VALIDATION OF THE MODIS-DERIVED PHENOLOGICAL CLASSES IN A MEGA-DIVERSE ZONE: THE RELEVANCE OF AN ACCURACY INDEX WITH POSSIBILITY MARGINS

Stéphane Couturier[1,2]

[1]Laboratorio de Análisis Geo-Espacial (LAGE), Instituto de Geografía, Universidad Nacional Autónoma de México (UNAM), Ciudad Universitaria, Circuito Exterior s/n, Coyoacán 04510, México DF, México.
[2]Centro de Investigación en Geografía Ambiental (CIGA), Universidad Nacional Autónoma de México (UNAM), Antigua Carretera a Pátzcuaro No. 8701, Col. Ex-Hacienda de San José de la Huerta, CP 58190, Morelia, Michoacán, México,

Corresponding Author's E-mail: andres@igg.unam.mx

Abstract— In this paper, the CONAFOR national systematic sampling (INFyS) and the presented methodology offered a spatially exhaustive, quantitative assessment of MODIS-derived cartography for an area which approximates the million km^2. In terms of the phenological diversity of the forest and vegetation covers included in the study, this exercise is the most extended, spatially exhaustive verification of phenology classes so far for global cartography.

1 INTRODUCTION

Global land cover products derived from remote sensing imagery are used in the monitoring of the environment at regional, continental, and global scales. The global land cover map MOD12Q1 is derived from a supervised classification of the MODIS bands (Friedl *et al*.: 2002). The land cover team of the MODIS sensor realized a cross-validation exercise of MOD12Q1 based on the set of training/ verification sites STEP (System for Terrestrial Ecosystem Parametrization) of the MODIS classifier, and found a global accuracy of 71.6% (MODIS: 2003). Since then, a series of validation exercises were done throughout the world by regional scientific teams, many of which are based on Landsat imagery and auxiliary information (e.g. Cohen *et al*.: 2003, Waser and Schwarz: 2006, Kalacska *et al*.: 2008, etc.). However, the sites of many validation studies are spatially relatively homogeneous in terms of thematic content (for example, a STEP site is homogeneous by design). As a consequence, the accuracy of a global product such as

MOD12Q1 estimated on these sites is likely optimistically biased with respect to the real global accuracy of the product (Jung et al.: 2006, Mayaux *et al*.: 2006).

The present study evaluates MOD12Q1 in a portion of approximately one million km^2 within the United States of Mexico, consisting of all land with vegetation cover not used for intensive agriculture. The inputs for MOD12Q1 validation include the geo-referenced database of the National Inventory of Forests and Soils (INFyS) in Mexico, based on an extensive, cyclic campaign of ground visits (CONAFOR: 2008), and the 2003 land cover and land use cartography (Serie III cartography) of the National Institute for Statistics, Geography and Informatics (INEGI) in Mexico. The latter cartography was derived from the interpretation of Landsat imagery (INEGI: 2007). In order to handle the difficulty of reference site heterogeneity, a validation method is proposed for global scale products, and comprises the construction of nested scenarii where reference sites, characterized by a combination of detailed ground information (here INFyS from CONAFOR) and medium resolution vegetation cover map (here, the INEGI Serie III cartography), are successively compared with the MODIS product.

A main focus of this thematic assessment is associated with the characteristics of the forested land cover, such as the leaf type (broad or needle leaf), and the canopy phenology (deciduous or evergreen). These characteristics are considered as crucial for the parameterization of vegetation models (Jung *et al.*: 2006). In section 2, the validation method and the reference database are described. In section 3, the global and per class results of the assessment are analysed and compared with other validation exercises of MOD12Q1. Section 4 makes a synthesis of the results, exhibits the merits of the accuracy assessment with possibility margins, and makes recommendations with respect to the current cartography in Mexico.

2. DATA AND ACCURACY ASSESSMENT ALGORITHM

2.1 Preparation of INFyS, INEGI Serie III and MOD12Q1 data

The INFyS is based on a systematic nationwide sampling frame (CONAFOR: 2008), with sampling sites laying on the portion of Mexico which is covered with vegetation and where no intensive agricultural land use occurs (according to INEGI Serie III cartography), an area of approximately 1 million km^2 (see CONAFOR: 2008). Each site consists of a set of four plots placed at the nodes of a Y pattern, circumscribed in a circle of approx. 112m diameter. Ground visits to each site are set with a periodicity of 5 years. This study uses information of the first period of the inventory, which was completed between 2004 and 2007 (the total number of visited sites was 24,659 all throughout the country, see INEGI: 2007). The INEGI serie III cartography was based on the visual interpretation, at scale 1:125 000, of Landsat images of year 2003, with the thematic support of previous cartography of INEGI (Serie I and II). The information on dominant vegetation cover in the INFyS sampling sites was obtained from CONAFOR and the Serie

III cartography was obtained from INEGI.

The MOD12Q1 cover for Mexico was available only for years 2003 and 2004, was acquired from the MODIS website (MODIS: 2001), and was resampled to the Lambert Conic projection of the INEGI cartography. The MOD12Q1 map of year 2004 was selected for its overall better temporal correspondence with the reference data; indeed, this map contains information of a yearly period intermediate between the Serie III cartography (2003) and ground visits of the INFyS (2004-2007).

2.2 Legend matching

MOD12Q1 is delivered with five legends (containing between 9 and 17 classes), corresponding to vegetation cover classification systems widely used in the international scientific community. Two legends (legend type 1, with 17 classes and legend type 5, with 12 classes) derived from the IGBP ('International Geosphere- Biosphere Programme') scheme, contain detailed characteristics (leaf type and phenology of the canopy) of forests, and include the shrubland class, an abundant land cover class in Mexico. The more aggregated legend was selected (type 5, with 12 classes, see table 1, first and second columns) since this legend offered higher compatibility with the INEGI legend and lower inclusion of mixed classes. Indeed, the Type 1 legend (with 17 classes) contains classes such as 'closed shrubland' and 'open shrubland', 'savannah' and 'woody savannah', not included in the INEGI classification scheme, and a poorly defined class of mixed forest which introduces uncertainty in the process of comparing with other cartography (Jung *et al*.: 2006).

TABLE 1: MOD12Q1 LEGEND TYPE 5 AND CONVERSION OF ATTRIBUTES OF INFYS TO THE IGBP TYPE 5 LEGEND:

Classes of the MODIS land cover map (MOD12Q1, Type 5 Legend)	Code	Class of the reference site	Conversion Primary label	Conversion Secondary label
Evergreen needleleaf forest	1	Conifer forest	1	-
Evergreen broadleaf forest	2	Pine-oak forest	1	4
Deciduous needleleaf forest	3	Oak-pine forest	4	1
Deciduous broadleaf forest	4	Oak forest	4	-
Shrub-like vegetation	5	Cloud forest	2	-
Grassland	6	Evergreen tropical forest	2	-
Annual crop	7	25-50% deciduous tropical forest	2	4
Evergreen crop	8	50-75% deciduous tropical forest	4	2
Human settlement	9	Deciduous tropical forest	4	-
Area covered with snow or ice	10	Shrubland	5	-
Bare soil or scarce vegetation	11	Mezquital and Huizachal	5	-
Water	0	Secondary vegetation	5	1-4 (according to forest type)
No data	255	Wetland	2	6
		Halophilous vegetation	5	6

The attribute conversion is as close as possible to the vision of the IGBP global classification scheme, based on the physiognomic dominance of the canopy (tree-like, shrub-like or herbaceous). For example, the INEGI 'secondary vegetation' class was converted to 'shrub-like vegetation' class as the primary label because according to the INEGI Serie III cartography, secondary vegetation is mainly shrub-like.

2.3 Verification design

Of the 24,659 INFyS reference sites, 140 per class (listed in table 1) were randomly selected for the accuracy assessment of the MOD12Q1 product. Figure 2 illustrates the distribution of the selected reference sites over the vegetation cover in Mexico.

The validation of global cartographic products is affected by biases whose treatment is the object of a vast research in the scientific community. The fuzzy characterization of reference landscapes is a popular approach to face this challenge (e.g. Jung *et al*.: 2006). In particular, most of the validation studies tend to avoid verification in areas of heterogeneous vegetation cover (e.g. Cohen et al.: 2003; Mayaux *et al*.: 2006), and yet the inclusion of these areas is essential to a statistically exhaustive (hence valid) accuracy assessment design (Stehman and Czaplewski: 1998; Herold *et al*.: 2008). In order to handle the difficulties associated with the verification of MODIS over heterogeneous vegetation cover, an algorithm adapted to the specificity of the global product and to typical multi-scale verification materials was built. This strategy consists in the elaboration of accuracy indices with possibility margins, i.e. indices with margins representing the possibility space of the real accuracy value of the map. These margins are obtained through different levels of temporal, thematic and positional tolerance (see Couturier et al., in press). In other words, the method makes a separation among various possible error types: real classification errors are separated from biases (fictitious errors) possibly due to the resolution of the MODIS product, from biases possibly due to the thematic fragmentation of the landscape and from biases possibly due to the temporal uncertainty associated with the landscape. The algorithm consists in four procedures (A, B, C, and D), illustrated in figure 1.

Prior to phase A, the simplified legend of the INFyS is converted to the MOD12Q1 Type 5 legend. For each INFyS site, a primary label and, in some cases (see table 1) a secondary label are assigned. Then, during phase A, a thematic coherence test between the verification datasets (see figure 1) was automatically launched on all verification sites, which divided the data in three cases:

In case INFyS agrees with Serie III (88.1% of the total area), MOD12Q1 label will be compared with INFyS label on phase B.

In case INFyS disagrees with Serie III but the disagreement may correspond to a possible vegetation cover change between 2003 and 2004-2007 (7.5% of the total area), MOD12Q1 label will be compared with INFyS label on phase B.

In case INFyS disagrees with Serie III and the disagreement does not correspond to a possible vegetation cover change (4.4% of the total area, e.g. INFyS = ‘oak forest’ and Serie III = ‘pine forest’), the reference site is considered unreliable, removed from the sample, and another reference site is sorted instead.

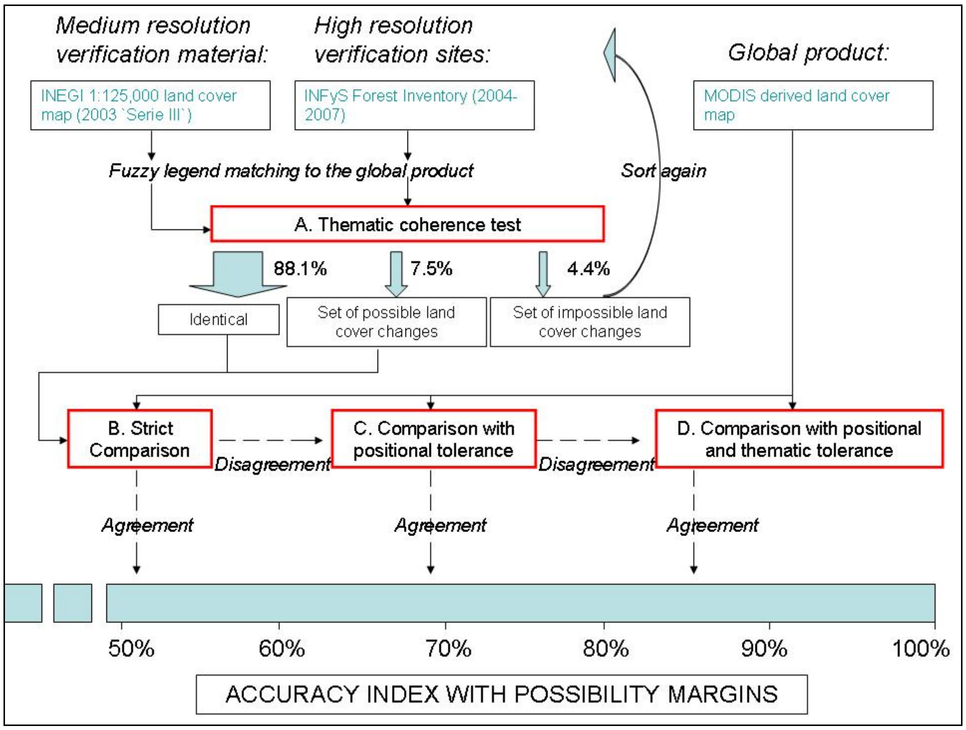


Figure 1: Global product validation algorithm.

Phases B to D are the verification algorithm by itself, which consist in the comparison of the reference sites with the map according to three nested scenarii: a first scenario (phase B) where a ‘strict’ verification (also known as ‘crisp’ or Boolean verification in the literature) is applied to the map, then a second scenario (phase C) where the agreement definition includes a 1km positional tolerance (algorithm introduced by Couturier et al.: in press), and finally a third scenario (phase D) which includes thematic and temporal tolerance (using an approach known as the thematic fuzzy approach in the literature, e.g. Laba *et al*.: 2002). If the site is considered as an error of the map for a given scenario, this same site is submitted to the next phase, or is considered as a strict error of the map if the scenario is phase D.

Phase B considers the strict comparison between the primary MOD12Q1 and INFyS labels. In phase C, the following Boolean test is made in a SIG: ‘Is there a Serie III polygon at a short distance of the reference site (less than 1km), where MOD12Q1 = Serie III’. In the positive case, phase C yields a match. In the negative case, phase C yields a miss and the site is submitted to phase D. Finally in phase D, the MOD12Q1 label is compared to the Serie III label and to the INFyS secondary label. If phase D yields a miss, the site is considered an error of the MOD12Q1 map in the strict sense of the word.

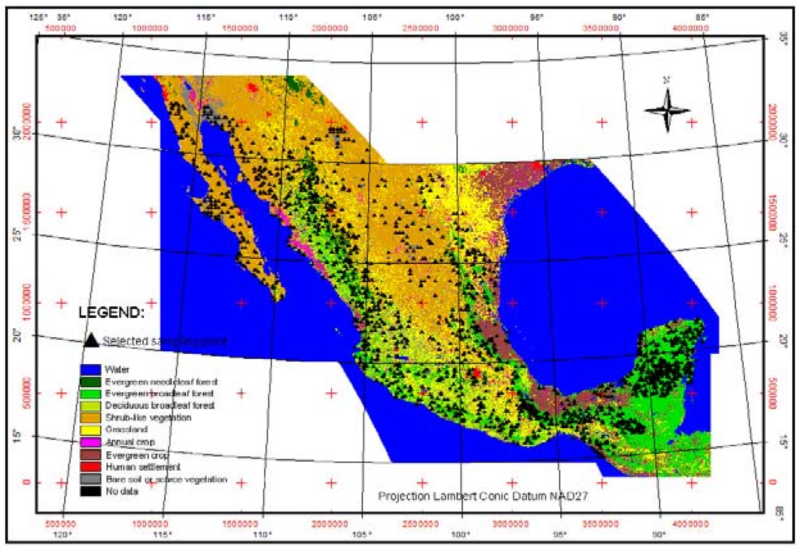
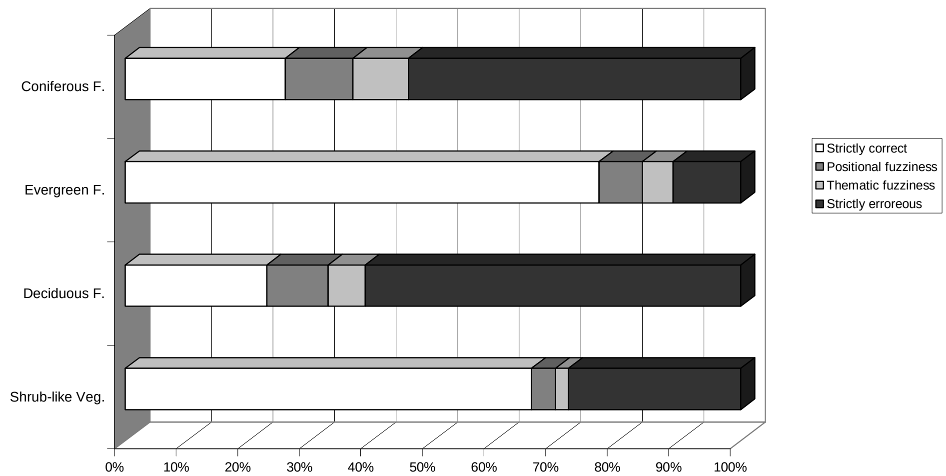


Figure 2: MOD12Q1 coverage over Mexico and selected sampling sites for validation.

3. RESULTS AND DISCUSSION

3.1 Global accuracy and confusion patterns

Based on the confusion matrices resulting from the each phase B, C and D, three accuracy indices were calculated per class. Since only total areas of reference data (not mapped data) was known, only the producer's accuracy was obtained, and represented with a column graph (figure 3). The confusion matrix derived from phase D is represented in table 2, using conventions of Stehman *et al*. (2003). This representation in area fractions allows a coherent analysis of confusion patterns between classes. Table 2 reflects the most 'optimistic' evaluation of this study, where the primary MODIS labels were verified against both INFyS and Serie III labels, with a certain positional tolerance. Global accuracy in the observed area is 65.0%. Note the very good accuracy of the map (88.9%) on evergreen broadleaf forest cover, as well as the poor accuracy of the map on conifer forest covers (46.0%), and on broadleaf deciduous forest cover (39.2%).



<u>Coniferous F.</u>: Forests dominated by conifers; <u>Evergreen F.</u>: Broadleaf forests dominated by perennial trees (e.g. perennial and sub-perennial tropical forests); <u>Deciduous F.</u>: Forests dominated by deciduous broadleaf trees (e.g. forests dominated by deciduous trees and deciduous / sub-deciduous tropical forests). <u>Shrub-like Veg.</u>: Shrub-like vegetation; includes landscapes dominated by secondary vegetation. The accuracy index with possibility margins offers more flexibility for comparisons with indices of other maps than an index calculated on the base of only one tolerance level.

Figure 3: Fuzzy producer's accuracy index for the MODIS classification of the vegetation cover, per phenology class.

<u>TABLE 2</u>: CONFUSION MATRIX FOR THE ASSESSMENT OF THE MODIS VEGETATION COVER, WITH AN AGREEMENT DEFINITION WHICH INCLUDES A POSITIONAL TOLERANCE OF 1000M, AND THE COMPARISON BETWEEN THE MOD12Q1 LABEL AND BOTH OF INFYS AND INEGI SERIE III LABELS WITH THEMATIC AND TEMPORAL TOLERANCE.

MODIS: Sitios INFyS:	1	2	4	5	6	7	8	9	11	0	n[a]	Frac.[b]	Prod[c]	StdErr[d]
Conifer F.	0.0319	0.0147	0.0048	0.0095	0.0075	0.0000	0.0009	0.0000	0.0000	0.0000	248	6.94	46.0	3.2
Evergreen F.	0.0023	0.0675	0.0012	0.0014	0.0001	0.0005	0.0026	0.0000	0.0001	0.0001	603	7.59	88.9	1.3
Deciduous F	0.0037	0.0557	0.0871	0.0199	0.0392	0.0009	0.0023	0.0039	0.0093	0.0000	521	22.19	39.2	2.1
Shrub-like V.	0.0056	0.0113	0.0058	0.4360	0.1119	0.0003	0.0106	0.0030	0.0188	0.0000	481	60.34	72.3	2.0
n[a]	148	745	244	438	269	8	64	8	37	2	1963			
Frac.[b]	4.36	14.93	9.89	46.75	18.62	0.17	1.67	0.69	2.92	0.01		100		
User's[c]	73	45	88	93	NA	NA	NA	NA	NA	NA			65.0	1.1
StdErr[d]	4.0	2.0	2.0	1.0	NA	NA	NA	NA	NA	NA				

Global accuracy was estimated at 65.0 +- 1.1%. The row entry numbers refer to the IGBP-MODIS class codes described in table 1.

Conifer F.: Forests dominated by conifer trees. Evergreen F.: Broadleaf forests dominated by evergreen trees ('perennial' and 'sub-perennial' tropical forests). Deciduous F.: Forests dominated by broadleaf deciduous trees

(ex.: oak forests and tropical dry, deciduous and sub-deciduous forests). Shrub-like V.: Landscapes dominated by shrub-like vegetation.
[a] n: sample size. [b] Frac.: Percent fraction per class to the total area. These fractions iqual the sum of column or row of the matrix, multiplied by 100. [c] *User's* and *Prod* refer to, respectively, the user's and producer's accuracy percentage. [d] StdErr: Standard Error with the binomial estimator.

On a site in the Northeastern United States of America (USA) where broadleaf evergreen forests prevail, Friedl *et al*. (2002) proceeded to a validation exercise of the MODIS classifier and obtain a high global accuracy level (75%), which our study would be in accordance with. However Cohen et al. (2003) claim a good performance of the classifier in the Northeast of the USA, on two sites of 50 km2, where broadleaf deciduous forests and conifer forests prevail, respectively, a result which contrast with the poor performance in our study area. On the contrary, our analysis corroborates the tendency of the results of Kalacska *et al*. (2008) over the total Costa Rican land, and with the tendency observed in the cross-validation exercise of the MODIS Land Cover team (MODIS: 2003). Both studies establish producer's accuracy levels of, respectively, 88% and 90.3% in temperate and tropical forests where evergreen trees prevail, and producer's accuracy levels of, respectively, 35% and 34.0% for predominantly deciduous temperate and tropical forests.

The analysis of the confusions of classes 1 and 4 in the matrix reveals that the MOD12Q1 product strongly tends to classify all treed land covers in Mexico as broadleaf evergreen forest (class 2). Indeed, the accuracy of class 2 for the user of the MODIS map ('user's' row) is 45%, the lowest of the four classes considered in the assessment. Kalacska *et al*. (2008) also found that the deciduous tropical forest of the Chamela site in Mexico tends to be classified as broadleaf evergreen forest (contribution of 43% to the total error). On the contrary, the deciduous tropical forest in the Costa Rican Santa Rosa site tends to be classified as agricultural land use (64.8% of the total error).

The confusion matrix also reveals that the majority of confusions occurs between one forest type and another, and the accuracy of the 'forest' class derived from table 2 is 73.0% in the entire Mexican territory. This means that the MOD12Q1 algorithm detects forested land with reasonable accuracy, comparable to the forest – non forest detection capability (72% accuracy) of the GLC 2000 product reported in South and South-East Asia (Stibig *et al*.: 2007), a performance which is worth stating in likewise mega-diverse Mexico.

3.2 Possibility margins of the accuracy index

The margins of figure 3 mark the limits of the space within which the real value of the accuracy index is very likely included (Couturier et al.: in press). It is interesting to note that the value of the accuracy indices for the dominant classes in Costa Rica, obtained by Kalacska *et al*. (2008), are included in this possibility space, and is close to the superior limit of the margin: the accuracy of class 2 (88%) and class 4 (35%) in Costa Rica are located on the 'upper' part of the possibility margin of classes 2 and 4 in this study on the Mexican territory (respectively 77-89% and 23-39%, see figure 2). The assignment of possibility (or 'fuzzy') margins to the accuracy index could appear as a caveat in the precision at which the estimate is done with respect to a unique index. However, in fact, to mark these limits means to inform the user about a real limitation of the reference assessment data/ methodology; this limitation, inherent to heterogeneity and associated reference data quality, is widely admitted in the remote sensing community (e.g. Powell *et al.*: 2004), and yet is usually ignored or not disclosed to the user in studies on global cartography.

4. CONCLUSION

In this work, the CONAFOR national systematic sampling (INFyS) and the presented methodology offered a spatially exhaustive, quantitative assessment of MODIS-derived cartography for an area which approximates the million km^2. In terms of the phenological diversity of the forest and vegetation covers included in the study, this exercise is the most extended, spatially exhaustive verification of phenology classes so far for global cartography.

From the results of the study one can emphasize that the quality and biases of the MOD12Q1 product (global accuracy index with possibility margins between 54.6% and 65.0%) confirm the tendencies reported in other validation exercises in Costa Rica (CR) and in the global cross-validation (GCV) effort of MOD12Q1 (accuracy of 61.3% in the Northern hemisphere of America), and mark trends associated with phenological classes where other validation efforts are possibly affected by a poor representation.

The producer's accuracy value of broadleaf evergreen forests is 88.9% (CR: 88% and VCG: 90.3%), but from the user's perspective, a pixel labeled broadleaf evergreen forest has less than 45% probability to be broadleaf evergreen forest in reality. For the other forest categories of the IGBP classification system, the accuracy is generally much lower: Conifer forests (46.0% accuracy), and broadleaf deciduous forests (39.2% accuracy versus CR: 35% and VCG: 34.0%). The confusions that contribute to the largest extensions of erroneously mapped forests are in the tropical dry forest and oak forest zones, where the MODIS classifier reports the presence of broadleaf evergreen forest and grassland, respectively.

The MOD12Q1 product strongly tends to classify any treed land cover in Mexico as broadleaf evergreen forest (class 2). It is difficult to ascertain the reason for the errors of the classifier beyond the hypothesis of a pronounced heterogeneity of forested landscapes in Mexico. Indeed, the inclusion of the secondary label of MOD12Q1 (designed to attend heterogeneous pixels) in the validation process enhanced the global accuracy index to 74.7%.

Given the systematic nature of the classifier's bias towards the broadleaf evergreen forest class, a suggestion for the eventual improvement of the classifier could be either to add regional-specific auxiliary information in the decision tree, or to consider expand the training set of the neural network with additional deciduous and conifer forest sites in

Mexico. Alternatively, the accuracy results could exhibit a discrimination limit of the MODIS sensor in sub-tropical heterogeneous forested landscapes. A challenge for the improvement of MODIS-derived future cartography is associated with the knowledge of the leaf type (needleleaf versus broadleaf) and the phenology (evergreen versus deciduous) of the vegetation cover, essential to the derivation of key biophysical variables of the forest (e.g. biomass, Leaf Area Index), of regional biogeochemical budgets (e.g. carbon emission or sequestration) and in ecosystem degradation studies.

This work also serves as a methodological proposal for the assessment of the up-to-date SEMARNAT cartography and the derived official deforestation indices in Mexico, which still lack error margins. The detection of the aggregated class 'forest' is achieved with 73% accuracy by the MODIS classifier, a finding which is relevant to non forest to forest change detection (vegetation regeneration). However, this study cannot document the capability of MODIS for the detection of deforested zones because the majority of the non-treed land cover (including agricultural land-use) is not sampled by the highly reliable INFyS.

Since 2003 the vegetation cover monitoring in Mexico, operated by SEMARNAT, is based on MODIS satellite images, comparable in resolution and discrimination capabilities to the SPOT-VEGETATION sensor, used by Stibig *et al*. (2007) in Asia. In order to document the quality of the official Mexican cartographic products, SEMARNAT could therefore consider sensors such as SPOT or ASTER (similar resolution as the Landsat sensor used in Stibig *et al*. 2007), for the validation of its MODIS-derived maps. The accuracy assessment method described here could be employed for this important purpose.

ACKNOWLEGMENTS

This work was initiated in the context of the project 'Evaluación del sensor MODIS para el monitoreo anual de la vegetación forestal de México' sponsored by the Sectorial Funds CONACYT – CONAFOR (project number 14741), and terminated during the CONACYT sponsored postdoctoral position of the first author. We thank the CONAFOR working team who provided us with the partial database of the Inventario Nacional Forestal y de Suelos (INFyS), and the INEGI working team who provided us with the Serie III Cartography. We are thankful to all the MODIS team in NASA for fluidly and freely distributing the MODIS data.

REFERENCES

1. Cohen, W.B., T.K. Maiersperger, Z. Yang, S.T. Gower, D.P. Turner, W.D. Ritts, M. Berterretche y S.W. Running, 2003. Comparisons of land cover and LAI estimates derived from ETM+ and MODIS for four sites in North America: a quality assessment of 2000/2001 provisional MODIS products, *Remote Sensing of Environment* 88: 233-255.
2. CONAFOR, 2008. Especificaciones técnicas para el monitoreo de la cobertura de la vegetación basado en imágenes de satélite MODIS:, URL: http://148.223.105.188:2222/ snif_portal/, accessed on June 2008.

3. Couturier, S., J.-F. Mas, G. Cuevas, J. Benítez, A. Vega and V. Tapia, 2009. Quantifying the thematic and positional accuracy of land cover maps in complex forested environments, *Photogrammetric Engineering and Remote Sensing*, in press.
4. Friedl, M.A., D.K. McIver, J.C.F. Hodges, X.Y. Zhang., D. Muchoney, A.H. Strahler, et al., 2002. Global land cover mapping from MODIS: Algorithms and early results, *Remote Sensing of Environment* 83: 287-302.
5. Herold, M., P. Mayaux, C.E. Woodcock, A. Baccini and C. Schmullius, 2008. Challenges in global land cover mapping: an assessment of agreement and accuracy in existing 1km datasets, *Remote Sensing of Environment* 112: 2538-2556.
6. INEGI, Informe 2007 Inventario Nacional Forestal y de Suelos, www.inegi.gob.mx/ rne/docs/Presentaciones/Mesa3/20/RodolfoOrozco.ppt, accessed on June 2008.
7. Jung, M., K. Henkel, M. Herold y G. Churkina, 2006. Exploiting synergies of global land cover products for carbon cycle modeling, *Remote Sensing of Environment* 101: 534-553.
8. Kalacska, M., G.A. Sanchez-Azofeifa, B. Rivard, J.C. Calvo-Alvarado y M. Quesada, 2008. Baseline assessment for environmental services payments from satellite imagery: A case study from Costa Rica and Mexico, *Journal of Environmental Management* 88 (2): 348-359.
9. Mayaux, P., H. Eva, J. Gallego, A. Strahler, M. Herold, S. Agrawal, S. Naumov, E. E. De Miranda, C. Di Bella, C. Ordoyne, Y. Kopin y P.S. Roy, 2006. Validation of the Global Land Cover 2000 map, *IEEE Transaction on Geoscience and Remote Sensing*, 44 (7): 1728-1739.
10. MODIS, 2001. USGS Distributed Active Archive Center: http://lpdaac.usgs.gov/ order.asp. accessed on April 2008.
11. MODIS, 2003. Validation of the consistent year 2003 V003 MODIS land cover product. MODIS land cover team: http://geography.bu.edu/landcover/userguidelc /consistent.htm
12. Powell, R.L., Matzke N., de Souza C., Clark M., Numata I., Hess L.L., and D.A. Roberts, 2004. Sources of error in accuracy assessment of thematic land-cover maps in the Brazilian Amazon, *Remote Sensing of Environment* 90, 221-234.
13. Stehman, S. V. and R. L. Czaplewski, 1998. Design and analysis for thematic map accuracy assessment: fundamental principles. *Remote Sensing of Environment* 64: 331-344.
14. Stehman, S. V., J. D. Wickham, J. H. Smith y L. Yang, 2003. Thematic accuracy of the 1992 National Land-Cover Data for the eastern United-States: Statistical methodology and regional results. *Remote Sensing of Environment* 86: 500-516.
15. Stibig, H. J., A. S. Belward, P. S. Roy, U. Rosalina-Wasrin et al., 2007. A land-cover map for South and Southeast Asia derived from SPOT- VEGETATION data. *Journal of Biogeography* 34: 625-637.
16. Waser, L.T., and M. Schwarz, 2006. Comparison of large-area land cover products with national forest inventories and CORINE land cover in the European Alps. *International Journal of Applied Earth Observation and Geoinformation* 8: 196-207.