest coverage of 15%. The forests planted are visible from space, and are apparent in my land cover change analysis. This is one of the few instances where the protective measures are cheaper than their benefits. Similar forests are also being planted in northeast Ulan Buh Desert in Inner Mongolia, in oasis areas of the southeastern Tengger Desert and in northern Shaanxi Province. Currently the government is trying aerial seeding, but it has only been successful where annual rainfall exceeds 400mm [Runnstrom, 2000]. Although they claim success, aerial photographs show it is not effective everywhere. The Northwest Institute of Forestry in Shaanxi surveyed national forest planting projects and found only a 40% survival rate [Runnstrom, 2000].

While tree planting has received lots of attention and funding from the government, it may not be the best method of halting desertification. Trees require lots of water and more attention than grasses or shrubs [Murphy, 2001]. Many times acres of trees are planted with no provision to tend to them, causing massive tree death. Planting forests of one type of tree, which was done throughout China, also makes them vulnerable to disease or insects [Murphy, 2001]. While it is not as successful as originally anticipated or as the Chinese government claims because of the high tree mortality rate, the effort not negligible; its forests are still visible on the 1 km scale in this analysis.

The speed of conservation in China is less than the rate of new cropland required for the growing population [Fullen and Mitchell, 1994]. Despite the huge effort the Chinese have put into controlling soil erosion, there is more erosion today than ever before [Edmonds, 1994]. The benefits from conservation projects are often
very localized to the study areas receiving extra resources to fight desertification and soil erosion. Implementing soil conservation is very difficult because in its beginning stage, the investments produce ecological benefits instead of economic benefits [Fullen and Mitchell, 1994]. This means the government often needs to invest lots of resources in conserving the environment before they gain an economic benefit from it. Often short-term and cheaper solutions that feed the population win over more expensive conservation solutions.

6.4 Conclusion

This project is a first step in understanding how land cover has changed in China over the past decade and a stepping stone for future studies to come up with reforms for agricultural practices to conserve China’s arable land while feeding its population—either cultivation techniques or criteria for what kind of land can be farmed and how intensely. Advances in agricultural technology allow farmers to grow more food on less land, offering the hope the China will be able to feed its growing population; in the same way, using GIS technology and incorporating remotely-sensed data to understand land degradation can allow government officials to better plan anti-desertification projects and better instruct farmers how to best conserve their cropland while maintaining or increasing yield.

ANOVA analysis shows the temperature and wind speed affect negative land cover, especially that areas of high wind or low precipitation are prone to desertification. The positive ANOVA test shows that areas of medium or high population are more likely to show land cover improvement. This might be because urban areas have benefited more from conservation efforts, like the “Three North” tree planting project, than remote areas. Arid and semi-arid areas are likely than sub-humid areas to show land cover improvement, but this might be because sub-humid areas tend to have more forest and cropland than savanna or desert, so there is less land cover to improve. The study also revealed that low and medium temperature areas improved more than areas with high average temperatures. The GIS analysis showed a spatial relationship to
desertification where forest and cropland changed to savanna, and savanna changed to desert. The area of intense desertification also falls within the semi-arid zone, suggesting again the climate constrains land cover change.

Relating land cover change with climatological and anthropogenic factors is one way to make a predictive model for future land degradation. Land that has climate factors that predispose it to degradation, such as low precipitation and high average wind speed, should be more intensely protected. Focusing conservation efforts on land whose climate factors are related to negative land use change allows for maximum and most efficient land conservation. Although this project can not make any direct conclusions about what causes negative land cover change, developing an explanatory model is the first of many exploratory projects necessary to reach that goal.
Bibliography


