GIS Analysis of Mangrove Degradation in the Central American Gulf of Fonseca

by

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Olivia Buchanan

Student Name (printed)

Signature

Date 4/22/19
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Abstract

The Gulf of Fonseca relies on its mangrove communities for its environmental, social, and economic well-being. Unfortunately, these areas have experienced considerable environmental change in the past several decades as result of both natural and anthropogenic causes. However, despite conservation attempts in the 1990s, little research has been performed to understand how this region’s mangrove environments have continued to change over time.

This study’s purpose was to determine the changes in mangrove health and extent between 1985 and 2010 using NDVI. Greenest pixel composite images for each year were composed via Google Earth Engine and analyzed in ESRI Arcmap 10.5. The NDVI change for the Gulf and each country was calculated; significance tests between the NDVI averages for each year were conducted for the entire Gulf and by country, each yielding statistically significant differences in means. Mangroves within preserved lands showed little to no change in vegetation health, and in some cases health improvement. Conversely, mangroves outside of preserved boundaries showed high negative NDVI change in vegetation health.

Attempts to determine changes in mangrove extent were inconclusive, and NDVI was found not to be an adequate proxy for determining extent. An NDVI threshold of 0.7 was used for distinguishing mangrove from non-mangrove land cover types and reclassifying accordingly. Area for mangroves would then be calculated for each year of the study period and compared to determine mangrove extent change. However, due to discrepancies in NDVI change, results were inconclusive in that extent was underestimated for 1985 and overestimated for 2010. Further study is suggested to fill this information gap, while utilizing the successful results for changes in mangrove health to identify areas in need of increased conservation.
1. Introduction

1.1 History of the Gulf of Fonseca

On the Pacific side of Central America lies the Gulf of Fonseca, which is shared by the bordering nations of El Salvador, Honduras, and Nicaragua. Lined with communities of mangrove trees and coastal villages alike, the Gulf — and more specifically the mangroves — plays a critical role in the social, economic, and environmental well-being of each nation. The mangrove communities act as: a nursery to both marine and terrestrial species; a coastal barrier against potential damage from winds and storms; a sink for sediment, pollution, toxins, a source of timber, firewood, medicine, etc. for local villages. Figure 1 displays a map of the study area.
Despite the numerous benefits that these mangrove communities provide to natural and societal systems, considerable degradation to the habitat has increased over time as result of deforestation for timber, improved gulf access for fisheries, and the establishment of aquaculture farms. The latter became particularly prominent in the 1980s as shrimp became a main export — especially in Honduras, which possesses the greatest amount of coastline along the Gulf. The Gulf of Fonseca (once again, Honduras in particular) provides an ideal home for shrimp farming with its warm water and air temperatures, and extensive salt flats and mangrove forests (Stanley & Cruz, 2002). Due to the success of this expanding private industry, Honduran government granted concessions to companies allotted for community land (estuaries, beaches, mangrove forest) to be converted into private property for shrimp farming. These farms generally consist of ponds ranging 5-20 hectares in size and lie along the edges of estuaries (Dewalt, Vergne, & Hardin, 1996). These ponds are stocked with postlarval shrimp (either caught from waters off the coast, or born and raised in hatcheries), which are then harvested after approximately six months of growth; the ponds are emptied to begin the cycle again.

Figure 2: An example of shrimp farming ponds replacing local mangrove forests of southern Belize (Ilka C. Feller/Smithsonian Institution, 2018)
Prior to this industry’s boom in Honduras, many poor individuals in the 1960-70s relocated to the then sparsely-populated coastal areas of the Gulf, in order to escape poverty in the nation’s interior regions. These communities became highly dependent on the mangroves and fishing industry for their economic and social livelihoods. As aquaculture companies gained community lands, conflicts between the public and private sectors arose. Public communities blamed shrimping companies for mangrove deforestation, alteration of the hydrology natural waterways/bodies and water quality (due to man-made canals for shrimp ponds), and depriving local farmers access to lagoons and the Gulf. Conversely, shrimping companies countered that ecological issues are result of poor agricultural management further inland, and that local communities are responsible for mangrove deforestation for the use of firewood.

As result of rising the tension between public and private sectors, the mysterious death of five local fishermen in 1993, and pressure from national and international environmentalists and non-governmental agencies, the Honduran government began passing legislation in the 1990s. This reform includes the formation of councils to handle formal environmental complaints and investigations, permit and Best Management Practice (BMPs) requirements for aquaculture farms, and a total of 70,000 hectares designated as protected land (Stanley & Cruz, 2002). The aquaculture industry was increasingly more cooperative as research made it more apparent that sustainable practices were crucial for the industry’s own survival. In the late 1990s-2000s, shrimp production slowed particularly in Honduras and to a lesser extent Nicaragua, as result of Hurricane Mitch in 1998 and the spread of various viruses throughout aquaculture farms of the region (Benessaiah, 2008).
El Salvador has a much smaller industry than that of Nicaragua and Honduras, and thus a much shorter and less eventful history. The industry began in the mid-1980s and boomed shortly after that nation’s civil war in the early 1990s. It initially depended on government funding, but the government’s ability to do so waned, and left the industry to rely on foreign investment and local demand to ensure its continuation (FAO, 2005). While some the nation’s shrimp farmers agree in interviews that the industry needs to shift to sustainable methods, their main priority still remains to be sustaining their income (Rogge, 2015).

1.2 Research Objectives

The mangrove communities of the Gulf of Fonseca provide critical ecosystem services to the region’s environmental, economic, and social prosperity. In order to ensure the continuation of this prosperity, it is crucial to understand the impact of these aforementioned land-use changes on the health of the mangrove communities. Research in the 1990s and 2000s investigated the amount of mangrove habitat lost to land use changes and estimated an approximate 22% of the Gulf of Fonseca has already been lost to these various land use changes (Dewalt, Vergne, & Hardin, 1996). More specifically, approximately one-third of this habitat loss is result of the shrimp farming industry, with the other two-thirds resulting from other procedures (such as poor resource management, timber use, etc.) (Dewalt, Vergne, & Hardin, 1996). However, there has been little to no study regarding the condition of the remaining mangrove habitat of the region, nor how this remaining habitat has changed over time. This lack of study in recent decades is significant considering the (ongoing) measures toward sustainability beginning in the mid-1990s and early 2000s, as well as the reduced production as result of disease and various other natural
phenomena. While there does exist data for mangrove extent of the region for 2010, this data does not indicate how extent and health of the region’s mangroves have changed over time.

This study aims to determine to what degree the health and extent of the Gulf’s remaining mangrove communities have changed by analyzing satellite imagery through ESRI ArcMap 10.5 program. The results for both parts of the study will determine if NDVI can serve as a proxy for calculating change in mangrove health and extent. ‘Greenest’ pixel composites of Landsat imagery for 1985 and 2010 were created via Google Earth Engine and used to determine the change in vegetation health and extent. These greenest pixel composite images are composed of the highest Normalized Difference Vegetation Index (NDVI) value for each pixel within each year of the study period. Vegetation naturally reflects near-infrared light (NIR) and absorbs red light, and this reflection can be made visible through the satellite imagery to represent photosynthetic productivity (vegetation health). The NDVI calculates and assigns a value between -1 and 1 to each pixel of the satellite image, indicating low to high photosynthetic productivity respectively; thus a high positive NDVI value is associated with high vegetative health (Google Developers, 2019). Google Earth Engine provides users with the ability to create ‘greenest’ pixel composite images by assembling the highest NDVI value for each pixel in a given study area and period into one composite image. In this study, composite images for the Gulf of Fonseca were created for the years 1985 and 2010.

These years were selected specifically based on data availability. The first full year of Landsat 5 imagery available is 1985, and thus is the first year of data available to create the greenest pixel composite. The year 2010 was selected based on available mangrove extent data (Giri, et. al. 2011), which provided a baseline for this study’s intentions.
In the first phase of this study, the NDVI for each year of the study period (using the greenest pixel composite images) will be used to determine the change in mangrove vegetation health over time (based on the available 2010 known mangrove extent). In the second phase, changes in mangrove vegetation extent will be calculated by using the NDVI of the greenest pixel composites for each year as a proxy for determining mangrove land cover versus non-mangrove land cover. These changes in mangrove health and extent will be analyzed for statistical significance both the greater Gulf area and additionally by each of the three bordering countries. Maps of these changes, for the total gulf area and for each country, will be created to display these changes over time. In determining which areas of the gulf’s mangrove communities show the greatest change in vegetative health and extent, areas most in need of conservation practices can be illuminated. Local municipalities can also determine areas in need of greater sustainable forestry and aquacultural practices to ensure the continuation of the local environmental and economic health.

2. Methods

2.1 Methodology Justification

This study is divided into two parts using ESRI ArcMap 10.5 for GIS analysis: calculating and assessing change in mangrove vegetation health (part 1) and extent (part 2). The flowchart displayed in Figure 3 explains this study’s procedure in completing the aforementioned parts. Datasets acquired in this study are shown in Table 1.
Figure 3: Study Methodology

Data Acquisition
- Google Earth Engine
- "greenest" pixel composition
- Mangrove forest boundaries
- Country boundaries

Data Processing
- Mask out water
- Calculate NDVI change over time by mangrove boundaries for the Gulf/each country
- Create coastal buffer for mangrove extent
- Reclassify with NDVI threshold separating mangroves vs. other land cover for each year
- Calculate mangrove area per year to find extent change

Data Analysis
- Evaluate variation in descriptive statistics of the Gulf/each country for health and extent
- Tests for statistical significance

End Products
- Map displays of changes in health and extent
- Graph displays of NDVI change
### Table 1: Data Acquisition

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Data Type</th>
<th>Source</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mangrove Boundaries</td>
<td>Polygon</td>
<td>Giri, et. al. 2011 - Global Distribution of Mangroves USGS</td>
<td>Baseline mangrove extent</td>
</tr>
<tr>
<td>El Salvador, Honduras, and Nicaragua Country Boundaries</td>
<td>Polygon</td>
<td>GADM</td>
<td>Create a coastline extent and geographic reference</td>
</tr>
<tr>
<td>‘Greenest’ Pixel Composite Images</td>
<td>Raster</td>
<td>Landsat 5 and Landsat 8 OLI, via Google Earth Engine</td>
<td>Mangrove health and extent change calculations</td>
</tr>
</tbody>
</table>

#### 2.2 Method for Calculating Change in Mangrove Health

To begin the process of calculating vegetation health of the region, the greenest pixel composite images were first cropped to the boundaries of the coastline so as to mask out the image’s reflection of water. Due to water’s absorption of NIR light, it typically appears dark black in the image and therefore would interfere with calculating NDVI of vegetation.

Once water was masked out of the study area, the composite images were additionally cropped to the 2010 known mangrove extent boundaries. With this data available, the study was able to use it as a baseline given that these areas are known mangrove areas for both 2010 and 1985. Hereby, NDVI change was only calculated for the known 2010 mangrove extent of the region, and does not include the approximate 22% of the region Dewalt, Vergne, and Hardin found in their study to be already lost (1996). The NDVI change for this area was calculated via
Raster Calculator by finding the difference between NDVI values of 2010 and 1985 composite images. The following equation shows this process of calculating NDVI change:

\[ NDVI \Delta = 2010 - 1985 \]

Given that the output of this calculation was a raster file with continuous data values, it was then converted to a discrete integer format in order to view the distribution of NDVI change values for the region. Descriptive statistics of each year’s composite image as well as the NDVI change output were calculated using the Band Collection Statistics for further evaluation of the NDVI change over time. Using these derived statistics, hypothesis tests at the 95% significance level of the two independent means for each year was conducted in order to determine if NDVI change over time is statistically significant. These hypothesis tests were conducted on the greater Gulf area and additionally for each country.

### 2.3 Method for Calculating Change in Mangrove Extent

To determine changes in mangrove extent between 1985 and 2010 (the latter year having known boundaries to use for validation), a buffer zone of extending inward from the coast was initially created to ensure that all possible mangroves of the area were included. Moreover, this process would help to reduce overlap between mangrove and non-mangrove land cover by limiting the area being reclassified. Mangroves communities are most commonly found within 10-15 kilometers of the coastline (Long, B. G., & Skewes, T. D., 1996). In this case study, there are known mangrove areas that extend more than 25 kilometers inward from the coast Nicaragua along the Río Estero Real. Thus, the buffer zone created for this study was extended to 30 kilometers inland to ensure known mangrove areas were included.
The NDVI values of the original composite images for the area were used as a proxy for distinguishing mangrove versus non-mangrove land cover. By selecting and identifying specific pixel NDVI values of the known mangrove extent areas, a general threshold NDVI value that separates the two land cover types was determined. Based on this observation and based on other previous studies, a threshold NDVI value of 0.7 was used to distinguish the land cover types and reclassify the composite images (Chen, et. al., 2017; Guha, 2016; Putra, 2015). All NDVI values greater than 0.7 were reclassified as mangrove, and all NDVI values below that threshold were reclassified as non-mangrove.

With these reclassified images, the intended procedure was to convert the raster layers to polygon in order to calculate area for the mangrove land cover for each year. The difference in area between each year would then be calculated and used to determine the change in mangrove extent over time.

3. Results

3.1.1 Results for Change in Mangrove Health for the Gulf of Fonseca

The difference in NDVI between 1985 and 2010 was calculated to determine change in vegetation health over time. Figure 5 displays the results of this calculation, with red and green indicating high negative and positive NDVI change (change in vegetation health) respectively; yellow displays areas of little or no NDVI change. Figure 4 shows the distribution of the NDVI change values for the area. For further reference the distributions of 1985 and 2010 NDVI are displayed in the Appendix.

Descriptive statistics for each individual year and the NDVI change were collected. As shown in Table 2, the average NDVI increased from 1985 to 2010 by 0.1036. The standard
deviation additionally increased between 1985 to 2010. A hypothesis test of the independent means for each year was then conducted at the 95% confidence level to determine if the NDVI change across the Gulf area was statistically significant. These hypothesis test results are displayed Table 3, showing a statistically significant difference in NDVI average for the Gulf over the study period.

Table 2: NDVI Descriptive Statistics for the Gulf of Fonseca

<table>
<thead>
<tr>
<th>Raster</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Maximum Value</th>
<th>Minimum Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>0.644</td>
<td>0.107</td>
<td>0.861</td>
<td>-0.272</td>
</tr>
<tr>
<td>2010</td>
<td>0.748</td>
<td>0.110</td>
<td>1.00</td>
<td>-0.298</td>
</tr>
<tr>
<td>NDVI Change</td>
<td>0.104</td>
<td>0.098</td>
<td>1.00</td>
<td>-0.823</td>
</tr>
</tbody>
</table>
Figure 4: Distribution of NDVI change for the greater Gulf of Fonseca area

Figure 5: Calculated NDVI change for the greater Gulf of Fonseca area

Mangrove NDVI Change* from 1985 to 2010

*NDVI Change was calculated only for mangroves within the known 2010 extent
### 3.1.2 Results for Change in Mangrove Health per Country

The calculated NDVI change was analyzed at the country level, in addition to the entire Gulf area. Descriptive statistics for each country are shown in Table 4. The results show that average NDVI increased over time for each country, with El Salvador experiencing the most change and Nicaragua the least. Honduras and El Salvador each decreased in standard deviation over the study period, while Nicaragua increased in standard deviation. Using these acquired data, hypothesis tests at the 95% significance level were conducted for each country comparing the independent means for each year. The results of these hypothesis tests are listed in Table 5, where each country proved to have statistically significant differences in NDVI averages over the study time.

### Table 3: Hypothesis Test Results for the Gulf of Fonseca 1985-2010

<table>
<thead>
<tr>
<th>Population Size (pixel count)</th>
<th>Critical Value</th>
<th>P-Value</th>
<th>Test Statistic</th>
<th>Significant Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>570,565</td>
<td>0.05</td>
<td>0.000</td>
<td>-510.44</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Table 4: NDVI Descriptive Statistics by Country

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Maximum Value</th>
<th>Minimum Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Salvador</td>
<td>0.639</td>
<td>0.774</td>
<td>0.135</td>
<td>0.104</td>
</tr>
<tr>
<td>Honduras</td>
<td>0.644</td>
<td>0.748</td>
<td>0.104</td>
<td>0.109</td>
</tr>
<tr>
<td>Nicaragua</td>
<td>0.646</td>
<td>0.739</td>
<td>0.093</td>
<td>0.105</td>
</tr>
</tbody>
</table>
Table 5: Hypothesis Test Results per Country

<table>
<thead>
<tr>
<th>Country</th>
<th>Population Size (pixel count)</th>
<th>Critical Value</th>
<th>P-Value</th>
<th>Z-Test Statistic</th>
<th>Significant Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Salvador</td>
<td>56,885</td>
<td>0.05</td>
<td>0.000</td>
<td>-239.17</td>
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<tr>
<td>Honduras</td>
<td>312,661</td>
<td>0.05</td>
<td>0.000</td>
<td>-383.63</td>
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<tr>
<td>Nicaragua</td>
<td>201,003</td>
<td>0.05</td>
<td>0.000</td>
<td>-263.36</td>
<td>Yes</td>
</tr>
</tbody>
</table>

3.2.1 Results for Change in Mangrove Extent for the Gulf of Fonseca

The intended procedure for calculating change in mangrove extent yielded unexpected results. Despite carefully selecting the NDVI threshold at 0.7, reclassifying the original greenest pixel composite images for each year yielded sporadic results in terms of which areas were reclassified mangrove or non-mangrove (Chen, et. al., 2017; Guha, 2016; Putra, 2015). Figures 6 and 7 display the results for 1985 and 2010, respectively.
Figure 6: Reclassified mangrove areas for the 1985 composite image

1985 Mangrove Extent Results

Conchagua Volcano

Cosiguina Volcano

Known 2010 Mangrove Boundaries

20 Km

10 Km
Figure 7: Reclassified mangrove areas for the 2010 composite image
4. Analysis

4.1.1 Discussion of Change in Mangrove Health of Gulf of Fonseca

As shown in Figure 5, the change in NDVI represents the change in mangrove health for the Gulf of Fonseca over time. Red indicates areas of high negative change, yellow of no change, and green of high positive change. While there is a majority of mangrove area (as per the 2010 known extent) that displays no change (yellow coloration), there was an overall increase in average NDVI (vegetation health) over time. The hypothesis test between the 1985 and 2010 NDVI averages were in fact statistically significant. This significant difference between the averages of the years indicates that there has significant change to mangrove health within the gulf area.

This statistical significance is likely due to the inclusion of outlying NDVI values thus affecting the average NDVI for each year used in the hypothesis test. These areas of outlying values were included in the test in order to yield the most accurate results of the condition of the current mangrove habitat. Although the areas yielding visibly high negative NDVI change are in small, specific regions throughout the gulf, they were significant enough to alter the results for the greater gulf area.

This significant difference in NDVI averages over the study period is noteworthy, although additionally notable is that of the increase in standard deviation. This increase indicates that the distribution of NDVI values for the Gulf over time increased in distance from the mean in both positive and negative directions. Although average vegetation health increased over time, there was enough change in both positive and negative extremes to affect the overall NDVI distribution.
4.1.2 Discussion of Change in Mangrove Health per Country

As with the results for the entire gulf area, the results were similar at the country level. Despite a majority of ‘no’ NDVI change values, each country increased average NDVI over time. Moreover, each country had statistically significant results in the hypotheses tests of the means. Once again, this significant difference is likely due to the small, specific areas of the map which show high negative NDVI change. This change, albeit in small, concentrated regions, was significant enough to alter the results for each country as it did for the greater gulf area.

Despite being the smallest of the three nations and having the least productive aquaculture industry, El Salvador proved to have the most amount of change in average mangrove health as evident by the change (difference) in averages of 1985 and 2010. However, it is possible that the nation’s size is the reason for this large amount of change in NDVI. With less mangrove area to contribute to the average, the small areas of concentrated high negative NDVI change are more likely to affect the results. Moreover, smaller areas of mangrove communities are more vulnerable to disturbance than larger areas which can absorb more impact from negative events, be they natural or anthropogenic. It is noteworthy that the mangrove areas of El Salvador included in this study do not lie within preserved regions and thus are vulnerable to environmental change.

Additionally noteworthy is that the standard deviation of El Salvador’s NDVI decreased over the study period. This change indicates that the distribution became more centered about the mean NDVI value, decreasing its distance from the mean in both the positive and negative
directions. Despite Figure 5 showing almost no positive NDVI change within El Salvador, this
decrease in standard deviation over time indicates improvement.

As anticipated, Honduras, which of the three nations possesses the most amount of
coastline and additionally has experienced the greatest amount of growth in its aquaculture
industry, displays geographic areas of concentrated high negative change in mangrove health.
These areas of high negative NDVI change are concentrated within unprotected lands and/or thin
fringes of mangrove forest lying further inland from the coast, and therefore are more vulnerable
to environmental changes, namely the development of shrimp farms. Region A of Figure 5
exemplifies this case, as it does not lie within a preservation area and exhibits high negative
NDVI change. Areas of no change along the coast mostly lie within or near preserved areas, and
have thus been protected from significant environmental change over time. Areas such as that
within Region B exhibited high positive NDVI change, indicating an improvement in mangrove
health over time. This change in Region B is especially noteworthy considering that these
mangroves are mostly along the perimeter of the Reserva Estero Real, and moreover the fringes
of the mangrove community itself which are often the most vulnerable.

Honduras, like El Salvador, shows a decrease in standard deviation and thus an overall
improvement in NDVI distribution over time. This change is indicative of the distribution
changing to become more centered about the NDVI average.

Although Nicaragua’s results were also significantly different between 1985 and 2010,
this nation had the lowest overall change in the mangrove health as compared to El Salvador and
Honduras. As made evident in Figure 5, the mangroves show a majority of no change, and in
some areas even have high positive change (improvement in health) along the perimeters of the
mangrove communities. Considering that these fringe mangroves communities along the perimeter can be most vulnerable, this is a noteworthy change of improvement. The majority of Nicaragua’s mangroves included in this study do in fact lie within the Estero Real Nature Reserve (indicated within Figure 1 of the study area). Thus these areas have largely been protected from environmental change over this study period. Additionally noteworthy is Nicaragua’s unique coastline which has a large peninsula to act as a barrier to shield the mangrove communities within the Gulf. The area with the highest concentration of high negative NDVI change is located within Region C of Figure 5, which coincidentally is not a preserved area and has been subject to environmental change over time.

Unlike El Salvador and Honduras, Nicaragua experienced an increase in standard deviation over time. Although the nation proved to have the least amount of change of the NDVI average, this change in standard deviation indicates that the distribution increased its distance from the mean. Thus, despite the areas of high positive NDVI change within the nation’s borders, there was enough change throughout the NDVI spectrum to increase the range of the distribution about the average.

4.2 Discussion of Change in Mangrove Extent for the Gulf of Fonseca

Due to the inconclusive reclassification results, this part of the study was successful in determining that NDVI cannot serve as a sole proxy for finding the change in mangrove extent. Despite careful measures taken in selecting the NDVI threshold at 0.7 (Chen, et. al., 2017; Guha, 2016; Putra, 2015), which was expected to distinguish mangrove versus non-mangrove land
cover, it is evident by the results that NDVI was in fact not an adequate proxy for making such a distinction.

As evident in Figures 6 and 7, the overall NDVI for 2010 was higher than that of 1985 for both known mangroves and non-mangrove areas. Figure 7 shows that there is greater contrast between mangrove areas and agriculture/aquaculture plots in 2010, which was expected to aid in distinguishing land cover and thus calculating mangrove area. Comparing Region A (the town of Choluteca) and the Gulf’s volcanoes in Figures 6 and 7, the NDVI has visibly increased in 2010 from 1985. This is also evident in the greater amount of area reclassified as mangrove in 2010 in comparison to the 1985 reclassification, implying that the entire region has higher NDVI both inside and outside of mangrove areas. While the 2010 reclassification overestimated the amount of mangrove areas, the 1985 reclassification actually underestimated mangrove extent and excluded areas which are both visibly part of forested area and also known to lie within the 2011 Giri et al. boundaries, as shown within Region C of Figure 6.

These inaccuracies are likely due to changes both within and outside of mangrove communities overtime. More specifically, areas within protected land have had little change over time, meanwhile land outside mangrove communities has changed due to increased agriculture/aquaculture and development. Region B of Figures 6 and 7 illuminate this increase in aquaculture as the lines of shrimp farms are more visibly prominent in 2010 than 1985. Another possible source of these discrepancies is the difference between Landsat platforms in 1985 versus 2010. Landsat 5 of the 1980s has different qualities and band ranges than that of Landsat 6 and 7, which have continuously larger band ranges and therefore can perceive reflectance slightly differently.
Due to this disproportion of NDVI change, it is evident that NDVI cannot be used as an accurate proxy for distinguishing mangrove and non-mangrove land cover types. In order to determine the change in extent for the area’s mangroves over time, a more intricate procedure is required. In further study, it is suggested to create a decision tree that is inclusive of more parameters than just NDVI, such as elevation, distance from coastline, proximity to water, and continuity of mangrove NDVI pixels. The inclusion of these other parameters is necessary to more accurately determine mangrove extent change. Moreover, this method is likely to significantly reduce the errors yielded in this study’s results.

5. Conclusion

Considering the amount of environmental change to the Gulf of Fonseca region in the past several decades — both natural and anthropogenic — there is an expected change in the condition(s) of the local mangrove communities on which this region so critically depends. As a result of little to no recent study on the region’s mangroves following the acts toward conservation and resource management in the 1990s and early 2000s, this study aimed to fill that information gap. In order to do so, this study was separated into analyzing changes in both mangrove health and extent for the Gulf region, from both an overall perspective of the Gulf and also at the level of each of the three bordering nations within the region.

Changes in mangrove health for both the greater Gulf area and for each individual country were found to be statistically significant, as made evident in the test for significance of NDVI averages for the study periods of 1985 and 2010. Although NDVI change appears to be largely categorized as ‘none’ across the region, there are concentrated areas of high negative
NDVI change within each country that contributes to this significant difference. Areas of ‘no’ change or even low change (indicating health improvement over time) were largely occurring within the borders of preserved lands. Conversely, the areas of high negative NDVI change were commonly found in areas that are not protected and thus vulnerable to environmental changes of both natural and anthropogenic scales. These results can be used not only in filling the information gap between the 1990 and the current decade, but moreover can be utilized by the countries of interest in determining which mangrove communities are most vulnerable to further degradation with time.

Alternatively, changes in mangrove extent for this study were inconclusive due to unforeseen estimations. Extent was underestimated for 1985 and, conversely, overestimated for 2010. These errors were likely due to disproportionate changes in surface reflectance both within and outside of mangrove communities and discrepancies between Landsat satellites over time. While current mangrove extent data does exist as of 2011, further study is required in order to determine how the mangrove extent has changed over time. In order to more accurately calculate this change in extent, a more intricate procedure of study is suggested which utilizes a decision tree that includes more parameters than just NDVI, such as elevation, distance from coastline, proximity to water, and continuity of mangrove NDVI pixels. This improved, more detail-inclusive method is likely to yield more accurate results that avoid erroneous land cover classification.

In conclusion, this study has successfully determined changes in mangrove vegetation health between the time period of 1985 to 2010, but proves there is more study required to find the changes in mangrove extent. With the successful results of this study, the knowledge gap
between the region’s previous and current status can be filled, and the countries of interest can
utilize these findings to improve mangrove conservation. Moreover, the inconclusive results of
part 2 of this study prompts further investigation by fellow environmental scientists, GIS
analysts, and the nations of interest alike to gain further insight into the mangrove habitat’s status
and identify areas in need of preservation.
6. Appendix

Mangrove NDVI 1985

Count (thousand pixels)

NDVI Value
7. References


