

Inter-calibration of deforestation estimates in the trinational Madre de Dios, Peru – Acre, Brazil – Pando, Bolivia (MAP)

Andrea Chavez Michaelson^{1,2}

Irving Foster Brown^{3, 4}

Hugo Fuentes⁵

Edith Pipa⁶

Joentina Nakamura⁷

Lucio Zancanela do Carmo⁷

1. University of Florida, Gainesville, FL, United States.
2. Universidad Nacional Amazónica de Madre de Dios, Puerto Maldonado, Madre de Dios, Perú.
3. Woods Hole Research Center, Woods Hole, MA, United States.
4. Universidade Federal do Acre, Rio Branco, Acre, Brazil.
5. Herencia, Cobija, Pando, Bolivia.
6. Gobierno Regional de Madre de Dios, Puerto Maldonado, Madre de Dios, Perú.
7. Unidade Central de Geoprocessamento, Governo do Estado do Acre, Rio Branco, Acre, Brazil.

Abstract. Estimating the accuracies of deforested areas and of deforestation rates has become a key factor for quantifying environmental services of tropical rain forests, particularly those linked to the reduction of greenhouse gas emissions from deforestation and forest degradation (REDD). In the trinational Madre de Dios, Peru – Acre, Brazil – Pando, Bolivia (MAP) region in southwestern Amazonia, representatives from regional governments, NGOs, and universities have started an initiative to determine the accuracy of their deforestation estimates. As a first step for accuracy assessment, inter-calibration exercises using areal estimates of large, well-defined pastures (>500 ha) have been used to derive the lower bound for relative uncertainty in estimates, considering that the perimeter/area ratio is the low for such pastures. A historical trajectory from 1986 to 2007 was reported and Landsat 5, IRS P6-LISS3 and CBERS 2B HRC imagery for 2008 to 2010 were analyzed using softwares SPRING 5.0, ERDAS Imagine 8.2 and ENVI 4.6. Six estimates of the ~600 ha pasture (10ded 59min S 69deg 38min W), 8 km west of the trinational boundary point, averaged 627 ha with a coefficient of variation of 4.8%. The difference between maximum and minimum estimates divided by the average was 11%, suggesting a minimum relative uncertainty on the order of 10%, and probably more for smaller areas. Deforestation rates should have considerably more relative uncertainty, a factor that needs to be considered for estimating greenhouse gas emissions from deforestation in the MAP Region.

Key words: land-cover changes, remote sensing, Madre de Dios, Acre, Pando Amazon.

1. Introduction

Estimating the accuracies of deforested areas and of deforestation rates has become a key factor for quantifying environmental services of tropical rain forests, particularly those linked to the reduction of greenhouse gas emissions from deforestation and forest degradation (REDD). In the trinational Madre de Dios, Peru – Acre, Brazil – Pando, Bolivia (MAP) region in southwestern Amazonia accelerated changes in land cover are foreseen as a result of infrastructure projects, such as the Inter-oceanic highway in southeastern Peru and other projects in Bolivia and Brazil. Reliable estimates of land-cover change are important for monitoring changes in the landscape due to timber extraction, pasture creation and other socio-economic influences. Assessing the dynamic nature of land cover changes continues to be a major challenge for global change research and the land-change science community (Lambin and Geist 2006; Gutman et al. 2004).

In tropical Latin America, land-cover changes have been related in the past to the development of the agricultural frontier made accessible by road and rivers. The most striking sites of deforestation and the most rapid agricultural expansion are in tropical lowlands. In the case of Peru, the paucity of roads has preserved the world's eighth largest tropical forest area, second only to Brazil in Latin America, with nearly 70 million hectares of natural forests, approximately 55% of the total national territory FAO and INRENA (2005), World Bank (2006). As a result, deforestation rates have been relatively low compared those in neighboring countries¹ with large Amazonian forests remaining Imbernon (1999). However, some areas in the Peruvian tropical forest have experienced an agricultural frontier expansion in the past twenty years and only scarce information about deforestation trends is available Naughton-Treves (2004). Deforestation figures of Peruvian forests have been inconsistent Elgegren (2005), Alcalde (2002). Official data on forest cover by region for the Peruvian Amazon exist since: 69,451,058 ha in 1975; 65,183,110 ha in 1990; 63,760,461 ha in 1995; 68,529,369 ha in 2000; and 68,345,031 ha in 2005 FAO and INRENA (2005), INRENA (1996). These numbers imply that forest cover has hardly changed since the mid 1970s; however, deforestation trends during the early 1990s have reported a significant decrease. Moreover, in the case of Bolivia, deforestation estimates have not been accurately reported Steininger et al., (2001).

The use of satellite imagery is a valuable tool for measuring land-cover changes and has been increasingly more accessible and its methodology has been tested and improved within many experimental projects and facilitated global change studies Keller et al. (2004); de Sherbinin (2004). However, despite these valuable efforts in exchanging methodologies and disseminating results on large-scale changes and deforestation rates, efforts to monitor local land change in tropical countries remain limited. Moreover, accuracy of deforestation estimates is controversial and lacks the appropriate monitoring system. While national and international measurements of deforestation are essential for credibility and quality assurance, local and regional deforestation estimates are critical because they guide the local actions on which REDD efforts will succeed or fail.

This research reported here provides initial accuracy assessment of a test deforested area between 1986 and 2009 along the transnational Peruvian/Bolivian/Brazilian border. The objective is to establish a cooperative initiative between representatives from regional governments, NGOs, and universities that will be able to present compatible information and the accuracy of regional deforestation estimates. This initiative allows the incorporation of local and regional

¹ Estimates of deforestation rate in neighboring countries such as Brazil and Bolivia are: Brazil, 1.7 million ha/yr forest-cover change between 1990-2000, increasing to 1.8 million ha/yr between 2001-2009, and Bolivia, 270, 400 ha/yr forest-cover change between 1990-2000 (www.inpe.br and FAO 2005) .

characteristics and aims to work on standardized monitoring techniques that could be used for specific drivers, such as timber extraction activities.

2. Methods

To estimate land cover change between 1986 and 2007, tasseled-cap indices were calculated for multi-date images and used to detect changes in forest and non-forest. For 2008-2010, forest and non-forest areas were processed through varied methodologies indicative of each participating institution.

2.1 Study Area

The research area is located in the province of Tahuamanu, Madre de Dios region within the MAP Region (Figure 1). The Tahuamanu Province has an estimated human population of 10,742 in 2007 (INEI, 2007). The inter-calibration exercises for accuracy assessment is a well-defined pasture area of approximate 600 ha (10deg 59min S 69deg 38min W), 8 km west of the trinational boundary point, that dates back from the late 1980s. During the 1985-1990, the government in Peru introduced policy incentives for cattle and pasture expansion. Increased agricultural credit and support for cattle acquisition fostered expanded forest clearing, especially for cattle pasture during this time period Alvarez Naughton-Treves (2003), Naughton-Treves (2004). Although the credit program established during 1985 and 1990 failed due to lack of economic competition and access to markets, and farmers did no longer benefit from cattle expansion incentives, this area of defined pasture remained almost unchanged and is therefore a reliable site for accuracy assessment comparisons through time.

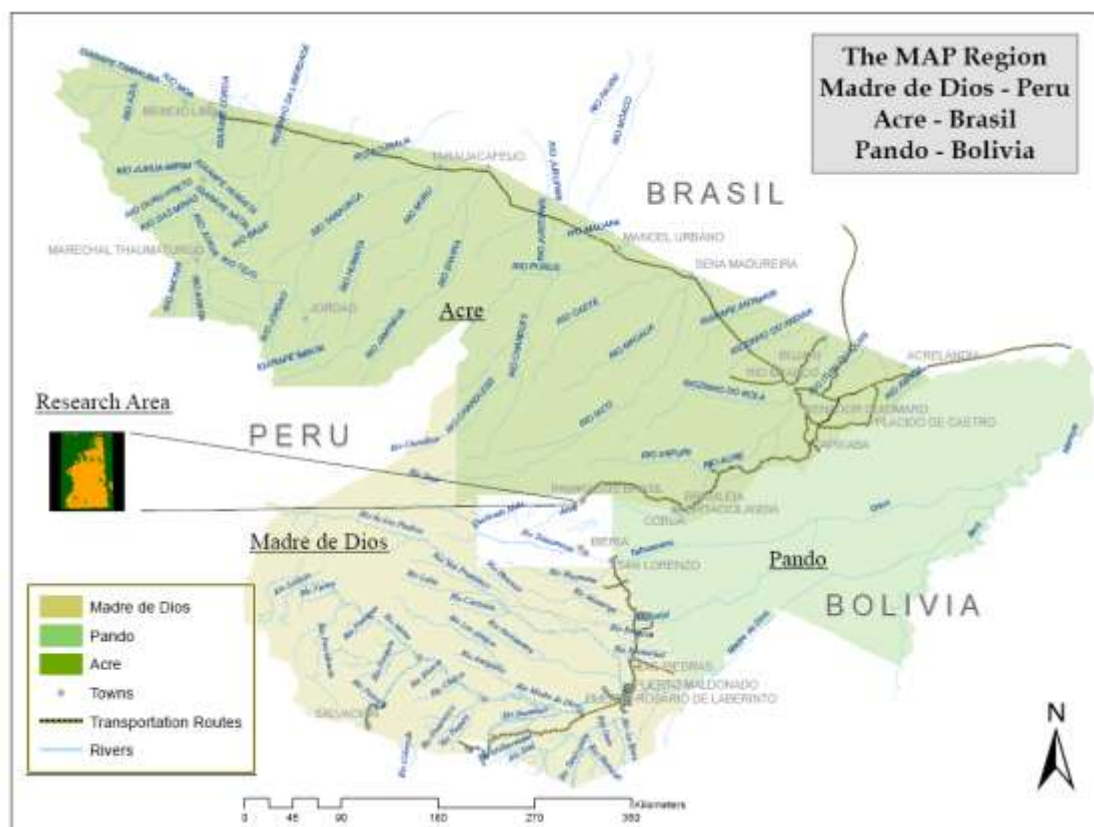


Figure 1. Research area within the tri-national frontiers in Peru, Brazil, and Bolivia.

2.2 Remote Sensing and Survey Data

Landsat satellite images for the study region were acquired from 1986, 1991, 1996, 2001, 2003, 2005, 2006, and 2007 (WRS Path/Row 003/068). These Landsat TM (1986, 1991, 1996, 2003, 2005, and 2006), ETM+ image (2001) and ASTER

(2007) were chosen based on cloud-free image availability (Table 1). All image preprocessing and analysis was conducted with ERDAS Imagine 8.4. Brightness, greenness and wetness indices for all acquired Landsat images using Landsat 5 TM coefficients for the 1986, 1991, and 1996 images and Landsat 7 and ASTER at-satellite reflectance for the 2001 and 2007 images were generated Crist and Cicone (1984), Kauth and Thomas (1976), Huang et al. (2002). Tasseled Cap (TC) classification and distinction within vegetation structures were based on studies by Cohen and Spies (1992) and TC performance for the Amazon by Guild et al. (2004). Each Landsat image (visible and near-infrared bands) was stacked with its respective TC images to create a nine-band composite. Unsupervised techniques were used to conduct a maximum likelihood classification, producing a 255-class image disaggregating all possible classes. Using ground-data training signatures and through intensive familiarity with the site from field visits, spectrally similar classes and final signatures for each year were grouped to produce a forest non-forest classification map for all acquired years. Further Landsat 5 and CBERS 2B HRC imagery for 2008, 2009, and 2010 were analyzed by different sources using softwares SPRING 5.0, ERDAS Imagine 8.2 and ENVI 4.6 (Table 2). Classes described as forest encompassed alluvial and *terra firme* forest, secondary forest as well as low hillside bamboo forest. Classes for non-forest included urban areas (village settings and roads), water (mainly rivers and creeks), crops and pasture.

Table 1. Sensor and image dates used for the historical deforestation trajectories of well-defined pasture research area in Peru 1986 – 2007. From Chavez (2009).

Sensor	Path/Row	Image Date	# of Bands	Extension (ha)
Landsat TM	003/068	12-Jul-86	6	N/A
Landsat TM	003/068	14-Oct-91	6	564
Landsat TM	003/068	23-Jul-96	6	554
Landsat ETM+	003/068	29-Jul-01	6	670
Landsat TM	003/068	13-Sep-03	6	663
Landsat TM	003/068	18-Sep-05	6	661
Landsat TM	003/068	16-May-06	6	643
ASTER		30-Jul-07	9	602
mean				647

Table 2. Sensor and image dates used for the accuracy assessment comparison by different sources of well-defined pasture research area in Peru 2008 - 2010.

Source	Sensor	Image Date	# of Bands	Extension (ha)
WHRC	CBERS 2B HRC	7-Jul-08	1	661
GOREMAD	Landsat 5 TM	13-Sep-09	3,4,5	657
GOREMAD	Landsat 5 TM	13-Sep-09	1,2,3,4,5	637
UCEGEO	Landsat 5 TM	13-Sep-09	3,4,5	622
Herencia	Landsat 5 TM	6-Jun-08	1,2,3,4,5	597
UCEGEO	IRS-P6-LISS3	2-Jul-10	3,4,5	590
mean				627
C.V%				4.8%

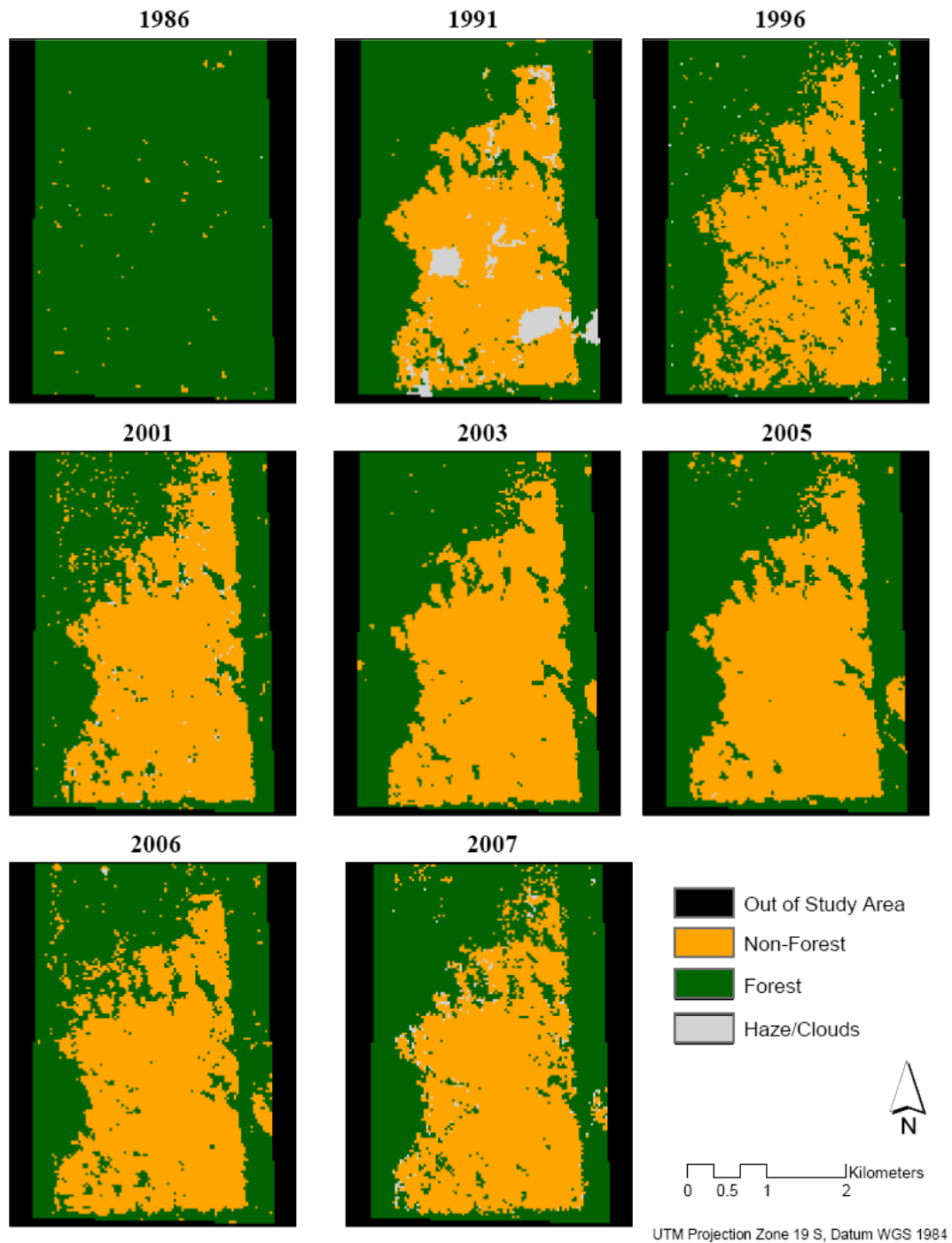


Figure 2. Historical deforestation trajectories of well-defined pasture research area path/row 003/068 in Peru 1986 – 2007.

3. Results and Discussion

A historical land cover trajectory of forest and non-forest classes were produced for 1986 to 2007 (Figure 2). A stratified random sampling scheme was used for selecting 30-50 training samples for each land cover to assess the accuracy of the 2003 image. Knowledge of the history of land-cover gained during the 2003-2005 field visits and training samples collected in 2003, allowed for ground-data and satellite data association back to 2001. Available accuracy for a 2003 image classification reports an overall accuracy of 85.5% which corresponds to the year most of the training samples were taken Chavez (2009).

The historical trajectory of the well-defined pasture averaged 647 ha in the 2000s (Figure 3). The six estimates of the ~600 ha pasture during 2008 and 2010

averaged 627 ha with a coefficient of variation of 4.8%. (Table 2). The difference between maximum and minimum estimates divided by the average was 11%. These data suggest that deforested areas estimated by participants in the MAP Region should have a minimum relative uncertainty of about 10%, and probably more for smaller areas. Part of the uncertainty relates to the date of imagery used, but a significant other part is related to the operational definition of forest used for forest fragments within the pasture (Figure 4). For manual digitizing these fragments were effectively lumped into a pasture classification (example CBERS2B in Table 1), while for digital classification schemes they tended to be differentiated (see Figure 2).

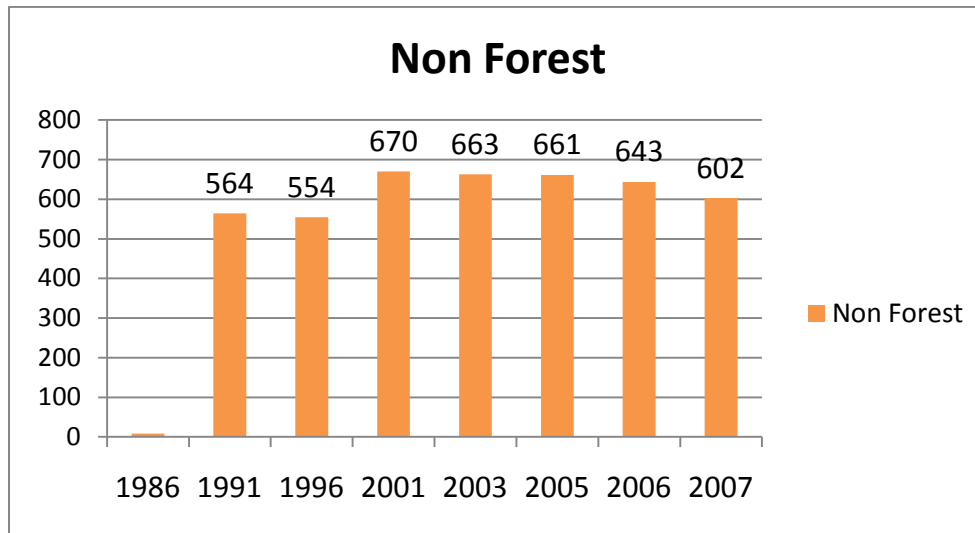


Figure 3. Historical deforestation trajectories in (ha) of well-defined pasture research area in Peru 1986 – 2007.

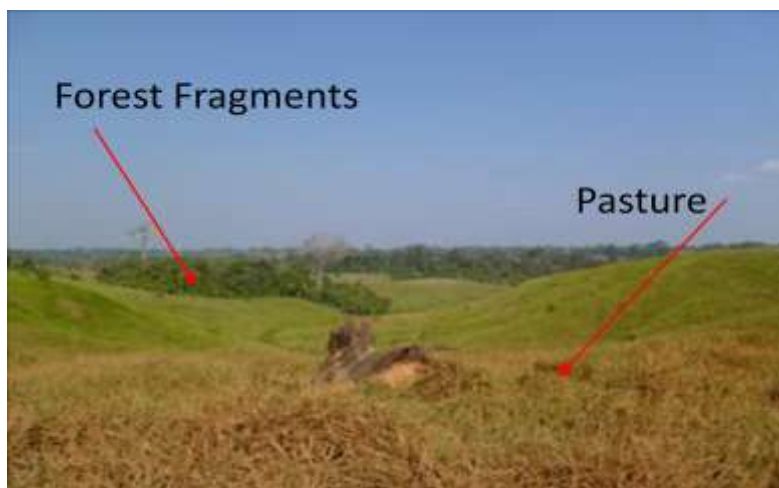


Figure 4. Research area showing the difficult task in delimiting non-forest (pasture) areas within forest edge fragments.

4. Conclusion

Deforestation rates, which are calculated using the difference in deforested area estimates between two successive dates, incorporate the uncertainty of their two sources, typically resulting in more relative uncertainty than their sources. If this initial study is representative of the uncertainty in accuracy of deforested area estimates from different imagery and professionals, then deforestation rates in this

region should have considerably more than 10% uncertainty in their accuracy. Further studies are needed to refine the boundaries of this uncertainty.

Acknowledgments

This activity is part of the MAP Initiative, an informal effort to promote regional collaboration. Funding for this effort came from the State Government of Acre, the Regional Government of Madre de Dios, the United State Agency for International Development and the Betty and Gordon Moore Foundation.

References

- Alcalde, M. **Diagnostico de la deforestación en el Perú**. Working Paper. Lima, Peru: USAID-INRENA-BIOFOR Activity, 2002.
- Alvarez, N.; Naughton-Treves, L. Linking national agrarian policy to deforestation in the Peruvian Amazon: A case study of Tambopata, 1986-1997. **Ambio**, v. 23, p. 269-274, 2003.
- Chavez, A. Public policy and spatial variation in land use and land cover in the sPeruvian Amazon. Dissertation Manuscript. University of Florida, Gainesville. 2009.
- Cohen, W.B.; Spies, T.A. Estimating structural attributes of Douglas-fir/Western Hemlock forest stands from Landsat and SPOT imagery. **Remote Sensing of the Environment**, v. 41, p. 1-17, 1992.
- Crist, E.P.; Cicone, R.C. A physically-based transformation of thematic mapper data-the TM tasseled cap. **IEEE Transactions on Geoscience and Remote Sensing**, v. 22, n. 3, p. 256-263, 1984.
- de Sherbinin, A. A guide to land-use and land-cover change (LUCC) research: A CIESIN thematic guide. The CIESIN web site: sedac.ciesin.columbia.edu/tg. 2004.
- Ellegren, J. **Deforestation in Peru**. Working Paper. 2005.
- Food and Agricultural Organization of the U.N. (FAO) & Instituto Nacional de Recursos Naturales (INRENA) **Actualización de la evaluación de los recursos forestales mundiales a 2005. Perú. Informe Final**. Lima: INRENA. 2005.
- Guild, L.S.; Cohen, W.B.; Kauffman, J.B. Detection of deforestation and land conversion in Rondônia, Brazil using change detection techniques. **International Journal of Remote Sensing**, v. 25, n. 4, p. 731-750, 2004.
- Gutman, G.; Janetos, A.; Justice, C.; Moran, E.; Mustard, J.; Rindfuss, R.; Skole, D.; Turner II, B.L. (Eds.). **Land change science: observing, monitoring, and understanding trajectories of change on the earth's surface**. New York: Kluwer, 2004.
- Huang, C.; Wylie, B.; Homer, C.; Yang, L.; Zylstra, G. Derivation of a tasseled cap transformation based on Landsat 7 at-satellite reflectance. **International Journal of Remote Sensing**, v. 23, n. 8, p. 1741-1748, 2002.
- Imbernon, J. A comparison of the driving forces behind deforestation in the Peruvian and the Brazilian Amazon. **Ambio**, v. 28, p. 509-513, 1999.
- INEI. **Análisis socio demográfico del departamento de Madre de Dios**. Lima, Perú: INEI, 2007.
- INRENA. **Monitoreo de la Deforestación en la Amazonia Peruana**. Lima. Perú, 1996.
- Kauth, R.J.; Thomas, G.S. The tasseled cap-a graphic description of spectral-temporal development of agricultural crops as seen by Landsat. **Final Proceedings: 2nd International Symposium on Machine Processing of Remotely Sensed Data**. West Lafayette, IN: Purdue University, 1976.
- Keller, M.; Silva-Dias, M.A.; Nepstad, D. C.; Andrae, M. The Large-Scale Biosphere-Atmosphere Experiment in Amazonia: Analyzing regional land use change effects. In: DeFries, R.S.; Asner, G.P.; Houghton, R.A. (Eds.), **Ecosystems and Land Use Change**. Geophysical Monograph 153. Washington, DC: American Geophysical Union. P. 321-34, 2004.

Lambin, E.F.; Geist, H.J. (Eds.) **Land-use and land-cover change: local processes to global impacts**. Heidelberg: Springer Verlag, 2006.

Naughton-Treves, L. Deforestation and carbon emissions at tropical frontiers: a case study from the Peruvian Amazon. **World Development** v. 32, n. 1, p. 173-190, 2004.

Steininger, M.K.; Tucker, C.J.; Townshend, J.R.G.; Killeen, T.J.; Desch, A.; Bell, V.; Ersts, P. Tropical deforestation in the Bolivian Amazon. **Environmental Conservation**, v. 28, n. 2. P. 127-134, (2001).

World Bank. **Análisis preliminar sobre gobernabilidad y cumplimiento de la legislación del sector forestal en el Peru**. Preparado para World Bank. Maroni Consultores SAC. Borrador. Washington, D.C.: The World Bank, 2006.