

Student thesis series INES nr 300

Remote Sensing of Deforestation Along the Trans-Amazonian Highway

Johan Westin

2014

Department of

Physical Geography and Ecosystem Science

Lund University

Sölvegatan 12



Johan Westin (2014). Remote sensing of deforestation along the trans-Amazonian highway
Bachelor degree thesis, 15 credits in *Physical Geography & Ecosystems Analysis*
Department of Physical Geography and Ecosystems Science, Lund University

Abstract

Remote sensing of deforestation along the trans-Amazonian highway

Deforestation is one of the biggest environmental challenges today. Especially severe has the deforestation of the Amazon rainforest been where at least 20% has been cleared the last 40 years. A time series analysis of deforestation rates between 1984 and 2013 has been performed on several sites close to the Trans-Amazonian highway BR230 in the Amazon and Para states. This is done by applying a supervised classification method to Landsat scenes to classify rainforest and deforested areas. It is concluded that annual deforestation rates often has been higher at the study sites than the general trend of deforestation for the Amazon in the past. In recent years deforestation often show to be lower than the trend for Amazonas. Reasons for the high rates in the beginning of the series could be closeness to towns, which makes it easier for deforestation and increases the export potential. Rates being lower in recent years are strongly related to the global economy but could also be a consequence of political governance due to increased awareness of the effects of deforestation, creation of protective areas and monitoring of illegal deforestation together with law enforcement.

Keywords: Deforestation, Amazon rainforest, remote sensing, Trans-Amazonian highway, BR230.

Advisor: Ulrik Mårtensson

Degree project: 15 credits in physical geography & Ecosystem analysis, 2014

Department of Physical Geography and Ecosystem Science, Lund University

Johan Westin

Svensk populärvetenskaplig sammanfattning

Fjärranalys av skogsskövling längs med den trans-amzoniska motorvägen

Skogsskövling är ett av de större miljöproblemen vi har idag. Speciellt snabb har skövlingen varit i Amazonas regnskog, där minst tjugo procent försvunnit de senaste 40 åren. Fjärranalys används för att uppskatta skogsskövling längs med den transamazoniska motorvägen (BR230). Analysen utförs genom en klassificering av satellitdata i en tidserie mellan 1984 och 2013 med hjälp av reflektansvärden. Resultatet visar att skövlingen ofta har varit högre än den generella trenden för Amazonas i början av tidsserien och att den ofta varit lägre på senare år. En anledning till de höga hastigheterna kan vara att studieområdena ligger nära städer eller byar och därför är dessa områden de som skövlats först. De låga hastigheterna kan kopplas ihop med den globala ekonomin och efterfrågan på marknaden. Andra anledningar är att brasilianska myndigheter försöker kontrollera skövlingen genom olika åtgärder som t.ex. genom övervakning och böter till de som olovligen skövlar och uppförandet av naturskyddsområden.

Handledare: Ulrik Mårtensson

Examensarbete: 15 hp i Naturgeografi & Ekosystemanalys, 2014

Institutionen för naturgeografi och ekosystemvetenskap, Lunds universitet

Table of contents

Abstract

Svensk populärvetenskaplig sammanfattning

1. Introduction	7
1.1 Aim	7
1.2 Study area	8
1.3 The trans-Amazonian highway	8
2. Deforestation in the Amazon	9
2.1 Illegal deforestation	11
2.2 Monitoring deforestation	12
3. Rainforests and the climate	12
4. Data	15
5. Method	16
5.1 Classification	17
5.2 Accuracy assessment	18
6. Results	20
7. Discussion	26
8. Conclusions	26

Appendix

References

1. Introduction

Deforestation is defined as the conversion of forest cover to non-forest land by human activities and is one of the biggest environmental challenges today (Encyclopædia Britannica, 2013). Forests all around the world are threatened by unsustainable deforestation but especially severe has the clearing of the tropical rainforests been. Exactly how fast the tropical rainforests has declined are a highly debated question and many studies show different results.

Rainforests are cut down for lumber and charcoal and the newly cleared areas are used as pastures, plantations, mines or settlements (The Nature Conservancy 2011). Rainforests are important as they provide ecosystem services and natural resources for people, like water purification and medicinal plants. About 70% of plants useful for treatment of cancer identified by the U.S. National Cancer Institute can only be found in rainforests (Wallace 2013).

The construction of roads has both a direct and an indirect effect on deforestation. Directly as forests has to be cleared to make room for roads and indirectly as roads enables transport of lumber, making deforestation possible.

1.1 Aim

The aim of this project is to assess the rate of which deforestation has occurred as a result of building the trans-amazon highway route in Brazil. Years when deforestation has been especially high will be localized and compared to deforestation rates for the whole Amazon region. The problems of unsustainable forestry and illegal deforestation are discussed and model projections will be studied to assess future changes to the Amazon.

Three hypotheses were formulated:

1. Deforestation rates are much lower today than in the past.
2. Deforestation has a big impact on climate change.
3. Climate change imposes a threat to the Amazon rainforest.

1.2 Study area

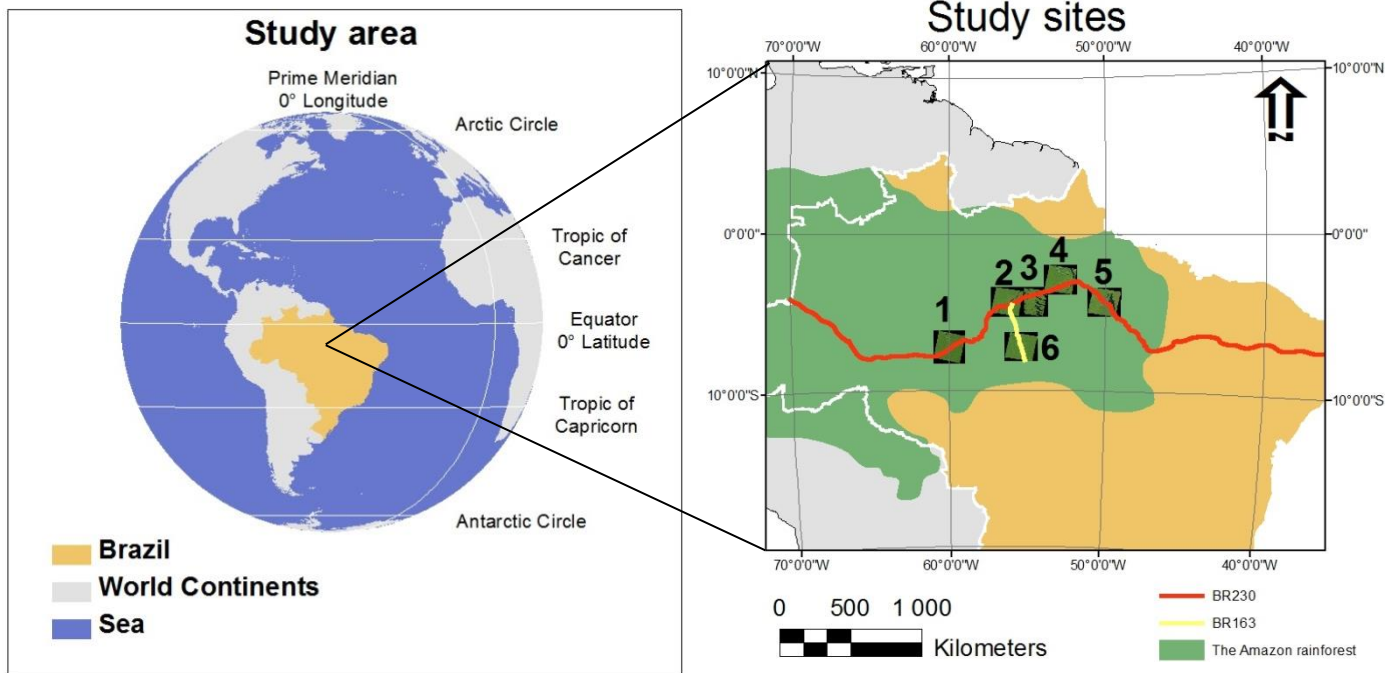


Figure 2. Study sites along BR230 and BR163. 1 = Apuí 2 = Itaituba 3 = Rurópolis 4 = Altamira 5 = Novo Repartimento 6 = Novo Progresso

The study area includes the rainforest along the trans-Amazonian highway route (BR230) in Brazil, South America (figure 1&2). The BR230 spans from the east coast of Brazil all the way through the Amazonas and ends at the border to Peru. The Amazon is the biggest rainforest in the world accounting for about 30% of the total global rainforests (Souza et al. 2013). The specific study sites were picked so that BR230 intersected them as much as possible and where deforestation had occurred. The study sites were named after towns close to them. One site along the highway BR163 was chosen as deforestation was much lower further along BR230. The towns chosen were: Apuí, Itaituba, Rurópolis, Altamira, Novo Repartimento and Novo Progresso (figure 2) and they are located in the states of Amazonas and Para.

1.3 The trans-Amazonian highway

The Amazonas forest was fairly untouched before the launch of the trans-Amazonian highway in 1972. Almost five centuries of European presence before 1970 deforested an area only slightly larger than Portugal (about 100 000 km²). The trans-Amazonian highway enabled access to areas of the Amazon rainforest previously being inaccessible (Fearnside 2005).

The road is 4,056 km long and is still being paved today (Dangerousroads 2013) The costs building the planned highways greatly exceeded the economic gains improved transportation would lead to (Fearnside and Lima de Alencastro Graça 2006). The reason for this was that the plans partly were motivated by territorial control rather than money. A decree law shifted the control of the land within 100 km from any planned highway (2.2 million km²) from state to federal government control. This law was revoked in 1987 making the area “terra devoluta”, unclaimed land. This together with the Brazilian tradition of giving land squatter’s

rights to those who invade public land led to uncontrolled deforestation along the Amazonian roads (Fearnside and Lima de Alencastro Graça 2006).

2. Deforestation in the Amazon

The problem of unsustainable deforestation is global but has been fastest in the rainforest of the Amazon where at least 20% has been lost the last 40 years (Wallace 2013). There has been a shift from small to large scale forest exploitation the last decades. Today small scale farmers account for about 30% of the total deforestation in the Amazonas region and medium to large scale companies account for the rest. Cattle ranching is the predominating type of land use (Fearnside 2005).

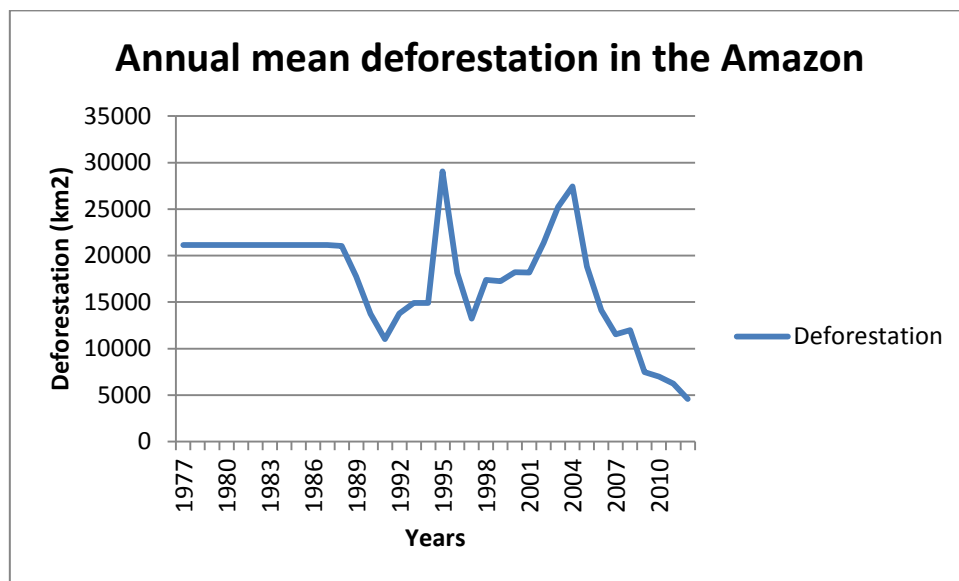


Figure 3. Annual mean deforestation rates for the Brazilian Amazon in km² (Butler 2013). An average was calculated for the first ten-year period (1977-1987) as data for some years in between was missing.

The National Institute of Space Research (INPE) has estimated deforestation back to 1977 (Butler 2013). There has been an almost continuous drop in annual deforestation rates from 2004 and forward in the Amazon (figure 3). One of the reasons for this is that the Brazilian government is implementing different strategies to try and control deforestation such as licensing procedures, surveillance, fines and creation of protective areas (Fearnside 2005). A strong positive correlation exists between the entry of state capital such as loans, tax cuts, investments in infrastructure and deforestation (Souza et al. 2013). Variations in global market prices also cause changes in deforestation rates; an example of this was between 2001 and 2004 when the deforested area for cropland was directly correlated with the mean annual soybean price (Azevedo-Ramos 2007). The economic crisis in 2007 further increased the downward trend of deforestation (Juan Robalino and Luis Diego Herrera 2009). The trend has taken on added importance since the United Nations Climate Change Conference in Bali, December 2007. One of the key decisions there was to launch a process to aid developing countries financially if they protect their forests (Hirsch 2008).

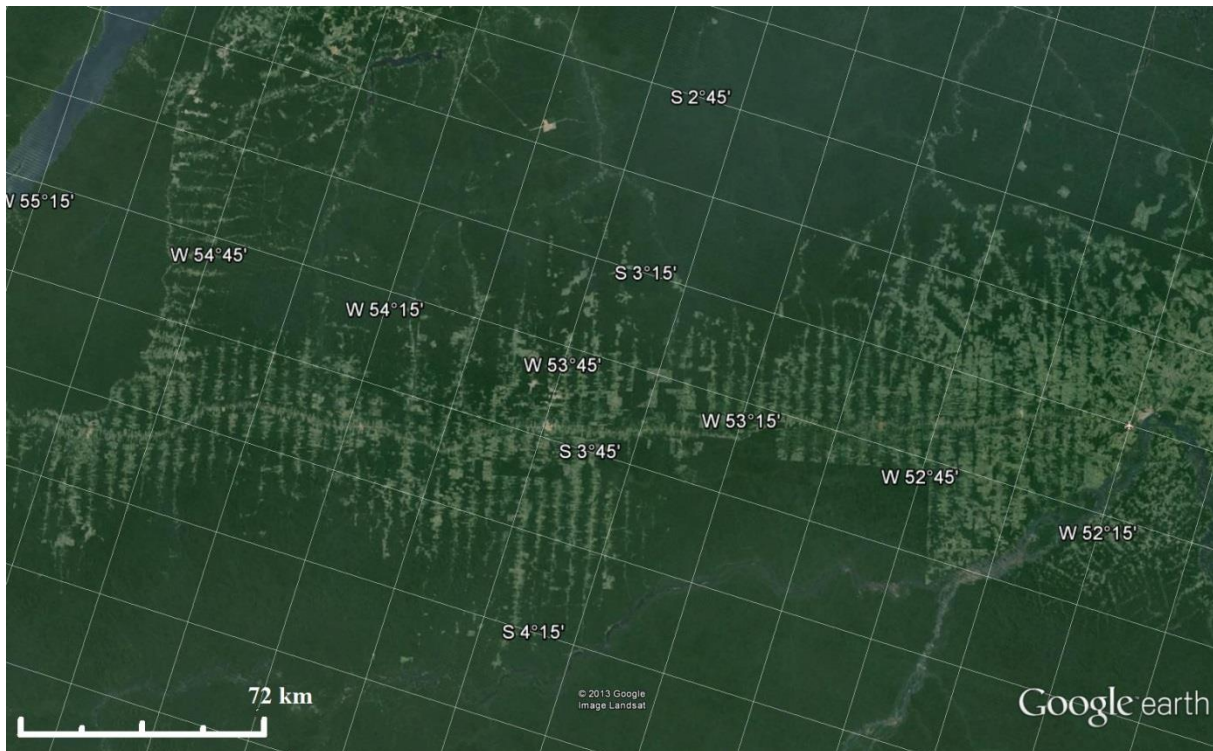


Figure 4. Fishbone deforestation in the Amazon close to the town Uruará. Image taken 10-4-2013.

Deforestation follows a predictable fishbone pattern in the Amazon (figure 4). Deforestation starts as legal and illegal roads, arrayed along the edges of main roads, penetrate remote parts of the forest. After the fish bones have been cleared it is transformed into a mixture of cropland, pastures, settlements and left-over forest by small scale farmers. Intense rainfall and erosion depletes the soils and crop yields fall. The farmers then convert the degraded land to pastures and clear new forest for crops. When the farmers have cleared much of their land they sell it or abandon it to large scale farmers who combine the land fragments to large areas of agriculture and pastures. This process makes the fish bones grow bigger with time until they eventually merge with each other (NASA 2011).

The negative effects on biodiversity have proved to be higher while practicing the fishbone pattern than for large-property deforestation patterns (Prist et al. 2012). The reason for this is that not enough forest is saved between the patches of deforestation. This results in biodiversity being affected in a much vaster area than would be necessary. The effect on habitat configuration is most apparent when the forest cover is below 30%. A study showed that fragmented landscapes (forest cover ~25%) showed a significant decrease in species richness compared to control landscapes (100% forest cover) (Prist et al. 2012). Forest fragmentation and edge effects from deforestation and selective logging have a big impact on the rainforest in the tropics. Fragmentation leads to biodiversity loss (Eben et al. 2008). A reason for this is a higher proportion of forest being close to the edges of the forest. The effects are higher fire susceptibility, both from an increased risk of ignition from anthropogenic sources and an increased penetration ability of fires into the interior of the forest, higher tree mortality (increases carbon dioxide (CO₂) emissions) and increased access to the interior of forests which leads to more hunting and resource extraction (Broadbent et al. 2008). Furthermore, it leads to changes in plant and animal composition as seed dispersal to suitable habitats gets limited and because of increased predation from animals due to less protective forest cover (Fahrig 2003).

Regional planning demands predictive models that can produce projections of deforestation trends based on different political choices. A model like this was developed by Soares-Filho et al. in 2006 and is built on the positive correlation existing between deforestation and new or paved roads in the Amazon and other various development parameters. The output is the projected future deforestation in the Amazon forest in 2050. There are eight different scenarios, one of the extremes is a “business as usual” scenario where all pavement of roads planned for 2027 (14 000 km) is constructed, law enforcement is low and agriculture and migration of people is allowed to expand in the Amazon forest. According to the model, about 40 percent of the Amazon forests would be cleared between the period of 2003-2050 in this scenario, going from 5.3 million to 3.4 million km². At the other side of the extremes is a “governance” scenario. In this scenario only 11 500 km of road pavement up to 2026, stronger law enforcement, agriculture prevented from spreading to inappropriate areas and an expansion of protected areas is included. The difference in the total area deforested by 2050 would be 1 million km² between these two scenarios. In the “business as usual” scenario about 100 mammal species (30%) would lose more than 40 percent of their habitats, compared to the “governance” scenario where it would happen to 39 species (10%) (Azevedo-Ramos 2007).

Protected areas play a very important role when it comes to conserving biodiversity. The study shows that these protected areas would do little alone in the “business as usual” scenario but that they can be very important when coupled with the “governance” scenario and could result in one-third of the deforestation being avoided (Azevedo-Ramos 2007).

2.1 Illegal deforestation

Although some deforestation is part of the country’s plans to develop its agriculture and timber industries, other deforestation is the result of illegal logging and squatters (Schmaltz 2006). The illegal logging trade is estimated to be worth between 30 billion and 100 billion dollars annually (Lynch et al 2013). The small to medium scale illegal deforestation has been hard to monitor using remote sensing, this is because at the time it has been detected and reported to authorities the deforesters are long gone. To try and solve this problem several live updated forest watch systems has been launched where the Amazonas is being remotely monitored every day.

2.2 Monitoring deforestation

Until 2004, the only method for monitoring deforestation in the Amazonas was the Program for deforestation estimates in the Amazonas (PRODES) (INPE, 2013). This system is purely based on high resolution Landsat images and the complex analysis of deforestation is time consuming. It serves merely as a historical record and is of no use when trying to track down deforestation.

In 2004 a new system called The Real-Time System for Detection of Deforestation (DETER) was launched by INPE. The system uses various satellites that generate images more frequently but at a coarser resolution than Landsat and are able to provide analyses of deforestation every two weeks. Collaboration between INPE and the Center for Environmental Monitoring (CEMAM) produces georeferenced satellite images on forest cover changes in the Amazon. The images are prepared with a 15-day interval to be distributed as georeferenced maps. The maps are designed to give the authorities important up-to-date information on where deforestation is taking place and where to concentrate enforcement efforts (Assunção et al. 2012).

SAD (Sistema de Alerta de Desmatamento) is a near-real time deforestation monitoring system based on MODIS (Moderate Resolution Imaging Spectroradiometer) daily image composites. It was started in 2009 and their Web-GIS portal provides geographical information about different threats to the Amazonas such as deforestation, fires or road construction. They also provide monthly reports with trends, geographical hot spots, spatial analysis and statistics on deforestation (Souza et al. 2009). This data can be accessed through their Web-GIS portal Imazongeo (URL 1 in the reference section).

3. Rainforest and climate change

The forestry sector is the third biggest emitter of greenhouse gases in the world (after energy and industry) and also speeds up global warming by the release of greenhouse gasses that was captured in the forest. Tropical deforestation accounts for 12% of the total global CO₂ emissions (The Met Office 2013).

Forests play a key role in controlling the climate as they act as CO₂ sinks, storing about 50 percent of the 34 billion tons of CO₂ created by mankind each year (Olivier et al. 2012). Furthermore, it helps with lowering temperatures through evaporation which cools the surface and increases cloud cover and precipitation (The Met Office 2013). A negative feedback exists as deforestation leads to less precipitation which leads to further forest die back due to lack of sufficient soil moisture and more forest fires (Christensen et al. 2013). The removal of forest cover means a direct increase of albedo since forest has lower reflectance potential than clear ground, this has a cooling effect. A lot of this effect is lost however, since controlled fires often are used in the Amazon to clear for agriculture and burned ground has a much lower albedo than clear ground (Myhre et al. 2013).

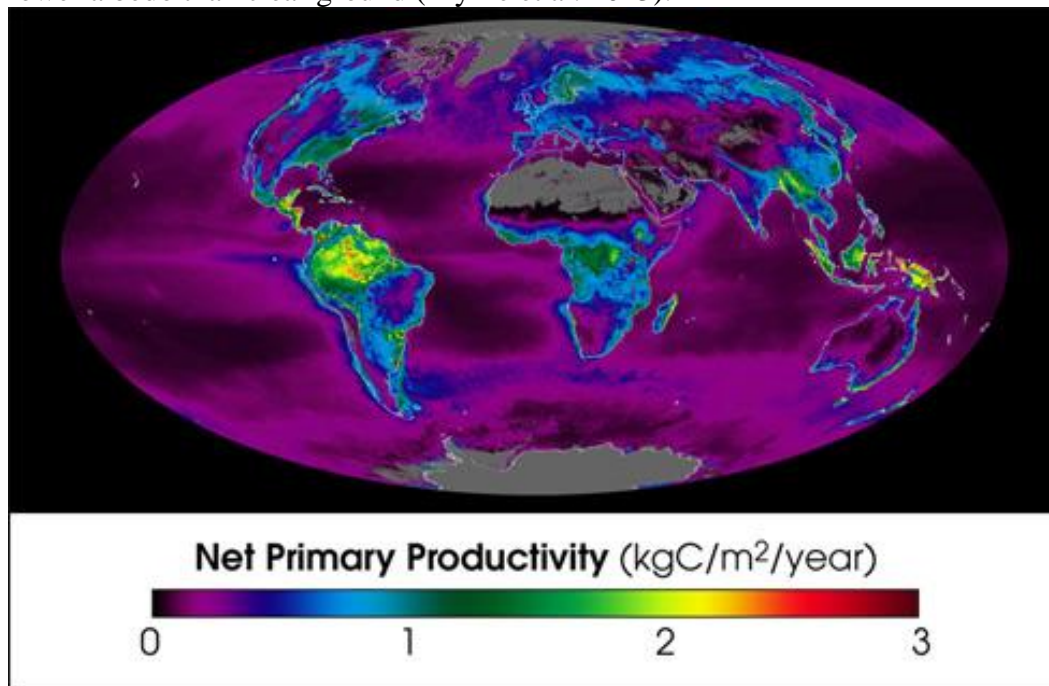


Figure 5. The map depicts the rate at which carbon is absorbed from the atmosphere by plants. It is based on the global, annual average of the net productivity of vegetation on land and in the ocean during 2002. Purple = little, blue = more, red/yellow= a lot. (NASA 2010)

The Amazon accounts for a big part of the total global terrestrial carbon uptake and deforestation therefore has a higher effect on global warming here than in other places around the world (figure 5). The net effect of the loss of carbon storage and increase of albedo leads to higher global temperatures (Myhre et al. 2013).

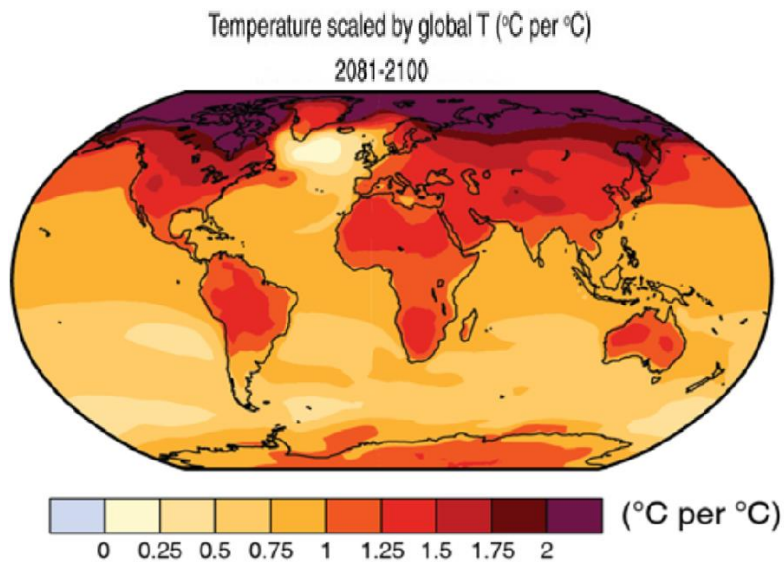


Figure 6. Temperature change patterns derived from simulations from the new coupled model intercomparison project CMIP5, scaled to 1°C of global mean surface temperature change. The patterns have been calculated by computing 20-year averages at the end of the 21st century and over the period 1986–2005 for the available simulations under all representative concentration pathways (RCP) (emission scenarios), taking their difference and normalizing it by the corresponding value of global average temperature change for each model and scenario. The normalized patterns have then been averaged across models and scenarios. The color scale represents °C per 1°C of global average temperature change (Collins et al. 2013).

Future climate change will have an effect on biomass and biodiversity in the Amazon. Most climate models project the Amazon region to be a future hotspot of warming (figure 6). The average temperature increase is projected to be 3.3°C (ranges from 1.8°C to 5.1°C depending on storyline and scenario) by the end of this century (Christensen et al. 2007). Changes in precipitation and temperature could lead to ecological mismatches where the climate has changed too much to be suitable for the plant and animal species living there. The combined effects of raised temperatures, lower precipitation and limits to carbon fertilization from global CO₂ increase could possibly force the tropical forest to be replaced by seasonal forest or savannah (Collins et al. 2013).

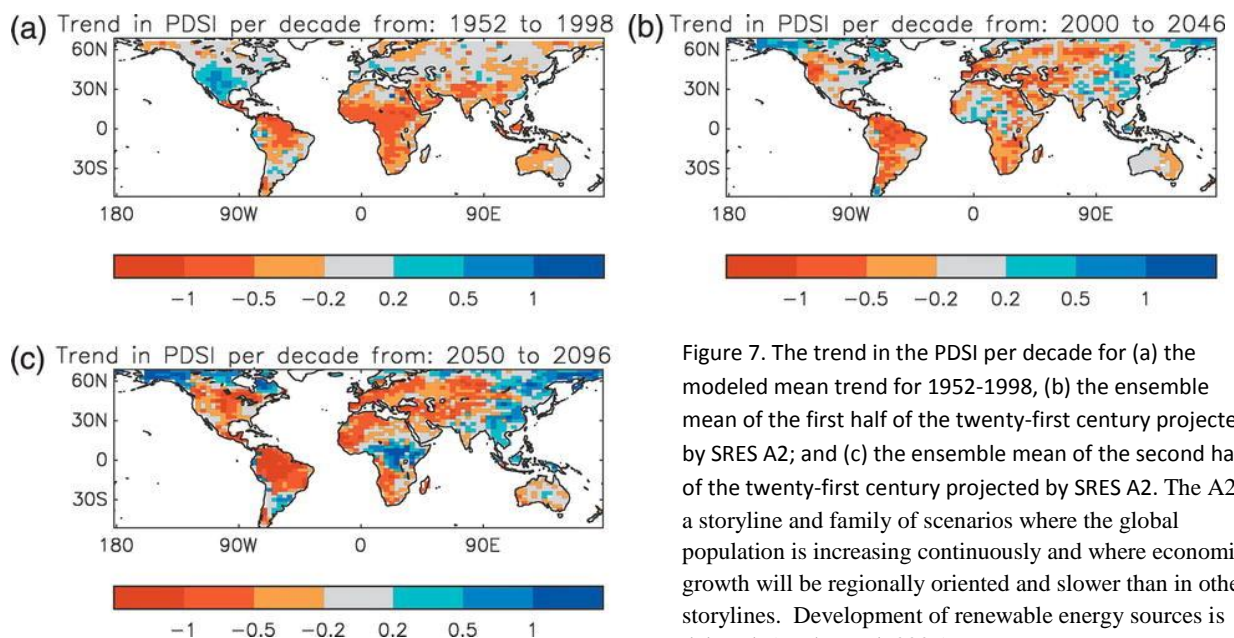


Figure 7. The trend in the PDSI per decade for (a) the modeled mean trend for 1952–1998, (b) the ensemble mean of the first half of the twenty-first century projected by SRES A2; and (c) the ensemble mean of the second half of the twenty-first century projected by SRES A2. The A2 is a storyline and family of scenarios where the global population is increasing continuously and where economic growth will be regionally oriented and slower than in other storylines. Development of renewable energy sources is delayed. (Burke et al. 2006)

Most climate models revised in the latest IPCC report project a significant decrease in precipitation in big parts of the Amazon region. This together with raised risk from fragmentation makes the forest more susceptible to fires. Climate change could increase fire risk even further as dry seasons might get longer. It is estimated that 58% of the Amazon is too humid for forest fires but climate change might reduce this number to 37% by 2050 (Collins et al. 2013). The Palmer Drought Severity Index (PDSI) was developed by Wayne

Palmer in the 60's and has been used together with the IPCC SRES A2 scenarios and the Hadley Centre Climate Model (HadCM3) to compute future global drought projections (Burke et al. 2006). As can be seen in figure 7, changes in the Amazon are projected to be particularly high. Forest fires have the potential to increase deforestation rates much faster than any human activities.

Regional carbon-climate feedback

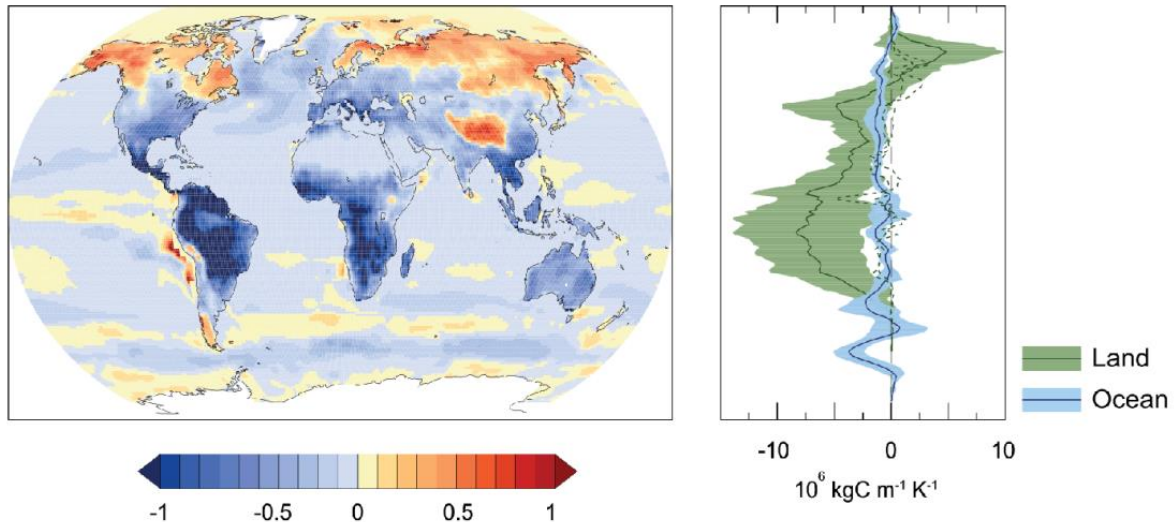


Figure 8. The spatial distributions of multi model-mean of changes in terrestrial and ocean carbon storage for 7 CMIP5 models using the concentration-driven idealized 1% per year CO_2 simulations. In the zonal mean plot, the solid lines show the multi-model mean and shaded areas denote ± 1 standard deviation. Models used are: BCC-CSM1-1, CanESM2, CESM1-BGC, HadGEM2-ES, IPSL-CM5A-LR, MPI-ESM-LR, and NorESM1-ME (Ciais et al. 2013).

There is high agreement between models that tropical ecosystems will store less carbon in the future and that northern ecosystems will store more (figure 8). This can be explained by an amplified photosynthesis in northern latitudes (mainly due to higher temperatures, CO_2 and precipitation) and by more respiration in tropical latitudes (due to less precipitation, temperatures getting too high and a limited nitrogen fertilization effect) (Collins et al 2013). This feedback speed up the increase of atmospheric CO_2 concentrations further as rainforests account for a big part of the total terrestrial carbon storage (figure 5).

4. Data

The satellite data used comes from the Landsat 4 and 5 Thematic Mapper (TM), the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and the Landsat 8 Operational Land Imager (OLI) sensors. The Thematic Mapper images consist of seven different spectral bands, band one corresponds to blue light (0.45-0.52 μm), band two to green light (0.52-0.60 μm), band three to red light (0.63-0.69 μm), band four, five and seven to near infrared and short wave infrared (0.76-2.35 μm). Band six is the thermal wave length band (10.40-12.50 μm). The ETM+ collects data in one more band than TM. The additional band covers band two, three and four but has a higher resolution (15 meters compared to 30). The OLI instrument collects data in nine spectral bands, however only the visible and the short wave infrared bands were used for classifications (USGS 2013). The Landsat scenes cover an area of 31110 km^2 .

The geodetic reference system of all the data layers used in this project is WGS84 and they are projected in Universal Transverse Mercator (UTM) zone N21 with a central meridian of -57. The Universal Transverse Mercator is a conformal, cylindrical projection with the axis of the cylinder in the equatorial plane and the line of tangency at any specified central meridian.

This makes the projection highly accurate when it comes to scale and shapes. The area error increases with distance from the central meridian (Snyder 1987).

Table 1. Summarization of the GIS data used.

Satellite data	Resolution	Usage
Landsat 4-5 TM	30 m	Classification of years 1984-1999
Landsat 7 ETM+ SLC-on	30 m	Classification of years 1999-2003
Landsat 7 ETM+ SLC-off	30 m	Classification of years 2003-2012
Landsat 8 OLI	30 m	Classification of 2013

Vector data	Usage
Continents	Map showing study areas
Roads	Creating buffer zone

The Landsat data was downloaded from the USGS Landsat Look Viewer (URL 2) and covers random years between 1984 and 2013 (dates for the specific scenes classified can be found in the appendix together with information on how to find them in the Landsat Look Viewer). Only data with less than 5% cloud cover was used to minimize area estimation errors. The road layer used to create buffer zones was downloaded from DIVA-GIS (URL 3). The vector files of South America and the country boundaries used to create figure 1 was produced by ESRI in 2008 and can be found in URL 4. A summary of the data used can be seen in table 1.

5. Method

All steps of the data analysis were carried out using the geographical information system (GIS) ArcGIS. The classifications will be performed using a supervised classification method, clustering pixels in an image into classes corresponding to user-defined training sites. The resulting area of deforestation will be divided by the number of years in between two scenes and with the total buffer zone area to get the rate of deforestation relative to the original forest cover. This rate will be referred to as the intensity of deforestation. To get the intensity for the Brazilian Amazon the yearly deforested area from INPE was divided by the total forest area for the Brazilian Amazon before 1970 (4,100,000 km²). The intensity will be used to compare rates of deforestation at different study sites.

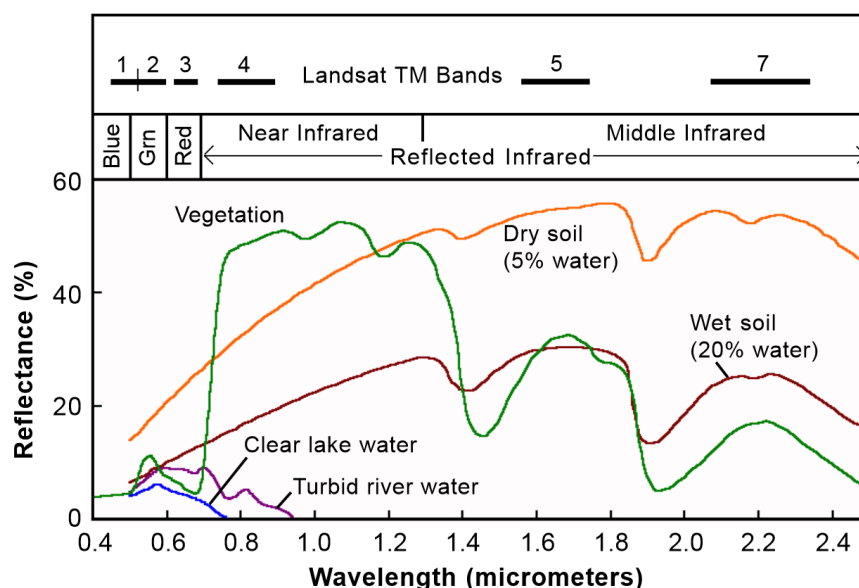


Figure 9: The spectral reflectance response from vegetation, soil and water in the visible to reflected infrared range. The distribution of the Landsat bands can be seen in the top of the figure (Microimages 2013).

Healthy vegetation absorbs most solar radiation in the blue (0.4 μ m) and red (0.6 μ m) wave length bands and this is why healthy vegetation appears green. The light collected is used for photosynthesis. Most radiation in the near infrared range is reflected by vegetation due to limitations in energy absorption. Bare soil reflects less radiation in the near infrared region than vegetation but more in the visible wave length bands. These differences in reflectance (figure 9) make it possible to distinguish between deforestation, forest and water in satellite images using their pixel values (Cronquist and Elg 2000).

5.1 Classification

The road layer was clipped to only include the area covered by the extent of all the satellite images in a site. This was done as the Landsat scenes do not coincide with each other perfectly; each scene is slightly misfit relative to each other. This measure was taken to avoid catching corrupted pixels in the edges of the scenes (present in all Landsat data) within the buffer zone. Since the road network layer used is a national layer covering all of Brazil it is not very accurate on a local scale and can therefore not be used together with the Landsat data without modifications. Then road segments were split into smaller segments and reshaped by fitting it visually to the road in the Landsat image. Buffer zones of 25km around the roads were created for each scene.

Next step is to create training sites for the classification. This is a crucial part where it is important to choose areas representable for the classes you expect to classify. The resulting classification will depend on what areas are considered to belong to the deforested and rainforest classes. Training sites for water and bad data was included to prevent water, clouds and distortion in the data from being classified as deforested area.

The interactive supervised classification method was used to classify the rasters. This tool uses the maximum likelihood method on a set of raster bands and produces a classified raster as output. The method considers both the variances and covariances of the reflectance signatures in the training classes created when assigning each cell in the raster to one of the classes. With the assumption that the distribution of each class is normal, a class can be characterized by the mean vector and the covariance matrix. The statistical probability that a cell belongs to a class is computed using these characteristics and Bayes' theorem of decision making. The cells are assigned to the classes they have the highest probability of being members to (ESRI 2010). The interactive supervised classification method creates a temporary classification raster file based directly on the training sites. This speeds up the process as it allows the user to preview the classification without having to first create a signature file and then run the maximum likelihood classification.

The temporary raster layers created were converted to polygons with class names. Next step was to overlay (intersect) the classified polygons with the buffer zone layer created earlier to get a layer only classified within the buffer zone. The geometry of the polygons was calculated in a new field in the attribute table. The result is the area for every polygon in the image. The deforested area was exported by selecting it based on its class value in the attribute table and summed up to get the total cleared area. All the polygons were summed up to get the total area of the buffer zone.

All classified images can be found in the appendix.

5.2 Accuracy assessment

To calculate the accuracy of the classifications one randomly chosen year from each study area was evaluated. Twenty control points were randomly distributed within the buffer zone. No control points were put in water as that would have improved the result of the validation. Each control point was validated manually by comparison of the classifications with the Landsat scenes used. Google Earth images, taken as close as possible to the Landsat dates, were also used as it provides higher resolution images.

The dates used for validation for the different study sites were:

- Novo Repartimento – 2005/7/4
- Rurópolis – 1999/8/10
- Itaituba – 2011/8/10
- Apuí – 1996/7/13
- Novo Progresso – 2004/6/28
- Altamira – 2008/7/2

Overall accuracy and the coefficient of agreement or Kappa (K), was calculated to be able to assess the accuracy of the classifications.

$$\text{Overall accuracy} = \frac{\sum A}{N}$$

A is the number of correctly mapped points in each class and N is the total number of points. This gives the probability that a randomly chosen point (from field or map) is correctly mapped.

Kappa (K) was calculated to get rid of the influence of chance.

$$\text{Kappa} = \frac{N * d - q}{N^2 - q}$$

Where N is the total number of points, d the sum of correctly mapped points and q is the sum of the products between the number of ground truth points and the number of map data points for each class (Viera and Garrett 2005). Confusion/error matrixes can be found in the appendix.

6. Results

Apuí

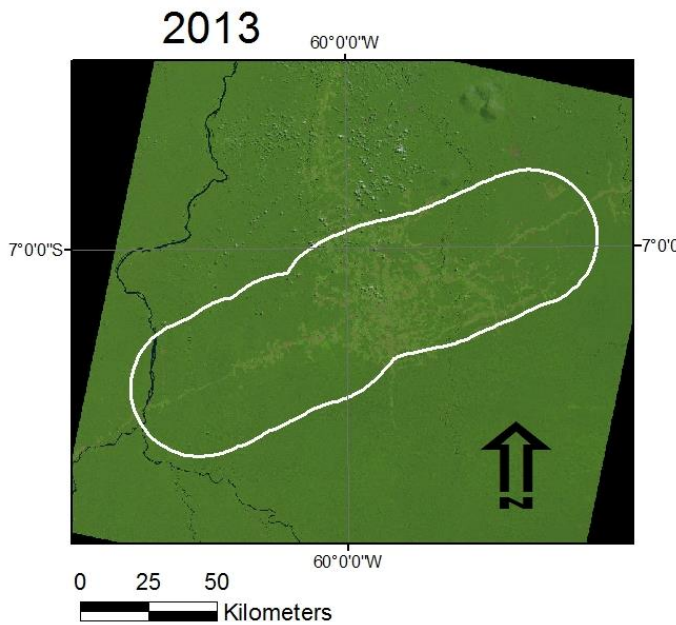


Figure 25. Landsat image from 2013 showing the extent of the area classified (white line) in the Apuí site.

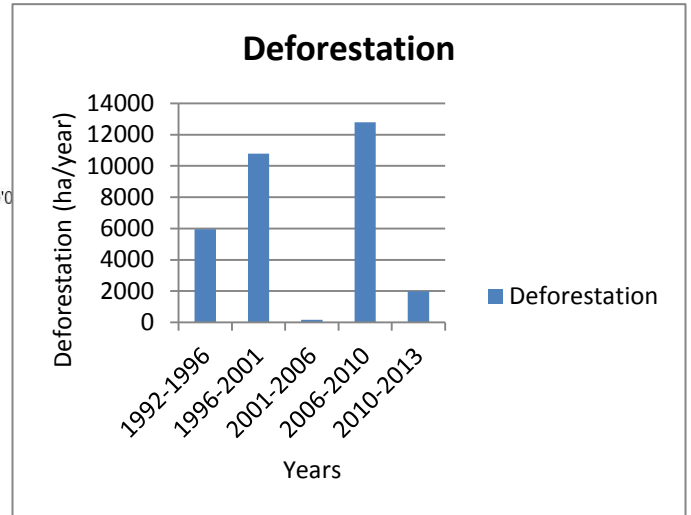


Figure 26. Yearly average deforestation rates for Apuí.

All the control points were accurately mapped in this site. There has totally been 135729.77 ha (15.6% of the total buffer zone) of forest lost between 1992 and 2013. The deforestation rate was 5963 ha (0.69%) per year between the years of 1992 and 1996. The rate increased to 10789 ha (1.24%) per year between 1996 and 2001. Deforestation decreased again to a rate of 161 ha (0.018%) per year the following period (2001-2006). A record high was set between 2006 and 2010 with a rate of 12796 ha (14.71%) a year. The speed of deforestation dropped again to 1981 ha (0.23%) per year in the last period (2010-2013).

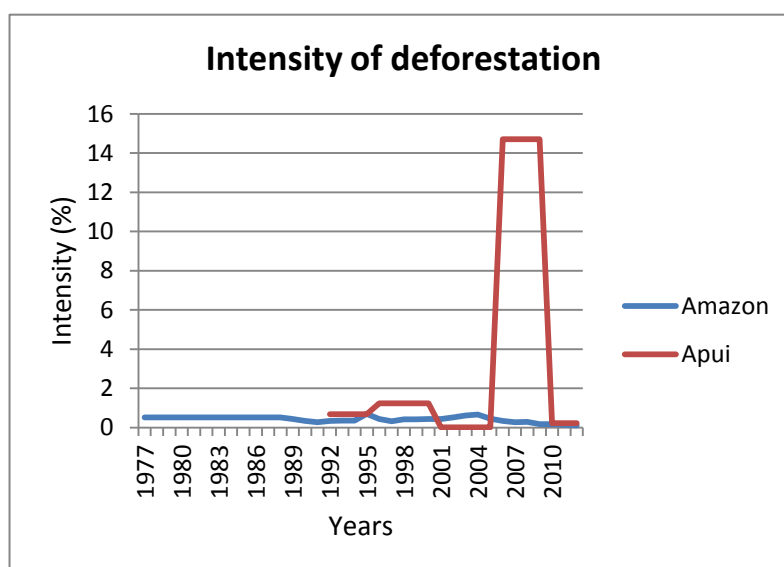


Figure 27. Mean annual deforestation intensity for Apuí and the amazon region.

The intensity of deforestation in Apuí follows the general trend for the Amazon fairly well, except between 2006 and 2010 when this site experienced a deforestation intensity of 14.71% a year (figure 27).

Itaituba

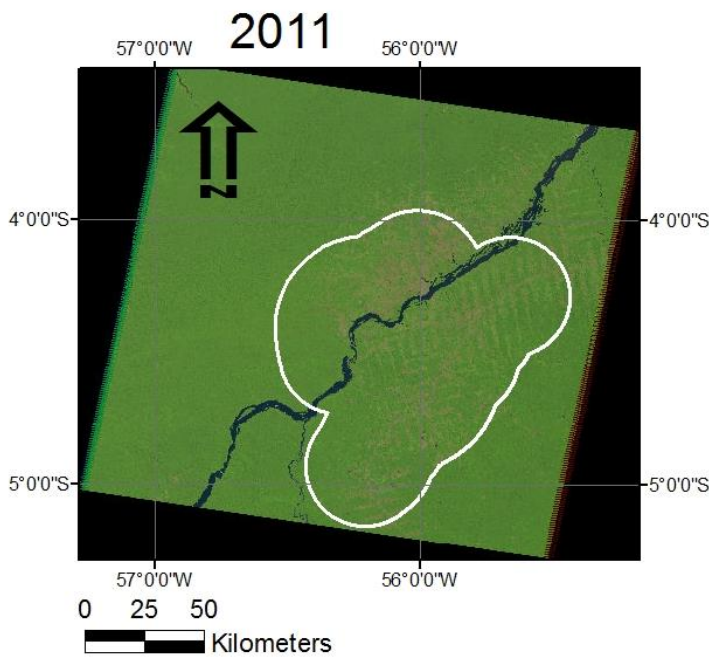


Figure 13. Landsat image from 2011 showing the extent of the area classified (white line) in the Itaituba site.

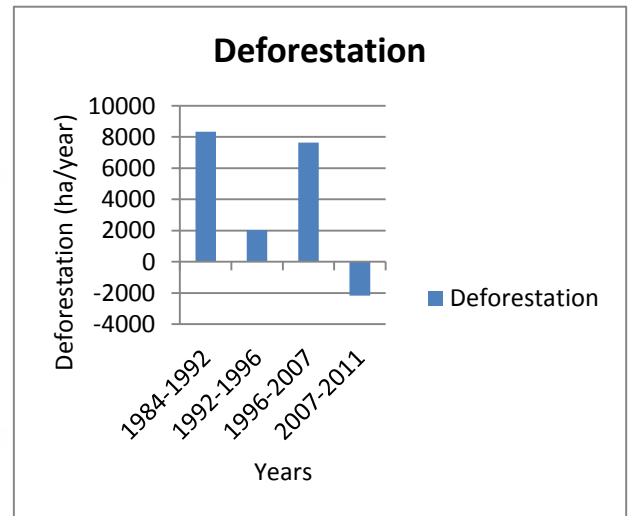


Figure 14. Yearly average deforestation rates for Itaituba.

The overall accuracy and Kappa value of this classification is 100%. The total area that has been deforested 2011 was 150049.79 ha or 14.17% of the total buffer zone. The yearly average rate between 1984 and 1992 was 8327 ha (intensity of 0.79%) per year. The trend declined in the period of 1992-1996 when it was 2043 ha (0.19%) per year. The trend bounced back to 7630 ha (0.72%) per year in the years of 1996-2007. The clearing of the rainforest stopped enough for forest regeneration rates to be faster than deforestation rates between the years of 2007 and 2011 showing an average growth rate of 2168 ha (0.20%) per year.

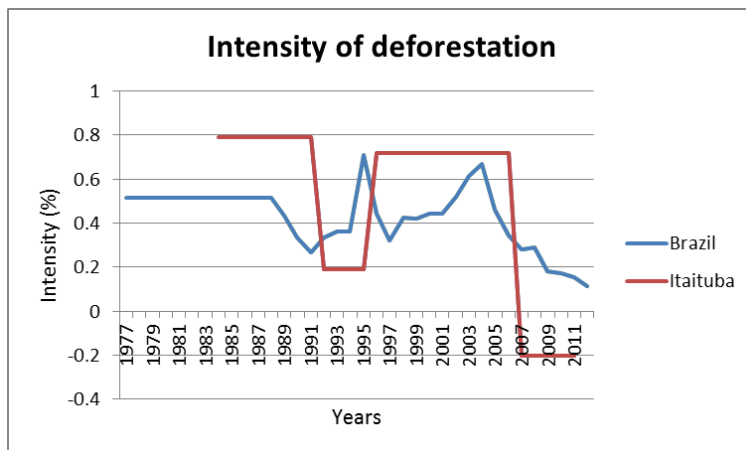


Figure 15. Mean annual deforestation intensity for Itaituba and the amazon.

The intensity of deforestation in Itaituba follows the general trend largely even if it over- and undershoots in all cases (figure 15). Especially high conformance can be seen between 1992 and 1996. An increase in deforestation occurred after this period and is consistent to the general trend. The drop after 2006 also coincides with a drop in the general trend, even if the drop in Itaituba goes much lower.

Rurópolis

2007

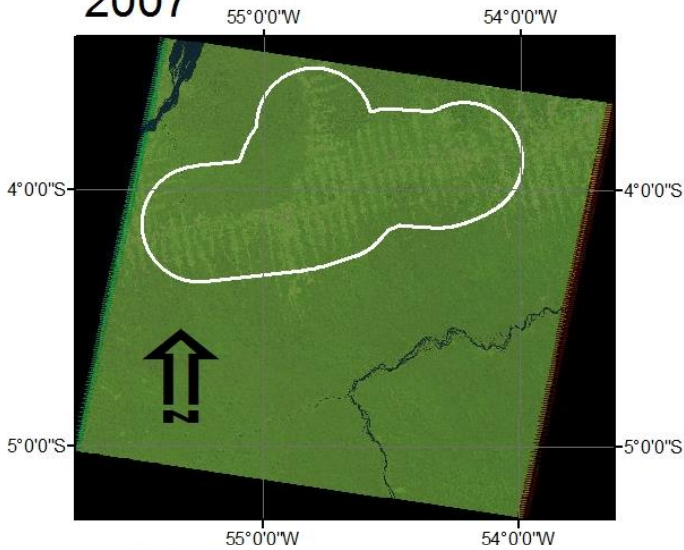


Figure 10. Landsat image from 2007 showing the extent of the area classified (white line) in the Rurópolis site.

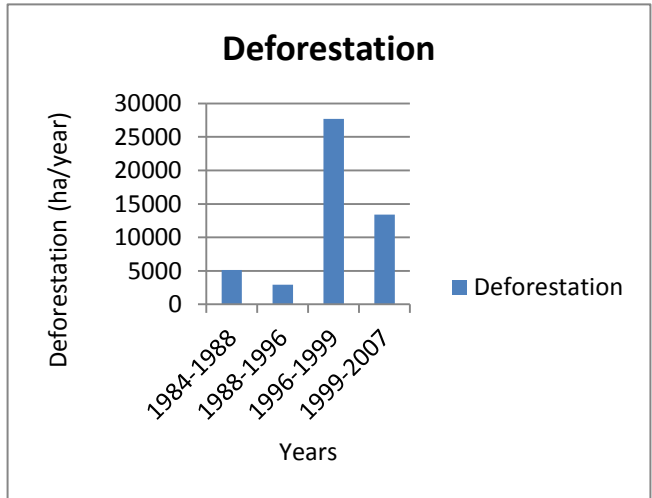


Figure 11. Yearly average deforestation rates for Rurópolis.

The overall accuracy of this classification is 90% with a Kappa value of 0.722, making the classification 72.2% better than chance. The total area of forest that has been cleared between 1984 and 2007 is estimated to 234184.23 ha or about 21 % of the total area of the buffer zone. Between the years of 1984-1988 the average yearly rate of deforestation was 5112 ha (intensity of 0.46%) per year. Deforestation was slower during the years of 1988-1996 with an average rate of 2912 ha (intensity of 0.26%) per year. Record levels were reached between the years of 1996-1999 with a rate of 27 721 ha (2.50%) per year. Deforestation rates continue to follow a fast trend with a rate of 13 409 ha (1.21%) per year between 1999 and 2007 (figure 11).

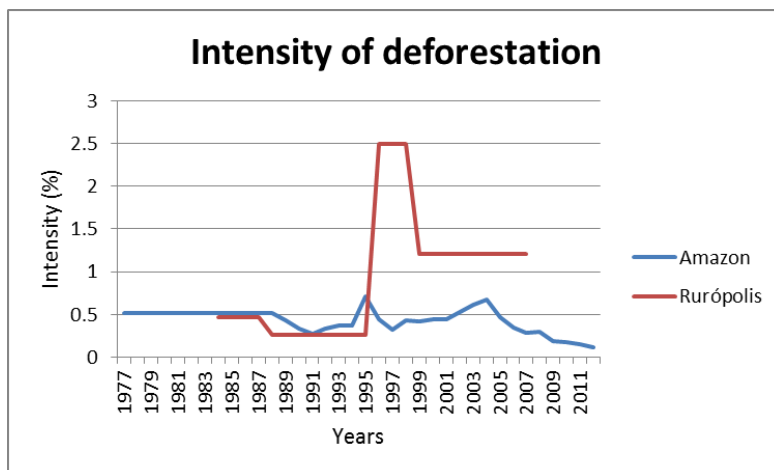


Figure 12. Mean annual deforestation intensity for Rurópolis and the Amazon region.

Rurópolis follows the Amazonian trend of deforestation intensity well in the beginning of the time series and catches a peak in 1995. Deforestation then continues in a much faster rate than the Amazonian trend (figure 12).

Altamira

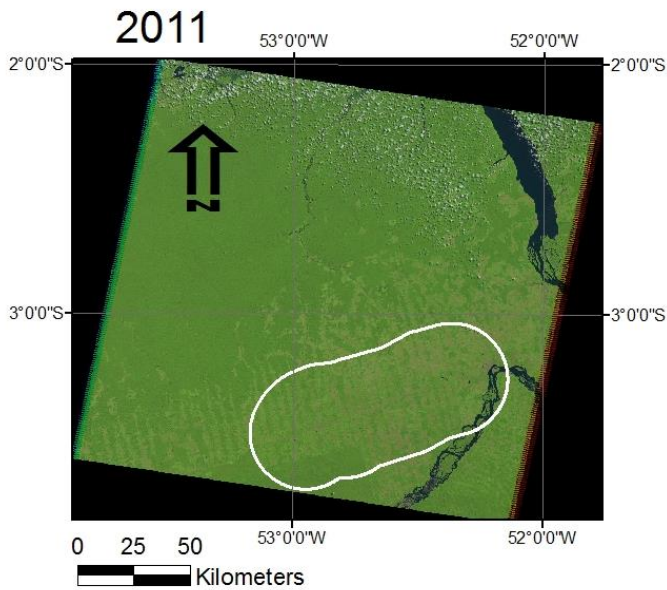


Figure 19. Landsat image from 2011 showing the extent of the area classified (white line) in the Altamira site.

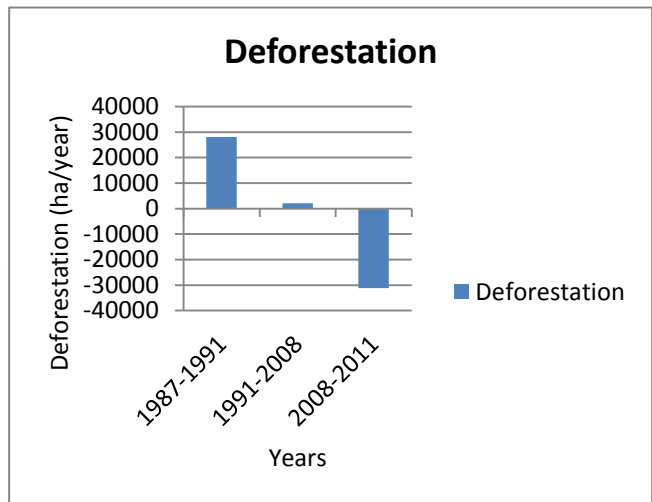


Figure 20. Yearly average deforestation rates for Altamira.

The overall accuracy of this classification is 95% and the kappa value is 0.875. The total area deforested between 1987 and 2011 was 54228.03 ha (9% of the total buffer zone). 28050 ha (4.65%) of forest was cut down on a yearly average between 1987 and 1991. The deforestation rate dropped to 2087 ha (0.35%) per year between 1991 and 2008. Forest regeneration occurred between 2008 and 2011 with a growth rate of 31151 ha (5.17%) per year.

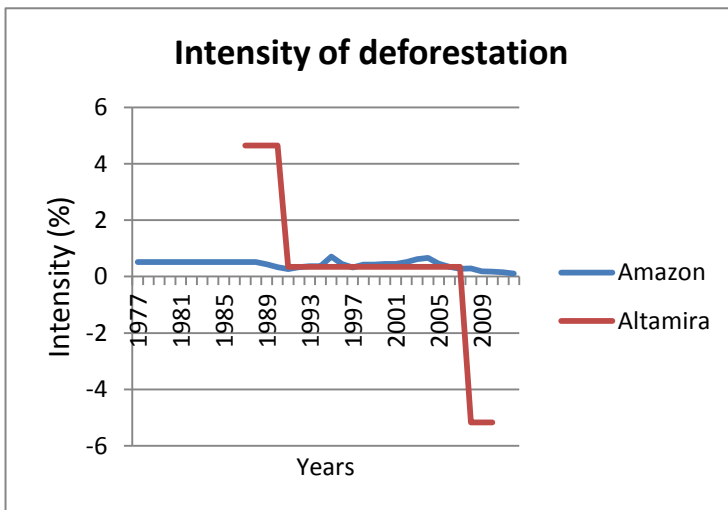


Figure 21. Mean annual deforestation intensity for Altamira and the Amazon region.

Deforestation was much faster between 1987 and 1991 than the Amazonian rate, as can be seen in figure 21. Both rates followed a similar trend between 1991 and 2008 and the site experienced regrowth between 2008 and 2011 when the Amazonian rate was close to zero.

Novo Repartimento

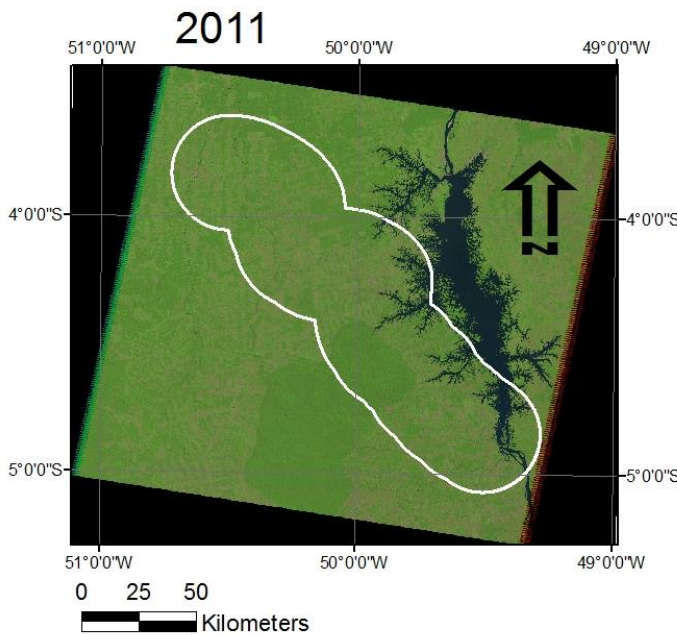


Figure 16. Landsat image from 2011 showing the extent of the area classified (white line) in the Novo Repartimento site.

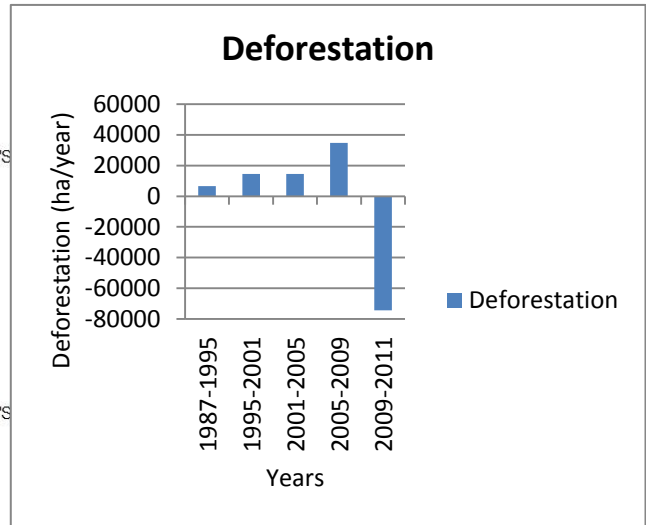


Figure 17. Yearly average deforestation rates for Novo Repartimento.

The overall accuracy of this classification is 90% and with a Kappa value of 0.835. The total area that has been deforested between the years of 1987 and 2011 was 188835.28 ha which is 17.6% of the total area of the buffer zone. Between 1987 and 1995 the deforestation rate was 6654 ha (intensity of 0.62%) per year. The trend accelerated 1995-2001 to a speed of 14458 ha (1.35%) per year. The rate continued in a similar speed, 14558 ha (1.36%) per year, during the years of 2001-2005. A high peak in the deforestation trend can be observed between 2005 and 2009 showing a rate of 34806 ha (3.24%) per year. 2009 was the year with the biggest deforested area and regrowth of the forest resulted in a growth rate of 74299 ha (6.93%) per year between 2009 and 2011.

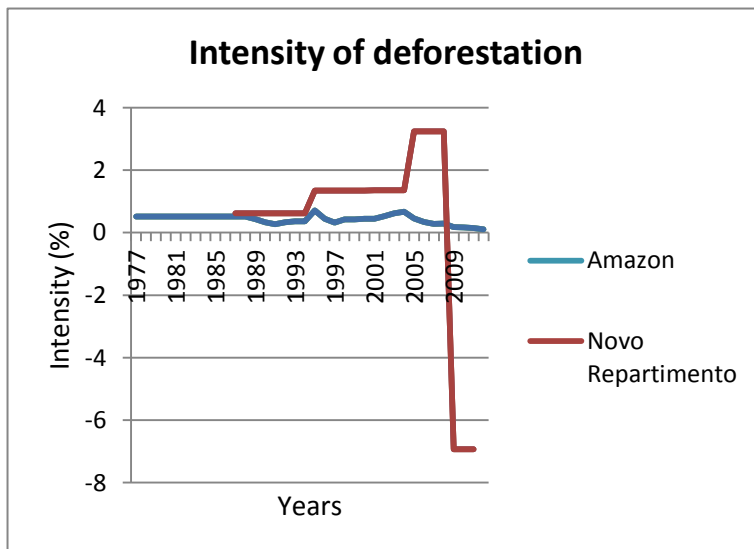


Figure 18. Mean annual deforestation intensity for Novo Repartimento and the amazon region.

This site follows the general trend for the Amazon between 1987 and 1995. Deforestation was higher than the general trend from 1995 to 2009 and lower between 2009 and 2011 (figure 18).

Novo Progresso

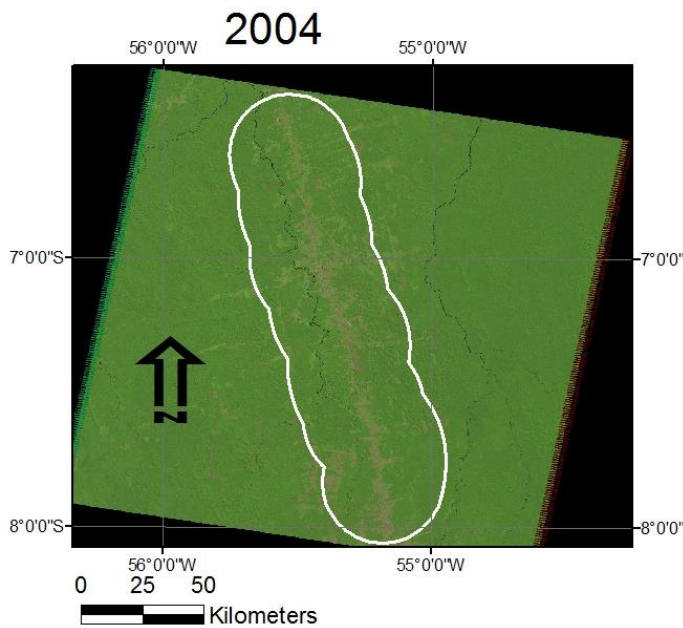


Figure 22. Landsat image from 2004 showing the extent of the area classified (white line) in the Novo Progresso site.

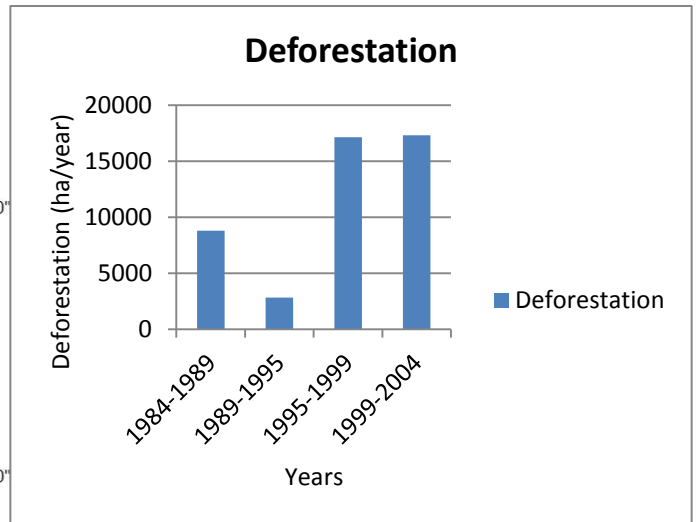


Figure 23. Yearly average deforestation rates for Novo Progresso.

The accuracy for this station is 100%. The total area deforested between 1984 and 2004 was 216057.82 ha. Between 1984 and 1989 the rate was 8793 ha (intensity of 0.96%) per year. The trend decreased during 1989 to 1995 with a rate of 2813 ha (0.31%) per year. The trend increased again to a rate of 17149 ha (1.88%) per year during the period of 1995 to 1999. A strong trend continued for the years between 1999 and 2004 with a rate of 17323 ha (1.9%) per year.

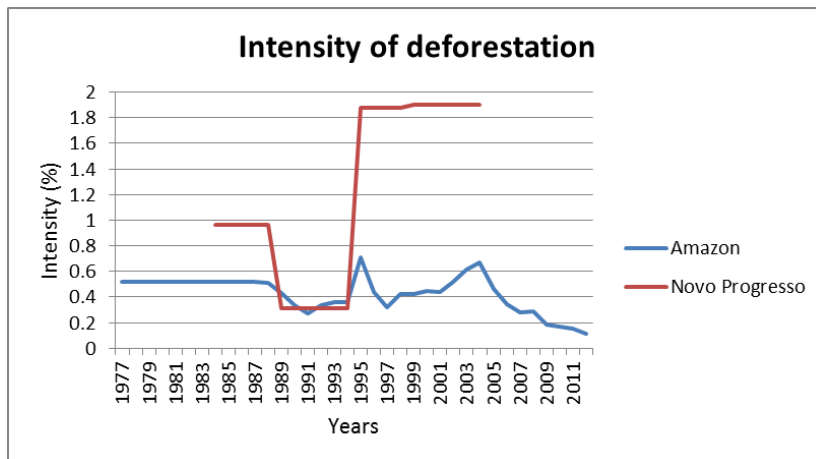


Figure 24. Mean annual deforestation intensity for Novo Progresso and the amazon region.

This site follows the trend of deforestation intensity when comparing to the Brazilian Amazon between 1989 and 1995. Deforestation rates have been faster than the trend for the time after and before that (figure 24).

7. Discussion

Cloud cover is often present in the Amazon which makes it hard to classify specific dates. Satellites that can see through clouds would be useful for monitoring under such conditions. Such satellites have historically been very expensive (between 250 million and 500 million euros each). However, a new generation of mini-satellites is being launched next year and will cost about 45 million euros. These include the British NovaSAR-S range (Lynch et al 2013). Synthetic Aperture Radar (SAR) can penetrate cloud cover and is useful for monitoring tropical areas (ESA 2013). Several satellite systems may provide more suitable data for higher detail classifications (e.g. OrbView-3 or QuickBird) but Landsat is free for anyone to use.

The Interactive classification method proved to be a good tool for easy, fast and flexible classifications. The validation method was very time-consuming since coordinates had to be tracked using Google Earth where it is hard to find old images in high resolution of specific dates. Because of this big parts of the validation had to be done using the same Landsat images that were used when creating the training areas, it would of course have been better if one would actually visit the study sites. A way to improve the accuracy assessment would be to use more validation points. The result of the classification is very dependent on if choosing to classify partly regrown forest as deforested or rainforest, one has to be very consistent when classifying.

Collecting data has been an issue. The Scan Line Corrector (SLC) in the ETM+ instrument at Landsat 7 failed in 2003, because of that, a lot of data is missing from that year and forward in most spots (USGS 2013). Data provided by other satellite systems would need to be used for these years. Earlier Landsat systems using the Multispectral Scanner (MSS) could be used for classifying the years between the launch of the Trans Amazonian highway in 1970 and 1982 when the Landsat 4 TM was launched.

One could argue that the buffer zone used in this project (25km) was too small as deforestation affects forest more than 50 km from roads. About 70% of deforestation occurs within 50 km from paved roads and 7 % occurs along unpaved roads at most (Azevedo-Ramos 2007). If the buffer zone would have been bigger, the estimated deforestation rates would probably have been lower in the beginning of the time series and higher in the end, since deforestation moves from being located close to the road to further away with time.

The UTM projection might not be the best choice of projections since area errors increase with distance from the central meridian. However, this distortion should be small as the study stations are located close to the -57 meridian specified.

8. Conclusions

Deforestation has not been steady along the trans-Amazonian highway, some time periods have experienced severe deforestation while there has been periods when forest regrowth has been faster than the clearing. The most important reasons for these variations are changes in demand due to fluctuations in the global market economy, investments in infrastructure (mainly roads) and governmental efforts against deforestation.

Most sites showed a higher deforestation rate in early years than the general rate for the Brazilian Amazon. A reason for this could be the sites geographical position relative to towns as closeness to towns allows for shorter transportation of timber. It seems reasonable that these areas were deforested earlier than areas further from civilization. The sites that showed a decrease in recent years usually had a much lower deforestation than the general rate for the

Amazon; some stations even experienced forest regeneration (Itaituba, Novo Repartimento and Altamira). This suggests that deforestation has moved outside the zone classified. This could be because a lot of the forest ground already has been deforested. Another reason could be efforts by authorities although it is hard to say as deforestation is correlated with many factors. Novo Progresso showed no sign of change in trend (figure 23&24) but that may be because of lack of recent data. The forest in the Apuí, Rurópolis and Novo Progresso site is still on a decline but deforestation rates are now relatively low.

Loss of habitat due to deforestation leads to biodiversity destruction. The fish-bone pattern practiced by small scale farmers is the most damaging to biodiversity and species richness. It is important to leave bigger patches of forest between the farm lands to minimize the effects on biodiversity and ecosystem services.

Illegal deforestation should be controlled using daily updated monitoring systems together with law enforcements. A big problem seems to be that property rights and land tenure questions are unclear and as a consequence of that a lot of land grabbing is taking place.

Deforestation in the tropics increases climate change and climate change has the potential to further increase the decline of the Amazon rainforest. Changes in the climate may at some point be too fast for some species to adapt to; this gives rise to ecological mismatches. Climate change has the potential to force the Amazon to transform into Savannah or seasonal forest; large uncertainties exist in the models results projecting how likely this is to happen though. In a scenario where precipitation will decrease, like is projected for large parts of the Amazon, forest fires will be more common and grow bigger. There should be a focus on reducing CO₂ emissions when developing modern agricultural technologies. Deforestation and greenhouse gas emission reduction targets should be central in future global climate agreements.

Appendix

Deforestation can be seen in figure 28-58 as red color and forest as green color. The text within brackets (path and row) in the figure text is used for localizing these spots easily with Landsat Look Viewer. The precise dates of the images are also provided in the figure text.

Rurópolis

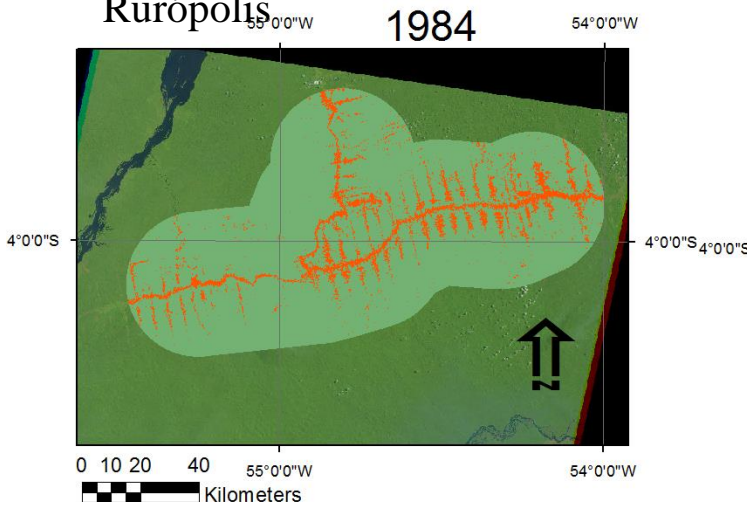


Figure 28. Deforestation in Rurópolis (Path227 Row63) 1984/8/24.

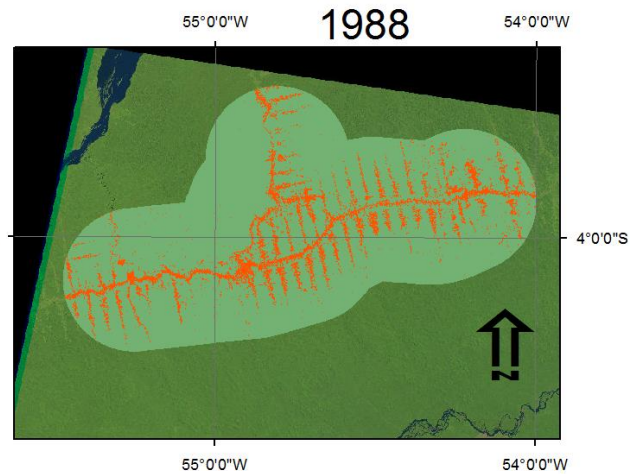


Figure 29. Deforestation in Rurópolis 1988/7/18.

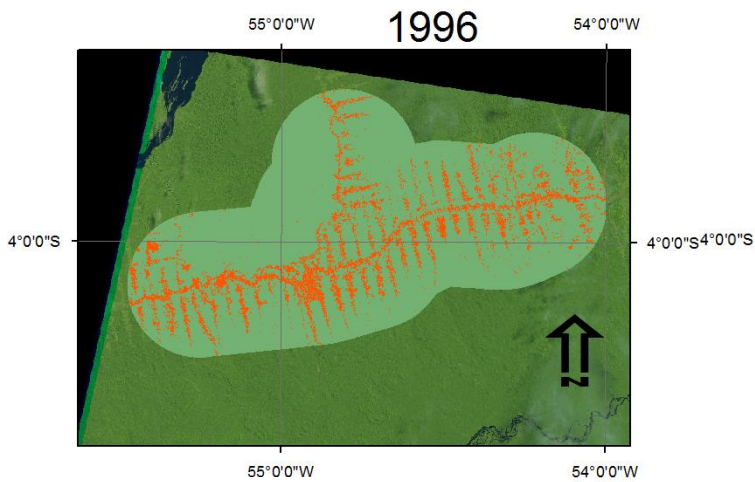


Figure 30. Deforestation in Rurópolis 1996/7/8.

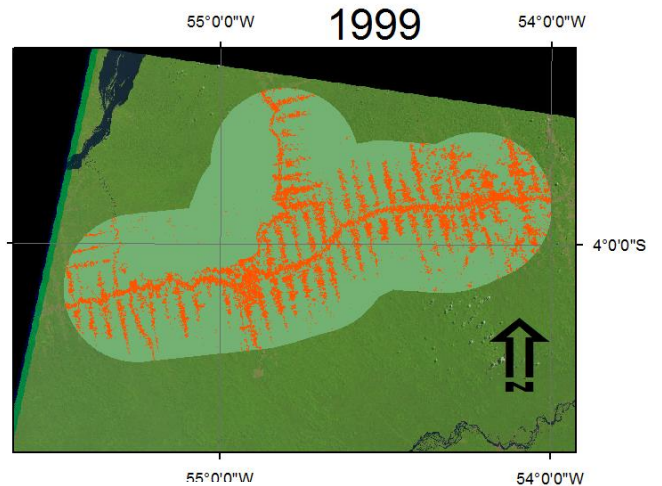


Figure 31. Deforestation in Rurópolis 1999/8/10.

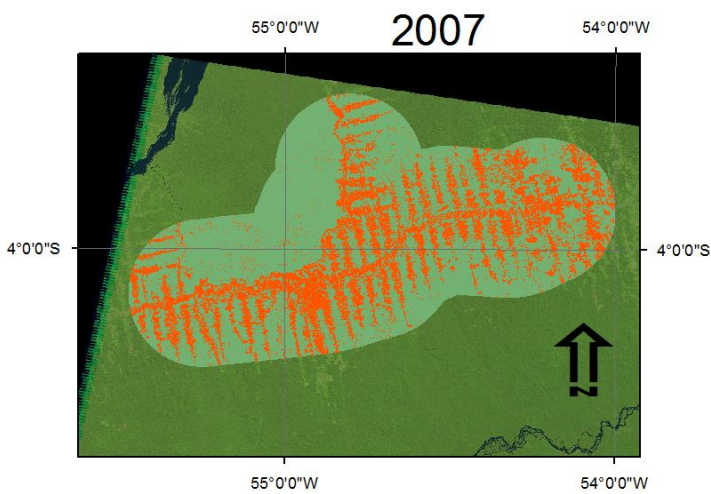


Figure 32. Deforestation in Rurópolis 2007/6/13

Itaituba

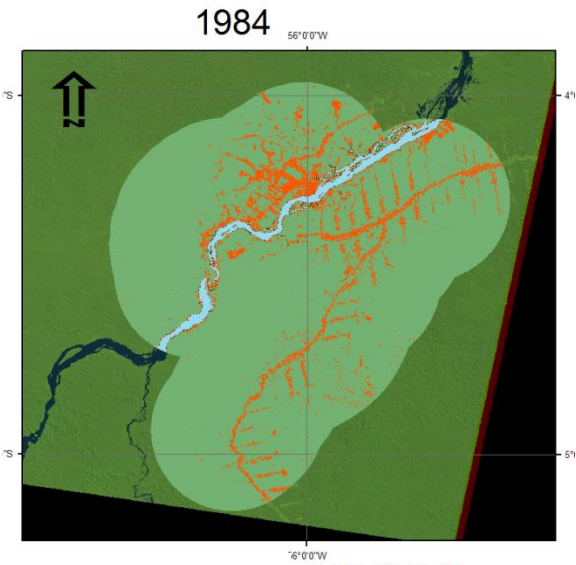


Figure 33. Deforestation in Itaituba (Path228 Row63) 1984/6/28.

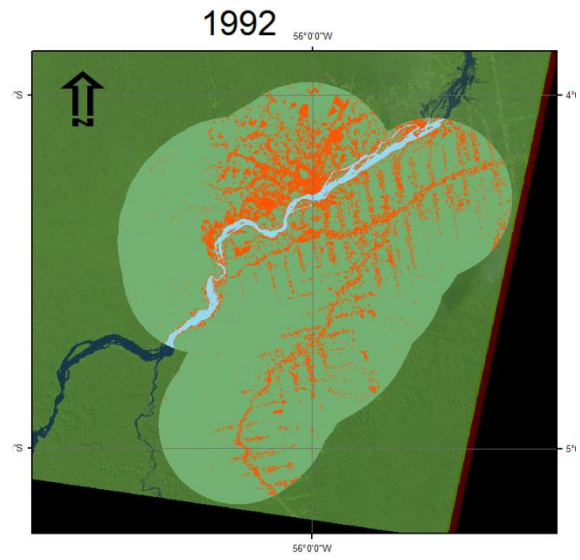


Figure 34. Deforestation in Itaituba 1992/6/18.

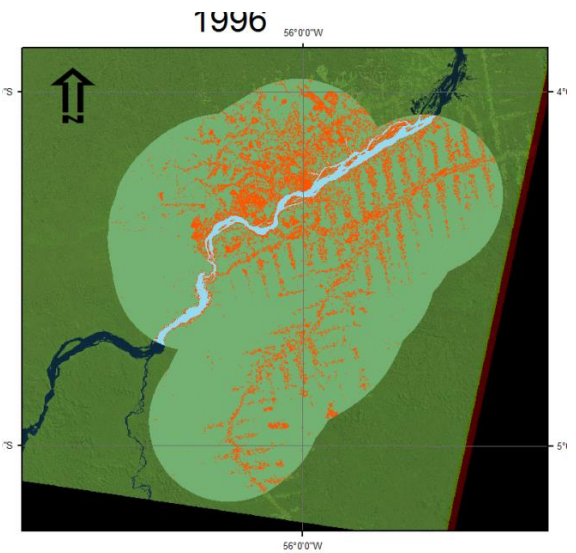


Figure 35. Deforestation in Itaituba 1996/6/13.

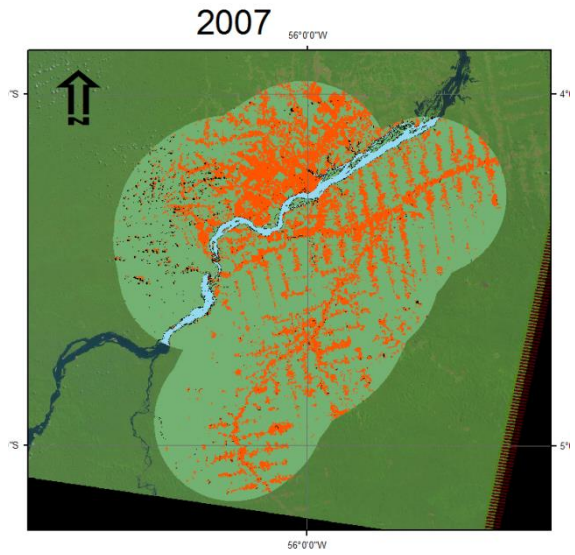


Figure 36. Deforestation in Itaituba 2007/6/28.

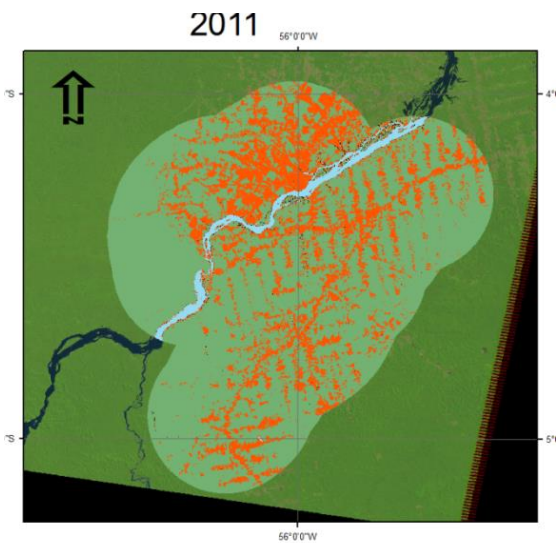


Figure 37. Deforestation in Itaituba 2011/8/10.

Novo Repartimento

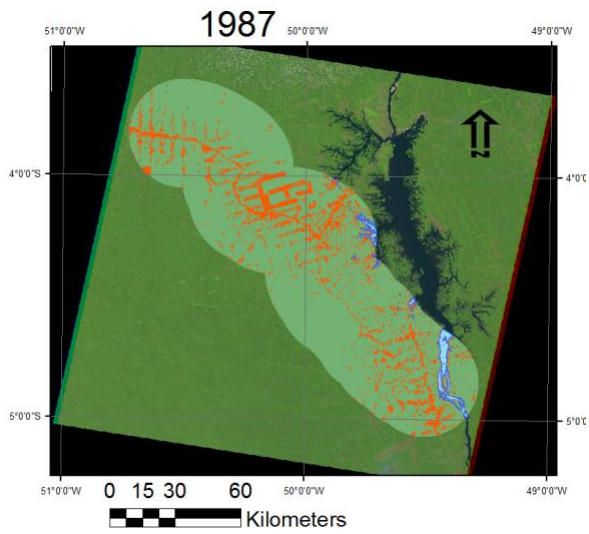


Figure 38. Deforestation in Novo Repartimento (Path224 Row63) 1987/7/27.

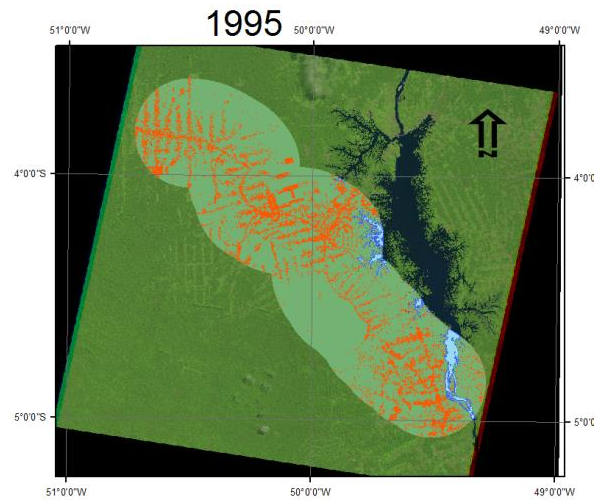


Figure 39. Deforestation in Novo Repartimento 1995/7/1.

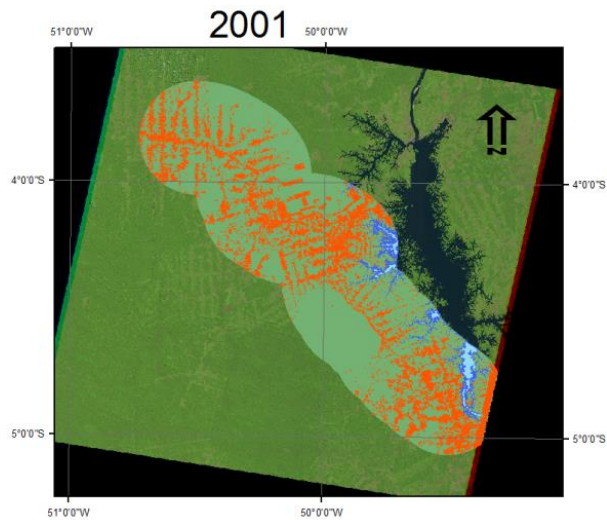


Figure 40. Deforestation in Novo Repartimento 2001/7/9.

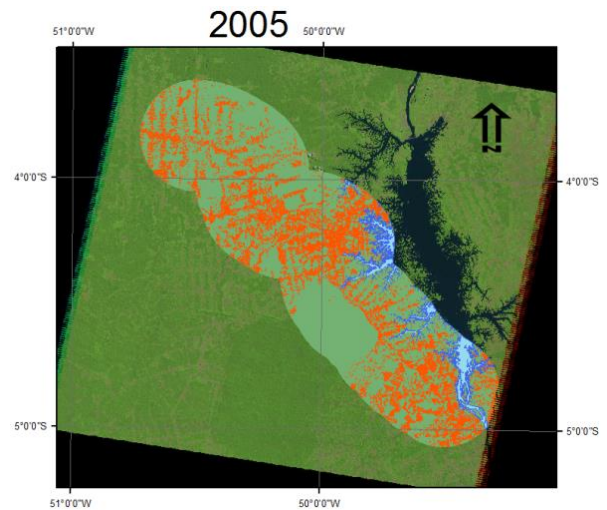


Figure 41. Deforestation in Novo Repartimento 2005/7/4.

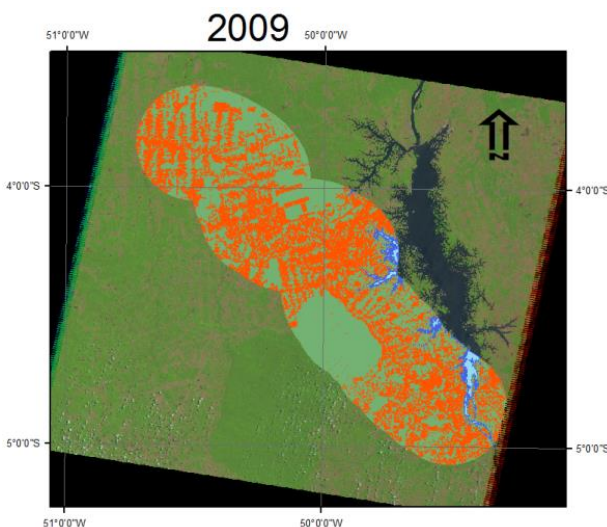


Figure 42. Deforestation in Novo Repartimento 2009/7/31.

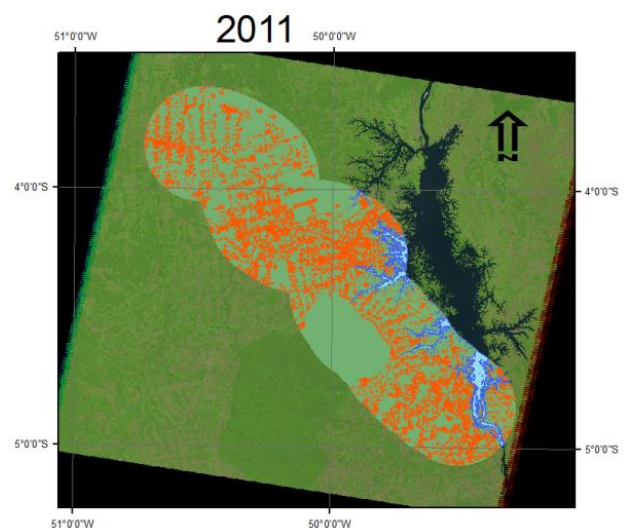


Figure 43. Deforestation in Novo Repartimento 2011/7/29.

Altamira

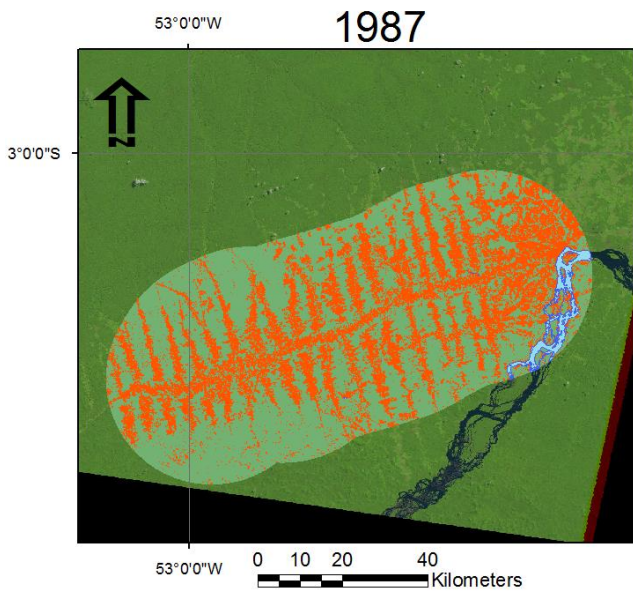


Figure 44. Deforestation in Altamira (Path226 Row62) 1987/6/23.

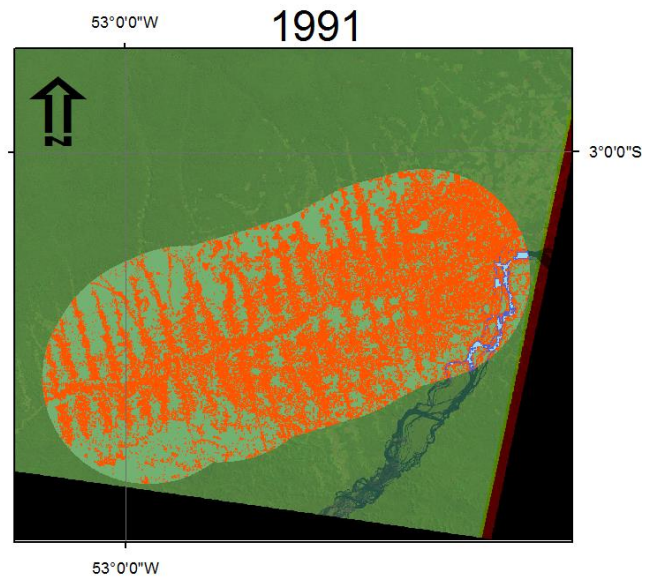


Figure 45. Deforestation in Altamira 1991/7/20.

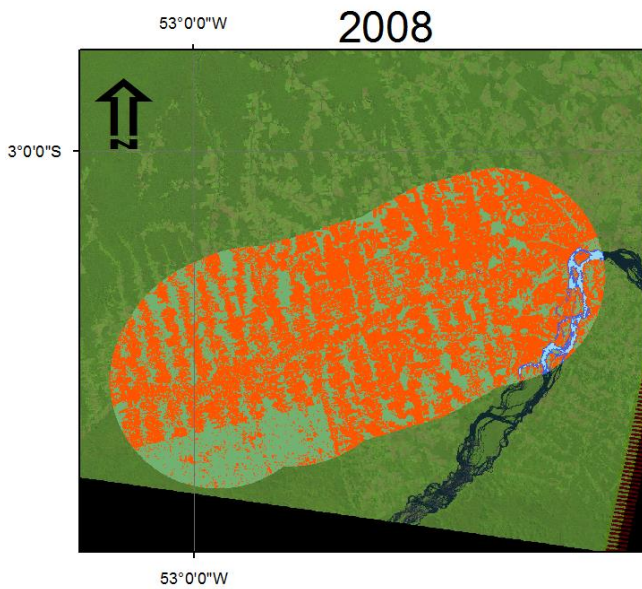


Figure 46. Deforestation in Altamira 2008/7/2.

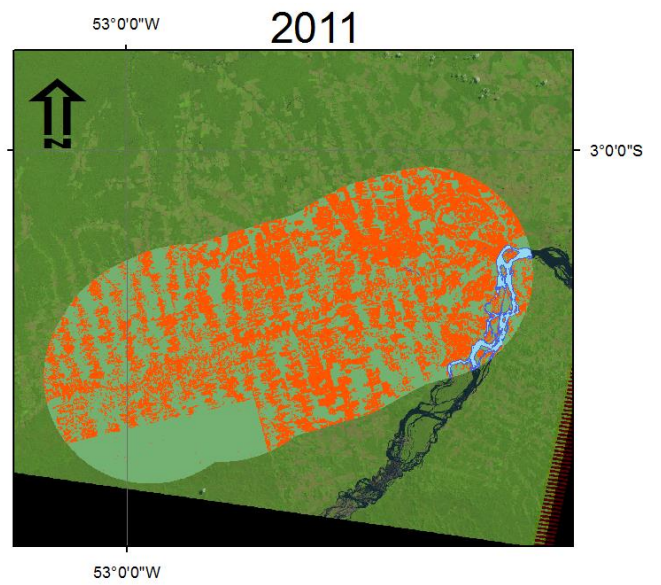


Figure 47. Deforestation in Altamira 2011/6/17.

Novo Progresso

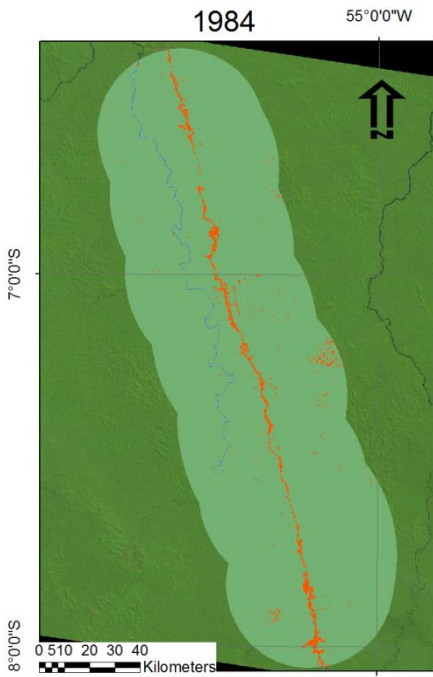


Figure 48. Deforestation in Novo Progresso (Path227 Row65) 1984/6/21.

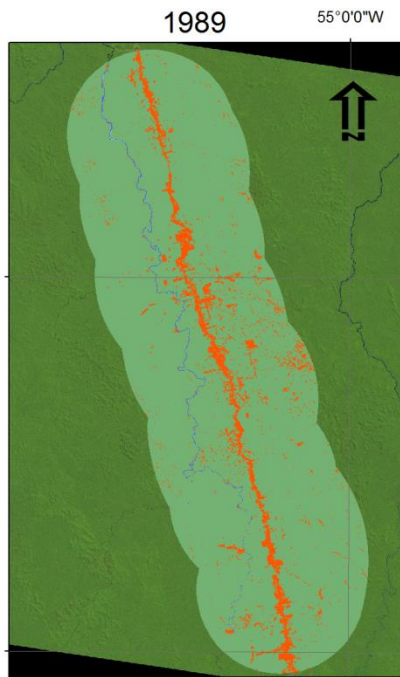


Figure 49. Deforestation in Novo Progresso 1989/6/19.

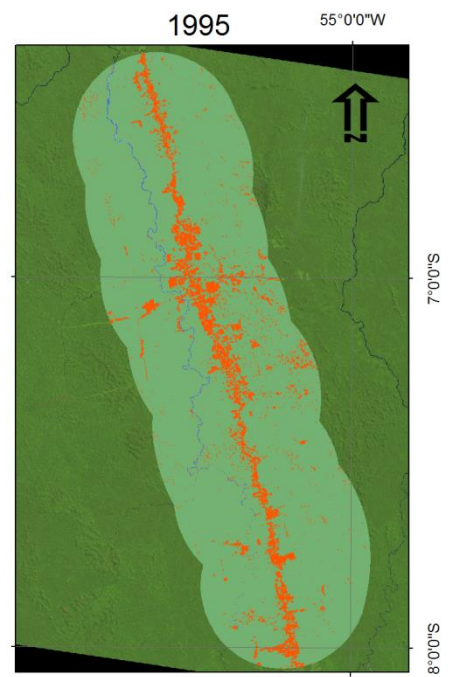


Figure 50. Deforestation in Novo Progresso 1989/6/19.

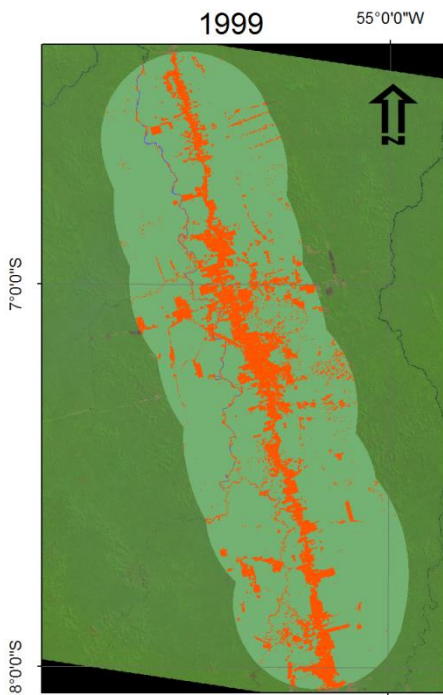


Figure 51. Deforestation in Novo Progresso 1999/7/25.

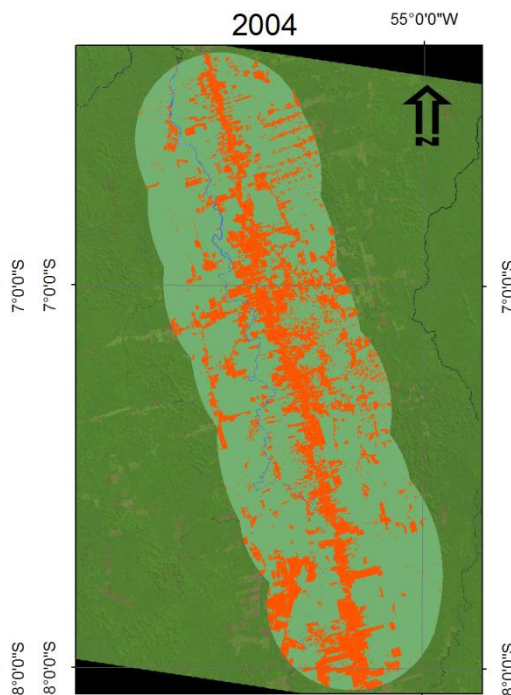


Figure 52. Deforestation in Novo Progresso 2004/6/28.

Apuí

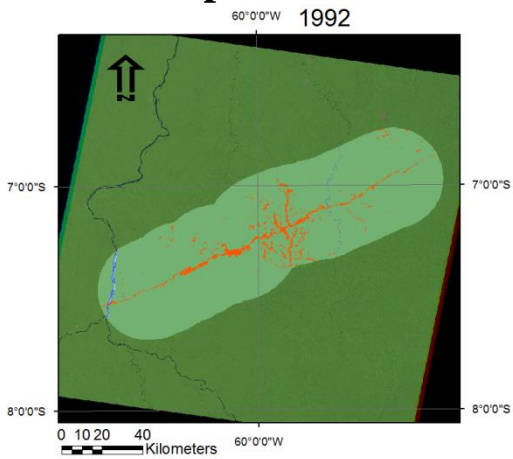


Figure 53. Deforestation in Apuí (Path230 Row65) 1992/8/3

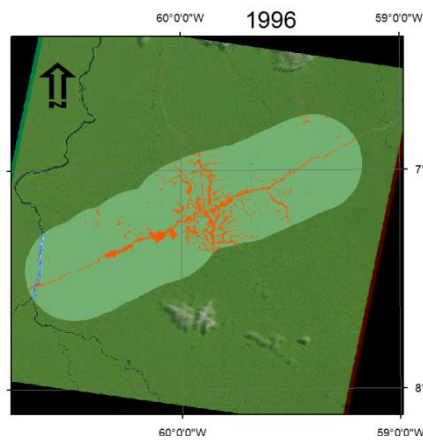


Figure 54. Deforestation in Apuí 1996/7/13.

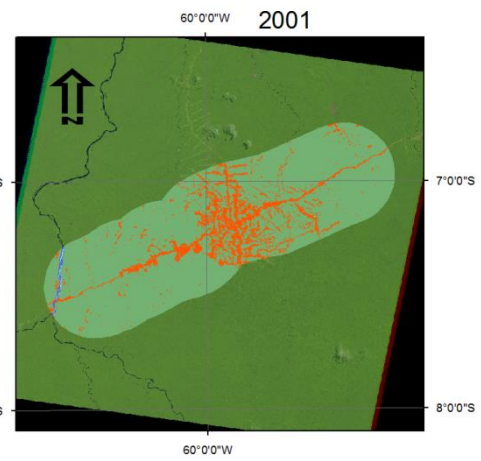


Figure 55. Deforestation in Apuí 2001/7/11.

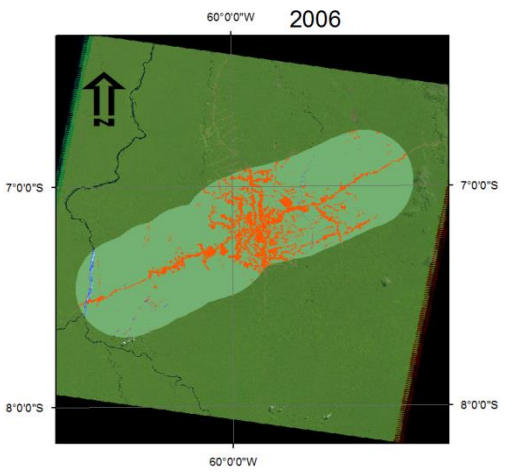


Figure 56. Deforestation in Apuí 2006/7/9.

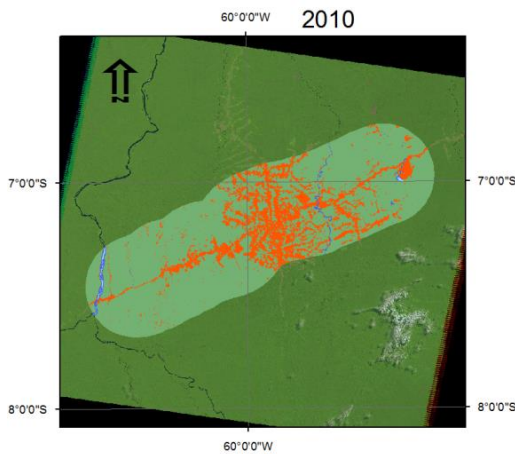


Figure 57. Deforestation in Apuí 2010/6/18.

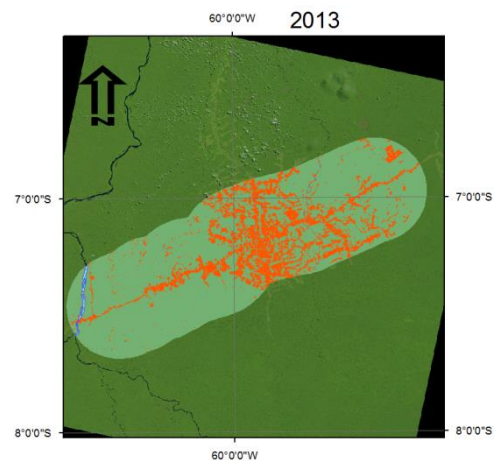


Figure 58. Deforestation in Apuí 2013/7/12.

Error/confusion matrixes for all sites can be found below. The map data represent the classified image and the ground truth is the manual observations of Landsat images. If for instance a point in the rain forest would be incorrectly classified as deforestation a number would be added to column 3, row 2.

		Ground truth			
		Class	I	II	Total
Map data	I	5	0	5	I = Deforested II =Rainforest
	II	0	15	15	
	Total	5	15	20	

Itaituba 100% accuracy

		Ground truth			
		Class	I	II	Total
Map data	I	6	2	8	
	II	0	12	12	
	Total	6	14	20	

Novo Repartimento. Kappa=0.835 Overall accuracy=90%

		Ground truth			
		Class	I	II	Total
Map data	I	7	2	9	
	II	0	11	11	
	Total	7	13	20	

Rurópolis. Kappa=0.722 Overall accuracy=90%

		Ground truth			
		Class	I	II	Total
Map data	I	0	0	0	
	II	0	20	20	
	Total	0	20	20	

Apuí. Accuracy 100%

Ground truth

Class	I	II	Total
I	5	0	5
II	0	15	15
Total	5	15	20

Map data

Novo Progresso. Accuracy 100%

Ground truth

Class	I	II	Total
I	14	1	15
II	0	5	5
Total	14	6	20

Map data

Altamira. Kappa=0.875 Overall accuracy =95%

References

- Assunção, J., C. Clarissa, E. Gandour and R. Rocha. 2012. Deforestation Slowdown in the Legal Amazon: Prices or Policies? *Climate Policy Initiative (CPI) / PUC-Rio de Janeiro*. Retrieved 15 february, 2014, from. <http://climatepolicyinitiative.org/wp-content/uploads/2012/03/Deforestation-Prices-or-Policies-Exec-Summary.pdf>
- Azevedo-Ramos, C. 2007. Sustainable development and challenging deforestation in the Brazilian Amazon: the good, the bad and the ugly. *Land use Unasylva*, 59: 12-16.
- Broadbent, E. N., G. P Asner, M. Keller, D.E. Knapp, P.J.C. Oliveira and J.N. Silva. 2008. Forest fragmentation and edge effects from deforestation and selective logging in the Brazilian Amazon. *Biological Conservation*, 141: 1745-1757. DOI:10.1016/j.biocon.2008.04.024.
- Burke, E. J., S. J Brown, and N. Christidis. 2006. Modeling the Recent Evolution of Global Drought and Projections for the Twenty-First Century with the Hadley Centre Climate Model. *Journal of Hydrometeorology*, 7: 1113-1125. DOI: 10.1175/JHM544.1
- Butler, R. A. 2013. State Deforestation in the Brazilian Amazon. Retrieved 25 of October, 2013, from http://www.mongabay.com/brazil-state_deforestation.html
- Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, et al. 2007. Regional Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, chap. 11. [In press]
- Christensen, J. H., K. Krishna Kumar, E. Aldrian, S.-I. An, I. F. A. Cavalcanti, M. de Castro, Dong, P. Goswami, et al. 2013. Climate Phenomena and their Relevance for Future Regional Climate Change. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, chap. 14. [In press]
- Ciais, P., C. Sabine, G. Bala, L. Bopp, V. Brovkin, J. Canadell, A. Chhabra, R. DeFries, et al. 2013. Carbon and Other Biogeochemical Cycles. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, chap. 6. [In press]
- Collins, M., R. Knutti, J. M. Arblaster, J.-L. Dufresne, T. Fichet, P. Friedlingstein, X. Gao, W. J. Gutowski, et al. 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, chap. 12 [In press]

- Cronquist, L. and S. Elg. 2000. The usefulness of coarse resolution satellite sensor data for identification of biomes in Kenya. Seminar essay nr. 72. Department of physical geography and ecosystem science, Lund University.
- Dangerousroads. 2013. Rodovia Transamazônica (BR-230). Retrieved 25 of October, 2013, from <http://www.dangerousroads.org/brazil/431-rodovia-transamazonica-brasil.html>
- Souza, C.M. Jr., S. Hayashi and A. Veríssimo. 2009. Near real-time deforestation detection for enforcement of forest reserves in Mato Grosso. Land Governance in Support of the Millennium Development Goals: Responding to New Challenges, Washington DC, USA, World Bank
- Souza, R.A., F. Miziara and P. Jr. Marco. 2013. Spatial variation of deforestation rates in the Brazilian Amazon: A complex theater for agrarian technology, agrarian structure and governance by surveillance. *Land Use Policy*, 30: 915-924
- Encyclopædia Britannica. 2013. Deforestation. Retrieved 15 of December, 2013, from. <http://global.britannica.com/EBchecked/topic/155854/deforestation>
- ESRI. 2010. Interactive Supervised Classification tool. Retrieved 18 of December, 2013, from. <http://help.arcgis.com/en%20/arcgisdesktop/10.0/help/index.html#//00nv000000z000000.htm>
- ESRI. 2011. How Maximum Likelihood Classification works. Retrieved 18 of December, 2013, from. <http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=How%20Maximum%20Likelihood%20Classification%20works>
- European Space Agency (ESA). 2013. The Applications of SAR data - An Overview. Retrieved 17 of December, 2013, from http://earth.esa.int/applications/data_util/SARDOCS/
- Fahrig, L. 2003. Effects of Habitat Fragmentation on Biodiversity. *Annual Review Of Ecology, Evolution & Systematics*, 34: 487-515
- Fearnside, P. M. and P.M. Lima de Alencastro Graça. 2006. BR-319: Brazil's Manaus-Porto Velho Highway and the Potential Impact of Linking the Arc of Deforestation to Central Amazonia. *Environmental Management*, 38: 705-716. DOI: 10.1007/s00267-005-0295-y
- Fearnside, P. M. 2005. Deforestation in Brazilian Amazonia: History, Rates, and Consequences. *Conservation Biology*, 19: 680–688. DOI: 10.1111/j.1523-1739.2005.00697.x
- Hirsch, T. 2008. The Incredible Shrinking Amazon RainForest, *World Watch*, 21: 12-17.
- Instituto Nacional de Pesquisas Espaciais (INPE), 2013. PROJETO PRODES MONITORAMENTO DA FLORESTA AMAZÔNICA BRASILEIRA POR SATÉLITE. Retrieved 17 of December, 2013, from <http://www.obt.inpe.br/prodes/index.php>
- Lynch, J., M. Maslin, M. Baltzer and M. Sweeting. 2013. Sustainability: Choose satellites to monitor deforestation. *Nature* 496: 293–294. DOI: 10.1038/496293a
- Microimages. 2013. Introduction to Hyperspectral Imaging. Retrieved 17 of December, 2013, from <http://www.microimages.com/documentation/Tutorials/hyprspect.pdf>
- Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestedt, J. Huang, D. Koch, J.-F. Lamarque, et al. 2013. Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, eds. Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, chap. 8 [In press]

- National Aeronautics and Space Administration (NASA). 2011. World of Change: Amazon Deforestation. Earth Observatory. Retrieved 17 of December, 2013, from <http://earthobservatory.nasa.gov/Features/WorldOfChange/deforestation.php>
- National Aeronautics and Space Administration (NASA). 2010. Carbon Cycle. Retrieved 17 of December, 2013, from <http://science.nasa.gov/earth-science/oceanography/ocean-earth-system/ocean-carbon-cycle/>
- Olivier, J.G.J., G. Janssens-Maenhout and J.A.H.W. Peters. 2012. Trends in global CO2 emissions; 2012 Report. Report for Netherlands Environmental Assessment Agency. DOI: 10.2788/33777. Retrieved 18 December, 2013, from. www.pbl.nl/en
- Prist, P.R., F. Michalski and J.P. Metzger. 2012. How deforestation pattern in the Amazon influences vertebrate richness and community composition. *Landscape Ecology*, 27:799–812. DOI: 10.1007/s10980-012-9729-0
- Robalino, J. and L.D. Herrera. 2009. Trade and Deforestation: A literature review. This paper appears in the WTO working paper series as commissioned background analysis for the World Trade Report 2010 on "Trade in Natural Resources: Challenges in Global Governance". Retrieved 18 December, 2013, from. http://www.wto.org/english/res_e/reser_e/ersd201004_e.pdf
- Schmaltz, J. 2006. Deforestation in Mato Grosso, Brazil. Retrieved 25 of October, 2013, from <http://visibleearth.nasa.gov/view.php?id=76095>
- Snyder, J.P. 1987. Map Projections: A Working Manual. U.S. Geological Survey Professional Paper 1395. 87-600250. Retrieved 18 of December, 2013, from <http://pubs.er.usgs.gov/publication/pp1395>
- The Met Office. 2013. Why is our climate changing? Retrieved 25 of October, 2013, from. <http://www.metoffice.gov.uk/climate-guide/climate-change/why>
- The Nature Conservancy. 2011. Facts About Rainforests. Retrieved 25 of October, 2013, from. <http://www.nature.org/ourinitiatives/urgentissues/rainforests/rainforests-facts.xml>
- Viera, A.J. and J.M. Garrett. 2005. Understanding Interobserver Agreement: The Kappa Statistic. *Family Medicine*, 37(5): 360-363.
- U.S. Geological Survey (USGS). 2013. SLC-off Products: Background. Retrieved 25 of October, 2013 from http://landsat.usgs.gov/products_slc_offbackground.php
- U.S. Geological Survey (USGS). 2013. Frequently Asked Questions about the Landsat Missions. Retrieved 17 of December, from. http://landsat.usgs.gov/band_designations_landsat_satellites.php
- Wallace, S. 2013. Farming the Amazon. National Geographic Magazine. Retrieved 25 of October, 2013, from. <http://environment.nationalgeographic.com/environment/habitats/last-of-amazon/>

URL's

- 1: www.imazongeo.org.br
2. <http://landsat.gsfc.nasa.gov/data/where.html>
3. <http://www.diva-gis.org/datadown>
4. http://www.baruch.cuny.edu/geoportal/data/esri/esri_intl.htm

Institutionen för naturgeografi och ekosystemvetenskap, Lunds Universitet.

Student examensarbete (Seminarieuppsatser). Uppsatserna finns tillgängliga på institutionens geobibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på LUP student papers (www.nateko.lu.se/masterthesis) och via Geobiblioteket (www.geobib.lu.se)

The student thesis reports are available at the Geo-Library, Department of Physical Geography and Ecosystem Science, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden. Report series started 1985. The complete list and electronic versions are also electronic available at the LUP student papers (www.nateko.lu.se/masterthesis) and through the Geo-library (www.geobib.lu.se)

- 298 Ludvig Forslund (2014) Using digital repeat photography for monitoring the regrowth of a clear-cut area
- 299 Julia Jacobsson (2014) The Suitability of Using Landsat TM-5 Images for Estimating Chromophoric Dissolved Organic Matter in Subarctic Lakes
- 300 Johan Westin (2014) Remote Sensing of Deforestation Along the Trans-Amazonian Highway