Fall 12-14-2018

Views from Above: Recent Forest History in the Far North of Madagascar

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Honors Thesis
Submitted
in Partial Fulfillment
of the
Requirements of HON 420
Fall 2018

By

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Abstract

This study is a spatial analysis of the forests west of Mt. d'Ambre National Park in the far northern portion of Madagascar. This area has little spatial, ethnographic, or historic data pertaining to the environment. After a research trip to this area from June to August 2017, the need for a temporal study of forest change materialized. Utilizing Landsat data, NDVIs were generated to assess forest cover density from 1978 to 2018. This spatial analysis saw deforestation across the study area. Deforestation in this area is mainly caused by agriculture, large foreign companies, recent immigration, and local exploitation of timber for income. (Gezon and Freed, 1999). Supplementing past research in this area, a spatial study provides context on a larger scale. Remotely sensed data has a limited scope temporally, but the significance of the environmental events since the 1970's forgives the short time span. Observing patterns of change in forests across primate habitat can provide a base for future research in behavior, ecology, and the interactions between humans and the immediate environment.

Keywords: Deforestation, Madagascar, Landsat, GIS (Geographic Information System), Primate, Mt. d'Ambre, Lemur

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Acknowledgements

I would like to profusely thank Benjamin Z. Freed for mentoring me and leading the research trip in 2017. A great thanks to David Coleman of EKU Honors Program for research and project guidance. Much gratitude is owed to Louis Phillipe d'Arvisenet for leading the research team and providing invaluable knowledge of lemurs and Madagascar. I would also like to thank Benjamin Andriamihaja of MICET, Dr. Tyler Huffman and Dr. Kelly Watson for the education on GIS and remote sensing, and all the Malagasy locals who assisted in the field research. This study would not have been possible without Eastern Kentucky University's Laura D. Kennamer Scholarship for helping finance the original research trip, and Jennifer White of EKU Education Abroad and Dean Sara Zeigler of EKU CLASS.

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Introduction

Destruction of land cover causes fragmentation of primate habitat and threatens species survival. Alteration of forest habitat shows a disparity in primate population density between damaged and non-damaged areas (Swift, 2012). Anthropogenic influenced areas can lead to ecological impacts that negative effects on populations. Habitat destruction, fragmentation, and climate change can all threaten primates (Graham, 2015; Aquino et al., 2016). A recent study shows that nearly half of the world's primates are facing "near-term extinction due to unsustainable human activities" (Estrada et al. 2017). The IUCN states the two highest disturbance in primate habitat loss are agriculture and logging/wood harvesting (Estrada et al. 2017). In the case of the Sumatran orangutans, forest loss is causing a dramatic decrease in population size. In the past two decades, it is estimated that approximately 1,000 individuals were lost (Supriatna, 2017). Orangutans are exhibiting 'irregular' behaviors, such as crop-raiding, and are found in seemingly unlikely areas (Campbell-Smith et al., 2011; Supriatna, 2017). Orangutans that lived in the degraded areas or human influenced spent significantly more time resting than wild orangutans. Gregory et al. modelled the species distribution for Borneo orangutans and concluded that without intensive conservation, climate, and land form protection, these populations will be lost. Protection of forests versus controlled repopulation efforts are currently being explored for the Sumatran orangutan (Wilson et al., 2014). Further, the Niger Delta Red Colobus is predicted that at the current rate of habitat loss, it may become extinct in five years or less (Ikemeh, 2015).

Other colobus species face similar environmental predicaments. In an area outside of Kibale National Park, Uganda, Black-and-White colobus monkeys experienced a 55% decline in an 8-year period (Chapman et al., 2005). Forest fragmentation brings primates in closer contact with humans, which can cause more instances of conflict and disease transfer. Habitats are disturbed at high rates. Some researchers have begun to reclassify habitats along a spectrum of anthropogenic disturbance, rather than intact versus degraded since there is little intact, undisturbed forest left (Dunham, 2016). In the Amazon, a region historically plagued by logging and forest destruction, primates are facing the same problems. The Critically-Endangered cotton-top tamarin has faced extensive loss in population size due to mainly habitat loss. With massive conservation efforts since the late 1980's, the tamarins only saw a slight decline in population between 2005 and 2012 (Savage, 2016). With involvement of local people, these efforts have nearly stemmed logging in this area. Success for the cotton-top tamarins was measured by stability, not growth. For atelids in the Peruvian Amazon, deforestation is "The most pervasive and common threat in the area we studied… hindering our work because of the noise of chainsaws and falling trees" (Aquino, 2016). Atelids were nearly exclusively found in the low to moderately disturbed areas. This issue extends globally and affects all taxonomic branches. Primate habitat is decreasing and negatively affecting populations. Methods in quantifying habitat loss and population change vary across locations. Utilizing available methods specific to certain geographic criteria is key in conducting a study on habitat loss.

In locations lacking extensive oral or written environmental histories, GIS (Geographic Information System) and remote sensing can illustrate factors that contribute to habitat loss for endangered primates. The study site in the far north of Madagascar is a data devoid area. Specifically, we lack a large amount of spatial and ethnographic data that can explain the fragmentation of potential habitat. The far north of Madagascar is a mosaic of dry land, riverine forests, secondary forests, farmland, and small villages. From June 2017 to August 2017, I was part of a behavioral research team focused on collecting data on Sanford's lemurs and Crowned lemurs. The research was headed by Dr. Benjamin Freed of Eastern Kentucky University. During the time spent in Madagascar, I was able to ground-truth coordinates, observe examples of fragmented lemur habitat, and understand what habitats are hospitable to these primate species. The area under study has been historically open to logging, *tavy* (slash-and-burn agriculture), and charcoal production (Gezon & Freed, 1999). A large agroforestry conservation effort in the extreme north of Madagascar, headed by the Project and ICDP, in the 1980's and 1990's did little to alleviate the impacts of deforestation.

Using GIS and remote sensing in data deficient areas to measure land cover allows large physical space to be processed, opposed to traditional methods such as line transects. It also allows a multi-temporal approach, which on-ground methods cannot. This study includes Landsat imagery from 1973, 1995, 2000, 2010, 2016, and 2017. There has only been one study with use of remote sensing in this area, conducted in 2004.

Forest Loss and Commodity Chains in Northern Madagascar by Gezon, Sweeney, Freed, and Green examines the socio-environmental relationship of deforestation and human-lemur interactions. The initial portion of this study was to identify areas of potential interest based on satellite imagery, rendered by G. Green and S. Sweeney. (Gezon et al., 2005) Green and Sweeney utilized a two-date multi-temporal composites to identify areas that experienced land cover change. The spatial portion of the study was to identify areas for ground research, not an overall assessment of the forest cover. The ground research found that where resources are sold for cash, there is an increase in clearing. Also, in areas with permanent immigrant populations, there was no significant degradation. In areas with short-term immigration, there was an increase in clearing. The significance of this article rests in its multi-disciplinary approach. This study contributed new understands in how land cover change patterns were different than other portions of Madagascar (Gezon et al, 2005). A more intensive spatial study in this portion of Madagascar will supplement older work and provide new areas to investigate.

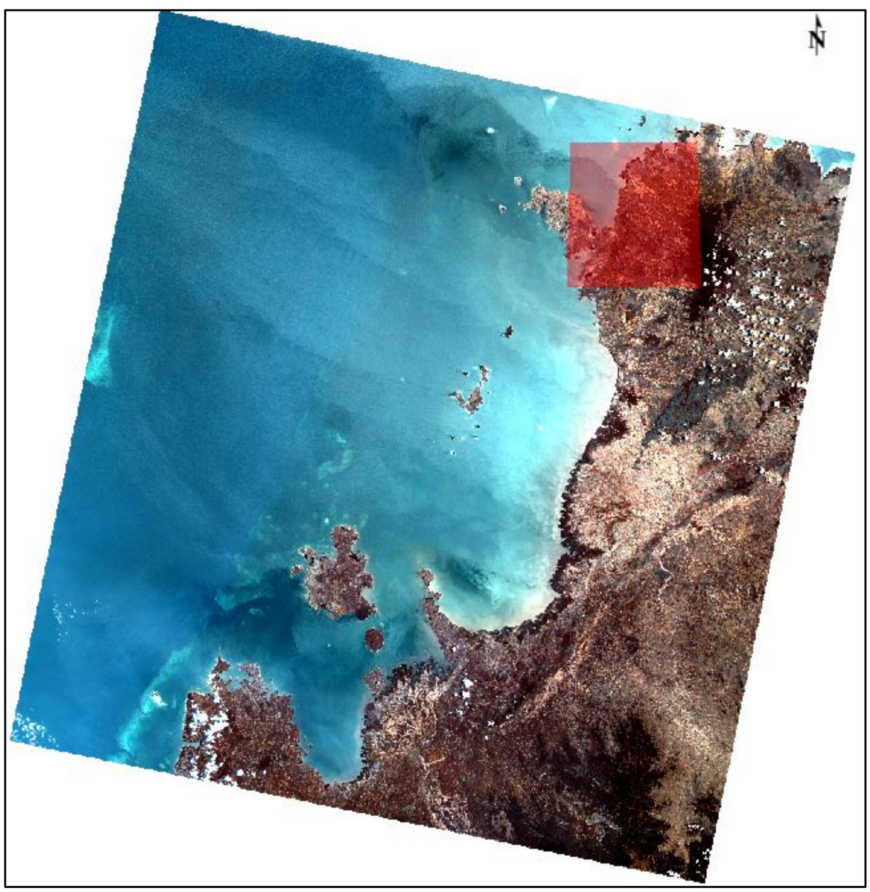
Certain issues need to be considered when conducting a longitudinal study using satellite imagery. Data must be corrected to season to avoid discrepancies between wet and dry seasons. High seasonal variability in vegetation requires temporally aligned images. The images need to be processed and devoid of pixels that cause errors, such as clouds. Acquiring older data can be challenging, especially if the metadata is incorrect or absent. There can be imaging errors caused by sensor errors. The scale of these discrepancies needs to be considered during analysis.

This study aims to contribute to the limited selection of spatial data in far northern Madagascar. I am looking at how forest cover has changed in this select area in an attempt to supplement the lack of historical data. Identifying anthropogenic factors contributing to the degradation of the landscape is necessary for conservation in contemporary research. Discovering the relationship between human expansion and its effect on potential primate habitat can continue to a wider set of spatial research. With the potential of future primate studies in this area, providing a spatial base to continuous research can benefit conservation assessments and guide research on the primate populations and the humans that inhabit this portion of Madagascar.

Methods

Area Background

The area under study is the extreme Northwest of Madagascar. The area lies west of Mt. d'Ambre National Park (12°37'00.00 S 49°09'00.00 E). The main area for analysis was demarked as a region of interest in a rectangle (Figure 1). Area was chosen visually and encompasses 2017 field site and other areas of potential primate habitat. Coordinates for the region of interest are stated in Table 1. Analysis will include all forest within the data frame of the image.



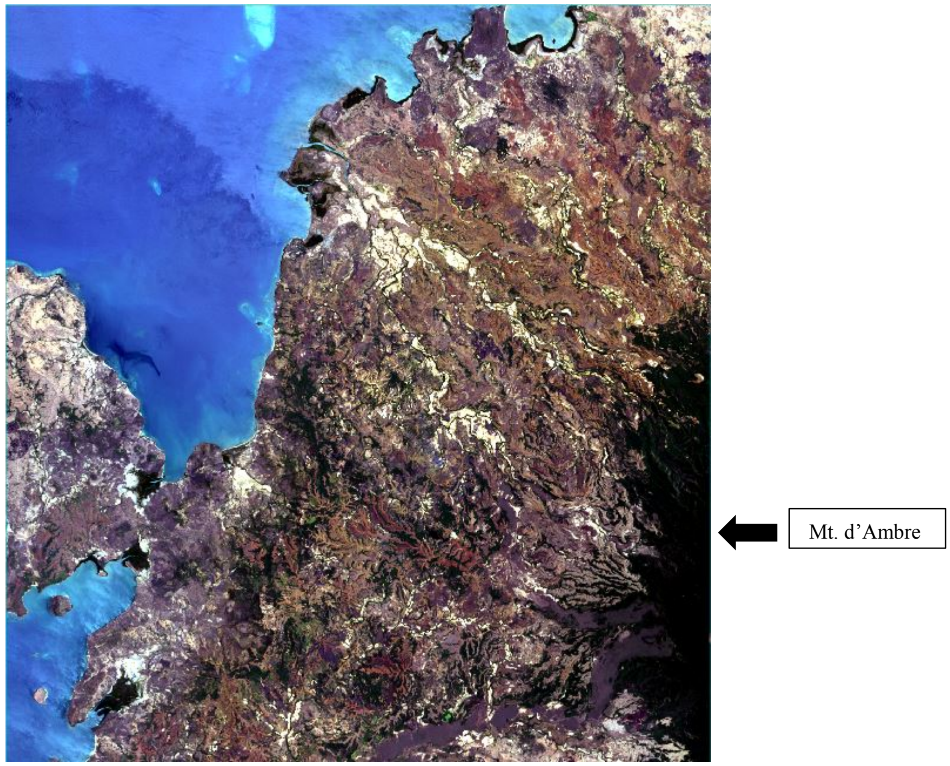


Figure 1. Top: Image of greater northern Madagascar (2018), Landsat 8 OLI/TIRS, True Color. The region of interest (ROI) is demarked in the transparent red rectangle. Bottom: Image of Northern Madagascar data frame (2018), Landsat 8 OLI/TIRS, True Color.

Data Frame	South	East
Top Right	12°17'50.90"S	49°9'0.92"E
Bottom Right	12°38.'20.78"S	49°8'52.19"E
Top Left	12.17'42.04"S	48°49'39.25"E
Bottom Left	12°38'12.46"S	48.4928.94"E

Table 1. Data frame coordinates for the region of interest used in analysis. The coordinates in the table correspond with the four corners of the region of interest shown above in figure 1.

Mt. d'Ambre National Forest is known for its high biodiversity, crater lakes, and primary rainforests. Approximately 25km-30km Northeast of the study area is Antsiranana, commonly Diego-Suarez. Antsiranana is a larger port city with a population of around 115,000. Areas immediate of Antsiranana are accessible by non-paved roads, and the extended areas around Mt. d'Ambre are not accessible by vehicle.

Data Background

Data used in this study were obtained from the United States Geologic Survey (USGS) EarthExplorer Portal. Images were collected by the Landsat satellites. "The Landsat Program is a series of Earth-observing satellite missions jointly managed by NASA and the U.S. Geological Survey" (U.S. Geological Survey). Landsat satellites detect the electromagnetic radiation reflectance at the visible and infrared wavelengths and monitor the land areas between 81°N and 81°S latitude (Green et al., 2005). Landsat 1 was launched in 1972. LANDSAT 8 is the current mission utilizing the advanced OLI and TIRS sensors. This study utilizes imagery from multiple Landsat satellites. Images were processed in the ENVI 5.4 (64-bit) by Harris Geospatial Solutions software licensed to Eastern Kentucky University. All images come pre-processed by USGS. Table b. displays the satellite missions, sensor, and bands of processed data for this study.

Date	Satellite	Bands
10/17/73	Landsat Multi-Spectral Sensor	4, 5, 6, 7
10/09/1978	Landsat Multi-Spectral Sensor	4, 5, 6, 7
10/09/1995	Landsat Thematic Mapper	1, 2, 3, 4, 5, 7
09/07/2005	Landsat Enhanced Thematic Mapper+	1, 2, 3, 4, 5, 7
10/29/2017	Landsat OLI/TIRS	1, 2, 3, 4, 5, 6, 7
10/29/2018	Landsat OLI/TIRS	1, 2, 3, 4, 5, 6, 7

Table 2. Landsat satellites utilized in study. The dates were selected by season alignment. Bands included all wavelengths pertaining to visual rendering.

Processing the Data

When downloaded from EarthExplorer, the decompressed data separates the image into individual .tiff files of the spectral bands. After decompressing, bands must be combined to form a cohesive, multispectral band. To achieve a multispectral image, the Layer Stacking tool was used to combine the separated bands. This was done for each data set. The region of interest (ROI) was established to create spatial consistency for the relevant areas. The ROI was selected as a polygon visually to researcher discrepancy, coordinates stated above.

To better achieve a stark visual for vegetation, false color composites were generated for each data frame. Vegetation has a higher spectral response in the near-infrared wavelengths. This puts the vegetation in a red color. This band combination allows easier visual analysis. The contrast can allow changes to be visually observed.

Lastly, the data was processed into an NDVI response image. An NDVI is a standardized index calculated from the Infrared bands and the Red band. The formula is

$$\text{NDVI} = (\text{RED} - \text{IR})/(\text{RED} + \text{IR})$$

NDVI's show vegetation greenness (biomass) on a scale of -1.0 to +1.0. Areas of dense vegetation have higher positive values, while areas of low vegetation, such as water, clouds, or snow, have low negative values (Chettri, 2013). The ranges represented in the NDVIs generated were assigned a multi-color scheme to match the range of values. Dark blue indicating no vegetation, such as water and clouds. Lighter blue indicating traces of vegetation, such as bare soil. Green indicating grassland and savannah. Yellow indicating secondary forests and scrub. Red indicating dense, high response vegetation, such as gallery forests and complete canopy.

Assessing Change

The area was subdivided into eight subsections. The subsections furthered visual consistency.

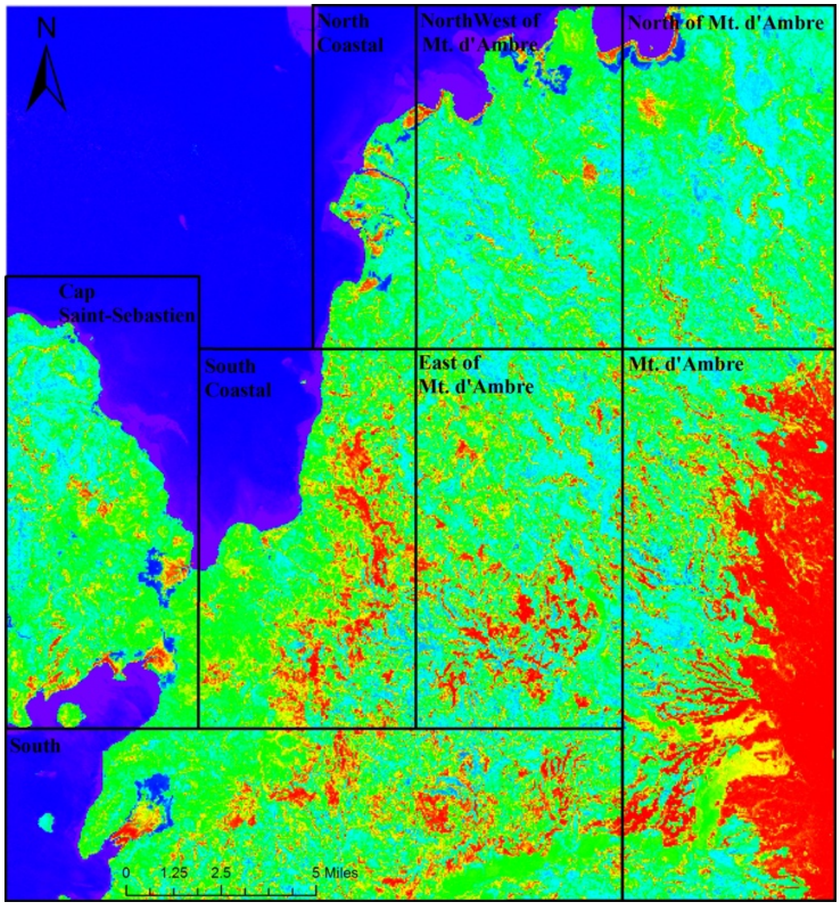


Figure 2. Image of subsections: Landsat 8 OLI/TIRS (2018) rendered in an NDVI. Subsections were selected visually to approximate geographic proportions. Map was generated in ArcMap 10.6.1.

The subsections are; Mt. d'Ambre, North of Mt. d'Ambre, Northwest of Mt. d'Ambre, West of Mt. d'Ambre, North Coastal, South Coastal, Cap Saint-Sebastien, and South. A decrease in forest cover, no change, or an increase in forest cover was established for each subsection between years. A decrease in forest cover is defined by a visible fragmentation or decrease in the dense red values to yellow or green values, referred to as deforestation. No change is defined as no visible difference between years. Increase is defined as a visible expansion of red or yellow values, referred to as regrowth.

The subsections above were visited during the 2017 field study, conducted by Dr. Benjamin Z. Freed and Nathanael R. Bartosch. Coordinates and observations were recorded regarding the forests in Mt. d'Ambre and the smaller forest fragments to the west. The forest conditions under analysis were ground-truthed during this field study. In addition, Freed (2012) also conducted forest condition assessment in these regions. The forest structure data are used in generating the analysis criteria in the paragraph above.

Results

Mt. d'Ambre:

1978: This is the baseline image. Data acquisition does not extend beyond this date.

1995: The interior of the park visibly has increased in the darker red values between these dates. The edges of Mt. d'Ambre show decrease and fragmentation in most areas. The northern portion of Mt. d'Ambre exhibits reduction from dense red values to sparse yellow values along the edges of the forest, while the interior retains the dense red values. The midwest edge of Mt. d'Ambre also shows deforestation. Larger portions of dense red values are separated by yellow values. The southern edge exhibits an increase in forest cover. The bottom corner of the Mt. d'Ambre subsection shows a slight expansion between 1978 and 1995. The dense red values in the detached forests expand and surround with yellow values. One anomaly is the upper left corner of the Mt. d'Ambre area. This upper left corner exhibits a slight increase of dense red values along the main forests, and a large expansion of yellow values connecting the dense red values. Another is an expansion of dense red values directly above the larger lava flow remnants.

2005: Between 1995 and 2005 exhibits a significant decrease. The extreme northern portion of Mt. d'Ambre was subjected to intense deforestation. There is almost nothing left of the dense red values in that area. The most northern point in the 2005 image shows fragmentation on the edge. The interior of Mt. d'Ambre National Park exhibits no change. The smaller forest groups in the northwest of Mt. d'Ambre gallery forest have also all but disappeared. The southernmost portion of Mt. d'Ambre exhibits little change. There is some decrease in forest cover along the upper lava flow. All other southern portions have no change.

2017: There is decrease in forest cover over a majority of the area from 2005 to 2017. The northernmost portion of the Mt. d'Ambre gallery forest has continued to decrease and fragment. The secondary forests to the northwest have exhibited decrease. The southern region of this area exhibits little to no change in forest density.

2018: The secondary forests to the northwest have exhibited slight decrease. The central and southern region of this area exhibits little to no change in forest density. There is no visible forest fragmentation.

West of Mt. d'Ambre:

1978: This is the baseline image. Data acquisition does not extend beyond this date.

1995: The primary dense red values in this image exhibit no change except in the northeastern area. The northeastern area shows fragmentation and decrease from dense red values to less dense yellow values. The greatest change in the West of Mt. d'Ambre is the growth of the less dense yellow values. The yellow values surrounding nearly all the dense red vegetation shows increase from 1978. The yellow values appear in between the larger dense red value forests. For example, the center of the image shows the increase in yellow values.

2005: There is decrease across the entire area from 1995 to 2005. The southern forests of dense red vegetation show some decrease in density and fragmentation along the edges. The southern portions do retain some size and cohesion compared to the rest of the West of Mt. d’Ambre. The northeastern area exhibits a large decrease with only small dense red areas remaining amid yellow and green values. The central area is obscured by some data error (clouds), which inhibits analysis. The northwestern area also shows a great decrease in density of total red/yellow value area. Only two smaller patches of dense red vegetation remain, and most yellow values have decreased to green values.

2017: Between 2005 and 2017, the size of the dense vegetation (red and yellow values) does not appear to change. The values of the consistent areas in the southern portion show increase in density. Yellow and orange values increase to darker red values in these areas. The northern area of the image exhibits little to no change in size with a slight increase in density values.

2018: There is no change between 2017 and 2018.

Northwest of Mt. d’Ambre:

1978: This is the baseline image. Data acquisition does not extend beyond this date.

1995: The 1978 to 1995 image shows an increase in vegetation density across the image. The size of the red areas remains consistent, there is more presence of the less dense yellow values. Yellow value areas increase in density from 1978 to 1995, especially in the extreme east portion and the western portion of the image. Forest that appear to not be connected by yellow values are now connected in 1995.

2005: There is large amounts of deforestation and density decrease between 1995 and 2005. The large forest of dense red values in the far east of the image is devastatingly reduced. The collection areas of dense red values and yellow values in the south and central portions of the image also exhibit great reduction. The western portion of the image also exhibits fragmentation and decrease in density. The coastal clusters of dense vegetation stay consistent and only decrease in size slightly. The forest in the peninsula in the north portion of the image decreases entirely to the green range of values.

2017: The decrease in forest density continues between 2005 and 2017 across the entire area. The northern coastal mangrove forests retain size and density from 2005 except for the extreme northeast coast, where the dense red values give way light blue values which indicates bare soil.

2018: There is little to no change between 2017 and 2018. The remaining dense red areas along the coast and to the east of the image retain size and density. There is no significant decrease or fragmentation along the central or southern portions.

North of Mt. d’Ambre:

1978: This is the baseline image. Data acquisition does not extend beyond this date.

1995: There is significant fragmentation and decrease in density across this area. The larger dense red forest divides in half and shrinks in size. The yellow forest portion slightly above the center large forest exhibits an increase in density. There is a slight increase in yellow valued forest islands. The top portion of Mt. d'Ambre exhibits an increase in density, and a slight regrowth that decreases fragmentation.

2005: Between 1995 and 2005, there are no dense red values concentrations in the North of Mt. d'Ambre area indicating significant deforestation. There is a small collection of orange and yellow values in the northwest portion, but no dense red values. The upper limits of Mt. d'Ambre National Park are non-existent. The coastal mangrove forest in the northern limit of the area exhibited a slight decrease in density and size. Another significant change is the decrease from green values to light blue values, showing a change from grassy conditions to bare soil. This change appears primarily in the northeast and southwest portions of the area.

2017: There is more decrease to green in the yellow values and an increase in the amount of light blue values. The remaining larger forest in the northwest exhibits fragmentation. The collection of yellow valued vegetation patches in the south exhibit a slight increase in density, showing dense red values. The northern coastal forest retains its size and density.

2018: There is little to no change between 2017 and 2018. The remaining red/yellow valued forests retain size and density. The light blue values remain consistent in size and density value. The mangrove forest along the coastal area is the only remaining significant dense red valued forest.

North Coastal:

1978: This is the baseline image. Data acquisition does not extend beyond this date.

1995: The primary dense red valued forests exhibit an increase in size and an increase in vegetation density. There is an increase in the less dense yellow valued forest surrounding primarily red valued forests and in the central portion of the image. The riverside forest increases in density. The area immediately south of the river exhibits an increase in yellow valued vegetation patches.

2005: There is significant deforestation between 1995 and 2005. The central dense red valued forests exhibit extreme decrease in density and size. The central forests also exhibit fragmentation in the remaining forests. The yellow valued forest collections decrease in value sharply. The extreme northern forest retains size but decreases in density. The riverside forest retains size and density. The most significant change is the increase in light blue values. Light blue values appear in the south portion, replacing the red and yellow valued forests. The riverside forests retain size and density, exhibiting no change.

2017: There is moderate decrease in size and density between 2005 and 2017. The extreme northern forest exhibits a decrease in density and a small decrease in size. The riverside forest exhibits a decrease in density value from red to orange but retains size. The collection of forests south of the river retain their size but exhibit a slight increase in value. The light blue values exhibit no change.

2018: There is little to no visible change between the 2017 and 2018 images. The river side forests exhibit a slight decrease in density values and no decrease in size.

South Coastal:

1978: This is the baseline image. Data acquisition does not extend beyond this date.

1995: The primary dense red value forests fragment and shrink slightly between 1978 and 1995. The northern portion of the continuous red shows significant fragmentation. There is an increase in yellow values across the image, prominently in the south, southwest, and coastal portions of the image.

2005: The period between 1995 and 2005 exhibits large scale decrease in density and fragmentation across the image. The southwest corner of the image shows all red and yellow values reduced to green and light blue values, complete deforestation. The dense red valued forest in the northern portion of the image are reduced in size significantly, decrease in value across the span, and fragment further. The larger collection of dense red, orange, and yellow values at the southcentral extreme decreases in size and density. This are is partially affected by clouds, disrupting true NDVI values. The primarily yellow valued coastal forests from 1995 are all reduced to green values by 2005.

2017: The dense red values in the central location of the image exhibit an increase in value and a regrowth in size. These forests visible regain cohesion. The southern dense red values retain size and density. The coastal forests exhibit regrowth with an increase in dense red values. While the northern dense red forest regrows, the physical shape changes with its southernmost extent decreasing and a fragmentation at the northernmost portion cuts into the primary cover. The light blue in the southeast corner exhibits no change.

2018: There is decrease in forest density between 2017 and 2018. The primary central forest decreases in size and density. The northmost extent reduces in value in its center from dense red to yellow. The southernmost collection of dense red and yellow values fragments. The light blue in the southeast corner of the image retains size and density.

Cap Saint-Sebastien:

1978: This is the baseline image. Data acquisition does not extend beyond this date.

1995: There is an overall increase in forest density and an expansion of yellow valued vegetation between 1978 and 1995. The large southern dense red expanse radiates all directs and has a buffer of yellow values. Yellow valued forest islands appear in the more central location of Cap Saint-Sebastien. The riverside forest in the east and the south also increase in size and density. The forests along the southern coast also increase in density and size. Overall, there is a decrease in fragmentation and an increase in density.

2005: There is a significant decrease in forest size and vegetation density between 1995 and 2005. The dense red values in the central portion of the image fragment and decrease. The central area exhibits significantly more green and light blue values showing deforestation. The southern forest and the east and south riverside forests exhibit the highest decrease in size and density. The southern forest is reduced to a fraction of the size and is comprised of less dense yellow values. The southern forest severely fragments with green values connecting. There is an increase in the light blue values in the southern portion of the image. The two riverside forests also decrease to predominantly less dense orange and yellow values, exhibiting massive density decrease.

2017: Overall, there is a decrease in forest size and density between 2005 and 2017. The northcentral forest is consistent and exhibits no change. The southern dense red valued forests decrease in size. The south and east river side forests increase in density but retain size. The light blue values increase in area and decrease in value, exhibiting continued deforestation.

2018: There is little change between 2017 and 2018. The southern dense red forest patches exhibit some change in size. The two river side forests remain consistent.

South:

1978: This is the baseline image. Data acquisition does not extend beyond this date.

1995: The south area shows a mix of regrowth and appearance of more yellow valued forests, with some deforestation and fragmentation in other portions of the image. The dense red forests in the east portion increase slightly in size and expand with moderately dense yellow values. The long, horizontal dense red forest at the extreme southeast reduced significantly. The dense red forests in the central portion of the image expand in size but fragment in a few areas. The dense red forests in the northcentral portion of the image fragment and ultimately change in shape. There is a regrowth from less dense yellow values to a denser red valued forest collection in the north left-of-center portion. The forest patches in the west portion of the image regrow and gain cohesion.

2005: There is massive deforestation between 1995 and 2005. The dense red forests in the east and central portions decrease in size and density significantly, may partially be due to cloud cover in image. The forests in the west are non-existent by 2005, giving away to green and light blue values. The southwest portion retains some dense red and less dense yellow values. The costal river side forest decreases in size and density significantly. Light blue values also begin to manifest in the southeast and east central portions of the image. Overall, the deforestation is vastly present between these two time periods.

2017: Overall, there is an increase in vegetation density and no change in forest size. There is a higher amount of dense red valued forests in the central and west portions of the image. The southwest and southeast retain their deforested green and blue values. The far west coastal river side forest increases in size and value between 2005 and 1995. Yellow forest islands with dense red centers reappear in the southwest portion.

2018: There is little to no change between 2017 to 2018.

Discussion

The anthropogenic influences on primate habitat are a main reason to use satellite imagery to assist in assessing land cover change. In most cases of deforestation, clearing of land for agriculture is the main pressing issue (Nagendra et al., 2004). Observing the changes in recent forest history allows researchers to identify key areas for study. In the case of the far north of Madagascar, further research in fragmented forests is planned. Potential research can include the human and primate interaction in historically fragmenting forests, based on this and earlier studies in these areas. Research from the 2017 field study on Crowned and Sanford’s lemur behavior may also continue. A more intensive spatial study, such as land cover classification or forest quantification is also possible with the data acquired. Discovering areas of change, whether deforestation or reforestation, will assist in all future research efforts.

While this study exhibits deforestation across the temporal span in all areas, the greatest visual difference is between 1995 and 2005. There are issues with using the 1973 and 1978 data in comparisons to later data which are encountered during the analysis.

The most prevalent was the spatial resolution difference between the older satellite images, Landsat MSS 1973/1978 and the newer satellites, Landsat EM/ETM+. This is especially prevalent when comparing 1978 and 1995 imagery. For example, a river and a beach seemingly appear in the North Coastal subsection.

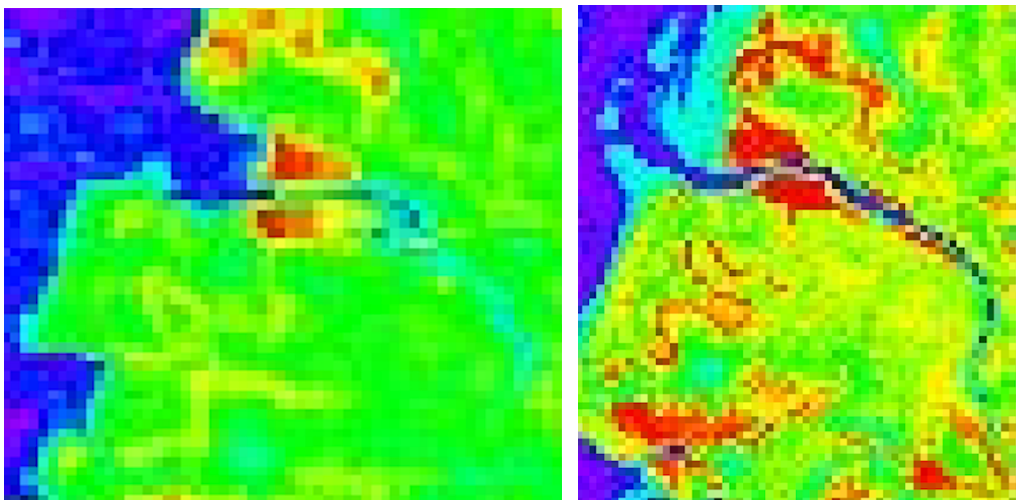


Figure 3. North Coastal subsection from 1978 (left) and 1995 (right). These images are an example of the discrepancies formed by different spatial resolutions.

Such large spatial disparities inhibit visual analysis. Disregarding the 1978 to 1995 comparison is necessary for this study to remain valid. In analyzing larger areas, this spatial disparity is less pronounced. Since this study entails observing areas represented by small collections of pixels, the 30 meters by 30 meters pixel size difference is significant. Recognizing and considering potential error due to the nature of image analysis is specific to data acquired and methods of analysis.

Massive scale deforestation events occurred in the ten years between 1995 and 2005. There is deforestation across the data frame between 2005 and 2017/2018, but the extent isn't as prominent as the previous ten years. The question presented by this is what events occurred between 1995 to 2005 that prompted a mass decrease of forest density. Satellite imagery is a snapshot in time. Processing data with high temporal resolution is key to establishing change. Historic and ethnographic data regarding land use and environmental events paired with satellite imagery is optimal for a cohesive understanding.

The North of Mt. d'Ambre is an example of a significantly deforested area between 1995 and 2005. Nearly all the dense red values disappear. This is the area that is geographically closest to the city of Antsiranana. The North of Mt d'Ambre has seen deforestation since logging in the 80's, which continues to today (Freed 2012). In the 2012 study, Freed also observed farming increasing southward and the path from the north through the national park becoming wide open since 2004. Being historically non-protected, closer to larger populations, and having relatively easy access may all contribute to the deforestation in the North of Mt. d'Ambre. According to Gezon et al. (2005), the North, Northwest, and west of Mt. d'Ambre has seen intense selective logging and nonregenerative farming since the colonial period. These field observations are consistent with this study's spatial data.

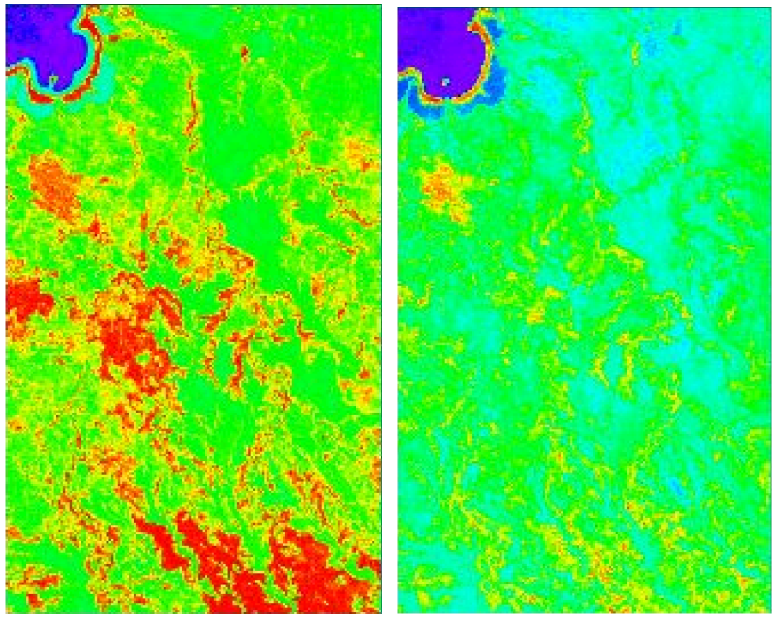


Figure 4. North of Mt. d'Ambre subsection1995 (left) and 2005 (right). The deforestation shown by the NDVI renderings is most pronounced in this subsection. The most affected areas include the southern and center western portions.

The interior of Mt. d'Ambre has remained consistent across the temporal span. There is some fragmentation on the edge, due to small scale farming. Both Freed, 2012 and Gezon et al., 2005 reported light agriculture of the edges of the national park, and underplanting (planting crops underneath the continuous canopy) along the boundaries. Between 1995 and 2005, there is an increase in the cohesiveness of the interior. A regrowth in the interior is possible due to the protected status of Mt. d'Ambre. In the study data frame, the northernmost portion of Mt. d'Ambre is reduced greatly. The deforested area is possibly outside of the park boundaries, leaving it open to utilization by locals. During a brief stay in the interior during the 2017 field study, two trees were felled within earshot of the camp. The individuals responsible claimed to be searching for honey, although it is possible they were searching for rosewood, or palisandre. Rosewood is a valuable commodity resource that was introduced by the French to sell to external markets (Gezon & Freed, 1999). Selective logging in national parks can decrease species diversity and survival. “Regardless of how long-ago trees were cut, clear-cut or selectively removed, logging decreased species diversity” (Brown & Gurevitch, 2004). Brown & Gurevitch conducted a study in Ranomafana National Park in southcentral Madagascar, which is one of Madagascar’s largest protected forests. Deforestation and change along protected forest areas is not unique to Mt. d’Ambre National Park.

Beyond the protected forests and forests near large settlements, there is still a decrease in forest density. The small forests that lie west of Mt. d’Ambre saw deforestation and fragmentation across the temporal span. These areas are largely unstudied, due to their high potential to be destroyed. While studying primates in these areas is difficult, it is not unrewarding. Observing primates in these conditions can lead to understandings about the immediate response to environment degradation, thus directions to proceed in terms of biology or conservation (Gibbons & Harcourt, 2009). Quantifying these small forest fragments and assessing their structural history is beneficial to future studies. Understanding forest history can help in assessing longevity of a field site.

The dry forests in the far south of Madagascar experienced similar degradation throughout previous fifty years. Sussman et al. (2006) assess ring-tailed lemur (*Lemur catta)* populations in relationship with the vegetation density gradients throughout the species’ entire geographic range. Major deforestation events occurred in the early 1970’s, 1985, and Post-1985 in the south, partially due to agriculture and charcoal production. The latest data acquired in this study is from 2000. Sussman et al. (2006) concluded that *Lemur catta* population density and forest canopy density was extremely related. In the areas with low forest canopy density there was less data available on ring-tailed lemur population and behavior. Sussman et al. (2006) states, "We know next to nothing about the behavior and ecology of the ring-tailed lemurs living in these types [less dense forests] of habitats" (p. 28). Areas with little vegetation or degraded forests that can support lemur populations are not being studied. A data devoid area can hold potential for research directions that explore the relationship of human altered environment and the response from primates. Patterns of fragmentation and regrowth observed in spatial analysis, such as in this study and Sussman et al. (2006), contribute to a wider field of study in locations experiencing similar conditions.

Conclusion

Destruction of primate habitat is an increasingly current issue and pervades current primate research. In a defeatist conclusion, these forests are being destroyed at high rates outside of protected areas. Destruction and fragmentation decrease species survival and primate density. Observing destruction and change is not sufficient in moving forward. The opportunist conclusion is that discovering areas that were previously considered uninhabitable or threatened and conducting research can lead to valuable conclusions in anthropological research. Creating recent forest history in Madagascar with intentions of utilization for further ground research constructs a multidisciplinary approach to understanding current issues. Identifying forest decrease or increase is a step in providing context for an area that lacks extensive data. This paper was to supplement the work of previous researchers and contribute a base for future studies in the far North of Madagascar.

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