HISTORICAL MAPPING AND MONITORING OF THE MANGROVE FORESTS OF

AMBERGRIS CAYE (BELIZE) USING MULTI-DATE LANDSAT IMAGERY:  A

TWENTY-SIX YEAR HISTORY


by

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ABSTRACT

Ambergris Caye of Belize has in the last three decades become a hotspot for tourism and attracts snorkelers, divers, sight seers, beachcombers, and vacationers from all over the world. This growth in the tourism economy of Ambergris Caye has led to an increased pressure on the mangrove ecosystems due to the direct removal of mangrove habitat and replacing it with sewage ponds and infilling for roads, housing units and hotels. Decisions on environmental policies are hard to make and are compounded when there is a lack of knowledge on the amount and distribution of resources. Knowing how the quantity and quality of mangrove forests have changed through time will help facilitate decisions about how environmental policy needs to adapt to community concerns on the sustainability of their natural resource based tourism economy. In this study, I analyzed historical Landsat TM and ETM+ imagery of Ambergris Caye to examine how mangrove forest cover has changed from 1986 to 2012. Four classes were used based on spectral similarities: mangrove, water, non-mangrove vegetation, and residential/urban/barren land. Once mangrove areas were delineated a Normalized Difference Vegetation Index (NDVI) was performed to assess the health of the mangrove vegetation through time. Specifically, I mapped the historical spatial distribution and health of mangrove forests, examined the land use/land cover changes to mangrove forest distribution and health and assessed the rate of change throughout the study area over a 26 year period. Ambergris Caye lost 766 ha of mangrove forests through out the study time period. In total mangrove coverage went

from 8535 ha in 1986 to 7769 ha in 2012 for a total decrease of 9%. Non-mangrove forest cover also decreased from 4408 to 3917 ha, an 11.1% decline. Mean while urban/barren growth increased 264% during the 26 year study. It is also important to note that Ambergris also lost 5% of its total land area to water. Mangrove quality on Ambergris decreased during the 26 year study period. In 1986, 3898 ha of mangrove forest was considered densely growing good quality mangrove habitat. By 1990 good quality mangrove forest coverage had decreased by 3% to 3777 ha. In 1995, mangrove quality dropped by 1% to 3731 ha. From 1995 to 2000 mangrove quality dropped by 9% with 3391 ha being considered good quality. From the year 2000 on mangrove quality dropped drastically going from 3391 ha to 2177 ha in the 2003/4 image. From 2003/4 to 2010/1 the good quality mangrove held relatively steady. However by 2012 only 1663 ha of quality mangrove habitat remains a 57% decrease in overall health from 1986 to 2012.

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CHAPTER 1

INTRODUCTION

Coastal marine habitats are some of the most productive and biologically diverse

ecosystems on the planet.  The appeal of these coastal resources has resulted in the rapid

expansion of human activity such as the growth of residential housing, urban centers of

commerce and tourist resorts.  In 1990, about 23% of the world's population lived within 100 km

of the coast (Small and Nicholls 2003) and by 1997 it was estimated that number had increased

to 37% (Cohen, et al. 1997).  Though the exact percentage of people living near coasts today

varies from study to study, there is a consensus that a large portion of the world's population,

44–60%, currently live within 100 km of the ocean (Valiela, Bowen and York, Mangrove

forests: One of the world's threatened major tropical environments. 2001, Culliton 1998,

GESAMP 2001, Biliana, Bernal, et al. 2002).

Due to the rapid rise of coastal human populations, coastal ecosystems throughout the

world are increasingly threatened due to anthropogenic environmental pressures (Rivera-

Monroy, Twilley and Bone, et al. 2004, Gardner, et al. 2003, Nemeth and Nowlis 2001).  Many

of the world's most economically depressed communities reside along the coast and rely on

mangrove and reef-based fisheries for their tourism-based economy and food security.  This

reliance is particularly true for small islands and tropical developing countries.  Population

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growth, combined with the inability of many local governments to adjust to changing public demands (internal and external) and environmental factors, makes these areas highly vulnerable (Biliana 2009).

Coastal habitats such as coral reefs, seagrass meadows, and mangrove forests in particular are being lost at alarming rates. Mangrove forests especially are one of the world's most threatened tropical and subtropical coastal ecosystems (Duarte, et al. 2009). To many people, mangrove forests have the reputation as harsh swamp lands that are breeding grounds for pests such as mosquitoes and a lost opportunity for growth. However, several studies indicate that mangrove forests are important in the overall health of marine ecosystems and provide humans many goods and services (Rodriguez and Feller 2004, Ramirez-Garcia, Lopez-Blanco and Ocana 1998, Kathiresan and Rajendran, Mangrove ecosystems of the Indian Ocean region. 2005, Green, et al. 1998). If damaged, the loss of healthy mangroves can cause a domino effect to surrounding connected marine and terrestrial environments.

Despite the importance of mangroves to the environment and in turn to humans, they are currently experiencing widespread habitat destruction (Held, et al. 2003, Liu, et al. 2008). Since 1980, mangrove forests around the world are being lost at a rate of approximately 2% per year (Valiela 2006). Worldwide, the total historical loss of mangroves is estimated at 35%, making mangrove forests the most threatened major coastal habitat in the world (Valiela 2006).

This pattern of mangrove destruction can be seen clearly in the Caribbean waters along the coast of Belize. During the last few decades, Belize has seen a decline in the overall health in the marine ecosystems off their coast, which have resulted in lower coral and fish abundances than other areas of the Caribbean. Mangroves provide cultural, ecological, and economic benefits, as well as physical protection during storms and hurricanes. Belize's growing tourism

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industry accounts for about 54% of the GDP (based on 2010 figures) (Kirkwood and Matura-Shepherd 2011). The fishing industry remains an important contributor, with export earnings of US$67.16 million in 2005 (3.8% of GDP in 2005) (Wilkinson and Souter 2008). Due to the countries dependence on tourism, fishing industries and coastal protection provided by mangrove ecosystems, the lives of many Belizeans are tied to the health of their mangrove forests.

As one of the biggest contributors to Belize's tourist and fishing economy, Ambergris caye has a growing population and real estate trade; thus mangrove conservation has become a hot topic for the Ambergris community. This terrestrial/marine system and its associated resources are largely responsible for the development of the tourist economy on this once remote caye. The mangroves of Ambergris Caye help support the presence of the world's second largest barrier reef. Cooper et al (2009) documented that mangroves contribute US$174–249 million per year to Belize's economy. And Wade (2012) valuated an estimated US$ 395- 559 million in the reef and mangrove related fisheries, tourism and shoreline protection services. In terms of national employment, an estimated 20 percent of national workforce is based on reef- related tourism (Wade 2012). However, the economy threatens this diverse system, on which it depends, because of rapid development. Decisions on environmental policies are often complex and compounded further by a lack of knowledge on the amount and distribution of natural resources. Delineating the quantity and quality of mangrove forest change through time will help facilitate how environmental policy needs to adapt to community concerns on the sustainability of their natural resource based tourism economy.

Due to dense foliage and a concentration of growth, mangroves are relatively easy to identify, as compared with other tropical vegetation (Rasolofoharinoro, et al. 1998). Multi-temporal studies of remotely sensed data are a widely used method for assessing changes in biophysical systems over time (Miller and Yool 2002). With the availability of historical Landsat

data, it is possible to assess land cover change and long-term impacts on mangrove expansion/contraction and health. Important landscape level environmental indicators can be extracted from Landsat data, including change in the size, configuration, and health of coastal habitats and vegetation cover (Klemas 2001).

A number of data sources exist on Belize's land cover, including Fairweather and Gray, 1994; Iremonger and Brokaw, 1995; White et al, 1996; Meerman and Sabido, 2001; Meerman, 2005; and Meerman et al, 2010. These datasets have largely assessed Belize's overall land cover, but have not specifically focused on mangrove forests. These studies have been produced through various methods and for different purposes, causing estimates of mangrove cover to differ significantly from study to study (Zisman 1998). In addition, of the few studies that focused on mangroves, none specifically focused on the mangrove forests of Ambergris Caye. Thus, the sources of information used that were good for the whole of Belize were not always so for Ambergris (Cherrington, et al. 2010).

The goal of this research is to examine, using remote sensing techniques, how the quantity and quality of mangrove forest cover of Ambergris Caye, Belize, has changed from 1986 to 2012. The specific objectives are as follows: 1) to determine the spatial distribution of land-use/land-cover change from 1986 to 2012 within the study area; 2) to analyze change and health of mangrove forests over time; 3) to display the effectiveness of geographic information systems and remote sensing as useful tools to document mangrove forest changes over time; and 4) to contribute to the knowledge of land-use/land-cover change patterns in mangrove systems.

CHAPTER 2

LITERATURE REVIEW

2.1 Belize

Belize, with a population of around 300,000 people, is located between $15^o52'$N and $18^o30'$ N and $87^o28'$W and $89^o14'$ W and is the second smallest country in Central America (Hartshorn, et al. 1984). Well known for its marine and terrestrial biological diversity, Belize is home to the planet's second longest unbroken reef system, known as the Belize Barrier Reef System (Hartshorn, et al. 1984, Clarke, et al. 2013). Belize's coastal zone, comprised of coral reefs, seagrass beds and mangrove forests, provides a wide array of commercial and non-commercial benefits critical to the country's economy. Annually, economic values mangroves provide have been estimated to be between US$ 200,000 - 900,000 per hectare (Gilman, et al. 2006). These ecosystems also provide protection from tropical storm surge and eroding wave action for the large coastal population and the millions of dollars in coastal property. They also support fish and coral reef communities and more recently are at the center of Belize's thriving tourism industry (Cooper, Burke and Bood 2009). In the span of just seven years, from 2003 to 2010, the percent of the GDP from tourism jumped from 14.6 % to 54% (Kirkwood and Matura-Shepherd 2011, Tietze, Haughton and Siar 2006). Tourists are comprised mostly of sport fishermen, divers, snorkelers, and sight seers. Belize draws over 800,000 tourists annually, leading to ever increasing coastal development (Clarke, et al. 2013). Also, due to the increase of

coastal resource utilization, the country's once rural population has migrated to areas within the coastal zone. According to Belize census data from 2010, over 40-45% of the Belizean population now live and work in the coastal zone (Clarke, et al. 2013).

Despite the importance of coastal and marine ecosystems, their benefits are oftentimes overlooked in coastal investment and policy decisions. Thousands of tourism and fishing jobs rely upon the health of mangroves. The resources of mangrove ecosystems are used throughout the tropics and subtropics for fishing areas, wildlife reserves, recreation, human habitation, and aquaculture (Green, et al. 1998). Of the growing coastal islands, Ambergris in particular has seen significant tourism expansion. As of 2007, Ambergris Caye was the most popular destination for overnight visitors to Belize, with 70% of all tourists staying on the island (NSTMP 2011). The tourism industry puts Belize in a precarious situation of balancing environmental concerns with economic growth and sustainability. Though government, non-governmental organizations and private entities recognize the importance of coastal ecosystems to the economy, the amount of money invested in protecting them is relatively small when compared to their contributions to the national economy (Cooper, Burke and Bood 2009).

2.2 Ambergris Caye

Ambergris Caye is the largest of the hundreds of cayes along Belize's coastline (8.1) and is located at approximately 18°N latitude and 88°W longitude on the southern edge of the Yucatan Peninsula. The island is 46 km in length and up to 8 km wide. Ambergris is parallel to the Belize Barrier Reef which was nominated in 1996 as a World Heritage Site under the UNESCO World Heritage Convention. The reef is one of the most popular destinations of Belize, as tourists can dive in the clear waters viewing colorful tropical fish, sea fans and corals. Once past the reef, the seabed drops in a series of plateaus where game fish such as kingfish,

marlin, mackerel, sailfish, tuna, and wahoo can be found (Godfrey 1996). The diversity and abundance of game fish in the area provides another economically important tourist attraction.

Ambergris Caye's tourist economy continues to grow and currently hosts 14 dive shops, 66 hotels and resorts, and 36 homes and villas available for rent. What was once a vibrant fishing community has been steadily declining and instead tourism has become the backbone for the Ambergris economy. The majority of the island's population is located in the only town on the island, San Pedro. In 1995 official figures put Ambergris's population at around 1,200, however Godfrey 1996 estimated that closer to 4,000 people resided on the island. In 2005, San Pedro town's total population grew to 12,400 (Central Statistical Office 2005). Today that number is thought to be even greater with San Pedro being considered one of the fastest growing municipalities of Belize and thus creating problems with when, where, and how to allocate resources. Housing that was once confined to San Pedro has now extended up and down almost the entire eastern coast of Ambergris with the beginnings of many homes and developments popping up on the west coast of the island.

Ambergris has two protected areas the Bacalar Chico National Park and Marine Reserve (BCNP & MR) established in 1996 and Hol Chan Marine Reserve established in 1987. Bacalar Chico is located on the very northern extent of Ambergris Caye. This marine reserve is managed by the Fisheries and Forest Departments and is part of the Belize Barrier Reef Reserve System. On the southern tip of Ambergris lies the Hol Chan Marine Reserve. Hol Chan was protected in efforts to protect fish species and has served as a dual purpose of both fish nursery and as a popular trip for snorkeling and diving.

2.3 Mangrove Vegetation of Ambergris Caye

Mangrove forest ecosystems support a diverse flora and fauna and are among the most productive plant marine communities in the world (Chapman 1976, Alonso-Perez, et al. 2003, U.S. Fish and Wildlife Service 1999).  Mangrove forests are comprised of facultative halophytic species that can tolerate salt water but it is not required for growth.  The word mangrove is not a formal taxonomic term to describe a specific species of tree, rather it is a term used to refer to woody plants, such as shrubs or trees, having specific physiological adaptations that allow them to thrive in coastal areas exposed to seawater (Tomlinson 1986).  These ecosystems are limited to areas that are partially inundated by brackish or seawater water and cannot persist in fresh water mainly as the result of interspecific competition from faster-growing freshwater wetland plants (Clough 1993, Twilley, Snedaker, et al. 1996, Sheridan and Hayes 2003, Kuenzer, et al. 2011).

Four species of mangrove have been documented on Ambergris Caye: the red mangrove (*Rhizophora mangle*), the black mangrove (*Avicennia germinans*), the white mangrove (*Laguncalaria racemosa*), and the buttonwood (*Conocarpus erectus*).  The red mangrove is most often found along the edges closest to the water and is easily identified by its network of aerial prop roots used to support the plant.  Red mangroves can attain heights of 25 to 38 m, but average 8 to 10 m on most shorelines, and occur as smaller trees in marginal habitats.  Black mangrove have distinctive horizontal cable roots that radiate from the tree and are usually found farther away from the water's edge.  The trees grow straight, attaining heights of 40 m and averaging 20 m and can be recognized by the small protrusions, extending 2 to 20 cm above the substrate, called pneumatophores that encircle the base of the tree.  The white mangrove and buttonwood species are generally located even further away from the edge of the water.  White

mangroves grow either in tree form or shrub form up to heights of 15 m or more.  Some white mangroves form erect, blunt-tipped pneumatophores if growing in anaerobic or chemically stressed soils.  Buttonwoods grow to 12 to14 m in height in a shrub or tree form (Tomlinson 1986).  Buttonwoods are able to grow in areas seldom inundated by tidal waters. The microroots stabilize fine silts and sands maintaining water clarity and quality (Snedaker 1982, Tomlinson 1986).

2.4 Usage and Functions of Mangroves

Mangrove forests support several critical terrestrial and marine ecological functions. They provide a major detrital base for food webs which allows these ecosystems to host large numbers of larvae and juvenile invertebrates (Lugo and Snedaker 1974, U.S. Fish and Wildlife Service 1999, Blasco, Saenger and Janodet 1996, Murray, et al. 2003, Sheridan and Hayes 2003, Alonso-Perez, et al. 2003, Rodelli, et al. 1984, Twilley, Coupling of mangroves to the productivity of estuarine and coastal waters. 1988, Sasekumar, et al. 1992).  Mangrove root systems provide physical habitat, protected nursery grounds and spawning areas for a wide variety of marine/estuarine fish as well as many other vertebrates and invertebrates (U.S. Fish and Wildlife Service 1999, Laegdsgaard and Johnson 1995, Robertson and Duke 1987).  Many of these fish, crustaceans, and mollusks are important to both commercial and sport fisheries (Rodelli, et al. 1984, Sasekumar, et al. 1992, U.S. Fish and Wildlife Service 1999, Green, et al. 1998, Mathews and Kapetsky 1988, Flores-Verdugo, et al. 1990, Alonso-Perez, et al. 2003).  For example, snappers and groupers start their juvenile period as planktonic larvae juveniles that settle and live in seagrass and among the shallow prop roots of red mangroves (Arreguin-Sanchez, et al. 1996).  Barnacles, oysters, sponges, tunicates and a variety of other organisms attach to their prop roots.  Coral reefs have been demonstrated to be more productive and diverse

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fish habitats when in the presence of mangroves than reef areas lacking mangrove cover (Mumby, Edwards, et al. 2004). Mangrove forests are also used by migratory birds, fish and mammals as stopover sites (Saenger, Hegerl and Davie 1983).

Due to the extensive root system of mangroves, they also act as a physical barrier against ocean dynamics, helping to prevent coastal erosion by stabilizing sediments and protect the coastline from the impacts of high tides and storm surges (Alonso-Perez, et al. 2003, Danielsen, et al. 2005, Kathiresan and Rajendran 2005, Giri, Zhu, et al. 2008, Marshall 1994, Tam and Wong 1999). Destroying mangrove cover has been known to increase the threat to human safety from erosion, flooding, storm surge and tsunami (Danielsen, et al. 2005, Kathiresan and Rajendran 2005, Dahdouh-Guebas, et al. 2002). Mangrove forests improve water quality and clarity by filtering or trapping land-derived debris, nutrients, pollutants and suspended matter which helps to reduce turbidity and enhance water clarity (Alonso-Perez, et al. 2003, Marshall 1994, Tam and Wong 1999, Lugo and Snedaker 1974, Saenger, Hegerl and Davie 1983, U.S. Fish and Wildlife Service 1999, Rivera-Monroy and Twilley 1996). While mangroves thrive in brackish, nutrient-rich waters, coral reefs thrive in clear, nutrient-poor waters. Thus mangroves are very important to any adjacent coral reefs and seagrass beds because they filter out the sediments, nutrients, and pollutants that would otherwise smother corals and seagrass beds and encourage algal growth (Lugo and Snedaker 1974, Marshall 1994, Walters, et al. 2008). Essentially, anthropogenic and natural threats impact not only mangrove habitats, but also adjacent ecosystems, such as seagrass beds and coral reefs (Lugo and Snedaker 1974, Kuenzer, et al. 2011, Farnsworth and Ellison 1997, Krauss, et al. 2008, Bosire, et al. 2008).

Threats to Ambergris mangroves are tourism, improper waste management, pollution, rapid coastal development, and ineffective institutional and legal frameworks. The construction

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of hotels and other infrastructure for tourism and residential purposes destroy mangroves resulting in destruction of not just the mangroves but also hundreds of species that live in the arboreal, sub-tidal, intertidal, and benthic communities associate with mangrove habitats. More tourists mean more clearing and filling of land to create roads, lodges, and hotels. More tourists also mean more solid and liquid waste. Lack of proper sewage treatment for many of the communities on the island as well as improper solid waste disposal has begun to pollute the environment especially mangrove habitats (see 2.1). San Pedro is one of the few communities of Belize with a sewage waste treatment facility, but the majority of the residents are not connected to the system but instead rely on pit latrines and septic systems (Young 2008). However, this sewage treatment plant is considered to be ineffective, expensive and limited to households in the core area of San Pedro (ICRAN 2002).

With the continued development of tourism, the people of Ambergris must carefully plan the course of its development paying close attention to the protection of the environment. The high intensity of future development of the fishing and tourism industries threatens the caye's ecology through uncontrolled expansion and exhaustion of resources (Godfrey 1996). Though there are laws and regulations created by Belize that can potentially provide strong protection for mangroves from alteration and destruction, projects are still allowed as enforcement of the laws are lacking. One such plan that has received approval and has already begun construction is the South Beach Belize that plans 369 acres project built on a site with 90+% mangrove that neighbors Hol Chan and which will eventually include hotels, villas, a casino, shopping areas, a network of canals and marinas, and a water theme park, as well as roads, drainage canals and supporting infrastructure.

2.1: Mangrove pollution. Left image: Mangrove propagules and dead fish in polluted waters on Ambergris Caye (February 2010). Right image: Mangrove roots interspersed with solid waste on Ambergris Caye (February 2011).



Images recorded by the San Pedro Sun February 2010 and February 2011.

2.5 Laws and Regulations

The leading regulation on mangroves is the Forests Act of Belize. Regulations under the Forests Act for the protection of mangroves are that no person may alter any mangrove in the jurisdictional waters of Belize without obtaining a permit from the Forests Department in the Ministry of Natural Resources, Environment and Industry, with the exception of limited "selective trimming." No permits will be issued within national parks, nature reserves, wildlife sanctuaries, or natural monuments. Private and public lands are subject to these laws and regulations. An application must be submitted for a permit and is subject to fees and procedures, such as requiring a public notice if the area to be impacted is greater than one acre. The Forests (Protection of Mangroves) Regulations states that no permit for the alteration of mangroves shall be issued unless the Department is satisfied that water quality shall not be significantly lowered or changed as a result of the proposed alteration; and the proposed mangrove alteration is not contrary to the public interest, or if the alteration significantly degrades or changes the environment that such action is, on the whole, beneficial and in the larger and long-term interest

of the people of Belize. Every person who violates any of the provisions shall be held liable upon

conviction to a fine not exceeding one thousand dollars, or to imprisonment for a term not

exceeding twelve months, or to both (Belize 2003, Belize 2007).

2.6 Remote Sensing of Mangroves

Satellite remote sensing, in its simplest form, is the process of recording various levels of

energy reflected and/or radiated from the earth by orbiting satellites.  Remote sensing

applications record bands of wavelengths which can later be analyzed, and results in the

identification of the object the energy has reflected and/or radiated from.  Depending upon the

object, energy is reflected, absorbed, transmitted, or emitted.  A sensor records the energy in

varying degree of reflectance. The amount of energy reflected, transmitted or absorbed by an

object or surface depends upon a wide variety of properties such as their physical and chemical

compositions, biophysical attributes, texture, and location of the object on the earth's surface,

and the viewing angle of the sensor itself (Fraser and Curran 1976).

The spectral signature is used to refer to the spectral response of an object or surface

feature as observed over a range of wavelengths.  Depending on the subject at hand, the amount

of solar radiation that is reflected, absorbed, transmitted, or emitted varies with wavelength.

When the recorded energy is plotted over a range of wavelengths, the connected points produce a

curve a spectral signature, also known as a spectral response curve. If the sensor system being

used has sufficient spectral resolution, the range of wavelengths the sensor is able to capture,

then objects or features on the earth's surface should be identifiable based on their respective

signature (Lillesand, Kiefer and Chipman 2004).

The vast majority of mangrove remote sensing studies have employed aerial photographs

or high resolution satellite imagery (i.e. spatial resolution between 5 and 100 m) such as Landsat

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(MSS, TM, or ETM+), SPOT (HVR, HRVIR, or HRG), ASTER, and IRS (1C or 1D) (Newton et al., 2009). IRS, ASTER, and SPOT data proved to be inadequate as full scenes of the study areas were unavailable and historical data were lacking. Landsat MSS, with a spatial resolution of 60 $m^2$, is insufficient in the identification of mangrove forests. Landsat 4/5 TM and 7 ETM+, with a spatial resolution 30 $m^2$, have been found to accurately identify mangrove forest communities however not to a species level. Landsat 5 TM satellite data was unavailable for Ambergris Caye. However, Landsat 4 TM, launched in 1984, and Landsat 7 ETM+, launched in 1999, provided adequate satellite coverage and provided the historical data necessary to analyze the mangroves of Ambergris.

Landsat satellite sensors are able to differentiate the unique spectral signature of ground features based on the radiometric response of these features in the visible (0.4 to 0.7 μm), near infrared (0.7 to 1.3 μm), and middle infrared (1.3 to 3 μm) bands of the electromagnetic spectrum (Lillesand and Kiefer 2000). Landsat 4 TM is comprised of 7 bands: three visible bands (1, 2, and 3), one near-infrared band (4), two mid-infrared bands (5 and 7), and a thermal band (6). Landsat 7 ETM+ is an 8-band multispectral scanner that has the same bands of the electromagnetic spectrum as Landsat 4 TM but has lower spatial noise (Masek, et al. 2001)than TM, a panchromatic band (band 8) with 15 $m^2$ resolution, and a thermal infrared band (band 6) with 60 $m^2$ resolution (Klemas 2001, Lillesand and Kiefer 2000). The thermal bands for both TM and ETM+ have coarse spatial resolution and as such its use in habitat mapping is limited and thus removed from analysis. The geographic coverage of each TM and ETM+ scene is an area 170 x 183 km in size (Lillesand and Kiefer 2000). Because the products of Landsat-4 and 7 are very similar following radiometric normalization, data from the two sensors may be used

together to measure and monitor changes in landscape phenomena over time (Vogelmann, et al. 2001).

In general, mangroves have distinct spectral signatures in relation to the other vegetation that grow in similar environment (Miller and Yool 2002). Due to their dense foliage, concentration of growth and the coastal location, mangrove forests are relatively easy to identify as compared with more inland vegetation.  Multi-temporal studies of remotely sensed data are a widely used method for assessing changes in biophysical systems over time (Miller and Yool 2002). With the availability of historical Landsat data, it is possible to assess land cover change and monitor regrowth and long-term adverse impacts on mangrove expansion/contraction and health.  Important landscape level environmental indicators can be extracted from Landsat data, including change in the size, configuration, and health of coastal habitats and vegetation cover (Klemas 2001).

CHAPTER 3

METHODOLOGY

3.1 Study Area

A time-series analysis of change in the terrestrial habitats of Ambergris Caye was
conducted using Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+),
aerial photographs and ancillary data collected from various sources ranging from 1986 to 2012.
The total land area of Ambergris Caye is 130 km$^2$.  Two Landsat 4TM and four Landsat 7ETM+
scenes for Ambergris Caye were required for each year of historical data collected.  Ambergris
Caye is located at Path 19/Row 47 and Path 19/Row 48 (8.2).

3.2 Data Acquisition and Collection

The remotely sensed data used for this study are Landsat Thematic Mapper (TM) and
Enhanced Thematic Mapper Plus (ETM+) imagery. All Landsat satellite data were downloaded
via http://glovis.usgs.gov.  Temporal resolution is a huge issue when trying to find the right
satellite images to use. Data should be selected with corresponding anniversary dates.
Anniversary dates are those dates that correspond with a season, month, or preferably week.
However, anniversary dates for Ambergris are impossible to procure due to cloud cover
obscuring most or parts of the island for months or years.  The logical alternative would be to
find images of the area in the same month or season (Jensen 2007).  Landsat TM satellite images
were acquired from 1984-2000 for Ambergris Caye.  Landsat-7 ETM+ images acquired from

2001-2012 for Ambergris Caye. Most all images were acquired in months of November and

December.  See table 3.1 for detailed information on images selected for Ambergris Caye.  Since

mangrove vegetation stays relatively unchanged there seemed to be no classification problems

caused by date selection.

**Table 3.1** Landsat scene selection

| Mosaic | Satellite | Sensor | Reference | | Location | Date |
|---|---|---|---|---|---|---|
| | | | Path | Row | | |
| **1:  1986** | Landsat-4 | TM | 19 | 47 | North | December 3, 1986 |
| | Landsat-4 | TM | 19 | 48 | South | December 3, 1986 |
| **2:  1990** | Landsat-4 | TM | 19 | 47 | North | November 20, 1990 |
| | Landsat-4 | TM | 19 | 48 | South | November 20, 1990 |
| **3:  1995** | Landsat-4 | TM | 19 | 47 | North | November 26, 1995 |
| | Landsat-4 | TM | 19 | 48 | South | November 26, 1995 |
| **4:  2000** | Landsat-5 | TM | 19 | 47 | North | February 9, 2000 |
| | Landsat-5 | TM | 19 | 48 | South | February 9, 2000 |
| **5:  2003** | Landsat-7 | ETM+ | 19 | 47 | North | October 23, 2003 |
| **2004** | Landsat-7 | ETM+ | 19 | 47 | North | February 12, 2004 |
| **2003** | Landsat-7 | ETM+ | 19 | 48 | South | October 23, 2003 |
| **2004** | Landsat-7 | ETM+ | 19 | 48 | South | February 12, 2004 |
| **6:  2007** | Landsat-7 | ETM+ | 19 | 47 | North | November 3, 2007 |
| | Landsat-7 | ETM+ | 19 | 47 | North | December 5, 2007 |
| | Landsat-7 | ETM+ | 19 | 48 | South | November 3, 2007 |
| | Landsat-7 | ETM+ | 19 | 48 | South | December 5, 2007 |
| **7: 2010** | Landsat-7 | ETM+ | 19 | 47 | North | December 13, 2010 |
| **2011** | Landsat-7 | ETM+ | 19 | 47 | North | January 14, 2011 |
| **2010** | Landsat-7 | ETM+ | 19 | 48 | South | December 13, 2010 |
| **2011** | Landsat-7 | ETM+ | 19 | 48 | South | January 14, 2011 |
| **8: 2012** | Landsat-7 | ETM+ | 19 | 47 | North | March 21, 2012 |
| | Landsat-7 | ETM+ | 19 | 47 | North | April 21, 2012 |
| | Landsat-7 | ETM+ | 19 | 48 | South | March 21, 2012 |
| | Landsat-7 | ETM+ | 19 | 48 | South | April 21, 2012 |

3.3 Image Preprocessing

Geometric correction of the imagery is required because raw satellite imagery usually

contain geometric distortions. These distortions must be corrected before the satellite scenes can

be used as a geographically accurate map. The sources of these distortions include variations in

altitude, sensor platform velocity, panoramic distortions, earth curvature, atmospheric refraction, relief displacement, and nonlinearities in the sweep of the sensor's instantaneous field of view (Lillesand and Kiefer 2000). Systematic distortions, which are predictable, are corrected prior to addressing random, or unpredictable, distortions. However, as stated earlier most all Landsat TM and ETM+ data products selected for the study were Level 1T (L1T), which provides systematic radiometric and geometric accuracy by incorporating ground control points, while also employing Digital Elevation Models (DEM) for topographic accuracy (Klemas 2001, Glovis 2013). Images that were not available as L1T were requested.

Random distortions were corrected with geometric correction and orthorectification. Separate models were required for orthorectification of the TM and ETM images. Ground control points (GCPs) were used to register the image data to a ground reference system. A GCP is "a location on the surface of the Earth that can be identified on the imagery and located accurately on a map" (Jensen 2007). Thirty GCPs were acquired throughout the Landsat images. GCPs and were incorporated into the TM model to geometrically correct the scenes. The appropriate projection and coordinate systems were applied. With an image to image correction algorithm, the Landsat TM image served as the georeferenced base map by which all other TM scenes were image-to-image rectified, as described in Klemas (2001). A geometric correction of the 2010 ETM+ scene for Ambergris Caye was performed with a separate model. All other scenes were geometrically corrected by performing an image to image correction, using the geometrically corrected 2010 scene for georeferencing. The image-to-image correction process provided for the co-registration of scenes is a necessary step in change detection for preventing errors caused by misregistration of scenes (Bouvet, Ferraris and Andréfouët 2003, Jensen 2007, Lillesand and Kiefer 2000). The images were mosaicked together in a process that combines

multiple images in to a single image (Jensen 2007). Color corrections were done via color balancing and histograms matching to make the images being mosaicked correspond. After the mosaic was successful, the final image was extracted via subset from the mosaicked image (8.3).

3.4 Image Classification Scheme

The vast majority of mangrove research that use Landsat TM and ETM+ use a simplified image classification schemes with broad categories (Klemas 2001, Miller and Yool 2002). Classes were broken down into the categories of Water, Mangrove, Non-mangrove Terrestrial vegetation, and Urban/Barren Land. Once classifications were attained a further break down of the mangrove habitat was attempted by masking out all non-mangrove information and a Normalized Difference Vegetation Index (NDVI) was performed for all masked images. NDVI was calculated for each mangrove area using the following algorithm: (band4 − band3)/(band4 + band3). NDVI is a commonly used and accepted as a parameter for evaluating an ecosystem's health as NDVI can help to determine vegetation health and vigor, and is found to be highly correlated with crown closure, leaf area index, and other vegetation parameters (Hayes and Sader 2001, Klemas 2001, Nayak and Bahuguna 2001, Tucker and Sellers 1986).

Satyanarayana et al. 2011 found that there was a high significance between NDVI and stem density. The sites with young and growing or mature mangroves with lush green cover showed greater NDVI values of 0.40-0.68 indicating healthy vegetation. Mature forests under environmental stress showed low NDVI values of 0.38-0.40 indicating an unhealthy situation. Similarly, Nayak and Bahuguna (2001), Kovacs et al. (2005), Giri et al (2007), Thu and Populous (2007), and Lee and Yeh (2009) all had similar results when using NDVI to represent the health of mangroves. However, just because the mangrove area is flagged as poor does not indicate that it is truly poor habitat. Instead it could be fringe mangrove or sparse dwarf

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mangrove non-indicative of poor habitat. To circumvent this concern the extent of good quality habitat for 1986 was used as a baseline starting point to more accurately assess the quality of mangrove vegetation. Once the NDVI was performed, the resulting images were reclassified as good or poor condition.

3.5 Unsupervised Classification

The classification method utilized and then adapted for this study was based on the approach of Gray et al. (1990) who used a selection of band ratios based on the physical properties and canopy spectra of mangrove vegetation. Landsat bands 3 and 4 are either side of Caribbean mangroves' red-edge (Ramsey and Jensen 1996) and combination with band 5 would appear to produce two broadly different ratios. This is in agreement with the work of Gray et al. (1990) who used the bands 3, 4, and 5 and the band ratios of 3/5 and 5/4 on mangroves in Belize. Gray et al. layer stacked 3, 4, 5, 3/5, 5/4 and then used them as the input to a principal component analysis (Gray, Zisman and Corves 1990, Green, et al. 1998, Paling, Kobryn and Humphreys 2008, Ueland 2005). However, the Principal Component Analysis (PCA) used to reduce the dimensionality of the data and aid in eliminating redundant information due to inter-band correlation was ill-suited to this particular location and performed poorly. Instead a layer stack of 3, 4, 5, 3/5, 5/4 was created and an unsupervised classification was then performed on the image (Gray, Zisman and Corves 1990, Green, et al. 1998, Paling, Kobryn and Humphreys 2008, Ueland 2005). The resulting image performed better and had greater accuracy.

Images were classified using an Iterative Self-Organizing Data Analysis Techniques (ISODATA) algorithm. An ISODATA algorithm requires the user to choose the initial estimates of class means, and then each pixel is assigned to classes with a similar mean; in this respect, ISODATA resembles an unsupervised classification (Long and Giri 2011). The process of

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assigning pixels to a class is repeated until reaching the maximum number of iterations set by the user. For this study, 300 clusters were generated using 26 maximum iterations and a convergence threshold of 0.990 (Paling, Kobryn and Humphreys 2008, Green, et al. 1998, Ueland 2005). Through manual interpretation, clusters were merged into four classes based on spectral similarities: mangrove, terrestrial non-mangrove, urban/barren land and water. Following classification and clustering, additional recoding was performed to eliminate apparent classification errors.

3.6 Accuracy Assessment

An accuracy assessment informs the user how much confidence they should have in the information derived from remotely sensed data (Jensen 2007). Unfortunately, an accuracy assessment cannot be performed on all images due to the historical nature of this study. An accuracy assessment of the classifications was performed on all scenes for which aerial photography or other ancillary data was available. If reference data did not cover the whole scene, the Landsat image was subset to match the spatial extent of the reference data and random points will be generated over the subset scene.

Most commonly, the accuracy of a thematic map is assessed with an error matrix, which compares classes in the thematic map with the classification of randomly selected samples of reference data (Powell, et al. 2004). The accuracy assessment sampling method chosen for this research was the stratified random sampling. This method is preferred because a set minimum number of samples are taken from each land-use/land-cover category. The main advantage of stratified random sampling is that all land-use/land-cover classes, no matter their spatial size in proportion to the study area, will have a minimum number of samples allocated for accuracy and error evaluation. It is very difficult to locate adequate samples for classes that only take up a

small amount of the study area without stratification (Jensen 2007).  An accuracy assessment

was conducted using a total of 400 stratified random points: 100 random points for all four

categories. The randomly generated classified points were then compared with ancillary data

such as personal correspondence, land cover maps, Google Earth™, and other high-resolution

aerial photography data to verify land cover classification accuracy (Mumby, Green, et al. 1999).

CHAPTER 4

RESULTS

4.1 Mangrove Change

Ambergris Caye slowly lost mangrove forests through out the study time period (Table 4.1). In 1986, Ambergris caye had 8535 hectares (ha) of mangrove forest. By 1990, that number fell by 248 ha (2% change) in 4 years. From 1990 to 1995 that number fell even more, as Ambergris lost an additional 6% of its total mangrove with 1995 at 7853 ha of mangrove. By 2000, mangrove cover grew to 8097 ha: a 3% increase. Mangrove coverage dropped to 7845 ha, a 3% decrease, in the 2007 and remained relatively unchanged numberwise by 2012. Final calculation of mangrove coverage was 7769 ha by 2012. In total mangrove coverage went from 8535 ha in 1986 to 7769 ha in 2012 for a total decrease of 9%.

In 1986, Ambergris caye had 4408 ha of non-mangrove vegetation. By 1990, the amount had remained unchanged. From 1990 to 1995 that number increased even more and gained 168 ha of non-mangrove forest cover with 1995 having 4576 ha. By 2000, non-mangrove cover droped to 4238 ha. From 2000 to 2010, non-mangrove coverage has remained relatively stagnant with another drop in coverage occuring in 2012. Final calculation of non-mangrove coverage was 3917 ha by 2012. In total non-mangrove coverage went from 4408 ha in 1986 to 3917 ha in 2012 for a total decrease of 11.1 % over the course of 26 years.

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Unlike non-mangrove and mangrove forests, Urban/Barren coverage increased during the 26 year study period. In 1986, Ambergris had 245 ha of Urban/Barren land. Ambergris experienced a 36 % increase in Urban/Barren from 1986 to 1990, with 1990 having 384 ha of Urban/Barren. Only one decrease in Urban/Barren coverage occurred: from 1990 – 1995 at 25 %. In 2000, Ambergris experience another large increase with 578 ha of Urban/Barren: an 47 % increase from 1995. Final calculation of Urban/Barren coverage was 892 ha by 2012. In total Urban/Barren coverage went from 245 ha in 1986 to 797 ha in 2012 for a total increase of 264% over the 26 year time period. Ambergris also lost 5% of its total land area to water.

Classified habitat maps are located in Figures 8.4 – 11 in the Appendix. The town of San Pedro is continually expanding. Lowlying mangrove forests were cut down and filled with dredged sand to level the area for San Pedro to build on. A sewage treatment pond is first spotted in the 1995 imagery directly south of San Pedro and in the middle of a patch of mangroves (8.6). With its installation the mangroves to its west and immediately surrounding it show increased NDVI. However, east of the treatment pond mangroves became thinner and eventually converted to water. In 2010, a large residential complex first appears on the west side of the island previous images show only a few small coastal urban areas (8.10).

Table 4.1: Habitat Classification Data of Ambergris Caye, Belize from 1986 - 2012.

| Ambergris Caye, Belize | | | | |
|---|---|---|---|---|
| Date | Total Land Area (ha) | Mangrove (ha) | Non-Mangrove (ha) | Urban/ Barren (ha) |
| 12-03-86 | 13188 | 8535 | 4408 | 245 |
| 11-20-90 | 13080 | 8287 | 4410 | 384 |
| 11-26-95 | 12735 | 7853 | 4576 | 306 |
| 2-09-00 | 12914 | 8097 | 4238 | 578 |
| 10-23-03 02-12-04 | 12842 | 8037 | 4156 | 625 |
| 11-03-07 12-05-07 | 12794 | 7845 | 4225 | 724 |
| 12-13-10 01-14-11 | 12945 | 7859 | 4243 | 842 |
| 03-21-12 04-21-12 | 12578 | 7769 | 3917 | 892 |
| Percent Change from 1986 to 2012 | -5% | -9% | -11.1% | 264% |

4.2 Mangrove Quality

Mangrove quality on Ambergris decreased drastically during the 26 year study period.  In 1986, 3898 ha of mangrove forest was considered densely growing good quality mangrove habitat (Figures 8.12 – 19).  By 1990 good quality mangrove forest coverage had decreased by 3% to 3777 ha.   In 1995, mangrove quality dropped by 1% to 3731 ha.  From 1995 to 2000 mangrove quality dropped by 9% with 3391 ha being considered good quality.  From the year 2000 on mangrove quality dropped going from 3391 ha to 2177 ha in the 2003/4 image.  From 2003/4 to 2010 the good quality mangrove held relatively steady.  However by 2012 only 1663 ha of quality mangrove habitat remains a 57% decrease in overall health from 1986 to 2012.

4.3 Accuracy Assessment

Only one accuracy assessment was attempted due to the lack of available aerial photographs during the time of viable satellite imagery dates. The only corresponding available satellite imagery were two Landsat 7 ETM+ images taken on December 13, 2010 and January 14, 2011. The two images were classified and then compared to the January 2010 Google Earth Imagery. Accuracy assessments reveal that 92% of the pixels in the December 13, 2010 and January 14, 2011 Landsat 7 ETM+ scene for Ambergris Caye were correctly classified. The water class was the only class not to have 92% or greater accuracy. The majority of errors were the result of mixed pixels. All pixels found to be in error were then reclassified correctly (Table 4.2).

Table 4.2: Accuracy Assessment of the 12/13/2010-2/14/2011 classified image.

| Ambergris Caye, Belize Accuracy Assessment | | | |
|---|---|---|---|
| Category | Number of Points Sampled | Correctly Classified Points | Percent Correct |
| Mangrove | 100 | 92 | 92% |
| Non-mangrove | 100 | 94 | 94% |
| Urban/Barren | 100 | 94 | 94% |
| Water | 100 | 88 | 88% |
| Total | 400 | 368 | **92%** |

CHAPTER 5

DISCUSSION

In 1986,  Ambergris Caye had 8535 ha of mangrove forest.  Most all of the 245 ha of

urban/barren build up occurred along the southeast coast of Ambergris in the town of San Padro.

By 1990, 248 ha of mangrove forest were lost while urban/barren gained 139 ha.  Some of the

loss was caused by the direct cutting and filling as San Padro expanded south.  The rest of the

loss is mostly due to mangrove areas being eroded and lost to the sea.  From 1990 to 1995,

mangrove forest declined an additional 434 ha (6% change) of its total mangrove coverage.  It is

in 1995 where the new sewage treatment plant is visible on the image for the first time.  Much of

this loss was due in part to the cutting of the mangrove forest in order to put the system in place.

Mangrove and non-mangrove areas were cleared, usually in square or rectangular parcels, and

converted temporarily to urban/barren in order to assess the land for sale or other useages in

1990.  By 1995, the increase in non-mangrove was caused by the urban/barren areas regrowing

vegetation and thus non-mangrove vegetation increased by 166 ha and urban/barren decreased by

78 ha.

In 2000 there was an increase of 244 ha in mangrove and 272 ha of urban/barren.   Non-

mangrove vegetation decreased by 338 ha.  Much of the decrease in non-mangrove forest was

due to urban expansion.  It was during 2000 that mangrove habitat quality saw its first drastic

decline.  Up until this point mangrove quality was decreasing at a slow rate.  Is it a cooincidence

that mangrove quality started declining at a higher rate at the same time that urban/barren started to really take off? This decline could be caused by an increase in the amount of liquid and solid waste that is polluting Ambergris. Or that the placement of tourism infrastructure, such as the creation of roads and canals that fragment mangrove areas causing a change in the hydrology of the area. From 2000 through 2012 Ambergris lost mangrove at a slower rate than during earlier years. Most all of the mangrove loss was along the east coast of Ambergris due to the building of resort hotels, residences, a shrimp farm, and the expansion of San Pedro towards the south just to name a few. Final calculation of mangrove coverage was 7769 ha by 2012. On the whole Ambergris Caye lost 766 ha of mangrove forests through out the study time period. In total mangrove coverage went from 8535 ha in 1986 to 7769 ha in 2012 for a total decrease of 9%. Mean while urban/barren growth increased 264% during the 26 year study. It is also important to note that Ambergris also lost 5% of its total land area to water. The removal of mangrove vegetation on nearby Pelican Caye and Twin Caye caused the islands to begin sinking and eroding (McKee and Vervaeke 2009). Nearby reef flats and seagrass beds are often destroyed along with the mangroves as dredge material are taken from those habitats.

Ambergris Caye's marine and wildlife reserves, Bacalar Chico and Hol Chan, have been successful and if not for these two areas the island's rate of loss for mangrove and for total land loss would have been greater. On Ambergris Caye's northern portion of the island there has been little change due in part by Bacalar Chico National Park (BCNP) (8.20). Mangrove cover change before the BCNP was put in to place indicated that mangrove vegetation had been on the decline and had lost 10 % from 1986 to 1995. In 1996, the BCNP was instituted and subsequently Landsat imagery taken during 2000 indicated that mangrove cover had increased by 5 percent. However from 2000 to 2012 numbers have remained relatively stable with few

increases or decreases.  Hol Chan Marine Reserve was enacted in 1987 on the south end of Ambergris.  It is at Hol Chan where mangrove has thrived with a 26% increase in mangrove from 1986 to 2012.

A decrease of 0.35% per year of mangrove coverage over the course of 26 years might sound to some people as being great, as it is lower than the 1% per year world average (FAO 2007), but when your whole livelihood is based on the ability of mangrove ecosystems to support the activities that draw tourists, greater thought and effort should go in to planning both small and large scale projects.  As it stands as of 2012 Ambergris mangrove coverage has decreased by 766 ha.  This loss does not take in to account the new SouthBeach Development, scheduled to begin work in early 2012, as work had only just begun at the time the last image for this project was taken.  Progress for the SouthBeach Project was not far enough along to see anything more significant than a newly built road. The SouthBeach Project proposes to destroy 150-170 ha of mangrove habitat to build hotels, villas, a casino, shopping areas, a network of canals and marinas, and a water theme park, as well as roads, drainage canals and supporting infrastructure.

Ambergris Caye's tourist economy continues to grow with the reef being one of the most popular destinations of Belize.  Despite the importance of coastal and marine ecosystems, their benefits are often overlooked in coastal investment and policy decisions.  The resources of mangrove ecosystems are used throughout the tropics and subtropics for fishing areas, wildlife reserves, recreation, human habitation, and aquaculture (Green, et al. 1998).  Ambergris' economy relies on the diverse flora and fauna that are supported by the mangrove forest ecosystem.  Often people over look mangrove communities and deem them to be wasted land that serves no purpose.  Though the link between mangroves, fisheries, manatees, coral reefs, migratory birds, and many more ecosystem services is obvious to many there is still prevalence

in society that mangroves are in the way of money making progress.  For example, in the

Environmental Impact Assessment Report completed in 2008 for SouthBeach Belize it states in

reference to the proposed site plan,

> "Presently the project site is in a mangrove swampland that covers about 90 % of the project site. Therefore the site currently has no agricultural value considering this fact. Moreso, the project site cannot even accommodate any other activity related to human benefit. The only potential for development on the project site is the one proposed by the developer."

SouthBeach Development Ltd. States that it plans to "utilize the existing 'mangrove swamp' land

and convert it into a pristine and modern residential subdivision."  The view that mangroves are

more of a hindrance that must be remedied is a common view.  However, once destroyed

mangroves cannot easily be replaced and should therefore be protected first and destroyed only

after much consideration of all other alternatives have been assessed.  The quality of the

Environmental Impact Assessments required for the building of the SouthBeach Project on

Ambergris was marginal at best and atrocious at worst.  An "Environmental Impact Assessment

(EIA)" purpose is to identify, predict, evaluate, mitigate, and manage the environmental and key

social and economic impacts of development projects, undertakings, programmes, policies or

activities (Belize 2007, Belize 2003).  SouthBeach EIA did indeed identify the damage to

mangroves but failed to properly predict, evaluate, mitigate or manage the environmental and

socioeconomic impacts that the project will cause.

The SouthBeach Project is just one of many projects that have already been slated for

Ambergris Caye.  Each of these new projects proposes requires varying degrees of habitat

destruction.  Many of these projects require that the entire property be cleared and backfilled.

The full scope of Ambergris' problem can be seen by observing local real estate properties for

sale or current projects under planning and construction where mangrove covered properties

abound.  Though mangrove conservation is a growing concern, so too are the concerns of the

people of Ambergris who hope to increase their economic and social wellbeing by the removal of mangrove forests for tourism growth. However, what can never be stated enough is that mangrove forests are well known for the ecological and economic benefits that they provide and to destroy those mangroves will be to destroy one's livelihood in the end. These losses negatively affect water quality, biodiversity, neighboring coastal ecosystem and eliminate source of income for local people (Wood and Johannes 1975). The future mangrove loss for Ambergris does not seem to be slowing down but rather speeding up. Other regions have already experienced the environmental issues that mangrove removal has produced and expensive efforts must be extended in order to save or rebuild their mangrove systems (Kathiresan and Bingham 2001).

Ambergris is currently in a constant state of growth with plans to build a new hotel or residential neighborhood being proposed monthly by hopeful foreign investors. Figure 5.1 is an image taken by Dr. Michael Steinberg. The image shows a once mangrove location ready for new housing units to make room for Ambergris' growing population and for increasing numbers of overnight tourists. Figure 5.2 is an image of a new and rather large residential site that first made an appearance on the 2010 satellite imagery. This is one of the first of the residential sites to be located on the west side of the island.

5.1 Aerial photograph of once mangrove area south of San Pedro (2012).



5.2 Newly blocked off residential plots, interspersed with mangrove, image taken via Google Earth (6/30/2010).



Though mangrove conservation is recognized to be of great concern to Ambergris, mangrove forests will continue to be cut down until such time that the true scope of the damage

wrought to the marine ecosystem is brought to fruition. Mangroves will continue to be cut down as the pros of short term gain due to increased monetary gained in response to increased tourisms outweigh the immediate cons. Long term cons of mangrove destruction are rarely addressed.

CHAPTER 6

CONCLUSION

The remote sensing techniques applied to this study show that mangrove forests are

decreasing from Ambergris Caye.  Although an overall average of 0.35% per year decrease

averaged over a 26 year period is considered a small change compared to world averages of 1%

per year, Ambergris is a small island with limited resources.  Along with the increase of urban

there has been a decrease in non-mangrove vegetation, mangrove vegetation and land lost to the

ocean.  Unsupervised classifications and NDVI analyses show that total healthy vegetation of

both mangrove and non-mangrove vegetation is on an overall decline over the 26 year period.

More work is needed to assess Ambergris Caye's mangrove forest health.  Ambergris Caye is

coming under increasing pressure as it is one of the fastest growing tourist destinations in Belize.

With mangrove resources providing the supporting goods and services that form the base of a

healthy coral and fisheries ecosystem of which the citizens of Ambergris rely upon it would

behoove the people of Ambergris to ignore an integral part to their livelihood.  All too often the

environment takes a back seat to increased tourism development decisions and the destruction

that comes with it.  While it is to be expected that some damage to the environment will occur,

efforts must be made to keep those damages to a minimum.  In an effort to keep those damages

down, the community needs to know what has already happened.  The techniques discussed in

this research are a valuable asset in the analysis of past conditions of the mangrove habitats and

the continued monitoring for the future. Remote sensing techniques will continue to improve as better satellites are created and techniques to analysis satellite images continue to improve. And though the overall mangrove area is decreasing on Ambergris Caye the protection afforded to the wildlife sanctuary and marine multi-use reserves of Bacalar Chico and Hol Chan have steadily built mangrove cover and land. These two locations draw thousands to Ambergris. The people of Ambergris Caye have an opportunity to take preventative measures to ensure the health of the coastal habitats so as to reap the continued rewards of their tourism and fisheries based economy. If their efforts are not sufficient enough to increase the mangrove growth and health mangroves and their associated habitats will continue to decline and will eventually impact the economy so that in the end they are left with a rundown tourist destination where few will visit and the left over poor quality environment that resulted from the ambitious tourist boom. Ambergris has not lost its chance to conserve and wisely use its natural resources; however Ambergris will have to formulate new and improved regulations build upon sound science, infrastructure to implement regulations, and the ability to enforce such regulations. Ambergris is a beautiful island and can continue to be one.

CHAPTER 7

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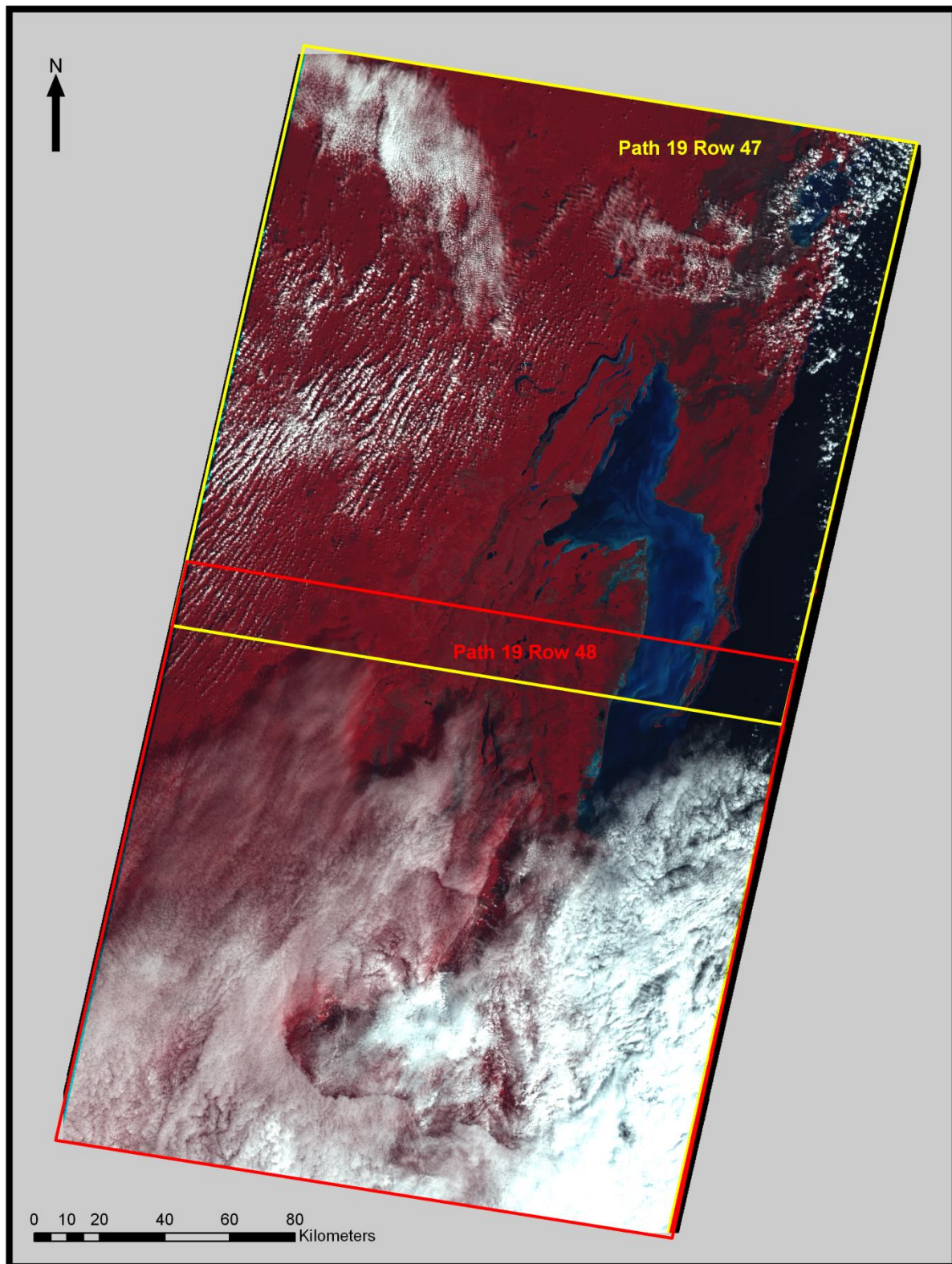
CHAPTER 8

APPENDIX

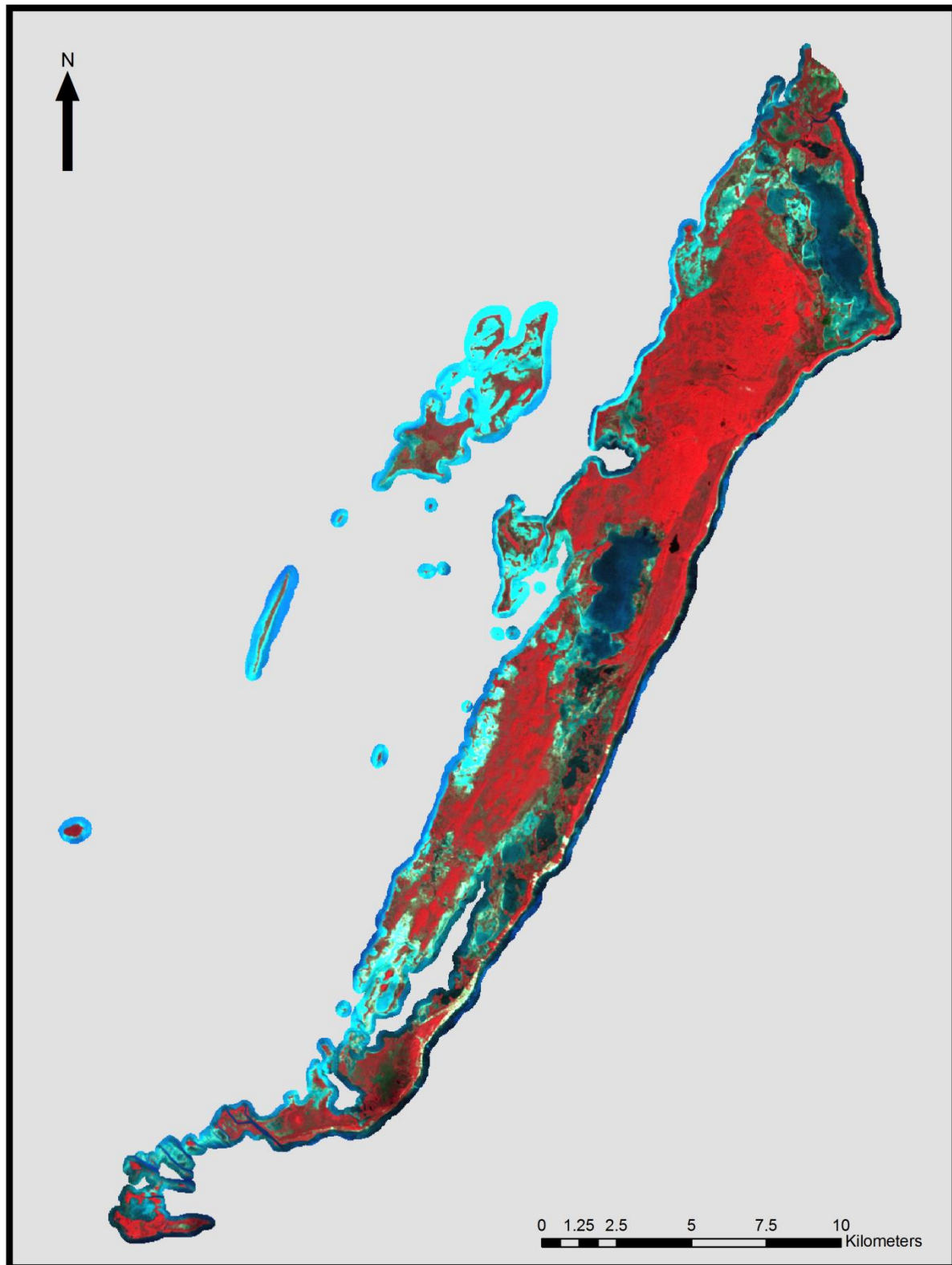8.1: Location of Ambergris Caye in Northern Belize
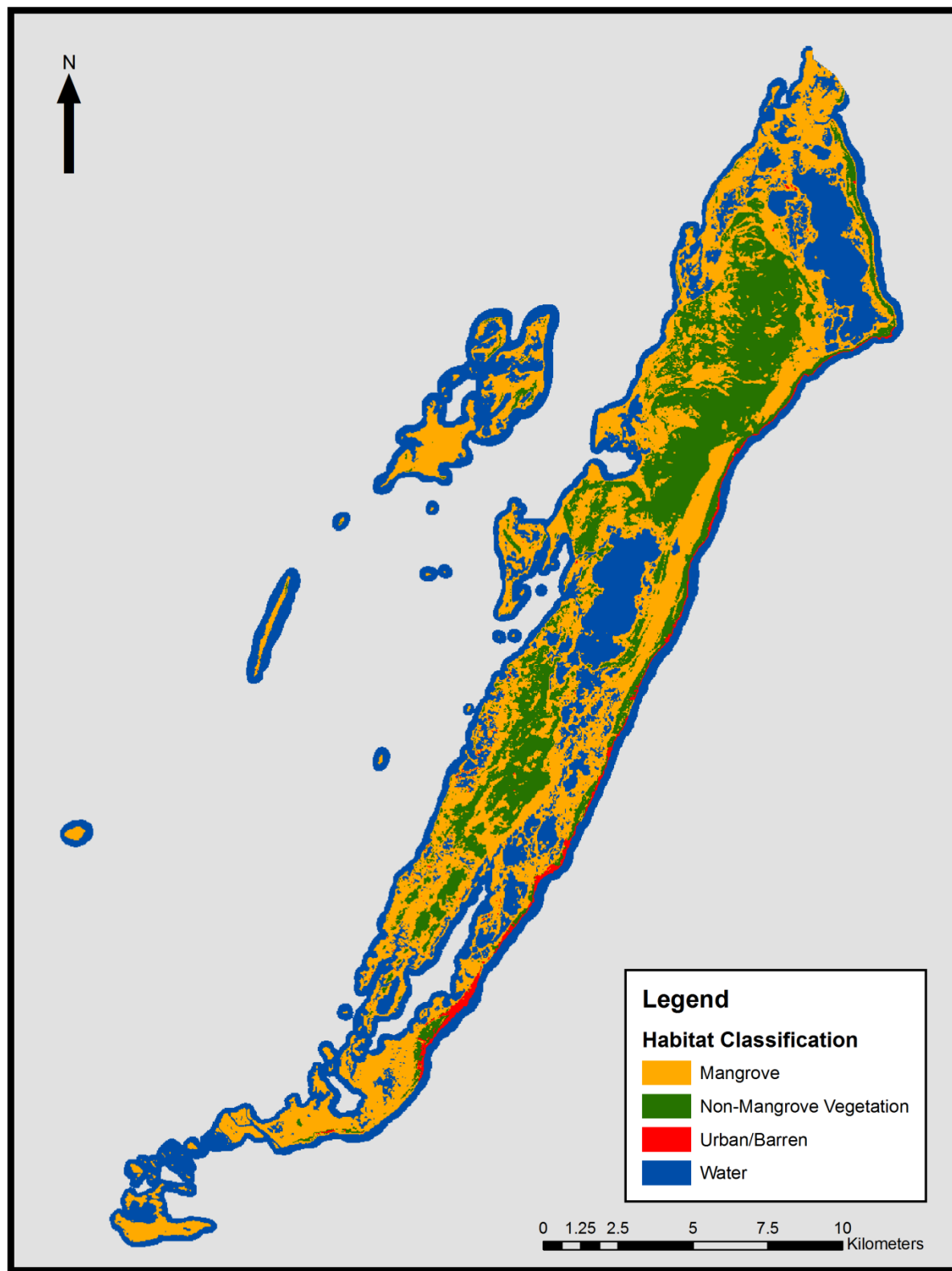


Source: University of Texas Libraries, available at: http://www.lib.utexas.edu/maps/belize.html

8.2: 1986 Landsat 4 TM Satellite Imagery Path and Row Location (RGB: Bands 4,3,2).

8.3: Subset mosaic 1986 Landsat-4 TM Image (RGB: Bands 4,3,2).

8.4: Habitat Classification of the 1986 Landsat-4 TM Image.

8.5: Habitat Classification of the 1990 Landsat-4 TM Image.
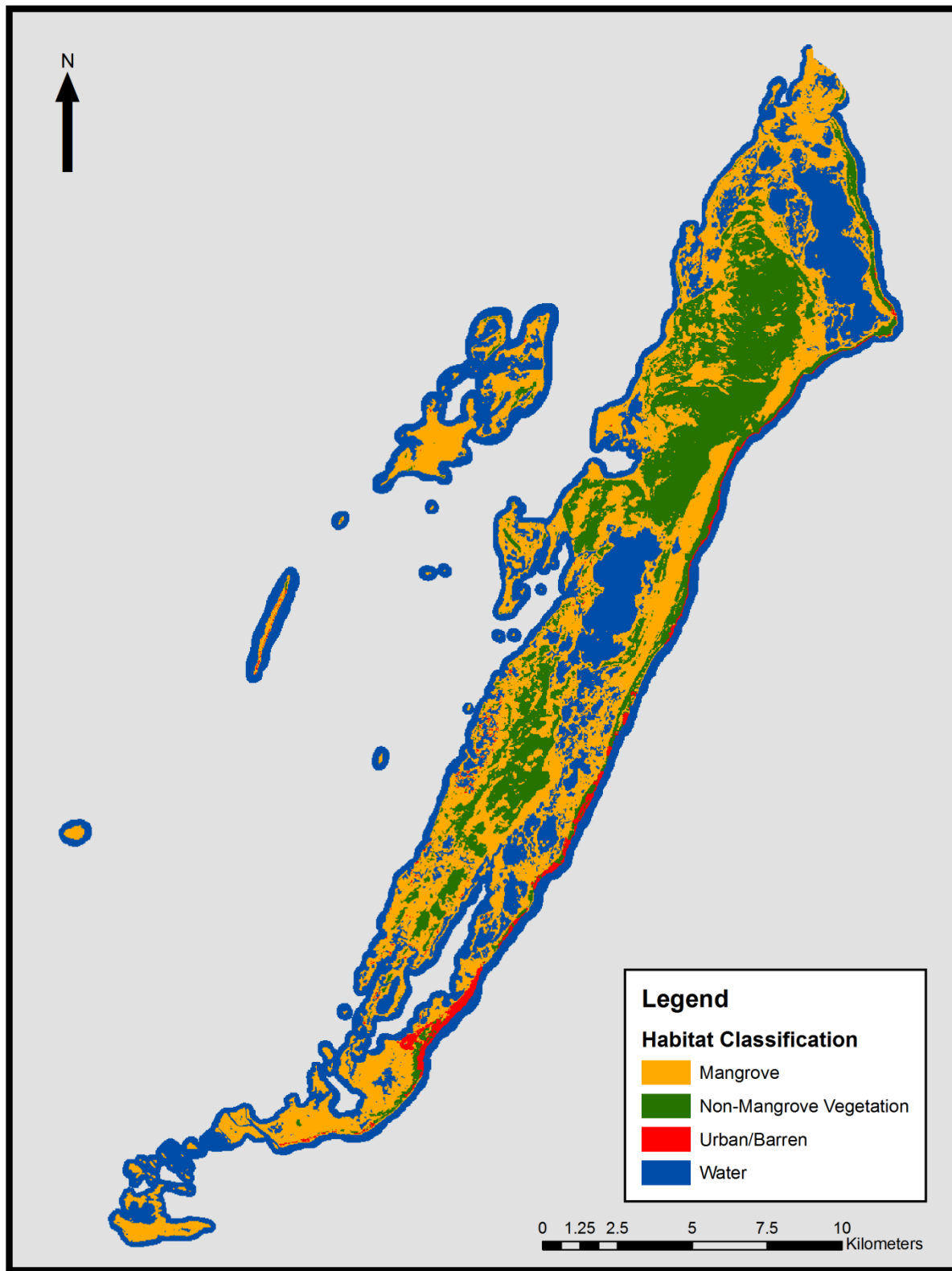
8.6: Habitat Classification of the 1995 Landsat-4 TM Image.
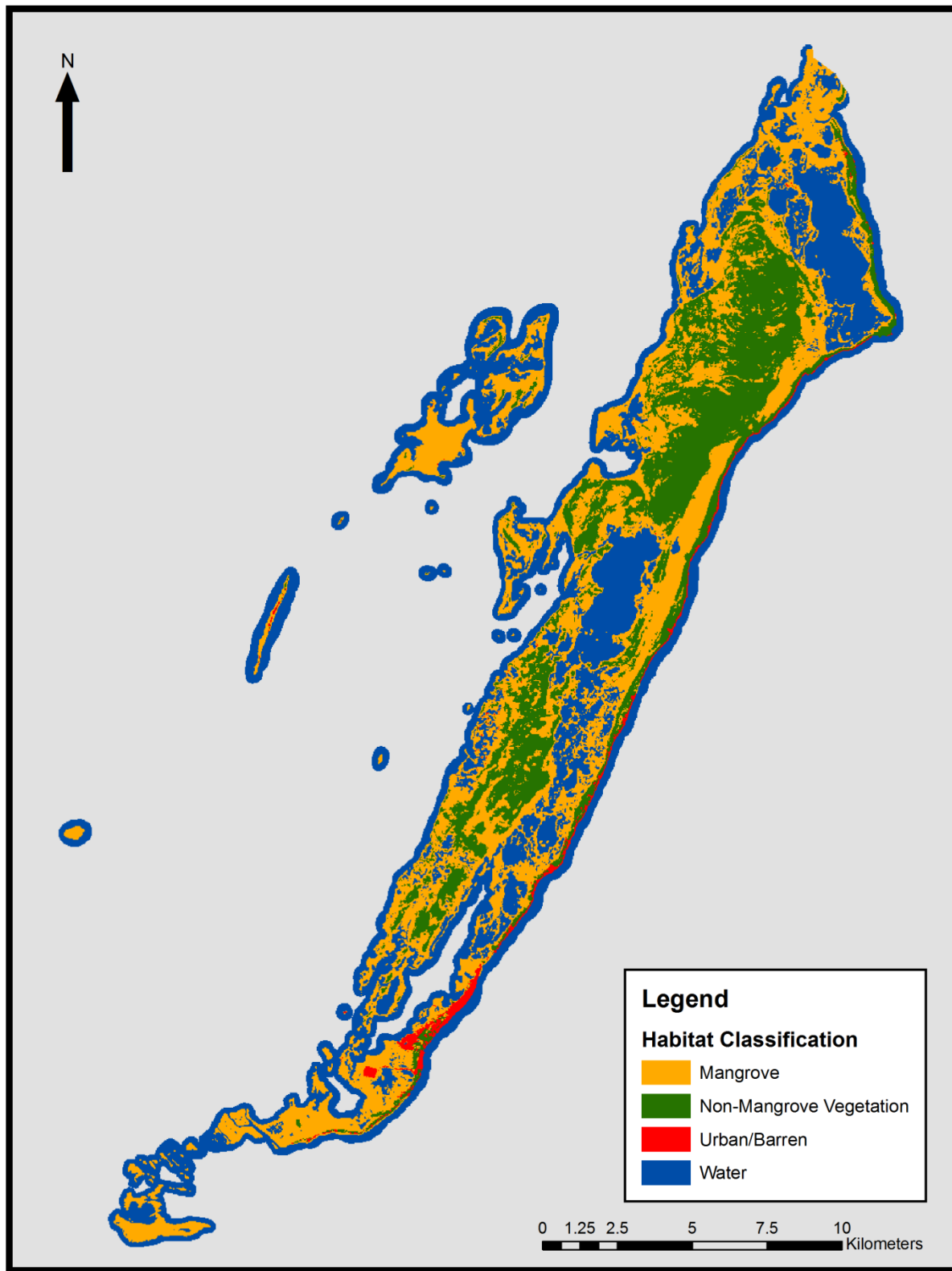
8.7: Habitat Classification of the 2000 Landsat-7 ETM+ Image.
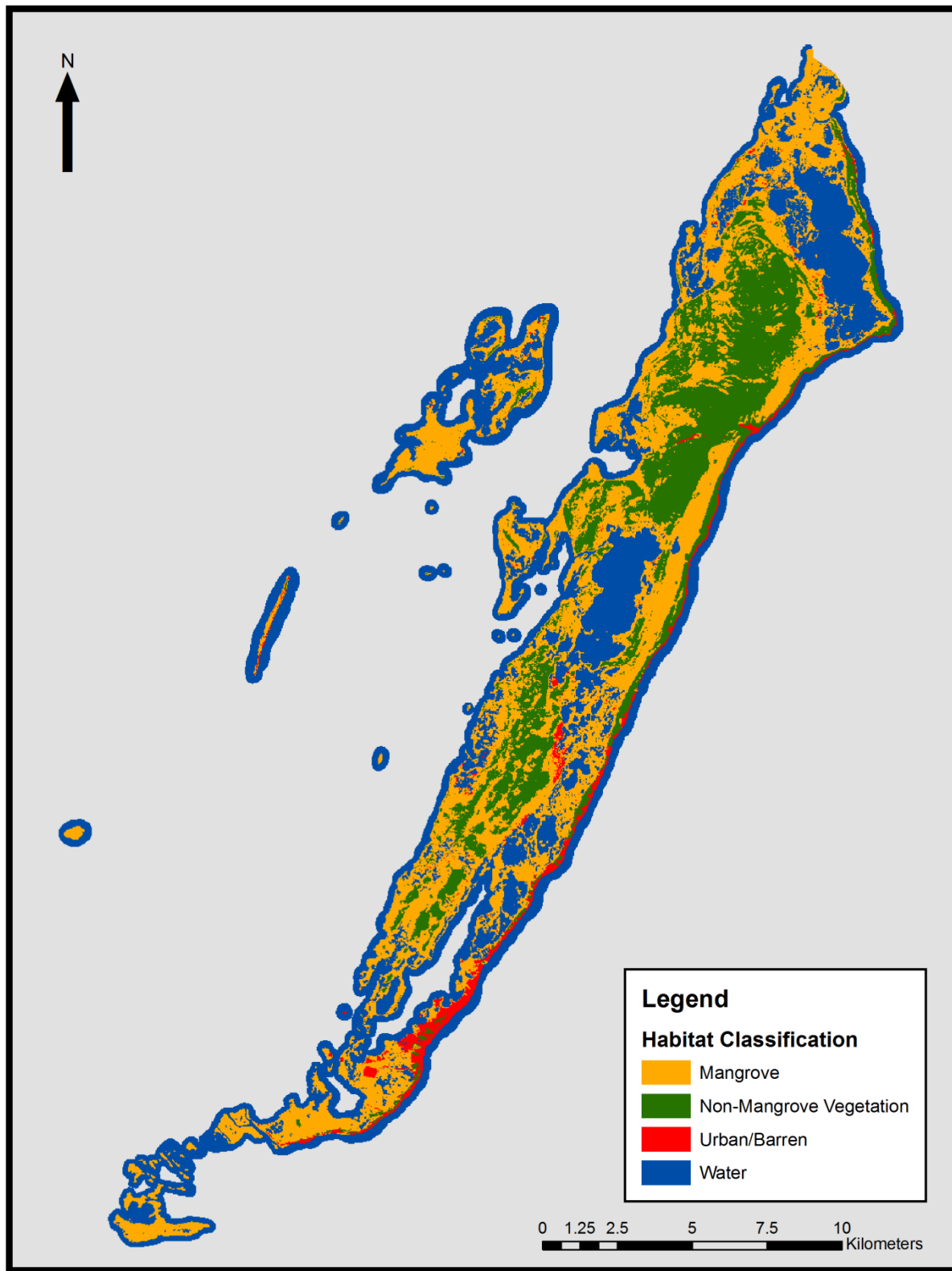
8.8: Habitat Classification of the 2003/4 Landsat-7 ETM+ Image.



Legend

**Habitat Classification**

- Mangrove
- Non-Mangrove Vegetation
- Urban/Barren
- Water
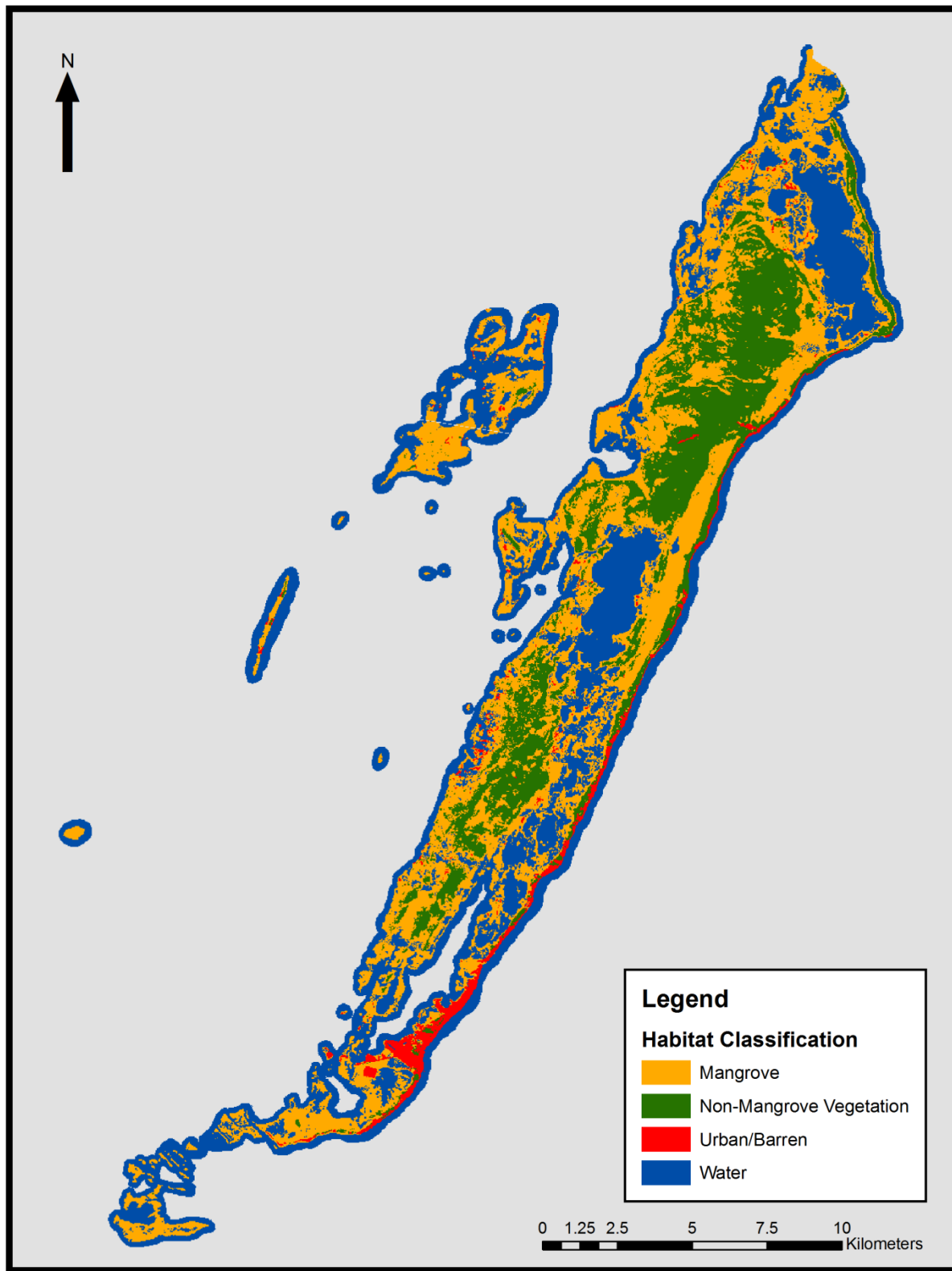
8.9: Habitat Classification of the 2007 Landsat-7 ETM+ Image.



Legend

**Habitat Classification**

- Mangrove
- Non-Mangrove Vegetation
- Urban/Barren
- Water
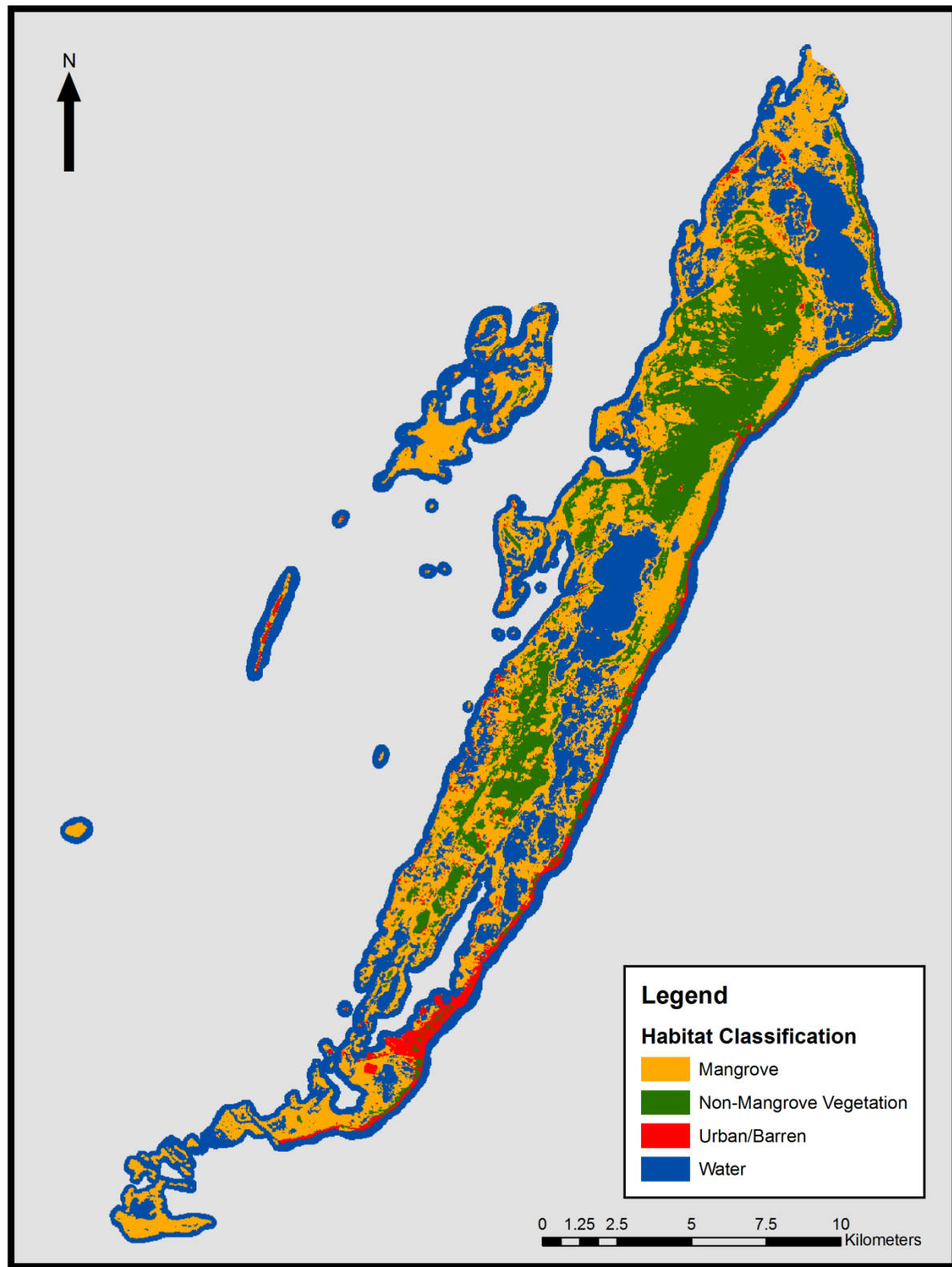
8.10: Habitat Classification of the 2010/11 Landsat-7 ETM+ Image.
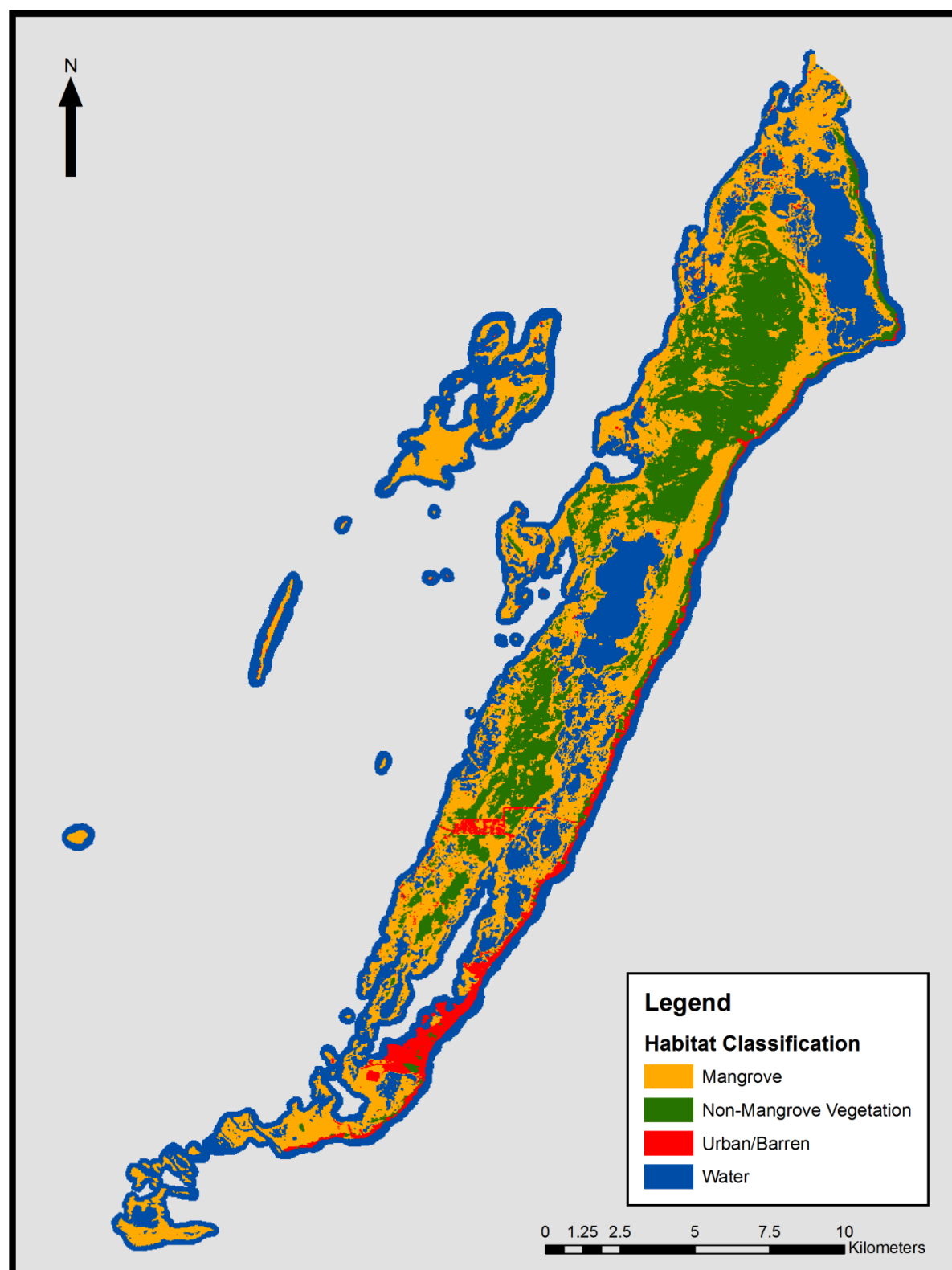
8.11: Habitat Classification of the 2012 Landsat-7 ETM+ Image.
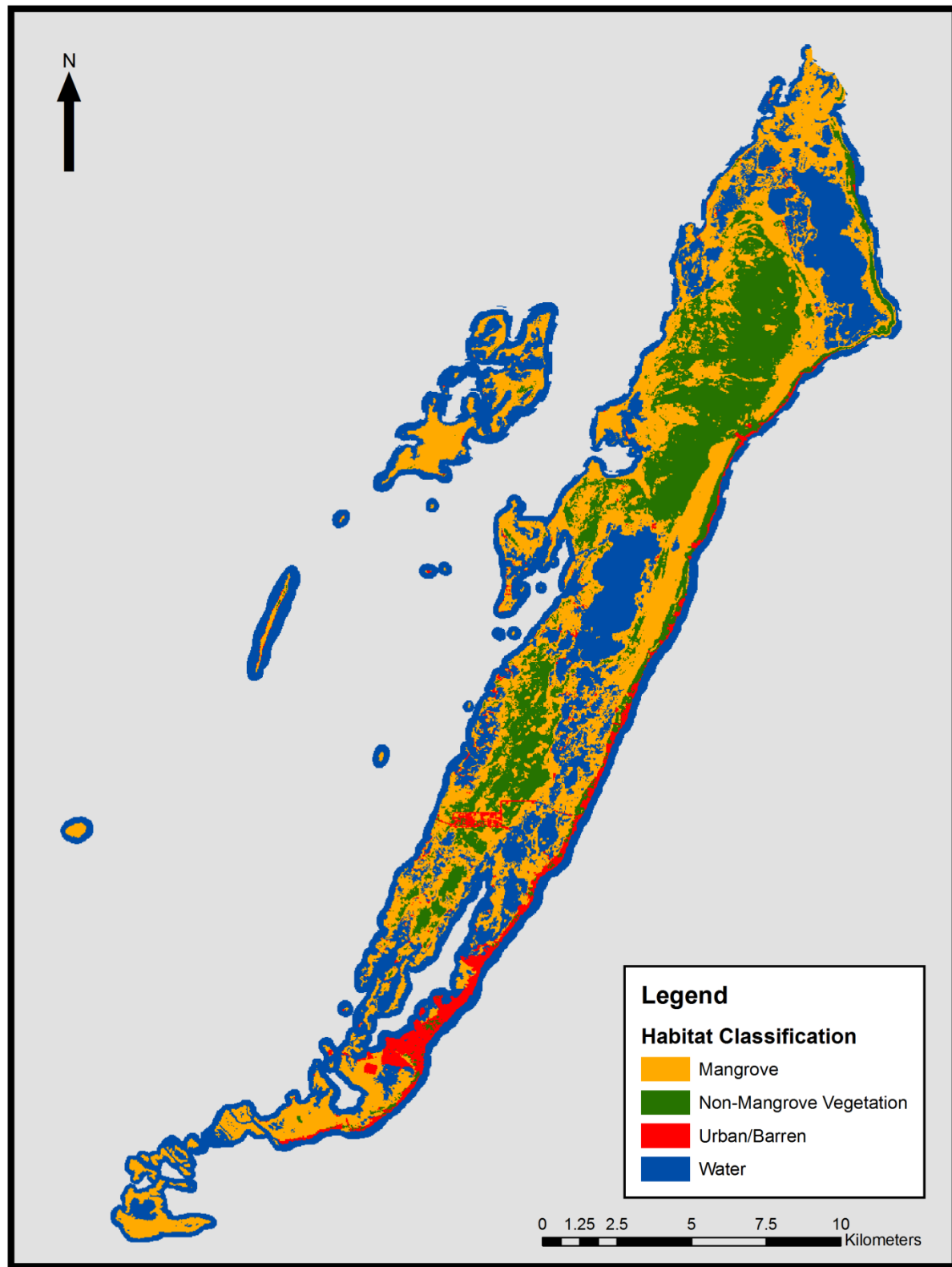
8.12: 1986 Mangrove Quality Classification.
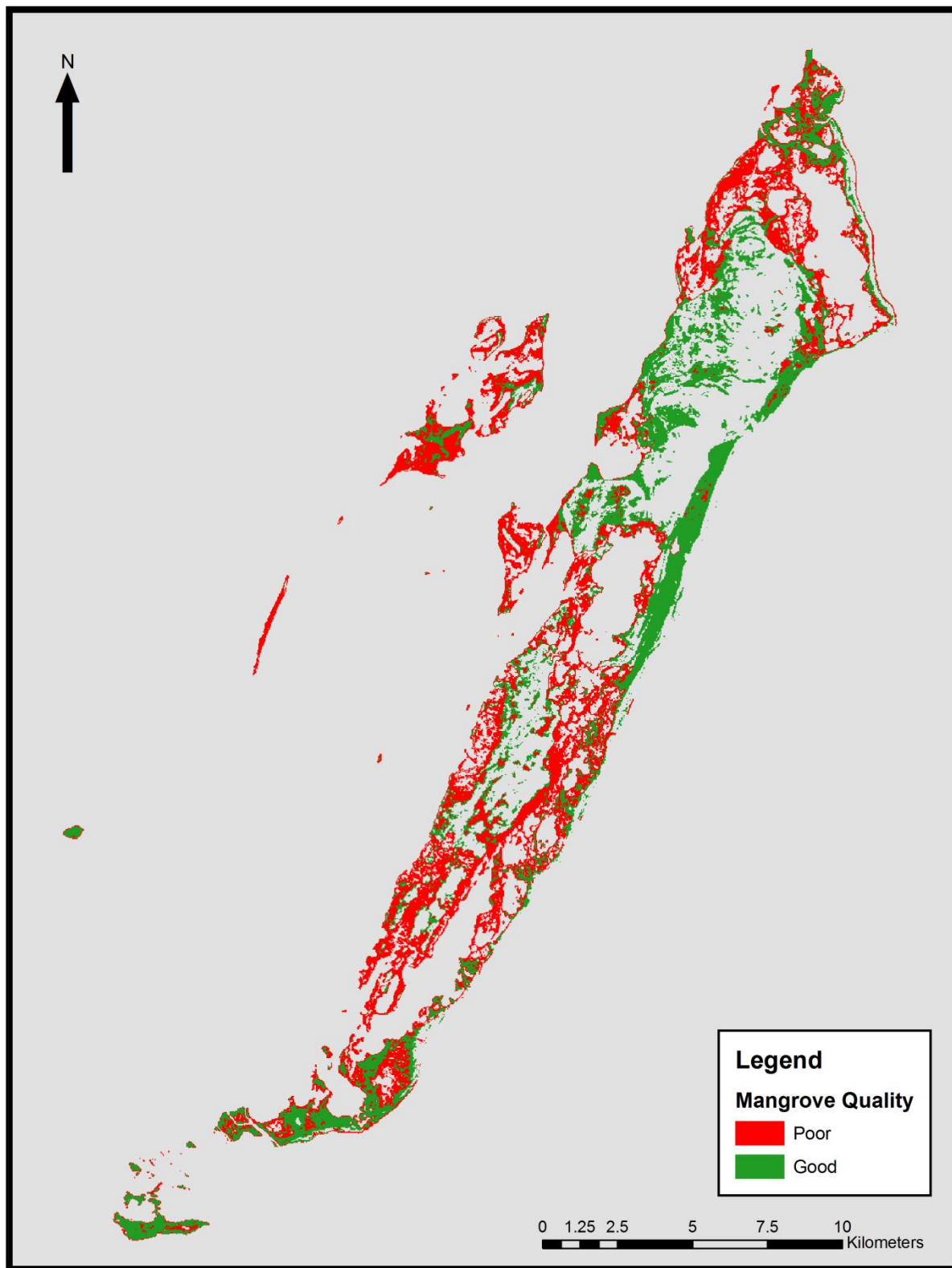
8.13: 1990 Mangrove Quality Classification.
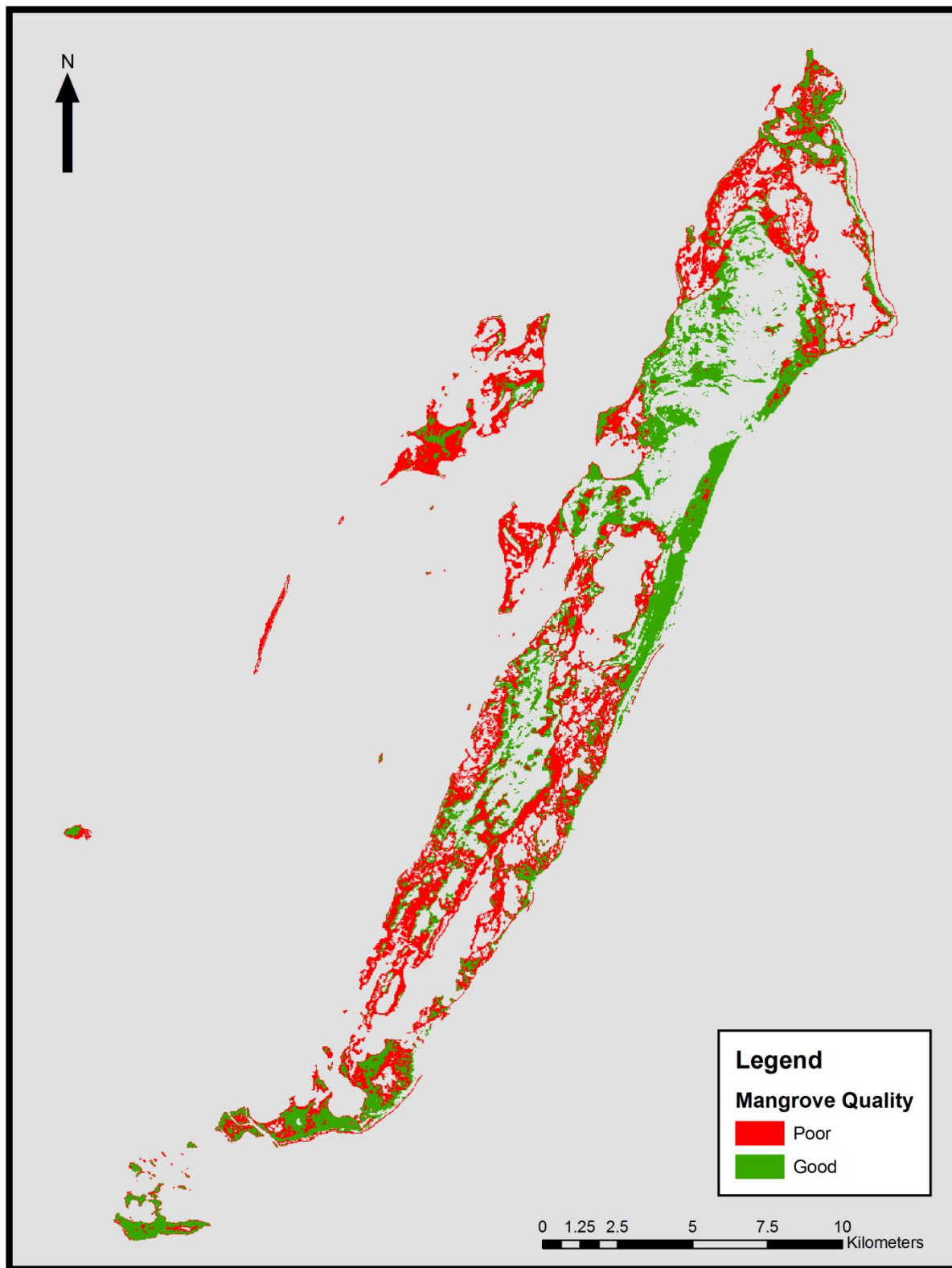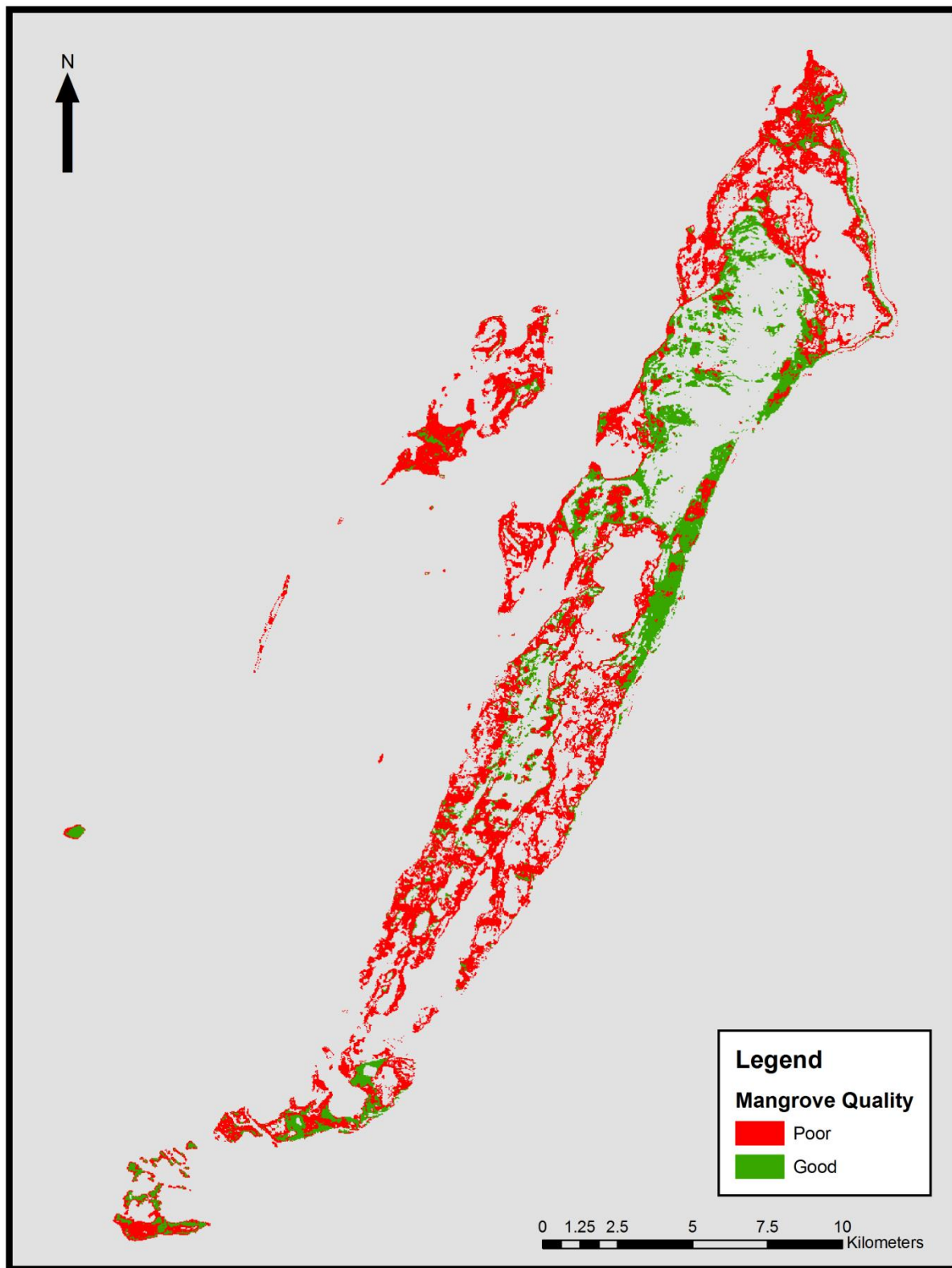
8.14: 1995 Mangrove Quality Classification.
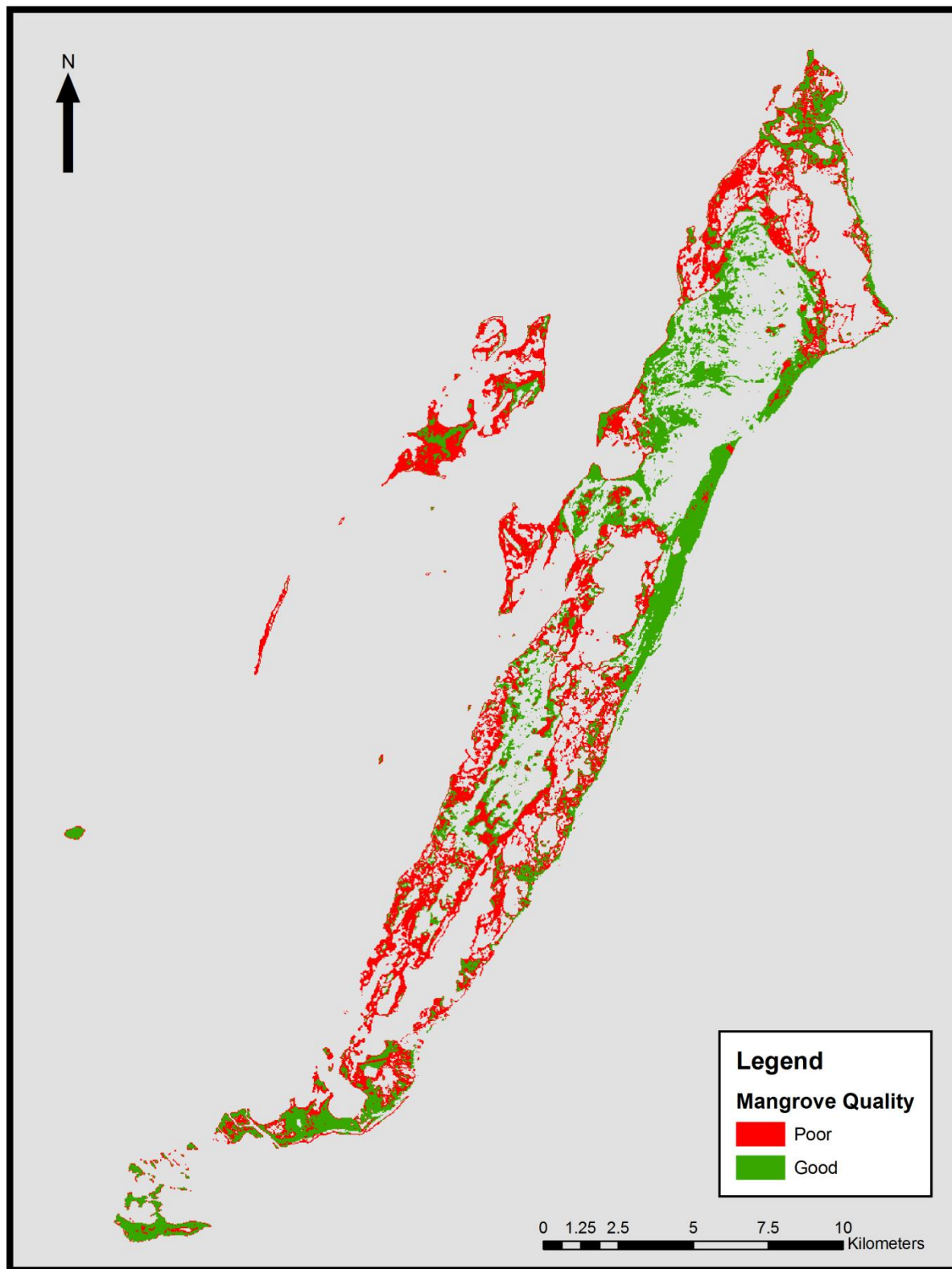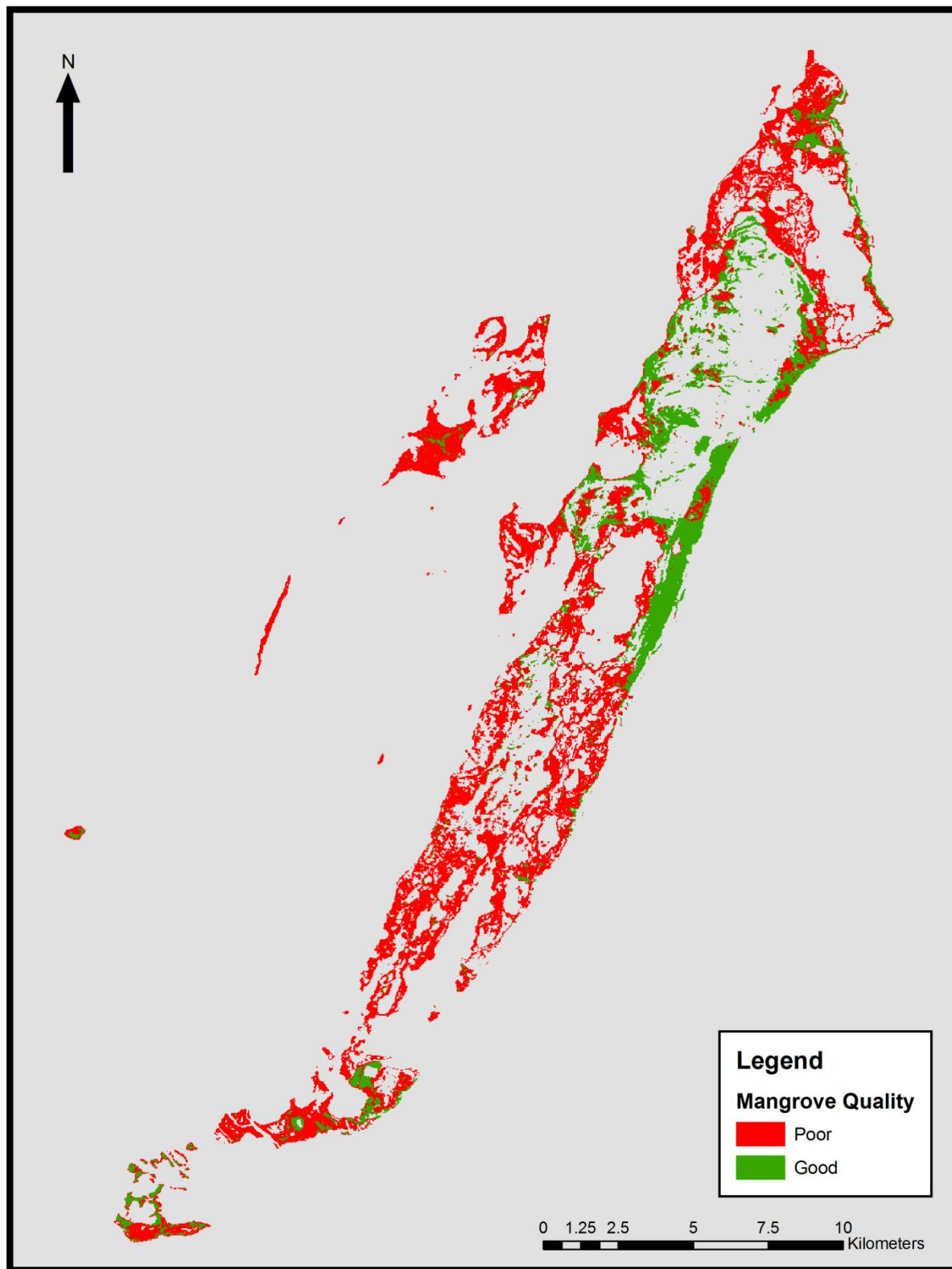
8.15: 2000 Mangrove Quality Classification.
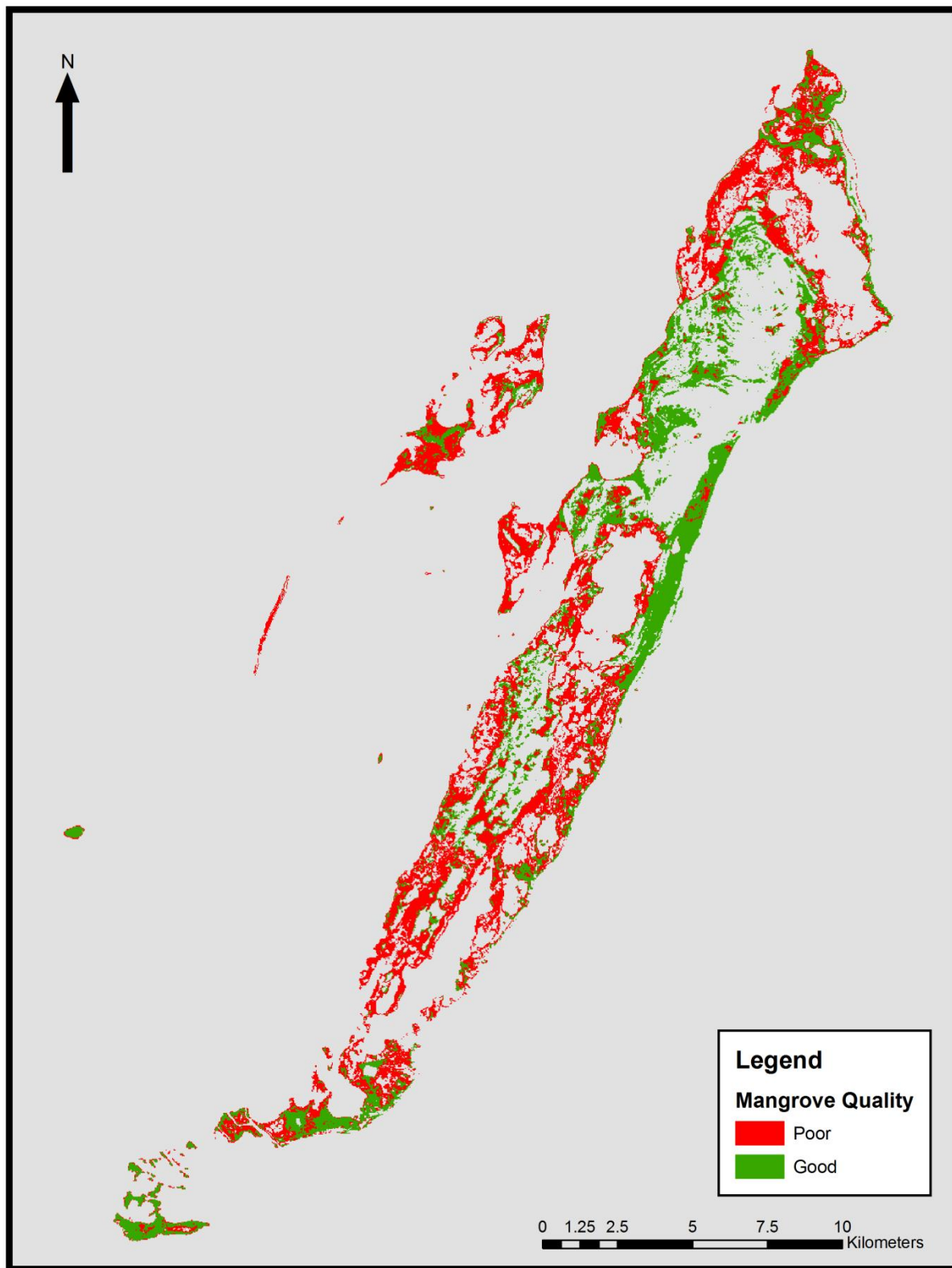
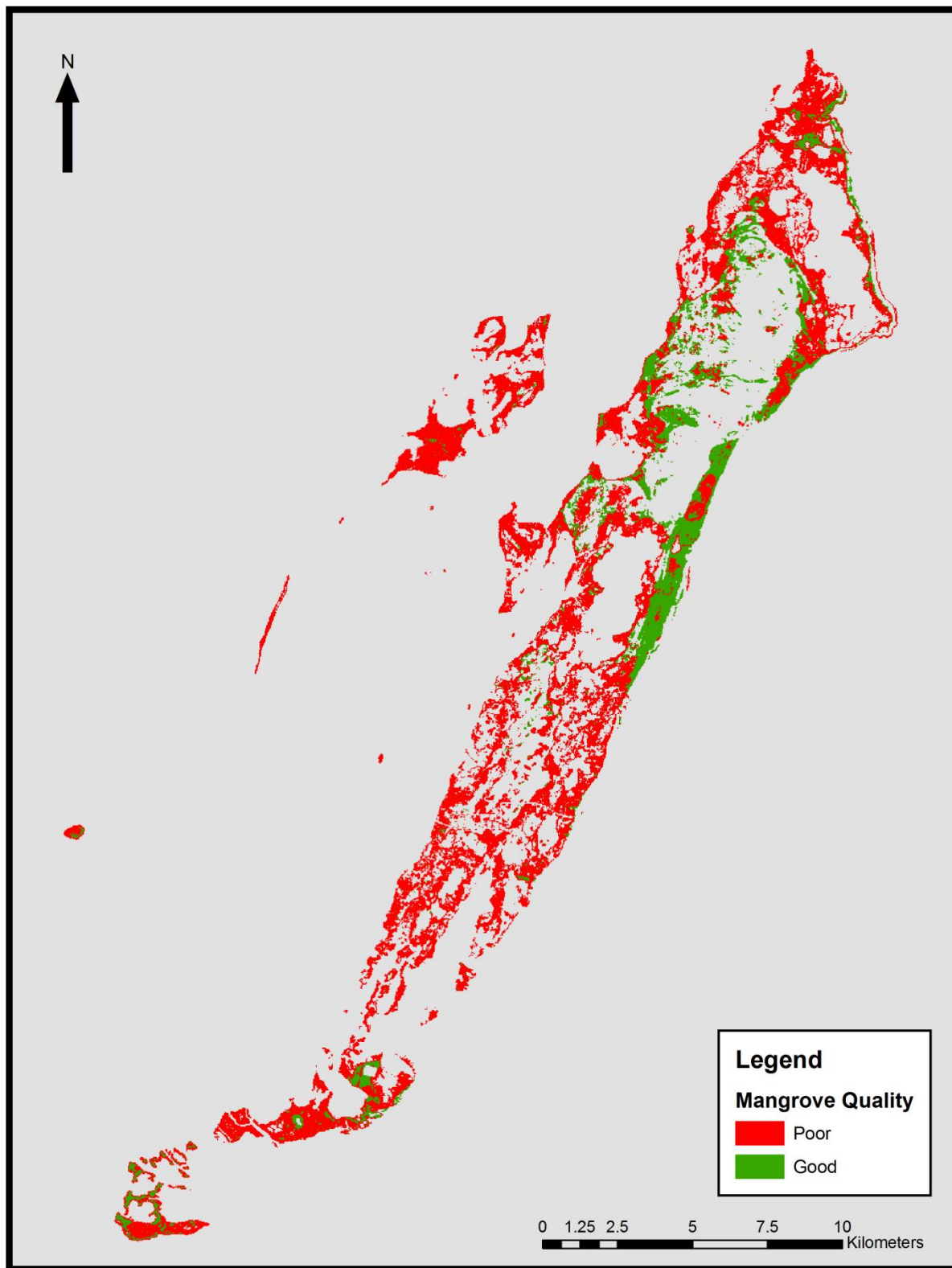8.16: 2003/4 Mangrove Quality Classification.
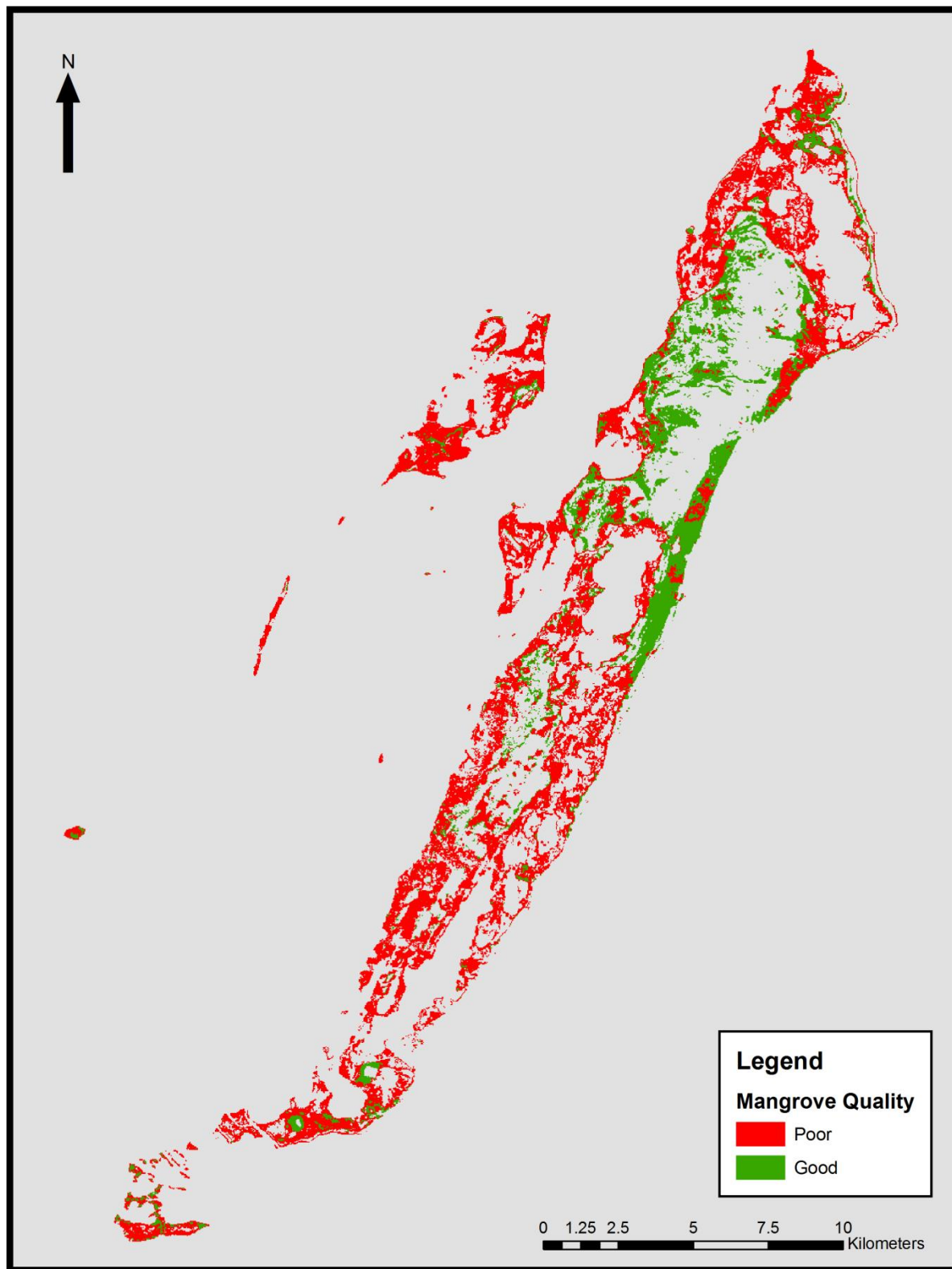
8.17: 2007 Mangrove Quality Classification.

8.18: 2010/11 Mangrove Quality Classification.

8.19: 2012 Mangrove Quality Classification.

8.20: Current Protected Areas of Ambergris Caye, Belize (1986 Image RGB: 4,3,2)