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Improvement of the forest cover-changes cartography from Global Forest Change for critical deforestation regions in Mexico. Case of the Lacandona Region 2014-2021.

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Abstract

Global Forest Change (GFC) is a global monitoring system with moderate resolution (Landsat, 30 m pixel) that allows knowing the location and magnitude of the losses or gains of global forest cover. Critical Forest Change (CFC) is a calibration system based on comprehensive photo interpretation (1:10,000 scale for change editing, and 1:5,000 scale for interpretation-confirmation of change strata), with diagnostic criteria supported by field data of the National Forest Inventory (scale 1:1, period 2014-2021). CFC reduces until 85.8% the overestimation of the forest loss of GFC in the case of the Lacandona Region (327,646 ha). The process included the analysis of data at 330 study sites and the interpretation of 1,190 frames of Spot-6 (April 28, 2014) versus Sentinel-2 (April 24, 2021) in higher resolution (10 m). The annual rate of forest loss obtained by GFC (4,526 $ha.yr^{-1}$) is 1.87 times higher than the LFC rate (2,415 $ha.yr^{-1}$). Through a comparative analysis between the cartography of GFC and CFC, it was possible to identify that 19.2% of the differences correspond to phenological changes (leaf fall deciduous, greenness variation, or alteration of the biomass due to eventual changes in humidity). 31.3% by Landsat spatial resolution limitations, 3.8% occurs in changes by industrial plantations, 11.6% of the differences can reduce by eliminating the GFC residuals outside the forest FAO definition (changes less than 0.5 ha), 7.4% of the differences correspond to atmospheric noise in the interpreted images, 6.8% to visual omissions and 19.9% there are no changes by interpretation. The cartographic adjustment of GFC by CFC is relatively fast (1,000 $ha.hr^{-1}$ per photointerpreter-expert). Its implementation improves the spatial coherence, periodicity, and legibility of the areas of change, strengthening the relevance of both systems in local policy decisions. Cartographic results of this work are available at http://selvalacandona.ecosur.ourecosystem.com

Keywords: Selva Lacandona; Critical Forest Change; Global Forest Change; Forest Monitoring; Deforestation.

Introduction, scope and main objectives

Global Forest Change (GFC) is a forest cover monitoring system based on Landsat sensors with 30 m resolution, annual temporality, and algorithms adjusted by massive training data worldwide (Hansen et al., 2013). This system is functional in regions where it is not technically possible to know the forest change sites in greater detail and consistency (USAID, 2019).

The map of changes due to degradation and deforestation in Mexico, from the United Nations Development Program (UNDP), obtained by visual interpretation at a scale of 1: 20,000, for the period 2007-2014, revealed significant differences regarding the magnitude and distribution of the losses of coverage between the exchange sites reported by UNDP and GFC. In general terms, there is a spatial incompatibility in 50.1% of the arboreous cover losses and 29.5% of the arbustive-arboreous cover losses between both sources of information at the national level (UNDP, 2015; Hansen et al., 2021).

In order to identify and explain with greater precision and accuracy the differences between the UNDP and GFC estimates, the calibration system *Critical Forest Change* (CFC) was developed. This system identifies and separates anthropogenic changes from natural changes and separates permanent changes from eventual phenological changes in regions with very heavy deforestation through four integrated techniques: 1) The exhaustive and profound visual interpretation of the sites of forest change (scale 1: 5,000 to 10,000). 2) Data mining from National Inventories. 3) Mapping complementary evidence on degradation, and 4) Permanent geostatistical comparison with other remote sensing sources.

This paper presents the case of the Lacandona Region, located on the border of Mexico and Guatemala, with abundant hydrocarbon and water reserves, which contributes to the climatic stability of the Petén rainforest, the largest and most biodiverse in Mesoamerica (O'Brien, 1995).

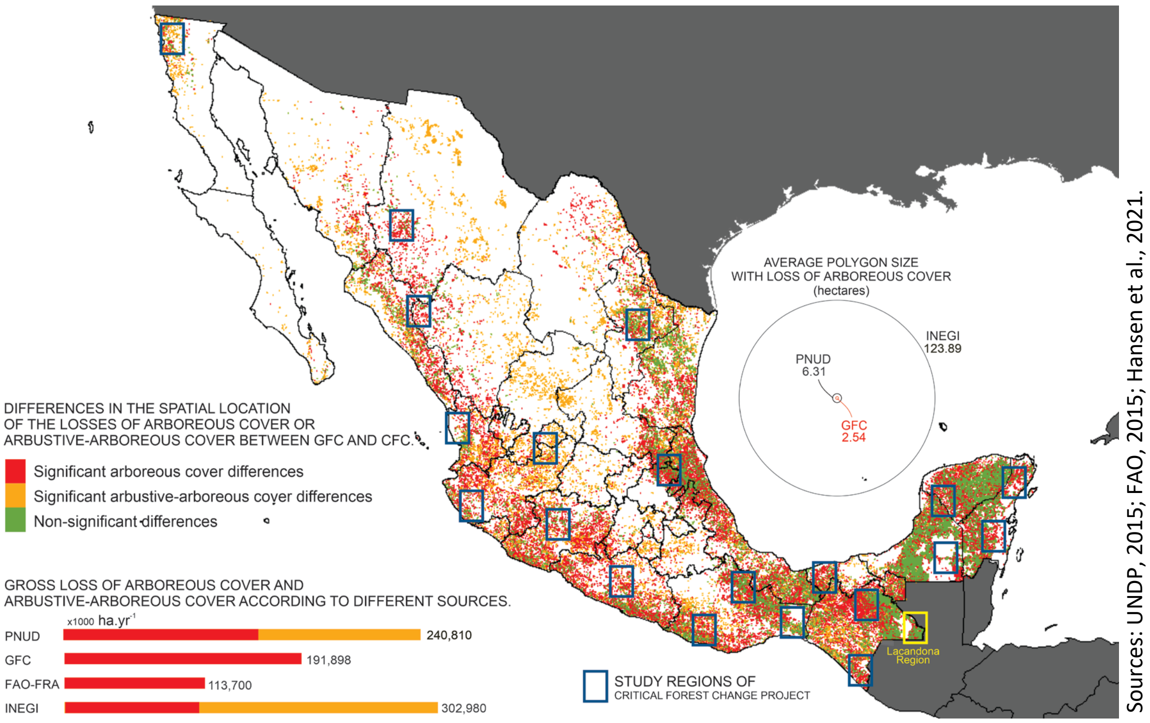

Fig. 1. Differences in the magnitude and location of the arboreous and arbustive-arboreous cover losses of the UNDP and GFC for 2007-2014 and the study regions under development by the CFC project.

Methodology/approach

1. Study area and period, data, and inputs.

The study area is in southeastern Mexico, on the border with Guatemala, between parallels 16° 4' and 16° 39' north latitude and between 90° 22 'and 91° 20' west longitude of the Greenwich meridian, and it has a total area of 327 thousand 646 hectares.

The study period (2014-2021) coincides with the new technological period of GFC that includes a sensor with more sweep permanence (Landsat 8), greater volume and quality of input data, and more adjusted algorithms to detect forest stratification.

Images of the multispectral constellation Spot-5 (April 24, 2014) with a spatial resolution of 6 m and images of the Sentinel-2 multispectral constellation were used to edit the CFC change map Copernicus (April 28, 2021) with 10 m. The field and laboratory data come from four information sources: 237 study sites of 400 m^2 that correspond to the National Inventory of Forests and Soils (CONAFOR, 2014), 30 field study sites of the National Institute of Statistics and Geography (INEGI, 2016), and 63 sites with multiple study approaches that come from surveys conducted by universities and national research centers.

2. Calibration of interpretation criteria.

Interpretation is a process where the textures, patterns, tones, shapes, and sizes of the elements contained in a satellite image can reflect different layers on the surface (Hall, 2003). For this study, eight types of strata were obtained: arboreous (A), arbustive-arboreous (a), herbaceous-arbustive (H), herbaceous (h), young plantation (g), mature plantation (G), strong eventual disturbance (e), and permanent disturbance (E), in addition to bodies of water (w) and human settlements (z). The concepts and quantitative criteria for identifying and evaluating trees and forests are equivalents between GFC and CFC.

The original stratum of the study site was determined using the Land viewer (EOS) and Geomedian Landsat (INEGI) image visualization tools, from the exact date of each survey and the validation of its field information regarding the spectral information available.

Based on the spectral validation and subsequent statistical analysis of the selected field data, eight physical and biometric indicators were obtained for each analysis stratum: number of trees, crown diameter, number of tree genera and species, the magnitude of fuels, crown cover, as well as the thickness and content of carbon in the litter, mulch layer, and mineral soil. Through a dispersion analysis, the most consistent physical or biometric indicators were obtained to calibrate the criteria of the interpreter specialist.

3. Edition-extraction of baselines and complimentary coverage.

The baseline is necessary to calibrate the tree cover area between GFC and CFC and to be able to know from the origin possible divergences in the comparison (Pereira, 2006). In the case of CFC, the arboreal and shrub-arboreal baseline (years 2000 and 2014) was edited using an edition-interpretation scale of 1: 5,000. A mosaic of 34 low-flying aerial orthophotos (2000) with 1.2 m resolution was used in this process. The GFC baseline was extracted from its platform and corresponded to the area with 10% or more tree cover (2000 and 2014). Complementary cartographic evidence was obtained to improve the evaluation: slash-grave-burn areas, industrial plantations areas, use of conventional agricultural practices, and other areas with strong disturbance.

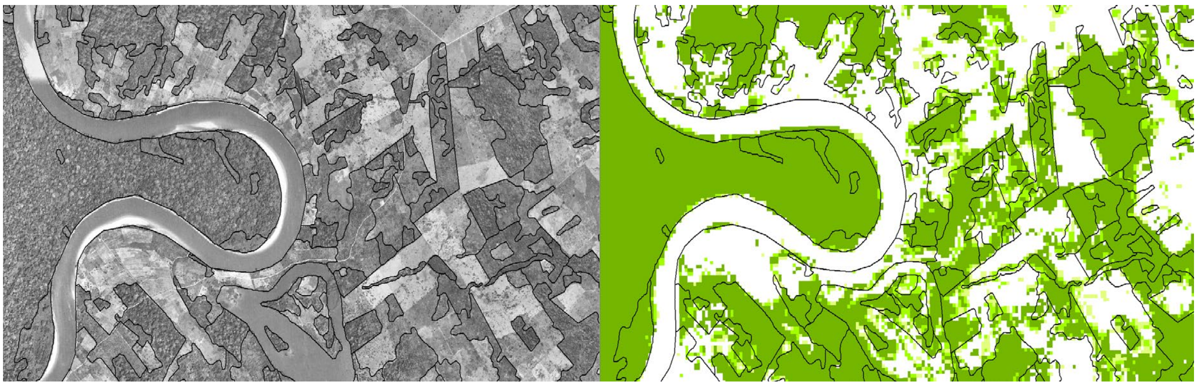

Fig. 2. Construction of the arboreous baseline for CFC (1: 5,000, left) and extraction of the arboreous baseline for GFC (30 m, right).

4. Editing-extracting the change sites for CFC and GFC.

GFC change sites were extracted directly from its electronic platform in an 8-bit raster format, without signature and at one arc-second resolution. The CFC change sites were edited by exhaustive interpretation of 1,190 frames, at an average scale of interpretation-confirmation 1: 5,000 and vectorization 1: 10,000, using ArcGIS Desktop 10.5 commands and resources.

Fig. 3. View of a section (scale 1: 10,000) during editing coverage changes (left, an image of Spot 2014; right, Sentinel 2021).

5. Analysis of the spatial differences between changes sites of GFC and CFC.

The causes of the differences between the arboreous losses of CFC and GFC were obtained through a detailed visual diagnosis in the polygons larger than 2.5 ha (1067 polygons, 63.7% of the total area with differences), and a quick visual diagnosis on the remaining polygons. (Fig. 4).

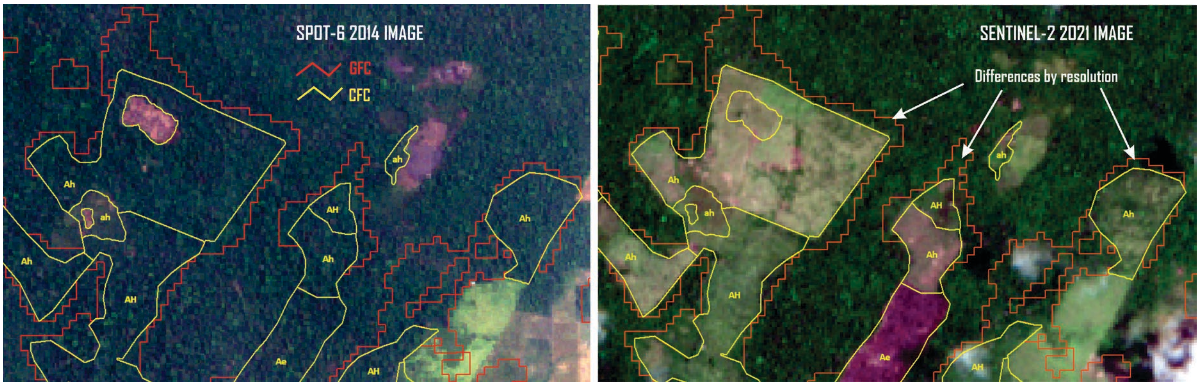

Fig. 4. Analysis of the differences between the boundaries of the GFC and CFC change sites. In this map section, differences by resolution (red lines) are the leading cause of divergence.

Results

From the information contained in the study sites with the most significant thematic congruence (n = 212), it can be stated that the degradation process of an arboreous stratum to an arbustive-arboreous stratum implies the loss of more than half of the trees and that the deforestation process (change from arboreous stratum to predominantly herbaceous stratum) means the reduction of three-quarters or more of the original trees. The most consistent indicators with the interpretation and delimitation of the change strata in the Lacandon Region were the number of trees and canopy cover (Table 1).

Regarding coverage losses, the CFC map reports 16,507 ha of arboreous or arbustive-arboreous loss (average polygon 4.4 ± 9.57 ha), while the GFC map records 31,686 ha of arboreous loss (0.98 ± 11.5 ha). 47.4% of the polygons and 41.6% of the GFC loss surface exactly match the CFC loss surface (Figure 4).

The 2014 baseline of GFC registered an arboreous area (240,211 ha) significantly higher than the arboreous and arbustive-arboreous area of CFC (200,591 ha). The spectral properties of the arbustive-arboreous stratum in the CFC baseline correspond approximately to the properties of the low and middle percentile of arboreous cover (10-50% canopy) in the GFC baseline (Table 2).

Eight leading causes can explain the spatial differences between GFC and CFC tree losses. These are the radiometric quality and the level of cleanliness of the source images (38.7% of the surface with differences), possible stratification errors of the GFC algorithm, especially of residues without a specific dispersion pattern (11.6%), and of other errors such as the detection of changes in areas that have no evidence of alteration (19.9%).

Other causes are related to visible changes, but that do not involve arboreous strata, but dominant herbaceous or arbustive strata (15.8% of the area with differences), or strata on periodically flooded areas (3.4%), and other changes derived from the productive cycle of plantations industrials such as oil palm, and rubber (3.8%). Finally, differences were detected due to omissions during the visual interpretation process (6.8%), which were later corrected from iterations with GFC (Table 3).

Cartographic results of this work are available at http://selvalacandona.ecosur.ourecosystem.com

Table 1: Physical and biometric indicators by stratum at the Critical Forest Change (CFC) study sites.

Indicators	Observations (study sites and repetitions)	Arboreous	Arbustive-arboreous	Herbaceous-arbustive	Herbaceous
		Avg ±Sdv	Avg ±Sdv	Avg ±Sdv	Avg ±Sdv
Trees/1	212	718 ±241	319 ±201	192 ±118	77 ±66
Crown diameter/1	212	3.1 ±2.5	2.45 ±0.9	2.52 ±1.2	2.66 ±0.8
Genders/3	212	18 ±5	15 ±4	5 ±2	3 ±1
Fuels/4	212	1507 ±1211	1177 ±1514	515 ±563	929 ±1446
Crown cover/5	212	92.6 ±17.2	44.25 ±36.7	25.1 ±49.9	0.91 ±1.88
Litter thickness/6	56 x 8	5.87 ±1.9	3.7 ±0.9	0.5 ±0.2	1.1 ±0.3
Mulch thickness/6	56 x 8	15.6 ±4.2	6.9 ±2.4	0.8 ±0.1	2.3 ±0.7
SOC Litter/7	56 x 8	3.2 ±1.7	2.3 ±0.9	0.9 ±0.2	0.2 ±0.1
SOC Mulch/7	56 x 8	5.4 ±1.9	3.0 ±1.3	0.9 ±0.1	0.2 ±0.1
SOC mineral soil/7	56	3.8 ±0.83	1.86 ±0.86	0.90 ±0.62	1.1 ±0.75

Symbols. "Avg" represents the arithmetic mean of the total, and "±Sdv" represents the standard deviation of the total population. Units. /1Total number of trees per hectare. /2Total average in meters of crown diameter. /3Total number of tree genera per 1600 m^2 cluster. /4Number of burning hours of woody pieces with a diameter less than 15 cm. /5Average percentage of shade per hectare. /6Milimeters thick. /7Dry weight of organic carbon (CO) per hectare. Notes: Reference weights are by drying at room temperature (not in an oven). Primary data source: National Forest and Soil Inventory (CONAFOR, 2009-2014) and National Survey of Soils, Land Use and Vegetation Program (INEGI, 2000-2018).

Table 2: Magnitude of the areas of change of GFC and CFC, according to specific change from 2014 to 2021.

Baseline 2014 (ha)	Trend 2014-2021	Type of change				
		Inicial stratum 2014	Final stratum 2021	Code	Change area (ha)	Total change area (ha)

GFC. 240,411 (Arboreous baseline)	Arboreous losses	Arboreous	No arboreous	An	31686	31686
CFC. 180,700 (Arboreous baseline) and 19,891 (Arbustive-arboreous baseline)	Deforestation	Arboreous	Herbaceous	Ah	8432	11472
			Strong disturbance	Ae	1765	
			Herbaceous-arbustive	AH	941	
			Young plantation	Ag	202	
			Mature plantation	AG	131	
			Settlements	Az	1	
		Arbustive-arboreous	Herbaceous	ah	3869	5435
			Strong disturbance	ae	370	
			Herbaceous-arbustive	aH	516	
			Young plantation	ag	305	
			Mature plantation	aG	365	
			Settlements	az	11	
	Degradation	Arboreous	Arbustive-arboreous	Aa	150	150
		Strong disturbance	Strong disturbance	ee	113	113
	Eventual loss of cover or biomass	Mature plantation	Young plantation	Gg	31	31
		Herbaceous-arbustive	Young plantation	Hg	261	1791
			Herbaceous	Hh	1440	
			Strong disturbance	He	73	
			Settlements	Hz	17	
		Herbaceous	Strong disturbance	he	321	367
			Settlements	hz	46	
	Other losses	Change in humidity with possible extraction		fF	518	538
		Flood due to change of river channel		xw	20	

Fig. 4. Spatial distribution of the changes in CFC (left) and the spatial differences of GFC regarding CFC (right).

Table 3: Analysis of the causes of spatial differentiation between the GFC and CFC change sites.

Leading cause	Description of the leading cause	The magnitude of the differences	
		Number of polygons	Surface of change (ha)
Resolution	Differences of GFC whose polygons do not intersect but can touch CFC polygons along their boundaries. The original resolution (30 m) has limitations to define the limits of the change site more precisely.	2346	6295
Atmospheric noise	Places of change in GFC could not be delimited by visual interpretation due to the effect of the clouds and shadows of the original scenes.	493	1497
Residuals	Differences of GFC constitute less than 0.5 ha with arboreous losses and do not present a specific dispersal pattern.	20563	2333
Industrial plantations	The changes in vegetation do not correspond to forest tree losses but changes in the vegetative cycle of industrial plantations with arboreal size.	392	772
Eventual loss of biomass	Differences in GFC are due to changes in the greenness of the satellite images, but they correspond to changes between relatively dense non-arboreous but herbaceous or arbustive strata.	1189	3183
Loss of moisture	There are differences in GFC in flooded areas that during dry periods present natural successions of vegetation. In some cases, there may be a subsequent extraction of arboreous or arbustive species.	20	682
No apparent changes	Differences of GFC without changes in texture, hue, or patterns between the two base images were detected. In addition, comparison tests were performed at the level of spectral bands to rule out changes in the non-visible range.	405	4005
Visual misinterpretation	During the comparison process, errors of omission of the photo-interpreter were corrected regarding arboreous losses adequately detected by the GFC algorithm.	342	1368
Total differences between GFC and CFC.		25750	20135

Discussion

Can *Critical Forest Change* improve *Global Forest Change* locally? Various studies around the world have identified possible GFC errors (Tropek, 2014). Among the causes or justifications stand out the conceptual heterogeneity, the diversity in the analysis approach, and the natural difficulty of mapping changes in environments with high biodiversity and with limited systematic information (Hansen et al., 2010; UNDP, 2015).

The results obtained in this work suggest that *Critical Forest Change* can improve the performance of the *Global Forest Change* algorithm in the conditions of the Lacandon region. Especially by corrections of phenological changes or correction of changes between strata that are not arboreal or changes in the life cycle of industrial plantations, as well as a significant improvement in the precision of the polygons of change. There is evidence that the CFC-GFC iteration also improves the visual interpretation process.

However, it should be noted that scale or resolution is not the only point of opportunity. The interpreter must gather knowledge and field experience of the specific area and the availability of sufficient, precise, and spectrally congruent quantitative data to develop an identification, analysis, and vectorization process equal to or superior to the performance of the *Global Forest Change* algorithm.

Conclusions

The interpretation at a detailed scale (1:5,000 to 1:10,000) and the treatment of data from the National Forest Inventory can significantly improve (up to 85.8%) the effectiveness of the global Global Forest Change algorithm in estimating tree losses of Lacandona Region by manually eliminating residuals and adjusting for possible stratification or confusion errors.

In addition, it is advisable to implement the analysis of changes by CFC in other critical regions with different environmental and cultural circumstances (Figure 1) and calibrate these studies with higher resolution images. This path as a whole can improve the spatial coherence, precision, accuracy, and readability of the critical areas of change detected by Global Forest Change and position the information generated by both systems in public policy, productivity, and sustainability decisions at the community or municipal level on Mexico.

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