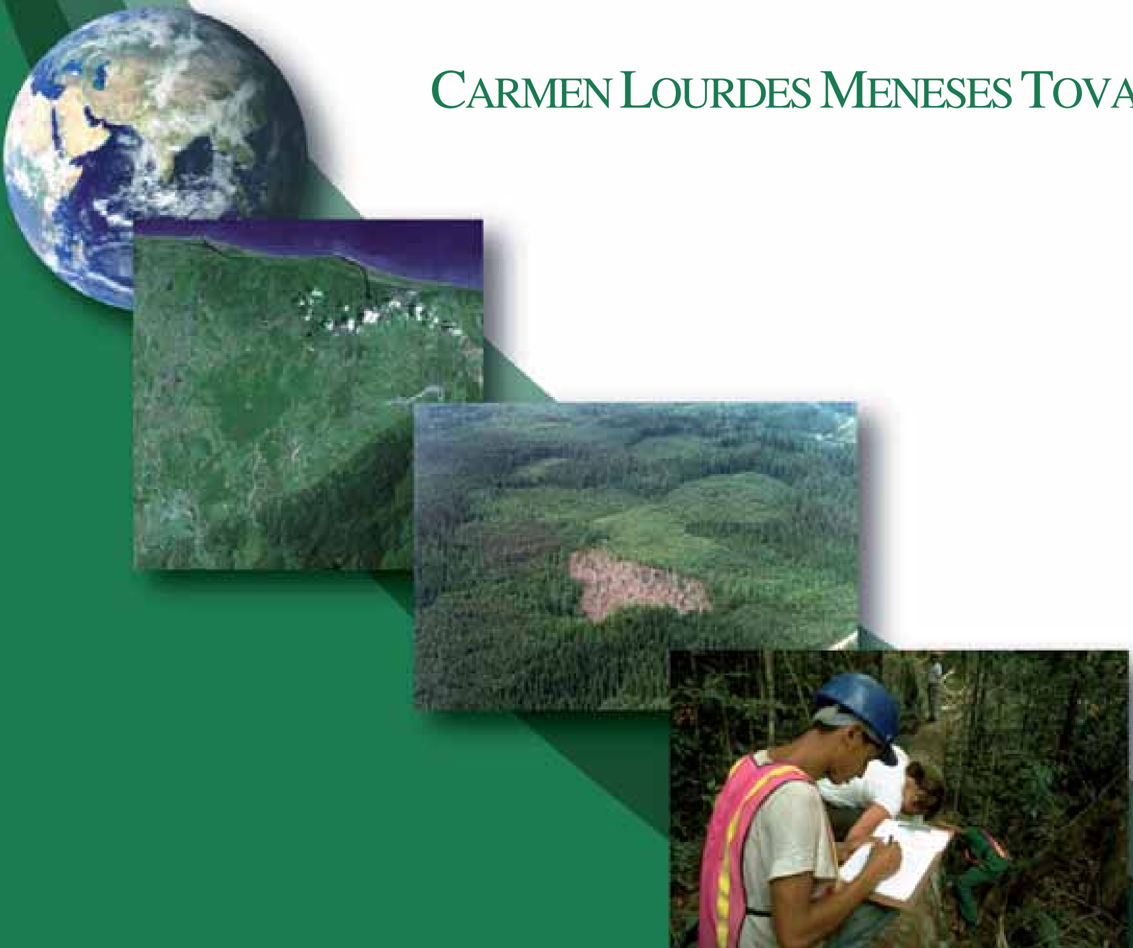
Forest Resources Assessment Working Paper 173

CASE STUDIES ON MEASURING AND ASSESSING FOREST DEGRADATION

ANALYSIS OF THE NORMALIZED DIFFERENTIAL VEGETATION INDEX (NDVI) FOR THE DETECTION OF DEGRADATION OF FOREST COVERAGE IN MEXICO 2008 – 2009

CARMEN LOURDES MENESES TOVAR



December, 2009

Sustainably managed forests have multiple environmental and socio-economic functions which are important at the global, national and local scales, and they play a vital part in sustainable development. Reliable and up-to-date information on the state of forest resources - not only on area and area change, but also on such variables as growing stock, wood and non-wood products, carbon, protected areas, use of forests for recreation and other services, biological diversity and forests' contribution to national economies - is crucial to support decision-making for policies and programmes in forestry and sustainable development at all levels.

Under the umbrella of the Global Forest Resources Assessment 2010 (FRA 2010) and together with members of the Collaborative Partnership on Forests (CPF) and other partners, FAO has initiated a special study to identify the elements of forest degradation and the best practices for assessing them. The objectives of the initiative are to help strengthen the capacity of countries to assess, monitor and report on forest degradation by:

- Identifying specific elements and indicators of forest degradation and degraded forests;
- Classifying elements and harmonizing definitions;
- Identifying and describing existing and promising assessment methodologies;
- Developing assessment tools and guidelines

Expected outcomes and benefits of the initiative include:

- Better understanding of the concept and components of forest degradation;
- An analysis of definitions of forest degradation and associated terms;
- Guidelines and effective, cost-efficient tools and techniques to help assess and monitor forest degradation; and
- Enhanced ability to meet current and future reporting requirements on forest degradation.

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Forest Resources Assessment Working Paper

Case Studies on Measuring and Assessing Forest Degradation

Analysis of the Normalized Differential Vegetation Index (NDVI) for the Detection of Degradation of Forest Cover in Mexico 2008 - 2009

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Abstract

This study attempts to find a relation between the Normalized Difference Vegetation Index (NDVI), estimated from MODIS images and the aerial biomass volume. The relation is estimated for various terrestrial ecosystems. The area studied includes the entire country of Mexico with an area of almost 2 million km² and a diversity of ecosystems from arid to temperate to tropical. The premise of the study is that NDVI is an indicator of vegetation health, since degradation of the ecosystem vegetation must be reflected in a decrease in the value of NDVI. The estimation of the biomass area is based on data from 22,000 plots measured in the field with results stored in a National Forest Inventory database. The observations were first made between 2004 and 2007 with updating of portions in 2008 and 2009.

The results reflect a correlation of 0.8334 between aerial biomass in carbon tons/ha and the value of NDVI as estimated from MODIS images. Moreover, the results indicate that a disturbance in a vegetation community is reflected in a corresponding fall in the value of NDVI. Owing to limitations in the estimation of aerial biomass in tropical communities, it was found that this relation can be improved upon even more. This methodology is used as an indicator of degradation and deforestation in the system, Forest Coverage Monitoring of Mexico, and will provide a path to a complete dynamic understanding of the terrestrial ecosystem of the country.

1. Introduction

The present study attempts to establish relations between forest usage and the Normalized Differential Vegetation Index (NDVI) estimated from satellite imagery.

The area of study is Mexico and covers almost 2 million km^2. Because of the extent, the study utilized images taken during the dry season with the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on the satellites Terra and Aqua.

The National Forest and Lands Inventory (INFyS) maintained by the National Forest Commission (CONAFOR) provides basic information and ground truth for the estimates. INFyS data was collected during the period 2004-2007 and updated in 2008-2009.

The indicators of the function of forest usage which we would like to relate to the euclidean space of the satellite images include: type of vegetation, number of live trees, number of species, crown diameter, total height, diameter at breast height (DBH), and estimates of wood volume and biomass.

Other supporting variables used included precipitation, temperature, number of days of rain per year, evaporation, a digital elevation model, ecological regions of the country, as well as variables related to anthropogenic effects.

2. Methodology

In order to understand the processes involved in changes in forest coverage we must first have a common set of definitions:

- The word “deforestation” indicates the act of deforesting or significantly stripping forest from an area that has been forested.
- In accordance with the definition of the United Nations Food and Agriculture Organization (FAO), "Forest" is land that encompasses more than 0.5 hectares, with trees greater than 5 meters in height, and with crown coverage of at least 10%, or trees capable of meeting these limits. It does not include vegetation coverage in agricultural zones such as, for example, wind breaks; nor does it include parks or gardens in urban areas (FAO, 2000).
- The FAO defines another term, “other wooded lands”. This refers to land that is not classified as forest, which is more that 0.5 hectares in extent with a crown coverage between 5 and 10 %, or with trees capable of attaining these limit; or land that is at least 10% covered with a mix of thicket, bushes and trees. It does

not include land that is predominantly used for agriculture or urban purposes (FRA, 2000).

In order to analyze the dynamics of change in the vegetation coverage, we need imagery processed with the same methodology and cartographic detail for two different epochs.

Historically, this analysis could only be done for the country by the National Institute for Statistics and Geography (INEGI). It was released as Series III of the Map of the Uses of Land and Vegetation based on satellite images taken in 2002. Series III could be compared to the Series II map based on images taken in 1993 using the same methodology (INEGI, 2004). The map of the Land Use and Vegetation from INEGI has a very complete legend, based on the floral and physiognomic composition of the plants, specifying the successive levels of vegetation.

Historically speaking, the impact on the vegetation coverage of the country began with the colonization by the Spanish and the subsequent processes of consolidation of the population and the development of railroads and oil.

As such, it is necessary to understand particular concepts used in Mexico:

"Primary vegetation" is defined as vegetation that preserves, in large part, its condition of density, coverage, and number of species, from its original, primary, ecosystem and from that represented in the cartography of Use of the Ground and Vegetation from INEGI at a scale of 1:250,000 (INEGI, 2004).

"Secondary vegetation" is defined as the vegetation present where it has substituted totally or partially for the original (primary) vegetation as a result of some changes in the use of the ground or because of natural causes or where there is evidence of recovery of the vegetation community in some of the successive stages of vegetation (INEGI, 2004). Secondary vegetation can be characterized as: "Herbs", "Bushes", and "Trees" (INEGI, 2004).

When speaking of changes in the vegetation coverage, we refer to the processes of "Loss", "Alteration", and "Recovery".

- In accordance with the FAO (**FRA**, 2005), **deforestation** is defined as the transformation of forest to other land uses or the reduction, over large tracts, of the crown coverage to less than the minimum of 10% coverage. (FAO, 2000).
- At the same time, the FAO states that **deforestation** implies **serious or permanent loss** of forest coverage and the transformation of **forest** into lands dedicated to other uses (FAO, 2000).

When we speak of loss of forest or deforestation we include two cases: The loss of primary vegetation, for example, Pine Forest (BP); and the loss of primary vegetation with replacement by secondary vegetation, for example, Pine Forest with secondary tree growth (BP/VSA). Both cases involve a distinct change in the use of the ground from its original use (CONAFOR, (a) and (b) 2005).

The alteration of the condition of the forest indicates a change or degradation in the coverage without necessarily a loss from its original condition, but a negative change to a structure that diminishes its capacity to generate service and products and can be considered a loss of biodiversity or a decrease in biomass. In this process we have to consider primary vegetation that changes to secondary vegetation and secondary vegetation that converts to inferior states for example from forest to bushes to herbals (CONAFOR, 2005).

On the other hand, we have a recovery process or the natural expansion of forest into areas where the land had been in use (UNFCCC - SBSTA, 2007).

In order to keep the terminology clear and consistent we have followed the terminology of the available data from the National Inventory of Forests and Lands (INFyS).

Methodology

The INFyS includes field measurements taken between 2004 and 2007. During this period, 25,000 plots were established. Their distribution enabled all of the vegetation communities of the country to be systematically sampled, including those in arid and semi-arid zones.

Each plot is formed of 4 subplots. Site measurements are taken of all trees with a diameter at breast height (DBH) greater than 7.5 cm. Among the variables that are included in INFyS are: number of trees, number of species, number of live trees, total tree height, commercial height, clean height, diameter at breast height, diameter of the crown, basal area, as well as 21 other quantitative variables and some 24 qualitative variables that can be observed such as: conditions impacting the trees, data on the state of the humus and uses of resources (CONAFOR, 2004).

In 2008, a process was begun of revisiting sites from the first INFyS in order to obtain information about growth and to estimate the change in function of the forest. 10% of the 25,000 sites were visited. Information about the ground, about forest fires and about sanitation was added (CONAFOR, 2009).

In addition, we have obtained MODIS images that cover the entire country. We have computed the Normalized Difference Vegetation Index (NDVI) for these images. NDVI is an indicator of the photosynthetic activity of a vegetation community and has been accepted for this purpose by the scientific community worldwide. NDVI is calculated from the red and near infrared bands of the satellite image, which makes it a product that is easy to calculate and reproduce and it can readily be applied to large areas (Goward, 1991) (Huete A. J., 1999).

The first step is to relate the information about the type of vegetation community as observed in the field as part of INFyS in 2004 - 2007 (more than 65,000 sites) with the value of NDVI derived from 32 days of MODIS images taken between December 2000 and September 2005 (53 months). The images are obtained from the Institute for Advanced Computer Studies of the University of Maryland in the United States.

The phenological behaviour of the different vegetation communities is shown in Figure 1 (CONAFOR, 2008).

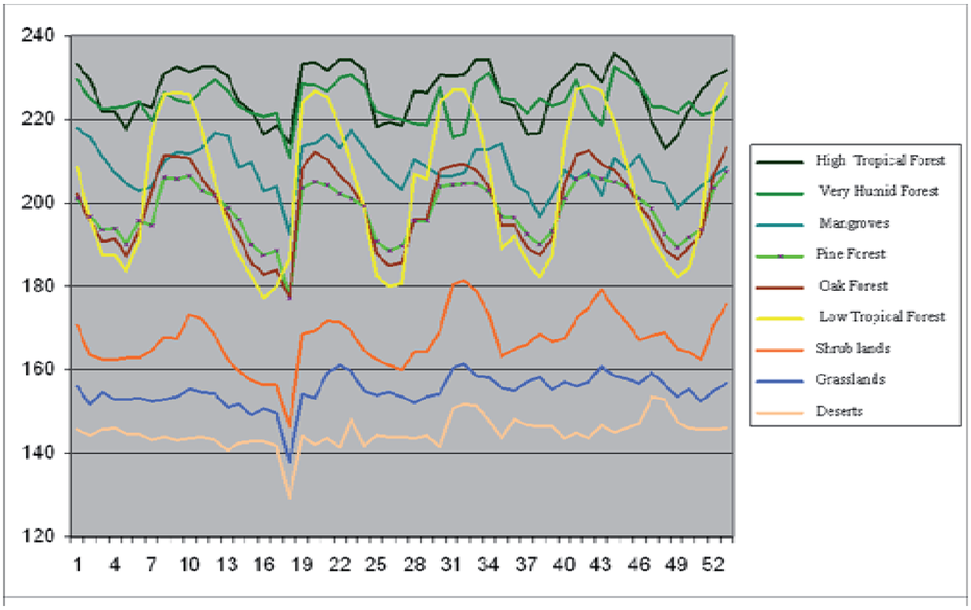


Figure 1. Monthly behaviour of NDVI for different vegetation communities.

In general we can differentiate patterns of vegetation communities ranging from arid zones such as deserts with low values of NDVI to the tall perennial forests that have high values of NDVI. Also the dynamic intra annual phenologic cycle can be observed for each community with indices that are very variable in lowland jungle or indices that are very stable in deserts.

The classes of vegetation of communities are defined according to the species most frequently encountered in the field as reflected in the INFyS database and according to the definitions of INEGI (INEGI, 2004).

Figure 2 shows a histogram of the frequency of NDVI for the country and we find different behaviour for different seasons: a quasi-unimodal pattern during the dry season, months of transition and a bimodal pattern during the wet season. This behaviour must be considered as a general pattern as the wet season does not occur in the same form for the entire country. The northern part of the country is under the influence of the temperate zones with four seasons. The southern part is under the influence of the tropical zones and the wet season is a little longer.

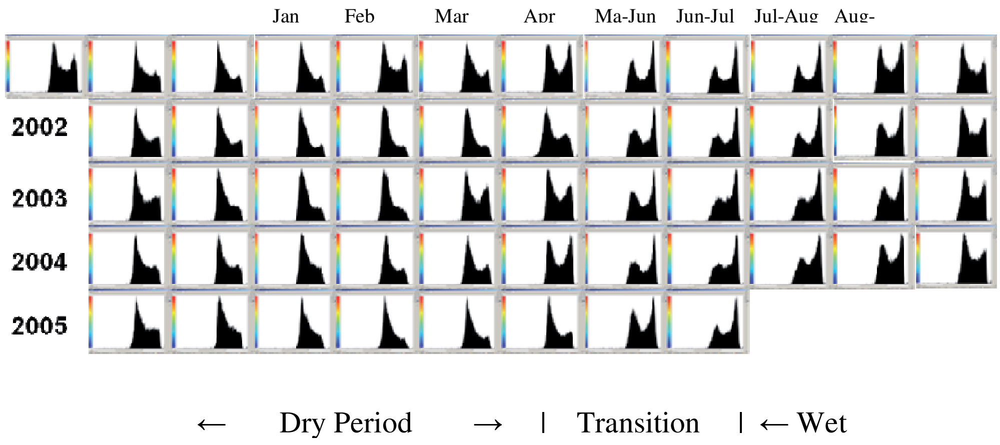


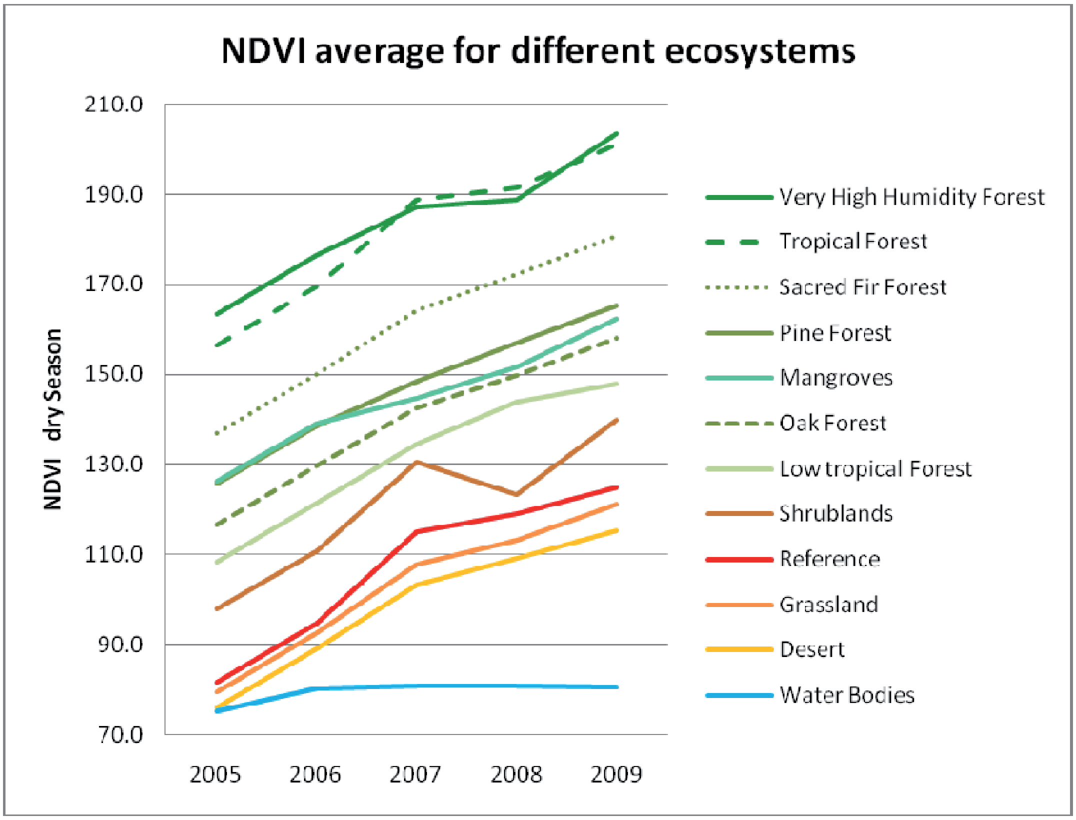
Figure 2. Histograms of the frequency distribution of NDVI in Mexico composed from monthly MODIS images.

This figure suggests the care that must be taken in selecting images for analysis of the change in ground cover. Dates taken in one season should not be mixed with those taken in another. In addition, care should be taken with images taken during the transition months, since they are variable and can be difficult to use and interpret.

Given these considerations, this study focused on the dry period for two important reasons: the first is cloud cover in the images; MODIS is an optical sensor; and, the second because of seasonal agriculture patterns. The dry season corresponds to a period of preparation for planting and during this period the arable fields appear as bare ground in the images. On the other hand, the period selected for analysis corresponds to the time when deciduous ecosystems are losing their leaves. Consequently, the behaviour of NDVI is mixed in with the response of the land. We must also be careful with cultivated zones where fruit trees can be confused with forested areas and irrigated areas that present high values of NDVI.

Focusing on the behaviour in the dry season, we first determine if there is some relation between NDVI and the type of vegetation community existing in the field using data from INFyS. To the 65,000 sites, we added a group of 2500 points located in water bodies where there were no field observations and which were obtained from visual inspection of high resolution satellite images.

In order to obtain an NDVI for the dry season, we used composite MODIS images taken between the 15th of February and the 15th of April, then estimated the average value of NDVI* for each year from 2005 to 2008.



*NDVI is translated and scaled (NDVI+1)*127 to have a range of 0 to 255 and corrected by water bodies NDVI´s.

Figure 3. Average behaviour of NDVI in the dry season for different ecosystems.

For each community the average NDVI was calculated as shown in Figure 3. This figure shows again a definite pattern relating the biomass contents of the ecosystems given that the very high humidity and the jungle forests are the communities that contain the majority of the biomass followed by sacred fir, Pine, Mangroves and Oak. At the same time, in the dry season, deserts have almost no biomass value until we get to water bodies with zero levels of photosynthetic activity as shown in Figure 4. In order to show this more clearly, in the figure, the classes are generalized into fewer categories.

A line of reference, shown in red, has been established as a threshold to separate Forests and Other Wooded areas as designated by FAO (FAO; 2004) from the other categories. This threshold is defined for each year according to the values of the NDVI which vary slightly from one year to the next depending on the climatic behaviour, the treatment of the images (Threshold) and the ecological region of the country. In order to fix the threshold of NDVI by processing and atmospherics and climatic effect, it takes 3000 points over water bodies and the NDVI average over those plots is used to calibrate the NDVI over the image. In figure 4 it looks like a constant value. In the monitoring process we must compare images with a very good warp in space (RMS is lower than 30 m); time (the images acquired between 15 February - 15 April) and radiometric values (corrected by water bodies NDVI).

In order to show the relation between NDVI and the biomass, we estimated the wood volume in m^3/ha the quantity of biomass in Ton/ha for 16942 plots measured in the field in INFyS. The equations for volume and biomass are taken from a bibliographic revision specific for each ecosystem. For those plots with information about diameter at breast height (DBH) and total height, we count only those trees where the DBH is 7.5 cm or greater. In the estimation it includes the seedling information for different strata. The values did not include succulent species in the arid zones. The following communities are not counted in the estimation of biomass or in the estimation of wood volume: Thalias, Savanas, Typhus (wet land), Palm, Mangrove and some jungle. From the total sampled of 1´305.307, 1´230.127 individuals have been considered as shown in Figure 4 (ECOSUR, 2009).

Figure 4 shows the relation between average biomass per unit area estimated in Ton/ha for each community with respect to the NDVI for the date of field survey ´s plot. The green coloured line shows primary forests, the red one represents primary forest with tree secondary vegetation condition and the blue represent primary forest with herbaceous secondary vegetation condition. The black line represents forest and other wooded forest (primary and primary with tree secondary vegetation condition). The biomass over tropical forest and the very humid forest looks to be underestimated.

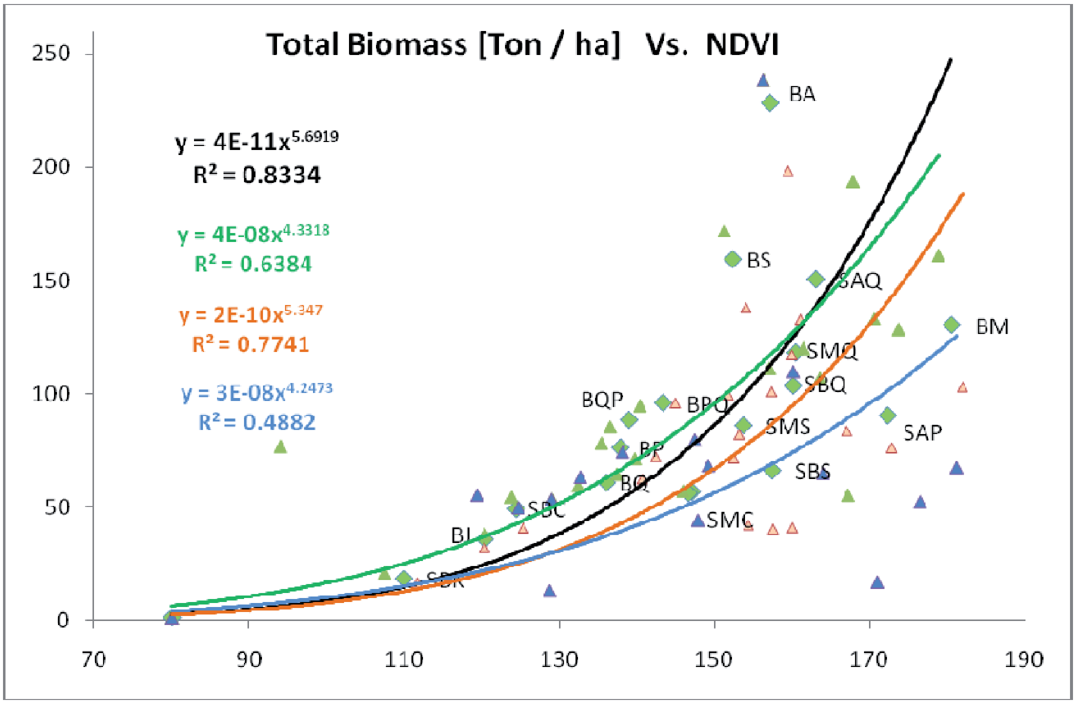


Figure 4. Average behaviour of aerial biomass per unit (Ton/ha), on the *y* axis, against the NDVI value of dry season, on the *x* axis for different ecosystems.

The results show a decline in behaviour depending on the grade of disturbance.

Figure 5 shows a classification of NDVI for the 2009 dry season which is based in very general terms on the categories of communities in the Map of the Use of Ground and Vegetation, Series III from INEGI. Field samples are categorized according to the species most frequently found in the field points taken from INFyS. This process was also applied over 2006, 2007 and 2008.

To obtain an indicator of the change in vegetation cover, we will compare the 2008 NDVI with that of from the 2009.

Figure 5. NDVI 2009 dry season classification from the plot survey.

These decreases can be an indication of degradation or of deforestation depending on the degree of decrease and the initial value (if it falls outside of the reference threshold for the community in 2009 it is considered to be deforestation, if not it is considered to be degradation). The increases can be related to the recovery of vegetation to disturbance or a natural increase of biomass.

Figure 6 shows in green the changes that indicate an increase in NDVI and in pink the decreases between 2008 and 2009.

In general, if there is not any disturbance between two years, the vegetation communities must show a natural increase of biomass. That behaviour is represented on the map because there is more green than pink. Even so, the major part of the decrease is very low, and, it is also part of the natural vegetation process. The methodology pays attention to the severe changes and those areas that move out of the forest range.

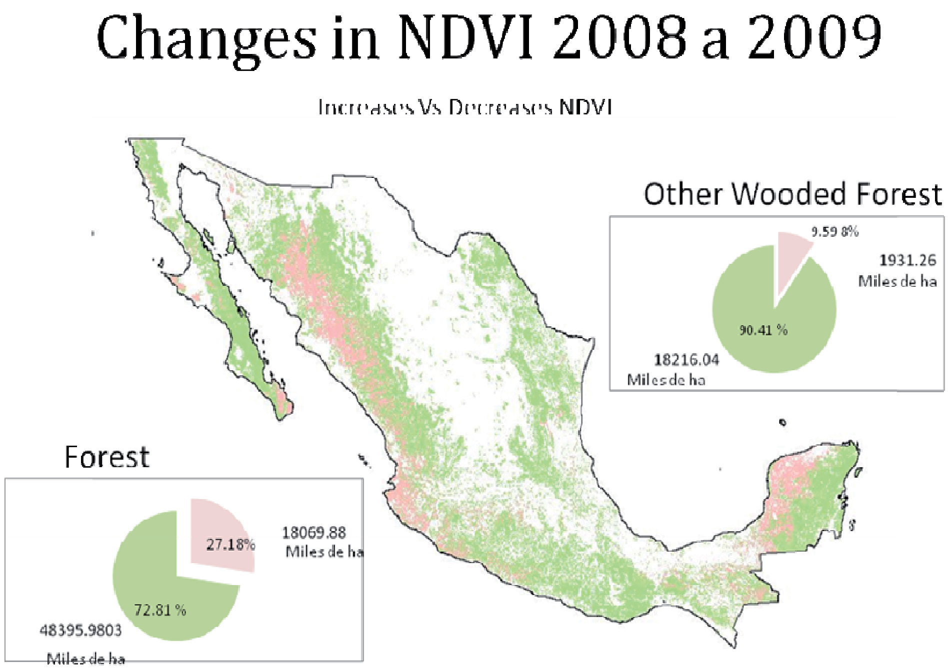


Figure 6. Differences between NDVI 2009 and 2008.

By the same definition of deforestation or loss (permanent change in use of the land) and based on the study of the dynamics of forest vegetation change between 1993 and 2002 (CONAFOR, 2005), we find that where there is loss of the forest ecosystem it is transformed as follows:

- Agriculture and animal production 45677.72 km^2 (82.3%)
- Human settlement 592.00 km^2 (1.0%)
- Inferred pasture 7795.68 km^2 (14.0%)
- Unvegetated 70.11 km^2 (0.4%)
- Other changes 1356.81 km^2 (2.4%)

The results obtained in the comparison if NDVI are combined with information related to the presence of anthropomorphic effects such as highways, urban areas, agricultural zones and electric energy usage (INEGI, 2004). They are also combined with a map of the energy usage taken from a mosaic of nighttime images from NASA and processed to represent zones with the existence of infrastructure. Anthropomorphic effects are determined as follows:

- 1.5 km buffer around areas of agriculture and animal production
- 1.5 km buffer around major highways
- 1.0 km buffer around urban areas
- Presence of electrical energy usage

From the universe of possible changes we filter the results according to several criteria:

- Areas of Forest and Other Wooded Areas;
- Areas of decrease related to anthropomorphic effects and considered for possible deforestation;
- High altitude area pushing the limits for the detection of change because of topographic shadow effects as indicated by other changes;
- Areas near water bodies are considered as other changes except in relation to the presence of mangroves;
- All of the changes with low or very low NDVI are denoted as without change;
- Areas of increase in NDVI related to or identified in earlier years as possible deforestation or damage related to the passage of hurricanes are denoted as possible recovery;
- Areas of decrease in NDVI but without leaving the threshold NDVI defined as categories Forest or Other Wooded Areas for 2008 (by community) and which, moreover, do not coincide with anthropomorphic activity are denoted as possible degradation.

3. Results

The analysis of values that indicated a decrease of NDVI between 2008 and 2009 in areas of Forests or Other Wooded Lands produced the following results:

CHANGE	%	TYPE CHANGE	SUP HA	% RELAT.	%TOTAL
Without changes	90.41	Deciduous behaviour	494245.43	28.31	25.59
		Normal behaviour	1251773.23	71.69	64.82
Other changes	6.32	Topography	59032.5	48.36	3.06
		Buffer water	63039.01	51.64	3.26
Possible degradation	1.58	Buffer roadway	3535.15	11.59	0.18
		Buffer agriculture	24428.8	80.07	1.26
		Buffer urban	179.82	0.59	0.01
		Illegal forest harvest	2364.33	7.75	0.12
Possible deforestation	1.69	Buffer agriculture	1606.72	4.92	0.08
		Buffer roadway	19781.33	60.56	1.02
		Buffer urban	46.86	0.14	0
		Illegal forest harvest	11213.07	34.33	0.58
		Detected by 2008	16.64	0.05	0

Table 1. Comparison between NDVI 2008 -2009 dry seasons in areas of Other Wooded Forest (OWF).

CHANGE	% TOTAL	TYPE CHANGE	SUP HA	% RELAT.	%TOTAL
Without changes	61.64	Deciduous behaviour	7545810.31	67.75	41.76
		Normal behaviour	3591806.96	32.25	19.88
Other changes	36	Topography	5893224.28	90.59	32.61
		Buffer water	611269.58	9.4	3.38
Possible degradation	2.15	Buffer roadway	20590.45	5.31	0.11
		Buffer agriculture	272199.07	70.2	1.51
		Detected 2008	87.5	0.02	0
		Buffer urban	950	0.24	0.01
		Illegal forest havest	93940.8	24.23	0.52
Possible deforestation	5.54	Buffer agriculture	6806.25	17.37	0.04
		Buffer roadway	1156.25	2.95	0.01
		Buffer urban	287.5	0.73	0
		Buffer water	16827.08	42.93	0.09
		Mangroves	1643.75	4.19	0.01
		Illegal forest harvest	12505.18	31.91	0.07
		Detected 2008	775	1.98	0

Table 2. Comparison between NDVI 2008 -2009 dry seasons in Forest areas.

Figure 7. Map of the decrease in NDVI between 2008 and 2009 Forests and Other Wooded Areas consider possible deforestation or possible degradation.

The major part of decreases was considered as natural changes or deciduous behaviour. Just 3.25% in Other Wooded Forest and 2.37% in Forest areas are tagged as possibly deforested or possibly degraded.

Figure 7 shows the location of the changes, in orange color the possible degradation, and, in red possible deforestation. In the case of possible deforestation are related to agricultural buffer areas.

The methodology applied in 2008 detected the damage caused by the passage of hurricane Dean and the damage caused by the floods that occurred in Panuco River and Tabasco estate.

Validation

From the data in INFyS we have 5 plots which have had remediation and which fall in areas identified as possible degradation:

Plot 71952 – Chiapas: Change in NDVI (2006 to 2008): from 192 to 174

Visited: 13 January 2006

Vegetation Community: Perennial high jungle with secondary vegetated Arboreal (SAP/VSA) in the 4 sites

Number of species (10, 11, 3 and 7); species with highest frequency: null, *Lysoloma acapulcense, Vernonia deppeana* and *Conostegio xalapensis.* Number of individuals: 26, 25, 20 and 15. Average diameter of the crown: 3.05, 3.96, 2.55 and 2.46 m. Coverage: 340, 492, 107 and 94%. Average height of trees by site: 11.6, 11.8, 6.7 and 8.5 m.


Visited: 1 July 2008

One of the sites changed to seasonal cultivation. Of the 1600 m^2 measured in the plot, the change in coverage was 400 m^2.

Plot 65961 – Campeche: Change in NDVI 2005 to 2008 from 194 to 178

Visited: 27 April 2005

Vegetation Community: Medium subperennifolia jungle with secondary vegetated Arboreal (SMQ/VSA) in 4 sites. Number of species: 12, 7, 12 and 10. Species with highest frequency: *Vitex gaumeri, Bursera simaruba, Lochocarpus castilloi* and *Croton reflexifolius.* Number of individuals: 17, 18, 27 and 38. Average diameter of the crown: 0.9, 1.27, 1.29 and 1.72 m. Coverage: 340, 492, 107 and 94%. Average height of trees by site: 9.7, 9.3, 11.1 and 9.5 m.

Visited: 14 May 2008

The four subplot show indications of damage from forest fire

Of the 67 individuals, 56 reported damage from forest fire, insects or wind.

Plot 66730 – Oaxaca: Decrease in NDVI 2006 to 2008 from 204 to 180

Visited: 27 October 2006

Vegetation Community: Perennifolic high jungle with secondary vegetated Arboreal (SAP/VSA) in the four sites. Number of species: 10, 7, 9, 7. Species with highest frequency: *Bauhinia ungulata and Brosimun alicastrum* in plots 2, 3 and 4. Number of individuals: 24, 22, 33 and 22. Average diameter of the crown: 6.8, 5.6, 6.5 and 6.1 m. Coverage: 975, 628, 1231 and 726 %. Average height of trees by site: 13, 11, 12 and 12.6 m.

Visited: 15 July 2008

107 individual plots reported well

Plot 63448 – Campeche: Change in NDVI 2006 to 2008 from 207 to 169

Visited: 14 May 2008

Vegetation Community: Medium subperennifolic tropical forest with secondary vegetated Arboreal (SAP/VSA) in four sites. Number of species: 7, 10, 4 and 2. Species with highest frequency: *Albertia edulis, Croton reflexifolius, Ceiba aesculifolia* and *Sweetia panamensis.* Number of individuals: 12, 19, 9 and 2. Average diameter of the crown: 1.7, 1.64, 2.3 and 0 m. Coverage: 39, 111, 47 and 0 %. Average height of trees by site: 9.9, 9.6, 8.5 and 8.19 m.

Visited: 3 September 2008

The photos show a deciduous ecosystem in the last visit with 10 out of 26 individual trees damaged by fire.

Plot 76944 – Oaxaca: Change in NDVI 2007 to 2008 from 207 to 221

Visited: 7 June 2007

Vegetation Community: Primarily very high humidity forest (BM) in four sites. Number of species: 4, 5, 4 and 4. Species with highest frequency: *In identification in the four sites.* Number of individuals: 11, 14, 13 and 11. Average diameter of the crown: 4, 4.6, 4.9 and 4.95 m. Coverage: 154, 251, 248 and 218%. Average height of trees by site: 15, 14, 17 and 18.75 m.

Visited: 19 June 2008


Of the 44 trees in the plot, 6 show damage by insect and 33 by other causes. Only one reported no damage.

4. Discussion

The NDVI is very sensitive to changes in the reflectance captured by the sensors. When comparing NDVI from one year to the next, we find different reasons for the change. Some of the changes reflect natural processes linked to the recovery of the health of the vegetation or to degradation of coverage. But there are many other reasons for which the reflectance can change. There are limitations to the use of the technology for the following reasons:

<u>*Anisotropic illumination considerations*</u> In the process of obtaining NDVI, we take images with different angles of incidence, that is the angle, sun-object-sensor can vary. As a primary factor we have the effect that is generated by the difference in the angle of

illumination by the sun which varies by some 20° depending on the latitude, the season of the year, and also by the hour when the image is taken. In order to be able to include the maximum number of images, we used both ascending passes (10:00 am) and descending passes (3:00 pm) for which the incidence angle seen by the sensor varied between ±20 and ±55°.

A second factor is the irregularity of the terrain in areas with large vertical gradients. These areas will look different to ascending and descending tracks and will generate different illumination over an image.

In addition, objects, in our case vegetation, can behave differently depending on the season and species. In particular, the number of hours of daylight and the direction of illumination varies greatly throughout the year.

Such factors generate anisotropy in illumination that affects the value of NDVI. The authors recommend a major study of the behaviour of the bidirectional distribution of reflectance from specific land cover and evaluating the effect on NDVI (Cihlar, 1994).

<u>*Atmospheric effect considerations*</u> According to Goward *et al.*, (1991), the atmosphere degrades NDVI by decreasing the contrast between the red band and the infrared band owing to the attenuation of the infrared band by water vapour in the atmosphere, aerosols, and contaminants. The net result is an underestimation of the quantity of greenness present on the surface (Teillet, 1995).

During the dry season there is high pressure over Mexico. This high pressure generates a stable atmosphere. It has the effect that any contaminants present can increase the distortion of the signal as well as generate a change in the estimation of NDVI. Also affecting this season of the year is a small quantity of atmospheric water vapor. This effect is difficult to eliminate and occurs in a form that is random and variable over the complete area of a scene.

<u>*Presence of clouds and cloud shadows*</u> The MODIS sensor is optical and, consequently, some of its bands are reflected by clouds. We have attempted to resolve this problem by creating images composed of the average of 10 or 16 days. The minimum period for generating a composite will vary according to the frequency of appearance of cloud. In the tropics, including parts of Mexico, it can be more than 30 days between cloud free images. The shorter composite images give a better idea of the dynamics of intra-annual change in vegetation. However, it comes at a risk of omitting most of the pixels because of the presence of clouds (Townshend, 1994).

In this project, 60 days was used to compose an average image free of clouds. During the dry season, the problem of clouds is less than at other times of years. The daily behaviour is that there are more clouds in the afternoon; therefore images from the morning were used more often.

Of the scenes that were used, the problem of clouds was present in a persistent form in the half that covered the south of the country. Of the 60 days analyzed, cloud presence was encountered in all of the Yucatan peninsula and part of the Gulf of Mexico, particularly in the area where rising topography forced wet air masses to rise over the Sierra Madre Oriental of Veracruz.

The dynamics of change of use of the land in Mexico is very variable. The objective of this study is an annual assessment. For this purpose, the composite image is considered adequate. The principal reason for the period chosen was the guarantee of the detection of changes in the whole of the country. That is to say with the least number of pixels missing or eliminated.

Another important aspect to consider is the process of elimination of clouds and cloud shadows from the scenes. Each scene is passed through a rigorous process of elimination of clouds. It is necessary to realize that the pixels around the clouds and their shadows can generate noise of contamination from the radiation captured by the sensor. This noise is difficult to eliminate from every image. The increase in radiation introduces a variation in NDVI that is manifested as an increase in vegetation health where there are remnants of clouds and a decrease in NDVI where there are remnants of shadows.

Noise from the reflectance of vegetated ground NDVI is extremely sensitive to reflectance or brilliance that exists under the canopy of the forest (bare ground, moisture content of the ground, leaf litter, snow or water) (Huete A. R., 1985). The ground under the vegetation has a significant natural variation throughout the year. This variation results from the rain cycle, snow, the accumulation of leaves or other combustible material, the organic content of debris and its roughness. For these reasons it is difficult to quantify the effect it has on NDVI overall in areas where freezing, snow, moisture or irrigated area introduce an error that can exceed ±15%.

In our case, we use images from the dry season (February, March and April) to try to minimize the effect on NDVI of the variable behaviour of the ground. However, we found that for these months, in the northern part of the country, there was occasionally snow that can cause a major error in the results. The images analyzed are not contaminated by the presence of snow. However, we cannot guarantee that variation in soil moisture resulting from a cabañuelas (break in weather during the rainy season) at the beginning of the year does not introduce errors in the comparison of NDVI over the northeastern part of the country.

Effect of treatment of the data or of saturation on NDVI Radiometric corrections to the images can degenerate the resulting information in areas with very low biomass content, but at the same time spoil the results in areas with high biomass content (Huete *et al.*, 1999). For this reason, it was decided to make no radiometric corrections to the data in calculating NDVI number in converting to 8 bit. (Huete *et al.*, 1999)

Phenological aspects of the vegetation The phenological cycle generates differences in the reflectance captured by the sensor in the red and infra-red bands. The NDVI is a measure of the fraction of photosynthesis active in the vegetative cover in a given pixel.

From a seasonal point of view, we know that the length of the life cycle during which plants are photosynthetically active varies according to its growth phase, its flowering stage, its stage in losing foliage and transferring nutrients, and the stage of fruit production and maturation. It also depends on the degree of health of the plant or the level of hydrologic stress which is sometimes expressed in the water content of the leaf cells. For that reason, we expect a change in NDVI. These differences in NDVI are real or natural changes in the vegetation (Huete et al., 1999).

Agricultural management Continuous change in vegetation coverage in areas subjected to agriculture whether seasonal or irrigation related generate important changes in the response of NDVI. These changes appear as an increase or decrease depending on the manner of the reflectance at the time the image is taken.

In general, in the dry period, agricultural lands with annual seasonal crops are in a state of preparation for sowing and light up in the image as unvegetated zones. However, irrigated agricultural lands possess a high state of vegetation from which we can obtain either a very high NDVI or a very low NDVI.

In this study, we discarded agricultural zones; however these zones continue to increase in forest areas and jungles adding adjacent areas to those that already possess an established infrastructure. It can be stated that these areas, in the majority of cases, are related to the presence of urban areas and presence of communication routes that permit the transport of crops. In this study, this change in the use of forest land from a jungle to agriculture can be manifested as an increase in NDVI when land that has been free of vegetation changes to an area with high index of vegetation growth. However it can also can be manifested as a decrease in NDVI originating from the degradation of forest and jungle as the ground is stripped.

Changes in the level of water bodies The NDVI of bodies of water is very low; so much so that any fluctuation in the level of the water generates a large change in NDVI. Some of these changes follow a normal behaviour pattern of hydrologic processes in the country. However, we give special attention to mangrove areas. In recent years, the development of shrimp farming in the country has been growing. These shrimp ponds generate changes in land use as mangrove swamps are converted into shrimp ponds. This change is reflected as a severe decrease in the value of NDVI.

With the limitations on the images and the limitations on the biomass found from the relation between NDVI and biomass volume we can do better. This is the first use of the volume of data derived from INFyS. It provides details. For example: some plots have as many as 39 trees and are given a condition of secondary shrub vegetation by which they change to a category of other lands according to the definitions of FAO. But at the same time, we encounter plots with a lower value of NDVI that are considered in condition of secondary forest vegetation but have standing dead trees or have only 2 or 3 individual trees.

5. Conclusions

These results must be considered as preliminary and, moreover, reflect the average behaviour of the country. The country requires more effort devoted to the use of the INFyS database. We suggest incorporating, in some manner, the estimation of aerial biomass of replanting together with a measurement of the humus and shrubs because they are part of the ecosystem and generate a contribution to the value of NDVI. The relations between NDVI and biomass have been truncated to consider only trees with a diameter greater than 7.5 cm.

Given the limitations on the existence of equations for arid zones, succulent species, and wetland species on the one hand and the technical limitations on the images as discussed in the previous chapter, the complete expression for the relation between NDVI and biomass is considered a very good with a R2 = 0.8334 and even better in the half that exceeded the limitations.

The data from INFyS can be used at the level of sites to increase the sample universe by a factor of 4, but it requires the use of images with better spatial resolution such as Landsat.

NDVI is a sensitive and viable tool for the detection of degradation and deforestation. As was shown in the validation, the five plots showed some type of degradation. The smallest unit, 400 m^2 in area, a measurement site, is reflected in a decrease in NDVI in a MODIS image pixel that represents an area of 62,500 m^2.

The estimation of aerial biomass can be a variable for measuring the function of the forest. One must take care that some deterioration may not be reflected in the aerial biomass which basically depends on the altitude and normal diameter. The damage from insects, fire or wind, decreases in the number of species or the presence of invasive species can only be detected by field observations. Except for the case of deterioration by insects or fire if it was detected by a change in NDVI.

The sites visited in the validation all showed a level of degradation in a short period of time which raises a number of questions: How much has the function of the forest changed due to these changes? If the degradation is a natural process, should it be considered degradation? Will this level of degradation be maintained? In a period of recovery, does the forest recover its function and improve its resistance to disease for example? How great must the impact be before it is considered degradation?

With future measurements of the national forest inventory and with better use of the existing inventory data we can fine tune the level of degradation.

Collaboration

Comisión Nacional Forestal CONAFOR: Coordinador de Planeación e Información Dr. Rodolfo Orozco Galvez. Personal of the Gerencia de Inventario Forestal y Geomática Gerente Ing. Rigoberto Palafox Rivas; Msc. Adriana Rodríguez, estimation of wood volume and the dynamics of change study; Lic. Vanessa Silva Mascorro, database manager; Nora Isabel Muñoz: processed the MODIS images; Dr. William Prescott U.S. Peace Corps volunteer automated the acquisition of MODIS images and traslation; Rafael Flores Subgerente Técnico del Inventario; Ernesto Díaz Ponce subgerente de Proyectos. Lic. Julissa Nayeli Orozco statistical analysis of the quality control process.

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