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Evaluating the Effects of Sea Level Rise on Sea Turtle Nesting Sites: A Case Study of the Archie Carr National Wildlife Refuge

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EVALUATING THE EFFECTS OF SEA LEVEL RISE ON SEA TURTLE NESTING SITES: A CASE STUDY OF THE ARCHIE CARR NATIONAL WILDLIFE REFUGE

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by

Melissa Ussa

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To: Dean Kenneth Furton
College of Arts and Sciences

This thesis, written by Melissa Ussa and entitled Evaluating the Effects of Sea Level Rise on Sea Turtle Nesting Sites: A Case Study of the Archie Carr National Wildlife Refuge, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this thesis and recommend that it be approved.

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DEDICATION

I dedicate this thesis to my parents, Aurelio and Ruby Ussa, who have supported and encouraged me no matter what challenge I undertake. No words can truly express my thanks, I love you both greatly.

I also dedicate this thesis to my brother Andres Ussa. Explore every opportunity that comes your way but never take anything or anyone for granted. Love you.

Lastly, I dedicate this thesis to the many people and sea turtles I have met through my passion in sea turtle conservation. My summers are never complete without sand, turtles, and great company.

"For most of the wild things on earth the future must depend upon the conscience of mankind".

-Dr. Archie Carr

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ABSTRACT OF THE THESIS

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by

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Florida International University, 2013

Miami, Florida

Professor Jeffrey Onsted, Major Professor

The purpose of this thesis was to determine the extent of sea level rise (SLR) impact on sea turtle nesting beach habitat on Archie Carr National Wildlife Refuge (NWR) as well as impacts on management strategies. The Archie Carr NWR is of exceptional importance due to the high density of Loggerhead, Leatherback, and Green sea turtles that nest there in the summer months. GIS data provided by the Archie Carr NWR and various SLR scenarios, provided by both the Intergovernmental Panel on Climate Change (IPCC) as well as leading scholars, were used to determine inundation area loss across the Refuge as well as nearby parcels targeted for possible acquisition. Inundation losses for the six scenarios were calculated to be in the 20-25% range. Approximately 26% of current lower priority parcels are reclassified as high priority when integrating this information. Therefore, a significant revision to future acquisition strategies is recommended.

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I. Introduction

Marine turtles are highly migratory species that travel globally from foraging to nesting grounds throughout the year. Since they travel large distances**,** sometimes covering entire ocean basins during their travels, the protection they may have in one area (for example, a marine sanctuary) does not ensure their survival in a neighboring area (Hawkes et al. 2009). As a result of their enormous distribution ranges, many cultures throughout history have relied on turtle meat and eggs for food, and the carapaces were prized for their beauty as well. The reliance on sea turtles for food, medicines, and cultural significance continues today. About one million people still consume some form of sea turtle each year. Human use leads to about 100,000 to 250,000 turtle deaths a year, despite numerous reports that the populations are in serious decline (Mansfield 2010). For example, it is now estimated that twenty percent of nesting sites in the Caribbean are completely gone, while fifty percent of existing nesting sites have reached critically low populations (McClenachan 2006). Emblematic of this population decline is the Loggerhead, which has declined forty-one percent since 1998 (Eckert et al. 2005)**.** With sea turtles reaching such low numbers, their future survival lies in question.

A few projects have experienced successful results from conservation tactics. An example of this would be Tortuguero, Costa Rica, which is the most important Green Turtle rookery in the Atlantic basin. Long-term conservation practices run by the Sea Turtle Conservancy have been in place since 1959 and have resulted in higher nesting populations. (Troëng and Rankin 2005). Conservation efforts in Tortuguero combine eco-tourism and environmental education for the local population.

The Archie Carr National Wildlife Refuge (NWR), Florida, USA is of exceptional importance because of the high density of sea turtles that nest there in the summer months. Of the five marine turtle species that frequent Florida waters; Loggerheads (Cc), Leatherbacks (Dc), and Green Turtles (Cm) nest on the Refuge's four separate segments that together make up 20.5 miles (approximately 33 kilometers) of beach.

Kemps Ridley and Hawksbill sea turtles can be found in Florida waters but do not nest in Florida. Kemps Ridleys can be found along the Gulf Coast and Hawksbills forage in Florida's Atlantic waters (Meylan et al. 1995).

About twenty-five percent of all the United States loggerhead turtles (*Caretta caretta*) nest on the Archie Carr National Wildlife Refuge and its affiliated beaches. The remainder of the Northwest Atlantic Loggerhead population nests along the rest of Florida's Atlantic and Gulf Coasts as well as in Georgia, South Carolina, and North Carolina (Lamont et al. 2012). The nesting beach on Archie Carr NWR even rivals that of Oman for loggerhead nesting density and is also the largest nesting beach in the western hemisphere for loggerheads (Comprehensive Conservation Plan 2008). The Refuge also supports smaller nesting populations of endangered green turtles (*Chelonia mydas*) and leatherback sea turtles (*Dermochelys coriacea*) (US Fish and Wildlife Service, 2001). Therefore, planning for the future nesting success of these species in this location would have significant impacts on worldwide populations.

Objectives and Hypothesis

Using GIS data provided by the Archie Carr National Wildlife Refuge as a tool for the calculation of the effects of sea level rise in a series of scenarios, the following are the objectives for this proposed research:

1. Determine what areas of the refuge will be most affected by sea level rise.

2. Examine how sea level rise would affect carrying capacity of the beach by looking at the average of each of the three species that nest in the refuge: Loggerhead, Green, and Leatherback.

3. Determine if land parcels that are labeled as highest priority for acquisition are situated in areas that will not experience major losses from inundation due to sea level rise.

As a result of my research, I expect that sea level rise will negatively impact sea turtle nesting on Archie Carr National Wildlife Refuge, especially in areas that have been developed and have armoring structures as these will not allow a landward progression of the beach. I hypothesize that by considering future sea level rise projections, carrying capacity, and available parcels for the refuge there could be a shift in the focus of land acquisition for certain parcels and future management goals.

An optimized parcel acquisition map can be prepared that will assist the Archie Carr National Wildlife Refuge with future management plans.

The following chapters will focus on a) explaining the nature of climate change, and more specifically sea level rise (SLR); b) the threats sea turtles face worldwide; c) how SLR negatively impacts nesting beach habitat, and d) the importance of the Refuge system and its future acquisition goals to the conservation of sea turtles. The final optimized parcel acquisition map will look at how nesting densities coincide with areas that are scheduled for future development as well as other parcels targeted for acquisition. Methods used to develop the map will be explained in detail and after discussing the results of my methodology I will offer some final conclusions, based on this research, about the future management of acquisition parcels in Archie Carr National Wildlife Refuge

II. Literature Review

Climate Change

Global Climate Change has been caused by human actions that have resulted in an increase in the amounts of greenhouse gases and aerosols present in our atmosphere (Houghton et al. 2005). These increases have led to an imbalance in the energy that is absorbed and emitted by the planet (Hansen et al. 2005). Global Climate Change can be further delineated by the calculations arrived at by Hansen et. al (2005) that show Earth is absorbing approximately 0.85 (± .15 watts per square meter more energy from the sun than it is emitting back into space. Earth is therefore retaining more heat that it has in the past. Data collected over the last 140 years show an alarming spike in temperatures in the 1900s (Houghton et al. 2005). In the last 50 years, during which the use of greenhouse gases and aerosols were at their peak, global average temperatures increased about 0.5 degrees Celsius (Houghton et al. 2005). Projections for the 21st Century depict an increase of 0.15-0.60 degrees Celsius per decade. These rates are considerably higher than any Earth's climate has seen for the last ten thousand years (Houghton et al. 2005). Projections therefore indicate an average increase ranging from two degrees to six degrees Celsius by 2100 (Houghton et al. 2005).

Climate change has introduced warming trends that have affected ecosystems throughout the world. These trends will continue to increase if the high rates at which greenhouse gases are emitted continue**.** The ability to change emission trends, human responsiveness and climate policies will determine if the worst of the climate change projections can be avoided. It would take hundreds of years if emissions were effectively reduced today to stabilize the climate carbon cycle (which is linked to temperature changes and sea level rise). According to studies conducted by the Intergovernmental Panel on Climate Change (IPCC) environmental analysts, to reach emissions averaging at 450 ppm carbon dioxide, a reduction of 670GtC to 490 GtC would have to be reached (Herbert 2007). Therefore, a change does not indicate immediate improvement; however it would lead to the gradual decrease in global climate change effects and would be a step in the right direction.

Sea level rise

Eighty percent of the increase in atmospheric temperature is expected to be absorbed by the oceans and thus cause thermal expansion (Hawkes et al. 2009). Already, ocean temperatures are 0.7 degrees Celsius warmer than they have been in the last 400,000 years (Hoegh-Guldberg et al. 2007). The rate of heat absorption would in turn drive a 10 to 60 cm increase in sea level by 2100 (Meehl et al. 2005).

In addition to thermal expansion is the threat of melting ice sheets. The Greenland and Antarctic Ice Sheets are both susceptible to global warming. In the case of Antarctica it is presently accumulating ice and therefore there is a net growth (although substantial melting occurs in the summer months) (Houghton et al. 2005). Yet if the current rate of global warming continues, a complete melting of the Greenland Ice Sheet would result in a 7m increase in sea level rise and the Western Antarctica Ice Sheet would result in a 6m increase in sea level rise (Houghton et al. 2005). The impact of one or both ice sheets melting would be highly detrimental to the areas that are at or close to sea-level. Increased coastal flooding, loss of ecosystems, loss of coastal wetlands, and economic impacts (i.e, property loss) would be a few of the results of sea level rise (Nicholls, Hoozeman, Marchand 1999). More recent studies point to a less drastic change in ice sheet loss than previously believed (IPCC 2010). Glacier studies from 2009 for the southeastern Greenland ice sheets suggest that there will be a leveling off of the acceleration in mass loss by 2100 (IPCC 2010). There are indications that losses in mass will move northward as shown by remote sensing data. These calculations have only been made possible by recent advances in satellite and airborne remote sensing technologies (IPCC 2010). The mass loss of the Antarctic sheets is thought to be a complex process that will vary regionally, led by changes in ocean temperature and precipitation (IPCC 2010). Despite these more recent studies, they are not conclusive. The next sets of projections are due to be released by the IPCC in late 2013.Therefore projections in my study will use scenarios from the available figures published by the IPCC from 2007 (IPCC 2007) and two recent projections presented by Zhang et al. (2012) and the National Research Council (2012).

An increase in sea level will exacerbate coastal erosion. More than seventy percent of the world's beaches are recessional (Bird 1985). Sea level rise increases the range of wave action on land and allows waves to affect areas at a higher elevation in the beach profile, moving more sediment out to sea (Zhang, Leatherman and Douglas 2004). Erosion would reduce the amount of coastline available, such as barrier islands (which are highly vulnerable to coastal processes), and could deteriorate the ecosystem and harm the endangered species present in these coastal areas. My work focuses on the inundation caused by sea level rise. The shoreline retreat caused by erosion is not considered in the analysis.

Sea Turtles

As a consequence of the highly migratory nature of sea turtle species, a large number of threats exist that endangers their likelihood of survival. Long-line fisheries, bottom trawlers and gillnets can affect sea turtle populations dramatically. Long-line hooks can trap adult sea turtles. Mortality caused by trapping takes away from the reproductive value of the species as that individual was of age to produce eggs (Lewison 2007). In gillnet fisheries; the sea turtle by-catch can be as many as 200 adult and juvenile turtles a year (Lewison 2007). Bottom trawler fisheries have been found to catch approximately 10,000 adult and juvenile turtles a year. Sea turtle bycatch occurs in all in fisheries where regulations, such as the use of TED's (Turtle Exclusion Devices) for bottom trawlers, have not been put in place or enforced (Lewison 2007).

Climate change poses several future problems for sea turtle populations. Temperature affects sea turtle life histories because they exhibit temperature sex determination (TSD). All species of sea turtles possess this trait and thus changing climate is a large determining factor for the future male to female ratio that will be produced Incubation temperatures over 28 degrees Celsius resulted in a female majority in Green turtle hatchlings. Temperatures below 28 degrees Celsius tend to produce 90-100% males (Standora et al. 1985). If temperatures continue to rise, a change of only 1-2 degrees Celsius will skew the male to female ratios, thus adversely affecting future propagation of the species.

Sea level rise resulting to climate change is a major issue. As human populations struggle to protect oceanfront property from erosion, sea turtles are losing their nesting beaches (Hawkes et al. 2009). Protection of the coastline would involve hard armoring (seawalls, gyrones, etc) that effectively reduce the amount of beach available. These hard armoring techniques are already in use in the Caribbean and have led to "coastal squeeze" which does not let the beach progress further inland; therefore there will be a smaller amount of space available for turtles to nest in the future (Hawkes et al. 2009). Coastal squeeze could cause major issues in areas that have high nesting densities. In these areas coastal squeeze could bring about a high incidence of overlapping nests (Mazaris et al. 2009), which would greatly decrease nesting success.

Because reactive solutions to erosion (i.e. sea walls) actually tend to increase erosion rates, as a result of increased wave energy, other techniques to reduce erosion have been considered. For example, setback regulations ban construction a certain distance from the ocean (Fish et al. 2008). Beach migration that could result from sea level rise would depend on the land-use behind the beach that would allow landward migration or be impeded by hard structures such as buildings (Fish et al. 2008). The setback regulation strategy is preemptive rather than reactive and creates a buffer that allows landward expansion of the shoreline. Without this buffer, as sea level rises, female turtles run higher risks of exposure to human development impacts and nests to salt water inundation (Fish et al. 2008).

The probability of sea level rise in a low-lying barrier island, such as where the Archie Carr National Wildlife Refuge is found, brings to the forefront preemptive techniques such as setback regulations. Future management decisions could profoundly impact the nesting density in certain areas of the refuge and therefore affect the reproductive success of the sea turtles that nest there. Future management decisions would therefore affect critical habitat and an assessment of how this could impact each beach located within the Refuge is essential. A focus should be placed on those that have higher densities of nests and that would therefore have a larger impact on the sea turtle populations in the Northwest Atlantic as well as worldwide.

When viewed from a worldwide prospective, marine sea turtles are a global resource in which many countries have a stake (Campbell 2007). Many countries continue to consume sea turtle meat. Ecuador, Peru, Australia, Cuba, Costa Rica, and Nicaragua are a few that still allow the custom, although consumption may technically be illegal within its borders. In Australia for example, non-indigenous people are prohibited from capturing or killing a sea turtle, and also from consuming the eggs. Yet, indigenous Australians (Aboriginal and Torres Strait Islanders) can do so as long as the use is for non-commercial purposes (Great Barrier Reef Marine Park Authority (GBRMPA) 1994).

In Nicaragua the cultural importance of sea turtles has changed over time. When initially studied, the ability of a Miskito Indian fisherman to share meat was significant to social interactions. It was an important additional protein source to Miskito Indians when there was seasonal scarcity (Campbell 2002). Once commercial turtling was introduced, perceptions changed within the Miskito communities to where it became an economic necessity. Turtle meat became harder to obtain as the population diminished as a consequence of increased hunting (Campbell 2002). Introducing cash values to turtle meat made meat-sharing among the communities disappear. Now thousands of turtles are killed in Nicaragua every year, all for commercial uses (Campbell 2002). The loss of sea turtle populations would have negative ecological impacts worldwide. For example, green turtles have foraging grounds in sea grass beds globally from the Gulf to Australian waters (GBRMPA 1994). Sea grass requires constant cutting to remain healthy and to promote horizontal growth along the sea floor (Sea Turtle Conservancy (STC) 2011). Sea grass beds provide a habitat for many juvenile species including juvenile sea turtles, fish and many species of crustaceans and shellfish. Many of the fish that require sea grass beds for their juvenile stage of development are important for commercial fisheries as well. A loss in green turtle populations would therefore lead to a decline in sea grass abundance that would in turn cause a major decline in juvenile fish habitat (STC 2011).

Conservation strategies pertaining to use are further put into contention by the scientific uncertainty that underlies the status of sea turtle populations (Campbell 2007). Migratory patterns make it difficult to determine the concise status of marine turtle populations because of the threats that are present along their migratory routes that cannot be accounted for. These threats include long-line fisheries, bottom trawlers and gillnets that can be encountered throughout a migratory route. Therefore it is complicated to establish the cumulative effect of the threats that are present in the ever-shifting sea turtle populations (Campbell 2007). Consequently, complications arise for experts that wish to put more exacting constraints and regulations because of the scientific uncertainty that surrounds the situation. However, continued monitoring and research efforts help ensure that any important decline in the population will not go unnoticed and that plans to avert any significant declines are put into action as soon as possible before it becomes highly detrimental.

Study Area- Archie Carr National Wildlife Refuge

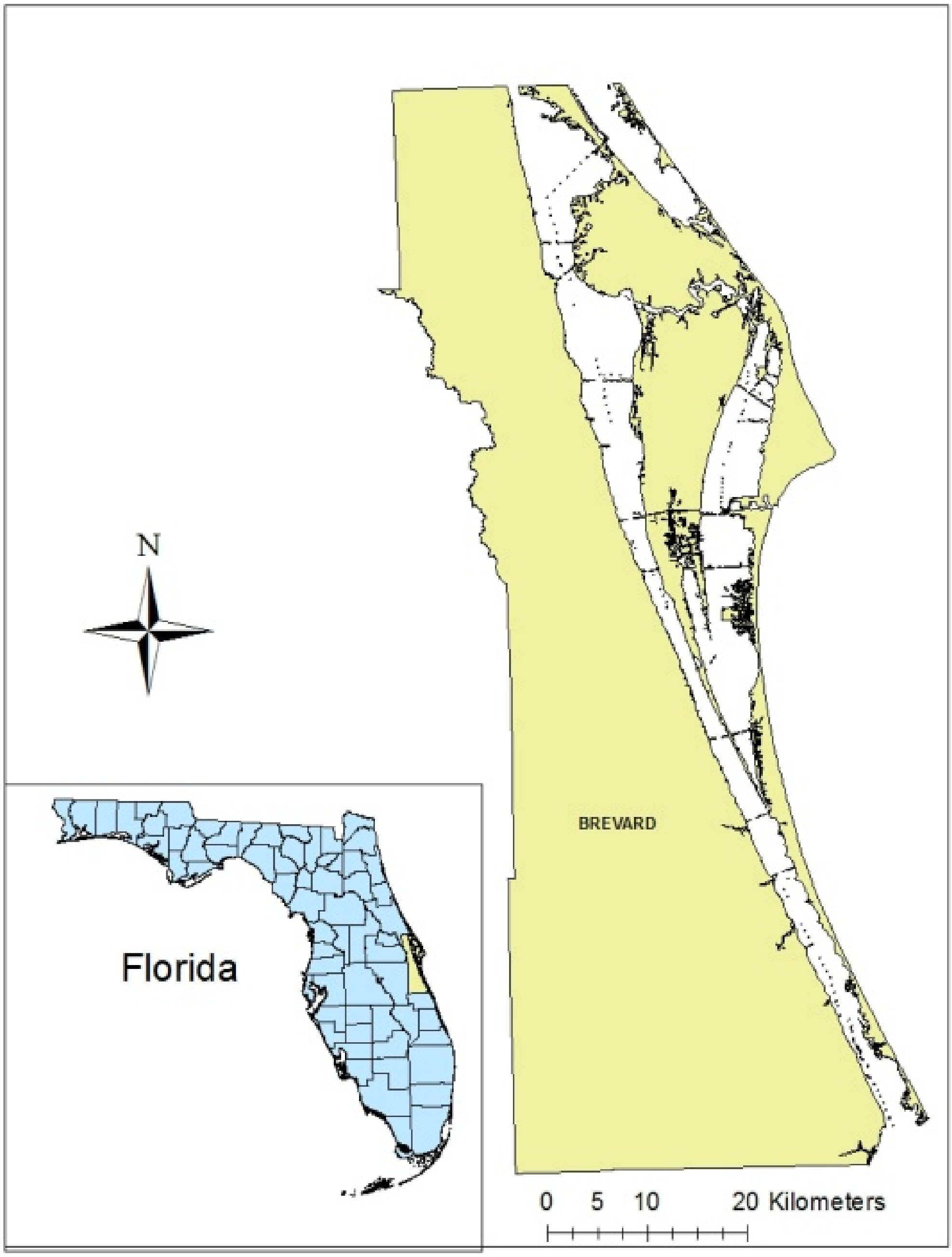

Figure 2.1 Depicts the greater study area where Archie Carr National Wildlife Refuge is found.

The Archie Carr National Wildlife Refuge is located in the Central Florida region, in the Brevard and Indian River counties. Figure 2.1 indicates the location of Brevard County in the state of Florida. As the human populations of both Indian River County and Brevard County continue to increase, there is an intensification of the pressure on the wildlife population in this area. In 2005, the population in Brevard was 519,000 people and in Indian River it was 126,400. By the year 2015 it is projected that the populations of both counties will increase 14-15% (CCP 2008).

The economy in the vicinity of Archie Carr NWR is largely dependent on tourism, agriculture, and fishing, all of which increase the threats that are present for the wildlife in the area and these threats are multiplied as the population changes. An increase in population in the area would also mean an increase in built structures as housing and commercial demands escalate. While development would be the main issue on the coast due to interference with nesting habitat, a rise in the amount of people populating the beaches would also interfere with nesting as increase in human population could lead to more disturbances during the nesting process for the female sea turtles.

Developmental demands began in the 1980s in the refuge area. Once it was realized that this would threaten the health of the refuge many land acquisition goals were made, namely by the Beach and Riverfront Acquisition and Save Our Coasts (SOC) organizations (Jackson et al. 1988). In 1982, Florida established the SOC, which raised over $275 million over the next decade. Money raised by SOC was used to purchase beaches and barrier islands. Save Our Coasts was used as part of Florida's Land Acquisition Trust Fund Program. Parcels of land were acquired in the Brevard and Indian

River counties that later served as the core land tracts to establish the Archie Carr National Wildlife Refuge (CCP 2008).

Conservation Tactics- Land Acquisition

Land acquisition is largely dependent on comparisons of the conservation value a parcel of land holds versus the cost associated with attaining the parcel (Czech 2002). Land acquisition for conservation also involves determining any socioeconomic and sociopolitical effects that may influence management objectives. It is simple to assess the cost of land prices; however, other nonmonetary factors, such as negative sociopolitical effects, are more difficult to assign value to (Czech 2002).

At first land acquisition for the Refuge system simply involved transferring large public, economically unproductive and inexpensive lands into the system. Acquisition was facilitated further when there was the discovery of an endangered species on public lands owned by the same government department (Czech 1997). As the economy continues to grow, there are less of these lands available for conservation use and land acquisition must continue through more expensive means.

Analyzing the cost benefit ratio of acquiring land for the assistance of endangered wildlife is essential in urbanized areas. In relatively to highly urbanized areas, land costs would be higher because of the higher land values. Yet the benefits of protecting endangered species could be seen as higher or equal to the cost of the land. It is important to not let apparent cost deter conservation strategies. While rural lands are more inexpensive, as lands become more developed, nearby ecosystems become more endangered (Dietz and Czech 2005).

Threats to ecosystems in urbanized sectors involve habitat fragmentation, pollution, and human disturbance due to a larger human population being present (Gritffith et al. 1989). Another way to look at it is areas where land prices are lower and where land is being developed more slowly, fewer threats to ecosystems are present (Griffith et al. 1989). Areas with larger human populations illustrate that the more fragmented and urbanized an area is the more critical habitat it could contain for some endangered species.

Yet the price may seem formidable to a refuge system that had limited funding for larger conservation strategies and goals. Addressing this issue requires that the USFWS work with public and private sectors to achieve a higher level of wildlife conservation (Meretsky et al. 2006).

A Look at Conservation Costs

While attaining private lands for conservation may seem expensive and difficult, around ninety –five percent of species can be found on private lands, which indicates conservation efforts should lean towards acquiring private lands (Merenlender 2004).

As funding is a major obstacle to acquiring land for conservation, various methods have been employed over the years to achieve land attainment. Public acquisition programs not only function at the federal level, but also at the state and local levels (Owens 1982). It began with the Land and Water Conservation Fund of 1965 where a small portion of the funds was used to acquire important conservation areas (Owens 1982).

Fee title acquisition can be the most straightforward way to attain and manage property for conservation because it allows for direct control of the property. Through fee title acquisition the Refuge system owns the lands. Therefore, fee acquisition allows the National Wildlife Refuge System to maintain full rights on the property as well as have the ability to adequately manage the property as the refuge sees fit (Owens 1982). Donations of land give an income tax advantage to donors, thus providing an incentive to donate land. An alternative to fee title acquisition is using conservation easements to acquire land.

Conservation easements are incentive-based approaches that rely on private land ownership to achieve conservation goals. Conservation easements are an agreement between the landowner and the organization that involves an exchange of rights. The owner agrees to comply to the conservation standards that the organization sets, giving land management rights to the organization for a fee (smaller than would be required for outright fee title acquisition). These easements tend to be less expensive than acquiring land parcels through fee titles. The incentive associated with the easement contributes to local community acceptance of conservation goals by helping private landowners reach their own private goals (i.e., help with expansion of farming capabilities) (Merenlender 2004).

A land trust (i.e., non-profit organization) typically acquires the conservation easement with their own funds and manages them with conservation of natural resources and ecosystems in mind. Conservation easements involve the transfer of rights, usually development and management options, from private landowners to the land trust (Merenlender 2004). The landowner still has certain rights and manages the easement within the standards set into place with the agreement. Over 1200 land trusts work around the U.S mostly in a local context, to help conserve lands for environmental purposes (Parker 2004). The USFWS runs a land trust called the National Fish and Wildlife Foundation that works to acquire lands to further their conservation goals (Merenlender 2004). Over forty percent of existing land trusts protect endangered species through full-fee acquisition or conservation easements (Parker 2004).

Providing a monetary incentive for conservation of endangered species habitat and pairing it with partnerships between landowners and federal agencies such as USFWS helps coordinate and advance conservation efforts more quickly. Cooperation between private and public land agencies is important as well because private land agency partnerships assist the land acquisition process as they are often able to purchase land more readily (Owens 1982).

Groups for Acquisition within the Archie Carr National Wildlife Refuge

In 1990, the Final Land Protection Plan for the then proposed Archie Carr National Wildlife Refuge outlined the properties that would be selected for acquisition. These properties were separated into four groups. Table 1 illustrates how the group's function. Group 1 consisted of land parcels with the highest priorities and priority for acquisition lessened with each group. Lesser priority lands were more likely to be acquired due to lower land values. Group 1 properties were of the highest priority due to being undeveloped land parcels east of State Road A1A (beachfront property) (CCP 2008). These lands were especially sought after using fee title acquisition to have full management capabilities on lands that would most affect sea turtle success.

Group Title	Priority Status	Location	Development Status	Mode of Acquisition
Group 1	Very High	East of A1A	Undeveloped	Fee Title Acquisition
Group 1	Very High	East of A1A	Minor Development	Fee Title Acquisition
Group 2	High	East of A1A	Undeveloped	Conservation Easements
Group 2	High	East of A1A	Minor Development	Conservation Easements
Group 3	Medium	West of A1A	Undeveloped	Cooperative Agreements with State/County
Group 4	Low	West of A1A	Undeveloped	Fee Title Acquisition
Group 5	Very Low	West of A1A	Undeveloped	Fee Title Acquisition

Table 1: Priority Designations. Description of priority for acquisition and mode of acquisition within Archie Carr National Wildlife Refuge

Group 2 lands were to be acquired by conservation easements as these parcels were developed lands east of A1A and therefore more likely to have private landowners unwilling to part with their beach houses for conservation purposes. Conservation easements for Group 2 parcels also meant that incentives were given to private landowners to follow light ordinance laws during the sea turtle nesting season in the summer months. If private landowners rented their property to tourists, entering into a conservation easement signifies that the landowner is given an incentive to properly educate visitors to the Archie Carr NWR on how to follow light ordinances as well as help sea turtle conservation efforts in general.

Group 3 lands were owned by either the state or one of the counties (Indian River and Brevard). The priority for these lands was to reach cooperative agreements with the entities that owned the lands and acquire them for conservation management purposes (CCP 2008).

The lowest on the tier for acquisition were Group 4 properties. These properties were to be acquired through the fee title method and were located around the core areas of existing refuge lands. Group 4 areas were undeveloped lands west of State Road A1A (CCP 2008). Figure 2.2 illustrates priority acquisition for kilometers 14.5 through 23.5.

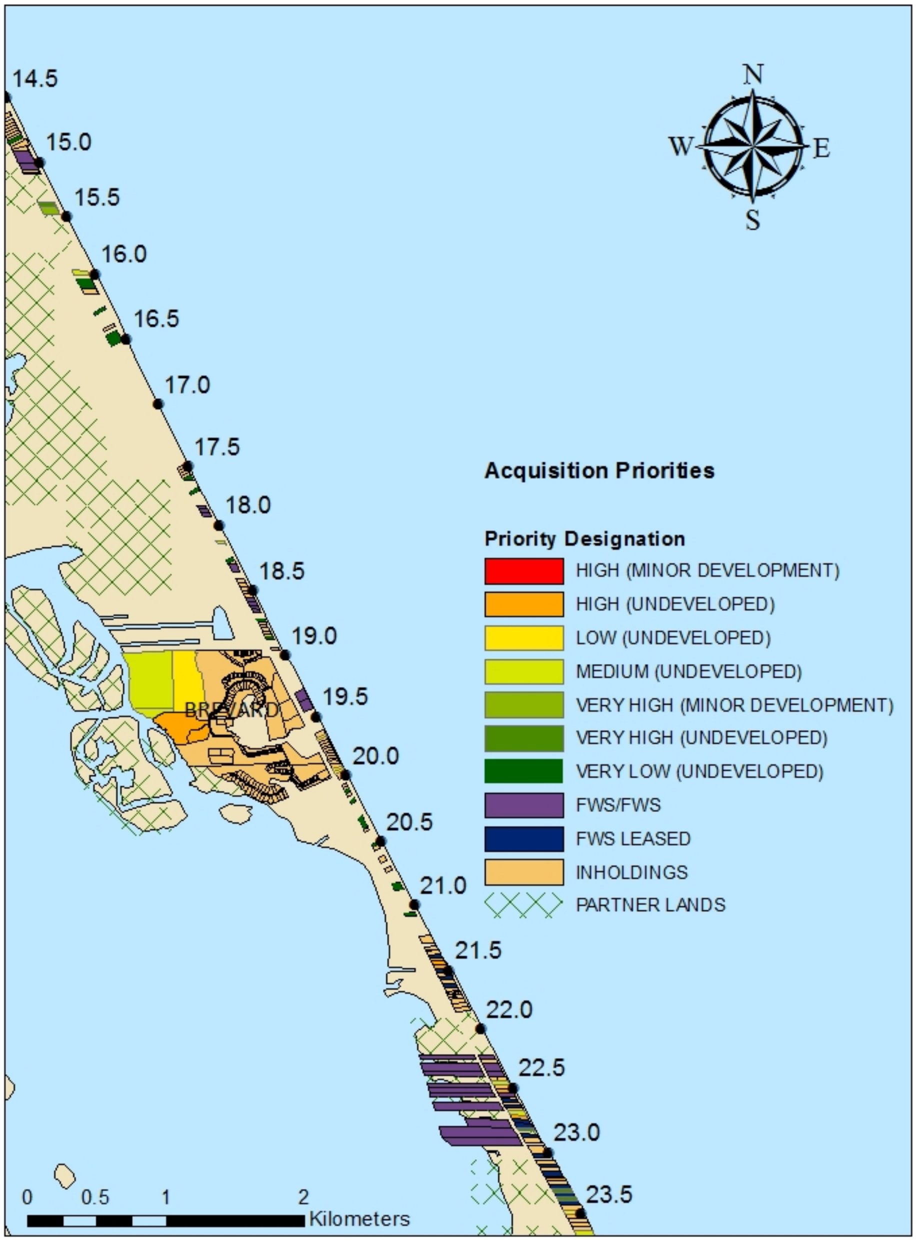

Figure 2.2: An acquisition map illustrating priority designation for future land acquirements.

Since 1990, when these priority lands were identified by the Land Protection Plan, encountering unwilling sellers allowed many of the prospective land parcels to be sold and developed. Therefore, these lands could not be obtained through the fee title method. Group 1 and Group 4 had 4, 281 acres that were developed due to unwilling sellers (CCP 2008). Also, these previously undeveloped lands were of higher priority (especially those in Group 1) and were to be attained through fee title acquisition before development but conservation easements could still bring these developed lands under Archie Carr National Wildlife Refuge management. Properties within the refuge acquisition boundary still remain with variable acquisition priorities. The Refuge is willing to attain properties through fee title acquisition (which is more expensive) for those with higher priority, depending on how close to the core-protected segments the parcels are. Those lands with higher precedence total 190 acres (CCP 2008).

Land acquisition within the state of Florida is an expensive enterprise. Many of the counties within Florida have some of the highest prices in the nation, especially in coastal areas (Ando 1998). The cost of the Archie Carr National Wildlife Refuge to the USFWS was an estimated $9,628,565 (Czech 2002). As a consequence of these high costs, determining where protection of crucial habitat in the future is needed will be essential to stretching the USFWS's limited budget.

III. Methodology

My research focuses on the projected impacts of sea level rise (SLR) and how it will affect future management priorities for the Archie Carr National Wildlife Refuge. My objective was accomplished in the following series of steps.

GIS Layers

I created maps in GIS of the four segments of the Archie Carr National Wildlife refuge that include information on: elevation, the status of ownership within the refuge, and current priorities for acquisition. Data for these maps of the Archie Carr National Wildlife Refuge were previously collected by the University of Central Florida's Marine Turtle Research Group (nesting density samples) and the Fish and Wildlife Service (acquisition priorities).

Sea Level Rise Scenarios

Using GIS, IPCC scenarios B1, A1T, A1B, A1F1 (IPCC 2007),1 meter SLR scenario (Zhang 2012), and 1.4 meter SLR scenario (NRC 2012) were tested with inundation polygons that will identify those areas that will be most affected.

Carrying Capacity

I determined the nesting capacity of the beach by using the measurement radii of 1.3 to 1.4 meters for nesting Green sea turtles and of 0.75 meters for nesting loggerhead sea turtles (Tiwari et al. 2006; Mazaris 2009). Nest carrying capacity shows the maximum amount of nests that are possible on the nesting beach.

Nest loss and Future Acquisition

I combined the nest carrying capacity with the inundation data results to determine the possible nest loss resulting from sea level rise. Using these methods a different scenario of refuge management plans and targeted land acquisitions will be explored.

My case study focuses on the projected sea level rise impacts for the end of this century (the year 2100). Projections were done by applying a broad range of sea level rise scenarios. Current 2012 elevation data were procured from the FIU GISRS Center Data Library**.** The beach area was determined by forming polygons using Google Earth images taken on December 3, 2010. These polygons represent the area that is currently available for nesting female sea turtles.

Six different scenarios were used to determine how sea level rise would affect sea turtle nesting habitat: the B1, A1T, A1B, A1FI scenarios, 1 meter and 1.4 meter SLR scenarios. The IPCC scenarios do not include contributions from the carbon-climate cycle or the increased flow from melting ice sheets (ICCP 2007). The exception is that they do include the increased flow from the ice sheets that was observed during 1993-2003 but these flow rates could change drastically (IPCC 2007).

The IPCC scenarios are divided into four families: A1, A2, B1, and B2. Each scenario has different quantitative and qualitative inputs that drive the outcomes. These inputs include population, economic growth (Gross Domestic Product), and energy use (IPCC 2007). Therefore each scenario family depends upon how each of these factors influences the model.

Each scenario has projected low and high sea level rise estimates as well as a linked global average temperature change. The B1 scenario has a low possible sea level change of 0.18 meters (18cm) and high of 0.38 meters (38cm). The B1 scenario is associated with global average temperature rise of 1.8 degrees Celsius as the best estimate, and a range that sits at 1.1-2.9 degrees Celsius.

The A1T scenario has a low sea level change of 0.20 meters (20 cm) and a high possible change of 0.45 meters (45 cm). The A1T scenario has an associated global average temperature rise of 2.4 degrees Celsius as the best estimate.

The A1B scenario has a low possible sea level change of .21 meters (21 cm) and a high of 0.48 meters (48 cm). The A1B scenario has a 2.8 degrees Celsius temperature rise as the best estimate.

The final scenario, A1F1, has a low sea level change of 0.26 meters (26 cm) and a high possible sea level rise of 0.59 meters (59cm). The A1F1 scenario has an average global temperature rise of 4.0 degrees Celsius. The temperature rises are linked with the thermal expansion that would lead to sea level rise.

Sea Level Scenarios	Sea Level Rise (meters)	Global Temperature Change (degrees Celsius) *best estimate
B1 scenario	0.18-0.38	1.8
A1T scenario	0.20-0.45	2.4
A1B scenario	0.21-0.48	2.8
A1F1 scenario	0.26-0.59	4.0

*Best estimate according to 2007 IPCC report

Table 2: IPCC Sea Level Rise Scenarios

As sea levels rise recent studies (later than 2007) should be considered. Therefore the projections of 1 meter SLR (which includes a focus on storm surge effects) and 1.4 SLR (which factors land-ice interactions more heavily into the scenario) should also be incorporated into this study.

The B1 scenario will be used as an example for the remainder of the present discussion. In addition to the B1 scenario example the kilometer increment from 12.5 to 13.5 was used to demonstrate the inundation changes in closer detail. For data collection purposes, the UCF Marine Turtle Research Group divided the refuge in half-kilometer increments. Half-kilometer divisions ease the process of identifying marked nests. The LIDAR elevation data was obtained in feet from the International Hurricane Research Center (Elevation Data 2012) and converted to meters. The LIDAR technology can be used over large areas to obtain accurate measurements of topography, buildings, and vegetation (Lidar 2012). The Raster Calculator tool was used to delineate the elevations where inundation will or will not occur. The following equations were used for each scenario where H is defined as the projected sea level rise and E is the elevation raster (restricted to the total possible beach nesting area). The equations were used to produce a new image that will classify cells into new values that depict what areas will be inundated according to each sea level rise scenario.

The final base equations and cell values for each scenario:
[E]> H, cell value 0
[E] ≤ H, cell value 2
No Data, E has no elevation value

Where the cell value 0 shows there is no inundation, since the elevation is higher than the projected sea level rise. And the cell value 2 shows there is inundation in those areas as they are at or lower than the projected sea level rise.

For the B1 scenario:
Low
[E]> 0.18
[E]≤ 0.18

High
[E]> 0.38
[E]≤ 0.38

Elevation

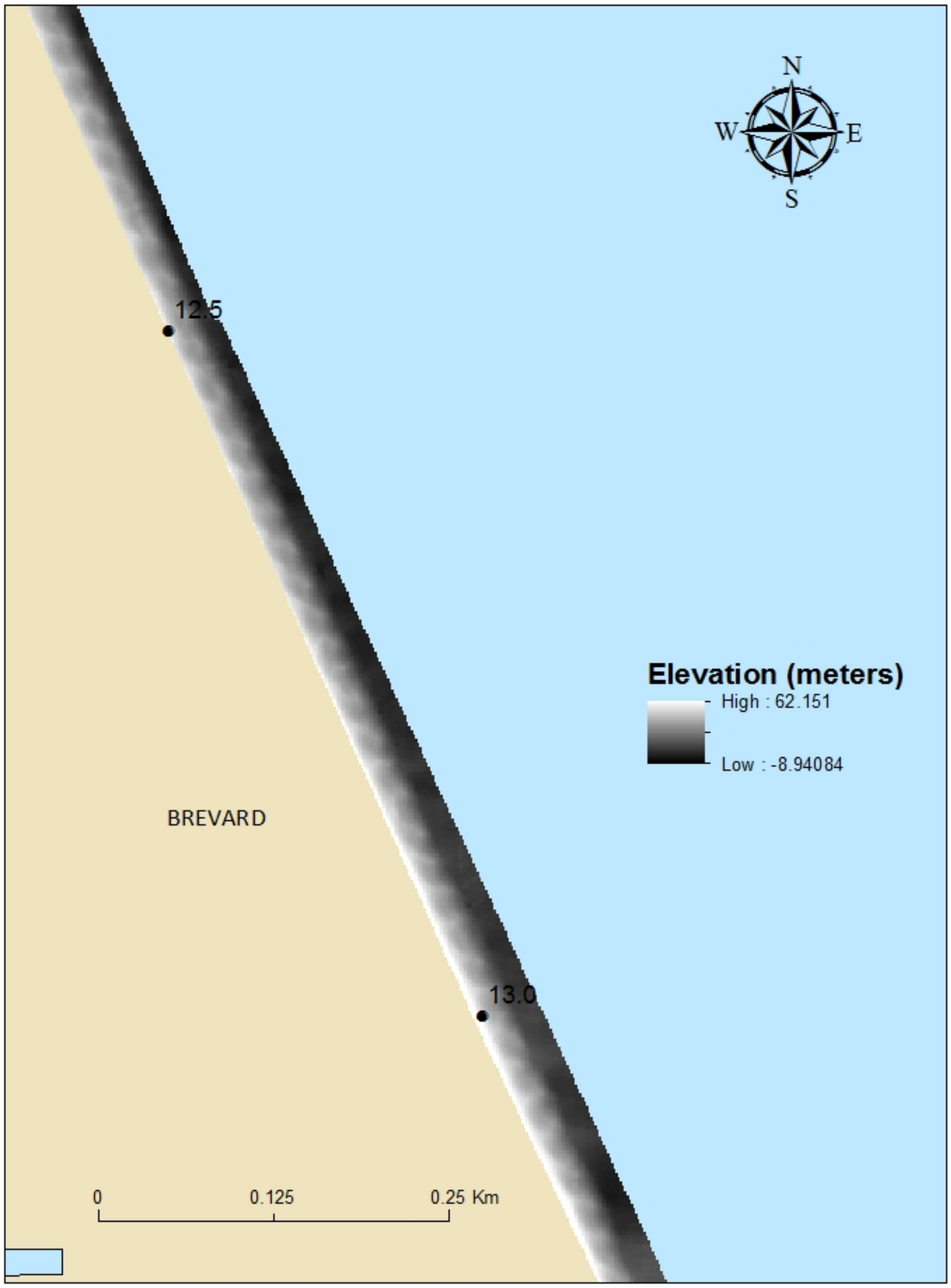

Figure 3.1: This figure shows an example of the range in elevation exhibited on one half kilometer of the beach. The high values shown on the map (i.e. 62.151 meters) are indicative of taller structures such as trees and buildings.

The LiDAR data procured from the International Hurricane Research Center (Elevation Data, 2012) were clipped to the polygons formed for each half kilometer of the beach on Archie Carr National Wildlife Refuge. Refuge parcels were originally in vector as polygons and then were converted to raster using the polygon to raster tool to allow for inundation analysis.

Next, the Raster Calculator tool was used and the base equations were input to determine inundation for the scenarios. For example, the first part of the sea level rise scenario B1 uses the equation: [E]> 0.18 which indicates that when elevation is above 0.18 meters there is no inundation.

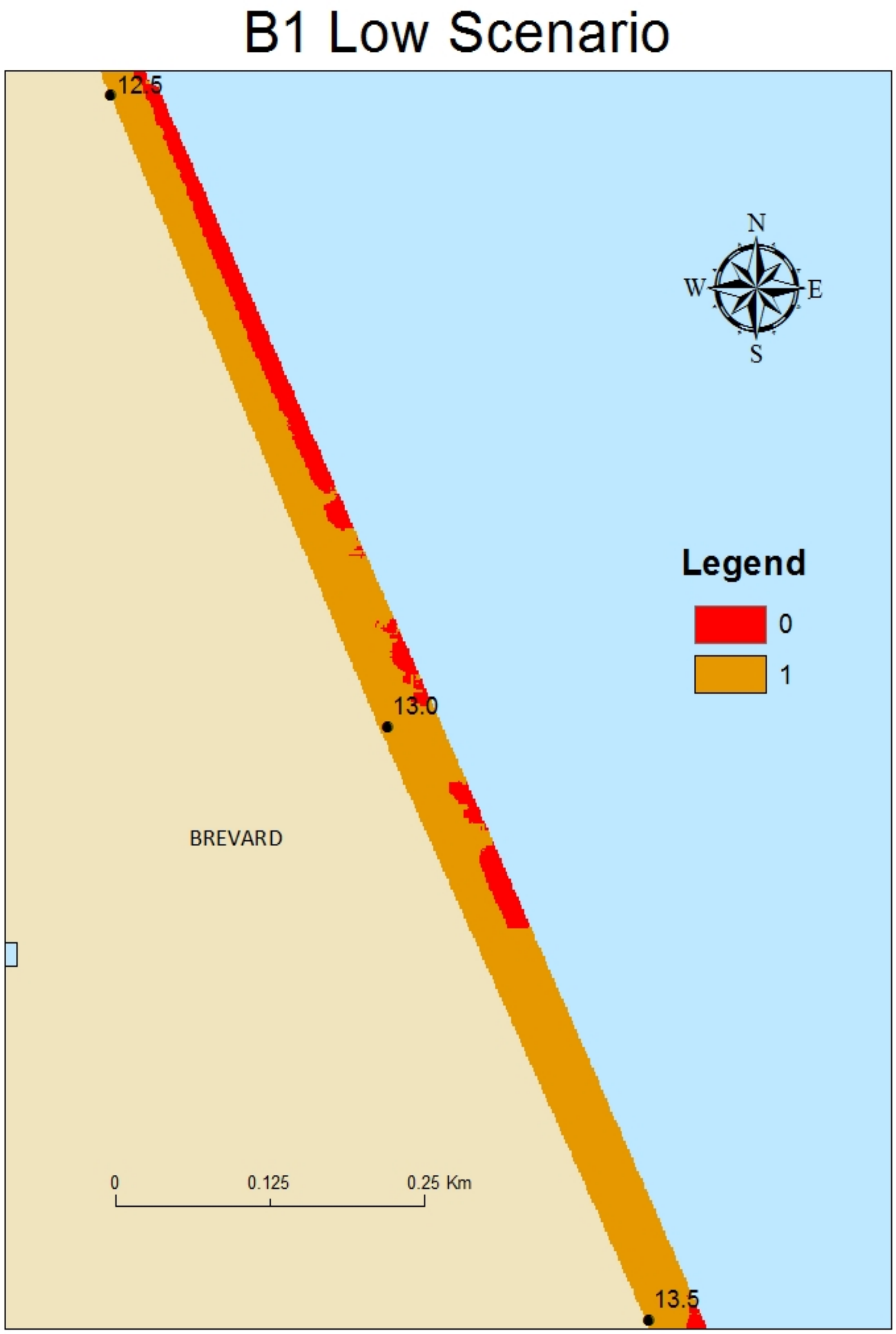

Figure 3.2: This figure shows the output where there is no inundation when elevation is above 0.18 meters from kilometer 12.5 to kilometer 13.5. Here the cell value 1 shows where there is no inundation.

Figure 3.3: This figure shows inundation when elevation is below or equal to 0.18 meters from kilometer 12.5 to kilometer 13.5. Here the cell value 1 shows where there is inundation.

Results from both raster calculations were then combined to form the final values as shown in the base equation:

$$[E] > 0.18, \text{ cell value } 0$$
$$[E] \leq 0.18, \text{ cell value } 2$$

Calculations were completed by using the raster calculator to combine the outcomes.

Once both portions of the equations were combined, new values were assigned by using the reclassify tool. The classify tool allows reclassification of the values assigned to areas that are not inundated (0) by the scenario versus those areas that are inundated (1) as shown in Figure 3.4.

Figure 3.4: This figure demonstrates the result of combining both equations for the low sea level rise portion of the B1 scenario. By combining the values for the B1 scenario, the cell value of 0 demonstrates those areas where E> 0.18m and the cell value of 2 demonstrates those areas where E≤ 0.18.

Therefore, figure 3.4 indicates the area lost to sea level rise under scenario B1 provided by the IPCC. The value of 0 shows us where the polygon will become inundated if this scenario was to occur; the value of 2 indicates the area that will remain out of the inundation zone.

The complete B1 low scenario was then converted back to polygons to determine area lost. This was done by using the raster to polygon tool. An example is shown in Figure 3.5.

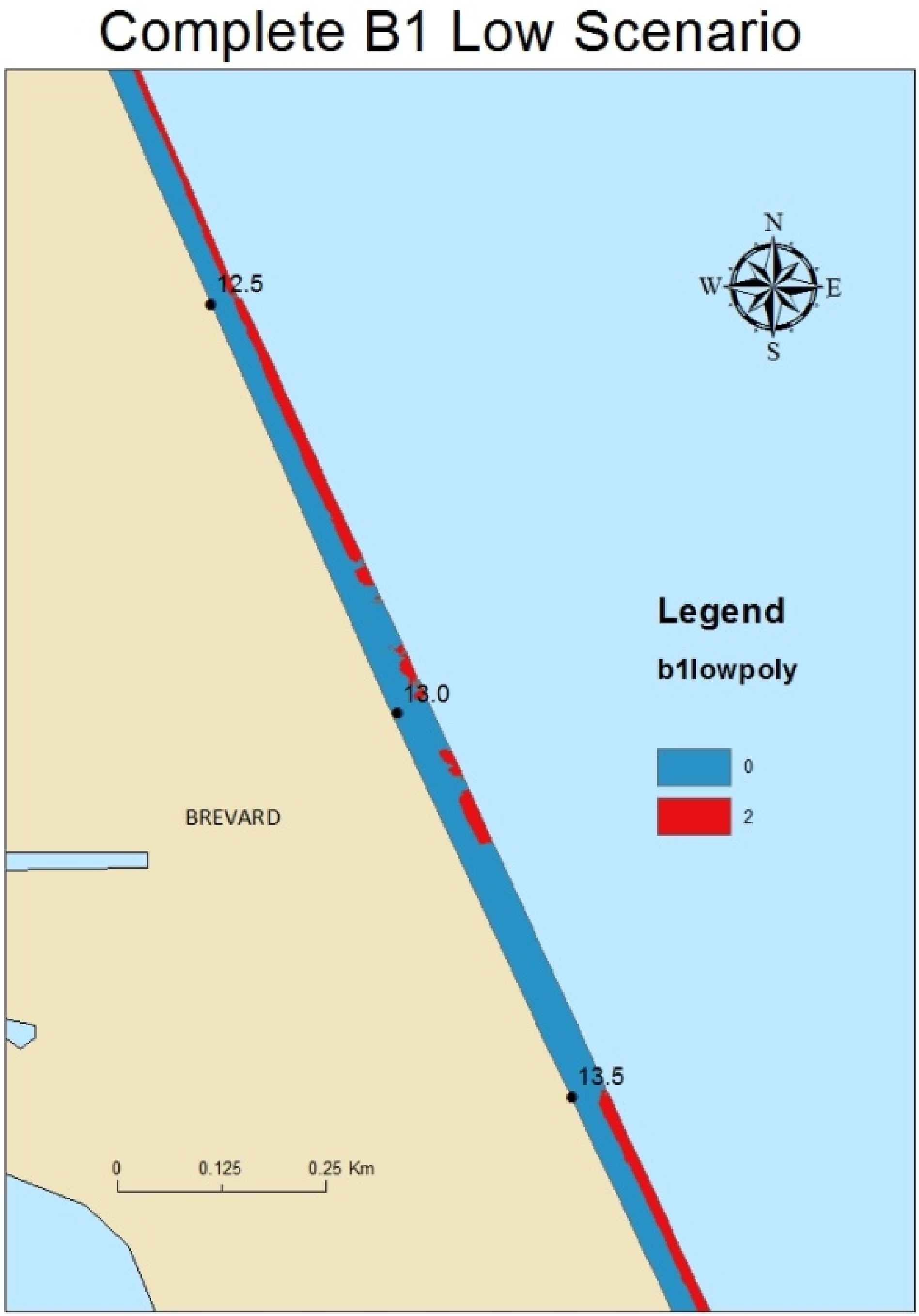

Figure 3.5: Demonstrates the complete B1 scenario for kilometer 12.5- 13.5 in polygons.

Then the attribute table for the scenario was accessed to use the calculate geometry tool to determine the area for each polygon. The add field option was used to add an area field to the attribute table. The geometry was calculated for the area field in square meters to help determine area lost to inundation. Percent loss was obtained by dividing the area for the Cell Value 2 by the total area for the polygons within the Refuge.

Nesting

Determining the carrying capacity of the Archie Carr National Wildlife Refuge requires the consideration of how the nesting process occurs. An area as much as 2 meters in diameter can be disturbed during the nesting process (Mazaris 2009). Disturbance is caused by body pitting, digging the egg chamber, and covering methods (Mazaris 2009). With sea level rise, a reduction in area available for nesting can mean an increase in chances of nest destruction by neighboring nesting female sea turtles. The ability for the beach to hold a certain density of nests is negatively affected by a reduction in nesting area (Mazaris 2009).

Three species of sea turtles nest on the Archie Carr National Wildlife Refuge. Nest diameters differ among the three species as they differ in their nesting behaviors. For example, Leatherback sea turtles prefer to nest in open sand near the water, not near or in dune vegetation (Kamel and Msrosovsky 2004). Nesting diameters have been determined in the past and have been estimated to have optimal radii of 1.3 to 1.4 meters for nesting Green sea turtles and of 0.75 meters for nesting loggerhead sea turtles (Tiwari et al. 2006; Mazaris 2009). A nesting diameter for the leatherback has not been found;

therefore the larger estimated radius of green sea turtles found by Tiwari et al. (2006) will be used.

Nesting data in the Archie Carr National Wildlife Refuge has been collected since 1988. In 1989, data collection was standardized to include the methods that are followed today. Data are recorded for each half kilometer as follows:

-Tallies are recorded for each Dc, Cm, and Cc false crawl*

-Tallies are recorded for each Dc, Cm, and Cc nest

*False crawls occur when turtles fail to nest (Richardson et al. 1999).

Further data are collected on carapace length, width, clutch size, as well as many other factors, but is not included here as it is not relevant to the present study. Therefore, nesting data for all three species has been collected for the last 24 years on the 20.5-kilometer stretch of beach.

Two methods were used to determine area loss and nest loss due to inundation. The first method (Method A) was simply taking the percentage of area loss for each scenario and using that as the percentage loss for each species. Therefore if there is a 22.68% loss in area for the B1 low scenario that signifies that there would be a 22.68% loss for all species in ACNWR. Method A does not account for the carrying capacity of the beach or the ratios of the three sea turtle species. The average number of nests from 2001 – 2010 were calculated for each species, totals are shown in the following chapter. The 10 year range was used to account for variability between high and low nesting years for each species. Average nest calculations were then used to determine the average loss of nests due to the area lost by inundation according to each scenario.

The second method (Method B) determines the maximum possible number of nests for each species. Using the determined radii for Loggerhead and Green turtle nests, the equation $A = \pi r^2$ was applied to find the carrying capacity of Archie Carr National Wildlife Refuge. The equation was used to determine the carrying capacity of the beach for A) Loggerheads B) Green Turtles and C) Leatherbacks independently. Area was calculated for each species nest and then the total area of the beach for each scenario was divided by this figure to determine the maximum number of nests for each species. The result was used along with the ratios of nesting for each species along ACNWR to determine loss of nests by scenario, considering the carrying capacity. For example, over the years 2001- 2010, nests totals averaged approximately 82.19% Loggerheads, 17.18% Green Turtles, and 0.22% Leatherbacks. Therefore for the high B1 scenario where there is a 23.05% inundation loss in area, the carrying capacity and area loss were used in combination to determine loss in nests.

After each scenario was processed with Methods A and B, ACNWR layers for future acquisition were combined with inundation polygons to determine where future management for land acquisition should focus. A1B1 scenario inundation polygons were used to perform an overlay with the parcel acquisition priority map. Regardless of the SLR scenario chosen, the relative differences between priority rankings would remain the same due to the similarities in percentage area loss among the scenarios in this study. The percentage of each parcel inundated was calculated. Inundation information was used to classify the parcels into categories from no inundation to the highest level of inundation. The inundation category field was then added to the original priority categories to get a new priority classification scheme, ranging from 2 to 8, with 2 being the highest priority and 8 being the lowest priority. These priorities were further condensed into a classification scheme ranging from 1-5; where 1 is the highest priority and 5 is very low priority, which is comparable to the original categorization implemented by the Refuge. Projected priority parcels were then compared to the original priority parcels to identify parcels that demonstrate significant changes in priority ranking. These areas are important to identify as they can be used to determine areas of high priority in relation to sea level rise for future sea turtle conservation plans within the Archie Carr National Wildlife Refuge. Results are shown in the following chapter.

IV. Results

The years from 2001-2010 have shown a substantial increase in nest counts, especially in the case of the green turtle where in 2001 there were only 163 nests and by 2010 there was 4095 nests from kilometer 5.0 to kilometer 26.0. Table 3 illustrates the large numbers of sea turtle that nest on Archie Carr National Wildlife Refuge. Table 4 summarizes the average number of nests for each species from 2001-2010.

Year	Cc	Cm	Dc	Year Totals
2001	13319	163	29	13511
2002	11631	2588	11	14230
2003	10091	569	37	10697
2004	7599	933	3	8535
2005	8854	3177	42	12073
2006	9018	1383	12	10413
2007	6405	3963	52	10420
2008	9502	2775	20	12297
2009	8668	1184	23	9875
2010	12233	4095	34	16362

Table3. Shows the number of nests tallied each year for each species that nests on Archie Carr National Wildlife Refuge. Over ten years, Loggerheads (Cc) total 97320 nests, Green turtles (Cm) total 20830 nests and Leatherbacks (Dc) total 263 nests.

	Cc	Cm	Dc	Totals
Averages	9732	2083	26.3	11841.3
Ratios (percentages)	82.1869	17.5909	0.2221	~100

Table 4: Shows the average nest count from 2001-2010 and also demonstrates the ratios that existed for each species from 2001-2010.

Sea Level Rise Scenarios

The scenarios tested in this study were the IPCC sea level rise scenarios that varied from 0.18 meters to 0.59 meters and the higher projections of 1.0 meter (Zhang et al. 2012) and 1.4 meters (NRC 2012). Inundation polygons were used to determine the area loss for each scenario. Percentage loss (area) for each scenario is shown in the following table.

Sea Level Rise Scenario	Sea Level Rise (m)	Percentage Loss (area)
B1 low	0.18	22.68
B1 high	0.38	23.05
A1T low	0.20	22.71
A1T high	0.45	23.17
A1B low	0.21	22.73
A1B high	0.48	23.22
A1F1 low	0.26	22.81
A1F1 high	0.59	23.41
Zhang et al. 2012	1.0	24.12
NRC 2012	1.4	24.73

Table 5: Percentage Area Loss. Losses range from 22.68% to 24.73%.

As can be seen by the classification for the elevation data in GIS (Figure 4.1) when the breaks are set to 0.18 and 1.4 meters, there is a small amount of elevations that fall under that range. Therefore, this explains why the percentages between the senarios are similar for inundation loss.

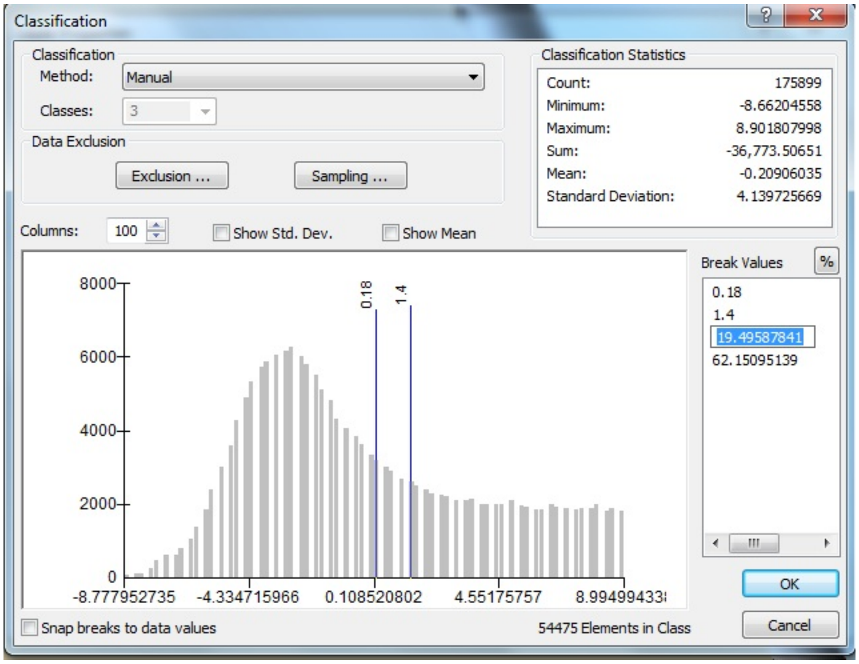

Figure 4.1: Elevation Range. Many of the elevation values lie outside of the scenarios chosen for this study.

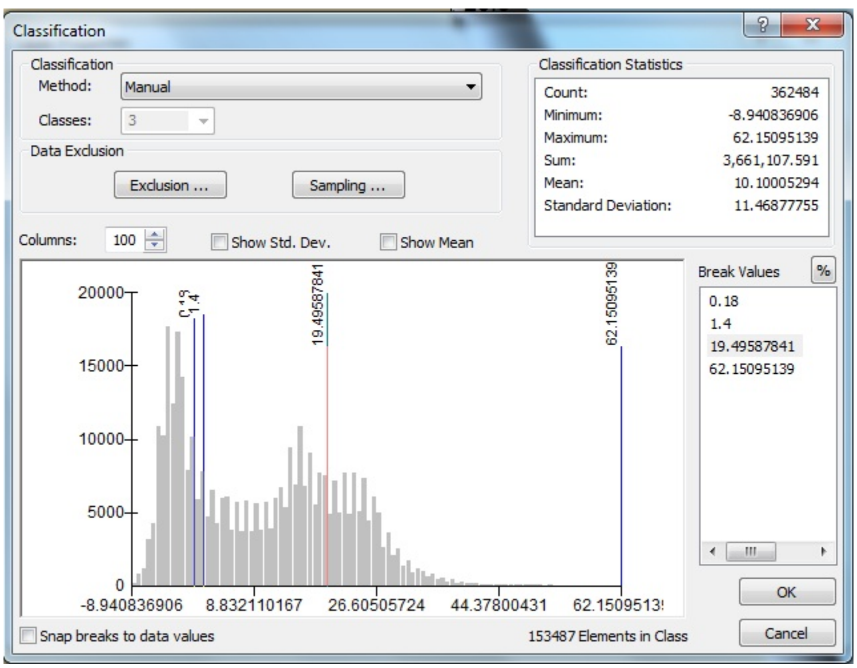

Figure 4.2: Wide view of Elevation Range. This view further exemplifies the small range of elevations depicted by the scenarios.

In the following figures an example from kilometer 25.0 to kilometer 25.5 is used to depict the changes seen in inundation for each sea level rise scenario. The value of 0 shows the areas that are not inundated and the value of 2 shows the areas that could become inundated under that particular sea level rise scenario.

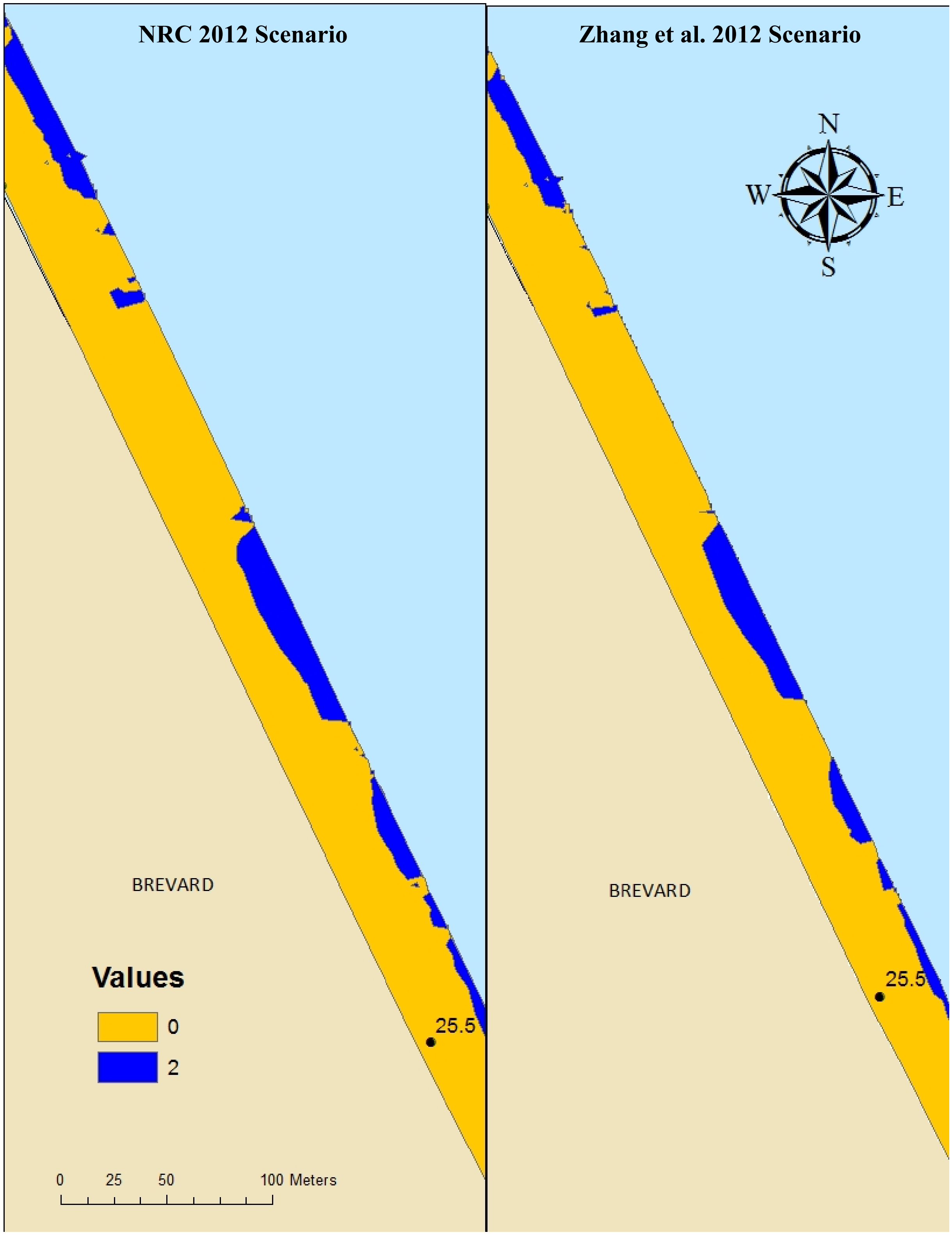

Figure 4.3: This figure depicts the two highest scenarios used in this study. The NRC 2012 scenario is slightly more inundated than the Zhang et al. 2012 scenario (by 0.61%).

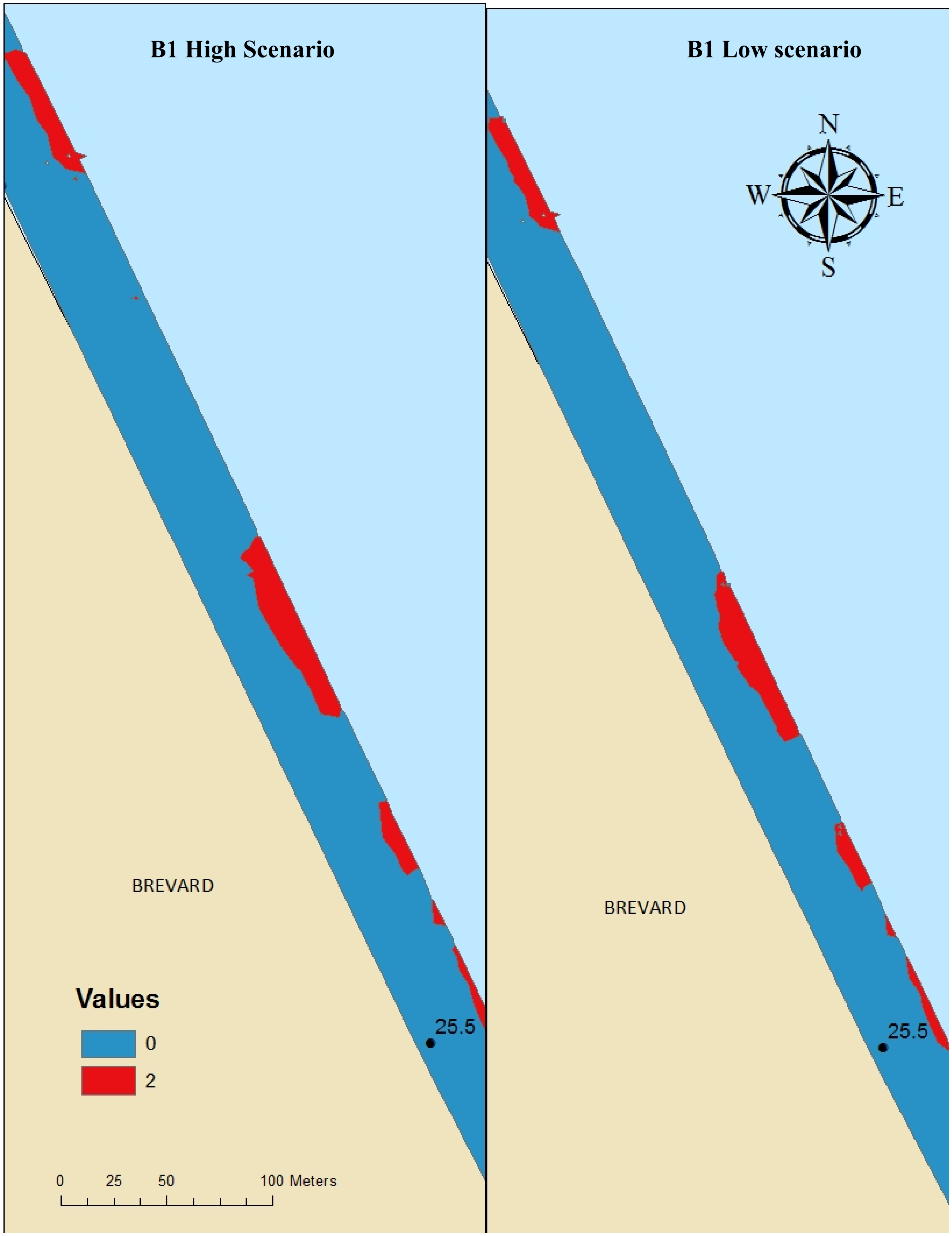

Figure 4.4: This Figure shows the high and low measurements for the B1 scenario. The B1high scenario is slightly more inundated than the B1 low scenario (by 0.37%).

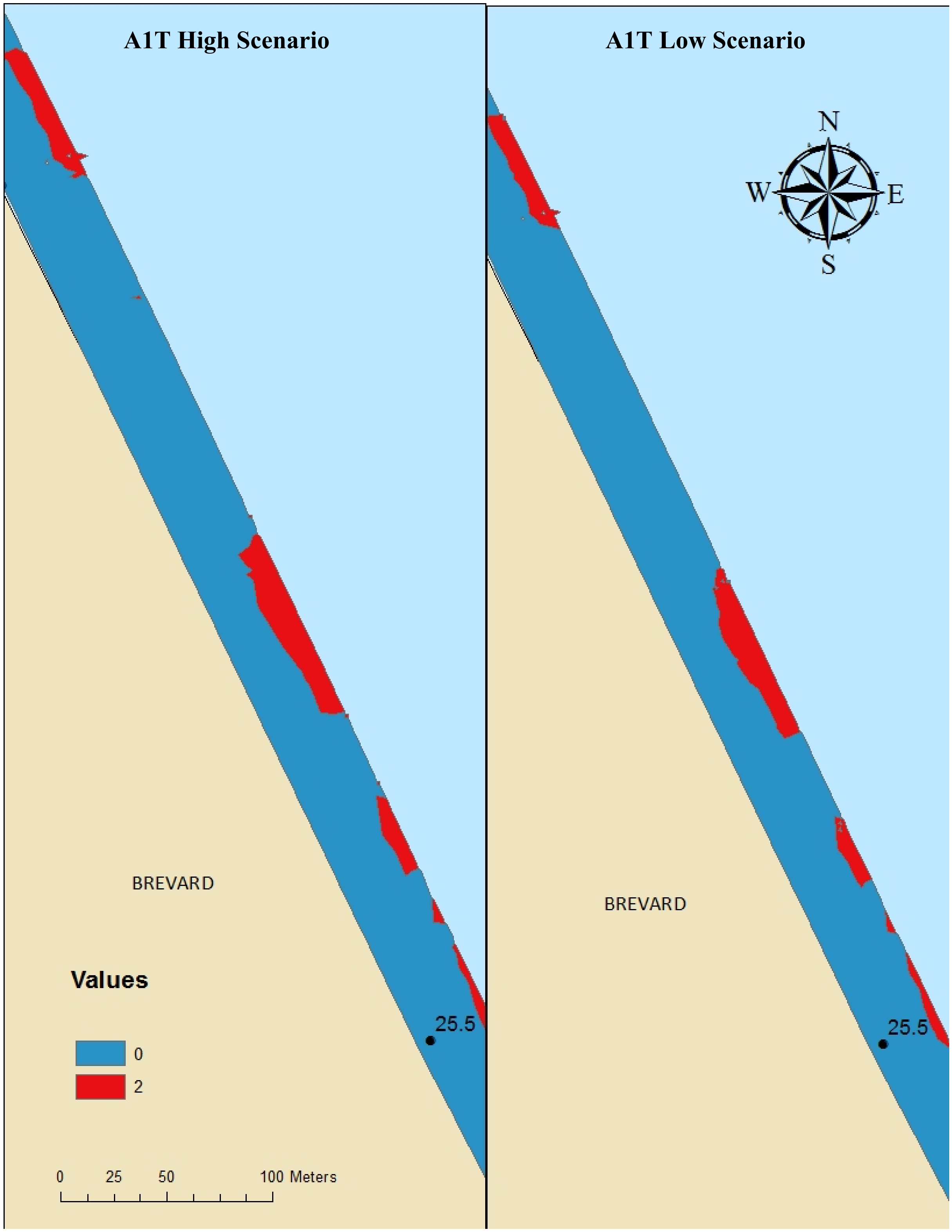

Figure 4.5: This Figure shows the high and low measurements for the A1T scenario. The A1T high scenario is slightly more inundated than the A1T low scenario (by 0.46%).

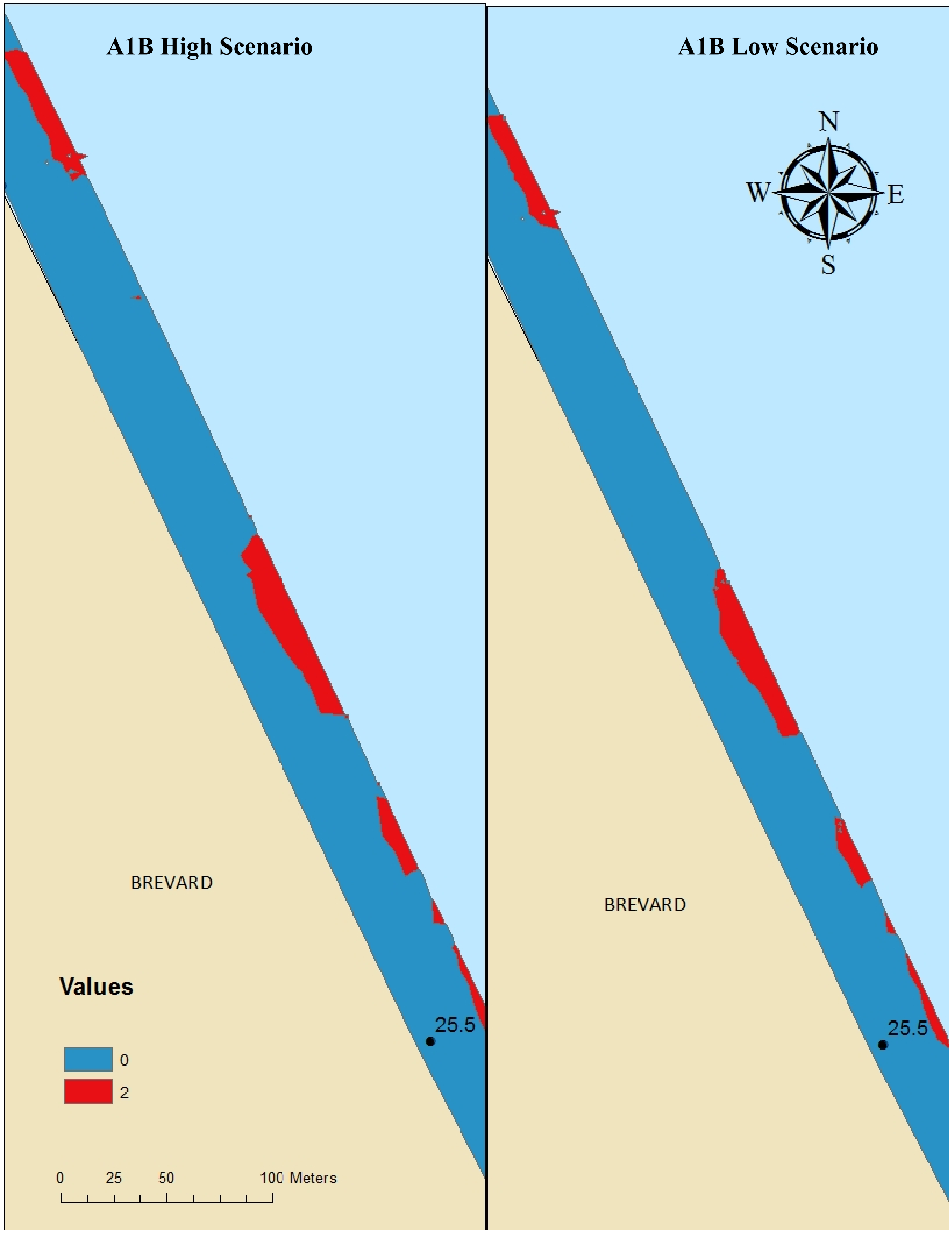

Figure 4.6: This Figure shows the high and low measurements for the A1B scenario. The A1B high scenario is slightly more inundated than the A1B low scenario (by 0.49%).

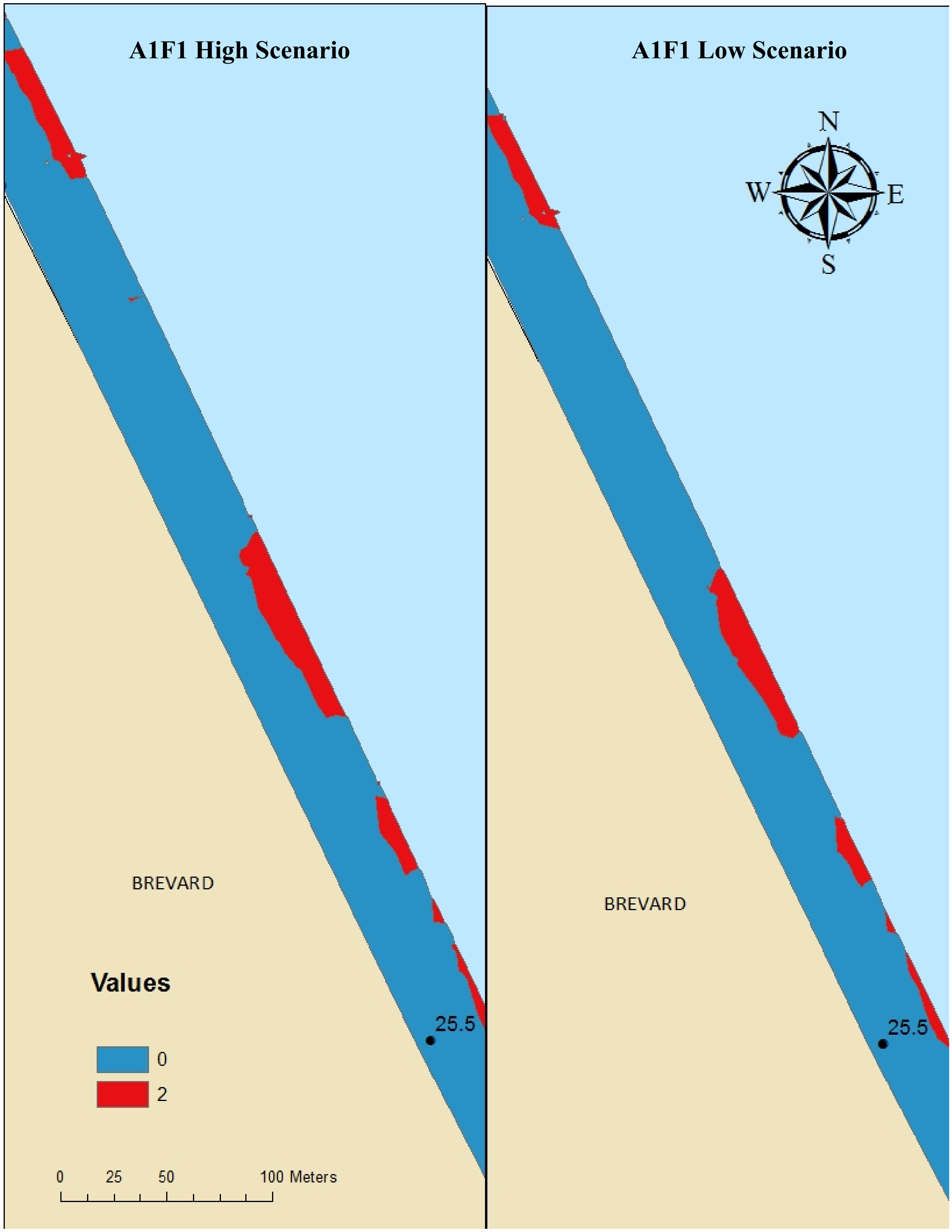

Figure 4.7: This Figure shows the high and low measurements for the A1F1 scenario. The A1F1 high scenario is slightly more inundated than the A1F1 low scenario (by 0.60%).

Nest Loss-Method A

Loss of nests relating to average nest count were calculated by using the percentage area loss caused by the inundation polygons.

	Cc	Cm	Dc
Averages	9732	2083	28.3
SLR Scenario			
B1 low	7524.8	1610.6	21.9
B1 high	7488.8	1602.9	21.8
A1T low	7521.9	1610.0	21.9
A1T high	7477.1	1600.4	21.7
A1 B low	7519.9	1609.6	21.9
A1B high	7472.2	1599.3	21.7
A1F1 low	7512.1	1607.9	21.8
A1F1 high	7453.7	1595.4	21.7
Zhang et al. 2012	7384.6	1580.6	21.5
NRC 2012	7325.3	1567.9	21.3

Table 6: Nest loss by SLR Scenario. Although a loss of approximately seven nests for Leatherbacks (Dc) may seem negligible, this species is critically endangered and the population continues to decrease (Martinez 2000).

As seen in the table above (Table 6) the average number of nests from 2001-2010 is projected to decrease from 9732 nests to 7325.3 nests. Projections show a decrease of over two thousand nests caused by the 1.4-meter increase in sea level projected by the National Research Council (NRC 2012). Yet even with the lowest projections from the IPCC (i.e. B1 low scenario) there is a similar decrease. The projected sea level rise scenarios could lead to nearly a quarter of the nests on the refuge becoming inundated by rising sea levels.

Carrying Capacity-Method B

Carrying capacity was partly determined by obtaining the minimal area a female turtle needs to create a nest without disturbing another nest (Mazaris et al. 2009). The area is larger than the actual diameter of the egg chamber since it includes factors such as nesting processes that are prior to the digging of the egg chamber (body pitting, camouflaging, etc., which can disturb neighboring nests (Mazaris et al. 2009).

Therefore, the maximum number of nests was estimated by using the radii mentioned in the previous chapter: 1.4 m for Leatherback and Green Turtles and 0.75m for Loggerhead turtles. The size of each nest was then calculated by taking the radii measurements and plugging them into the area equation: $A = \pi r^2$. Thus, for Leatherbacks and Green Turtles the equations are as follows: A= (1.4). The area in this case would equal 6.158 square meters. Taking the square of this number results in an area of: 2.48 m^2. Rounding this number the cell size can therefore be described as 2.48 meters by 2.48 meters. The same process is applied to the radius for Loggerhead nests. Results are shown in the following table.

Species	Radius (m)	Area (square meters)	Cell Size (m)
Cm, Dc	1.4	6.158	2.48 X 2.48
Cc	0.75	1.767	1.33 X 1.33

Table 7: Cell size calculations determined by the area equation.

There are an extremely high number of nest combinations possible between the three sea turtle species that nest on Archie Carr National Wildlife Refuge. Therefore the exact combination the future will bring is unknown. The average ratio of the three species will be used as a guide to the proportional loss for the scenarios used in this study.

	Carrying Capacity (number of nests)	Area needed according to average ratios
Cm, Dc	136720.37	12826.12, 161.94
Cc	476394.53	17197.86

Table 8: The results of calculations for the current carrying capacity of the beach according to the minimum area required by each species to nest. This also includes the minimum area that is therefore needed for the average number of nests from 2001-2010.

Carrying Capacity with Inundation	B1 low scenario	NRC 2012 Scenario
Cm, Dc	105712.19	102909.42
Cc	368348.25	358582.17

Table 9: This table depicts the carrying capacity of the beach after area lost due to inundation has been factored in. Therefore the table shows the carrying capacity of the beach after the projected inundation for the lowest SLR scenario (0.18m) and the highest SLR scenario (1.4m).

The combination of the three previous tables (tables 7, 8, and 9) therefore conveys a carrying capacity that is larger than the carrying capacity for the average number of nests that occur from 2001-2010. Despite this, it must be taken into consideration that these calculations calculated using averages. Sea turtles could create nests that are larger or smaller in area and that would in turn affect the carrying capacity of the beach. Thus, these calculations are only a rough sketch of what could occur on Archie Carr National Wildlife Refuge.

Future Acquisition- Priority Maps

The Archie Carr National Wildlife Refuge published a Comprehensive Conservation Plan in 2008 that outlined the parcels that were targeted for future acquisition. These parcels were prioritized by development status, location and mode of acquisition. In the following figures the combination of SLR inundation polygons and acquisition parcels are used to observe which areas are actually of high priority for the refuge. The scenario used for observation was the mid-ranged A1B1 high scenario due to the relative difference in percentage area loss.

Natural breaks were used to determine the cut off for each inundation category and then the original priority classifications were added to the inundation priorities to obtain the overall priority.

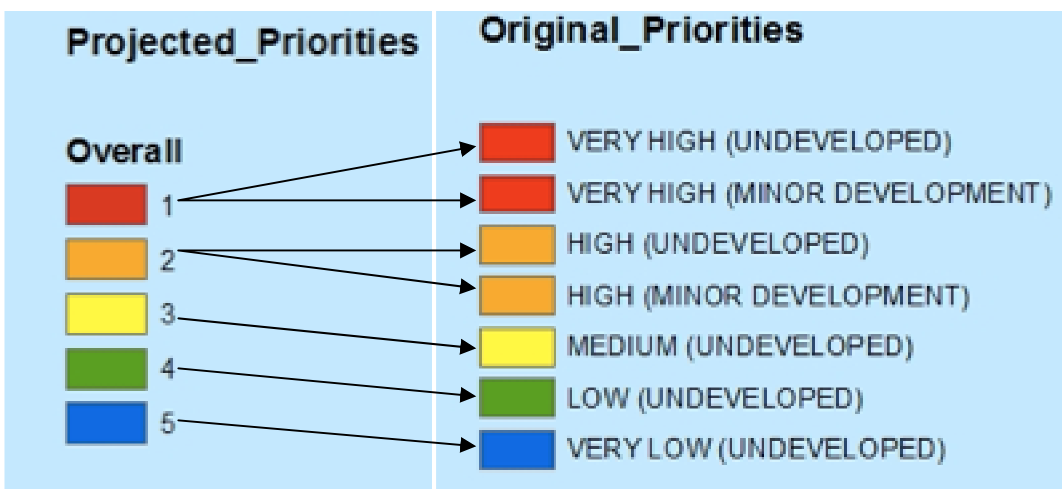

Figure 4.8: This figure indicates how original priority categories fall into the overall projected priority categories (1-5).

Figure 4.9 shown below depicts the first segment of priority parcels and the final overall priority map. Important priority changes within the segment are shown in Figures 4.10 and 4.11.

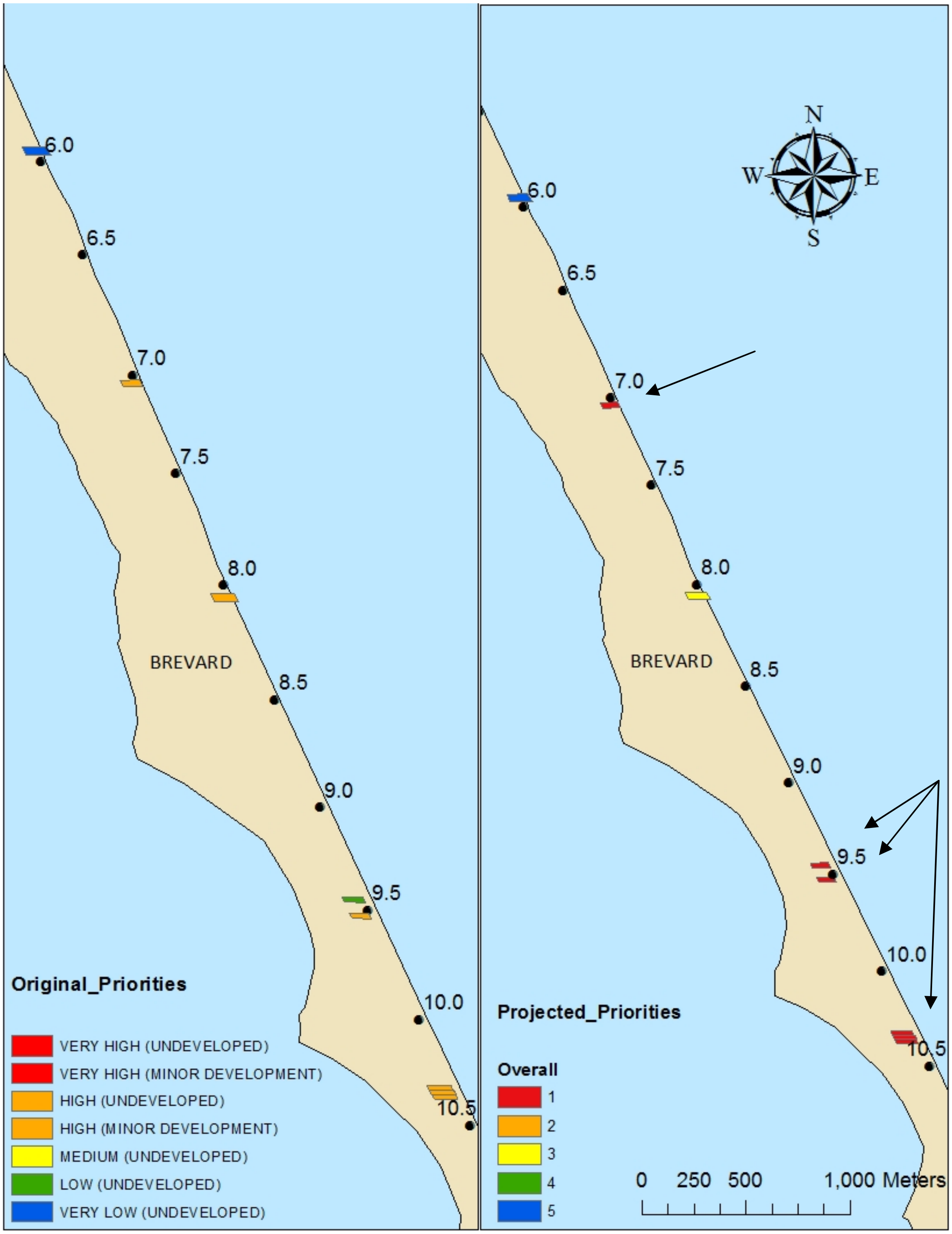

Figure 4.9: Segment 1- Original priorities described in the Comprehensive Conservation Plan (2008) are shown on the left section of the figure. Five changes in parcel priorities can be noted in this figure.

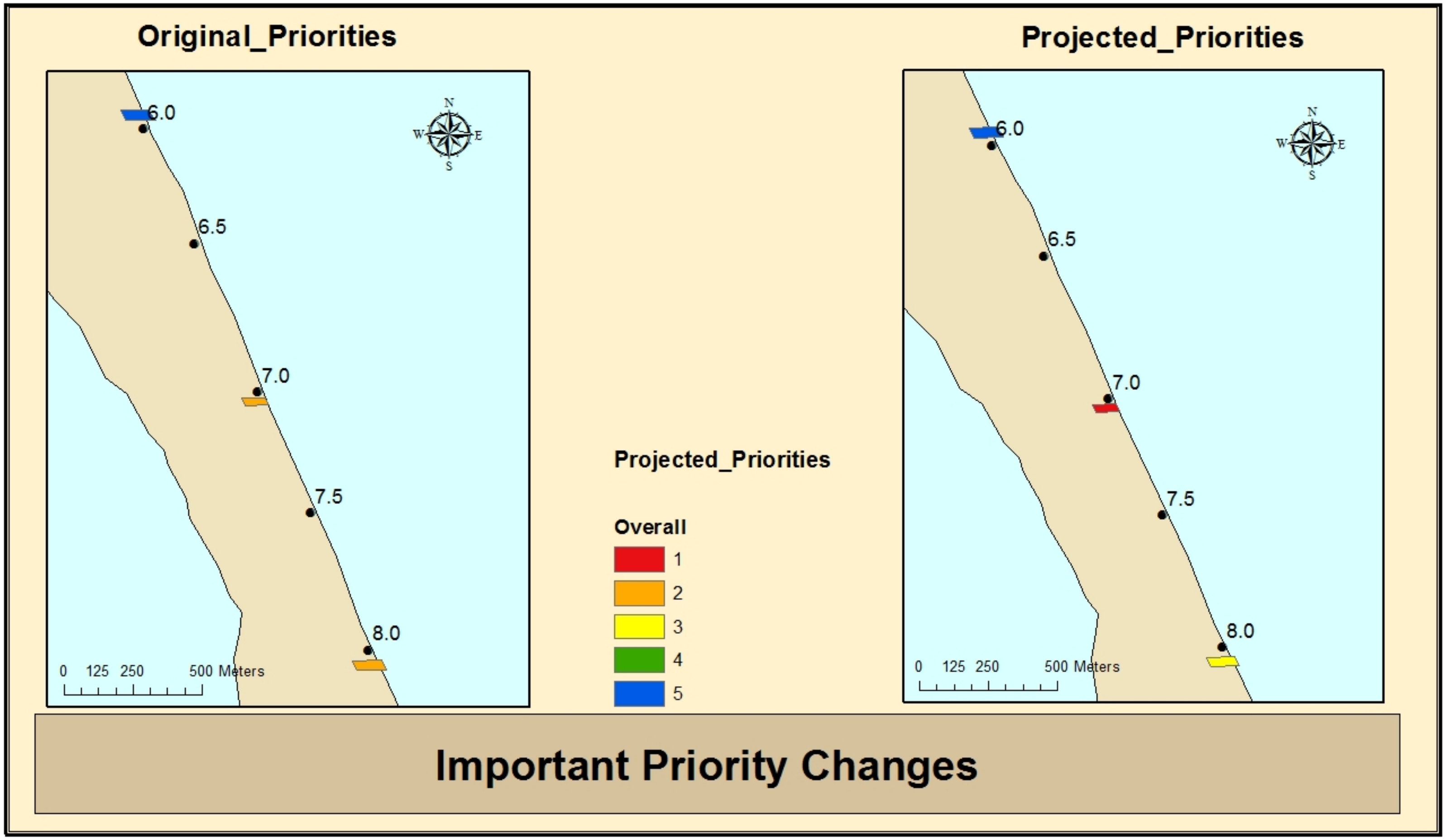

Figure 4.10: This figure shows an important change in priority for the parcel located near kilometer 7.0. Priority changes from a high priority to a very high priority.

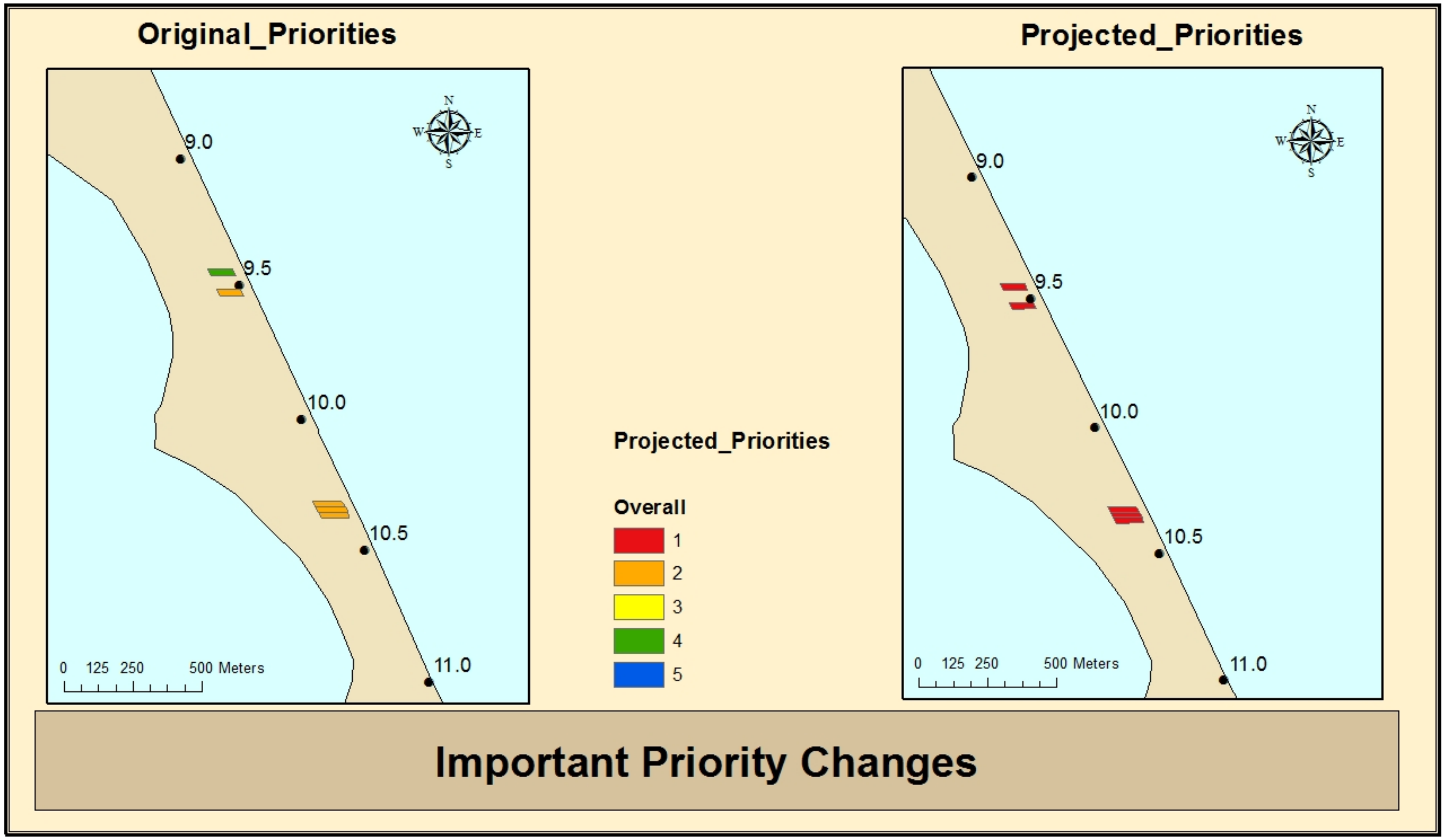

Figure 4.11: This figure depicts three important changes for five parcels located from just north of kilometer 9.5 to kilometer 10.5. The first parcel shown in this figure should be particularly noted for its change from a low priority parcel to a very high priority parcel.

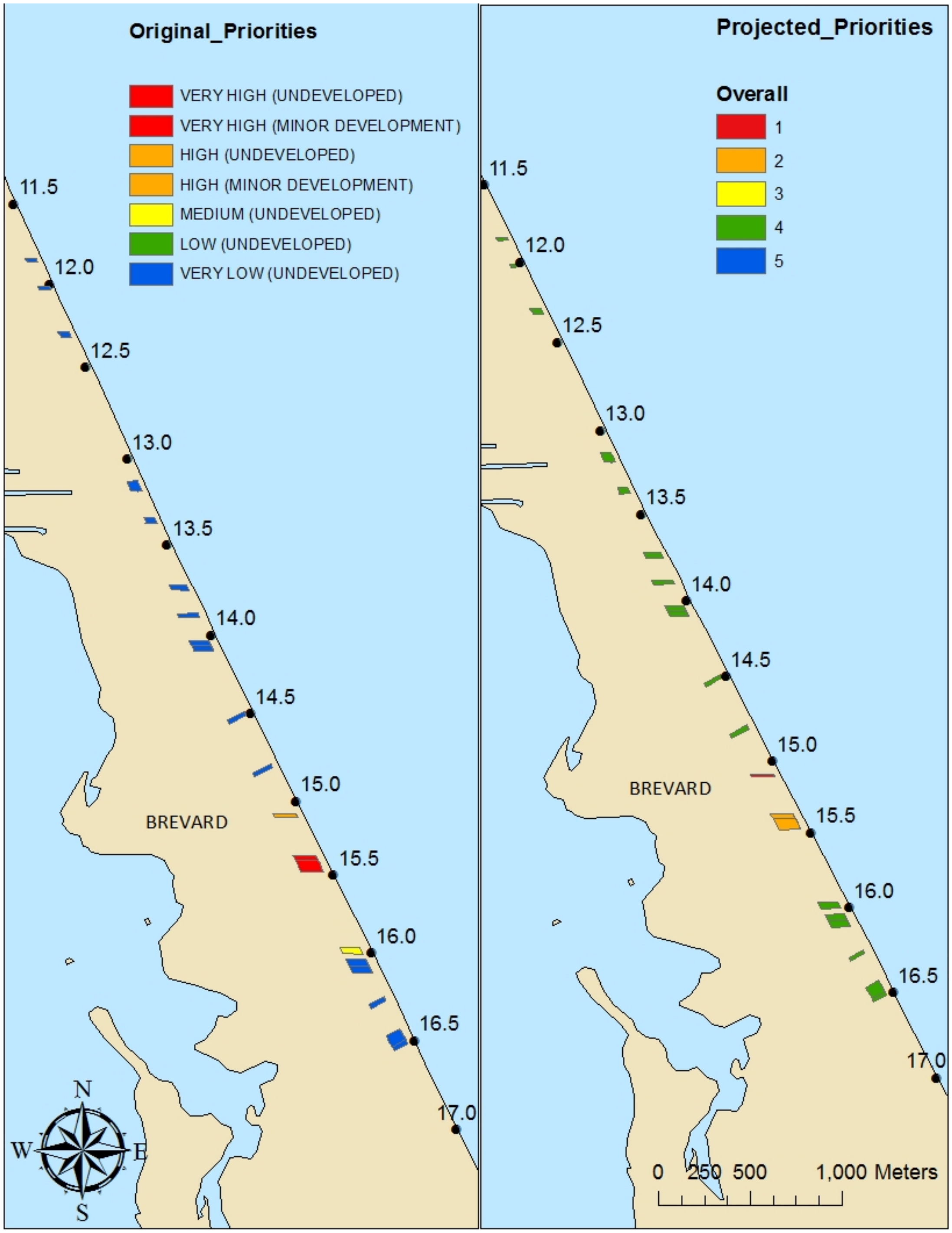

Figure 4.12: Segment 2- A majority of the parcels shown in this figure depict a minor increase in priority.

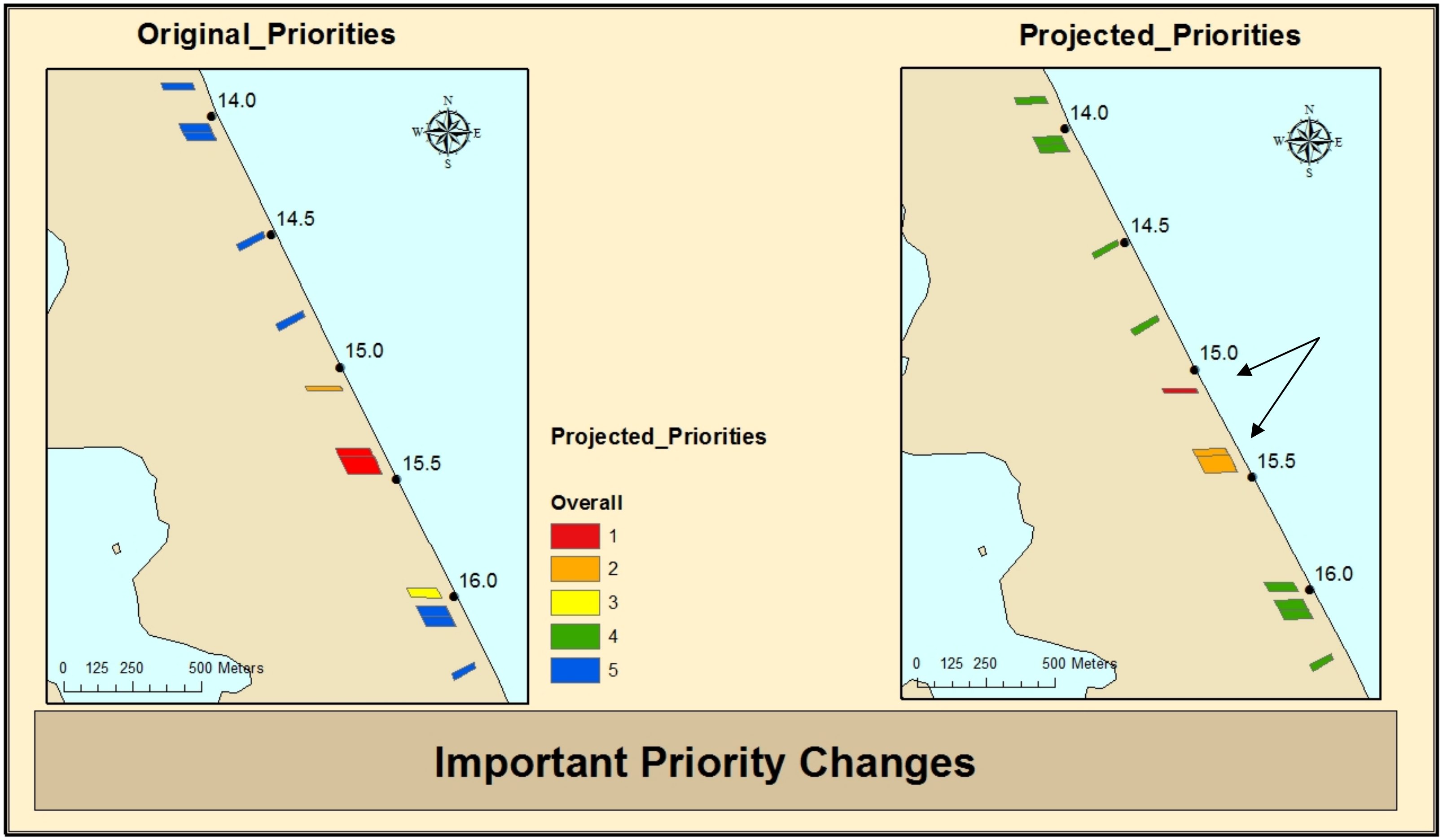

Figure 4.13: The parcels located from kilometer 15.0 to kilometer 15.5 show changes (starting from the parcel furthest north) from a high priority to very high priority as well as very high priority to high priority. Many parcels make the shift from very low priority to a low priority status.

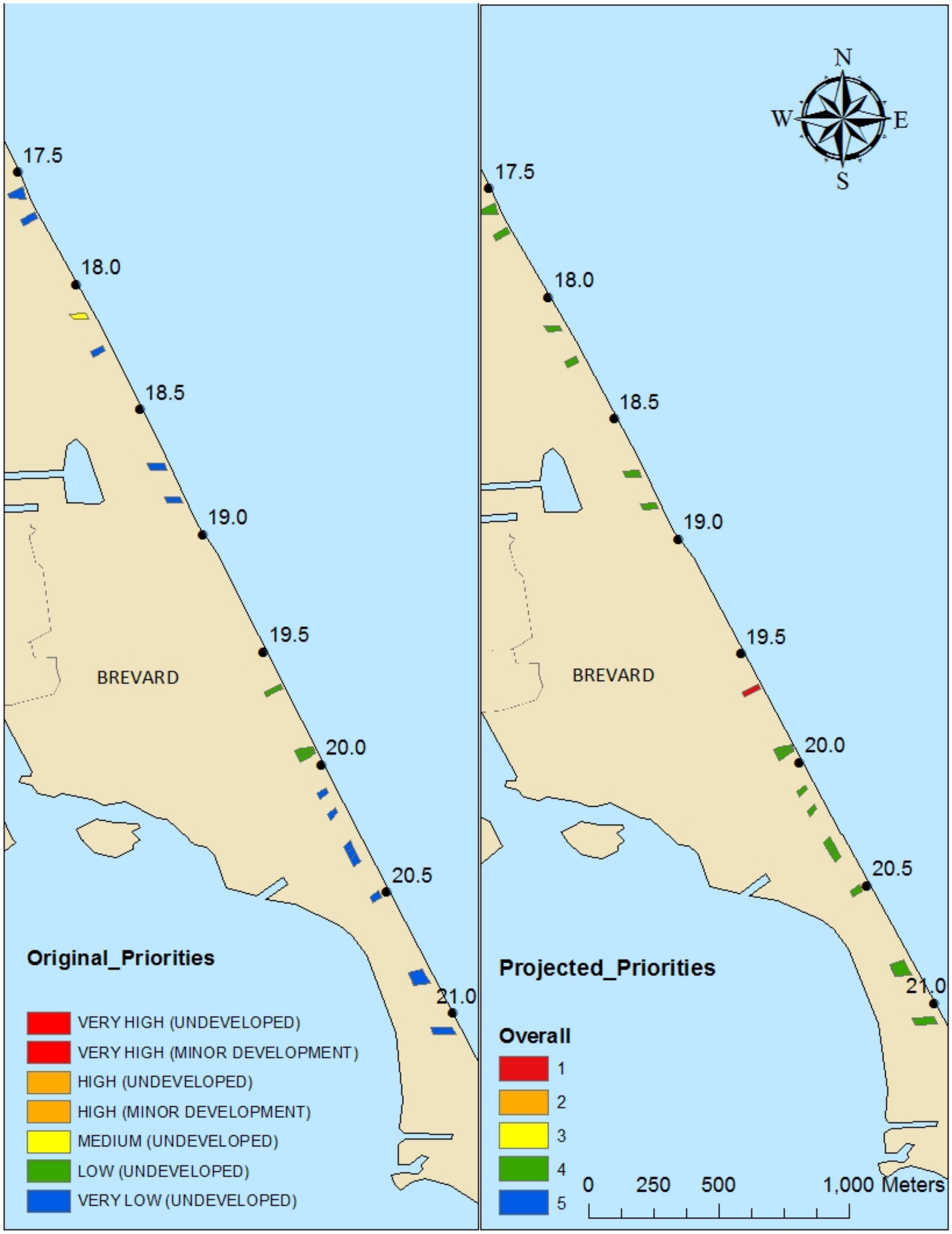

Figure 4.14: Segment 3- Many parcels in this figure depict a change from a very low priority status to a low priority status.

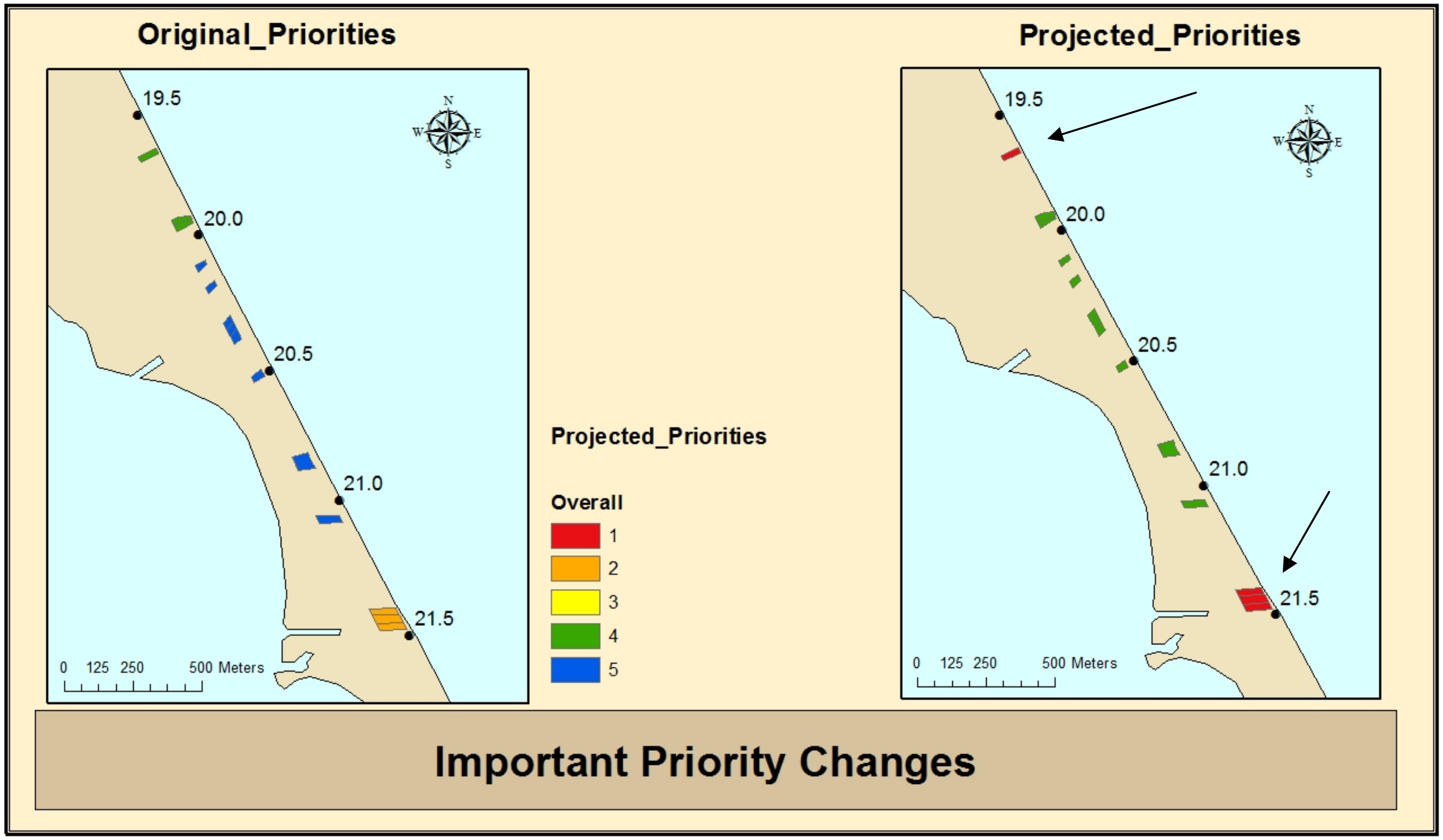

Figure 4.15: The figure shows a closer view of the important priority changes from Figure 4.13. The parcel located south of kilometer 19.5 shows a change in priority status from low priority to high priority. The three consecutive parcels located north of 21.5 show a change from high priority status to very high priority status.

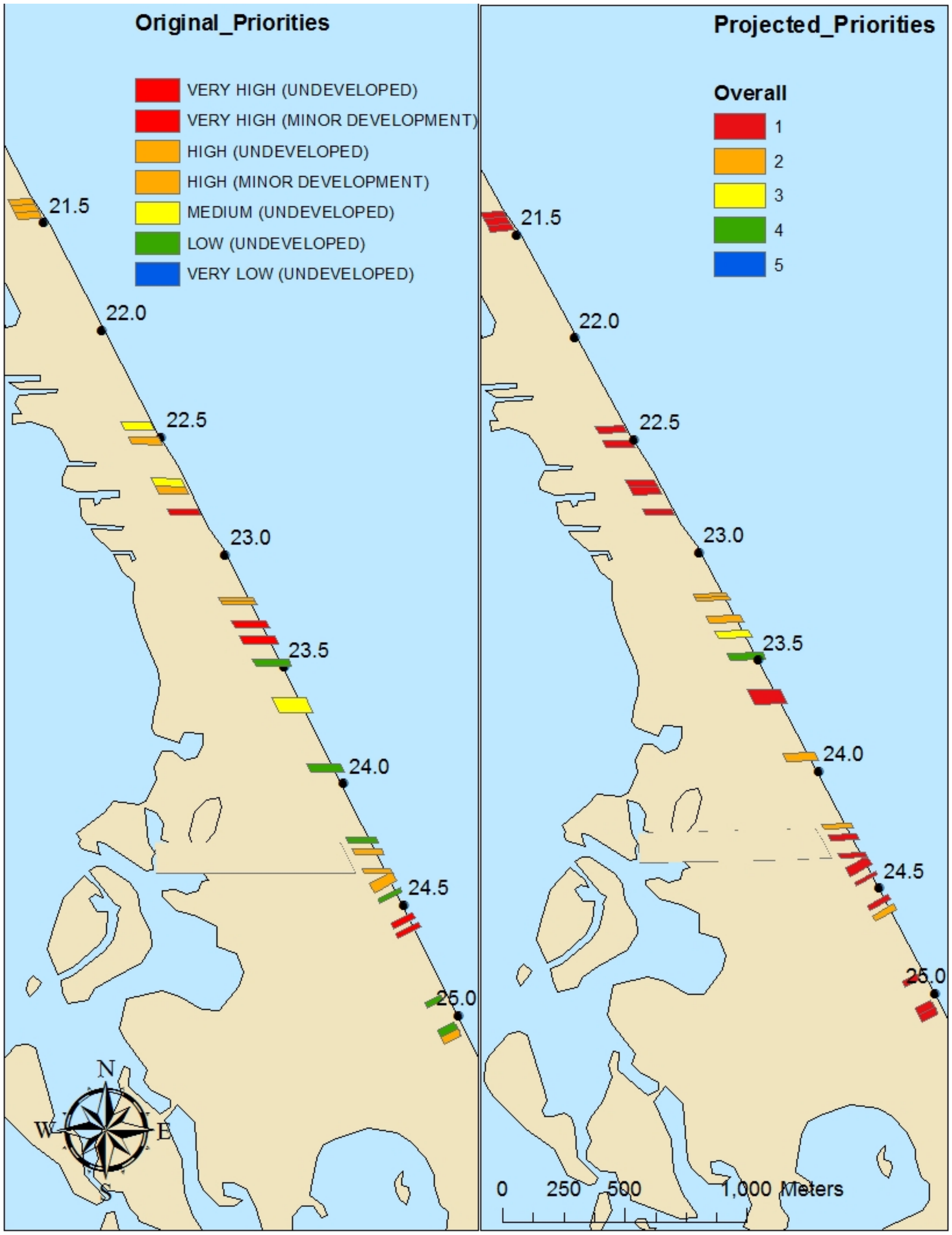

Figure 4.16: Segment 4-This figure depicts the last segment of priority acquisition parcels chosen by the Archie Carr National Wildlife Refuge in 2008. In the final overall priority map shown on the right section of the figure, there is a large quantity of very high priority status parcels.

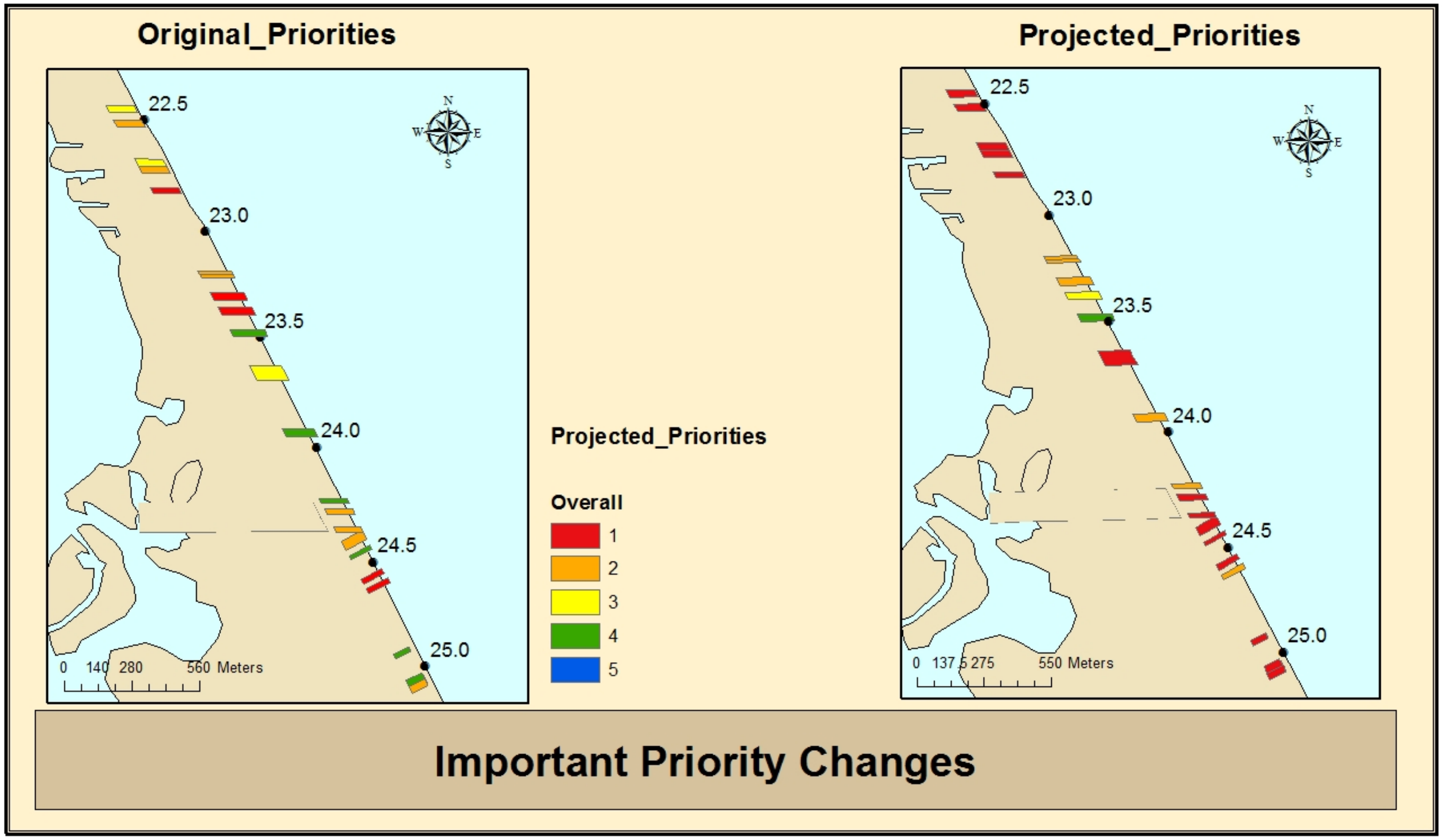

Figure 4.17: Parcels from just north of kilometer 22.5 to kilometer 23.0 all result in very high priority status in the projected priority map. Five other parcels in this figure show an increase to the high priority status.

V. Discussion

Analysis results from my study highlight the need to consider how future sea level rise affects the future area available and conservation standards to support an important nesting beach. Because of a steep upper beach slope, relatively small differences in percentage area loss were found until the dune area is reached for the ten scenarios tested in this study. Despite these small differences and the carrying capacity capabilities of the beach, a near quarter loss of nesting beach is not to be discounted.

Historical shoreline changes, ranging from the 1800s to 2005, on the east coast of Florida have a long–term rate of change of 0.20 ± 0.60 m/yr (Morton and Miller 2005). The long-term rate is a low shoreline retreat because of beach re-nourishment projects (i.e., foreign sand added to the beach to increase beach area) and low tidal and wave energy (Morton and Miller 2005). Historical shoreline erosion rates and storm surge affects were not factored into this study and therefore an exacerbation of inundation losses due to these circumstances could negatively impact carrying capacity further and therefore decrease the available area for nesting processes on Archie Carr National Wildlife Refuge. However, future research will include these shoreline erosion calculations. Though the specific quantity of beach loss will differ when incorporating shoreline erosion into the methodology, it is likely that the relative ranking of parcels inundated would remain similar.

Although carrying capacity after inundation losses remains larger than then average area needed for nesting (from 2001-2010), the level of SLR does not necessarily allow for increases in nesting populations. The increase in green turtle nesting population shown in Table 3 demonstrates that large increments in population are possible. Considering that the average green sea turtle nest radius is 1.4 meters, continued increases in nesting green turtles would greatly decrease the carrying capacity of the beach, thus decreasing the area available for Loggerheads and Leatherbacks to nest.

Inundation losses for the B1, A1T, A1B, A1F1, Zhang et al. (2012) and National Research Council (2012) scenarios were calculated to be in the 20-25% range yet this number does not fully illustrate the losses that can be seen in specific areas of the beach when studied on a map. Losses due to lower elevation can cause a major drop in width on certain portions of beach, which, when considering placement of buildings and other structures (i.e. sea walls) can negatively impact the ability of the beach to migrate landwards and thus results in a constricted amount of area available for nesting along major nesting density stretches of the beach.

Accounting for the results of this study could shift the focus of the order in which the Refuge will acquire parcels for conservation purposes in the future.

Conclusions

Sea turtles are integral players in coastal ecological systems. Their conservation is therefore crucial. The Archie Carr National Wildlife Refuge proposed in the Comprehensive Conservation Plan (2008) to obtain shoreline retreat estimates to better plan future management efforts. Refuge and land management partners realized that sea level rise would result in a likely reduction of habitat for several of the endangered species that inhabit the area, including the three sea turtle species that nest along the ACNWR coast. As a result, the fifth wildlife and habitat management goal in the Comprehensive Conservation Plan stipulates that the impacts of climate change need to be understood to adapt management and refuge resources to properly protect native wildlife and habitats (CCP 2008).

Another refuge that has undergone adaptive measures for sea level rise is the Alligator National Wildlife Refuge located in North Carolina. The Alligator National Wildlife Refuge was established to protect elevated shrub wetlands, pocosins, which provide habitat for endangered species (Lin and Petersen 2013). The refuge managers have put into motion plans that maintain habitat and reduce the rate of erosion. Management goals encompass allowing species the time to adapt to sea level rise and increased salinity by attempting to maintain the present habitat structure as long as possible (Lin and Petersen 2013). By prioritizing management goals refuge managers allow for the highest degree of success for the endangered species in the refuge.

The importance of this study therefore resides in the future management outlook for the nesting beach in Archie Carr National Wildlife Refuge. The impact of inundation area loss due to sea level rise can be best appreciated when compared with the priority acquisition parcels proposed in 2008. Although some SLR is unavoidable, future damage can be partly mitigated through proper planning and allocation of resources.

Changes in parcel priority status due to sea level rise scenarios should be considered for future management options within the refuge as they indicate parcels with the least amount of area loss. A change of approximately 26% in lower priority parcels to parcels of high priority status indicates a possible change in focus for future acquisition. Parcels with the highest priority status would result in the Refuge obtaining the highest quality lands for the future conservation goals outlined in their Comprehensive Conservation Plan. Consequently, based on the results from this study, I strongly recommend a revision to the planned parcel acquisition strategy.

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