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Utilizing Remote Sensing Imagery to Monitor Vegetation Change within World Heritage Sites

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by

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ABSTRACT

World Heritage sites provide a glimpse into the stories and civilizations of the past. There are currently 1007 unique World Heritage properties with 779 being classified as cultural sites, 197 as natural sites, and 31 falling into the categories of both cultural and natural sites (UNESCO & World Heritage Centre, 1992-2015). However, of these 1007 World Heritage sites, at least 46 are categorized as in danger and this number continues to grow. These unique and irreplaceable sites are exceptional because of their universality. Consequently, since World Heritage sites belong to all the people of the world and provide inspiration and admiration to all who visit them, it is our responsibility to help preserve these sites.

The key form of preservation involves the individual monitoring of each site over time. While traditional methods are still extremely valuable, more recent advances in the field of geographic and spatial technologies including geographic information systems (GIS), laser scanning, and remote sensing, are becoming more beneficial for the monitoring and overall safeguarding of World Heritage sites. Through the employment and analysis of more accurately detailed spatial data, World Heritage sites can be better managed.

There is a strong urgency to protect these sites. The purpose of this thesis is to describe the importance of taking care of World Heritage sites and to depict a way in which spatial technologies can be used to monitor and in effect preserve World Heritage sites through the utilization of remote sensing imagery. The research conducted in this thesis centers on the Everglades National Park, a World Heritage site that is continually

affected by changes in vegetation. Data used include Landsat satellite imagery that dates from 2001-2003, the Everglades' boundaries shapefile, and Google Earth imagery. In order to conduct the in-depth analysis of vegetation change within the selected World Heritage site, three main techniques were performed to study changes found within the imagery. These techniques consist of conducting supervised classification for each image, incorporating a vegetation index known as Normalized Vegetation Index (NDVI), and utilizing the change detection tool available in the Environment for Visualizing Images (ENVI) software.

With the research and analysis conducted throughout this thesis, it has been shown that within the three year time span (2001-2003), there has been an overall increase in both areas of barren soil (5.760%) and areas of vegetation (1.263%) with a decrease in the percentage of areas classified as sparsely vegetated (-6.987%). These results were gathered through the use of the maximum likelihood classification process available in the ENVI software. The results produced by the change detection tool which further analyzed vegetation change correlate with the results produced by the classification method. As well, by utilizing the NDVI method, one is able to locate changes by selecting a specific area and comparing the vegetation index generated for each date.

It has been found that through the utilization of remote sensing technology, it is possible to monitor and observe changes featured within a World Heritage site. Remote sensing is an extraordinary tool that can and should be used by all site managers and organizations whose goal it is to preserve and protect World Heritage sites. Remote sensing can be used to not only observe changes over time, but it can also be used to pinpoint threats within a World Heritage site. World Heritage sites are irreplaceable sources of beauty, culture, and inspiration. It is our responsibility, as citizens of this world, to guard these treasures.

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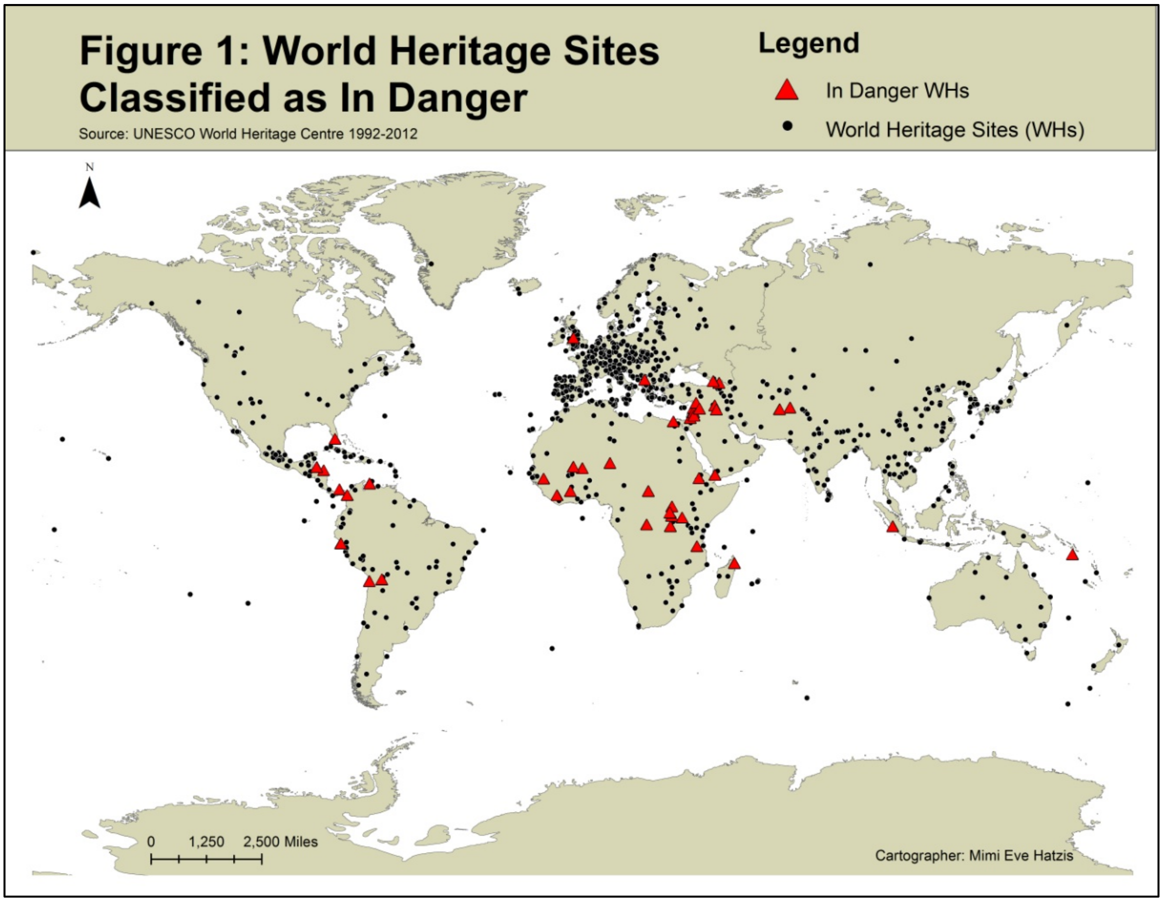
CHAPTER 1 INTRODUCTION

1.1 Overview

When it comes to preserving World Heritage sites (WHs), "we are fighting a losing battle", not only are we losing sites, but we are losing stories (Kacyra, 2011). This statement was produced by Ben Kacyra, the founding director of CyArk, during the filming of a Technology, Entertainment, and Design (TED) Talks presentation in Edinburgh, Scotland. What he is describing is the accelerating rate at which World Heritage sites face destruction. There are currently 1007 unique World Heritage properties with 779 being classified as cultural sites, 197 as natural sites, and 31 as a mix of both cultural and natural sites (UNESCO & World Heritage Centre, 1992-2015). However, there are at least 46 World Heritage sites that are categorized as in danger and this number is only increasing (UNESCO & World Heritage Centre, 1992-2015). Figure 1, titled "World Heritage Sites Classified as in Danger", locates these sites on a world map. The main causes for site destruction are divided between two cases: natural phenomenon such as earthquakes, tornadoes, or floods and human caused destruction such as urban sprawl, acid rain, air pollution, or terrorism. Though the reason World Heritage sites are classified as in danger can vary greatly, what is known is that the amount of sites being labeled as in danger is increasing tremendously.



1.2 Problem Statement

There is a strong urgency to protect these sites. Traditionally, many cultural and natural heritage sites have previously utilized techniques including optical fiber sensors, geodetic methods, and gypsum strips to monitor the sites. However, more recent advances in the fields of geographic and spatial technology have enabled a more efficient way of supervising our World Heritage sites. Through the employment and analysis of more accurately detailed spatial data, World Heritage sites can be better managed. The purpose of this thesis is to describe the importance of taking care of World Heritage sites and to depict a way in which spatial technologies can be used to monitor and in effect preserve World Heritage sites through the utilization of remote sensing imagery.

CHAPTER 2 BACKGROUND INFORMATION

2.1 Background Information About World Heritage Sites

Heritage as defined by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) during the World Heritage Convention (WHC) is “our legacy from the past, what we live with today, and what we pass on to future generations” (World Heritage Kit, 2008). World Heritage sites (WHs) are classified as cultural and/or natural sites, belonging to all the people of the world. The sites are areas that are irreplaceable sources of beauty, culture, and inspiration. Whether it is the Acropolis of Greece, the Galapagos Islands located in Ecuador, or the Banks of the Seine in Paris, these sites make up the heritage and culture of the world.

As seen in Table 1 titled, "World Heritage Sites by Type", there are currently 1007 unique World Heritage sites. From this amount, 779 properties are classified as cultural, 197 as natural, and 31 as a mix. The cultural sites refer to "monuments, groups of buildings and sites with historical, aesthetic, archaeological, scientific, ethnological, or anthropological value". Cultural sites can include buildings, statues, and historic centers. Some examples include the Birthplace of Jesus: Church of the Nativity and the Pilgrimage Route in Bethlehem, Palestine, the León Cathedral in Nicaragua, and the Medieval City of Rhodes located in Greece. On the other hand, natural sites refer to "outstanding physical, biological, and geological formations, habitats of threatened species of animals and plants and areas with scientific, conservation, or aesthetic value" (World Heritage Kit, 2008). Examples of natural sites include national parks or coastlines such as the Isole Eolie or Aeolian Islands of Italy, the Great Barrier Reef in Australia, and the Great Smokey Mountains National Park located in the United States of America.

Table 1: World Heritage Sites by Type			
Total Properties	Cultural Properties	Natural Properties	Mixed Properties
1007	779	197	31
Source: UNESCO World Heritage Centre 1992-2015, United Nations			

Understanding the importance of maintaining these sites, UNESCO's mission is to “encourage the identification, protection, and preservation of cultural and natural heritage around the world” (World Heritage Kit, 2008). In fact, as stated in the “World Heritage Information Kit”, among the many objectives involved in UNESCO's mission, the organization also aims at persuading all countries to ensure the security of these national sites of heritage, aims at encouraging all countries to submit heritage sites within their national territories for inclusion on the World Heritage List, and aims at helping all countries safeguard these designated properties by supplying necessary assistance where and when needed (World Heritage Kit, 2008).

The significance of World Heritage sites was first discussed during the 1972 general conference meeting of UNESCO. This ground breaking conference is also referred to as the 1972 Convention Concerning the Protection of the World Cultural and Natural Heritage as well as the World Heritage Convention. With the understanding that cultural and natural heritage sites are continually being threatened by destructive forms of decay, in addition to changing social and monetary conditions, UNESCO produced a document titled the “Convention Concerning the Protection of the World Cultural and

Natural Heritage". This document shall be referred to as "the Convention". The Convention is a set of documentation standards made applicable to many heritage sites worldwide. The document not only underlines the importance of preventing the deterioration or complete disappearance of any site of cultural or natural heritage, but it states the responsibilities of State Parties to the Convention; or in other words, it states the responsibilities of those countries who agree to the terms and conditions of the Convention. These responsibilities center around protecting and preserving World Heritage sites. For example, Article 4 states that "each State Party to this Convention recognizes ... (their) duty of ensuring the identification, protection and transmission to future generations of the cultural and natural heritage" (Convention, 1972). This particular Article entails that all State Parties of the Convention provide assistance in the preservation of World Heritage sites to the highest of its ability and resources in order for the sites to continue to exist for future generation. As well, if further assistance, whether financial or technical is required, international assistance should be consulted (Convention, 1972). In addition to establishing the duties of State Parties of the Convention, the document creates an Intergovernmental Committee for the Protection of the Cultural and Natural Heritage of Outstanding Universal Value, known as the World Heritage Committee. Founded within UNESCO, the World Heritage Committee is currently composed of 21Committe Members elected by their respective General Assembly. (Rules of Procedure, 2013). Countries that are associated with this committee include, but are not limited to Poland, India, Finland, Germany, and Algeria.

Members of the World Heritage Committee convene annually to define the World Heritage Fund, allocate financial assistance, inscribe a variety of new properties on the World Heritage List, and are presented with the responsibility of examining reports dealing with the state of conservation of inscribed properties. The World Heritage Committee is ultimately involved in examining the progress of conserving specific World Heritage sites. For UNESCO World Heritage sites the process of monitoring the sites can depend on different policies and programs. While, policies center around regulations that focus on ensuring the maintenance of the natural and built environment of sites, programs tend to include utilizing different forms of technologies for the preservation of World Heritage sites. While the common policies and programs are essential to World Heritage site preservation, there are newer spatial technologies that exist which could and should be utilized to facilitate the process of preserving and in effect monitoring World Heritage sites.

2.2 Traditional Tools and Techniques Used to Monitor World Heritage Sites

The key process of monitoring World Heritage sites involves examining the sites individually and over time. This is because there are a number of observable changes that occur through time which can significantly affect World Heritage Sites. Examples of these changes range from cracks that have the potential to progressively expand due to induced stress within a structure's material (this is common for cultural heritage sites) or changes in land cover caused by natural phenomena such as desertification, erosion, and deforestation (this is more common for natural heritage sites). Many techniques can be employed in order to monitor and preserve these sites properly (Alshawabkeh & El-

Khalili, 2013). These methods are divided between traditional and newer, innovative technologies. Traditional technologies that have been used as a tool for observing variations in World Heritage sites include optical fiber sensors, geodetic methods, and gypsum strips (Alshawabkeh & El-Khalili, 2013; Glisic et al., 2007; Inaudi and Glisic, 2004). For example, fiber-optic sensors have been recognized as an excellent choice for structural health monitoring for World Heritage sites that are man-made such as the pyramids of Egypt (Inaudi et al., 2005). "Being durable, stable and insensitive to external influences, they are particularly interesting for the long-term health assessment of civil structures" (Inaudi et al., 2001). A benefit of this technology is that a single reading unit could be used to monitor more than one fiber pair in a variety of structures. While the type of system can be installed into bridges, anchors, tunnels, and harbor structures, it can also be used on structured World Heritage sites. In fact, this technique has been used on a number of World Heritage sites as a tool for monitoring not only deformations, but changes in pH values, temperature, and gas concentrations.

While extremely valuable, traditional methods have a disadvantage of requiring contact tools including scaled sensors and geodetic targets (Alshawabkeh & El-Khalili, 2013). These components entail manual maintenance and installation at the location of the World Heritage site being observed. Because these techniques depend heavily on accessibility, their usage is more of a hassle than easily manageable. Fortunately, advanced technology is changing the way in which World Heritage sites are preserved. More recent spatial technologies including geographic information systems (GIS), laser scanning, and remote sensing which are all beneficial tools that can be utilized for better monitoring and overall safeguarding of World Heritage sites.

2.3 Remote Sensing

Spatial information technologies involve Geographic Information Systems (GIS), Global Positioning Systems (GPS), remote sensing, spatial data management and much more. While each field is of individual importance, remote sensing is a more recent approach in the preservation of World Heritage sites. Remote sensing is the art and science of collecting data about an object without the use of direct contact with the data. In other words, it involves measuring data at a distance, instead of in situ (Schowengerdt, 2007). Remote sensing is a useful method for monitoring World Heritage sites because it can provide historical records, can reduce the amount of field work, can provide images with clear detail, and can allow for three-dimensional viewing of data.

There are three types of remote sensed images: aerial photography imagery, non-photographic imagery, and softcopy photogrammetry. Aerial photography imagery refers to the acquisition of imagery through the use of aircraft and film while non-photographic imagery uses aircraft or spacecraft through a combination of scanners and/or other devices. Lastly, softcopy or digital photogrammetry is the use of images that have been digitally recorded. While each type of remote sensed image is important, what shall be focused on and utilized in the methodology section of this thesis is non-photographic imagery. This type of imagery utilizes satellite based scanning systems that can include

Landsat, Satellite Poul l'Observation de la Terre (SPOT), Indian Remote Sensing (IRS), and Radar Satellite (RADARSAT).

Landsat, a popular satellite based scanning system, is utilized in the methodology of this thesis. The launch of Landsat 1, "the first of many earth-orbiting satellites designed for (the) observation of the earth's land areas", occurred in 1972 (Campbell, 2002). Designed for the purpose of observing the earth's geologic areas, Landsat offered systematic repetitive examinations of the earth. As Campbell explains, "Landsat images depicted large areas of the earth's surface in several regions of the electromagnetic spectrum, yet provided modest levels of detail sufficient for practical applications in many fields" (Campbell, 2002). The Landsat Multi Spectral Scanner (MSS) and the Return Beam Vidicon (RBV) acquired imagery of the earth from 1972-1978 on board Landsat 1, Landsat 2, and Landsat 3. At the time, the Landsat system provided a reliable set of high resolution images of the earth to the scientific community. The system included a sensor which had multiple spectral bands, allowed for a high spatial resolution, provided repeating coverage of the earth of about 18 days, and supplied imagery of a large area (Schowengerdt, 2007). In addition, the Landsat MSS released general purpose imagery directly into digital format. Throughout the years, there have been a number of advances made in the field of satellite based scanning systems. For example, pertaining to the Landsat series and since the 1972 debut of the system, there have been improvements made with four new MSS systems as well as the creation of two Thematic Mapper (TM) systems and the Enhanced Thematic Mapper Plus (ETM+) system (Schowengerdt, 2007). The main differences between each advancement depends on its characteristics. For example, the ETM+ system has an average resolution of about 30 meters and a revisit interval of 16 days (Unsalan & Boyer, 2011).Table 2, titled "The Landsat Family and Corresponding Properties" displays the advances made within the Landsat family from 1972 to 2013.

Table 2: The Landsat Family and Corresponding Properties

Satellite	Launch Date	End of Service	Resolution (m)	Revisit Interval (days)
Landsat 1	7/23/1972	1/6/1978	RBV 80; MSS 80	18
Landsat 2	1/22/1975	2/25/1982	RBV 80; MSS 80	18
Landsat 3	3/5/1978	3/31/1983	RBV 30; MSS 80	18
Landsat 4	7/16/1982		TM 30; MSS 80	16
Landsat 5	3/1/1984		TM 30; MSS 80	16
Landsat 6	10/5/1993	10/5/1993	Pan 15; ETM 30	16
Landsat 7	4/15/1999		Pan 15; ETM+ 30	16
Landsat 8	2/11/2013		Pan 15; ETM+ 30	16

Source: Unsalan, C. & Boyer, K. L. (2011). *Multispectral Satellite Image Understanding: From Land Classification to Building and Road Detection*. New York, U.S.A.: Springer. Page 8.

Landsat is credited with many important contributions to the scientific community. To begin, due to the increase of available multispectral data of large areas on the earth's surface, there was an expansion of the number of individuals with interest in the analysis of the multispectral data, enlarging the populace of scientists with an interest in multispectral analysis. Another contribution Landsat made was with the continual availability of digital data. Not only did popularity of digital analysis grow, but so did the development of image analysis software such as Environment for Visualizing Images (ENVI) which is also utilized in the methodology section of this thesis. A third contribution of Landsat was its role as a model for development so other satellites designed for land observation would become just as successful.

2.4 Characteristics of Remote Sensing Data

Since, remote sensing systems can range from active microwave processes to passive systems such as satellite systems, there are a number of principles used when analyzing remote sensing data. These principles or characteristics include spectral differentiation, radiometric differentiation, spatial differentiation, geometric transformation, and the interchangeability of pictorial and digital formats (Campbell, 2002). To start with, the science of multispectral remote sensing involves "observing features at varied wavelengths in an effort to derive information about these features and their distributions" (Campbell, 2002). When an image is viewed at different wavelengths, specific features become more evident and obvious to the analyst that would not be so clear at another wavelength. Spectral differentiation involves the spectral band locations, the spectral band width, and the number of bands. Analysis of images depend on examining spectral differences in the amount of energy reflected or emitted from objects or areas of interest. In other words, when analyzing a set of images, it is essential to observe any changes in color found within the images.

The analysis of remote sensing data also involves radiometric differentiation. This principle entails that when an acquired image is examined, any differences in the brightness of features within a scene are taken into account as significant. Another principle of remote sensing is spatial differentiation. Some landscapes differ greatly in how complex they are spatially. While some areas may be displayed clearly at very coarse levels of detail, others may be so complex that the finest level of detail is needed to observe specific characteristics.

Two other principles that pertain to remote sensing are geometric transformation and the interchangeability between pictorial and digital formats. Each remote sensing image displays a landscape in a specific geometric relationship that is established by the design of the instrument utilized, by the operating conditions, and by other factors. According to Campbell, "the ideal remote sensing instrument would be able to create an image with accurate, consistent geometric relationships between points on the ground and their corresponding representations on the image" (Campbell, 2002). Such an image would be able to create the basis for precise measurements of geometric attributes such as the areas and distances. However, it is important to take into account that there are usually, if not always, positional errors that occur. Positional errors are inherent and not accidental. At times, these errors can be removed or reduced, but it is a characteristic of remotely sensed images that should not be ignored when analyzing images.

A final principle of remote sensing is the interchangeability between pictorial and digital formats. These are the two forms used for viewing remote sensing data. Any image generated by remote sensing systems can be displayed in digital format through the subdivision of the image into smaller areas of identical size and shape and then by symbolizing the brightness of the areas through the use of discrete values (Campbell, 2002). While pictorial and digital data are associated with different methods of representation, the information expressed by each are the same and any image can be displayed in either format.

For remote sensing data, the smallest units are pixels or picture elements. These are usually "discrete, distinct units, identifiable on the image" (Campbell, 2002).

Focusing on digital imagery, how pixels are created depends primarily on the scanner utilized by the satellite system. Types of scanners include the whiskbroom scanner, paddlebroom scanner, and pushbroom scanner. Each scanner is known for following a different process. For example, a whiskbroom scanner, used by satellites such as Landsat TM incorporates several different detector elements, which are aligned in track, in order to obtain parallel scanning during each cycle (Schowengerdt, 2007). Another commonly used scanner is the paddlebroom, used by MODIS and AVHRR, which includes a double-sided rotating mirror that continuously scans in the cross-track direction. Lastly, pushbroom scanners, used by SPOT, also scan in a cross-track direction, but the main difference between a paddlebroom and pushbroom scanner is the amount of detector elements employed when scanning the full area of a data scene. In effect, the grid of pixels which form a digital image is produced based on the scanner used in the satellite system.

Though remote sensing data involves profile point measurements of a flight path, what is more intriguing is the analysis of two-dimensional spatial images (Schowengerdt, 2007). This is because remote sensing systems such as those in connection to satellites provide a continuous and consistent view of the world. This is a final characteristic pertaining to remote sensing systems that is especially important. It is their ability of providing "inherent repeating coverage of the same area on the earth" (Schowengerdt, 2007). The revisiting of the same location is significant for monitoring purposes. This allows the imagery produced by the remote sensing systems to be analyzed for change detection purposes for both cultural and natural features. As well, these images can be used to monitor the earth's oceans and atmosphere. This characteristic is important for monitoring both short and long term changes as well as the impact of human activities on the Earth. Some changes that can be studied using remote sensing technology include global change detection such as deforestation and global warming, agricultural changes such as yield production and soil erosion, and mapping of land use or topography. In addition to visiting the same place repeatedly, most satellites such as Landsat are in sun-synchronous orbit. In other words, these satellites not only revisit the same area continuously, but they revisit them at the same local time. This can be essential when monitoring images of areas based on seasonal variations. For example, this could be useful for observing changes in the amount of vegetation of an area for every spring season for a five year time span. Additionally, expanding on the usages of remote sensing analysis is the utilization of remote sensed data to monitor World Heritage sites.

2.5 Remote Sensing Approach for Monitoring World Heritage Sites

Of the 1007 World Heritage sites, there are at least 46 sites which are categorized as in danger and that number is steadily increasing (UNESCO & WHC, 1992-2015). According to the World Heritage Convention, Article 11.4 states that the List of World Heritage in Danger "may include only such property forming part of the cultural and natural heritage as is threatened by serious and specific dangers, such as the threat of disappearance caused by accelerated deterioration, large-scale... projects or rapid urban or tourist development projects" as well as "serious fires, earthquakes, (and) landslides" (Convention, 1972). Table 3 titled, " World Heritage in Danger by Region", displays a count of World Heritage sites classified as in danger based on region. As seen in the table, most cultural sites that are in danger are cataloged as in the Arab States region. On the other hand, most of the natural sites that are in danger are located in the African region. There aren't any mixed sites (sites that are classified as both cultural and natural) that are labeled as in danger in any region. As seen in the table, the highest percentage of World Heritage sites categorized as in danger belong to the African and the Arab States region with percentages of 35and 28, respectively.

Table 3: World Heritage in Danger by Region

Regions	Cultural	Natural	Mixed	Total	Percent (%)
Africa	3	13	0	16	35
Arab States	13	0	0	13	28
Asia and the Pacific	2	2	0	4	9
Europe and North America	4	1	0	5	11
Latin America and the Caribbean	5	3	0	8	17
Total	27	19	0	46	100

Source: UNESCO World Heritage Centre 1992-2015, United Nations

While there are many techniques utilized to monitor in danger World Heritage sites, advances in spatial information are making this technology a more efficient tool. Spatial technologies are associated with a number of applications that provide ongoing monitoring of natural and cultural heritage sites. For example, with the use of satellite systems, remote sensing imagery can provide continual data acquisition for all of the earth with time frames ranging from hours to weeks. As well, with access to satellite based imagery in digital format, immediate analysis of an area can be conducted. For instance, by comparing temporal, or time-series, satellite imagery, the remote sensing technology becomes an extraordinary tool in observing changes in ground terrain. These changes can range from changes in vegetation to changes in the amount of ice coverage within an area. In addition, remote sensing has the ability to pinpoint potential threats to World Heritage sites, further preserving our world's valuable treasures (Bewley, 2003). With improvements in the scale of resolution of up to 60cm, remote sensing imagery has the ability to assist in the creation of accurate maps and comparative analysis. Many organizations and projects have become more closely associated with the usage of remote sensing tools as a way to improve the flow of information and communication within the field of World Heritage sites.

A huge accomplishment made towards the union remote sensing technology and its usage toward monitoring World Heritage sites is the Open Initiative on the Use of Space Technologies to Support the World Heritage Convention, also known as, the Open Initiative. The Open Initiative is a program, born through an agreement signed by both UNESCO and the European Space Agency (ESA) in June 2003 at the Paris Air Show. This agreement was meant to encourage the utilization of observational satellites as a tool for observing and monitoring both cultural and natural World Heritage sites. The Open Initiative aspires to form a collaboration between space agencies, non-governmental organizations (NGOs), the private sector, universities, and research institutions to assist developing countries with the remote sensing technology in order to improve their conservation practices. The main purpose of the Open Initiative program originates from the belief that data collected from space will be used to monitor World Heritage sites. Following the acquisition of data and through a variety of analytical activities, the techniques used could alert those of authoritative power to changes within an area of study. The focus on assisting developing countries is fundamental due to the fact that developing countries are greatly challenged by a number of obstacles including conflicting demand of economic development and issues with social equity (Fletcher et al., 2007). Because of this, developing countries are the least likely to have the accessibility of protecting the World Heritage sites of their nation. It is the duty of countries that have that ability to assist these countries where they are can. In order to manage the demands of preserving World Heritage sites, collaboration between the cultural heritage of the region, the environment, and the society is essentially required and of significant importance to the maintenance of the sites.

Another major contribution to this field is the book titled, From Space to Place: an Image Atlas of World Heritage Sites on the 'In Danger' List. Launched during UNESCO's 36th General Conference in 2011, this book was put together as a joint effort by both UNESCO and the United States Geological Survey (USGS) organization. It is a book that provides a new way of looking at the world's shared heritage. The book utilizes remote sensing imagery of the Earth to help us understand the physical and natural world we live in. From Space to Place: an Image Atlas of World Heritage Sites on the 'In Danger' List depicts the 31 sites which, at the time of production, were on the World Heritage in Danger list. The book does not only describe, in detail, the 31 sites that are threatened by human and natural factors, but also uses satellite imagery to further explain the site. In addition, detailed photographs of vulnerable features or species are provided for those sites whose threats are not easily captured by satellite. As well, the image atlas combines both Landsat imagery with higher resolution imagery. This higher resolution imagery come from a number of sources including IKONOS, Corona, Quickbird, and

Worldview satellites (UNESCO, 2011). Together these images provide a wider perspective on how to protect and manage the multiple endangered world treasures. The purpose of the image atlas is to allow others to understand how remote sensing plays an important role in managing UNESCO World Heritage sites. By comprehending the significance of the data displayed in the image atlas, the risks associated with threatened World Heritage sites can be minimized by assisting "researchers and site managers to better evaluate and manage World Heritage sites" (UNESCO, 2011).

Data provided by remote sensed systems is an especially useful tool in mitigating threats associated with World Heritage sites. Satellite imagery and remote sensing technology provide a new way of understanding the looming risks faced by cultural and natural sites. Satellite imagery is also beneficial for its ability to utilize space technologies in acquiring accurate and precise information that is then used to improve the way World Heritage sites are periodically reported and studied. In effect, this technique leads to improvements in visualization and documentation of information about the cultural and natural World Heritage site. This then leads to better monitoring practices including observing measurement and calculation variations of features and areas and determining whether a conservation project is or is not successfully implemented. By integrating the remote sensing technology with the preservation of World Heritage sites, historians, planners, and resource managers are provided with a baseline dataset for analyzing patterns and/or change in land cover of World Heritage sites which is extremely important, taking into account the number of heritage sites on the List of World Heritage in Danger (Stubbs & McKee, 2007).

CHAPTER 3 STUDY AREA AND DATA SET

3.1 Background Information on the Study Area

In the previous chapter, the importance of World Heritage sites is discussed. As well, the background information introduced describes advances in remote sensing technology which can be used to monitor and preserve World Heritage sites. The methodology section of this thesis expands on this topic by providing an in depth analysis of a World Heritage site where remote sensed imagery is used to observe geological changes at a World Heritage site. In effect, the focus of this chapter is to describe the selected World Heritage site and explain why the site was chosen. In addition, this chapter introduces the data set utilized in the methodology along with some common characteristics that pertains to the data.

In 1872, Yellowstone became the world's first national park and eventually would become a natural World Heritage site. This was unprecedented because more than one million acres of land would be classified as a public park. However, the idea was eventually accepted and for more than a century, many nations have continued "this work of transforming the great landscapes of (all countries)... from our history into an extraordinary public treasure" (Repanshek, 2013). As a result of these accomplishments, every individual of this world can claim to be a shared owner of more than 400 national park sites, of which over 90 are official World Heritage sites. The landscape of these natural World Heritage sites can span from high mountain tops, respected battlefields, distinguished monuments, and picturesque seashores (Repanshek, 2013). These places are filled with inspiration and create a connection between individuals and the past. These magnificent sites deserve respect and it is our duty to preserve them.

The World Heritage site that will be further analyzed in the methodology section of this thesis is called the Everglades National Park. Located in the United States at the coordinates N25 33 16 and W80 59 47, the Everglades anchors Florida's southern tip along the Gulf of Mexico. The park's boundary travels from the Gulf of Mexico in the west, to the Tamiami Trail in the north, to the Florida Keys to the south, and includes most of Florida Bay. The Everglades National Park as displayed in Figure 2, "Mapping Everglades Ecosystems", spans over 565,000 hectares and is the largest designated sub-tropical reserve on the continent of North America that can be explored by canoe, powerboat, and kayak. Described as a "flowing river of grass", with its vast assortment of water habitats, this World Heritage site contains a rich biodiversity of life creating a sanctuary for over 400 bird species and over 60 known reptile species. As well, this World Heritage site is known to contain over 20 rare, endangered, and threatened species including the manatee, the Florida panther, and the snail kite. Reasons for such diversity can be explained by the interface at which the Everglades lies. Not only is "the interface between temperate and subtropical America... (but it is also) between fresh and brackish water, shallow bays and deeper coastal waters, thus creating a complex of habitats supporting a high diversity of flora and fauna" (UNESCO, 1992-2015).

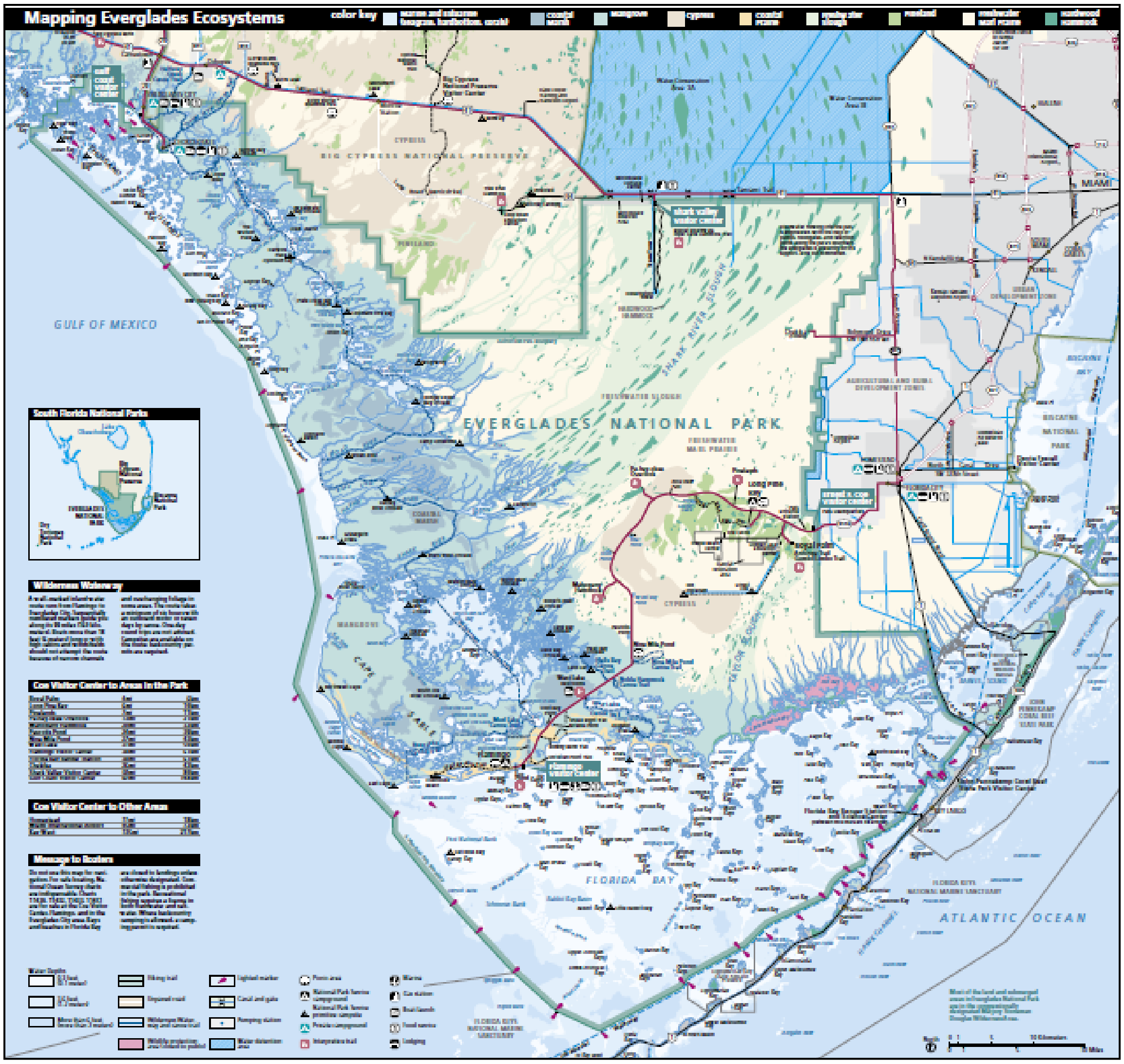


Figure 2: Mapping Everglades Ecosystems
Source: National Park Service U.S. Department of the Interior

The Everglades was declared a national park in 1947 under the May 1934 Act of Congress, but it was in 1979 that the park was inscribed on the World Heritage List as a natural WHs known for its wetland and international significance (UNESCO and the World Heritage Committee, 1979). However, in 1993, the Everglades was placed on the World Heritage in Danger List. The main cause for this decision was based on the destruction and damage done to the site by Hurricane Andrew in August of the previous year. It had been indicated that there were a huge number of threats to the park that had been steadily increasing since its inclusion as a World Heritage site. These issues included changes in the hydrological system and results caused by urban growth in the adjacent area, specifically Miami. Other factors affecting the decision to include the Everglades onto the in Danger list include an increase in "nutrient pollution from agricultural activities, reduced water levels from flood control operation and mercury contamination of fish and wildlife" (UNESCO and the World Heritage Committee, 1993). In response to the addition of this World Heritage site onto the in Danger list, government actions have been initiated. At the time, the government provided the site with 4.5 million U.S. dollars that would be used for monitoring and research purposes. Efforts had been made to resolve nutrient pollution, structural changes were made to the water system in order to replenish water levels in the northeastern part of the park, and 107, 000 acres of protected land was added to the park (UNESCO and the World Heritage Committee, 1993).

After many improvements to the preservation of the Everglades National Park the World Heritage site was removed from the List of World Heritage in Danger in June 2007. Though the World Heritage Committee applauded the United States for its scientific and financial involvement in the rehabilitation of the World Heritage site including improvements made to the water infrastructure and improvements in nutrient quality such as a large scale nature restoration project launched in 2000 that aimed at restoring water channels to reclaim some of the natural water flow, the Everglades was soon to return to the list of World Heritage in Danger. During its 34th session in 2010, the World Heritage Committee inscribed the Everglades National Park once more on the List of World Heritage in Danger. The Everglades was added to the list per request by the United States because of the continued degradation of the site's aquatic ecosystem. For instance, the amount of water inflow had been reduced by more than 60 percent while nutrient pollution continued to rise and is connected to eutrophication or loss of marine habitats in the region (UNESCO and the World Heritage Committee, 2010). The benefits of including the site on the Danger List is to mobilize support for sites whose outstanding universal value is at risk. Placed on the Danger List, the World Heritage Committee requested that the United States "invite a joint World Heritage Centre/(International Union for Conservation of Nature) IUCN reactive monitoring mission to assess the state of conservation of the property, contribute to establishing a Desired State of Conservation for removal of the property from the List of World Heritage in Danger, and revise the current corrective measures as necessary" (UNESCO and the World Heritage Committee, 2010). This is meant to evaluate the status of the World Heritage site in greater detail and to create a better plan to preserve the site.

3.2 Remote Sensing Technology and the Everglades

The Everglades National Park was once believed to be one of the most threatened ecosystems in the United States(Light & Dineen, 1994). Fortunately, numerous efforts have been taken to conserve the Everglades National Park such as the Comprehensive Everglades Restoration Plan (CERP), the largest ecological restoration project conducted. To help restore the habitats of the Everglades, the South Florida Water Management District (SFWMD) and the U.S. Army Corps of Engineers (USACE) had teamed together to launch a unique environmental effort known as CERP (Freeman, 2008) . The plan was to capture recycled fresh water that flows toward the ocean and gulf and redirect its route to areas that necessitate the water. Not only is this water useful for the ecosystem of the Everglades, but it is also helpful for nearby cities and farmers. While there has been progress attributed to programs such as these, the utilization of remote sensing can strongly benefit the Everglades National Park. This technology can be used as a way to more efficiently prevent further destruction to the area and can be used to pin point areas that are or may become threatened.

One of the major uses of remote sensing imagery is to monitor environmental hazards. An environmental hazard is universally acknowledged as a state of events which have the potential to not only threaten the surrounding natural environment, but to also negatively affect the health and welfare of individuals within the area. Some examples include pollution, excessive development of an area, and vegetation degradation such as deforestation and desertification. An environmental hazard also includes natural disasters such as tsunamis, earthquakes, and hurricanes. So, ranging from destruction caused by hurricanes, over development of urban areas within close proximity to the park, and degradation of vegetation within the park, the Everglades has experienced a number of issues throughout its time on the World Heritage List. By comparing temporal or time series satellite images, remote sensing becomes an excellent tool in observing changes that occur over time.

An example of comparing temporal data can be seen in Figures 3.A-B which show remote sensed imagery of Mount Kenya National Park/Natural Forest, another well-known natural World Heritage site located in Kenya, Africa and its surrounding area. Both images are captured in January and displayed in their true color. However, Figure 3.A is from 1987 and Figure 3.B is from 2011. Even without knowing that this area is affected by desertification, when first comparing the two images it can visually be seen that there are some changes in land cover. Looking more closely it can be concluded that there is a decrease in the amount of vegetation cover, displayed as shades of green, over the twenty four year time span.

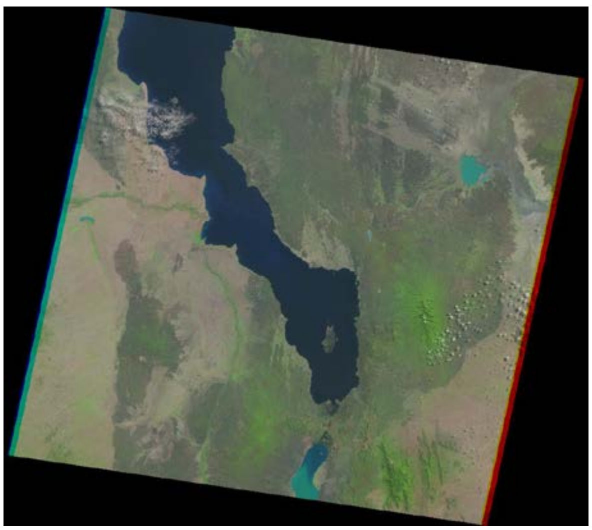
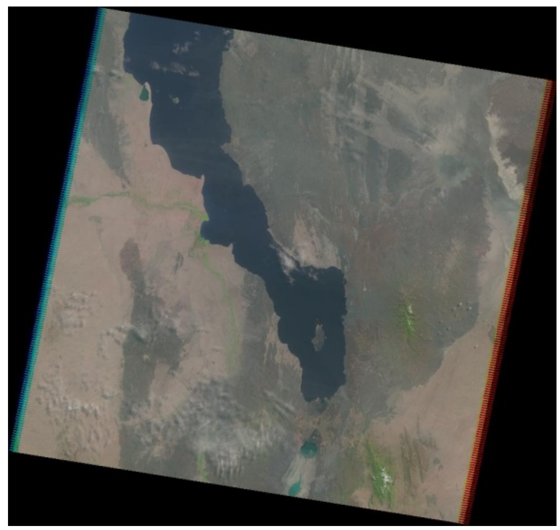



Figure 3.A: Mount Kenya National Park/Natural Forest 1987
(LT51680601987008AAA03)
Figure 3.B: Mount Kenya National Park/Natural Forest 2011
(LT51680602011010MLK00)
Source: USGS and NASA Landsat 4-5 TM

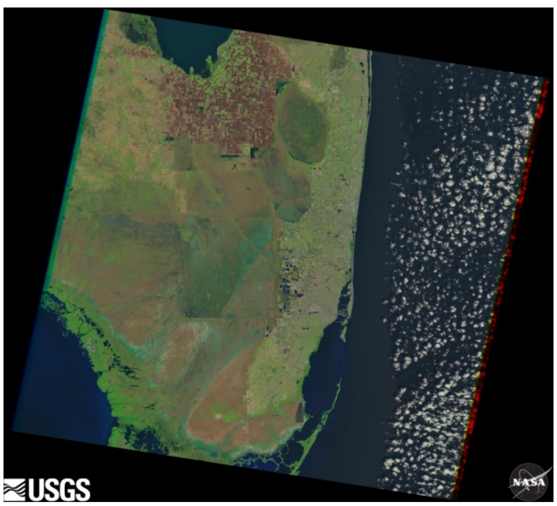
In the methodology section of this thesis, satellite based imagery will be utilized in a similar way to analyze areas of the Everglades. While changes in vegetation can be seen by simply viewing some images in grayscale, colored schemes, or multispectral form, the Environment for Visualizing Images (ENVI) software will be used to incorporate different techniques to receive a more accurate account of the information stored within the imagery. Such techniques include utilizing the classification method, the normalized difference vegetation index (NDVI) formula, and the change detection tool which will all be discussed in more detail in Chapter 4.

3.3 Information Pertaining to the Data

The source of the data utilized in this thesis is Landsat. As described in Chapter 2, Landsat is one of the satellite based scanning systems that provides detailed imagery of the Earth. Chapter 2 also explores the history of the Landsat system as well as important properties corresponding to the various Landsat systems. The United States Geological Survey (USGS) provides free and available satellite imagery on their website which can be found at www.earthexplorer.usgs.gov. It is on this website that all satellite imagery included in the methodology can be found. For the methodology section of this thesis, the data analyzed is categorized as either L7 ETM+ SLC-on (1999-2003) or L7 ETM+ SLC-off (2003-present). In other words, all data used comes from a Landsat 7 satellite system between the time frame of 1999 to the present. This kind of satellite system which was first launched in 1999, is known for a variety of corresponding characteristics. For example, Landsat 7 data uses an ETM scanner with a 30 meter resolution and a revisit interval of 16 days.

There are two main sets of satellite images that are to be later analyzed in greater detail. Since the location of the Everglades National Park is defined as approximately N25 33 16 and W80 59 47, the World Heritage site can actually be found in two different satellite imagery areas. For example, there are two images: February 13, 2003

(LE70150422003044EDC00) and March 28, 2013 (LE70150422013087EDC00) located at path 15 and row 42 which are examined later. Figures 4.A-B display the images that will be further analyzed. These images were chosen because of the ten year time span between the first and second image captured. Because these images are both within a 6 week period of the date captured, they fall within a decent seasonal time frame for comparison purposes. These images were also chosen because they are clearer than other images available. The images have a cloud coverage of less than ten percent.



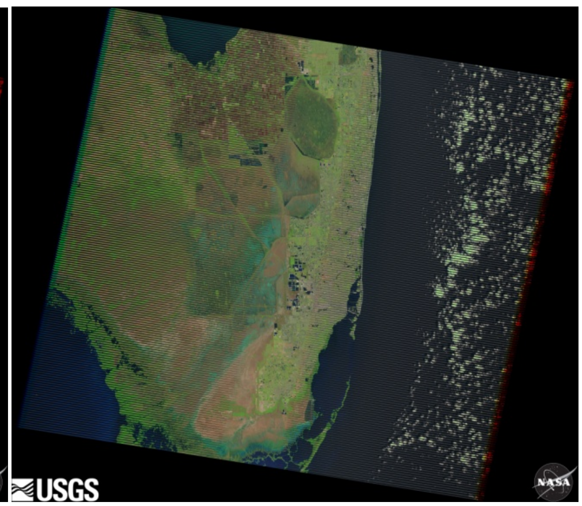


Figure 4.A: Everglades Imagery February 13, 2003
Figure 4.B: Everglades Imagery March 28, 2013
Source: USGS and NASA Landsat 7

The next set of images, shown in Figures 5.A-C, consist of images captured on April 3, 2001 (LE70160422001093EDC01), March 21, 2002 (LE70160422002080EDC01), and March 24, 2003 (LE70160422003083EDC01). Also, consisting of imagery with a less than ten percent cloud coverage, these images fall within a 10-13 day time difference over a three year time span. Table 4: Characteristics Corresponding to the Data Analyzed, provides additional information on the data that will be analyzed. The purpose of both analyses is to observe vegetation change over both a ten year time span and a three consecutive year time span.

Figure 5.A: Everglades Imagery April 3, 2001
Figure 5.B: Everglades Imagery March 21, 2002
Figure 5.C: Everglades Imagery March 24, 2003
Source: USGS and NASA Landsat 7

Table 4: Characteristics Corresponding to the Data Analyzed						
Date	ID Number	Center Latitude	Center Longitude	Path	Row	Cloud Coverage (%)
Comparison #1						
February 13, 2003	LE701504220 03044EDC00	25°59'34.80"N	80°27'41.76"W	15	42	1.17
March 28, 2013	LE701504220 13087EDC00	25°59'22.38"N	80°24'08.35"W	15	42	3.32
Comparison #2						
April 3, 2001	LE701604220 01093EDC01	25°59'34.80"N	81°57'47.52"W	16	42	0.00
March 21, 2002	LE701604220 02080EDC01	25°59'34.80"N	81°58'53.40"W	16	42	2.12
March 24, 2003	LE701604220 03083EDC01	25°58'28.92"N	81°58'51.60"W	16	42	0.43
Source: U.S. Geological Survey Earth Resources Observation and Science (EROS) Center L7 ETM+SLC-off (2003-present) and L7 ETM+SLC-on (1999-2003)						

3.4 Software and Training

The software utilized when analyzing the two sets of satellite imagery is called Environment for Visualizing Images (ENVI). Both ENVI Classic and the newer interface called ENVI 5.2 are used in this thesis. ENVI combines both sophisticated image processing methods with complex geospatial techniques to extract essential information that can assist in the making of more efficient solutions. This software is used for all kinds of satellite imagery including multispectral data, hyperspectral data, and Light Detection and Ranging (LiDAR). While prior knowledge of the software is important, ENVI does provide a number of tutorials that assist individuals with a number of techniques and processes. Other software that is utilized in this thesis include ArcGIS, specifically ArcMap which is used for the production of original maps.

CHAPTER 4 METHODOLOGY

4.1 Introducing the Data

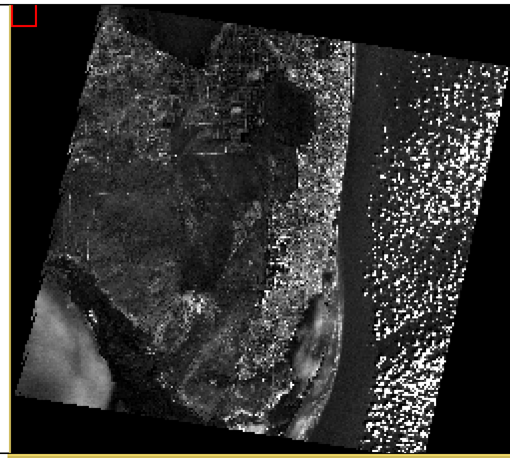
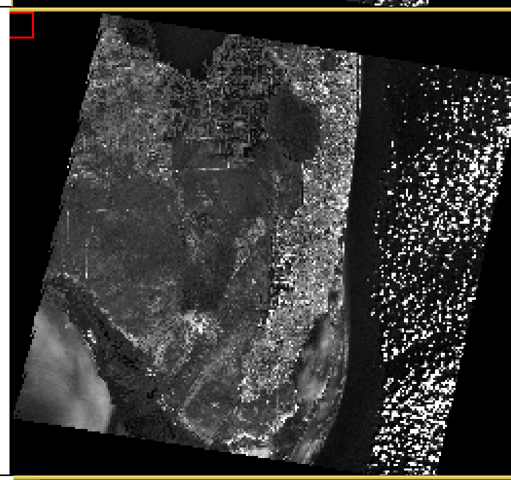
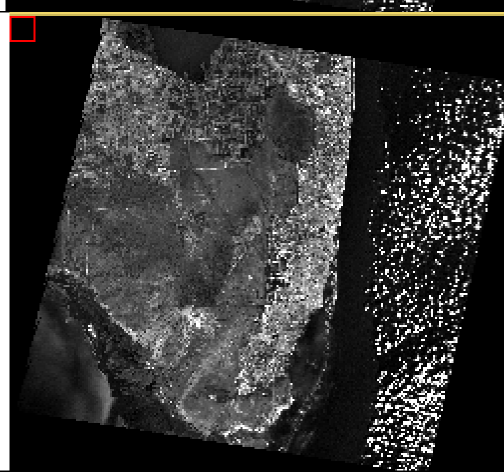
As explained in Chapter 3, the software that is utilized throughout the methodology of this thesis is called Environment for Visualizing Images or ENVI. ENVI is compatible with a number of satellite imagery systems including IKONOS, SPOT, QuickBird, WorldView, and Landsat. ENVI is used not only to view the study data, but the software also provides ways in which to analyze change between images. Processes that involve analyzing change include the classification method, utilizing the Normalized Difference Vegetation Index (NDVI), and using the change detection tool, all available in ENVI.

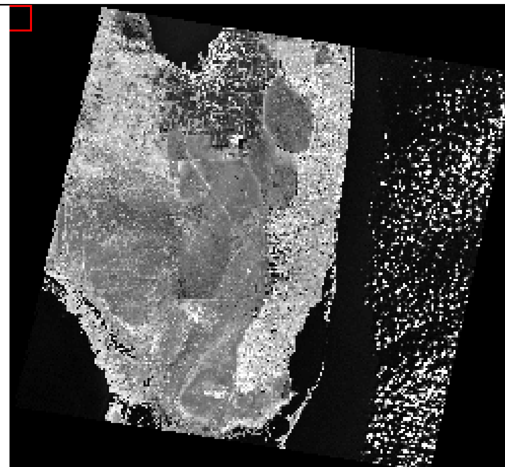
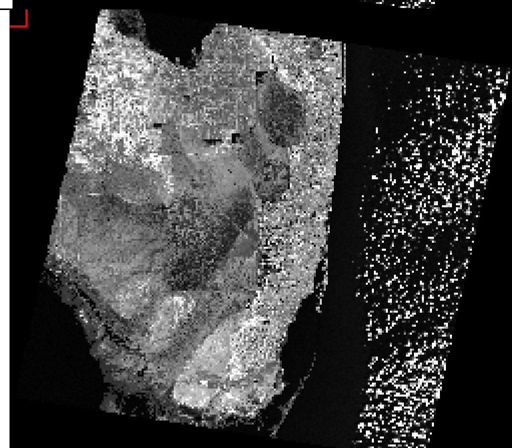
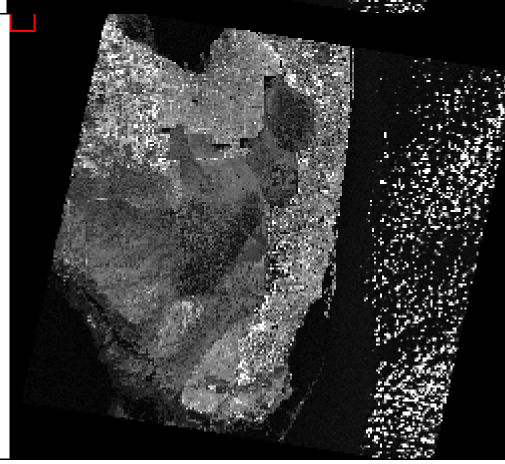
4.1.1 Band Properties

Though most data is freely available on the USGS's website (www.earthexplorer.usgs.gov), some data does require a user to request the satellite imagery prior to it being made fully available. Once the data is made available to the user, the data can be downloaded. The download usually contains an image file and a level 1 package which is a zipped file that requires further file decompression. Fortunately, ENVI Classic is capable of automatically layer stacking the image data. In other words, the ENVI software is able to create a new multi-band file from a specific metadata file within the zipped folder. Once the ENVI software organizes the data, it is important to save the file with the appropriate six band layers as an ENVI Standard file. Following this, it is useful to then load the image in true color.

When comparing images, the files that will be studied are those which contain six band layers: Band 1, Band 2, Band 3, Band 4, Band 5, and Band 7. These files exclude Band 6.1, Band 6.2, and Band 8 which are usually included in the downloaded package. Table 5, titled "Information Pertaining to Different Band Layers", explores the different band layers that are included within a studied image file. As well, the table explains the difference between each band layer's associated wavelength.

Table 5: Information Pertaining to Different Band Layers

Band Numbers	Scroll Window	Information
1		(0.4830 µm, blue-green) This short wavelength of light is able to penetrate more effectively than any other band. This band is usually used for monitoring aquatic ecosystems.
2		(0.5600 µm, green) This band is similar to band 1, but it is usually used when analyzing vegetation.
3		(0.6620 µm, red) This band is useful for distinguishing differences between vegetation and soil and is usually used for monitoring vegetation health.

4		(0.8350 µm, near infrared) At this wavelength, water absorbs most of the light so this is a great band for differentiating water/land interface.
5		(1.6480 µm, mid-infrared) Since this band is sensitive to moisture, it is usually used to monitor vegetation and soil moisture. In addition, this band is used to differentiate clouds and snow.
7		(2.2060 µm, mid-infrared) This band is also used for analyzing vegetation moisture, but is also used for the mapping of soil and geology.

Source: Horning, N. (2004). *Selecting the Appropriate Band Combination for an RGB Image using Landsat Imagery Version 1.0*. American Museum of Natural History, Center for Biodiversity and Conservation. Available from http://biodiversityinformatics.amnh.org.

4.1.2 Image Subsetting

Since the methodology is meant to analyze a specific World Heritage site, it is more efficient to edit the data provided by USGS. The term used for this is image subsetting. Image subsetting is used to not only resize data, but the tool enables a user to reduce the number of bands associated with an image. Since, the number of bands has been reduced in the previous section, the size of the image can be the next item edited. By cropping the image, any analyzed vegetation change becomes constrained to the study area, which in this case is the World Heritage site. There are three ways to crop an image: subsetting via an image (in this case, an image can be cropped by entering the image size by lines and samples), subsetting via a map (in this case, an image can be cropped by entering specific coordinates that determine the extent of an image), and subsetting via Region of Interest (ROI) or ENVI Vector File (EVF). This third option is used throughout the methodology.

In order to subset via a ROI or EVF, a predefined area such as a ROI or EVF is used to determine the extent of an image. In this case, the area that is predefined is the borders of the Everglades National Park. Since, the area being studied is simply the Everglades National Park, it is important to crop out any area that does not fall within the site's borders. By importing a shapefile containing the extent of the park, ENVI converts the shapefile to an EVF which is the format in which ENVI is able to view the shapefile. Figure 6.A displays the shape of the new EVF while Figure 6.B shows an overlay of the vector file on the image file.

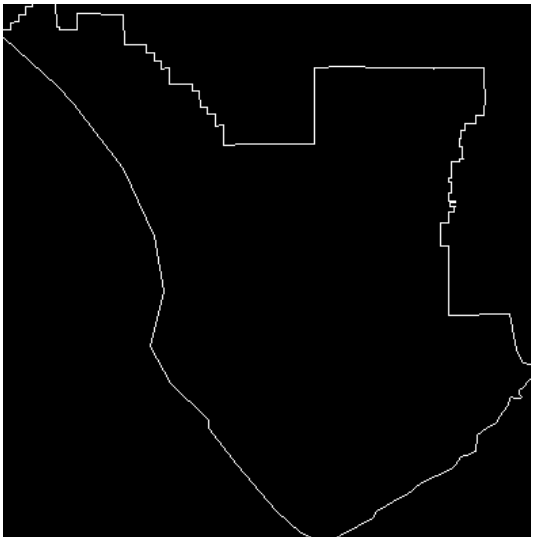
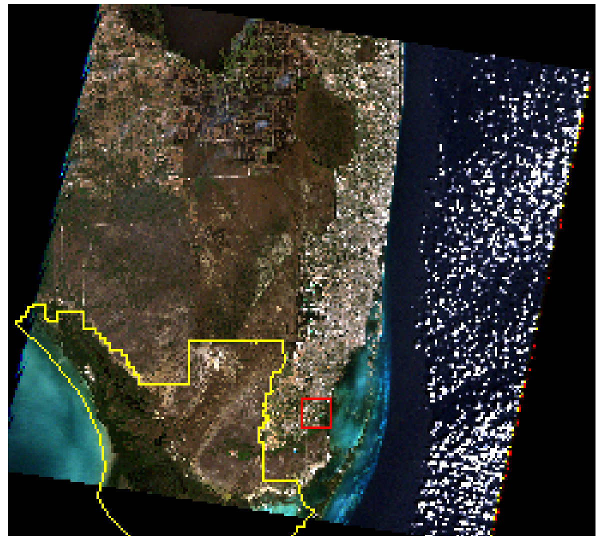
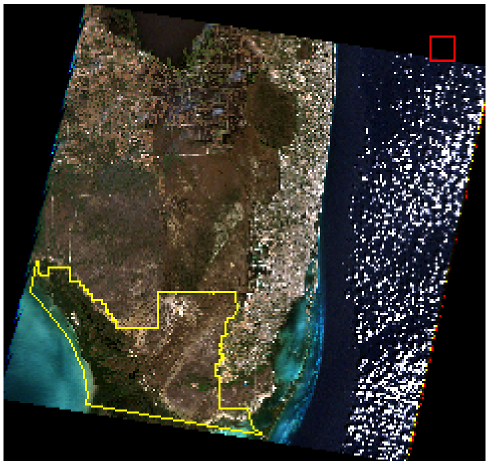
 

Figure 6.A: Everglades National Park World Heritage Site Borders
Figure 6.B: Overlay of ENVI Vector File on Image File
Source: Everglades National Park Boundary from the National Park Service and Colorado State University. Available from http://fcelter.fiu.edu/data/GIS/?layer=enp#layer.

However, since the EVF falls outside of the image file boundary, other techniques must be implemented in order to accurately create a cropped image. In this case, ENVI 5.2 and ArcGIS are utilized to successfully alter the border file. In ENVI 5.2, a newer interface provided by ENVI, a polygon is drawn around the borders that fall within the ENVI vector file. Then utilizing ArcGIS's ArcMap, the Feature to Polygon tool is used to convert the EVF into an ArcGIS polygon. This new polygon and the ENVI 5.2's edited polygon are then intersected using the Intersect tool to create a new vector file that could be used in ENVI Classic to subset the original image file. As seen in Figure 7.A and 7.B, the image file has been cropped to fully focus primarily on changes that may occur within the Everglades National Park.



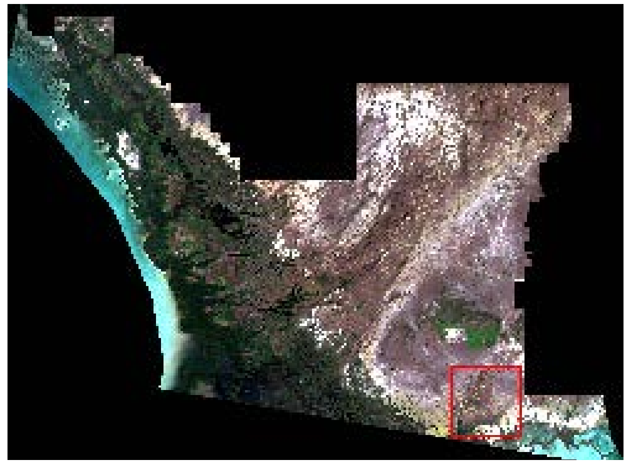


Figure 7.A: Intersected Polygon Overlayed on Image File
Figure 7.B: Cropped Image via ENVI Vector File

4.2 Band Combinations

Before analyzing satellite imagery through the use of change analysis techniques, it is useful to visually interpret the data that is available. This can be done by viewing the satellite images in a number of different band combinations. The term associated with this process is image enhancement. Image enhancement is "the modification of images to make them more suited to the capabilities of human vision" (Eastman, 2001). For visual analysis, color composites involve selecting specific bands to use in an image file. By selecting specific band combinations, the human eye is used to it fullest capabilities. Based on the band combination used, the focus of the subject can change. In addition, a user is able to compare temporal data in this way by linking data. Linking the data is another tool that is especially useful when comparing and analyzing change in different satellite images. It enables images that are displayed in ENVI to be linked geographically so that the same area that is viewed in one display can be viewed in another display.

The following include some examples of how multiband imagery can be used to identify different features in an image. While there are a number of combinations that can be displayed, the band combinations that are the most useful for the purpose of this thesis include Band Combination 3 2 1, Band Combination 4 3 2, and Band Combination 7 4 2. Band Combination 3 2 1, as displayed in Figures 8.A-C, is a color composite that is as close to true color that is available with a Landsat ETM image. This band combination is used for observation purposes since blue usually displays bodies of water and green usually displays vegetation. As Figure 8.B-C show, band combinations can be used to compare images over time (Sample: 3257 and Line: 6227). It can be seen that there are some color changes between the ten year time period and with further analysis a better understanding of the images will be acquired.

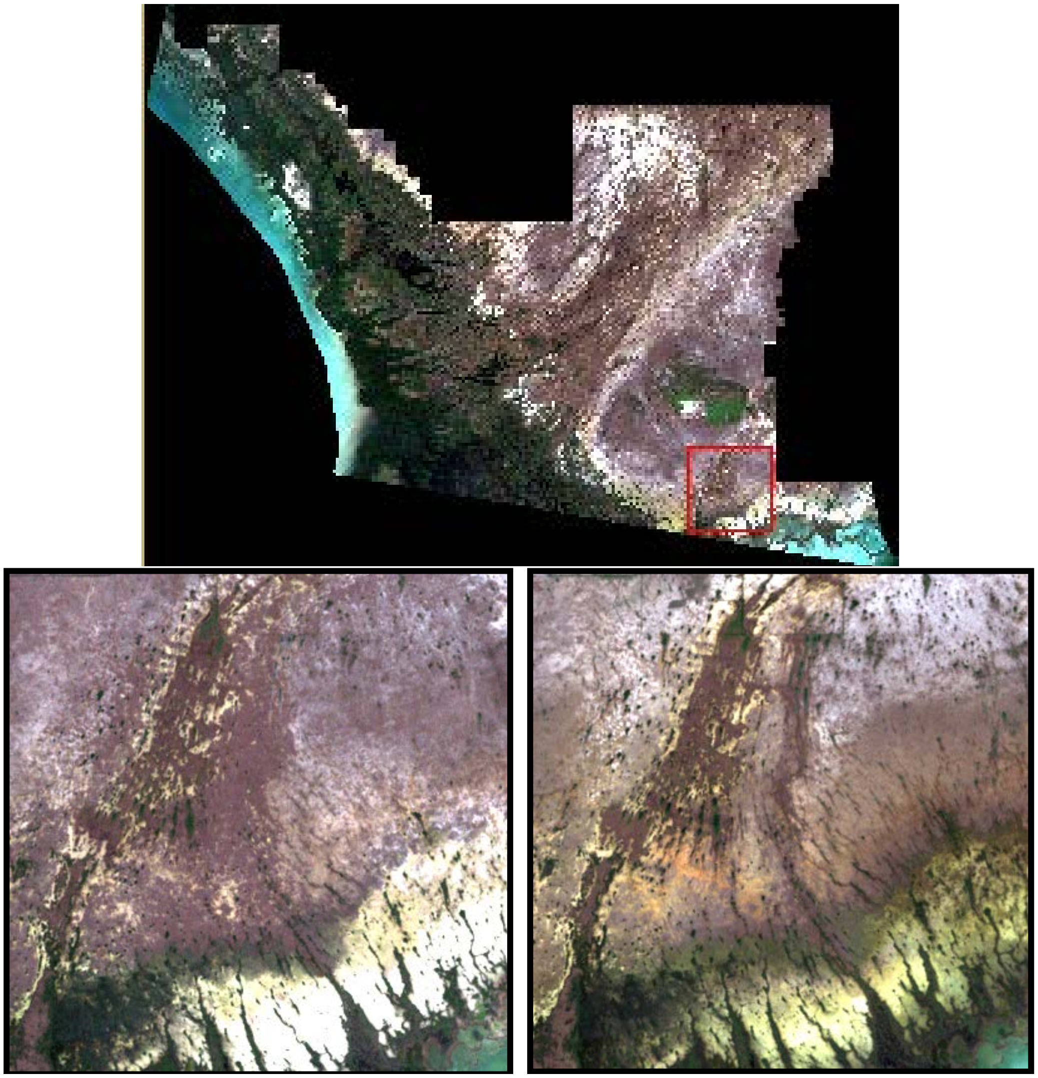


Figure 8.A: Band Combination 3 2 1 for the Cropped Image
Figure 8.B: Band Combination 3 2 1 for Sample 3257 and Line 6227 for 2003
Figure 8.C: Band Combination 3 2 1 for Sample 3257 and Line 6227 for 2013

Band Combination 4 3 2 is another common band combination used when analyzing vegetation change. This band combination includes the near infrared wavelength or band 4 which makes land and water boundaries more understandable. In addition, Band Combination 4 3 2 displays vegetation in shades of red. Figures 9.A-B show an example of this where the shades of red depict varying degrees of vegetation (Sample: 6400 and Line: 5278). It can be seen that when comparing the imagery, from

2001 to 2002, the color that depicts vegetation appears to be shifting toward darker shades of red. It can be concluded that there are evident changes in vegetation between the two year time span. Whether that change involves an increase or decrease in vegetation can be studied further through a variety of remote sensing techniques.

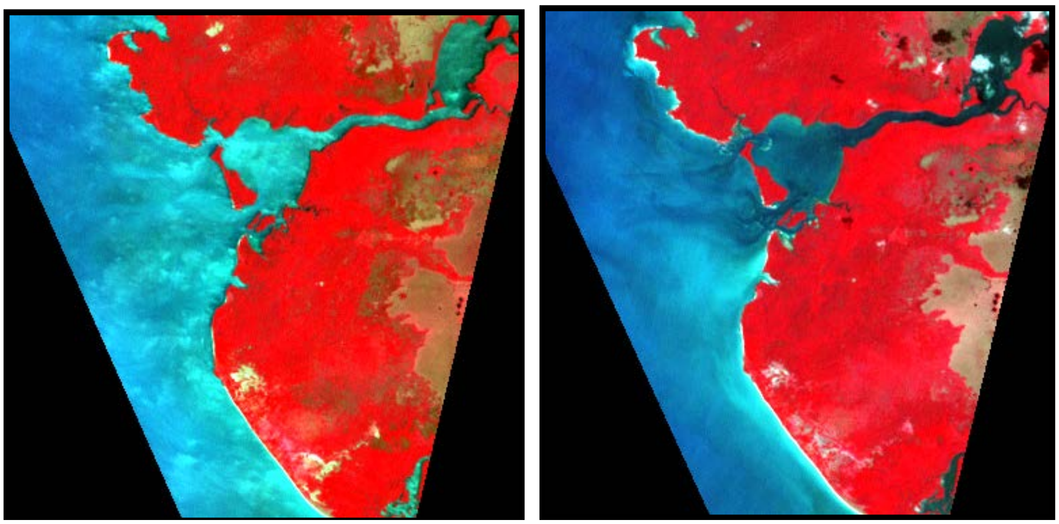


Figure 9.A: Band Combination 4 3 2 for Sample 6400 and Line 5278 for 2001
Figure 9.B: Band Combination 4 3 2 for Sample 6400 and Line 5278 for 2002

A final band combination of importance is Band Combination 7 4 2. This band combination is similar to Band Combination 4 5 3 since shades of green clearly represent areas of vegetation. When viewing an image with this band combination, it can be seen that brighter shades of green display healthy vegetation, darker shades of green display grassland, pink displays barren soil, shades of orange and brown display vegetated areas, shades of blue display bodies of water, and magenta displays areas of urban development. Figures 10.A-B demonstrate a section of the Everglades National Park (Sample: 3254 and Line: 5906) where vegetation appears to be in decline. Near the middle area of the image, it appears that the shades of green are becoming darker from the year 2003 to 2013. This decrease in vegetation can be caused by many factors such as the expanding urbanization in certain areas of the World Heritage site. It is useful to keep track of these areas of vegetation difference in order to prevent too large of a change within an area. While satellite images can be analyzed simply through the combination of different bands, there are techniques available through the ENVI software that enable a user to further study geographic changes. These techniques and tools include classification, using specific formulas such as NDVI, and using the change detection tool, all available through ENVI.

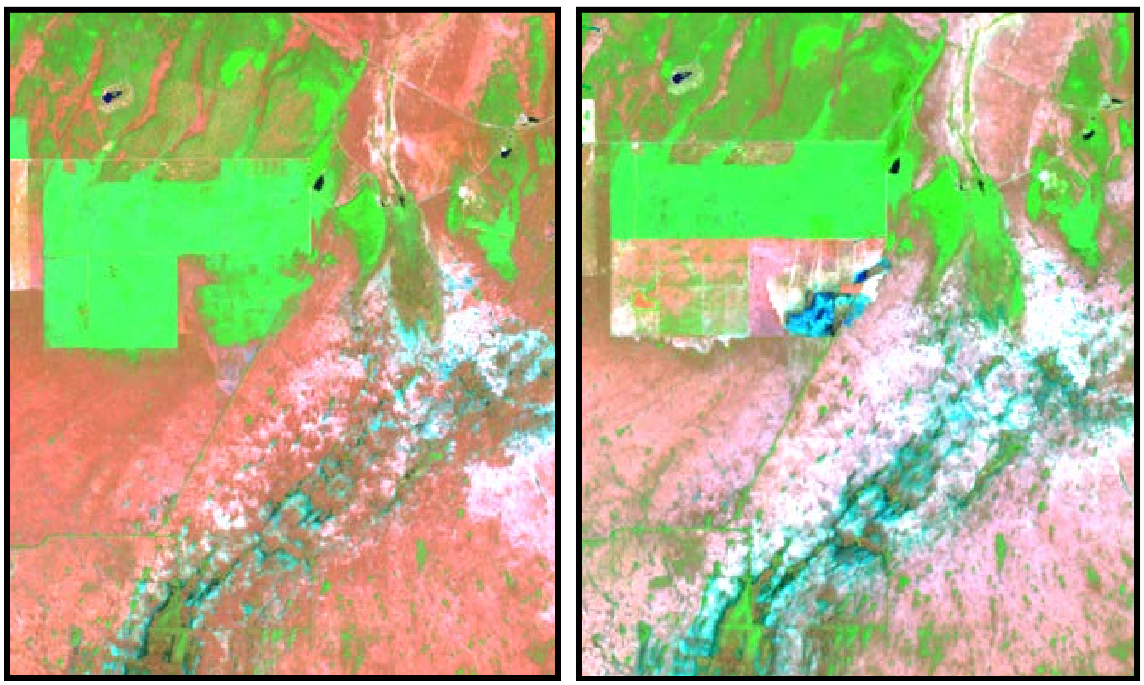


Figure 10.A: Band Combination 7 4 2 for Sample 3254 and Line 5906 for 2003
Figure 10.B: Band Combination 7 4 2 for Sample 3254 and Line 5906 for 2013

4.3 Classification Process

Classification is the "grouping of objects into classes based on their similarity with respect to one or more variables" (Davis & Simonett, 1991). There are two main categories a classification process is placed within: unsupervised classification and supervised classification. Unsupervised classification involves clustering individual pixels into different spectral classes. The procedure is based on ground information collected through field observations and/or analysis of air photos. On the other hand, supervised classification assigns pixels directly to ground information classes through selected training sites. In the methodology section of this thesis, supervised classification is used to get a better understanding of what is going on in the different satellite images being studied.

4.3.1 Unsupervised Classification

The purpose of classification is to distinguish and assign specific ranges of pixel values in spectral bands to different classes within an image. It is important to understand that unsupervised classification determines different classes based on a classification algorithm. This procedure is conducted without much input from a user. The process generates a unique set of spectral classes which are then assigned to different features such as grass, trees, and water. When performing this method, the amount of spectral classes per land cover class can be selected (10 or 15 classes is a good number to start with). There are two kinds of unsupervised classification algorithms incorporated within the ENVI software: K-Means and Iterative Self-Organizing Data Analysis Technique (ISODATA). The K-Means and ISODATA technique are both unsupervised classification techniques that computes the initial mean of each class within a data space and then iteratively combines the pixels into the closest class using a technique called minimum distance (EXELIS, 2014). During each iteration, ENVI recalculates the class means and reclassifies the pixels based on the new mean. For each technique, the iteration process continues until the "number of pixels in each class changes by less than the selected pixel change threshold or the maximum number of iterations is reached" (EXELIS, 2014). Though unsupervised classification is not utilized in the methodology, supervised classification is conducted. The reason for excluding unsupervised classification is because for this methodology different forms of vegetation analysis are conducted and only one form of classification was found to be necessary to portray the significance of utilizing classification as a form of vegetation analysis.

4.3.2 Supervised Classification

While unsupervised classification is initially done by a computer and further decoded by the user, supervised classification is conducted when a user's a priori knowledge of an area and its features is utilized as a training database for the software to more easily identify the different classes within an image. There are three main parts to supervised classification. These include a training stage, classification stage, and an output stage. First, a training dataset should be created by using ENVI's Region of Interest (ROI) tool. The ROI tool allows the analyst to allocate similar ranges of pixels to particular categories. These categories or classes can depict urban areas, water areas, residential areas, vegetated areas, and unclassified areas. Next, the classification stage involves selecting one of the many supervised classification methods made available in the ENVI software. Some examples include Minimum Distance classification, Mahalanobis Distance classification, and Maximum Likelihood classification. Maximum Likelihood classification is utilized in the analysis process of this thesis. This kind of classification computes the probability of a given pixel belonging to one of the specific classes defined using the Region of Interest tool and places the pixel within the class with the highest probability (EXELIS, 2014). For those pixels that do not fall into a specific category, ENVI places them in a separate category called unclassified area. The output stage consists of the processing stage where the final output is provided by ENVI. Figure 11 displays an example of a training dataset while Figure 12 shows an example of a classified image. In this example, the satellite image dated February 13, 2003 is studied using the Maximum Likelihood classification method. The region of interests include water area, barren soil area, sparsely vegetated area, grassland area, and healthy vegetation area. A color is assigned to each region to better visualize what pixel represents which class. As well, the regions selected accumulate over 5,000 pixels each for better results. The final result, Figure 12, shows the Everglades with six different pixel colors. It can easily be seen which area appears to dominant the image. There is a combination of large areas of barren soil and vegetation. It can be seen that the closer the pixel is to the water area, the higher the level of vegetation. ENVI also created an unclassified area class automatically for the area that does not fall within the World Heritage site's boundaries. An accurate classified image is one with an applied mask.

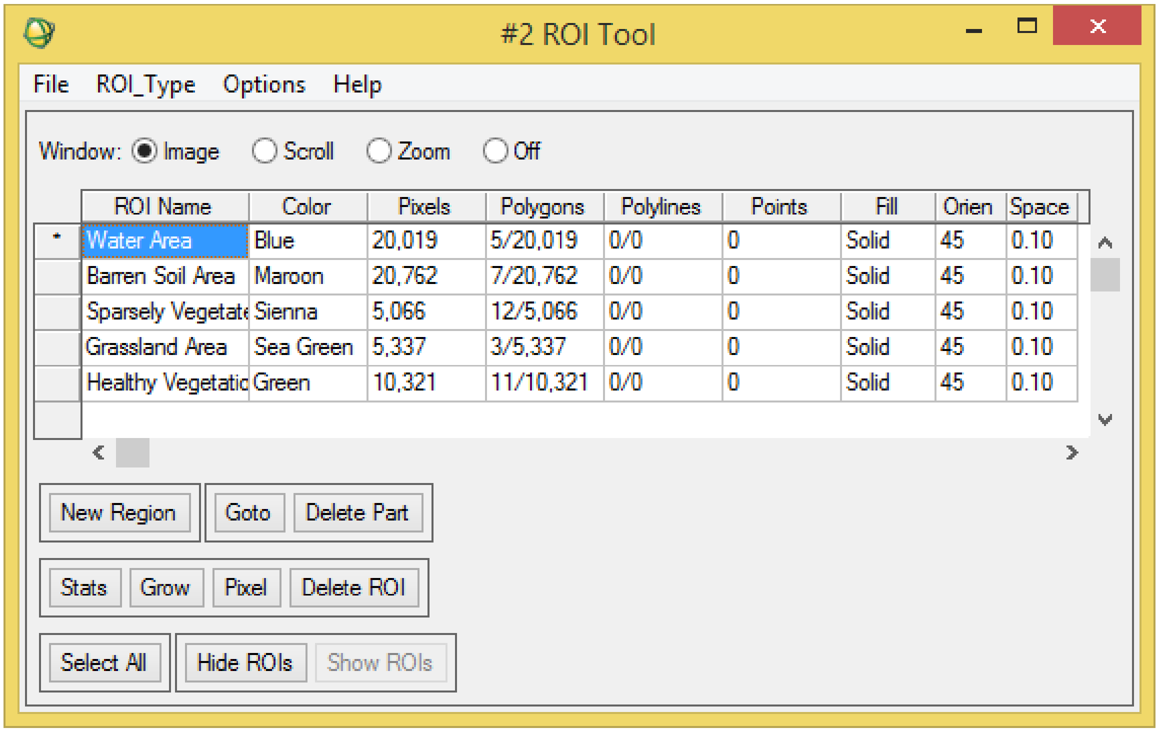


Figure 11: Region of Interest Tool in ENVI

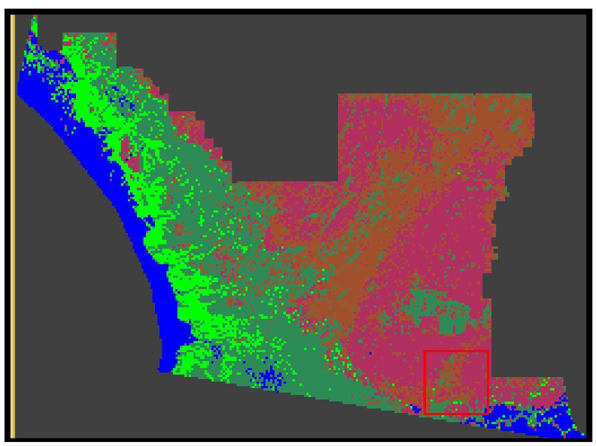


Figure 12: Classified Image-February 13, 2003

4.3.3 Building and Applying a Mask

Building a mask is important for masking out areas that are unwanted and unnecessary for statistical purposes. For example, if a mask is not used during the classification process, it is possible for the background area (whose pixel value is usually zero) to be classified into a region of interest class. This creates inaccurate information when comparing statistics and further analyzing the images. Due to this, masking is especially important for this thesis. There are two parts to using a mask. The first is building a mask and the next is applying the mask. The mask is built by importing the EVF previously used to crop the image and then saving the new masked file. Following this, the mask is applied to processes by selecting the appropriate mask band. As seen in Figure 12, a mask is used in the classification technique in order for the image to be accurately displayed. This is why in the figure, rather than the background of the image being classified as one of the defined classes, the background is instead the color gray.

4.3.4 Importance of Google Earth in Supervised Classification

Google Earth is a virtual globe and geographical information software that maps the earth through the incorporation of remote sensing imagery. Released in 2005, Google Earth is available for use on personal computers running on both Windows and Mac operating systems. This product, which can be purchased free of cost, is an essential part of the classification process. Google Earth which has been classified as a "true global earth image library archive" displays satellite images of the earth at about a 15 meter resolution, making it possible for an analyst to clearly observe specific areas such as the Everglades (Almeer, 2012). In fact, the ENVI software allows a user to link a satellite image being studied to its actual location in Google Earth. As well, Google Earth contains a tool that allows an individual to view an area over time. This historic data can be used as ground truthing for supervised classification. By using the coordinates of an area within a satellite image and comparing it to features presented in Google Earth during the corresponding time period, it is possible to create an accurate dataset that can be used in ENVI during a supervised classification processes. However, though Google Earth is an extremely useful tool, it can lead to over estimations of ground truthing. In effect, an analyst must be cautious when creating regions of interest during a classification process.

4.3.5 Further Analysis of Classified Imagery: Statistics and Confusion Matrix

Further analysis of classified satellite images is conducted through the examination of class statistics and through the making of a confusion matrix. Post-processing is required for classified images in order to evaluate the accuracy of the classification method. The ENVI software contains a function which allows the user to extract statistics from an image used in the classification process. A statistical report is based on the Digital Numbers (DN) of each band. The DN represents the brightness of an individual pixel, meaning the higher the DN, the brighter a pixel. This is why for the area falling outside of the Everglades' borders, the DN is zero. These statistics can be displayed as basic statistics, histograms, and average spectra which are computed for every class. Reports can depict maximum, minimum, mean, and standard deviation values, as well as display histograms of frequency. In addition, a statistical report tends to include detailed information about each class such as the amount of pixels classified into every class, the percentage of each class distribution, and the area of each class. The statistics generated will be discussed further in Chapter 5.

The classification process is a long and complex process which at times can lead to inaccuracies. A confusion matrix or contingency table is usually used for measuring the misclassification of satellite imagery (Dozier & Strahler, 1983). It "compares (the) image class to (the) actual class for a sample of pixels from the image" (Davis & Simonett, 1991). In other words, what is being compared are the classes from the resulting classification images and the classes from the regions of interest that were selected prior to the classification process. The most basic statistic derived from the table is a percentage representing the value of correctly classified pixels. The confusion matrix lists both the user's and the producer's accuracy as both a percentage and amount of pixels. As well, there are some terms that are of great importance. For example, the accuracy is based on the proportion of the total number of classified pixels that are correct. Also, omission and commission errors are important terms. Commission errors or errors of inclusion measure the amount of an area that falls within a category that it does not belong within. On the other hand, omission errors or errors of exclusion measure the amount of an area that is excluded from a category in which it belongs. By studying a confusion matrix, one is able to determine if they need to reexamine the classification process and possibly make some changes to the input data.

4.4 Normalized Difference Vegetation Index (NDVI)

Vegetation interacts with solar radiation in a way that differs from other natural material. Figure 13 titled, "Vegetation Spectrum", displays what is meant by this statement. In the diagram, it can be seen that vegetation is usually absorbed in the red and blue wavelengths and where atmospheric water is present and reflects in the green wavelength and near infrared (NIR) wavelength (Elowitz, 2013). Examining the relationship between these characteristics can provide meaningful information about the amount of vegetation within an image. The relationships discussed are often referred to as vegetation indices (VIs).

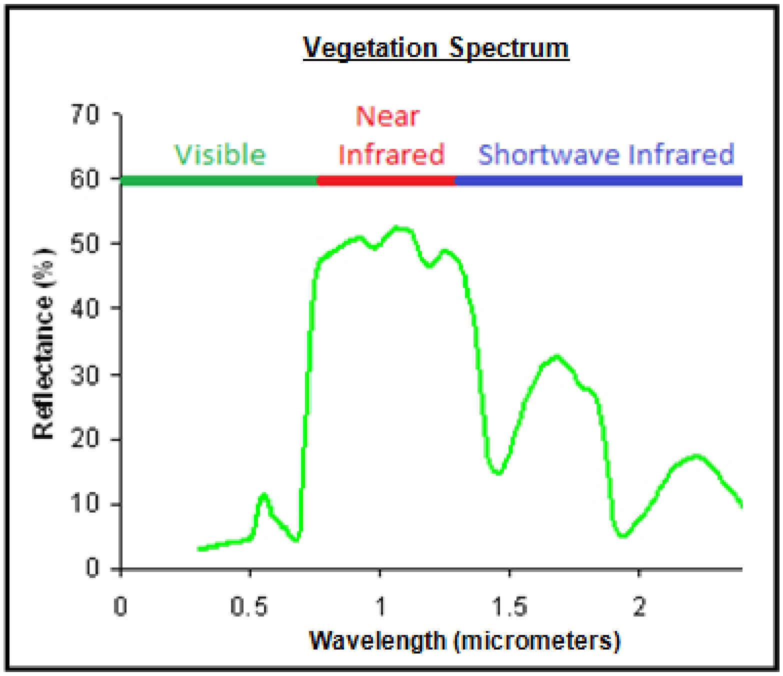


Figure 13: Vegetation Spectrum
Source: Elowitz, M. R. (2013). What is Imaging Spectroscopy (Hyperspectral Imaging)?. Available at: www.markelowitz.com/Hyperspectral.html.

There are a number of vegetation indices that can be used to measure vegetation in the Everglades. These indices are divided into several categories including broadband greenness, narrowband greenness, light use efficiency, canopy nitrogen, dry or senescent carbon, leaf pigment, and canopy water content. For this thesis, Normalized Difference Vegetation Index (NDVI) is most useful. NDVI falls under the broadband greenness category. Broadband greenness describes the health of green vegetation. Vegetation indices that fall within this category are designed to provide an understanding of the overall state of vegetation within an area. The Normalized Difference Vegetation Index is the difference of the amount of near-infrared (NIR) and red bands (R), divided by the sum of the two (Huete et al., 1997). In other word, the formula is usually presented as (NIR-R)/(NIR+R). Since it is a nonlinear function, its value varies between -1 and +1 with healthy vegetation usually falling between the values of 0.20 to 0.80. In other words, the higher the percentage of green vegetation, the closer the NDVI value is to +1. NDVI has been used to measure real world scenarios including seasonal vegetation changes, land cover classification, and large-scale changes in vegetation conditions (Huete et al., 1997). Figure 14 displays an example of a product of the NDVI formula. Part of the Everglades is featured in the lower right corner. Using a green to white color scheme, this figure shows that the darker the shade of green, the more vegetation there is within that area. Results produced by analyzing images using the NDVI formula will be discussed further in Chapter 5.

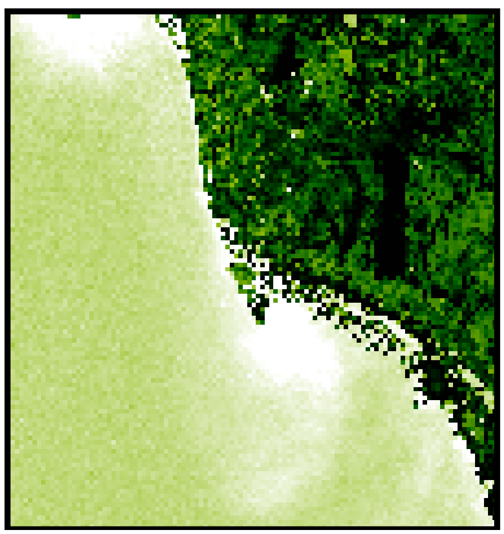


Figure 14: Example of a Product of the NDVI Formula Along the Everglades Border

4.5 Change Detection Technique

Change detection is the process of discovering variations in the state of an area by monitoring it at an assortment of dates (Singh, 1989). It involves quantifying temporal characteristics through the use of multi-temporal datasets. While change detection can be used to observe crop stress detection, assessment of deforestation, and monitoring shifting cultivation, what is being analyzed in this thesis is changes in vegetation. Using remote sensing data for change detection is essential because "change in land cover must result in changes in radiance values and changes in radiance due to land cover change must be large with respect to radiance changes used by other factors" (Singh, 1989). Fortunately, the ENVI software has a multispectral tool which enables the user to observe changes between two datasets. This tool called Change Detection, highlights areas of change based on band ratio or feature index techniques. The Change Detection approach offers both a Change Detection Statistics tool for comparing classification images and a Change Detection Difference Map tool used for comparing single-band images. The Change Detection Statistics tool is used to accumulate a detailed account of alterations between two images that have been classified. The Change Detection Difference Map tool is mainly utilized to produce an ENVI classification image that displays variations between an image from its initial and final state. Both categories are utilized in the methodology section of this thesis and the results are discussed further in Chapter 5.

CHAPTER 5 RESULTS AND DISCUSSION

The purpose of the methodology is to provide an in depth analysis of a case study where remote sensing can be used to monitor a specific World Heritage site. The site which is focused on is called the Everglades National Park, a natural World Heritage site that has been placed on the "In Danger" list twice since its inscription as a WHs. As Chapter 4 explains, while it is possible to compare satellite images through their true color and different band combinations, the ENVI software enables an analyst to further study geographic areas and changes through the use of a number of available techniques and tools. The techniques and tools concentrated on include the classification process, using specific formulas such as the Normalized Difference Vegetation Index, and using the change detection tool. This chapter provides the results acquired through this analysis and discusses the potential of remote sensing technology in combination with the monitoring of World Heritage sites.

5.1 Classification Results

Because of the size of the Everglades National Park, the World Heritage site is large enough that it can be found in two different satellite imagery areas. However, due to scanning issues, the main dataset being compared is located at path 16 and row 42. This data set contains three images dated April 3, 2001, March 21, 2002, and March 24, 2003. This dataset compares four consecutive years with dates that fall within a two week range.

The first change analysis technique utilized is classification. As previously mentioned, the purpose of classifying images is for the ENVI software to understand and assign ranges of pixel values within a spectral band to classes of interest. In this case, the classes of interest include areas of water, areas of barren soil, areas of sparse vegetation, and areas of vegetation. Through the use of analyzing the original satellite images in specific band combinations and assistance from Google Earth, regions of interest were selected and categorized. These regions of interest or ROIs were used during the classification process to produce a Maximum Likelihood supervised classification image. The Maximum Likelihood Classification (MLC) classifier calculates the probability that a specific pixel belongs to a certain class and each pixel is assigned to a class based on highest probability. These classification images were then accepted or rejected based on the confusion matrices they each produced. As well, statistics were computed to better understand what is presented in the images.

5.1.1 Comparing the Dataset: 2001-2003

This dataset compares satellite imagery on a three consecutive year time span from 2001-2003. The imagery is from the spring season and the dates include April 3, 2001, March 21, 2002, and March 24, 2003. The full scene for each satellite imagery within this dataset contains over 2,550,000 points. Based on the maximum likelihood classifier, the points in this dataset are distributed into four classes (areas of water, areas of barren soil, areas of sparse vegetation, and areas of vegetation). The class statistics supplied through ENVI's class statistics tool is shown in Table 6-8 for each consecutive year from 2001-2003. As well, Table 9 compares the percentage difference of each class distribution between 2001 and 2002 and the difference between 2001 and 2003. Based on the data collected through the classification process, it can be seen that (excluding the areas of water class) the two largest percentages of class distribution for spring 2001 is vegetated areas and sparsely vegetated areas, for spring 2002 is vegetated areas and barren soil areas, and for spring 2003 is vegetated areas and barren soil areas. With further analysis the calculation of the percent differences for the years 2001-2002 and 2001-2003 is computed. These numbers are displayed in Table 9 where it is seen that there is a consecutive yearly increase in the percentage of both barren soil areas (2.919% to 6.312% to 8.679) and vegetated areas (11.067% to 11.721% to 12.330%) and a continuous decrease in the amount of sparsely vegetated areas (11.067% to 11.721% to 12.330). These results are very powerful and open a world of further research on the areas of change. Since classification is able to display areas of change, further research can be conducted to understand why the changes may be occurring as well as whether the changes in class distribution are positively or negatively affecting the Everglades.

Table 6: Class Distribution Statistics for Spring 2001

Class Name	ROI Points	Classified Points	Percentage of Class Distribution (%)	Area in Meters²
Water Area	15,707	374,042	14.670	336,637,800
Barren Soil Area	2,506	74,421	2.919	66,978,900
Sparsely Vegetated Area	2,010	229,597	9.005	206,637,300
Vegetated Area	10,361	282,184	11.067	253,965,600
Masked Area	0	1,589,541	62.340	1,430,586,900

Table 7: Class Distribution Statistics for Spring 2002

Class Name	ROI Points	Classified Points	Percentage of Class Distribution (%)	Area in Meters²
Water Area	22,134	355,114	13.927	319,602,600
Barren Soil Area	2,285	160,954	6.312	144,858,600
Sparsely Vegetated Area	2,062	145,316	5.699	130,784,400
Vegetated Area	14,093	298,860	11.721	268,974,000
Masked Area	0	1,589,541	62.340	1,430,586,900

Table 8: Class Distribution Statistics for Spring 2003

Class Name	ROI Points	Classified Points	Percentage of Class Distribution (%)	Area in Meters²
Water Area	15,043	373,080	14.632	335,772,000
Barren Soil Area	2,006	221,306	8.679	199,175,400
Sparsely Vegetated Area	1,593	51,461	2.018	46,314,900
Vegetated Area	5,324	314,397	12.330	282,957,300
Masked Area	0	1,589,541	62.340	1,430,586,900

Table 9: Comparing the Percentages of Class Distributions 2001-2003

Class Name	Class Distribution for 2001 (%)	Class Distribution for 2002 (%)	Class Distribution for 2003 (%)	Difference 2001-2002 (%)	Difference 2001-2003 (%)
Water Area	14.670	13.927	14.632	-0.743	-0.038
Barren Soil Area	2.919	6.312	8.679	3.393	5.760
Sparsely Vegetated Area	9.005	5.699	2.018	-3.306	-6.987
Vegetated Area	11.067	11.721	12.330	0.654	1.263

These class distribution changes can be observed throughout the satellite imagery. Since there is an increase in both the amount of barren soil areas and vegetated areas, there should be an increase in the colors maroon and green throughout the classification images. On the other hand, there is also a decrease in the amount of sparsely vegetated areas, so there should be a decrease in the sienna color throughout the classification images. Figures 15.A-C display the classified image that lies within the borders of the World Heritage site for the years 2001, 2002, and 2003. The change that is most evident in these images is the increase of barren soil areas and vegetated areas. As well, Figures 16-18 display sections of the classified imagery where vegetation change is most apparent.

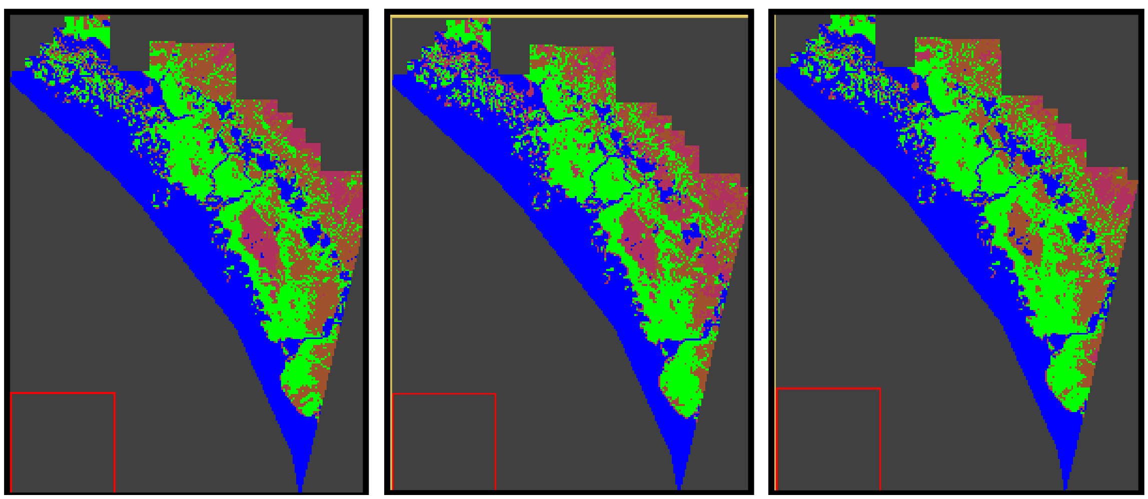


Figure 15.A: A: April 3, 2001 Maximum Likelihood Classifier
Figure 15.B: March 21, 2002 Maximum Likelihood Classifier
Figure 15.C: March 24, 2003 Maximum Likelihood Classifier

As stated, many differences in vegetation computed using ENVI's Class Statistics tool can be seen in sections of the satellite imagery. Each class is represented by a specific color. For example, water areas correspond to the color blue, barren soil areas correspond to the color maroon, sparsely vegetated areas correspond to the color sienna (a lightshade of brown), and vegetation areas correspond to the color green (a bright shade of green). For example, Figures 16.A-C, depict an area located around the Gulf of Mexico, one of the borders of the Everglades. Figures 16.B-C compare classified imagery for the year 2001 and 2002 for the area located at sample 6321 and line 4789. It can be seen that there is an increase in the color maroon or barren soil areas and there is a decrease in the color sienna or sparsely vegetated areas. These changes correspond to what was found in the class statistics. Between 2001 and 2002, the amount of barren soil areas increased from 2.919% to 6.312% and the amount of sparsely vegetated areas decreased from 9.005% to 5.699%. Next, Figures 17.A-C compare the classified imagery from 2001-2003.Focusing mainly on changes in vegetation, the amounts of barren soil areas and vegetated areas increase while the amount of sparsely vegetated areas decreases. In fact from 2001 to 2003, the amount of vegetated area had a percentage increase from 0.654% to 1.263% between the three year consecutive span. Lastly, the final images of classification for the dataset, Figures 18.A-C, show that though there are changes in specific areas of the Everglades, there are still some areas that are less affected by class distribution changes. Though this may seem of little importance, it can be very helpful when using classification methods to pinpoint areas of change. By knowing what areas are unaffected by change, it facilitates the process of knowing which areas are in fact affected by vegetation change and which areas should be focused on more closely.

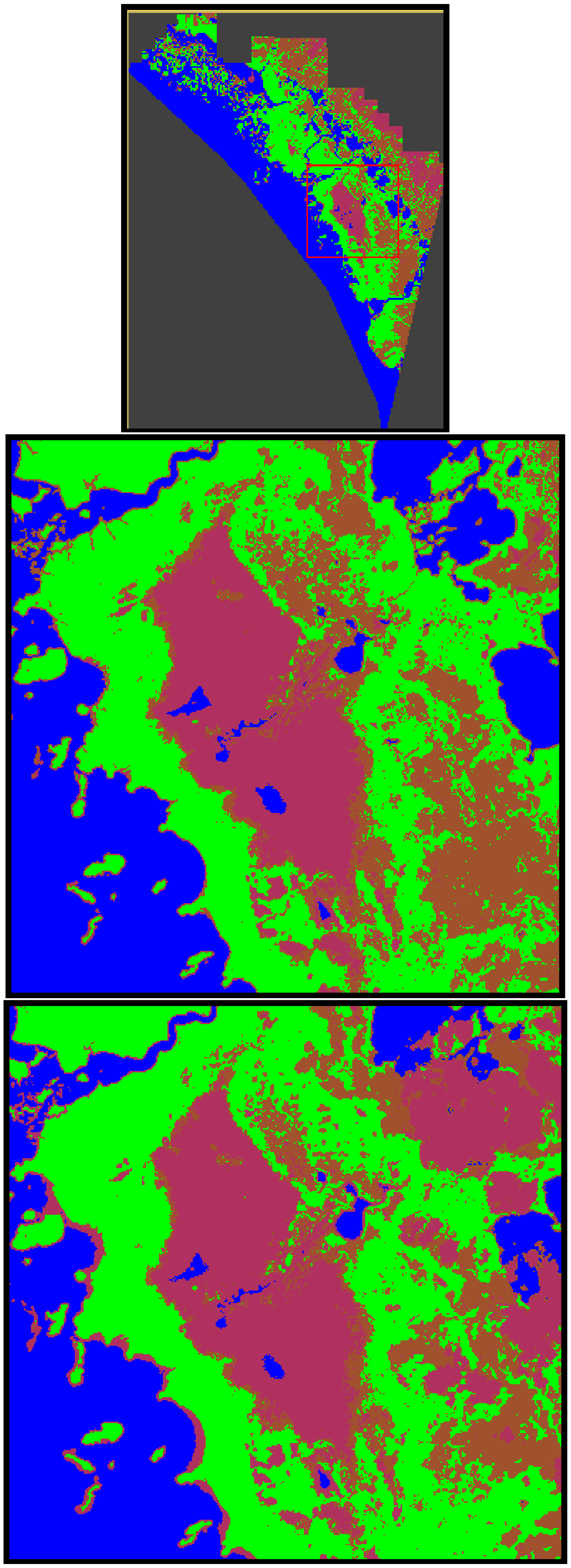


Figure 16.A-C (top to bottom): A: Red box displays the area being studied, B: Sample 6321 and Line 4789 for year 2001, C: Sample 6321 and Line 4789 for year 2002

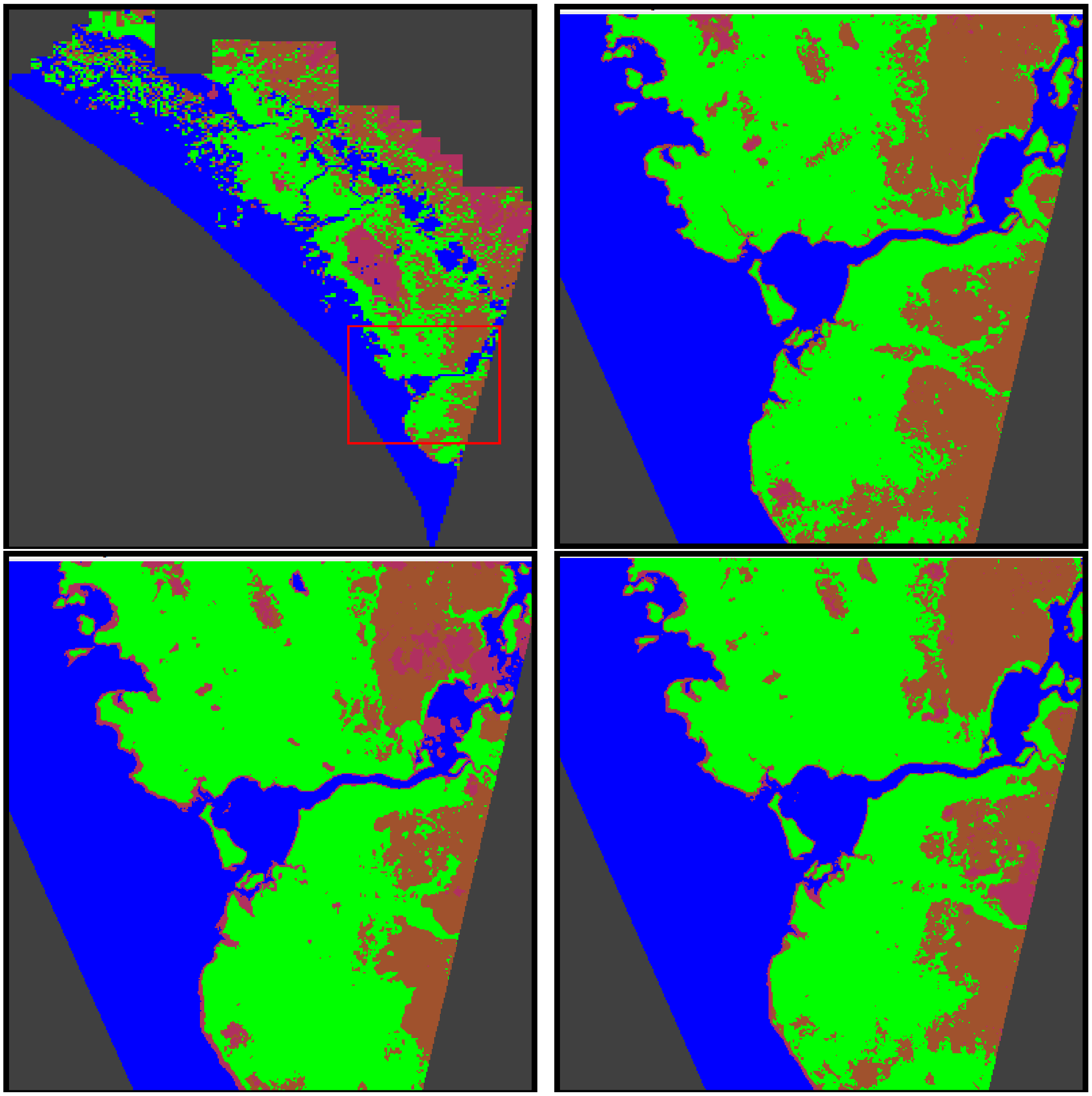


Figure 17.A-C (top to bottom, left to right): A: Red box displays the area being studied, B: Sample 6400 and Line 5278 for year 2001, C: Sample 6400 and Line 5278 for year 2002; D: Sample 6400 and Line 5278 for year 2003

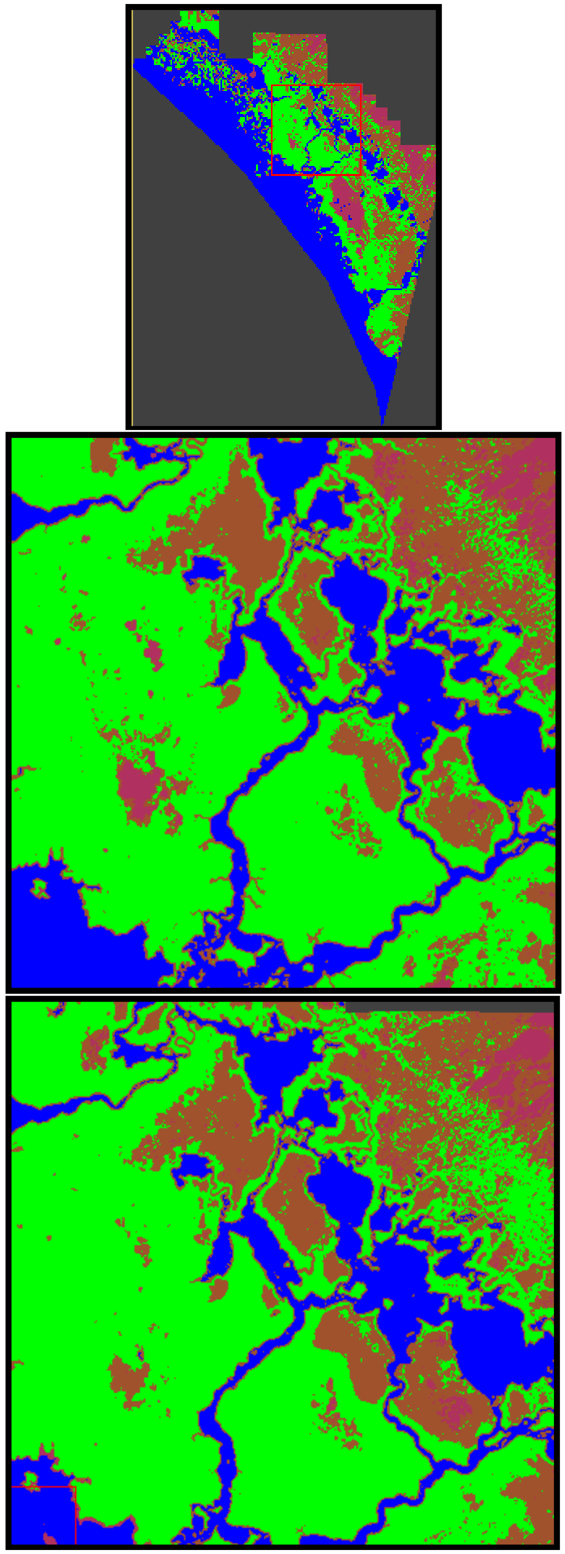


Figure 18.A-C (top to bottom, left to right): A: Red box displays the area being studied, B: Sample 6213 and Line 4480 for year 2001, C: Sample 6213 and Line 4480 for year 2003

Post-processing methods such as creating a confusion matrix are necessary for evaluating the accuracy of a classification process. A confusion matrix calculates the misclassification of satellite imagery and allows an individual to decide if the classification process should be reexamined. In this situation, ENVI generates a confusion matrix that compares the classification image and the regions of interest defined for each image. Figures 19.A-C display the confusion matrices for the dataset while Table 10 depicts essential parts of the various matrices in one chart.

Overall Accuracy = (30481/30584) 99.6632%
Kappa Coefficient = 0.9945

Ground Truth (Pixels)

Class	ROI:2001 Wate	ROI:2001 Barr	ROI:2001 Spar	ROI:2001 Vege	Total
Unclassified	0	0	0	0	0
Water Area [B	15707	0	0	0	15707
Barren Soil A	0	2477	14	8	2499
Sparsely Vege	0	29	1987	43	2059
Vegetation Ar	0	0	9	10310	10319
Total	15707	2506	2010	10361	30584

Ground Truth (Percent)

Class	ROI:2001 Wate	ROI:2001 Barr	ROI:2001 Spar	ROI:2001 Vege	Total
Unclassified	0.00	0.00	0.00	0.00	0.00
Water Area [B	100.00	0.00	0.00	0.00	51.36
Barren Soil A	0.00	98.84	0.70	0.08	8.17
Sparsely Vege	0.00	1.16	98.86	0.42	6.73
Vegetation Ar	0.00	0.00	0.45	99.51	33.74
Total	100.00	100.00	100.00	100.00	100.00

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Water Area [B	0.00	0.00	0/15707	0/15707
Barren Soil A	0.88	1.16	22/2499	29/2506
Sparsely Vege	3.50	1.14	72/2059	23/2010
Vegetation Ar	0.09	0.49	9/10319	51/10361

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Water Area [B	100.00	100.00	15707/15707	15707/15707
Barren Soil A	98.84	99.12	2477/2506	2477/2499
Sparsely Vege	98.86	96.50	1987/2010	1987/2059
Vegetation Ar	99.51	99.91	10310/10361	10310/10319

Overall Accuracy = (40526/40574) 99.8817%
Kappa Coefficient = 0.9979

Ground Truth (Pixels)

Class	ROI:2002 Wate	ROI:2002 Barr	ROI:2002 Spar	ROI:2002 Vege	Total
Unclassified	0	0	0	0	0
2002 Water Ar	22132	0	0	0	22132
2002 Barren S	2	2285	18	2	2307
2002 Sparsely	0	0	2036	18	2054
2002 Vegetati	0	0	8	14073	14081
Total	22134	2285	2062	14093	40574

Ground Truth (Percent)

Class	ROI:2002 Wate	ROI:2002 Barr	ROI:2002 Spar	ROI:2002 Vege	Total
Unclassified	0.00	0.00	0.00	0.00	0.00
2002 Water Ar	99.99	0.00	0.00	0.00	54.55
2002 Barren S	0.01	100.00	0.87	0.01	5.69
2002 Sparsely	0.00	0.00	98.74	0.13	5.06
2002 Vegetati	0.00	0.00	0.39	99.86	34.70
Total	100.00	100.00	100.00	100.00	100.00

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
2002 Water Ar	0.00	0.01	0/22132	2/22134
2002 Barren S	0.95	0.00	22/2307	0/2285
2002 Sparsely	0.88	1.26	18/2054	26/2062
2002 Vegetati	0.06	0.14	8/14081	20/14093

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
2002 Water Ar	99.99	100.00	22132/22134	22132/22132
2002 Barren S	100.00	99.05	2285/2285	2285/2307
2002 Sparsely	98.74	99.12	2036/2062	2036/2054
2002 Vegetati	99.86	99.94	14073/14093	14073/14081

Overall Accuracy = (23957/23966) 99.9624%
Kappa Coefficient = 0.9993

Ground Truth (Pixels)

Class	ROI:2003 Wate	ROI:2003 Spar	ROI:2003 Barr	ROI:2003 Vege	Total
Unclassified	0	0	0	0	0
2003 Water Ar	15043	0	0	0	15043
2003 Sparsely	0	2002	5	0	2007
2003 Barren S	0	4	1588	0	1592
2003 Vegetati	0	0	0	5324	5324
Total	15043	2006	1593	5324	23966

Ground Truth (Percent)

Class	ROI:2003 Wate	ROI:2003 Spar	ROI:2003 Barr	ROI:2003 Vege	Total
Unclassified	0.00	0.00	0.00	0.00	0.00
2003 Water Ar	100.00	0.00	0.00	0.00	62.77
2003 Sparsely	0.00	99.80	0.31	0.00	8.37
2003 Barren S	0.00	0.20	99.69	0.00	6.64
2003 Vegetati	0.00	0.00	0.00	100.00	22.21
Total	100.00	100.00	100.00	100.00	100.00

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
2003 Water Ar	0.00	0.00	0/15043	0/15043
2003 Sparsely	0.25	0.20	5/2007	4/2006
2003 Barren S	0.25	0.31	4/1592	5/1593
2003 Vegetati	0.00	0.00	0/5324	0/5324

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
2003 Water Ar	100.00	100.00	15043/15043	15043/15043
2003 Sparsely	99.80	99.75	2002/2006	2002/2007
2003 Barren S	99.69	99.75	1588/1593	1588/1592
2003 Vegetati	100.00	100.00	5324/5324	5324/5324

Figure 19.A: Confusion Matrix for Spring 2001 Maximum Likelihood Classification
Figure 19.B: Confusion Matrix for Spring 2002 Maximum Likelihood Classification
Figure 19.C: Confusion Matrix for Spring 2003 Maximum Likelihood Classification

Table 10: Confusion Matrices for Dataset, Years 2001-2003						
Year	Overall Accuracy (%)	Kappa Coefficient	Commission (%)	Omission (%)	Producer Accuracy (%)	User Accuracy (%)
2001	99.663	0.995	4.470	2.790	99.303	98.883
2002	99.882	0.998	1.890	1.410	99.648	99.528
2003	99.962	0.999	0.500	0.510	99.873	99.875

Information included in Table 10, "Confusion Matrices for Dataset, Years 2001-2003", includes the overall accuracy of the classification, kappa coefficient, commission and omission percentage, and producer and user accuracy percentage. Since the overall accuracy, which is based on the proportion of correctly classified pixels to the total number of classified pixels, is over 95% for each year's classification, the method does not need to reexamined. However, because the percentage for overall accuracy is rather high, it can be assumed that there may have been some overestimations made during the ground truthing process. The kappa coefficient or k is another way to measure the accuracy of the classification. The percentage of commission and omission errors is also not too high, so that is good as well. Something that is also beneficial towards this study is that the producer and user accuracy are within a similar range for each yearly confusion matrix.

5.2 Results from Change Detection Processes

Similar to classification, change detection is another tool that helps with visualizing where changes in vegetation are occurring. As previously discussed, change detection is a tool available in the ENVI software that uncovers variations within a specific area through the comparison of data over an assortment of dates. For the purpose of this thesis, what is being monitored in the satellite imagery are changes in vegetation within the World Heritage site. There are two parts of the Change Detection tool that will be utilized to further analyze this dataset that dates from 2001-2003. The two approaches are known as Change Detection Difference Map and Change Detection Statistics.

5.2.1 Change Detection Difference Map for the Dataset: 2001-2003

Change Detection Difference Map is used to compare single-band images or classified images and in effect create a new classification image which displays the variations between the initial and final state of a specific area. In other words, the difference is calculated by subtracting the initial state image from the final state image. While brighter pixels represent a positive difference, dimmer pixels represent a negative change. In this case, the there are two change detection difference maps created: one for detected change between classification images from 2001 and 2002 and the second for detected change between classification images from 2001 and 2003. These images can be seen in Figures 20.A-B. Before constructing the change detection difference map, ENVI incorporates different parameters to correspond with the new classified image. Table 11 expands on these characteristics. There are 11 classes defined with each being connected to the amount of change that is depicted in an image. The more important classes include Class 1, Class 6, and Class 11 which are represented by the colors red, gray, and blue, respectively. While Class 1 represents a positive change, Class 6 does not represent any change, and Class 11 represents a negative change. Figures 21.A-E display examples of the variety of classes. Figures 21.C-E depict the values for Displays #1, #2, and #4. These displays correspond to the 2001 classification image, the 2002 classification image, and the change detection difference map between 2001 and 2002. The change detection difference map tool is useful for pinpointing changes that have occurred between two classified images over a specific time span.

Table 11: Definitions for Simple Difference Class Thresholds

Class 1	Change +5	> 0.80
Class 2	Change +4	> 0.60
Class 3	Change +3	> 0.40
Class 4	Change +2	> 0.20
Class 5	Change +1	> 0.00
Class 6	No Change	Equal to 0.00
Class 7	Change -1	< -0.00
Class 8	Change -2	< -0.20
Class 9	Change -3	< -0.40
Class 10	Change -4	< -0.60
Class 11	Change -4	< -0.80

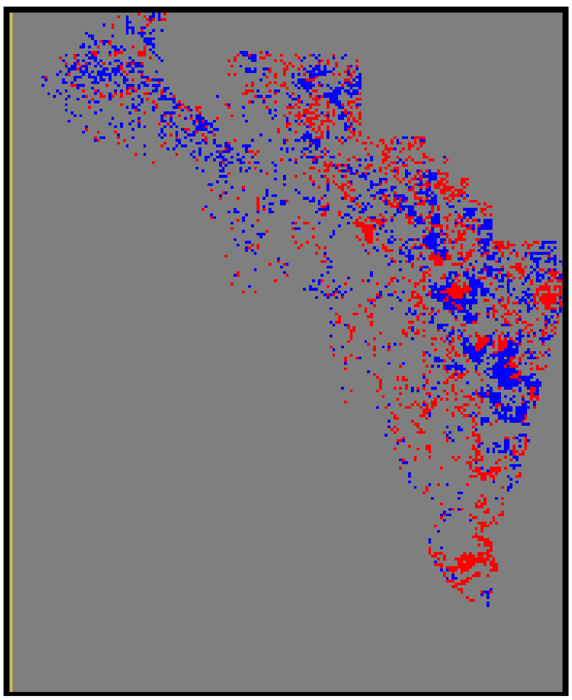
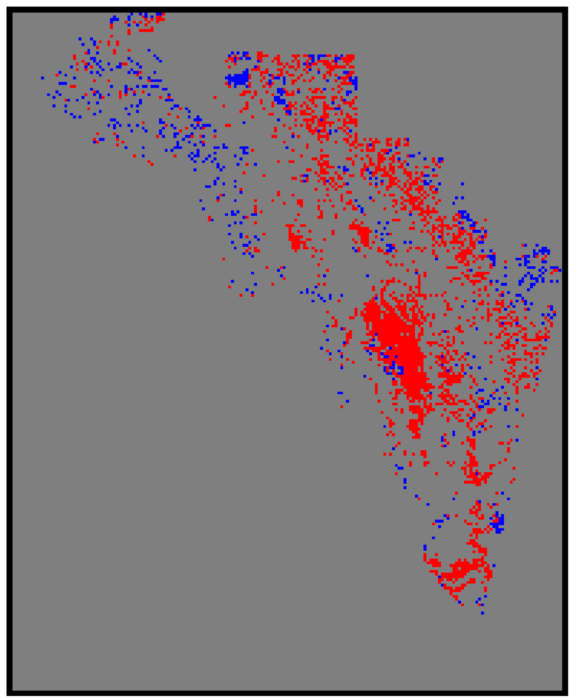
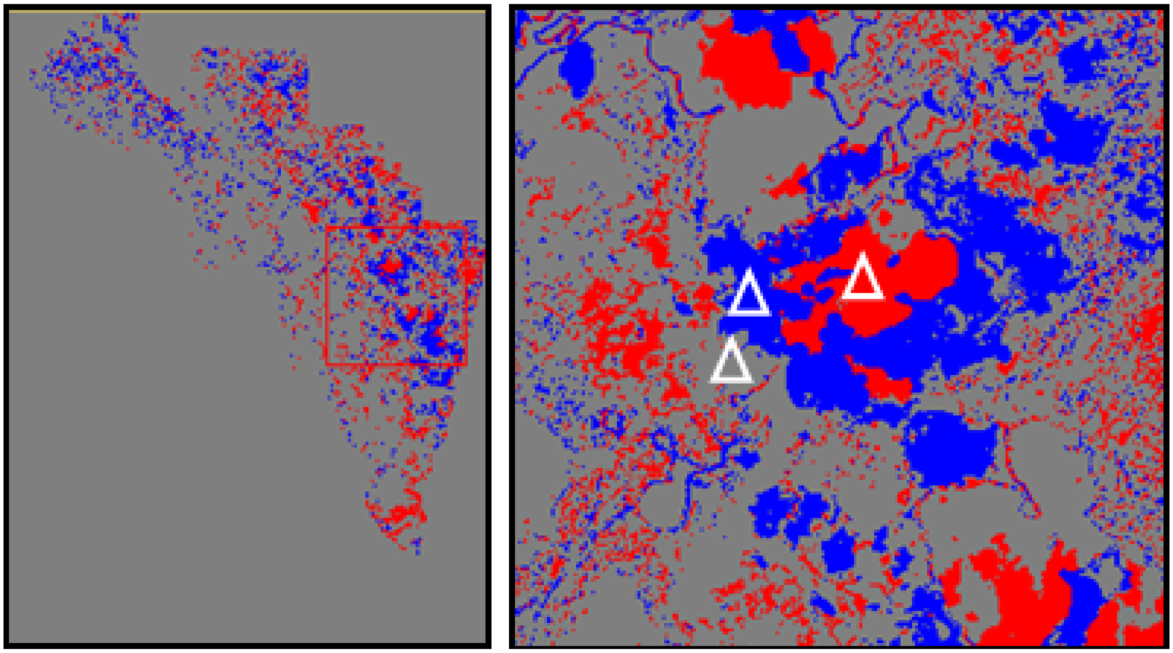



Figure 20.A: Change Detection Difference Map 2001-2002
Figure 20.B: Change Detection Difference Map 2001-2003



Disp #1 Data: 1 {Water Area [Blue] 15707 points}
Disp #2 Data: 2 {2002 Barren Soil Area [Maroon] 2285 points}
Disp #4 Data: 1 {Change (+5)}

Disp #1 Data: 4 {Vegetation Area [Green] 10361 points}
Disp #2 Data: 4 {2002 Vegetation Area [Green] 14093 points}
Disp #4 Data: 6 {No Change}

Disp #1 Data: 3 {Sparsely Vegetated Area [Sienna] 2010 points}
Disp #2 Data: 2 {2002 Barren Soil Area [Maroon] 2285 points}
Disp #4 Data: 11 {Change (-5)}

Figure 21.A: Change Detection Difference Map 2001-2002
Figure 21.B: Cropped Image within Red Box from Figure 21.A
Figure21.C: Class 1 Featured in Figure 21.B as White Triangle with Red Filling
Figure 21.D: Class 6 Featured in Figure 21.B as White Triangle with Gray Filling
Figure 21.E: Class 11 Featured in Figure 21.B as White Triangle with Blue Filling

5.2.2 Change Detection Statistics for the Dataset: 2001-2003

The Change Detection Statistics tool is used to gather a comprehensive account of the variations within the classified images. These tabulations can be supplied as pixel counts, percentages, and area amounts in a number of units such as square meters. A very important aspect included in Table 12 and Table 13 which display the change detection statistics between both 2001-2002 and 2002-2003, is the image difference. This class-for-class statistic compares the initial and final state of each classification image and calculates the amount of change between each time period. These findings correspond to the calculations in Table 9. For example, between 2001 and 2003, there is a decrease in the amount of areas of bodies of water and areas of sparse vegetation. On the other hand, there is an increase in the amount of pixels for the barren soil area class and the vegetated area class.

Table 12: Change Detection Statistics 2001-2002

	2001 Water Area (15707 points)	2001 Barren Soil Area (2506 points)	2001 Sparsely Vegetated Area (2010 points)	2001 Vegetation Area (10361 points)	Row Total	Class Total
Unclassified	0	0	0	0	0	0
2002 Water Area (22134 points)	352211	133	2770	0	355114	355114
2002 Barren Soil Area (2285 points)	20502	55764	66677	18011	160954	160954
2002 Sparsely Vegetated Area (2062 points)	1329	18212	109453	16322	145316	145316
2002 Vegetation Area (14093 points)	0	312	50697	247851	298860	298860
Class Total	374042	74421	229597	282184	n/a	n/a
Class Changes	21831	18657	120144	34333	n/a	n/a
Image Difference	-18928	86533	-84281	16676	n/a	n/a

Table 13: Change Detection Statistics 2001-2003						
	2001 Water Area (15707 points)	2001 Barren Soil Area (2506 points)	2001 Sparsely Vegetated Area (2010 points)	2001 Vegetation Area (10361 points)	Row Total	Class Total
Unclassified	0	0	0	0	0	0
2003 Water Area (25428 points)	365262	1238	2796	0	369296	369296
2003 Barren Soil Area (2216 points)	3740	41278	30153	213	75384	75384
2003 Sparsely Vegetated Area (2375 points)	5040	29100	116733	2712	153585	153585
2003 Vegetation Area (12587 points)	0	2805	79915	279259	361979	361979
Class Total	374042	74421	229597	282184	n/a	n/a
Class Changes	8780	33143	112864	2925	n/a	n/a
Image Difference	-4746	963	-76012	79795	n/a	n/a

5.3 Vegetation Index Results

As previously discussed, there are a number of vegetation indices available through the ENVI software. For this thesis, Normalized Difference Vegetation Index or NDVI is utilized to measure the amount of vegetation found within the satellite imagery. The formula associated with NDVI is (NIR-RED)/(NIR+R) and can be computed as (float(B4)-float(B3))/(float(B4)+float(B3)) when inputted as band math in the ENVI software. In this case, by writing float, the software knows to compute the result as a decimal point and B4 and B3 represent Band 4 and Band 3, respectively.

5.3.1 Comparing the Dataset: 2001-2003

Figure 22 depicts the Normalized Difference Vegetation Index results for each image within the dataset. The color scheme utilized is a green to white where the darker shades of green represent more vegetation and the lighter shades of green represent less vegetation. This is why the lightest green is located where there are bodies of water. The benefit of incorporating the NDVI formula into this methodology is that it enables an individual to locate areas where vegetation is in decline or areas where vegetation increases. Figures 23.A-D show an example of vegetation change within an area located at Sample 6213 and Line 4480. Figure 23.A displays the original image of the World Heritage site using the band combination 7, 4, 2. The band combination is used to enhance and differentiate the various features in the imagery. While the bright green point show areas of vegetation, the pinkish brown pixels represent less vegetated areas. This corresponds to the NDVI images in Figures 23.B-D where the lighter pixels or less vegetated areas are associated with the less vegetated areas seen in Figure 23.A. It is common for the amount of vegetation to fluctuate seasonally and yearly around bodies of water. As the red circle featured in Figures 23.B-D displays there are changes in the amount of vegetation within this specific area. If an individual chooses to study areas of change, they could compare the NDVI data found at each of these locations. Figures 24-25 expand on this idea.

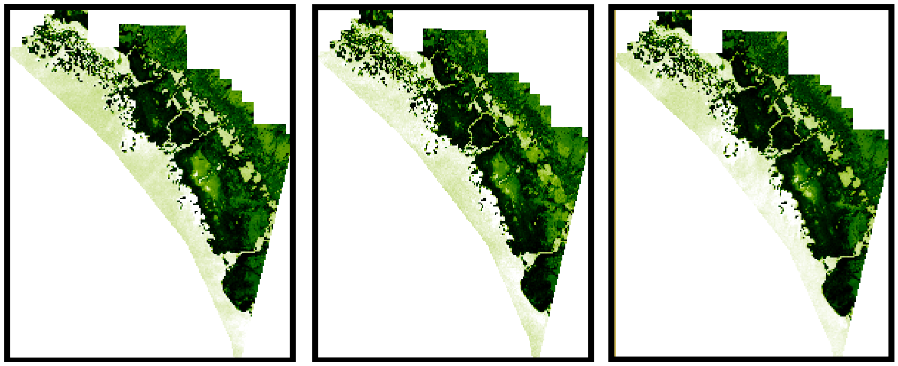


Figure 22.A-C: A: Scroll Window of NDVI for Year 2001, B: Scroll Window of NDVI for Year 2002, C: Scroll Window of NDVI for Year 2003

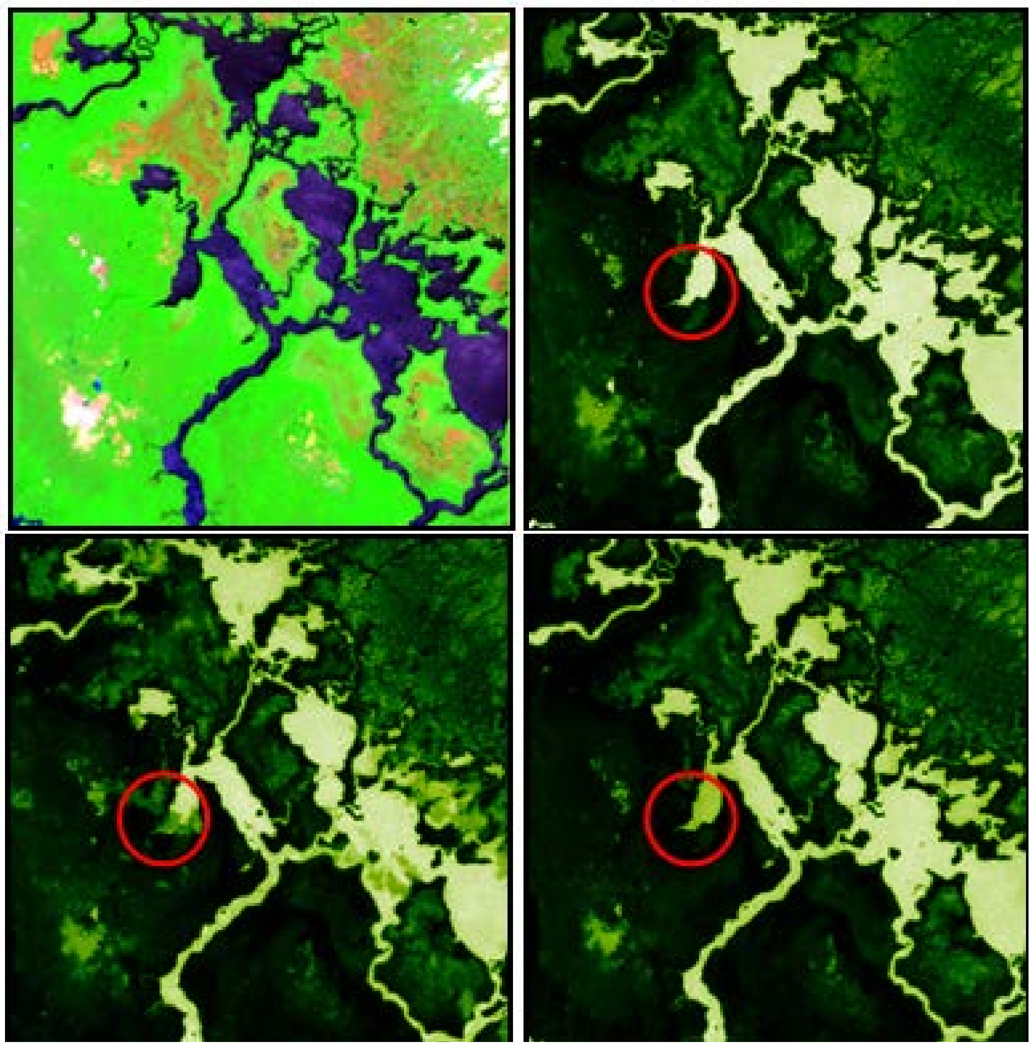


Figure 23.A-D (top to bottom, left to right): A: Sample 6213 and Line 4480 for Band Combination 7, 4, 2 General Image of the Everglades National Park, B: Sample 6213 and Line 4480 NDVI for Year 2001, C: Sample 6213 and Line 4480 NDVI for Year 2002, D: Sample 6213 and Line 4480 NDVI for Year 2003

Once the NDVI process is conducted, a value is given to each pixel within the satellite imagery that corresponds to the amount of vegetation within that specific point. The value ranges from -1 to +1 where healthy vegetation tends to fall between 0.20 to 0.80. So, the larger the percentage of green vegetation, the closer the pixel's NDVI value is to +1. Figures 24-25 display examples of areas of low and high vegetation based on the computed NDVI values. For example, in Figures 24.A-C within the highlighted red circle, lies a body of water. This body of water is more likely to contain less vegetation than land areas as seen by the lighter shade of green attributed to the encircled area. As well, Figure 24.D depicts the NDVI value corresponding to each figure. The values range from -0.4463 to -0.3846; such low values are connected to low vegetation areas. On the other hand, a high vegetation area is featured in the red highlighted circle in Figures 25.A-C. The area presented is the boundary between water and land, but the focus is on the NDVI values calculated for the land mass. As Figure 25.D shows the NDVI values range from 0.4609 to 0.5000. These values fall within an adequate range of healthy vegetation (that range as stated previously, is 0.20 to 0.80). It is common for land areas located along bodies of water to contain more vegetation than areas farther from bodies of water. This tool is helpful when comparing temporal satellite imagery. If a researcher is focusing on a specific area that appears to have a decrease in the amount of vegetation over time, yearly NDVI values can be compared to accept or reject that idea. This method is also useful for individual areas where projects are conducted to increase the amount of vegetation within the World Heritage site. Seasonal or evenly weekly data could be used to determine if the project is successful or not. The following section focuses on the statistics that is available for analysis when utilizing this technique.

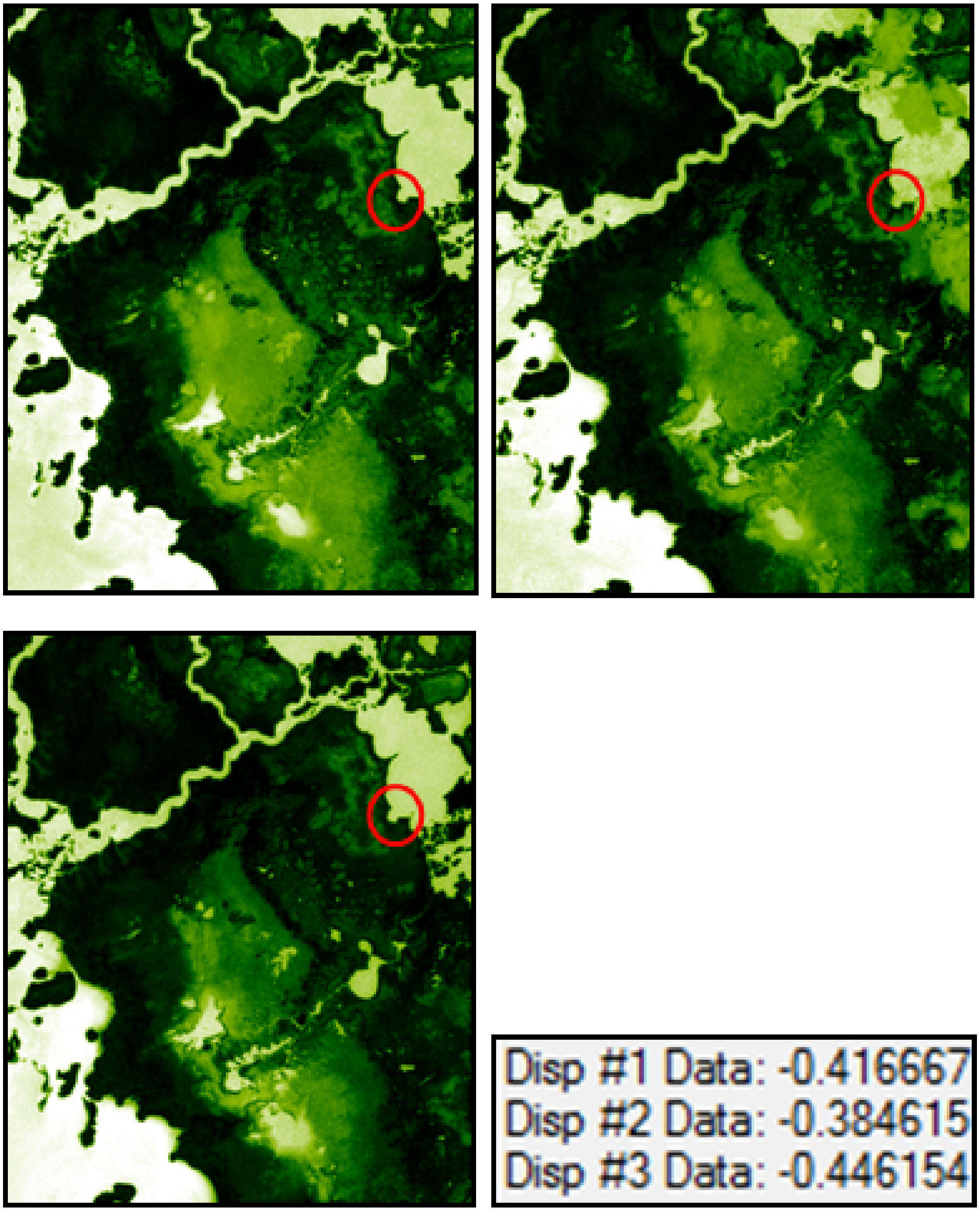


Figure 24.A-D (top to bottom, left to right): A: Display 1 at Sample 6321 and Line 4789 NDVI for Year 2001, B: Display 2 at Sample 6321 and Line 4789 NDVI for Year 2002, C: Display 3 at Sample 6321 and Line 4789 NDVI for Year 2003, D: NDVI Information for Each Display

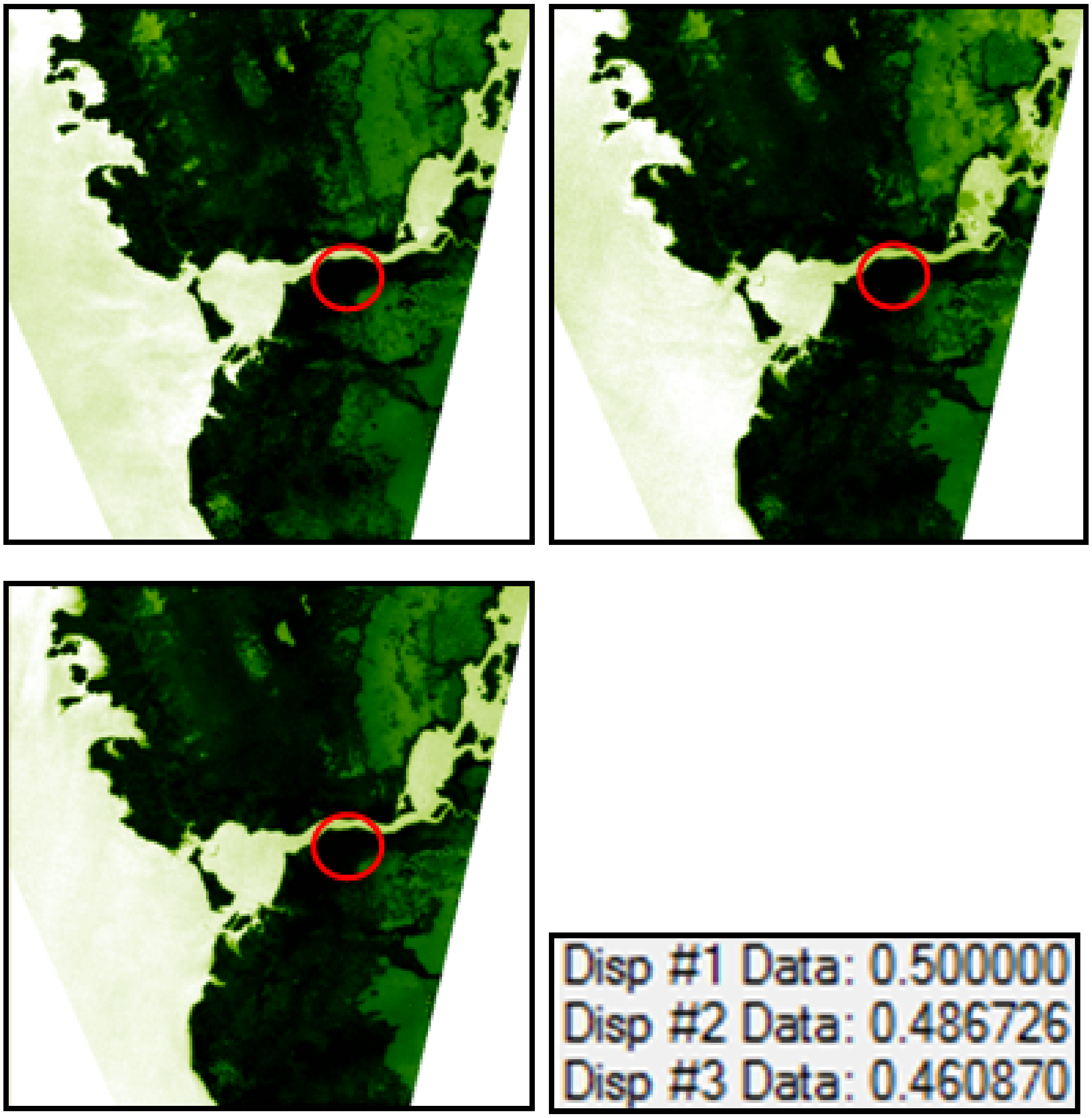


Figure 25.A-D (top to bottom, left to right): A: Display 1 at Sample 6400 and Line 5278 NDVI for Year 2001, B: Display 2 at Sample 6400 and Line 5278 NDVI for Year 2002, C: Display 3 at Sample 6400 and Line 5278 NDVI for Year 2003, D: NDVI Information for Each Display

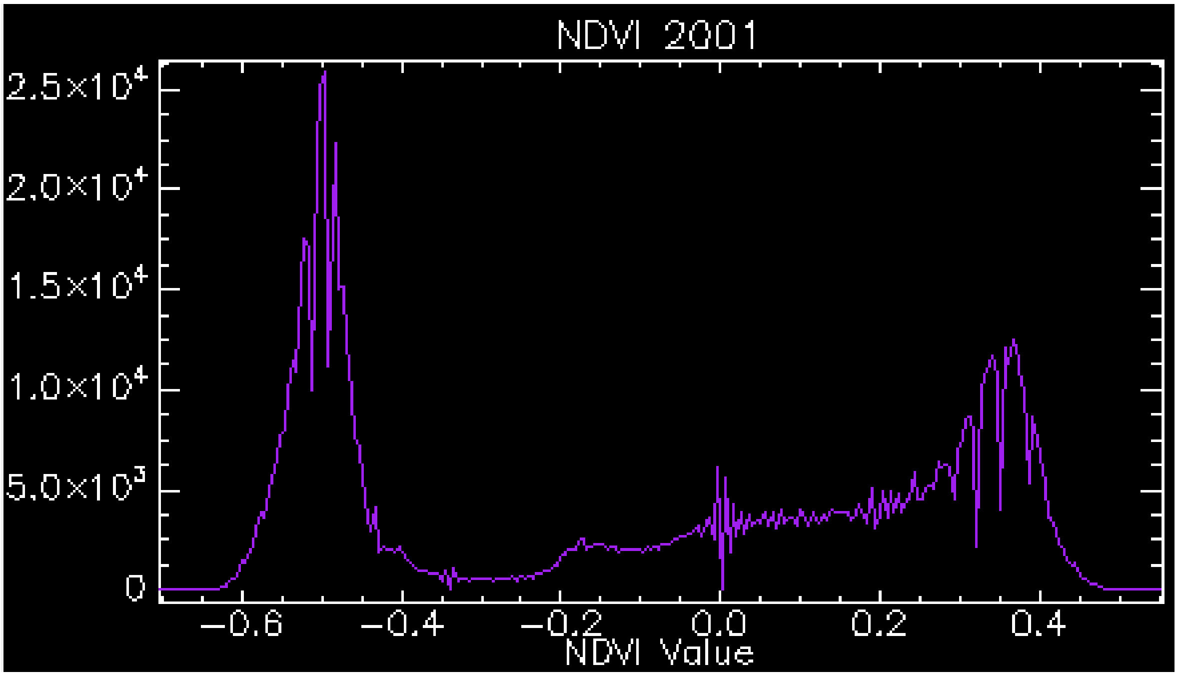
5.3.2 Statistical Results

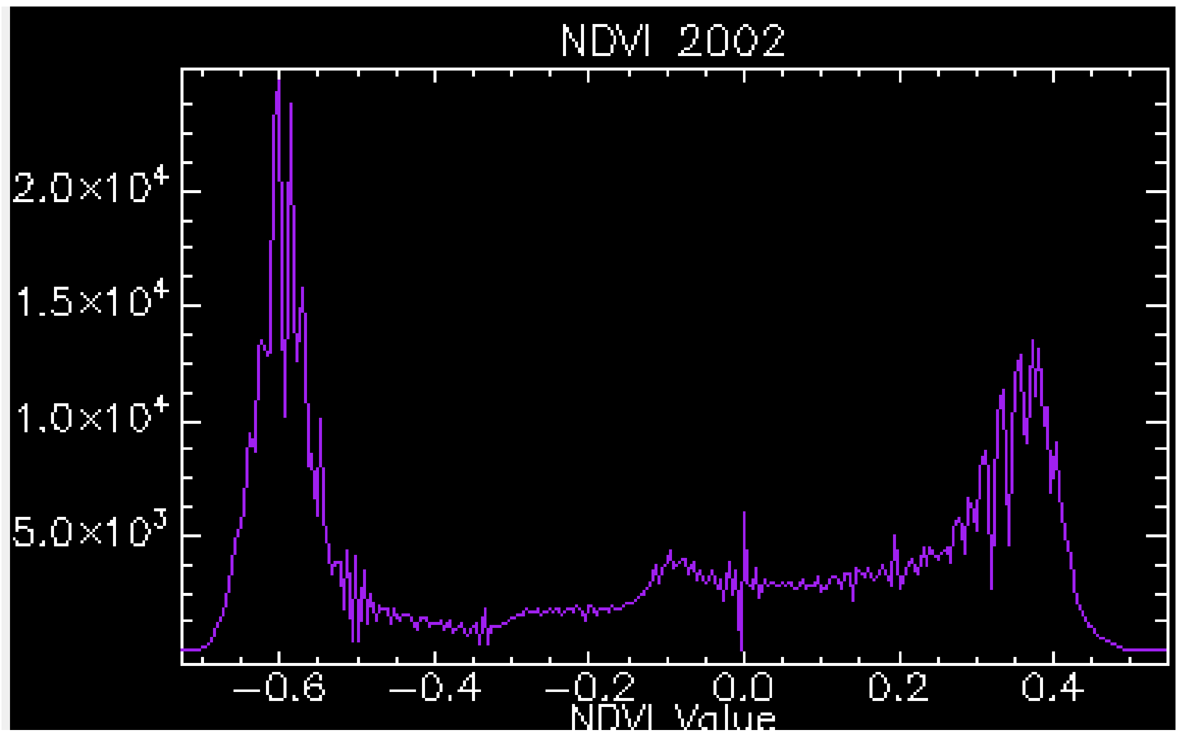
Once the Normalized Difference Vegetation Index is acquired for each satellite imagery, there are statistics available within the ENVI software that can be used for further analysis. For example, Table 14, "Normalized Difference Vegetation Index for

Spring 2001-2003", states important information pertaining to the NDVI formula and the yearly results accumulated from 2001-2003. This information includes the minimum NDVI value, the maximum NDVI value, the mean value, and the standard deviation. As well, as featured in Figures 26.A-C, a graph is provided for each yearly NDVI result. The data presented in the histograms correspond to the information contained within Table 14. What is most interesting to observe is the different peaks along the graph. The most noticeable peaks are the minimum and maximum NDVI values for each year between 2001 and 2003. While, 2002 has the highest amount for the minimum value category, 2001 has the highest amount for the maximum value category. These values can be analyzed for a number of reasons and give an idea of what exactly is occurring within the data when NDVI is conducted.

Table 14: Normalized Difference Vegetation Index for Spring 2001-2003

Year	Minimum Value	Maximum Value	Mean Value	Standard Deviation
2001	-0.7045	0.5538	-0.0842	0.3644
2002	-0.7284	0.5520	-0.1158	0.3984
2003	-0.6632	0.5276	-0.0793	0.3890


NDVI 2001
2.5×10⁴
2.0×10⁴
1.5×10⁴
1.0×10⁴
5.0×10³
0
−0.6
−0.4
−0.2
0.0
0.2
0.4
NDVI Value


NDVI 2002
2.0×10⁴
1.5×10⁴
1.0×10⁴
5.0×10³
−0.6
−0.4
−0.2
0.0
0.2
0.4
NDVI Value

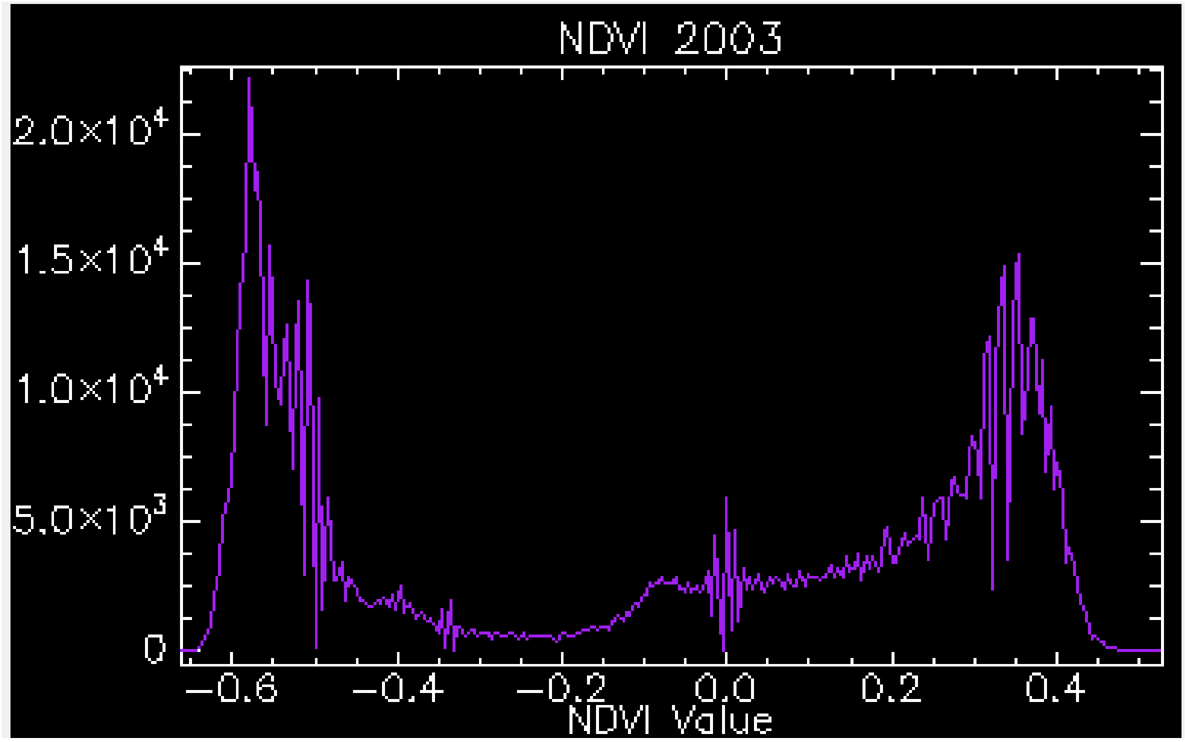
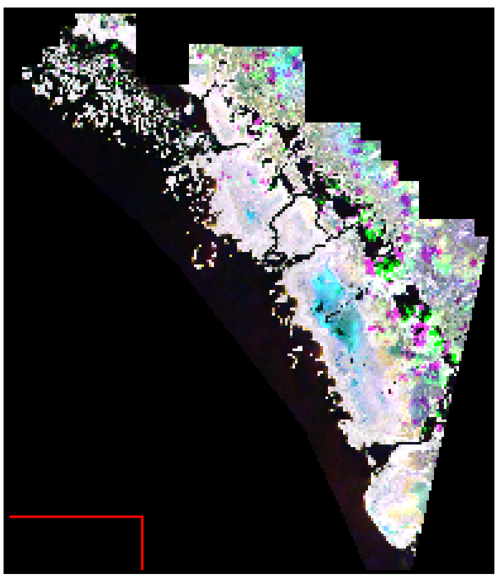


Figure 26.A: NDVI Graph for 2001
Figure 26.B: NDVI Graph for 2002
Figure 26.C: NDVI Graph for 2003

5.4 Discussion of Results

By further analyzing Band 4, one is able to get a better understanding of the results formulated throughout this thesis. While, Band 4 is a useful band for analyzing water and land boundaries, it is also useful for observing changes in vegetation. This can be done by creating an image composite using the same band for each scene dated from 2001 to 2003. In this example, Band 4 for 2003 is assigned to R, Band 4 for 2002 is assigned to G, and Band 4 for 2001 is assigned to B. Figures 27.A-B depict the results created from this band combination. As seen in Figure 27.A, the main colors are displayed as green, red, blue, and gray. When analyzing temporal data in this way, it can be assumed that areas depicted by shades of red such as magenta display locations where vegetation has increased over the three year time span. As well, areas depicted by shades of green display locations where vegetation is evident and has remained at a constant amount and areas depicted by shades of blue display locations where vegetation has decreased over the three year time span. Lastly, the areas displayed as shades of gray represent areas where little or no change has occurred; these areas are not limited to vegetated areas. Figure 27.B displays an area of the Everglades National Park. This area provides an up-close example of the variety of colors produced when creating a composite image of this band combination.



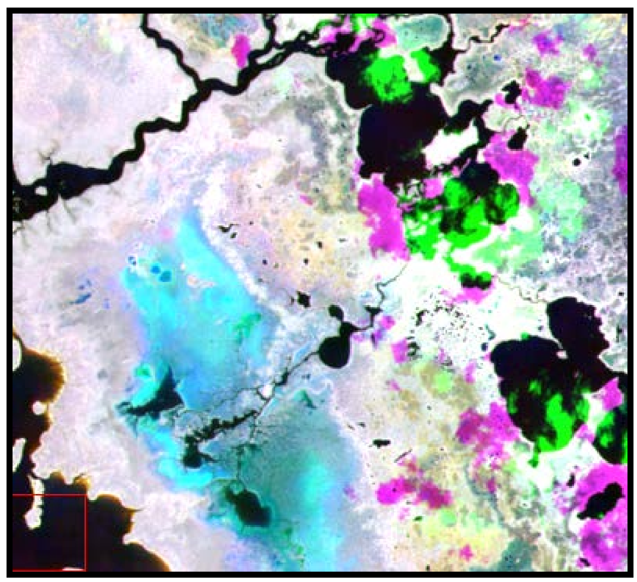


Figure 27.A: Everglades National Park: Band Combination 4 (year 2003), 4 (year 2002), 4 (year 2001)

Figure 27.B: Everglades National Park: Band Combination 4 (year 2003), 4 (year 2002), 4 (year 2001) at location Sample 6205 and Line 4920. The colors displayed in this figure represent a variety of situations: shades of red display locations where vegetation has increased over the three year time span, shades of green display areas where vegetation is evident and has remained constant in amount, shades of blue display locations where vegetation has decreased over the three year time span, and shades of gray display areas where little or no change has occurred over the three year time span.

For this thesis, satellite imagery captured by aircraft or spacecraft is utilized. The satellite imagery is acquired from a Landsat satellite system. The perfect satellite imagery would be one in which all features are clear, with a high resolution, and there would be little or no cloud cover. However, this is not usually the case for imagery available to the public. In fact, there are many limitations associated with acquiring available satellite imagery. To begin with, when comparing temporal satellite imagery, it is important that there is available data provided over an understandable time span. For example, when comparing seasonal data, it is better if there is imagery within a time span where even slight changes can be detected. In this thesis, for the dataset, the imagery is compared on a yearly basis for the following dates: April 3, 2001, March 21, 2002, and March 24, 2003. While the data is captured annually within the spring season, the difference between the dates range from 10-13 days, an effective time period for comparison purposes.

However, once the data is selected, they must be requested and individually examined. The imagery should clearly display a good portion of the area of study. At times, satellite imagery from different paths and rows can be combined to form a greater area of study. Since, the data available to the public is mostly free, it is common for the data to have some flaws. For example, since most imagery is constrained to a 15 or 30 meter resolution, there are instances where an area of study may be too small to be observed in a particular dataset. There are other options when this occurs, but it usually involves paying a fee. The smaller the resolution, or the closer the imagery is to a study area, the higher the cost for the imagery. Another major issue connected to line scanning is a problem commonly found in Landsat 7 imagery. It means that a satellite system did not fully capture an image, there are usually gaps in the imagery which constrains analyzing processes. There is not an easy way to fix such line scanning issues and an individual is left to search for better or similar data.

Another limitation when conducting this kind of remote sensing analysis is the availability of software. While many schools can offer software for satellite imagery analysis, it is not always common place. An alternative could possibly be purchasing a student version of the software. For example, ENVI has a student version available which can be useful for some individuals. While there are some issues pertaining to remote sensing analysis, larger organizations and corporations have more capability to utilize this technology to monitor and preserve World Heritage sites. The capacity of research is huge and should be incorporated by more organizations for the protection of these sites.

CHAPTER 6 CONCLUSION

In addition to being able to pinpoint exact areas of vegetation change, remote sensing techniques utilized throughout this thesis have provided statistics that can be further analyzed. Table 15 is a culmination of the findings produced by the three main methods discussed: classification method, change detection method, and vegetation index method. Through the research and analysis conducted throughout this thesis, it has been shown that within the three year time span (2001-2003), there has been an overall increase in both areas of barren soil (5.760%) and areas of vegetation (1.263%) with a decrease in the percentage of areas classified as sparsely vegetated (-6.987%). These results were gathered through the use of the maximum likelihood classification process available in the ENVI software. The confusion matrix and statistics pertaining to this classification process correspond to the results discovered. The results produced by the change detection tool which further analyzed vegetation change correlate with the results produced by the classification method. As well, by utilizing the NDVI method, one is able to pinpoint changes by selecting a specific area and comparing the vegetation index generated for each date.

Table 15: Culminations of Results When Comparing Data from 2001-2003

Method Name	Change in Amount of Barren Soil	Change in Amount of Sparse Vegetation	Change in Amount of Vegetation
Classification	Increase	Decrease	Increase
Change Detection	Increase	Decrease	Increase
Vegetation Index (NDVI)	n/a	n/a	Pinpoints areas of major change

World Heritage sites are significant areas that exude culture, biodiversity, and history. As previously discussed, Figure 1 titled, "World Heritage Sites Classified as in Danger", displays the locations of the current World Heritage sites classified as in danger. The reasoning for these sites belonging to this list vary from excessive development of an area and destruction caused by natural events such as erosion, weather related incidents, and changes in vegetation to lack of funding needed to preserve the sites and war within or around a site. However, it is essential to monitor these in danger sites as well as all World Heritage sites because the implications that can arise from not maintaining the sites are crucial. Not only would the world lack important sites where culture and history are conveyed, but natural habitats will also be destroyed. Areas of high biodiversity will be lost forever. Lands that are so pristine and natural can be forgotten. This is why it is essential for all humans to try to preserve these areas.

Fortunately, through the utilization of remote sensing technology, it is possible to monitor and observe changes that occur within a World Heritage site. Remote sensing can be used to not only observe changes depicted in temporal data, but it can also be used to identify threats within a World Heritage site. Remote sensing is an extraordinary tool that can and should be used by all site managers and organizations whose goal it is to preserve and protect World Heritage sites. World Heritage sites are irreplaceable sources of beauty, culture, and inspiration. It is our responsibility, as citizens of this world, to guard these treasures.

Based on the results generated throughout this thesis, for further research I would recommend analyzing the many World Heritage sites that are categorized as in danger. It would be essential for the imagery gathered to be collected from sources that provide lower resolution and less cloud coverage. While, similar processes used in this thesis can be incorporated into other studies of World Heritage sites, there are many more techniques that can be utilized depending on the World Heritage site's situation. As this thesis portrays, remote sensing is a powerful tool and has unlimited capabilities in the field of preserving World Heritage sites.

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APPENDIX

A: The World Heritage In Danger List

Appendix A: The World Heritage In Danger List				
World Heritage Site	Date Inscribed	Danger List	Category	Country
Minaret and Archaeological Remains of Jam	2002	2002	Cultural	Afghanistan
Cultural Landscape and Archaeological Remains of the Bamiyan Valley	2003	2003	Cultural	Afghanistan
Belize Barrier Reef Reserve System	1996	2009	Natural	Belize
City of Potosí	1987	2014	Cultural	Bolivia (Plurinational State of)
Manovo-Gounda St Floris National Park	1988	1997	Natural	Central African Republic
Humberstone and Santa Laura Saltpeter Works	2005	2005	Cultural	Chile
Los Katíos National Park	1994	2009	Natural	Colombia
Comoé National Park	1983	2003	Natural	Côte d'Ivoire
Mount Nimba Strict Nature Reserve	1981	1992	Natural	Côte d'Ivoire,Guinea
Virunga National Park	1979	1994	Natural	Democratic Republic of the Congo
Garamba National Park	1980	1996	Natural	Democratic Republic of the Congo
Kahuzi-Biega National Park	1980	1997	Natural	Democratic Republic of the Congo
Okapi Wildlife Reserve	1996	1997	Natural	Democratic Republic of the Congo
Salonga National Park	1984	1999	Natural	Democratic Republic of the Congo
Abu Mena	1979	2001	Cultural	Egypt
Simien National Park	1978	1996	Natural	Ethiopia
Historical Monuments of Mtskheta	1994	2009	Cultural	Georgia
Bagrati Cathedral and Gelati Monastery	1994	2009	Cultural	Georgia
Mount Nimba Strict Nature Reserve	1981	1992	Natural	Guinea

Río Plátano Biosphere Reserve	1982	2011	Natural	Honduras
Ashur (Qal'at Sherqat)	2003	2003	Cultural	Iraq
Samarra Archaeological City	2007	2007	Cultural	Iraq
Old City of Jerusalem and its Walls	1981	1982	Cultural	Jerusalem (Site proposed by Jordan)
Rainforests of the Atsinanana	2007	2010	Natural	Madagascar
Tomb of Askia	2004	2012	Cultural	Mali
Timbuktu	1988	2012	Cultural	Mali
Air and Ténéré Natural Reserves	1991	1992	Natural	Niger
Bahla Fort	1987	P 1988-2004	Cultural	Oman
Fort and Shalamar Gardens in Lahore	1981	P 2000-2012	Cultural	Pakistan
Birthplace of Jesus: Church of the Nativity and the Pilgrimage Route, Bethlehem	2012	2012	Cultural	Palestine
Palestine: Land of Olives and Vines – Cultural Landscape of Southern Jerusalem, Battir	2014	2014	Cultural	Palestine
Fortifications on the Caribbean Side of Panama: Portobelo-San Lorenzo	1980	2012	Cultural	Panama
Chan Chan Archaeological Zone	1986	1986	Cultural	Peru
Niokolo-Koba National Park	1981	2007	Natural	Senegal
Medieval Monuments in Kosovo	2004	2006	Cultural	Serbia
East Rennell	1998	2013	Natural	Solomon Islands
Crac des Chevaliers and Qal'at Salah El-Din	2006	2013	Cultural	Syrian Arab Republic
Site of Palmyra	1980	2013	Cultural	Syrian Arab Republic
Ancient City of Aleppo	1986	2013	Cultural	Syrian Arab Republic
Ancient City of Bosra	1980	2013	Cultural	Syrian Arab Republic
Ancient City of Damascus	1979	2013	Cultural	Syrian Arab Republic
Ancient Villages of Northern Syria	2011	2013	Cultural	Syrian Arab Republic
Tombs of Buganda Kings at Kasubi	2001	2010	Cultural	Uganda
Selous Game Reserve	1982	2012	Natural	Tanzania
Everglades National Park	1979	2010	Natural	United States of

				America
Coro and its Port	1993	2005	Cultural	Venezuela (Bolivarian Republic of)
Historic Town of Zabid	1993	2000	Cultural	Yemen
Source: UNESCO World Heritage Centre 1992-2015				