

NASA/CR–2014-218274



Myanmar Ecological Forecasting: Utilizing NASA Earth Observations to Monitor, Map, and Analyze Mangrove Forests in Myanmar for Enhanced Conservation

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Prepared for Langley Research Center
under Cooperative Agreement NNL11AA00B

May 2014

Available from:

NASA Center for Aerospace Information
7115 Standard Drive
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Abstract

Mangroves supply many essential environmental amenities, such as preventing soil erosion, filtering water pollution, and protecting shorelines from harmful waves, floods, storms and winds. The Mangroves in Myanmar not only provide citizens with a food source, but they also offer firewood, charcoal, and construction materials. The depletion of mangroves is threatening more than the biodiversity however; Myanmar's fiscal livelihood is also in harm's way. Mangroves are valued at \$100,000 to \$277,000 per square kilometer and if managed in a sustainable fashion, can infuse constant income to the emerging Myanmar economy. This study analyzed three coastline regions, the Ayeyarwady Delta, Rakhine and Tanintharyi, and mapped the spatial extent of mangrove forest during the dry season in 2000 and 2013.

The classifications were derived from Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operation Land Imager (OLI) imagery, as well as the Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) digital elevation model information. This data was atmospherically corrected, mosaicked, masked and classified in ENVI, followed by ArcGIS to perform raster calculations and create final products. Forest degradation collected from 2000 to 2013 was later used to forecast the density and health of Mangroves in the year 2030. These results were subsequently presented to project partners Dr. Peter Leimgruber and Ellen Aiken at the Smithsonian Conservation Biology Institute in Front Royal, VA. After the presentation of the project to the partners, these organizations formally passed on to the Myanmar Ministry of Environment, Conservation and Forestry for policy makers and forest managers to utilize in order to protect the Myanmar mangrove ecosystem while sustaining a healthy economy.

Introduction

Mangrove forests are one of the most valuable, thriving, and diverse ecosystems on the planet, but they are becoming increasingly exploited and mismanaged (Lee 1999; Giri et al. 2008). In Myanmar, many of these mangrove stands flourished for centuries, virtually untouched until extensive deforestation began in the late 1970's. At the time there was no legislation to promote sustainable forest management, and as a result the forests were depleted at alarming rates. During the 1990's, multiple environmental acts were passed to help regulate tree harvesting processes, including the 1992 Forest Law and the 1995 Forest Policy, but they were only mildly successful and difficult to enforce (Oo 2002). The 2000's brought a new chapter as Myanmar's expanding economy and lifted political embargos created an explosion of infrastructure and agriculture, once again encroaching on the mangrove's habitat. Even with the increasing development and encroachment on mangroves, Myanmar's long state of isolation has made it one of the most species rich countries in all of South-east Asia, and is considered to be one of the last strongholds for large mammals such as tigers and elephants (Leimgruber et al. 2005). In a country with such rich biodiversity and a large dependence on natural resources for income, fuel, and food, preserving Myanmar's mangroves and raising awareness about sustainability has become a national priority.

This study mapped the spatial extent of three main mangrove regions along the coast of Myanmar during 2000 and 2013, including the Ayeyarwady Delta, Rakhine and Tanintharyi regions (Oo 2002). The three regions are spread along the coast and vary in population density, which provides a valuable comparison among the regions as to how human and economic pressures can affect mangroves. The Ayeyarwady Delta is centrally located and has the highest population density, followed by Rakhine to the north, and the most remote region being the Tanintharyi to the south. A land change model was then used to produce change maps between 2000 and 2013 and project mangrove coverage to the year 2030 to help resource managers and policy makers craft future decisions. Once the mangroves were classified and projected, SRTM data were used to derive tree canopy heights and biomass estimations using allometric equations.

Mangroves in Myanmar house thriving biodiversity and provide citizens with essential natural products such as food, firewood, and construction materials (Oo 2002). This ecological forecasting project helped the Myanmar government visualize and quantify their current largest mangrove areas, as well as shed light on the success of previous preservation efforts that may influence future conservation strategies. This project ultimately allowed important decision makers to assess the negative impacts that have occurred due to the deforestation and degradation of mangrove ecosystems. To successfully implement this study and its findings, Dr. Peter Leimgruber and Ellen Aiken at the Smithsonian Conservation Biology Institute were irreplaceable as they officially handed off the project and its decision making tools to the Myanmar Ministry of Environment, Conservation and Forestry. The project will serve as a valuable reference for efficiently allocating resources and man power, while adapting new management strategies to the changing mangrove landscape.

Methodology

Data Acquisition:

A total of 12 scenes from Landsat 7 and 8 encompassing these study areas were downloaded from the U.S. Geological Survey Global Visualization Viewer (GloVIS) website. Three scenes encompassed the Rakhine region (path 134/row 46, path 135/row 46, path 134/row 47), two scenes for the Tanintharyi region (path 130/row 51, path 130/row 52), and one scene for the Ayeyarwady Delta region (path 133/row 49). Six Landsat 7 scenes were downloaded within a November through May time period during Myanmar's dry season for 2000 and six Landsat 8 scenes were downloaded for this same six-month period for 2013 in order to reduce phenological differences that may interfere with the image classification (Kovacs, Wang, and Blanco-Correa 2001; Oo 2002). The imagery acquired was also selected based on lowest cloud cover and visibility, which can prove difficult in tropical regions where cloud cover is high (Sano et al. 2007). The Landsat 7 and 8 imagery were all Level 1 terrain-corrected (L1T) products, which have been radiometrically and geometrically corrected through the inclusion of ground control points and digital elevation model data for topographic accuracy (NASA 2011). Landsat has visible, near infrared, and shortwave infrared bands that are suited to distinguishing between the spectral signatures of different land cover types, and will be used for the calculation of NDVI (Normalized Difference Vegetation Index), and will assist in the mangrove classifications and change detections for 2000 – 2013.

In addition to the Landsat imagery, ASTER digital elevation model data, Shuttle Radar Topography Mission (SRTM) digital elevation data, and SRTM Waterbody Data were downloaded from the Earth Explorer website for these locations. The SRTM Data were derived from the joint 11-day mission operated by NGA and NASA aboard the Shuttle Endeavour (Ramirez 2009). The 30m ASTER DEMs were generated from the ASTER sensor operated by NASA and Japan's Ministry of Economic Trade and Industry (METI) onboard the Terra satellite (Tan 2012).

Processing:

The Landsat imagery was first atmospherically corrected using the QUAC (QUick Atmospheric Correction) tool in ENVI (Exelis 2013). The individual bands (excluding the thermal, coastal aerosol, and cirrus bands) were then stacked and an NDVI was created from atmospherically corrected reflectance values and added to the layer stack as well. The ASTER DEMs were then loaded into ENVI and mosaicked together. Two masks were then generated; one mask based on elevation, and one based on the SRTM Waterbody Data shapefile. The elevation mask was set to remove all areas in the Landsat image greater than 35 meters, and the SRTM water boundary data masked out all coastal waters. The elevation mask threshold was set to 35 meters, as mangroves are not expected to grow above this mark (Fatoyinbo and Simard 2013). Through these two masks, the areas of the image to be classified were reduced in order to limit misclassification and gain greater focus and accuracy on the mangroves themselves.

Once the Landsat tiles were masked, the remaining portion of the images were classified using an Iterative Self-Organizing Data Analysis Technique (ISODATA) unsupervised classification with parameters set to 7 iterations, minimum 40 classes (100+

classes for Ayeyarwady and Rakhine due to difficulty of separating spectrally similar classes) , and a convergence threshold of 2.5%. The classes were then grouped and sieved with a group minimum threshold of 65.

In addition to the classification maps for each of the three regions, biomass maps were produced using canopy heights derived from the SRTM DEM data and mangrove height and biomass equations. A global stand height-biomass allometric equation has been calculated for mangroves and was used to produce the biomass statistics for this project (Fatoyinbo and Simard 2013; Fatoyinbo et al. 2008; Saenger and Snedaker 1993):

$$\text{Height (m)} = 1.12 \times H_{\text{srtm}} - 2.19$$

$$\text{Biomass} = 10.8 \times H \text{ (m)} + 34.9$$

Change maps were also produced using a change detection map tool from 2000 – 2013 using Idrisi. These change maps were then input into the land cover change model in Idrisi in order to project mangrove cover for 2030.

Data Analysis:

Mangrove area and extent were quantified from the classification, change, and projection maps for the 2000 - 2030 period. In addition to quantifying the area and extent of mangroves, these maps demonstrated the changes occurring for mangroves within each region and areas most at risk in the future. The height and biomass data were visualized through a histogram in order to better represent the distribution of different mangroves within and among the three regions.

A validation was also performed for the mangrove extent classification maps using the accuracy assessment tools in ENVI Classic. Error matrices were produced based on the accuracy of the classification compared to the ground truth regions of interest digitized in ENVI. Accuracies ranging from 46% to 84% were recorded among the three regions based on this initial validation effort. Due to the lack of time, this project was unable to further pursue improvements in map accuracy for the Ayeyarwady Delta region, which had the lowest accuracy reported. Based on the error matrices and visual assessment of the maps, sources of error and uncertainty were difficult to identify in some locations due to the lack of high resolution imagery, especially when going back in time towards 2000. Perhaps future studies will be able to further delve into specific regions in Myanmar's coastal regions that contain more high resolution imagery available through Google Earth, which can also be used as a validation exercise through the generation of random points (Potere et al. 2009; Tateishi et al. 2011).

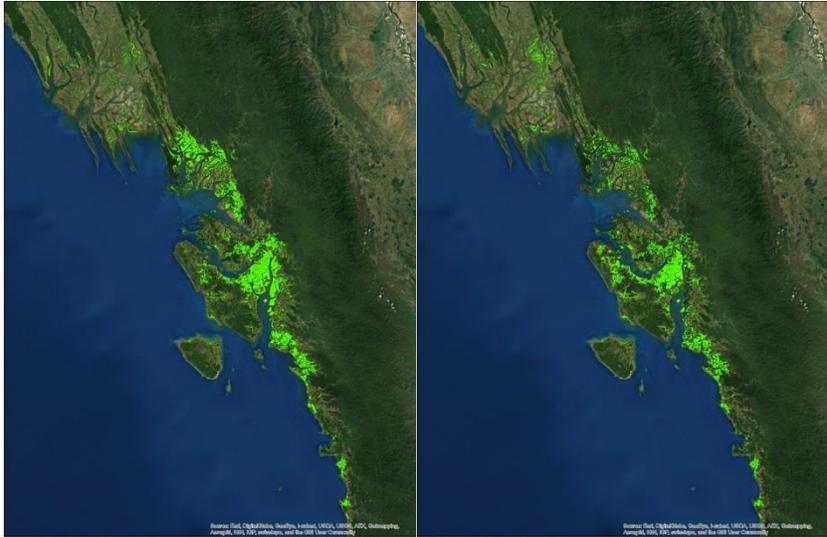
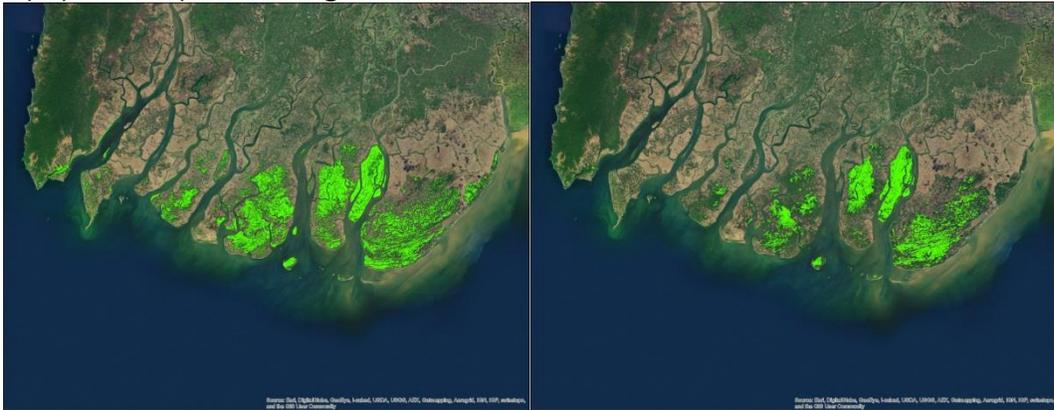
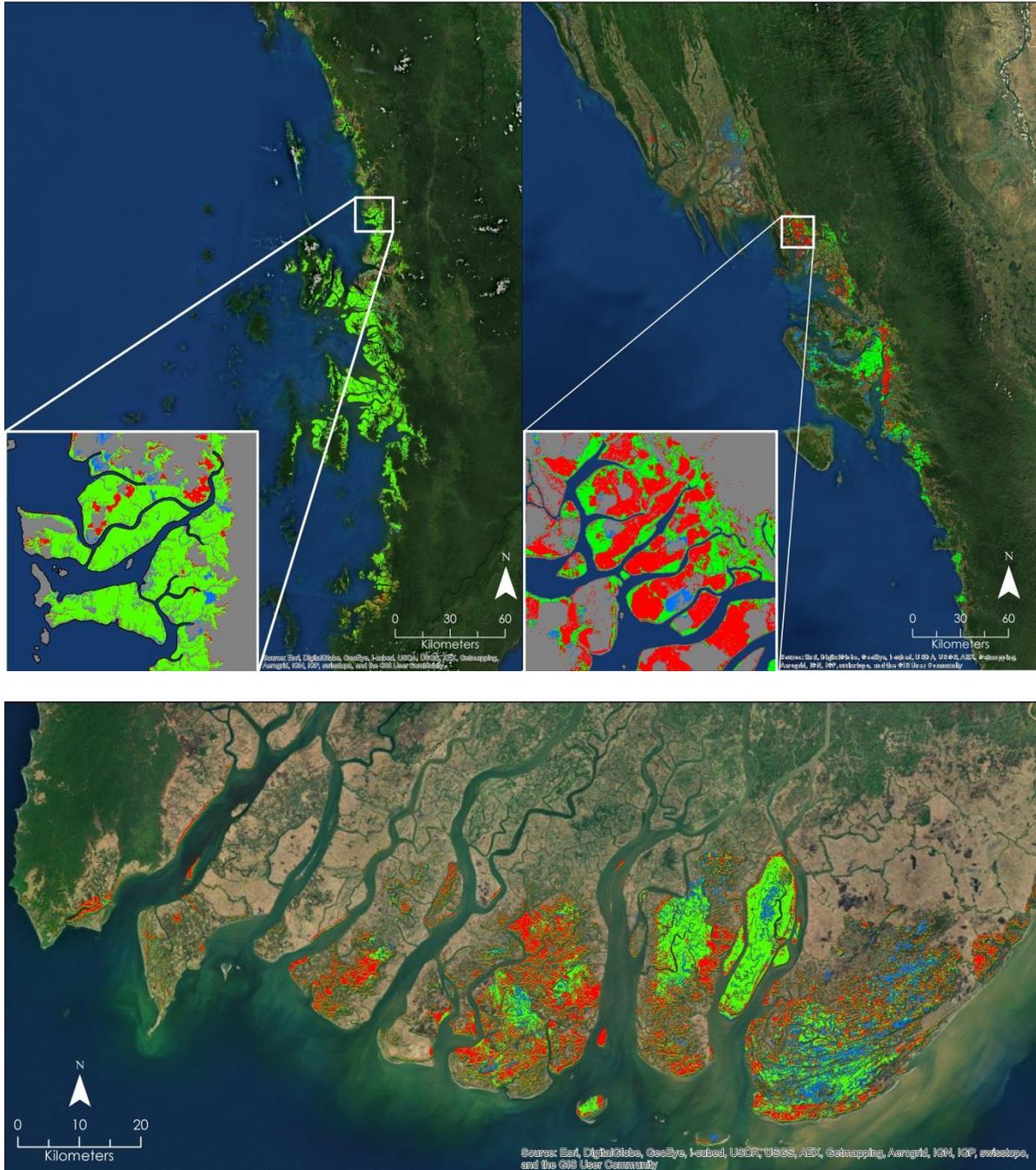


Figure 1: Aside from the Ayeyarwardy region, mangrove extent change is difficult to see from such a distance, hinting that small scale deforestation and afforestation are very common

Ayeyarwardy Delta Region



2000-2013 Change



Mangrove Change 2000-2013

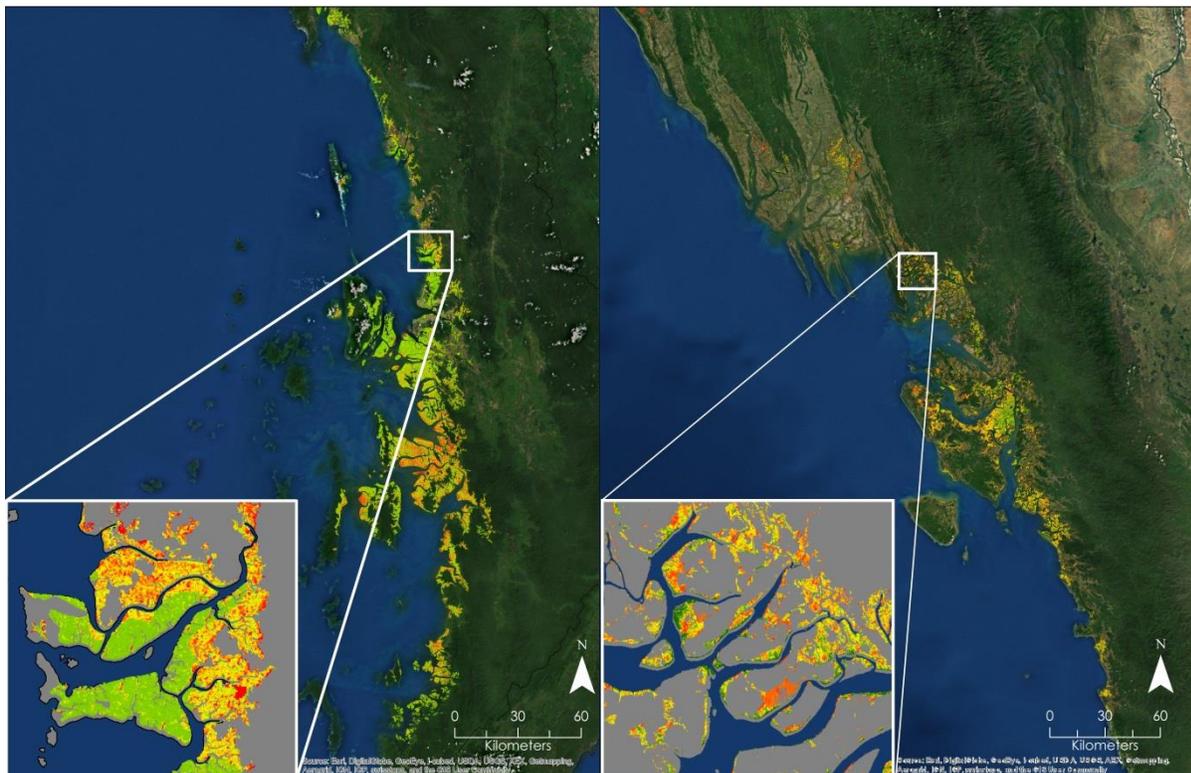
- Deforestation
- Afforestation
- Mangrove

Figure 2: Magnified areas shown in the inset boxes highlight deforestation and afforestation from 2000 to 2013. Tanintharyi saw minimal change, Rakhine experienced modest change, and the Ayeyarwady Delta was drastically modified. (Note: The Ayeyarwady map is at 1/3 the scale of the other two)

Projected mangrove change

The Idrisi Land Change Modeler produced two future map projections for 2030 based on mangrove change inputs from 2000 – 2013, ASTER elevation data, and a population map. Between the three regions, a total mangrove area of 1376km² was lost, nearly a twofold increase from the deforestation extent from 2000 – 2013. The Rakhine region lost the most mangroves at 782km², followed by the Ayeyarwady Delta at 332km², and the Tanintharyi at 262km². The “soft” prediction map, which produced a scale of mangrove vulnerability, illustrated the widespread risk to mangroves within the three regions (figure3). Much of the medium to high risk areas appeared to lie in the more fragmented stands, particularly evident for the Ayeyarwady Delta and Rakhine regions. The “hard” prediction maps for 2030 showed a slightly different picture, with the Ayeyarwady Delta and Rakhine regions being particularly hard hit while the Tanintharyi region remained largely untouched (figure4). As illustrated by the higher risk areas in the vulnerability maps for the Ayeyarwady Delta and Rakhine regions, the smaller fragmented mangrove stands are largely gone by 2030 in the hard prediction results.

Projected Vulnerability 2013-2030





Projected Vulnerability

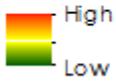
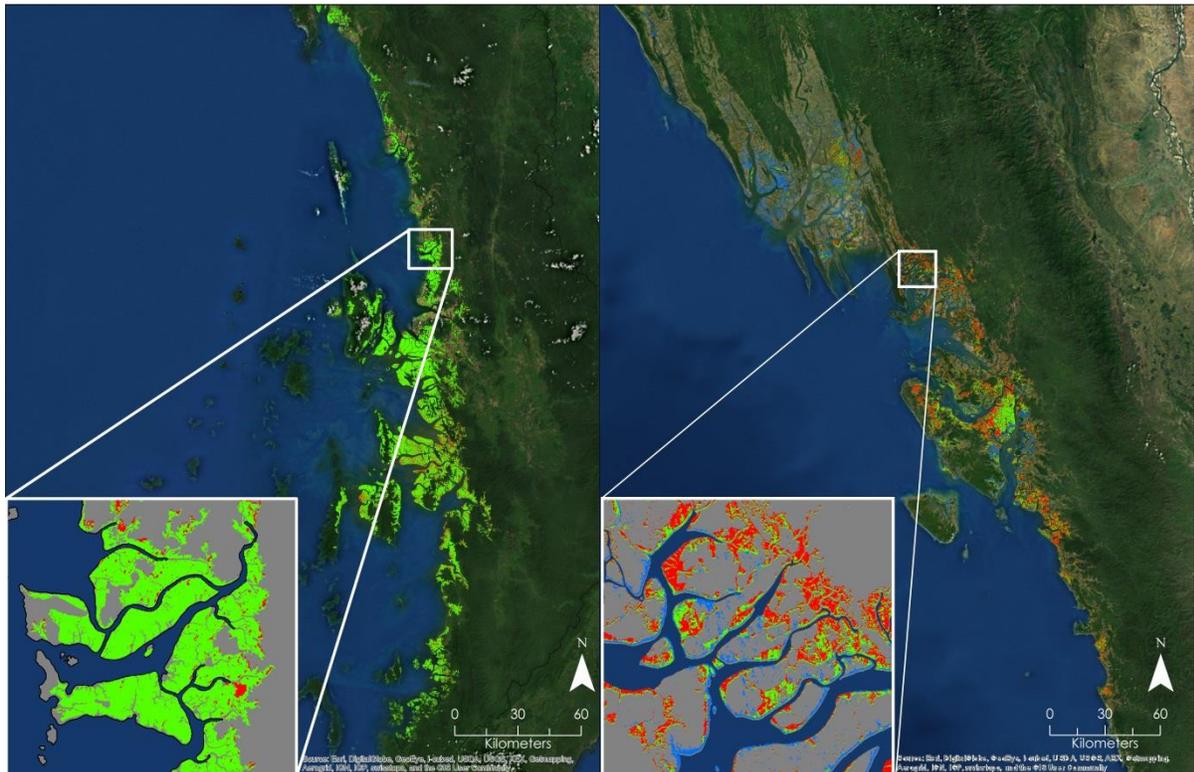


Figure 3: Vulnerability represents an area's potential to change, and helps highlight mangrove regions most at risk for future deforestation. Mangrove stands in orange and red are the most likely to vanish by 2030.

2013-2030 Change





**Mangrove Change
2013-2030**

- Deforestation
- Mangrove

Figure 4: The Rakhine and Ayeyarwardy regions are forecasted to undergo disastrous deforestation from 2013-2030. Many of the smaller fragmented stands will not survive and this loss will put heavy stress on both local communities and the environment if not managed sustainably.

Rakhine	Km²
2000	1734
2013	1470
Projected 2030	688
Ayeyarwardy	Km²
2000	818
2013	462
Projected 2030	130
Tanintharyi	Km²
2000	2075
2013	2040
Projected 2030	1778

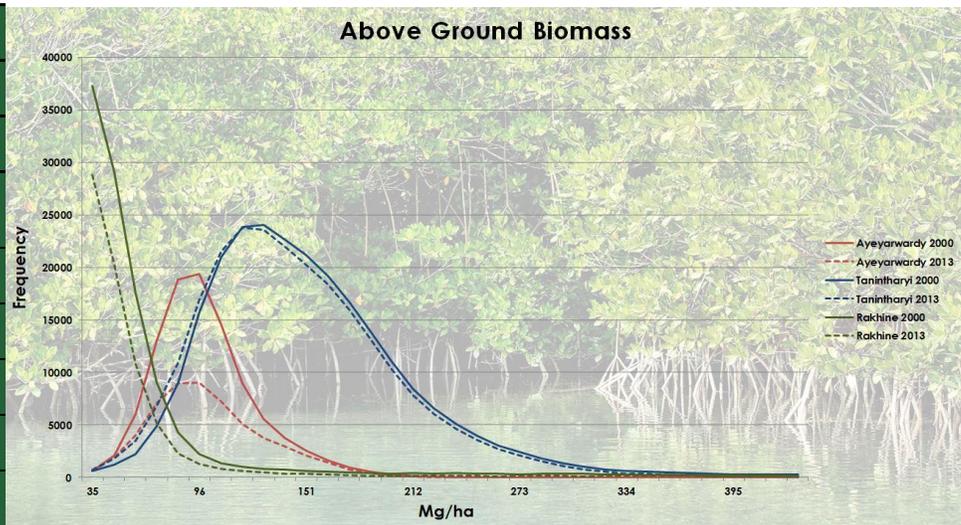


Figure 5: With total mangrove areas and biomass production rapidly declining over time, carbon capacity, biodiversity, natural resource production, and lucrative export availability will also drop.

Discussion

2000 – 2013 Change

Though the Ayeyarwady Delta probably had a much larger proportion of mangroves originally, pre-2000 deforestation rates coupled with the high population density resulted in this region having the lowest mangrove area of the three. The Tanintharyi region has a lower population density, which may explain the healthy state of mangroves in that remote region compared to the Ayeyarwady Delta and Rakhine regions (Oo 2002). Signs of pre-2000 mangrove disturbance were visible within the 2000 Landsat 7 imagery, indicating the pressures already faced by the mangroves due to increasing economic development as Myanmar enacted political reforms and left its previous isolated state.

The losses seen since 2000 were largely due to agricultural expansion and large scale deforestation (Giri et al. 2008). There was some evidence of mangrove clearing for aquaculture, but this was minor compared to the other two causes of disturbance. As seen in the change maps, there was also some afforestation, which may be evidence of efforts by Myanmar's government and collaborative efforts with NGOs to replant mangrove forests and protect existing stands. Myanmar has acknowledged the potential benefit of coastal mangroves, and has previously enacted some legislation and set up mangrove plantations to attempt regrowth efforts (Oo 2002). The Ayeyarwady Delta saw massive deforestation during this 13 year period, but the two main mangrove stands to the south appear largely unharmed, a reflection of their status as protected areas, including the Mein-ma-hla Kyun Wildlife Sanctuary. The Rakhine region also saw major deforestation in a few central areas, while the Tanintharyi was largely untouched, most likely due to the remote nature of the region.

2013 – 2030 Change

The huge area of loss projected in the future for Myanmar's mangroves indicates a need to address current methods of natural resource management and enforcement. While the total loss of mangrove area was much greater by 2030 than from 2000 – 2013, there was hope for some of Myanmar's mangroves in the Tanintharyi region, where the projected change map showed very little loss in 2030 compared to the other two regions. However, this may be a result of continued low population density within the Tanintharyi, reflecting issues of accessibility and proximity rather than better conservation practices. A total of 2031km² was lost between the three regions, roughly equivalent to the area of Maryland's Prince George's County, Howard County, and half of Washington, DC's area combined. Without a change in current practices and laws, mangroves are projected to be largely non-existent in the Ayeyarwady Delta and Rakhine regions, where large segments of Myanmar's population will be vulnerable to natural disasters and negative impacts on the local economy, side-effects of a major loss in mangroves.

Errors, Uncertainty, and Future Work

There were several sources of uncertainty and error in this project. When conducting unsupervised classification, there will always be certain pixels that prove difficult to assign to the proper class due to mixed land cover present within the pixel or other artifacts that may interfere with the classification. The lack of ground truth and

unfamiliarity with the different forms of mangrove species within the region also hampered the classification process, as mangroves in different stages of growth and degradation took different appearances in different regions. Although the 35m mask was able to narrow the classification area, there was still other vegetation present that could be hard to distinguish from mangrove cover, and could pose a problem in border regions when the mangroves would mix with other vegetative cover. The validation effort sought to quantify the error found within each of the three classified regions, but there were limitations in the lack of high resolution imagery available in Myanmar for the years of interest.

The Land Change Modeler had the potential to contain much uncertainty as is expected with any model. Thus we decided to follow the lead of the Myanmar ecological forecasting team from the summer of 2013 to not forecast our predictions beyond 2030, where uncertainty would be sure to increase drastically. Although there is no way to validate the future projection, we did get an indication of the confidence of the projection maps based on the amount of disturbance seen within currently protected mangrove areas. Though there was some deforestation within the Mein-ma-hla Kyun Wildlife Sanctuary in the Ayeyarwady Delta, it was still relatively well-off compared to the surrounding mangrove stands, increasing our confidence in the predictive ability of the model.

There is much that can still be added to this project in the interest of Myanmar's mangroves. Due to time constraints and logistical hurdles, we were not able to completely map the coast of Myanmar in its entirety. Providing extent, change and projection maps for the coast of Myanmar would be valuable to our project end users and partners, and would allow comparison with mangrove data previously measured by other studies, including the global mangrove maps produced for the year 2000 by Chandra Giri's team at the USGS (Giri et al. 2011).

We also did not have detailed ancillary data to make any conclusions based on forest management, fuelwood use, agriculture, fishing rates, or aquaculture. Future endeavors could provide a more comprehensive picture of the state of Myanmar's mangroves, including extent maps going further back in time, assessing the damage and recovery before and after natural disasters such as the 2004 tsunami and cyclone Nargis in 2008, the construction of the port in Dawei, and replicating our methods using open source software in order to increase accessibility and reduce costs for our end users.

Conclusions

Mangroves are a valuable natural resource that offer a multitude of environmental and economic benefits. They facilitate pollution filtration, protection from storms, waves, and wind, and are home to a diverse range of species. Economically, mangroves are valued at \$100,000 to \$277,000 per square kilometer and provide many tangible benefits in the form of food, firewood, and construction materials (Green et al. 1998).

Through the classification and change maps produced for 2000 – 2013, this project has demonstrated the major loss in mangrove extent that has occurred within the three largest mangrove regions of Myanmar. Our future projections for mangrove extent to 2030 paint an even grimmer picture for Myanmar's mangroves, with an even greater area forecast to be lost. From 2000 to 2030, an area equivalent to the size of Prince George's county, MD; Howard county, MD; and half of Washington, DC was forecast to be lost. The scale of this loss is having a profound influence on Myanmar's economy and the livelihoods of Myanmar's citizens. With projections indicating mangrove health and extent only to get worse, Myanmar's economy will only suffer further as the abundance of local aquatic species decreases, environmental quality degrades, and as the risk of storm damage increases without the protective coastal barrier provided by mangroves.

Myanmar's government has acknowledged the importance of mangroves and has facilitated some efforts to replant mangroves through plantations and local efforts, but as shown by the change maps, the rate of deforestation and degradation is far surpassing the regrowth effort (Oo 2002). Unless Myanmar introduces more effective mangrove legislation, protection, and enforcement practices, its coastal mangroves will only continue to decrease as the country increasingly opens itself up to economic development and the pressures of global markets. New natural resource management strategies will need to be developed to adapt to the changing nature of Myanmar's mangroves.

The satellite remote sensing methods used to produce the maps for this project offer a rapid, low cost solution for monitoring Myanmar's mangroves. Traditional methods would require much time, effort and money in the form of field surveys by plane or trips into the field, which may not be feasible over such a large area and in remote regions of Myanmar (Blasco, Aizpuru, and Gers 2001). With free Landsat imagery archives spanning over 40 years with a spatial resolution ideal for capturing mangrove forest disturbance, and elevation data available online in the form of SRTM and ASTER imagery, rapid, large scale mapping and monitoring efforts can be conducted (Goward et al. 2006). With the ability to update maps in a timely manner, Myanmar will be better suited to inform its policy makers to the conditions of coastal mangroves and will be in a better position to focus its rehabilitation and conservation efforts. We hope that the tools and methods produced by this project will allow Myanmar to recover quickly in the interest of its economy and people.

Acknowledgments

We would like to thank our project partners Dr. Peter Leimgruber and Ellen Aiken at the Smithsonian Conservation Biology Institute for their advice and collaborative efforts. Our project also benefited greatly from the advice and mentorship of our science advisors, Fritz Policelli and Dr. Temilola Fatoyinbo of NASA GSFC, and we would like to thank them for their time. We would also like to thank the summer 2013 Myanmar ecological forecasting team for taking the time to introduce us to the Idrisi Land Change Modeler. And lastly, we would like to thank the NASA DEVELOP National

Program Office for providing the logistics and support needed to keep our project running smoothly, even during a government shutdown.

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REPORT DOCUMENTATION PAGE

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1. REPORT DATE (DD-MM-YYYY) 01-05-2014		2. REPORT TYPE Contractor Report		3. DATES COVERED (From - To) November 2013	
4. TITLE AND SUBTITLE Myanmar Ecological Forecasting: Utilizing NASA Earth Observations to Monitor, Map, and Analyze Mangrove Forests in Myanmar for Enhanced Conservation				5a. CONTRACT NUMBER NNL11AA00B	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Weber, Samuel J.; Keddell, Louis; Kemal, Mohammed				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER 389018.02.15.01.47	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, Virginia 23681				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001				10. SPONSOR/MONITOR'S ACRONYM(S) NASA	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) NASA/CR-2014-218274	
12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 43 Availability: NASA CASI (443) 757-5802					
13. SUPPLEMENTARY NOTES Work was performed by Science Systems and Applications, Inc., for STARSS II and Wise County under NASA Contract NNL11AA00B Langley Technical Monitor: Michael L. Ruiz					
14. ABSTRACT Mangroves supply many essential environmental amenities, such as preventing soil erosion, filtering water pollution, and protecting shorelines from harmful waves, floods, storms and winds. The Mangroves in Myanmar not only provide citizens with a food source, but they also offer firewood, charcoal, and construction materials. The depletion of mangroves is threatening more than the biodiversity however; Myanmar's fiscal livelihood is also in harm's way. Mangroves are valued at \$100,000 to \$277,000 per square kilometer and if managed in a sustainable fashion, can infuse constant income to the emerging Myanmar economy. This study analyzed three coastline regions, the Ayeyarwady Delta, Rakhine and Tanintharyi, and mapped the spatial extent of mangrove forest during the dry season in 2000 and 2013. The classifications were derived from Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operation Land Imager (OLI) imagery, as well as the Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) digital elevation model information. This data was atmospherically corrected, mosaicked, masked and classified in ENVI, followed by ArcGIS to perform raster calculations and create final products. Forest degradation collected from 2000 to 2013 was later used to forecast the density and health of Mangroves in the year 2030. These results were subsequently presented to project partners Dr. Peter Leimgruber and Ellen Aiken at the Smithsonian Conservation Biology Institute in Front Royal, VA.					
15. SUBJECT TERMS Biomass; Canopy height; Deforestation; Mangroves; Myanmar; Remote sensing					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)
U	U	U	UU	20	19b. TELEPHONE NUMBER (Include area code) (443) 757-5802