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Measuring Tropical Deforestation with Error Margins: A Method for REDD Monitoring in South-Eastern Mexico

Stéphane Couturier[1], Juan Manuel Núñez[1] and Melanie Kolb[3]
[1]Laboratorio de Análisis Geo-Espacial, Instituto de Geografía, UNAM,
[2]Centro de Investigación en Geografía y Geomática 'Ing. Jorge L. Tamayo' (CentroGeo),
[3]Comisión Nacional para el Uso y Conservación de la Biodiversidad (CONABIO),
Mexico

1. Introduction

In the second half of the twentieth century, high rates of land use and land cover (LULC) change with severe deforestation trends have caused ecosystem degradation and biodiversity loss all throughout the tropical and sub-tropical belts (Lambin et al. 2003). Estimating the rate of change in tropical forest cover has become a crucial component of global change monitoring. For example, the viability of worldwide schemes such as the reduction of emissions from deforestation and degradation (REDD) depends on an accurate change estimate. Much research has covered the subject of tropical deforestation and degradation (Achard et al., 2010), however, there is so far very little information on the accuracy of quantitative estimates, leaving much room for uncertainty at regional and global scales. In Mexico, for example, the national projections for the rate of deforestation in the past three decades have ranged from 260,000 to 1,600,000 ha/year according to the record of academic studies and official reports (Velázquez et al., 2002). The estimate depended on the total area under study, on remote sensing materials and ground measurements involved in the computation of change rates, but above all none of the studies did contemplate a sampling scheme that would permit the computation of error margins for the rate of change. As a consequence, the alleged recent reduction in deforestation is subject to much political controversy in Mexico. Although, recent advances in Geographic Information Science (GIS) have been made for the accuracy assessment of maps, a standard method for assessing land cover change has not yet been established.

This chapter presents a methodological framework for the measurement of tropical deforestation in Southeast Mexico, based on the experience of accuracy assessment of regional land cover maps and on-site measurements of tropical forest cover in Mexico. In this chapter, we first describe the status of the accuracy assessment of forest cover change maps, an emerging branch of research in GIS. We review the studies that relate to the measurement of deforestation in Mexico and focus on studies where the method for measuring forest cover change is explicitly described. Another section is dedicated to the challenges related to forest canopy change definitions for the assessment and to a sampling design that would encompass the extent of both change and non-change classes. We discuss the need for systematic data as one of the technical limitations to achieve robust estimates. The next sections focus on the framework that is being developed as well as the planned application of the framework in the case of forest cover maps in Southeastern Mexico. As a conclusion, special emphasis lies on the distinctive features which make this case a pioneering experience for deforestation assessments as well as a possibly valuable benchmark for cartographic agencies dealing with forest cover mapping in other sub-tropical regions of the world. Recommendations are drawn for the design of future REDD norms and regulations in Mexico.

2. A review of forest cover change studies and reliability issues

2.1 Deforestation globally and the emergence of REDD

According to the Global Forest Assessment of the year 2010, tropical deforestation is estimated at 16 million ha per year in the period 1990-2000, and a 13 million ha per year in the period 2000-2010 (FAO, 2010). This assessment is a report from the Food and Agriculture Organization (FAO), based on a global database of national estimates of forest area change for the period 1990-2010. These figures reflect in fact a significant institutional effort, at national level, of many sub-tropical countries, for tropical forest mapping since the 1980s. It is thought that the estimated reduction of net forest loss between the 1990s and 2000s is largely due to afforestation, natural forest regrowth, reforestation and forest plantations (Achard et al., 2010). However, the gross deforestation rate is still unacceptably high by the standards of global change processes that have trespassed several internationally recognized planetary boundaries (Rockström et al., 2009), especially biodiversity loss and climate change.

Carbon emissions and fluxes from fossil fuels, cement production and various non-tropical land use changes, mainly as a result of our modern urban consumption habits worldwide, contribute for an estimated 85% of the anthropogenic emissions of greenhouse gases, a major driver of climate change (van der Werf, 2009). The remaining 15% is contributed by deforestation, as well as peat and forest degradation in the tropics, principally through the release of carbon dioxide. This latter emission, estimated at 1.5 +- 0.4 GtC yr-1 is considered significant in the global carbon budget. As a consequence, international discussions were initiated at the United Nations Framework Convention on Climate Change (UNFCCC) 11th Conference Of Parties (COP 11, 2005) on the issue of REDD in sub-tropical countries. The need to provide incentives for REDD was, however, not mentioned until COP-15 (Copenhagen Accord, 2009) in the final declaration of the Heads of State and governments. This declaration encourages the 'immediate establishment of a mechanism including REDD-plus to enable the mobilization of financial resources from the developed countries'. Decision 4/CP.15 deals with the establishment of 'robust and transparent national forest monitoring systems and, if appropriate, sub-national systems'. Indeed, the largest uncertainties of the global carbon budget are on the side of the land-use change balance (IPCC fourth Assessment report: Solomon et al., 2007). Sub-tropical countries are thus expected to demonstrate that they are fulfilling requirements in the framework of the REDD mechanism.

2.2 Forest cover change studies in Mexico

In the United States of Mexico (USM, hereafter 'Mexico'), according to official information in 2007, the extent of forest ecosystems (tropical and temperate forest) was estimated at 65.3

million hectares, which means a significant loss compared to an estimated 69.2 million hectares in 1993. However, the official document "Mexico's REDD+ vision" (CONAFOR, 2010), states that the country went from losing on average 354,035 hectares of forest extent each year for the period 1993-2002 to 155,152 ha for the period 2002 -2007. This means a decrease in deforestation rates of over 50%, highlighting the fact that for the last 5 years 99.9% of the deforestation has occurred in the tropical forests.

This information on deforestation is built on the basis of visual interpretation of medium resolution satellite imagery at the national level (1:250 000 scale) (Mas et al., 2002). As a consequence the interpretation of the deforestation phenomenon is limited to this scale. Additionally, an explicit estimate of error margins for this calculation is not provided. In fact, numerous studies in the country have focused on measuring deforestation, but the diverging results have contributed to a perception of high uncertainty and none has been able to offer error margins to the calculations. This situation of high discrepancies about the forest cover loss is illustrated in table 1, where academic studies and official sources are separated and compared.

Academic sources		**Official sources**	
Source	**(ha/year)**	**Source**	**(ha/year)**
Grainger, 1984	1,600,000	FAO, 1988	615,000
Repetto, 1988	460,000	SARH, 1992	365,000
Castillo et al., 1989	746,000	SARH, 1994	370,000
Myers, 1989	700,000	FAO, 1995	678,000
Toledo, 1989	1,500,000	FAO, 1997	508,000
Masera et al., 1997	668,000	CONAFOR, 2004	260,000
Velázquez et al., 2002	550,000	FAO (Torres, 2004)	775,800
Sánchez-Colón et al., 2008	484,000	SEMARNAT, 2006	365,000
Sum	6,708,000	Sum	3,936,800
Average	838,500	Average	492,100
Stdev	±451,417	Stdev	±181,851

Table 1. Deforestation rates estimated in Mexico for the last three decades.

Variations in the inputs, projections, scale and timing, have probably contributed to the high variability of the results, and many difficulties have hampered efforts for a unified methodology that might have permitted statistical information on its reliability. Estimates of rates of deforestation seem contradictory and a consequence is a low credibility of the sources and an institutional weakness at designing regulation policies.

Since 2001, the National Commission of Forests (CONAFOR), dependent of the National Environmental Agency in Mexico (SEMARNAT), is in charge of updating the vegetation cover and its change in Mexico, in parallel with the regional LULC cartography produced by the National Institute of Statistics, Geography and Informatics (INEGI: 2002 'Serie III' map, and 2007 'Serie IV' map). None of this cartography to date has been generated with an international standard accuracy assessment scheme as described in this chapter. Since 2004, CONAFOR has established a periodical forest inventory every 5 years ('Inventario Nacional Forestal y de Suelos', INFyS: CONAFOR, 2008); The Mexican territory is monitored, based on a systematic grid of ground plots over the entire vegetation cover of Mexico.

2.3 Accuracy assessment of maps

Global reports on deforestation and forest degradation stem from the FAO and are based on a global database of national estimates of forest area change. These national estimates are obtained through governmental agencies of sub-tropical countries, using Land Use/ Land Cover (LULC) maps at a regional scale, intermediate between local (> 1:50,000) and continental (1:5,000,000). However, the quality of these LULC maps are usually unquestioned, taken for granted, just as if each spatial unit on the map perfectly matched the key on the map, which in turn perfectly matched ground reality. The minimum mapping unit, which defines the scale of the map, is commonly the only information available about the spatial accuracy of these maps and no statistically grounded reliability study is applied as a plain step of the cartographic production process.

Since the 1990s, the classification of satellite imagery has become the standard for LULC mapping programs at the regional scale. However, the classification process is affected by different types of error (Green and Hartley, 2000; Couturier et al., 2009) related in part to the limited discrimination capacity of the spaceborne remote sensor. Indeed, the difficult distinction, on the satellite imagery, between categories (or 'thematic classes') of a cartographic legend (e.g. a density grade of a forest cover) can cause a high percentage of errors on the map, especially maps that were generated by coarse resolution, global satellite sensors. This is why a forest management policy whose strategy is simply 'process map information and rely on the quality of the map' is highly questionable.

In Mexico, as discussed earlier, none of the regional cartography is evaluated using a statistically grounded assessment. This is most unfortunate since the statements of the CONAFOR governmental agency on recent deforestation rates is based on these maps (online geoportal: CONAFOR, 2008). These official statements and figures are then passed unquestioned on to the FAO database. Moreover, the absence of such estimate indicates that these figures stand without error margins, and as such, without statistical validity, so that the deforestation rate may remain the focus of controversial academic and public discussions nationwide. It is worth stating that the online availability of the satellite imagery – a feature advertized by this governmental agency - does not increase the reliability of a parameter derived from the imagery. The extraction of the parameter based on colour tones of the satellite imagery available online is far from trivial and it is simply impossible for a user to quantitatively derive the global reliability of the cartography from internet access to the imagery.

An error bar is sometimes present aside the legend of National Institute of Statistics and Geography (INEGI) maps and indicates an estimate of positional errors in the process of map production. However, the procedure leading to this estimate is usually undisclosed, and any objective interpretation of this estimate by the user is thus discouraged (Foody, 2002). Moreover, such error bar indicates a very reduced piece of information with respect to the thematic accuracy of the map.

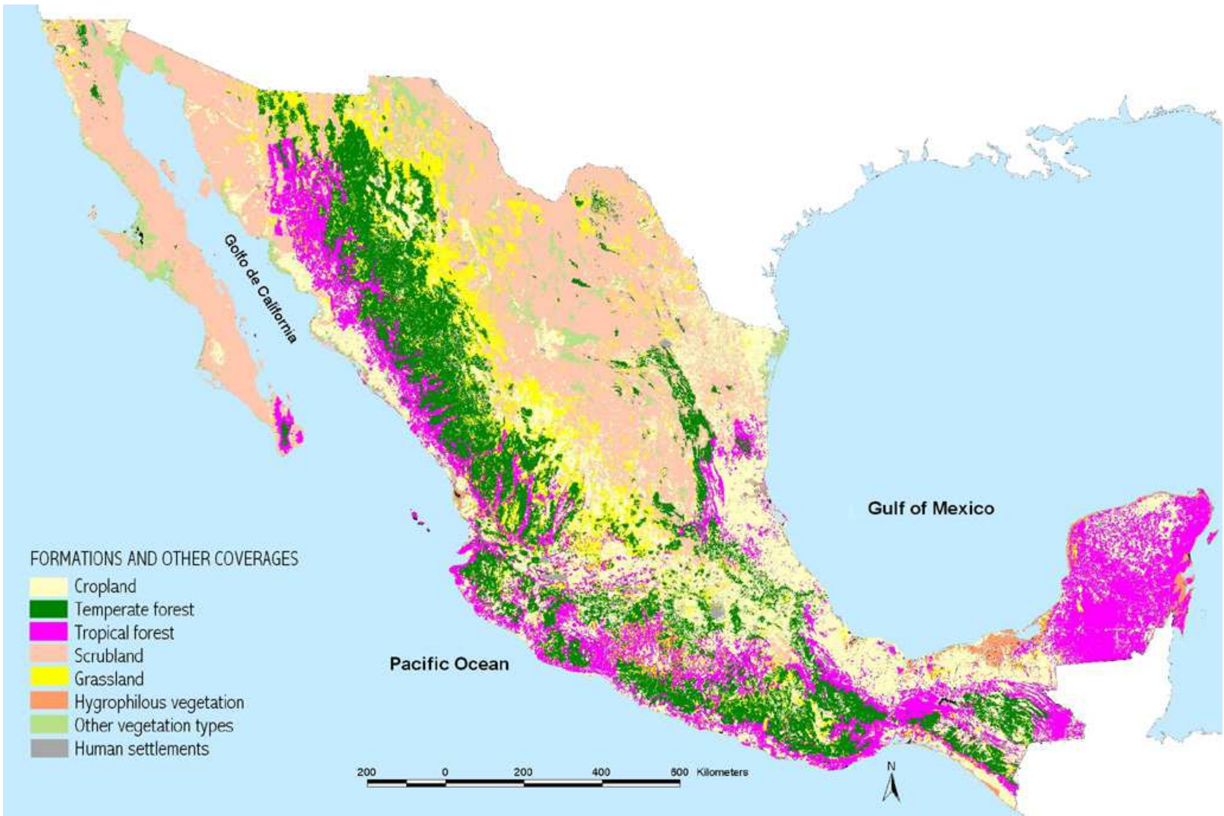

Fig. 1. National Forest Inventory map of Mexico in the year 2000 (taken from Mas et al., 2002)

Instead, the accuracy of a cartographic product is a statistically grounded quantity, which gives the user a robust estimate of the agreement of the cartography with respect to reality. Such estimate is essential when indices derived from cartography – i.e. spatial extent statistics, deforestation rates, land use change analysis - are released to the public or to intergovernmental environmental panels. The accuracy of a map also serves as a measurement of the risk undertaken by a decision maker using the map. On the other hand, this information also allows error propagation modeling through a GIS (Burrough, 1994) in a multi-date forest monitoring task. The construction of the statistically grounded accuracy estimate is generally named 'accuracy assessment'.

Assessing the accuracy of LULC maps is a common procedure in geo-science disciplines, as a means, for example, of validating automatic classification methods on a satellite image. Generally, map accuracy is measured by means of reference sites and a classification process more reliable than the one used to generate the map itself. The classified reference sites are then confronted with the map, assuming that the reference site is "the truth". Stehman and Czaplewski (1998) have proposed a standard structure for accuracy assessment designs, which are divided into three phases:

1. Representative selection of reference sites (sampling design),
2. Definition, processing and classification of the selected reference sites (verification design),
3. Comparison of the map label with the reference label (synthesis of the evaluation).

Agreement or disagreement is recorded in error matrices, or confusion matrices (Card, 1982), on the basis of which various reliability (accuracy) indices may be derived. For regional scale LULC maps, because of budget constraints and the large extension of the map, the complexity of accuracy assessments is increased. Only relatively recently, comprehensive accuracy assessments have been built and applied to the regional or continental LULC maps. In Europe, Büttner and Maucha (2006) reported the accuracy assessment of 44 mapped classes (including 3 forest classes) of the CORINE Land Cover (CLC) 2000 project. In the United States of America (USA), Laba et al. (2002) and Wickham et al. (2004) assessed the accuracy of 1992 maps of, respectively, 29 and 21 LULC classes for the Gap Analysis Project (GAP) and the National Land Cover Data (NLCD). As a part of the Earth Observation for Sustainable Development (EOSD) program of Canada, Wulder et al. (2006) provide a review on issues related to these three steps of an accuracy assessment design for regional scale LULC cartography, and the accuracy of this program is assessed in the Vancouver Island for 18 classes (Wulder et al., 2007).

A noteworthy study in a sub-tropical area is the one in South and Southeast Asia (Stibig et al., 2007), with an accuracy assessment obtained at the biome level. A study at the biome level does allow a deforestation study (forest – non forest change) with error margins, but does not allow a land cover change study with more detailed processes (e.g. 'forest to forest with alteration'), also important in REDD management requirements. Another study deals with the accuracy assessment of the National Forest Inventory (NFI) 2000 cartography in Mexico (figure 1). This assessment was carried out in four eco-geographical areas (Couturier et al., 2010).

2.4 Accuracy assessment of forest cover change maps

Operational forest mapping at the national level using satellite imagery is now a regular task for most of the sub-tropical countries. However, reducing the uncertainty in the national and global carbon budget for REDD mechanisms requires the capability to estimate changes of forest extents in a reliable manner. Technical capabilities and statistical tools have advanced since the early 1990s. Methods have been implemented for forest cover change at national level(e.g. Velázquez et al., 2002), based on either coarse (e.g. Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), SPOT-VEGETATION) or medium (e.g. Landsat, SPOT) resolution sensors or a combination of both:

- Identification of areas of rapid forest cover change from coarse resolution imagery
- Analysis of wall-to-wall coverage from coarse resolution imagery to identify locations of large deforestation fronts for further analysis with a sample of medium resolution imagery
- Analysis of wall-to-wall coverage from medium resolution imagery from visible or radar sensors

Several studies state that coarse resolution imagery alone should not be used to map changes in forested areas, owing to uncertainty levels (e.g. Achard et al., 2010, Couturier, 2010), which are higher than levels of area changes (Fritz et al., 2009). Land cover maps obtained through coarse resolution imagery can serve as a prior stratification against which future change can be assessed. The use of medium resolution imagery for historical assessment of deforestation has been boosted by the recent free availability of the Landsat Global Land Survey Database(www.glovis.usgs.gov). However, in all cases no accuracy assessment (with a sampling design and higher resolution imagery) of forest cover change has been achieved.

A method has been developed at South Dakota State University (SDSU), as part of the NASA Land Cover and Land Use Change program, to improve the measurement of deforestation at pan-tropical level (Hansen et al., 2008). The method is based on a prior stratification of tropical forests according to forest cover change probabilities derived from time series of coarse resolution imagery. An analysis of medium resolution imagery on the stratified layer permits a rectification or refinement of the first step stratification. This method allowed a targeted sampling of medium resolution imagery, which saves costs because of the synergy coarse – medium resolution data. However, the method did not provide a rigorous protocol for error estimation. For example, one of the challenging features of an assessment design is related to sampling intensity (ratio of sampled surface over total studied surface) for the most extended non-change classes. The strategy does not precisely address this sampling challenge and the results are possibly affected by a strong bias in areas where coarse resolution imagery indicates no-change, because change may have been missed due to the limitation of coarse resolution imagery.

Other academic efforts have focused on making operational the analysis of medium – resolution imagery for comprehensive forest change estimation. For example, the Forest Resources Assessment 2010 programme (FAO, 2010) prepares a Remote Sensing Survey of 20 km x 20 km plots placed on an extensive systematic grid (around 0.9% of the land surface in sub-tropical areas). This approach is expected to deliver globally to regionally accurate estimates of forest cover change in periods 1990-2000 and 2000-2005 for those countries or regions where sampling intensity is sufficient (e.g. Brazil: Broich et al., 2009; the entire Congo River basin: Duveiller et al., 2008). In some regions, this approach has been assessed against wall-to-wall cartography based on medium resolution imagery (e.g. for Brazil: Eva et al., 2010).

Whether through wall-to-wall or sample-based approaches, information derived from fine spatial resolution imagery is the most appropriate data to rigorously assess the accuracy of land-cover change estimation (Achard et al., 2010). For this purpose, the European Space Agency (ESA) is launching an action with the Joint Research Council (JRC) to build a database of high resolution satellite imagery susceptible to produce better estimates of forest cover change in Latin America and South East Asia up to the year 2010.

Díaz-Gallegos et al. (2010) have proposed and applied an accuracy assessment scheme to regional land cover change for the first time in Mexico. The assessed LULC maps are official national level INEGI Serie I (year 1978: INEGI, 1980) and National Forest Inventory (year 2000) maps over several states of Southeast Mexico. The assessment is based on a systematic aerial photograph coverage, and is well adapted to available reference material in Mexico. However, the sampling intensity (43 pairs of photograph) was probably not sufficient to ensure a statistical representation over change and non-change classes. Additionally, some features in the sampling design (e.g. stratification per center of aerial photograph) impeded the calculation of error margins from the accuracy indexes obtained in the study.

Finally, on all the above-cited studies (including the popular FRA study), estimates of deforestation were considered with a minimum mapping unit above 5 hectares. This means only an extensive component of deforestation is measured, and in particular, these estimates do not correspond to the forest definition emitted by FAO as an international standard, as will be seen in the next section.

3. Challenges for the reliable measurement of deforestation

3.1 Forest definitions and forest cover change definitions

As adopted by the United Nations Framework Convention on Climate Change (UNFCCC) at the 7th Conference of the Parties (COP-7, 2001) under the 'Marrakesh Accords', 'For LULC and forestry activities under Article 3, paragraphs 3 and 4 of the Kyoto Protocol (http://unfccc.int/kyoto_protocol/items/2830.php), the following definitions shall apply: (a) 'Forest' is a minimum area of land of 0.05-1.0ha with tree crown cover (or equivalent stocking level) of more than 10-30 percent with trees with the potential to reach a minimum height of 2-5m at maturity in situ. A forest may consist either of closed forest formations where trees of various stories and undergrowth cover a high proportion of the ground, or open forest….' COP-7 further noted that parties recognize that there should be some flexibility. To date, most countries are defining forests with a minimum crown cover of 30%.

As any definition choice would, this official definition (the FAO definition of forest) leads to a number of challenges for consistent forest monitoring worldwide. For instance, a minimum area of 0.05 – 1.0 ha implies that deforestation (understood officially as the 'direct human-induced conversion of forested land to non forested land', UNFCCC, Marrakech Accords, 2001) can certainly not be derived from cartography at 1:250,000 scale (whether generated by medium or coarse resolution imagery); Clearings due to the establishment of large scale mechanized agriculture may be detectable on the coarse scale map but not the removal of forest patches of 0.05 – 1.0 ha. Therefore, coarse scale cartography may detect the amount of a *specific type* of deforestation, which is not deforestation under FAO definition. However, this specific type of deforestation (large area deforestation) is the one reported in FAO worldwide reports and not FAO defined deforestation. It seems though that the FAO definitions of forest and deforestation agreed under the UNFCCC will also serve as a reference for the future REDD mechanism (The Marrakech Accords).

A difficulty in any definition of forest cover change is to handle a sufficiently small minimum area of forest (e.g. 0.5 ha in the FAO definition) and a compatible scale of the available cartography from governmental agencies. Another potential difficulty is related to the variety of vegetation types in a diverse environment, some within the FAO definition of forests and some outside this definition but within the 'Other Forested Land' (OFL) definition. At national level it may be desirable to count the removal of such vegetation cover as deforestation because of its ecological function. Yet the inclusion of many vegetation types within the deforestation count may cause greater levels of uncertainty in deforestation figures. Additionally, there is no official definition of forest *degradation*, but in a REDD-plus context, it is directly related to a loss of carbon stocks in forests due to human activities.

3.2 The sampling design challenge

Apart from the forest definition issue, the *a posteriori* (posterior to mapping efforts) spatial detection of estimated change, and the general dominance of non-change on the map, both pose a challenge for their validation with reference sites. The selection of reference sites is a statistical sampling issue (Cochran, 1977), where strategies have varied according to the application and complexity of the spatial distribution. Stehman (2001) defines the probability sampling, where each piece of mapped surface is guaranteed a non-null probability of inclusion in the sample, as being a basic condition for statistical validity. In most local scale applications, reference sites are selected through simple random sampling. Two-stage (or double) random sampling has been preferred in many studies in the case of regional cartography; in a first step, a set of clusters is selected through, for example, simple random sampling. This technique permits much more control over the spatial dispersion of the sample, which means much reduction of costs (Zhu et al., 2000), and was adopted in the first regional accuracy assessments in the USA, for LULC maps of 1992 (Laba et al., 2002; Stehman et al., 2003).

A random, stratified by class sampling strategy means that reference sites are sampled separately for each mapped class (Congalton, 1988). This strategy is useful if some classes are sparsely represented on the map and, therefore, difficult to sample with simple random sampling. This strategy was adopted by Stehman et al. (2003) and Wickham et al. (2004) at the second stage of a double sampling design and might be useful for the assessment of change classes.

Finally, systematic sampling refers to the sampling of a partial portion of the mapped territory, where the portion has been designed as sufficiently representative of the total territory. This strategy, adopted as a first stratification step, is attractive for small scale datasets and reference material of difficult access. Wulder et al. (2006) define a systematic stratum for the future (and first) national scale accuracy assessment of the forest cover map in Canada.

4. A framework for deforestation measurement with error margins

This research proposes a framework for reliable deforestation measurement in Mexico, with key features based on forest definitions and sampling design. This framework is aimed at contributing to technical specifications for REDD monitoring in Mexico.

4.1 Remote sensor discrimination capacity

As discussed earlier, the deforestation according to UNFCCC talks (FAO definition) cannot be derived through coarse scale (e.g. 1:250,000) data because the minimum area of 0.05 – 1.0 ha is not resolved by coarse scale data. Clearings for large agriculture (usually) mechanized projects or for a massive newly settled migrant population (e.g. relocation programs in Indonesia, colonization of land in the Amazon), may be detected with coarse resolution imagery based on digital analysis (see PRODES (2010) in Brazil). On the contrary, small agricultural clearings or clearings for peripheral settlements require higher resolution data (< 50m x 50m, achieved by medium resolution imagery). Even smaller clearings or degradation of the forest canopy require high resolution (10m x 10m or smaller) imagery and a greater visual control on the interpretation of the imagery. With the experience from earlier studies, we propose to handle three levels of sensor discrimination capacity for the assessment of deforestation and degradation in Mexico (Table 2).

Depending on its capacity, a sensor is able to detect a complex or a simple process; this suggests (next sub-section) that definitions of deforestation should be compatible with the capacity of sensors, in order for the measurement of deforestation to be more reliable. The measurement of a complex process (e.g. forest degradation) also means higher costs than the measurement of a simpler process (forest to non-forest). Also, the use of a sensor of higher capacity (from 1 to 3) means more costs for the measurement of a given process.

Sensor discrimination capacity	Minimum detectable area (ha)	Indicative temporal resolution of sensor set	Access/ indicative cost in Mexico	Processing cost for an area of 200x200km (indicative)
Capacity 1: Resolution 250-1000m (e.g. MODIS, AVHRR)	6-100	Daily	Free	1 day person
Capacity 2: Resolution10-30m (e.g. Landsat, ASTER, SPOT XS multispectral)	0.05-0.30	3 days	$US 250 per scene of 180x180 km^2 /Free*	3 days person
Capacity 3: Resolution 0.5-5m (ej. Quickbird, GeoEye)	0.01	3 days	$US 20 / km^2	30 days person

* Free under governmental agreement for government agencies, higher education and research institutions.

Table 2. Grouping of sensors according to their discrimination capacity for deforestation and degradation processes.

4.2 Forest cover change definitions

The definition of deforestation stems from the FAO definition of forest and refers to the forest – non forest change in a 0.5 ha surface or more. We will name this definition as the '*FAO deforestation*'. Symmetrically we define as '*consolidated reforestation*' the change from non forest to forest in a 0.5 ha surface or more. These processes can be detected by medium (Capability 2) to high (Capability 3) resolution sensors (Couturier et al., 2010). It is further proposed to attach the 'degradation' process to a physiognomic concept of forest compatible with its detection by remote sensors. Our proposal is to define *forest degradation* as the permanence of forest with a loss of more than 30% of its canopy cover (e.g. a canopy cover of 70% becomes a canopy cover of 40%). It is thought that this process might be detected by medium resolution (Capability 2) sensors, but should be preferably detected (with much higher reliability) by high resolution (Capability 3) sensors.

Because of the difficulties associated with a necessary 0.5 ha minimum mapping unit (or less) for the measurement of FAO deforestation (for this reason, deforestation rates in FAO reports are not 'FAO deforestation'), and because of the attractive characteristics of capacity 1 sensors (daily availability of data), we propose to consider other forest definitions as well.

In the first place, we propose the notion of '*extensive deforestation*', which would refer to the removal of forest in a convex area of 6 ha, and would be associated to a process susceptible of being detected by Capacity 1 sensors. Obviously, the measurement of FAO deforestation is more costly than the measurement of extensive deforestation.

Finally, forested land is ecologically considered to have many life forms in mega-diverse Mexico (Table 3), a few of which are not included in the FAO definition of forest (e.g. some low tropical forests, sub-tropical shrublands, Chaparrales, open oak forests). Many are defined as 'forested vegetation' in Mexico (according to forest law LGDFS) and included in the FAO category of Other Forested Land (OFL). To report the removal of this forested vegetation is very relevant in the case of Mexico.

Formation	Vegetation Type
Temperate Forest	1. Cedar forest, 2. Fir forest, 3. Pine forest, 4. Conifer scrubland, 5. Douglas fir forest, 6. Pine-oak woodland, 7. Pine-oak forest, 8. Oak-pine forest, 9. Oak forest, 10. Mountain cloud forest, 11. Gallery forest.
Tropical forest	*Humid/ evergreen & sub-evergreen tropical forests:* 12. Tropical evergreen forest, 13. Tropical sub-evergreen forest, 14. Tropical evergreen forest (medium height), 15. Tropical sub-evergreen forest (medium height), 16. Tropical evergreen forest (low height), 17. Tropical sub-evergreen forest (low height), 18. Gallery forest.
	Deciduous & sub-deciduous forests: 19. Tropical sub-deciduous forest (medium height), 20. Tropical deciduous forest (medium height), 21. Tropical sub-deciduous forest (low height), 22. Tropical deciduous forest (low height), 23. Tropical forest of thorns.
Scrubland	24. Sub-montane scrubland, 25. Spiny Tamaulipecan scrubland, 26. Cactus-dominated scrubland 27. Succulent-dominated scrubland, 28. Succulent-cactus-dominated scrubland, 29. Sub-tropical scrubland, 30. Chaparral, 31. Xerophytic scrubland, 32. Succulent-cactus-dominated cloud scrubland, 33. Rosetophyllic scrubland, 34. Desertic xerophytic rosetophyllic scrubland, 35. Desertic xerophytic microphyllic scrubland, 36 *Prosopis* spp.-dominated, 37. *Acacia* spp.-dominated, 38. Vegetation of sandy desert.
Grassland	39. Natural grassland, 40. Grassland-huizachal, 41. Halophilous grassland, 42. Savannah, 43. Alpine bunchgrassland, 44. Gypsophilous grassland.
Hygrophilous vegetation	45. Mangrove, 46. Popal-Tular (Hydrophilous grassland), 47. Riparian vegetation.
Other vegetation Types	48. Coastal dune vegetation, 49. Halophilous vegetation.

Table 3. Classification scheme of the INEGI land use land cover cartography (only natural land cover categories are indicated):

For this reason we propose the definition of *total forest cover* that encompass woody plants of low size and shrubs which are not secondary vegetation, at the intersection of the notions of 'Forested vegetation' in Mexico and Other Forested Land in the FAO nomenclature. The notion of '*FAO-Mexico deforestation*' is then defined as the change of total forest cover (Forest + Other Forested Land for FAO) to non-forested cover in a 0.5 ha area. It is noteworthy to mention that Capacity 1 sensors are not likely to detect change in low size forest cover with reasonably high accuracy, even for areas of more than 6 ha (see Couturier, 2010).

In synthesis, we define three notions of deforestation, one of them detectable by Capacity 1 sensors and two by Capacity 2 and 3 sensors, as showed in Tables 4 and 5. The accuracy assessment of the process implies the use of a sensor with more capacity than the sensor involved in the map production process.

Type of Detectable Process	Definition
Extensive deforestation	Change from forest to non-forest in a convex area of 6 ha.
Consolidated extensive reforestation	Change from non-forest to forest in a convex area of 6 ha.
Extensive permanence of forest	Permanence of forest in a convex area of 6 ha.
Extensive permanence of non-forest	Permanence of non-forest in a convex area of 6 ha.

Table 4. Processes detectable by capacity 1 sensors (low spatial resolution)

Type of Detectable Process	Definition
Deforestation (FAO or FAO-Mexico)	Change from forest to non-forest in an area of 0.5 ha.
Consolidated reforestation (FAO or FAO-Mexico)	Change from non-forest to forest in an area of 0.5 ha.
Degradation (FAO or FAO-Mexico)	Permanence of forest but with a decrease of more than 30% of canopy cover (e.g. A canopy cover of 70% decreases to 40%).
Regeneration (FAO or FAO-Mexico)	Permanence of forest but with an increase of more than 30% of canopy cover (e.g. A canopy cover of 40% increases to 70%).
Forest permanence (FAO or FAO-Mexico)	Permanence of forest in an area of 0.5 ha.
Non-forest Permanence (FAO or FAO-Mexico)	Permanence of non-forest in an area of 0.5 ha.

Table 5. Processes detectable by capacity 2 and 3 sensors (medium to high spatial resolution)

4.3 Sampling design for LULC change classes

The method comprises a sampling design that efficiently controls the spatial distribution of samples for all classes of the forest cover change map, including sparsely distributed (or ' rare') change classes. Previous assessments have relied on two-stage sampling schemes, where simple random or stratified by class random sampling was employed in the first stage. Couturier et al. (2007) demonstrated that these strategies fail in the case of sparsely distributed (rare) classes. This research proposes a two-stage hybrid scheme where proportional stratified sampling is employed for the rare change classes.

The first stage of the sampling design consists in the selection of two subsets of Primary Sampling Units (PSUs). The first subset of PSUs is obtained with a simple random selection and shall be used for the assessment of non-change classes. The second subset of PSUs is obtained with a proportional random selection of PSUs, and shall be used for the assessment of change classes. In the latter selection, the probability of selection attributed to each PSU is proportional to the abundance of the change class in that PSU, as described in Stehman et al. (2000, further discussed via personal communication); this mode of selection is retained as an appropriate way for including all classes, in the sample while maintaining a low complexity level of statistics (i.e. standard stratified random formulae to compute estimators of accuracy).

According to this scheme, the PSU selection process is made independently for each change class and a given PSU can be potentially selected multiple times (for rare classes as well as for common classes). This hybrid selection scheme, differentiated according to non-change (a common class) and change (a rare class), was proposed and detailed in Couturier et al. (2007), where its potential advantages with respect to sampling designs formerly applied in the literature were evaluated.

Once the sample PSUs are selected, all points of the second stage grid included within these PSUs are assigned the attribute of their mapped class. The full second stage sample consists of the selection of 200 points [Secondary Sampling Units (SSUs)] for each class mapped in the area. For each non-change (common) class, the selection is a simple random sorting of points within the second stage grid in the first subset of PSUs. For change (rare) classes, the selection of points is obtained via proportional random sampling in the second subset of PSUs, this time with a probability inversely proportional to the abundance of the class. This mode of selection can preserve equal inclusion probabilities at the second stage within a rare class (see the option of proportional stratified random sampling advocated in Stehman et al. 2000. A sequence of ArcView (2010) and Excel-based simple Visual Basic routines, for easy and fast repeated use on vector attributes of each class, was specifically designed to perform this proportional selection at both stages.

5. Preparing the framework for the case of Southeastern Mexico

The Grijalva and Usumacinta rivers in Southeastern Mexico are two of the most important in Mexico and North America. In terms of stream flow, the Usumacinta river (ranks 7th worldwide) is the most important in the Gulf of Mexico after the Mississippi river. The Grijalva – Usumacinta basin, one of the major rain-laden regions in Mexico (figure 2) is characterized by a contrasted anthropogenic transformation of the landscape, ranging from a highly modified coastal plain, to two mountain chains with mainly indigeneous agricultural management, to some very well conserved forested lands on the Guatemala border. This contrast reflects the level of incorporation of agricultural products to local, regional or international markets. This research first presents some results of a LULC change study in the Grijalva – Usumacinta basin, based on INEGI national level maps (sub-section 5.1). And then results of a deforestation study which approaches the FAO forest definition are obtained in the Marquéz de Comillas area (sub-section 5.2), a highly dynamic agricultural frontier within the Usumacinta watershed.

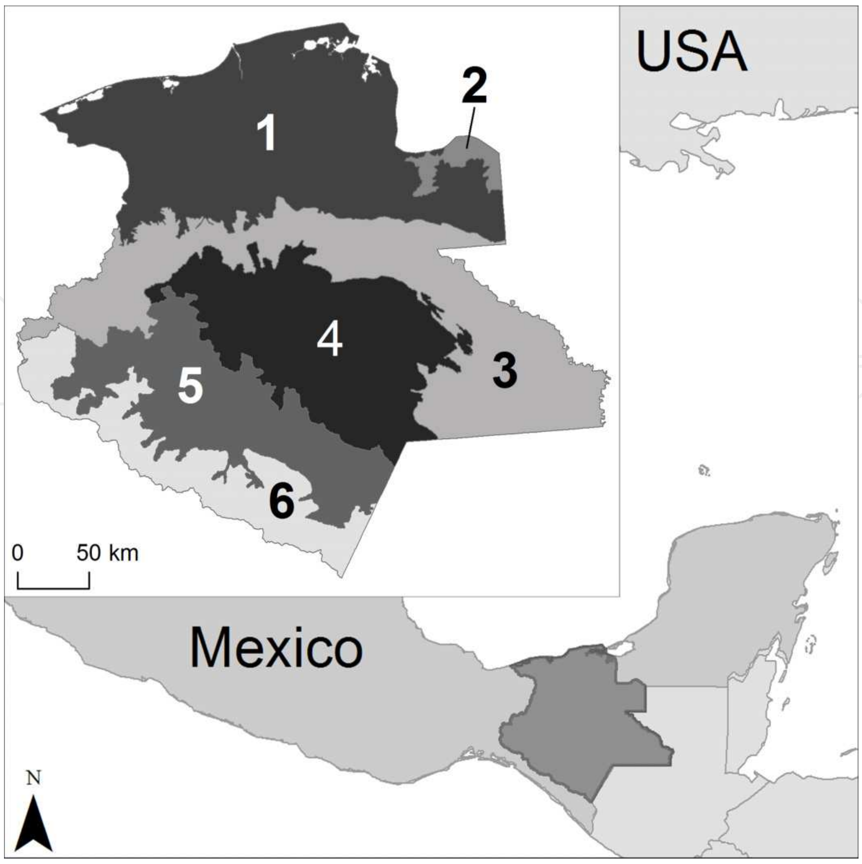

Fig. 2. The Grijalva-Usumacinta watershed and its ecoregions with the main vegetation types. 1) Gulf of Mexico Coastal Plain with Wetlands and Tropical evergreen forest, 2) Hills with High and Medium Tropical sub-evergreen forest, 3) Hills with Medium and High Tropical Evergreen Forest, 4) Chiapas Highlands with Conifer, Oak, and Mixed Forest, 5) Chiapas Depression with Low tropical deciduous and medium tropical sub-deciduous Forest, 6) Central American Sierra Madre with Conifer, Oak, and Mixed Forests.

5.1 'Extensive deforestation' measurement derived from regional maps in Southeastern Mexico

Three spatial data sets of LULC from the INEGI 1:250 000 series were used to analyse changes during the periods 1993–2002 and 2002–2007. For this purpose, the 55 original LULC classes were grouped into 18 categories (Table 6) following a hierarchical classification system developed for the INEGI maps. This system takes into account the vegetation dynamic and gives consistent results in time series analysis (Velázquez et al. 2002).

The level of anthropogenic modification of the forest cover is reflected in the appellation 'primary' versus 'secondary' in order to estimate the forest degradation. Forest degradation is understood as a forest change from a well conserved state ('primary') into a highly modified ('secondary') state. Additionally, 3 temperate and 2 tropical forest types were distinguished in order to specifically analyse LULC changes in each of these forest classes. Pastures for extensive cattle ranching and several agricultural classes were considered, as they are responsible of deforestation processes. Once possible and impossible transitions were established, thematic errors of the maps were detected and corrected with a revision of additional maps.

Formation	**Vegetation and land use types**	**Categories of analysis**	**Original land use and cover classes**
Temperate forests	Coniferous and broad leaved	Coniferous forests (1)	Primary *Juniperus* forests, primary fir forests, primary pine forests, primary pine-oak forests
		Broad-leaved forests (2)	Primary oak forests, primary oak-pine forests
		Montane cloud forests (3)	Primary montane cloud forests
Tropical forests	Rain	Rain forests (4)	Primary evergreen forests (tall, medium and low), primary sub-evergreen forests (medium), primary sub-evergreen forest of thorns (low)
	Dry	Dry forests (5)	Primary deciduous forests (low), primary sub-deciduous (medium)
Hydrophilic vegetation	Mangrove forests, reed, halophilic vegetation	Mangrove forests, reed (6)	Primary and secondary mangrove forests, reed, primary and secondary halophilic vegetation, primary halophilic grasslands
Secondary vegetation	Temperate forests	Secondary coniferous forests (7)	Secondary *Juniperus* forests, secondary fir forests, secondary pine forests, secondary pine-oak forests
		Secondary broad-leaved forests (8)	Secondary oak forests, secondary oak-pine forests
		Secondary montane cloud forests (9)	Secondary montane cloud forests
	Tropical forests	Secondary rain forests (10)	Secondary evergreen forests (tall, medium and low), secondary semi evergreen forests (medium), secondary sub evergreen forest of thorns (low)
		Secondary dry forests (11)	Secondary deciduous forests (low), secondary sub deciduous forests (medium)
Pastures	Pastures	Pastures (12)	Cultivated and induced grasslands, savanna
Cultivated areas	Agriculture	Irrigated agricultura (13)	Irrigated, eventually irrigated, suspended irrigation
		Permanent crops (14)	Permanent and semi-permanent
		Rain fed agricultura (15)	Annual crops
	Plantations	Forest plantations (16)	Forest plantations
Others	Urban areas	Urban areas (17)	Urban areas
	Other vegetation types	Othervegetation types (18)	Primary palm forests, induced palm forests, bare, primary and secondary riparian vegetation and forests

Table 6. Land use land cover (LULC) categories of analysis and classification scheme of the original LULC classes in the Grijalva-Usumacinta watershed (Southeast Mexico).

Deforestation and other changes were mapped to calculate the surface distribution and to capture the patterns of change and permanence. The proportion of change with respect to the initial extent (LULC rate of change), was calculated for each year as follows (FAO, 1996):

$$R = [(1-(A_1-A_2)/A_1)^{1/t})-1]*100 \quad (1)$$

where 'R' is the annual change rate in percentage, 'A1' is the area at 't1' , 'A2' the area at 't2' and 't' the number of years in the period. For deforestation rates, primary and secondary forest classes were aggregated and the results were multiplied by –1 to obtain positive numbers for negative change rates.

One way to determine LULC change dynamics is to establish the major change processes resulting from observed changes; these were defined as:

- deforestation, the conversion of forest into land use classes,
- forest degradation, a process leading to a temporary or permanent deterioration in the density or structure of the vegetation cover,
- transitions, change between different land use classes, and
- regeneration, the transitions of any land use into secondary vegetation.

The land use change processes were identified based on annualized change probabilities calculated with Markov chain properties based on area change matrices with the software package DINAMICA-EGO (Soares-Filho et al. 2009). Afterwards, the transitions with a probability greater than 0.00 were used for an analysis of the major change processes and the related dynamics by subsuming them into principal change processes:

$$P^t = M * V^{1/t} * M^{-1} \quad (2)$$

where 'P' is the annualised probability of change, 'M' the Eigen values of the matrix, 'V' the associated Eigenvectors and 't' the number of time steps within a time period.

The detailed LULC change data revealed that from 1993 to 2007, the major land cover losses were in tropical rain forests, temperate coniferous forests (both >300 000 ha) and secondary tropical dry forests (128 000 ha). For other land cover categories, the loss was smaller and mainly between 1993 and 2002. The primary tropical dry forests had the lowest cover loss (4000 ha). Secondary vegetation increased in almost all forest types, though most gain belonged to secondary coniferous forests (227 000 ha). Among land use classes, the extent of pasture increased most (392 000 ha) followed by rain-fed agriculture (264 000 ha).

However, for the reasons developed in this chapter, the results presented in tables 7 & 8 should be read with caution. The INEGI cartography, a key input of this study, lacks error margins, and does not permit a rigorous assessment of deforestation, forest degradation or regeneration rates in Mexico. Indeed, the partial accuracy assessment of the 2000 NFI map (Couturier et al., 2010) called for prudence in interpreting land cover change from Landsat-based INEGI-like maps, especially in the case of degradation studies. In contrast with the relatively high levels of accuracy of vegetation cover with little modification (classes labeled as 'primary' in the INEGI legend), many errors were reported for classes of highly modified vegetation cover (classes labeled as 'secondary vegetation'). For instance, in the Cuitzeo watershed, the accuracy of sub-tropical scrubland (78%), oak-pine forest (97%), pine forest

Forest type	1993-2002 Deforestation rate (%)	2002-2007 Deforestation rate (%)	1993-2007 Deforestation rate (%)
Coniferous forests	0.77	0.55	0.69
Broad-leaved forests	1.33	1.31	1.33
Montane cloud forests	0.38	0.18	0.31
Tropical rain forests	0.91	0.68	0.83
Tropical dry forests	2.62	1.55	2.24
Total	1.02	0.70	0.90

Table 7. Deforestation rates for different forest types (Kolb and Galicia, 2011).

	1993-2007		1993-2002		2002-2007	
Land cover and land use classes	**Δ Area (ha)**	**Change rate**	**Δ Area (%)***	**Change rate**	**Δ Area (%)***	**Change rate**
Coniferous forests	-316,258	-6.08	79	-6.61	21	-5.13
Broad-leaved forests	-96,317	-6.16	85	-7.39	15	-3.91
Montane cloud forests	-118,878	-3.34	87	-4.34	13	-1.5
Tropical rain forests	-305,440	-2.41	78	-2.79	22	-1.72
Tropical dry forests	-4,263	-3.31	88	-4.36	12	-1.41
Hydrophilic vegetation	1,798	0.02	248	0.07	-148	-0.08
Secondary coniferous forests	227,023	3.09	81	4.06	19	1.37
Secondary broad-leaved forests	50,772	2.89	101	4.56	-1	-0.04
Secondary montane cloud forests	93,881	2.14	89	3.03	11	0.57
Secondary tropical rain forests	93,596	0.74	91	1.05	9	0.18
Secondary tropical dry forests	-127,520	-2.22	78	-2.59	22	-1.55
Pastures	391,513	1.12	69	1.24	31	0.91
Irrigated agriculture	18,294	1.14	99	1.76	1	0.03
Permanent agriculture	-151,041	-3.46	56	-2.69	44	-4.82
Rain-fed agriculture	263,653	2.11	60	2.08	40	2.17
Forest plantations	2,132		10		90	59.29
Other vegetation types	3,816	0.06	7	0.01	93	0.17
Urban areas	15,038	2.94	41	2.09	59	4.49

Table 8. Areas of land use and land cover (LULC) change and change rates for each category and period (Kolb and Galicia, 2011). Δ Area is the difference in area for the different LULC classes for 1993-2007. Δ Area in percentage for 1993-2002 and 2002-2007 is relative to the total change area for 1993-2007.

(79%) and fir forest (76%) contrast with the accuracy of highly modified oak forest (46%), highly modified pine forest (12%) and highly modified mixed forest (45%). From both the taxonomical and landscape points of view, a class of highly modified vegetation cover is close to a wide set of land use classes as well as low modification vegetation cover classes, which makes it prone to more confusions than a class of low modification vegetation cover. These low accuracy levels, however, appear as a real challenge for improving the quality of future forest cover cartography because degradation estimates are probably characterized by very poor reliability, and yet degradation studies are an important part of the REDD - based forest management.

In this research, the accuracy assessment method proposed for the case of *extensive deforestation* measurement with regional LULC cartography consists in a multi-spectral SPOT coverage for reference data and a sampling design defined in section 4.3 where SPOT frames are the PSUs. In the extent of the Grijalva – Usumacinta region, a total of 5 SPOT images per change class and 7 SPOT images for non change classes is thought to achieve a good spatial distribution of the sample. SSUs should be constructed as squared frames centered on the points of the periodic INFyS, and the amount of SSUs should be selected so as to achieve a sampling intensity of at least 4% for all classes.

5.2 'FAO deforestation' measurement in the Marquéz de Comillas area

The forest monitoring program over the Marquéz de Comillas area is an instrument to measure the impact of conservation programs around the Montes Azules Biosphere Reserve (figure 3). The main objective is the measurement, via remote sensing, of the forest cover at the landscape scale. Part of the challenge is to establish deforestation estimates with error margins at a scale approaching the FAO forest definition.

For this purpose, forest cover was defined as: "Areas densely covered by tree vegetation, photosynthetically active at the evaluation season, and canopy cover of more than 30% of the observation area". This definition makes no reference to forest use (e.g., plantations, forest area under management), successional stages (secondary forest or 'acahual', vs low modification or 'primary' forest), or seasonal conditions (sub-evergreen forests). The purpose of this definition of forest cover is to provide a general framework on the dynamics of forest cover.

Landsat TM, ETM + and SPOT HRVIR multispectral images from three different years were used to develop forest cover maps (Table 9). Values were sampled in homogeneous reflectance areas, which were used to search for patterns from a number of independent variables containing spectral and spatial information on the forest cover. From these patterns, a pixel-based probability of ownership to the forest class was derived. We then used a multivariate logistic regression model, in which different spectral and spatial transformations (e.g., vegetation indices and topographic information obtained from a Digital Elevation Model) were the independent variables. The accuracy of the map was measured at every date of study (1990, 2000, 2010), using a stratified random sampling, the visual appraisal of colour composites of Landsat/ SPOT original data and auxiliary ground data.

The forest cover data was derived with accuracies of 91% and Kappa coefficient (K) of 0.7055 for 1990, 88% and K = 0.7540 for 2000 and finally in 2010 the accuracy was estimated at 88% and Kappa coefficient of 0.7660. The estimated annual deforestation rate was -2.1% for the entire period, showing a net loss of 88 098 hectares. In 1990, 95% of the study area was forest cover, while in 2000 forest cover had decreased to 78% and, finally, by 2010 the forest cover declined to 61%. The results show a loss of 4,557 ha/year for the period from 1990 to 2000, down to 4,252 ha/year for the period 2000 to 2010 (Figure 4).

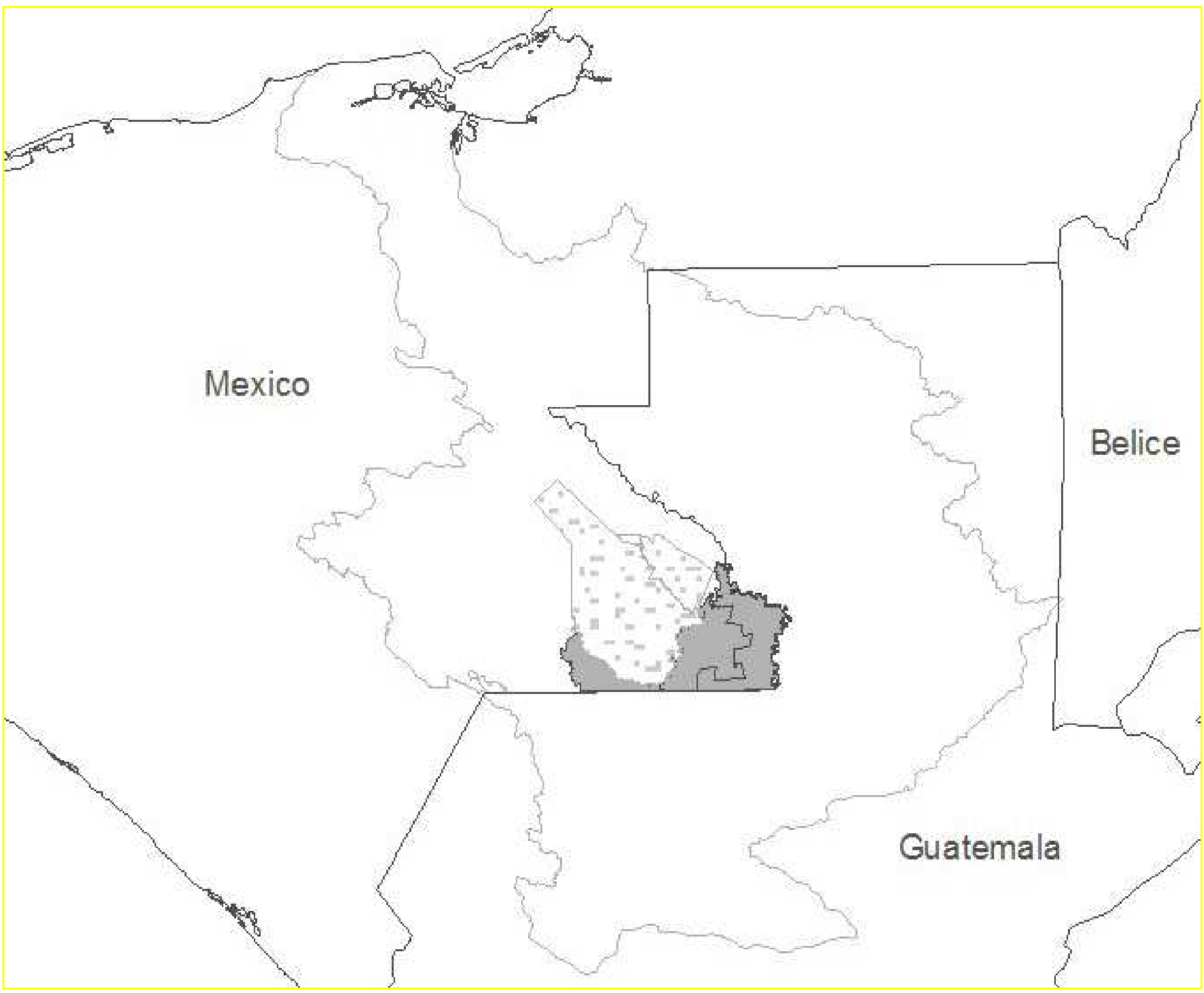

Fig. 3. The 'Marquéz de Comillas' study area is located between Montes Azules Biosphere Reserve (grey dots) and the Mexico-Guatemala border. The Usumacinta watershed was delineated in grey. The study area includes the Mexican municipalities of Maravilla Tenejapa, Marquéz de Comillas and Benemérito de las Americas, in the state of Chiapas.

Platforms & Sensors	Number of scenes	**Spectral bands**	**Pixel size (m)**	**Year**
Landsat 5 TM	2	7	30	1990
Landsat 7 ETM+	2	7	30	2000
SPOT 5 HRVIR	4	4	10	2010

Table 9. Principal characteristics of Landsat TM, ETM + and SPOT HRVIR used for forest cover mapping.

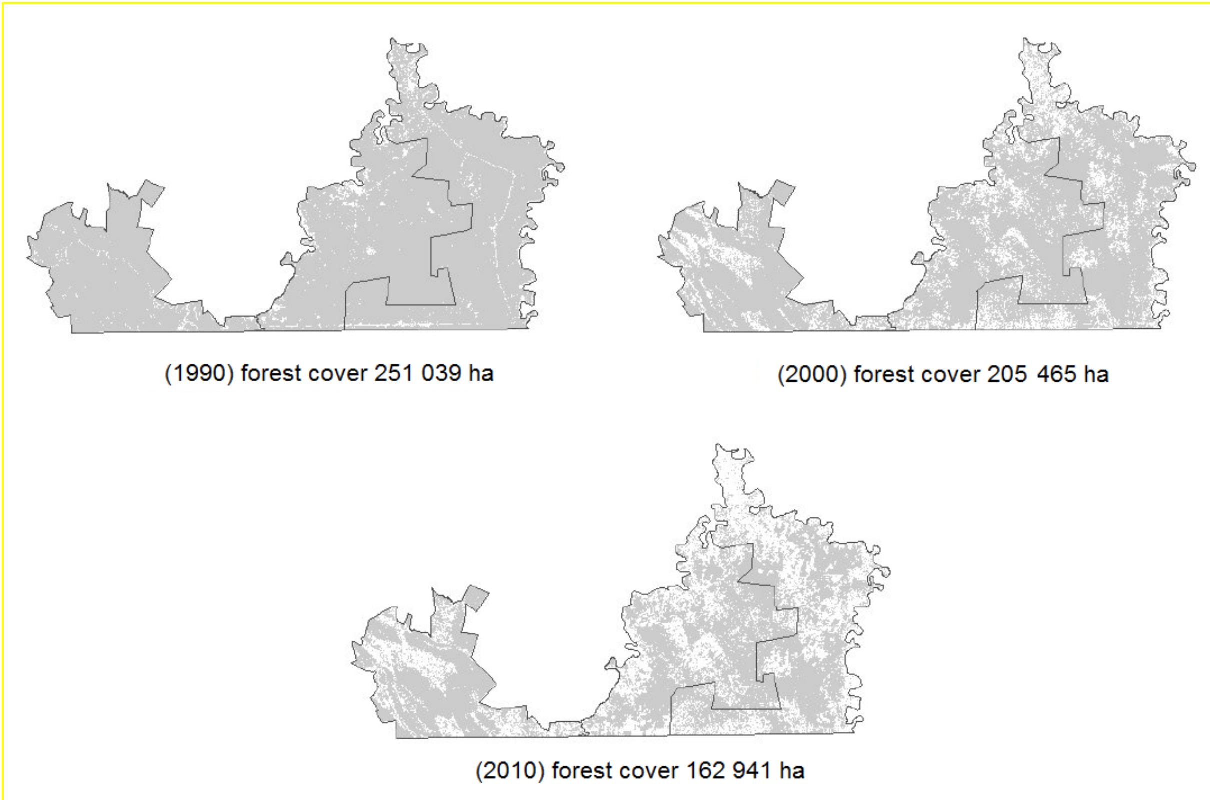

Fig. 4. Forest cover data 1990, 2000 and 2010 for the study area in Chiapas, Mexico.

The accuracy indices correspond to each individual forest cover map in 1990, 2000, and 2010, but the accuracy of the deforestation rate, still cannot be derived. The tools presented in this research will provide grounds for the measurement of *total deforestation* (because the forest definition of this study approaches the FAO definition) in this area, and more generally in the region surrounding the Biosphere Reserve.

For the sake of comparison, we identified studies specific to the region and with forest definitions similar to ours. The rate of change obtained in this study (2.13%) is quite comparable with those reported by Velazquez et al. (2002) about forests in the period 1993 to 2000 (2.06%) and almost equal to that reported for the Lacandona rainforest in the period 1984 to 1991 (2.14%), after 1978 when the Montes Azules Biosphere Reserve was officially decreeted (Mendoza and Dirzo, 1999).

Our deforestation figures are also above the national figures in the same period. According to official FAO reports for the period 1990 to 2010 in Mexico, about 298 000 hectares was lost (FAO, 2010). If we were to compare local with national figures, annual forest loss was estimated in this area at about 4,463 hectares, representing 1.5% of the national loss, in just 0.1% of the country. However, as said earlier, the deforestation definitions are not compatible, by at least two aspects: in the first place the Minimum Mapping Unit of forest is much smaller in our study than in the INEGI national cartography (source of the FAO 2010 Mexico report) and also the percentage of canopy cover is stricter in our study and would not encompass a large variety of forest covers at the national level. In any case, this study perhaps highlights the importance of spatial variability in the dynamics of forest cover throughout the country, and illustrates at what point a national average of *extensive* *deforestation* hides the magnitude of the fragmentation of forests and of spatial differences throughout the country.

In this research, the accuracy assessment method proposed for the case of local forest - non forest cartography consists in a panchromatic SPOT coverage for reference data and a sampling design defined in section 4.3 where SPOT frames are the PSUs. In the extent of the Marquéz de Comillas area, a total of 2 SPOT images per change class and 3 SPOT images for non change classes are thought to achieve a good spatial distribution of the sample. SSUs should be constructed as squared frames centered on a regular grid of the area, and the amount of SSUs should be selected so as to achieve a sampling intensity of at least 4% for all four classes.

6. Conclusion

International schemes such as REDD related to tropical forest monitoring, critically depend on the reliability of forest cover maps and tropical deforestation rates. In contrast with the poor (almost null) information on this reliability in the world, this chapter provides much evidence from previous studies and experiences that high uncertainty and imprecision still characterize the cartography, remote sensing data, and the forest definitions from which these rates are produced. For example, the FAO reports, which include per-nation tropical deforestation rates (flowchart on figure 5a), are based on national level cartography, provided by sub-tropical agencies, which understandably produce cartography that do NOT (and maybe CANNOT) correspond to the FAO definition of forest, in the first place because this definition requires very fine scale mapping (0.5 hectares Minimum Mapping Unit). Additionally, for the overwhelming majority of governmental agencies in the world, the quality of the cartography is easily confounded with the spatial resolution, or temporality of the satellite imagery used in the map production process. Confusions between thematic classes on the imagery that lead to errors on the map are simply ignored, so that the derived deforestation rates, forest extent baselines, etc. are quantities without error margins, therefore without statistical support.

A rigorous accuracy assessment scheme with appropriate forest definitions and adapted remote sensing data is thus a pending challenge in sub-tropical countries where the baseline cartography is essentially produced. This research proposes a novel deforestation assessment framework, adapted to typical materials and cartography in sub-tropical countries and suitable for REDD schemes. This framework comprises two features. The first feature consists in considering a set of three definitions of forest cover change based on the FAO definitions of forests as well as the Mexican standards on the forest cover definitions. This set of forest cover change definitions permits different levels of deforestation assessment (‘*FAO deforestation*’ which would reflect *total* deforestation and corresponds to flowchart illustrated in figure 5b, and only ‘*extensive deforestation*’) and considers the need for reporting change of a diversity of vegetation types in Mexico. Accordingly, remote sensors with low or high discrimination capacity are suited to different definitions of deforestation/degradation. The second feature, derived from recent theoretical advances made by the geo-science community, consists in a sampling design that efficiently controls the spatial distribution of samples for all classes, including non-change classes.

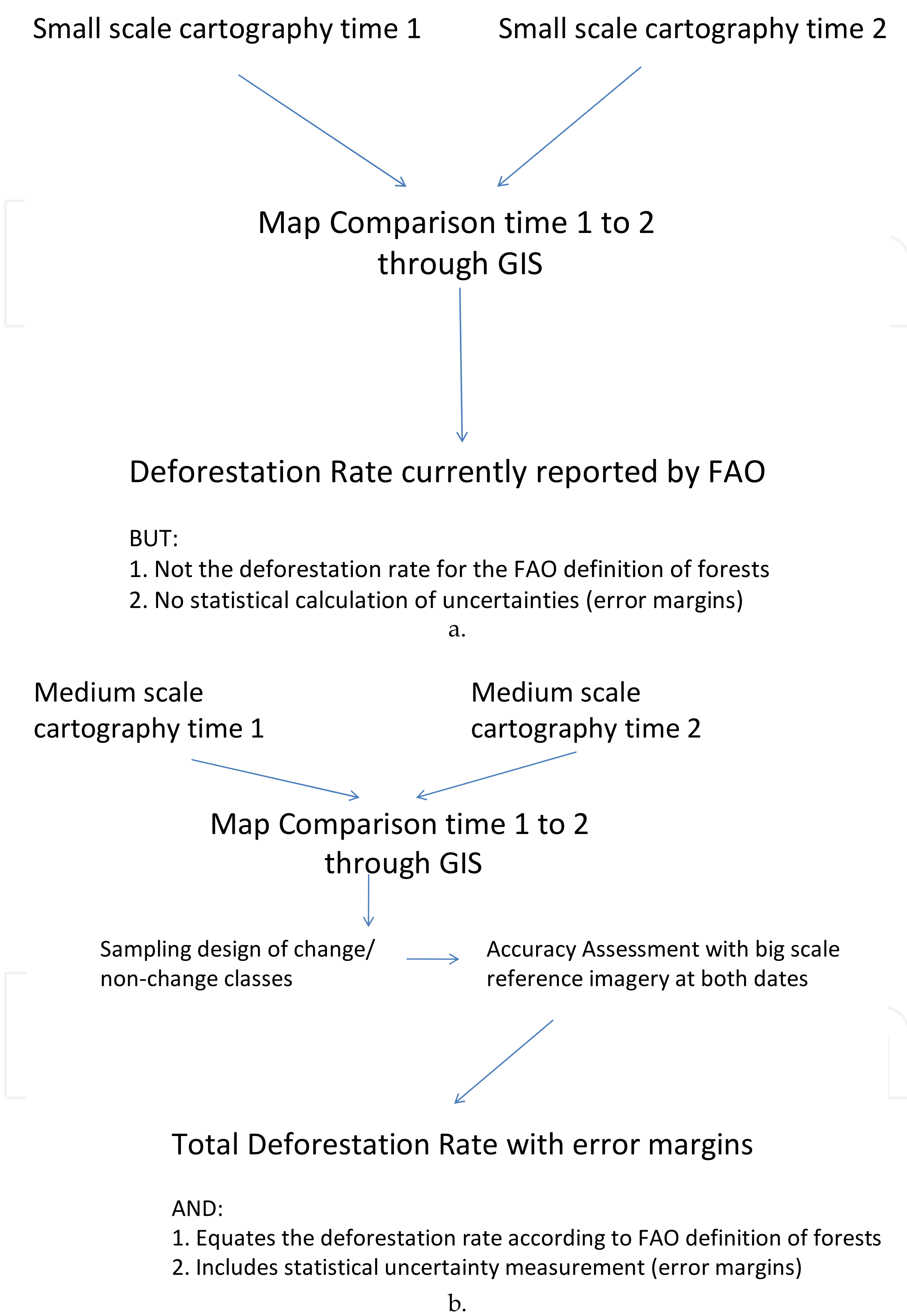

Fig. 5. Sequence of GIS for deforestation calculation: a. Traditional sequence (which leads to FAO deforestation figures currently), b: Proposed sequence (which is compatible with FAO definition of forests and includes error margins)

This chapter provides the planning for future application of this framework on two cases of ongoing deforestation measurement and analysis, at regional and landscape scales, in bio-diverse Southeast Mexico. The first case is the use of typical national level (INEGI) cartography in the Grijalva – Usumacinta basin and the second case is a more optimal use of medium resolution imagery for the measurement of the deforestation in accordance with the FAO definition of forest, in the highly dynamic edge of a National Biosphere Reserve (Montes Azules). In addition, since 2003, the monitoring of deforestation in Mexico is partly ensured using the MODIS sensor (CONAFOR, 2008), which is comparable with the SPOT-VEGETATION sensor used by Stibig et al. (2007) in Asia. We recommend the method presented here be extended to the national level for comprehensive accuracy assessment of these SEMARNAT vegetation cover annual maps. This method would ensure very reasonable costs and would contribute to solve the polemical discussions on the reliability of deforestation rates and land use change rates in the country. We conclude that the work presented here contributes to set grounds for the quantitative accuracy assessment of forest cover change cartography in the context of the REDD programme.

7. Acknowledgments

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8. Abreviations

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CLC	CORINE Land Cover Program of Europe
CONAFOR	the Mexican National Commission of Forests (Comisión Nacional Forestal)
COP	Conference Of Parties
CORINE	European 'Coordination of Information on the Environment' Program
EOSD	Earth Observation Sustainable Development Program of Canada
ESA	European Space Agency
FAO	Food and Agriculture Organization
FRA	Forest Resources Assessment
GAP	Gap Analysis Project in the USA
GFA	Global Forest Assessment of the United Nations
GIS	Geographic Information Science
HRVIR	High Resolution Visible and Infra Red
INEGI	National Institute of Statistics, Geography and Informatics in Mexico
INFyS	National Inventory of Forests and Soils in Mexico
IPCC	Intergovernmental Panel on Climate Change

JRC	Joint Research Council
Landsat GLC	Global Land Cover program of the Landsat satellite
LULC	Land-Use and Land-Cover
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration of the USA
NFI	Mexican National Forest Inventory
NLCD	National Land Cover Data of the USA
OFL	Other Forested Land
PSU	Primary Sampling Unit
REDD	Reduction of Emissions from Deforestation and Degradation
SPOT	French Satellite for Earth Observation (Systeme Pour l'Observation de la Terre')
SSU	Secondary Sampling Unit
SEMARNAT	National Environmental Agency (Secretaría del Medio Ambiente y Recursos Naturales)
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USM	United States of Mexico

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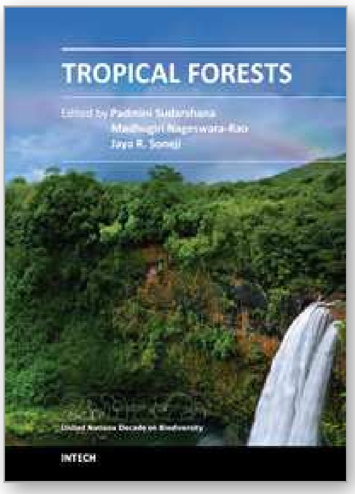

Tropical Forests

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The astounding richness and biodiversity of tropical forests is rapidly dwindling. This has severely altered the vital biogeochemical cycles of carbon, phosphorus, nitrogen etc. and has led to the change in global climate and pristine natural ecosystems. In this elegant book, we have defined "Tropical Forests" broadly, into five different themes: (1) tropical forest structure, synergy, synthesis, (2) tropical forest fragmentation, (3) impact of anthropogenic pressure, (4) Geographic Information System and remote sensing, and (5) tropical forest protection and process. The cutting-edge synthesis, detailed current reviews, several original data-rich case studies, recent experiments/experiences from leading scientists across the world are presented as unique chapters. Though, the chapters differ noticeably in the geographic focus, diverse ecosystems, time and approach, they share these five important themes and help in understanding, educating, and creating awareness on the role of "Tropical Forests" for the very survival of mankind, climate change, and the diversity of biota across the globe. This book will be of great use to the students, scientists, ecologists, population and conservation biologists, and forest managers across the globe.

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
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中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821