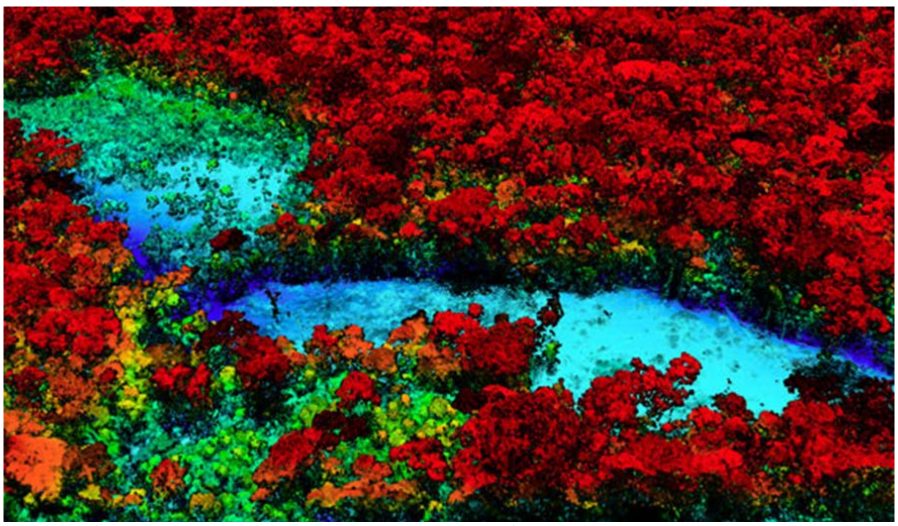
# Assessment and future prospects of remote sensing techniques to evaluate forest damage in the Peruvian Amazon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**Introduction**

Rapid deforestation, degradation, and loss of biodiversity characterize the current logging practices in the Peruvian Amazon. Environmental and government bodies have implemented many forest, climate, ecosystem policies and programs in previous decades to mitigate the destructive effects of the system, but the diverse landscape and complex political and social structures prove difficult obstacles to overcome. Every step towards environmental protection depends on accurate and up-to-date data, remote sensing, mapping methodologies, and analyses as a starting point. However, the diffuse patterns of forest degradation caused by Peru's *habilitado-enganche* system of selective logging present difficulty in assessing the damage in a safe, cost-effective manner (Oliveira *et al.* 2007). The onset of the computer age and the use of satellites drastically improved the quality and quantity of geographic data. Specifically, the technologies of Landsat satellite imaging, remote sensing, GIS, LiDAR, CAO, and CLASlite provide excellent sources of data and analysis (Backhaus and Beule 2007). The specific types of satellite-based forest data include temporal forest loss, canopy gaps, carbon stocks, and declines in biomass.

The development of satellite and remote sensing techniques provide researchers in Peru with the most cost-effective and accurate way to monitor changes in forest cover and degradation over large geographic areas. Despite the enormous advantage and wide range of technical applications supplied by remote sensing (Asner *et al.* 2009), the limitations of utilizing technology to enact policies or management plans often overshadow their success. The biggest problems with implementing remote sensing are the sheer cost for human and technological capacity in the isolated areas of the Amazon, and the virtual "gap" between converting raw data into effective policies for positive change. Each source of land-use data has a specific domain of applicability and oftentimes a program chooses data unsuitable for a certain study and narrows the focus of the information to yield a biased map (Verburg *et al.* 2011). The quality of data, such as images with cloud cover and lack of regional analyses (as opposed to comprehensive Amazon patterns), also pose more obstacles for the accessibility of accurate satellite images and meaningful policy implementation.

I argue the improvement of remote data acquisition and subsequent policy enactment in the Peruvian Amazon relies on the enhancement of satellite technology and algorithms to mitigate the effects of cloud cover and regional discrepancies, linking the disconnect between scientific data and policy, establishing a benchmark, or baseline, for each category of data, and the validation of current data.

**Methods**

My forestry assessment group, Ecology/Management, covers the three separate yet inter-related topics of remote sensing, ecology, and management. My section, remote sensing, conducts an in-depth analysis of the applications and limitations of satellite and automated approaches to assess forest degradation, while the Ecology study underscores the various and far-reaching ecological impacts caused by selective logging in Peru. Ecology and remote sensing complement each other because technological mapping approaches still require expert field work for ecological assessments to actually make use of the data acquired, and ecology work often uses satellites and computer modeling. The third facet of our group, management, addresses the problems and possible alternatives for managing the forestry system in the Peruvian Amazon. Management serves as a way to integrate my study of technological advancements and the ecological subject matter into a cohesive recommendation for improving the destructive logging activities in the dynamic Peruvian Amazon.

My methodology consists of researching and reviewing multiple peer-reviewed journals, scholarly articles, and satellite-based websites. I distinguish the available tools and software for remote sensing applications, and the major impediments hindering their potential uses. The articles, dissertations and websites provide an understanding of the modern approaches of remote sensing and exact quantifications from case studies in Peru and Brazil, as well as ideas for approaches to implement the techniques more reasonably. Given the literature-based approach to my study, a succinct literature review of the topic follows the methods section and addresses the current knowledge of the subject matter, as well as faults and gaps.

**Literature Review**

The literature review serves as a basis for understanding the complex topic of remote sensing as it applies to the forestry system in Peru. I conducted my study from scholarly sources available on the subjects of satellite approaches, current and previous software systems, and data-use policies. The various sources contain many overlapping arguments from different perspectives, and I focus my review around the main points.

Gregory Asner, professor and scientist at the Carnegie Institution for Science, established himself as the leading scientist and author in the field of remote sensing by developing breakthrough technologies for mapping from the air, and writing a variety of extensive articles on remote techniques. Asner wrote many sources I focus on, although I do draw many points from other authors with differing approaches.

The various satellite technologies have increased substantially in capacity, cost-effectiveness, accuracy, and flexibility since the first Landsat satellite launch in 1972 (Mayer and Lopez 2011). Most of the articles begin with a clause addressing the profound importance of remote sensing for forest management, as well as the various technologies in the context of specific environmental issues. Asner *et al*. (2009) states how there exists an enormous range of possible remote sensing approaches, but stakeholders often poorly demonstrate or implement critical steps. Asner (2009) also observes the necessity of large-scale mapping initiatives to assess forest degradation and the viability of employing these practices anywhere in the world. Mayer and Lopez (2011) note the diversity of infrastructure for technology to monitor environments from a global to local scale, as well as the technology's accelerated growth. Verburg (2010) addresses the key role land cover data plays in climate change assessments and Engel-Cox and Hoff (2005) mention environmental policies' strong dependence on environmental monitoring data. Finally, Backhaus and Buele (2005) observe the different satellite technologies available for use in thirteen main environmental issues and note the profound emphasis agencies place on remoteness, or assessment of forestry issues from a distance using technology, for performing routine tasks.

Asner's 2005 case study of the Brazilian Amazon and Oliveira's 2007 Peruvian study provide excellent quantified data about the uses of remote techniques to detect selective logging and the effectiveness of land-use allocation in the rainforest. Both authors underscore the importance of remote sensing to detect diffuse patterns of forest degradation. The researchers also both utilized the Carnegie Landsat Analysis System (CLAS), conceived by Asner himself, which uses complex detection algorithms to map and analyze high-resolution satellite imagery. Oliveira's study addresses the profound conservation value of the Amazon rainforest in many biodiversity inventories. He expands on the topic by producing and analyzing quantified percentages of the various impacts of geographic and political factors on forest clearing. Similarly, Asner reports on the ratios of cleared forest to untouched forest in five Brazilian states. Both studies also affirm the CLAS methodology as a precise and accurate measurement of canopy gaps caused by selective logging, and account for any errors or uncertainty.

Given the emphasis on Gregory Asner's innovative research in many reports and remote sensing articles, CLASlite and the Carnegie Airborne Observatory (CAO), also conceived by Asner, serve as the technological focal point of my paper. Rhett Butler, in his 2011 article, "Breakthrough technology enables 3D mapping of rainforests, tree by tree," interviews Asner regarding the technological capacity of CAO, which uses a technique called Light Detection and Ranging (LiDAR), and what the system can do to help the forest degradation problem in Peru. The interview provides valuable insight on the methodology, application, and future of the powerful satellite-based system. Another study conducted by Asner, "Automated mapping of tropical deforestation and forest degradation: CLASlite," describes the functionality, challenges, and potential applications of the user-friendly software he designed in 1999.

In addition to the Carnegie systems of analysis, the journal articles also cover the technological aspects of specific algorithms used by mapping software, and the roles of uncertainty and cloud cover in acquiring accurate data. Asner *et al.* underscores the importance of using algorithms capable of processing a variety of satellite imagery and implementing methods to support a wide range of tropical forest and atmospheric conditions in the August 2009 article. The automation of satellite-based mapping requires complex algorithms, or computer instruction sequences, to produce accurate maps for the specific topic being studied. Asner discusses the processes used to convert raw Landsat satellite images into meaningful land cover change maps. Cloud cover proves to be one the most prominent obstacles in producing an accurate assessment of canopy gap changes at different temporal scales. One of Asner's (2001) articles, "Cloud cover in Landsat observations of the Brazilian Amazon," directly examines the role of cloud cover probability analysis in mapping methodologies.

Although the authors ubiquitously express the significance of remoteness for managing forests and discuss the technological specifications, a few other reports also discern the various limitations in applying the techniques and possible solutions. Asner (2001, 2009) briefly discusses the technical shortcomings preventing accurate data acquisition, such as the aforementioned cloud cover barrier and the issues associated with developing a system for rapid mapping of forest cover. However, the quick pace of computer advancement and growing number of earth observation systems provide ample opportunities for more precise data in the future.

Mayer and Lopez (2011) observe the more remarkable drawbacks of applying remote sensing to modify the forestry system: high cost of implementation, lack of human and technological capacity in isolated regions, lack of data at appropriate scales, and the many political hurdles to overcome. Verburg *et al.* (2010), Leeuw *et al.* (2010), and Engel-Cox and Hoff (2005) all conduct in-depth analyses of the complex political factors preventing raw scientific data from being properly utilized in enacting environmental policies. These three sources provide excellent perspective on the challenges remote sensing must overcome to solve environmental problems.

While no articles directly link the topics of remote sensing to the *habilitado-enganche* system in a comprehensive manner, my analysis and conclusion sections serve as a framework to link remote sensing techniques to a plausible management scheme for improving Peru's forestry system.

**Analysis**

**1. Current Technology**

Improving the deleterious *habilitado-enganche* system of selective logging in the Peruvian Amazon relies on data. Environmental data, specifically forest cover change obtained by aerial earth observations, provides an accurate, objective outlook on the changes occurring in the rainforest by using a variety of satellite-based techniques. In this section, I present a study of modern methodologies for assessing forest cover, followed by an overview of selective logging case studies in Peru and Brazil, and conclude with a discussion of the challenges and solutions of implementing remote sensing with a cheaper and more advantageous approach in the Peruvian Amazon.

Gregory Asner's Carnegie Airborne Observatory (CAO) and Carnegie Landsat Analyis System (CLASlite) both utilize aerial photography and automated computer models to assess land cover changes in the forest canopy 7,000 feet below. However, each system provides a different group of stakeholders with access to differing forms of data.

Despite the wide range of remoteness techniques currently available, most systems remain esoteric and require trained experts to utilize and maintain them. CLASlite's revolutionary approach uses Landsat satellite images at 30 m spatial resolution and places the user in control of the software by allowing non-experts to map and interpret forest changes at any scale (Asner *et al.* 2009). The software, launched as a beta in 1999 and for public use in 2008, seeks to make forest monitoring an everyday activity for untrained users and expand the capacity of governments and organizations to monitor forests with satellite observations. Currently the Carnegie Institution disperses the software based on license request from any government, non-governmental organization (NGO), or academic institution in the Andes, Amazon, and Guyana Shield regions of South America (Carnegie Institution for Science 2010).

CLASlite algorithms use calibration, atmospheric correction, cloud-masking, and spectral signal processes with various satellite sensors. The last two steps of map-producing decompose single pixels into fractional surface covers and classify the images into forest cover or forest disturbance. The software can easily map more than 10,000 $km^2$ of forest area in one hour, and the outputs include percentage maps of vegetation cover and bare soils coupled with measures of uncertainty for each pixel (Asner *et al.* 2009). CLASlite effectively converts "raw" satellite imagery into detailed maps indicating areas of deforestation, providing the user with accurate and meaningful images to be analyzed (Carnegie Institution of Science 2010). The algorithms use the spectral properties of each 30 m pixel to produce a map of green (forest cover), red, and blue (areas of degradation). Figure 1 illustrates the wealth of information an image produced by CLASlite wields versus an unprocessed Landsat image (Carnegie Institution of Science 2010).

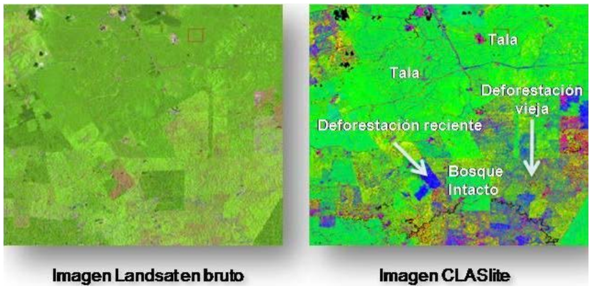


Figure 1. "Raw" Landsat image on left. Image produced by CLASlite on right.

The versatile software also allows for user-specified parameters to assess certain fields of interest and different temporal and physical scales. The seemingly simple idea of creating accessible, easy-to-use software can greatly advance the way different stakeholders conduct field and remote studies in the isolated regions of Peru.

While CLASlite presents an innovative way to map and study forest cover, the 30 m resolution of images often doesn't accurately detect small-scale, regional changes in forest cover or have the ability see unsanctioned roads beneath the canopy. The CAO's approach to mapping the dynamic rainforest yields more precise and higher-resolution images than the CLASlite software. The observatory is a modified aircraft with optical, chemical, and laser (LiDAR) sensors on board. Together these components comprise the newest Carnegie project; the Airborne Taxonomic Mapping System (AToMS). Unlike CLASlite, AToMS does require expertise for operation, but LiDAR methods facilitate mapping at a 10 cm spatial resolution and also reveal the biochemical properties of individual trees. The high precision of the mapping allows Asner's crew to visualize strikingly realistic 3 dimensional models of the vegetation structure below the forest canopy. (Butler 2011).

LiDAR determines horizontal and vertical distances by using the product of the speed of light and the amount of time necessary for a laser to travel to the object on the ground (Lim *et al.* 2003). Automated machines on the aircraft process the physical and chemical information returned by the lasers and output 3D maps of forest structure and biomass. The real power of CAO lies in the ability to measure and assess trees and vegetation on the ground in a faster, more accurate, and cost-effective way than fieldwork conducted by ecologists. Asner still validates his maps by conducting systematic, diffuse fieldwork on the ground, but aims to make the methods as automated as possible in the near future (Butler 2011).

**2. Case Studies**

Carnegie has not yet released any comprehensive studies of the Amazon using CAO, but the system is currently being used on a campaign to map carbon stocks in Peru and has the potential to greatly improve monitoring by the REDD (Reducing Emissions from Deforestation and Forest Degradation) program (Butler 2011). However, different researchers have implemented CLASlite in the Amazon to study logging dynamics. Here I examine two case studies, one conducted in Peru and the other in Brazil.

Oliveira *et al.* (2007) applied CLASlite methodology to Landsat ETM+ (Enhanced Thematic Mapper Plus) images covering 79% of the Peruvian Amazon from 1999 to 2005 to assess whether land-use allocation policies actually serve to protect the forest and determine what land types exhibit the most damage. In the past decade, the Peruvian government has expanded indigenous and natural protected areas; however policies have also established 31% of the forest as permanent resource production zones for timber-extraction. The research team analyzed the 30 m spatial resolution images over the six-year period (24 images per year) and used CLASlite to produce annual incremental damage maps of disturbance (any change in forest cover) and deforestation (usually clearing caused by logging) for the most afflicted areas. The team validated the results via a large-scale field survey in the forest and found the software to have very few errors (Oliveira *et al.* 2007).

The results of the study show average rates of forest disturbance and deforestation as 632 square kilometers per year and 645 square kilometers per year, respectively. Although the software assessed 79% of the Peruvian Amazon, most of the detected damage occurred in only the two regions of Pucallpa and Puerto Maldonado. Out of the whole study area, indigenous territories included 9% of disturbance and 11% of deforestation and only 1-2% of degradation occurred within natural protected areas. The fractional quantifications indicate the success of land-use allocation policies in Peru.

While the policies don’t appear to completely mitigate illegal logging practices, the small percentage of damage in protected areas shows the importance of demarcating land to protect the forest. However, land-use was not the only factor studied. Many authors note the positive correlation between Amazonian logging patterns and road access and creation (Salisbury 2007, Asner *et al.* 2009), and this case accentuates the relationship. The team estimated 75% of the total Peruvian forest damage occurred within 20 km of the nearest road (legal or unsanctioned). Figure 2 compares a heavily deforested area and a more isolated region and emphasizes the role of land titling and access to transport routes in the context of forest damage. After factoring in the differences in geography and access to roads, CLASlite found deforestation 10 times more likely in indigenous and unmarked zones than in natural protected areas (Oliveira *et al*. 2007).

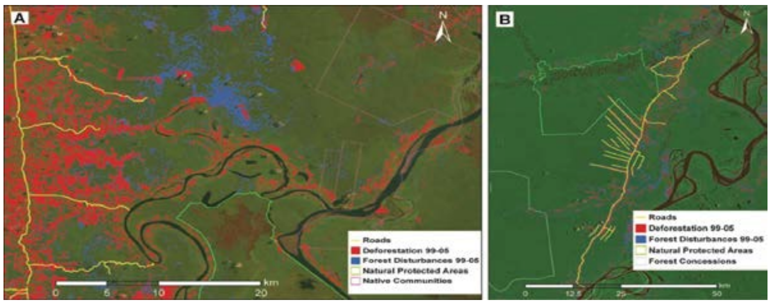


Figure 2. (A) shows forest damage near Pucallpa, Peru where damage (red) is the greatest along roads and extends into protected areas along the river. (B) shows forest damage in the more remote area of Iquitos, Peru where little damage occurred, but still focused around transport routes.

The land-use case study in Peru showcases the profoundly versatile and practical power of CLASlite to assess logging impacts in remote, dynamic forests. The results provide insight on the effectiveness of land-use allocation policies and the role of road access in the Amazon. Despite the troubling complexities of governance in these remote regions, subsequent policy reforms and land titling can better protect the rainforest in the future. The logging issue needs to be approached from an interdisciplinary perspective (Salisbury 2007, 284), and the CLASlite study in Peru serves as a prime example of the way remote sensing can inform policy makers.

Asner *et al.* (2009) conducted an ecological study of selective logging impacts in the Brazilian Amazon using CLASlite and Landsat ETM+ images from 1999-2002. He used four Landsat images, one from each year, as input for CLASlite and the algorithms automatically perform calibration, atmospheric correction, and analysis. The program accents areas of forest and non-forest for each year, and differentiates forest clearing from diffuse disturbances caused by selective logging (Asner *et al.* 2005, 2009).

CLASlite algorithms use either single-image analysis to calculate net loss of forest cover or multi-image analysis to trace temporal, gross changes in canopy cover. Asner found the net decrease of forest cover in the study area to be 3.5%. This percentage reflects a large loss over the short time period of three years; however the multi-image analysis measured a gross forest disturbance rate of 5.7%. Differing rates of secondary forest regrowth and leaf return rates explain the discrepancy between the two forest loss percentages (Asner *et al.* 2009). The research team's study indicated selective logging caused 98% of the diffuse forest loss in the region. Asner cites the importance of using the gross rate forest loss for carbon and forest monitoring because it contains information about net rates of change and the areas most afflicted by selective logging (2009).

The two case studies above extend Gregory Asner's CLASlite to examine the complex dynamics of selective logging and forest loss in the Amazon. Both studies expose the ease-of-use and adaptability of the software to any forest monitoring problem. Despite the promising concept of CLASlite and the continuously growing capacity and accuracy of remote sensing techniques, the Peruvian forestry system has still not properly incorporated remote sensing into a solution for better monitoring because of many different constraints. Below I explain the limitations of applying remote sensing technology to environmental problems and follow with a brief discussion of solutions in the conclusion.

**3. Challenges and Limitations**

Modern satellite technology, with ever-expanding capacity and decreasing costs, provides ample opportunities to map and analyze a range of environmental issues, however a variety of technical, political, and socio-economic challenges contribute to the technologies falling far short their potential (Engel-Cox and Hoff 2005, Mayer and Lopez 2011). Socio-economic and political problems outweigh the technical limitations in terms of difficulty and ambiguity, but I do expand on the challenges faced by mapping software systems briefly.

The technical limitations of creating and maintaining accurate mapping software include masking cloud cover, following design-specific requirements, and the inevitable need for field validation work (Asner 2000, Asner *et al.* 2009, Verberg *et al.* 2010). Cloud cover masking proves to be a crucial step in computer image analysis because of the high concentration of clouds in the Amazon and the major obstacle they pose to acquiring a clear image of forest cover. The location of the rainforest in the sub-tropical climate region and in the Inter-Tropical Convergence Zone results in a large amount of clouds and precipitation in the forest. The "dry" season from June-September has relatively clearer conditions in the south, but even during this time the northern basin remains drenched (Asner 2000). CLASlite and other software algorithms use raw satellite imagery to automatically determine atmospheric surface reflectance and conceal the water vapor blocking forest cover (Asner *et al.* 2009).

While cloud cover has become less of a problem as masking algorithms continue to improve, other technical barriers still exist. Asner *et al.* (2009) underscores design requirements and challenges for creating successful mapping software. The first specification addresses the need of "sufficiently general" methods capable of operating with a variety of forest conditions. The unique forest architectures in the vast Amazon exhibit different spectral properties and the system should be able to determine areas of deforestation even between different forest types. As stated above, the methods should also be able to mitigate a range of atmospheric conditions; most notably cloud cover. Similarly, the algorithms should accommodate a variety of satellite imagery (Asner *et al.* 2009). For example, CLASlite has the capability of analyzing Landsat, ASTER, MODIS, and SPOT images (Asner 2009). The last specification for the software requires the system to be easily accessible to non-expert users, which implies simple applicability to a desktop computer. (Asner *et al.* 2009). The two main drawbacks of the CLASlite software include the program's inability to classify anthropogenic versus natural forest change and the continued reliance on subjective field work for validation (Asner *et al.* 2009, Verburg *et al.* 2010).

Financial and political issues comprise the principal limitations of applying remote sensing to policy reform in the Peruvian Amazon. However, the aforementioned interdisciplinary nature of forestry problems (Salisbury 2007, Engel-Cox and Hoff 2005) forces the technical aspects of the system to connect with the societal and economic factors in order to yield a synoptic and meaningful solution (Engel-Cox and Hoff 2005). Despite the importance of linking disciplines to enact policy reform, de Leeuw *et al.* (2010) note the "apparent little academic interest in the societal contribution of environmental remote sensing." Remote sensing began as a way to identify environmental problems, but in the past two decades remoteness spread to applications in policy control (de Leeuw *et al.* 2010). To further expand upon non-technical challenges, I break the following section into four parts: cost, resources, data, and politics.

**a. Cost**

The most obvious limitation to remoteness is the sheer cost of the products and staff for training. In all cases the demand for the technology must be high enough to offset the initial cost. This observation indicates why some policies make more use of the products than others (Mayer and Lopez 2011). Asner *et al.* (2005) addresses the importance of acquiring and analyzing regional data (in addition to large-scale mapping) to make accurate assessments, however regional studies often may be very costly and impossible to implement in certain isolated areas (Verburg *et al.* 2011).

Although Landsat's freely available images alleviate some of the cost issue, most organizations now have the requirements of using finer-resolution data for use with Geographic Information Systems (GIS) or other software. While cost still remains a prevalent limitation today, advances in the near future will render technologies more and more economically efficient and feasible for implementation in the Amazon (Mayer and Lopez 2011).

**b. Inadequate Resources**

In addition to cost, many governments or organizations in the Amazon do not possess the personnel, training, or technological resources to effectively utilize available data in the remote borderlands. The hard-to-access, isolated regions of the Amazon pose problems for the dissemination of technological knowledge, especially in areas where there may not even be electricity. Collaboration between remote sensing scientists, GIS analysts, policymakers, and indigenous people could lessen the issues of training and resources as well as bolster native involvement in mapping initiatives (Mayer and Lopez 2011). Furthermore, the increasingly automated nature of mapping software, such as using methods to automatically update forest or road changes, can serve to moderate staffing shortages in the borderlands (Mayer and Lopez 2011).

**c. Data**

The strong dependence of policy enactment on spatial monitoring data requires that the data must be appropriate for the study, rendered at the correct spatial and temporal scale, accurate, current, and consistent (Mayer and Lopez 2011, Engel-Cox and

Hoff 2005). In the past, most land cover data derived from free Landsat images produce coarse, inaccurate measures compared with the modern higher-resolution approaches of LiDAR and MODIS. The information revolution in the past decade and ever-expanding monitoring approaches facilitate rapid, large-scale data availability like humans have never witnessed before. However, the vast quantities of data available present both great opportunities and great challenges (2005). Different data originate from a variety of monitoring techniques and sources, but Verburg *et al.* (2010) states how "each source of land use/cover data has its own domain of applicability and quality standards," and often programs choose data without considering the suitability of the information for the application.

Other data-related challenges include the discrepancies between temporal and spatial scales for datasets, possible positional errors caused by georeferencing, and a lack of a large-scale baseline dataset for land use and land cover in the Amazon (Verburg *et al.* 2010, Engel-Cox and Hoff 2005). Data characteristics highly influence the limitations associated with remote sensing applications, but data in the context of policy making presents the most ambiguous and complicated challenge.

**d. Political Factors**

Often the limitations of remote sensing applicability exist because of complex political, scientific, and data-use dynamics. Despite technological improvements, the use of remote techniques for environmental evaluation policies remains low, and many authors attribute this disparity between policy and data as the "science-policy value gap" (Mayer and Lopez 2011, de Leeuw *et al.* 2010, Engel-Cox and Hoff 2005).

Environmental concern acts as a major influencer of public support for remote sensing, and in the opposite way, remoteness also serves to foster environmental awareness. Al Gore notes how the first airborne image of earth taken in 1968 "exploded into the consciousness of mankind," and within a few years of the picture being taken governments enacted several environmental policies and established the first Earth Day (de Leeuw *et al.* 2010). Therefore environmental policy development and airborne earth observations commenced at the same time, but most current case studies focus on the benefits, methods, and product specifications rather than the function in terms of policy support (2010). Policy makers implement data into decision making in an often complex, ambiguous, or jargon-filled manner making subsequent analysis and use of the data a convoluted process (Engel-Cox and Hoff 2005). This disparity between data and policy indicates how expanding technological capacity doesn't necessarily translate into instant "solutions" to the problem.

Engel-Cox and Hoff (2005) define the science policy value gap as inherent "differences in perspectives, motivators, and values between the scientific and policy culures." Scientists, organized by discipline, seek truth through rational tests and provide environmental policies with specialized information. Policymakers, in contrast, try to gain support based on reasoned arguments and response to power centers (2005). The culture clash of power (policy) and truth (science) often results in a "narrowing focus," or "optimal extraction" of the data by policymakers to promote their own agendas and goals (Verburg *et al.* 2010, Scott 1998, Engel-Cox and Hoff 2005). Even with such notable cultural differences, the two realms of science and policy remain inherently connected in their roles of improving forestry systems.

The conclusion section briefly recapitulates the functionality of modern mapping software as they relate to Peruvian forestry and provides a synoptic view of the science-policy data compact model in the context of the *habilitado-enganche* system.

**Conclusion**

The varied and complex challenges faced by stakeholders in the Peruvian Amazon present a high degree of difficulty for making improvements to the selective logging system. However, the rapid pace of technological advancements in the field of satellite-based systems will continue to provide plentiful opportunities to use forest cover data in the future. Sears and Pinedo-Vasquez (2011) suggest weak governance and lack of monitoring as two primary reasons for the failure of forest reforms in tropical regions. Gregory Asner's two innovative Carnegie systems provide objective, unrivaled potential in verifying where forest loss occurs and inform governments about the effectiveness of land-use allocation (Asner *et al.* 2009, Oliveira *et al.* 2007, de Leeuw *et al.* 2010). Additionally, the easy-to-use, versatile software can be extended to monitor the four main elements of the *habilitado-enganche* system: documents, capital, labor, and timber. The adaptable nature of the selective logging system facilitates widespread corruption and falsified documents, and remote sensing techniques can serve to mitigate the illegalities

(Sears and Pinedo-Vasquez 2011). For example, local organizations can use CLASlite or GIS coupled with field-based research to demarcate and highlight areas with a high concentration of labor, or areas with scarce capital and rampant illegal documents to streamline where and what to focus on for improvement.

While this report focuses on the technical aspects of remote sensing applications, the science-policy data compact model introduced above can apply to the *habilitado-enganche* system in Peru and vastly improve transparency between scientists and stakeholders to make better use of remote data for policy implementation. The model assists in making data more understandable by following the simplified conversion of: monitoring data → information → knowledge → policy. The path of data conversion requires interactions between head scientists and midlevel policy makers in the Peruvian Amazon to ensure the data reaches the decision makers in an appropriate manner and format. The model requires data to meet five criteria to assure proper transformation into useful policy information: relevance to the issue, timeliness, clarity to the policymaker, integrity (sound science), and visualization (maps or graphs) (Engel-Cox and Hoff 2005).

In addition to the science-policy data model, establishing global, regional, and local baselines for forest topics serves as another solution to mitigating data ambiguity. Compiling a worldwide dataset for public knowledge would provide organizations with accurate benchmarks to use for validation of new data, streamline policy efforts around the globe, foster collaborative projects, and improve the way forestry systems operate (Engel-Cox and Hoff 2005, Verburg *et al.* 2010). The Group on Earth Observations (GEO) met in July 2010 to discuss a project for funneling satellite data into free and open database called the Global Earth Observation System of Systems (GEOSS). This revolutionary dataset initiative will be fully online by 2015 and will undoubtedly assist researchers and policy makers in Peru, and all around the globe, in establishing benchmark quantifications for forest cover in the Amazon, and ultimately lead to more sustainable logging practices (Stone 2010).

Remote sensing has been central to forest assessments for the past three decades and will only increase in accuracy, capacity, and applicability in the near future. However, the culturally, ecologically, and politically dynamic landscape of the Peruvian Amazon exemplifies the intrinsic cross-disciplinary nature of the logging practices in the rainforest. In the future remote sensing, land-use allocation, and cultural studies should all be conducted in synchronicity along with applying the science-policy data model in logging centers in Peruvian forests.

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