LETTER

Landscapes, legibility, and conservation planning: multiple representations of forest use in Panama

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Abstract

In recent years, conservationists have increasingly used satellite imagery based analyses for planning. We used forest plots and satellite image analysis to study the same landscape of forests used and managed by Wounaan indigenous peoples in eastern Panama. We studied 20-, 10-, and 1-year-old rice swiddens, single tree extraction sites for dugouts, and homegardens in comparison with multi-use mature forests to examine whether Wounaan forest use histories could be distinguished by vegetation patterns and Landsat satellite imagery. We found that forest use histories were discriminated by vegetation structure and floristics, but these uses were largely obscured in satellite images. We discuss how conservation planning is impacted by these different methods, particularly how the perceived objectivity of satellite imagery may be used to dichotomize culture and nature. We conclude by encouraging the critical use of satellite imagery in conservation by using mixed methods at multiple temporal and spatial scales.

Introduction

The last two decades have been witness to an increasing emphasis on planning in environmental conservation. Environmental organizations and governments that once prioritized conservation activities on an ad hoc or opportunistic basis now utilize systematic conservation planning. Often dominated by ecological data, conservation planners have embraced the need to include social data in assessing conservation sites. As Gorenflo & Brandon (2006, p. 723) recently noted "in a world dominated by humans, efforts to expand biodiversity conservation must consider the human context of any potential conservation location." Yet, researchers have noted that the incorporation of social data remains a significant challenge to conservation (Miller & Hobbs 2002; Gorenflo & Brandon 2006; Sarkar *et al.* 2006; Chan *et al.* 2007).

A key component of conservation planning is the use of satellite imagery analysis to assess both ecological and social characteristics of areas. For example, planners may use satellite imagery to do gap analyses as to whether priority conservation regions contain protected areas, to identify less disturbed sites for conservation activities, or to assess how people are changing land covers (such as fragmentation or afforestation) to program conservation and development activities. Satellite imagery permits the visualization of landscapes at multiple spatial scales and also allows the examination of temporal change. Satellite imagery not only provides new landscape perspectives, but new data based on light reflectance. An analyst can differentially evaluate the light reflectance data of satellite images to highlight particular landscape patterns, including archaeological ruins, urban settlement, and forest cover. As a result, satellite images often make legible once cryptic environmental patterns, particularly at regional and national scales. The legibility of satellite imagery together with the decreasing cost of desk-top analysis and low cost or free imagery have allowed satellite imagery to become ever more widespread (Leimgruber 2005; Baker & Williamson 2006). In published studies about conservation (Leimgruber *et al.* 2005) and forestry (Li *et al.* 2007), relatively low-cost and high-resolution Landsat is the platform most frequently used for research.

A number of recent studies have indicated that satellite imagery may be insufficient to understand land-use practices related to conservation. Researchers have found that forest impoverishment from logging and fires is not visible with Landsat analysis (Nepstad *et al.* 1999; Asner *et al.* 2003). More recent work found that selective logging was only visible in Landsat imagery with extensive analysis (Asner *et al*. 2005), and identified in Landsat and SPOT images only via the concentration of large gaps and linear skid trails (de Wasseige & Defourny 2004). Lu *et al.* (2003) noted that Landsat vegetation classification best correlates with stand height rather than biomass, making it difficult to distinguish between older successional stages. In addition, forest regrowth varies with edaphic, climatic, and forest use history, rendering site-specific the relationships among spectral properties and forest age (Vieira *et al.* 2003). As well, in the lowland tropics cloud cover often prevents satellite sensors from collecting reflectance data from vegetation (Asner 2001; Sano *et al.* 2007).

Questions remain as to what extent satellites' light reflectance values render accurate representation of social and ecological realities. We sought to address this issue by examining how satellite imagery portrays local Wounaan indigenous peoples' use of forest resources in eastern Panama. We asked whether and how Wounaan forest use histories are distinguished by vegetation patterns and how those same forest use histories are manifested in satellite imagery. These results have significant implications for conservation science and practice, as our work in the region indicates that conservation decisions are increasingly made using regional and national land cover data in office distant from field locales.

Study area

We carried out research in eastern Panama, an area of prominent conservation interest as part of the Darién/Chocó biogeographic region (Gentry 1986; Brooks *et al.* 2002). The area is dominated by lowland tropical moist forest and has a distinct dry season from December to April. Annual rainfall was 2000 to 2500 mm with temperatures averaging 27°C in the study village (Instituto Geográfico Nacional Tommy Guardia 2003). Wounaan indigenous peoples live in this region of eastern Panama and neighboring Colombia. Research was carried out in the Wounaan community of Majé (Figure 1), located in eastern Panama Province. It had 89 households in 2003.

Methods

Based on semi-structured interviews with a stratified random sample of 89% of heads of households we chose rice swiddens, homegardens, and selective tree harvest (for dugouts) as prominent forest uses for study. We also selected mature forest, uses of which include medicinal plant harvest, hunting, and fiber plant harvest. These land-use types represent differing land-use process (Appendix S1). For each land use we sought areas that were approximately 20, 10, and 1 year old in 2003 and for each age cohort of land use selected three sites at which to establish plots (Table 1). However, we found only two sites of 20-year-old rice swiddens.

At each site, we established 20 × 20 m vegetation plots with the consent and accompaniment of the landholders. We randomly selected plots of at least 10% of area or determined adequate sampling by the leveling off of a species-area curve. Single tree extraction plots were centered on the *Anacardium excelsum* (Kunth) stump. In homegardens, we mapped the entire garden and selected the area behind the house for a plot. Throughout each plot we mapped, tagged, and named all trees ≥ 10 cm diameter at breast height (DBH) and measured DBH, height, and crown width and diameter. We took the same measurements of all trees and saplings ≥ 1 cm DBH or taller than 1.3 m in the southeast 10 × 10 m of each plot. If individuals were palms, we measured leaf number, height to initiation of spear leaf, and placed a ring of cord around the spear leaf to record leaf productivity. In the center of each plot we used a Magellan 12XL geographic positioning system (GPS) to take a location reading, averaged over 2 minutes.

The lead author analyzed data using Minitab statistical software (Minitab, Inc., College Station, PA). The width and length of tree crowns were averaged into one crown diameter measure, which was used to calculate area of a circle for crown size. These crown sizes were square root transformed given their Poisson distribution (Sokal & Rohlf 2000). Importance value (IV) per species was calculated using IV = relative density + relative frequency + relative basal area. Tree height, DBH, and crown area were combined in a cluster analysis of plots using Ward's linkages and Euclidean distances (Shaw 2003).

We used path 11, row 54 of a Landsat Thematic Mapper image from 7 February 1985 and a Landsat Enhanced Thematic Mapper image from 31 December 2002 to examine vegetation patterns. These images represent different periods in the dry season; however, they were the most cloud free images available within a 2-year period of sought dates. The lead author analyzed data using ER Mapper software V. 6.3 (Earth Resources

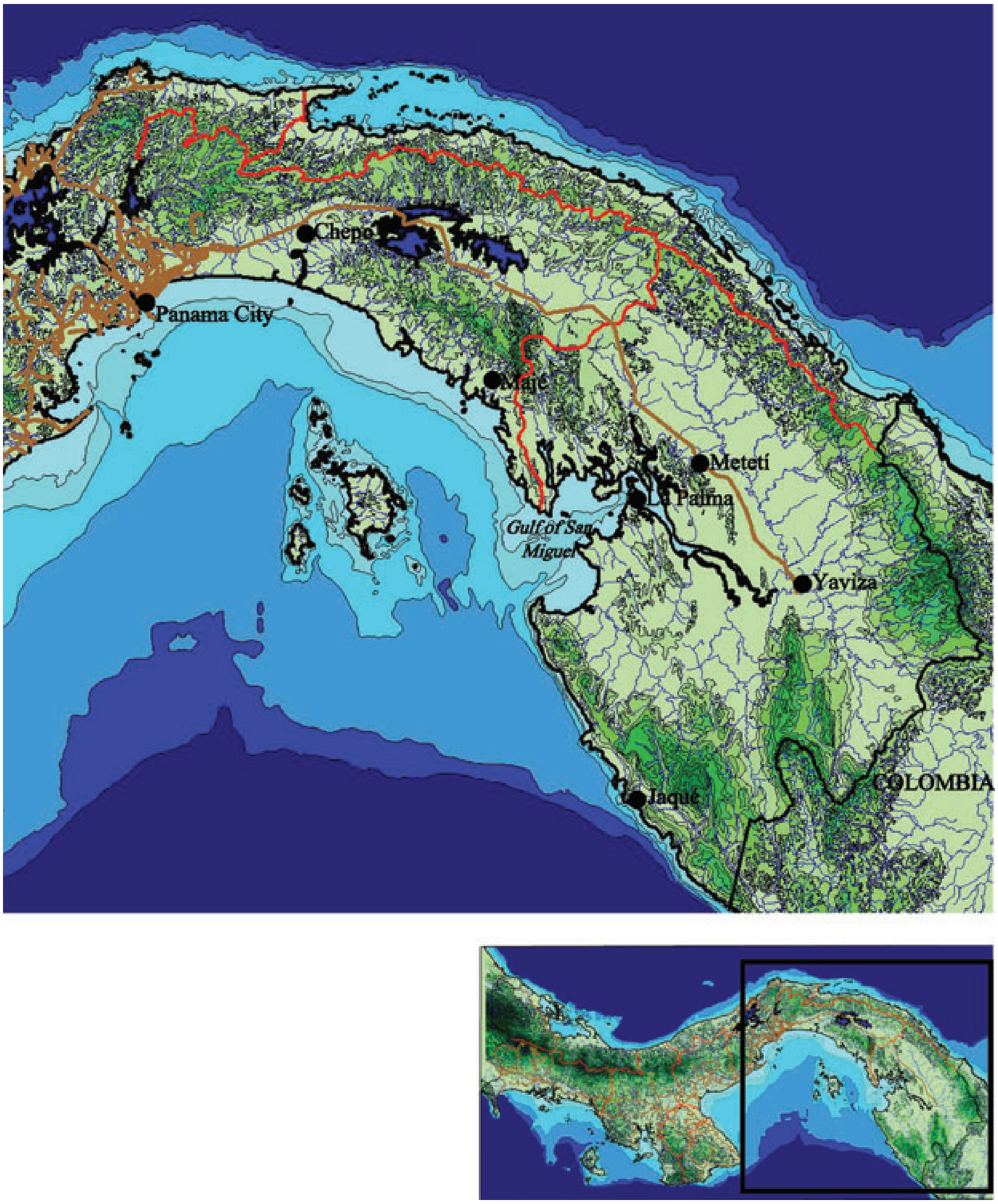

Figure 1 Map of eastern Panama.

Mapper, Perth, Australia). The 1985 image was georeferenced to the 2002 image using 10 ground control points with a root mean square error of less than one. Clouds and cloud shadow were masked using a supervised classification with maximum likelihood. Cover types were the same used by the Panamanian environmental agency for this area, with the young secondary forest category expanded to include more areas. The lead author selected training regions based on forest ecology fieldwork throughout the Landsat scene. A supervised classification was carried out to assess land cover types. The authors and community leaders walked the village boundary with a GPS unit to obtain a shape file of Majé lands. We discussed the image analyses and results with community members and leaders in 2004 and 2005.

Results

We found that vegetation could be differentiated between these land-use plots, using common indicators of forest structure and species diversity. Multi-use mature forest had the highest basal area, high density, and most

Table 1 Plot characteristics

Land-use type	Site age (in 2003)	Site area (m^2)	Site ID #	Plots per site
Multi-use mature	NA	>240,000	10	4
Forest	NA	>240,000	15	4
	NA	>240,000	19	4
Rice Swidden	26	15,600	3	4
	21	5,400	2	2
	12	4,000	6	1
	12	10,800	8	3
	10	7,500	5	2
	1	4,000	4	1
	1	4,800	7	1
	1	8,400	9	1
Homegarden	23	2,198	30	1
	19	1,166	29	1
	20	1,036	28	1
	9	418	27	1
	10	945	26	1
	10	383	25	1
	1	864	24	1
	1	316	23	1
	1	326	22	1
Single tree	18	400	11	1
extraction	21	400	14	1
	22	400	21	1
	12	400	12	1
	11	400	13	1
	10	400	1	1
	1	400	16	1
	1	400	17	1
	1	400	18	1

diversity (Table 2) for stems $\geq$ 10 cm DBH. The combination of high density with high diversity meant that the importance value of the five most dominant species was fairly low, at 24%. Sites of single tree extraction were most similar to mature forest; however, the lower basal area in these plots results from removing the dugout tree, which averaged 191 cm basal diameter. Diversity indices for stems $\geq$ 10 cm DBH were low for single tree extraction sites because these plots, unlike the others, are in mature gallery forest, where the dugout species *A. excelsum* is distributed and where roughly hewn boats are easier to push out.

The rice swidden data illustrate greater vegetation complexity with age since swiddening (Table 2). Basal area, density, and diversity increase over time and as a result the importance percentage of the five most dominant species decreases. These older swiddens have higher density than mature forest, likely a result of increased light. Homegardens also demonstrate increasing vegetation complexity over time. However, the diversity of homegardens sites is quite low: even in 20-year-old homegardens the majority of stems are composed of five dominant species. Differences in structural complexity of these land-use types were also indicated by diameter histograms (Appendix S2).

A cluster analysis using DBH, height, and square root normalized crown area of trees greater than 10 cm DBH revealed that plots tend to group together based on their land use and age (Figure 2). The mature forest plots clustered together, and the 10- and 20-year-old homegardens were most similar to these, a result of trees in larger sizes classes. The 10- and 20-year-old swiddens also grouped together. Several mature forest plots are mixed in with the swiddens as a result of logging proximate to one mature forest site. The young swiddens and homegardens with few or no trees formed their own cluster.

Floristics, displayed by importance percentage, also distinguished the land-use types and their ages (Table 3). Mature forests had slow-growing species, such

Table 2 Summary statistics of trees $\geq$10 cm DBH by land-use type

Land-use type ~ age in 2003	Basal area (m^2/ha)	Density (per ha.)	Shannon div index	Simpson div index	Imp% (5 Dom Spp)
Multi-use mature forest	41.96	510	1.62	0.97	24
Rice Swidden					
20	18.55	645	1.35	0.94	34
10	12.13	550	1.21	0.92	56
1	0	0	0	0	0
Homegarden					
20	23.01	308	0.95	0.86	68
10	3.74	308	0.73	0.86	88
1	0	0	0	0	NA
Single tree extraction					
20	18.49	508	1.15	0.89	47
10	28.27	416	1.14	0.92	62
1	23.14	258	1.24	0.95	51

Figure 2 Cluster analysis of multi-use mature forest, Swidden, and Homegarden Plots in Majé.

as *Manilkara zapota* and *Copaifera aromatica* (see Correa *et al.* 2004 for species authorities). The single tree extraction sites had slow-growing, mature forest species, such as *Quararibea asterolepis* and *M. zapota*, species found in moist soils, such as the palm *Socratea exorrhiza*, and shade intolerant species, e.g., *Cecropia peltada*. Rice swiddens of all ages were dominated by shade intolerant species, such as *C. peltada* and *Apeiba tibourbou*. Dominant homegarden species were all fruit trees, most commonly the exotics *Mangifera indica*, *Cocos nucifera*, and *Musa paradisiaca*. Of the approximately 170 tree species found in all plots, only seven were also found in homegardens, indicating the high degree of Wounaan homegarden management. Given land-use differences apparent in vegetation plots, we sought to examine whether remotely sensed satellite imagery also revealed land use. However, the prevalence

Table 3 Dominant species (of stems $\geq$ 10 cm DBH) per land-use type

Land-use type ∼age in 2003	1st importance %	2nd importance %	3rd importance %	4th importance %	5th importance %
Multi-use mature forest	*Cavanillesia platanifolia*	*Castilla elastica*	*Manilkara zapota*	*Simaba cedron*	*Copaifera aromatica*
Rice Swidden					
20	*Pera arborea*	*Apeiba tibourbou*	*Schefflera morototoni*	*Miconia argentea*	*Plumeria rubra*
10	*Cecropia peltada*	*Apeiba tibourbou*	*Trichospermum galeottii*	*Schefflera morototoni*	*Annona spraguei*
1	–	–	–	–	–
Homegarden					
20	*Mangifera indica*	*Cocos nucifera*	*Inga spectabilis*	*Syzgium malaccense*	*Musa paradisiaca*
10	*Mangifera indica*	*Cocos nucifera*	*Carica papaya*	*Citrus sinensis*	*Musa paradisiaca*
1	–	–	–	–	–
Single tree extraction					
20	*Castilla elastic*	*Manilkara zapota*	*Cecropia peltada*	*Socratea exorrhiza*	*Astrocaryum standleyanum*
10	*Quararibea asterolepis*	*Solanum hayesii*	*Castilla elastica*	*Inga urceolata*	*Astrocaryum standleyanum*
0	*Manilkara zapota*	*Apeiba tibourbou*	*Dipteryx oleifera*	*Castilla elastica*	*Pera arborea*

of cloud cover and cloud shadow prohibited analyses of land cover change between 1985 and 2002 across this landscape (Appendix S3). Instead, this allowed us to focus on land cover in the Majé community.

In the analyzed satellite images Majé's lands are bounded by the pink line and the village center is indicated by the purple squares of homegarden plots (Figure 3). In the 1985 images the now 20-year-old sites were recent. In both the unclassified and classified images, mature forest plots are clearly located within the forest areas. The single-tree harvest plots also appear as forested pixels. That is, the removal of the dugout tree, creating a hole in the overstory canopy of about 27 m in diameter (using the measurements of 10 dugout-sized *A. excelsum* trees) or almost an entire pixel (28.5 m), could not be distinguished from the surrounding forest. The six plots composing the swidden sites class out appropriately as young secondary forest. The three homegarden plots class out as grass because the spectral signature of bare earth around plants is similar to that of dry grasses and bare earth. Additional nonplot results of satellite image analyses are found in Appendix S4.

In the 2002 images the full sequence of plots is illustrated (Figure 3, lower images) and detailed in Table 4. The mature forest plots remain classified as mature forest. The single-tree harvest sites remain classed as forest, except one site classified as secondary forest that was harvested in 2002. Interestingly, the gallery forest along which *A. excelsum* trees are naturally distributed are readily indicated by the dark green linear features in this early dry season image. Half of the 20-year-old swiddens class out as young secondary forest and the remainder, along with all of the 10- and 1-year-old swiddens are classed as mature forest. Homegarden sites class out grass-dominated sites with a 1-year-old classed as mature forest.

Discussion

We found that much Wounaan forest use could not be distinguished using analyses of Landsat satellite images, particularly fine scale and historic uses. Selective harvest of large trees, most of the rice swiddens, and one homegarden site were not distinguishable from mature forest using Landsat satellite imagery and broad supervised classification methods. We selected forest uses that would be most visible across a landscape scale; however, a number of important, additional Wounaan uses are likely to remain illegible in satellite imagery. For example, small sugar cane fields, nontimber forest products, including the economically important basketry and wood carving species, and construction materials are not visible in such commonly used satellite imagery.

These findings have substantial implications for how conservation is practiced given the significant reliance on satellite imagery and analyses for conservation planning and science. Dependence on satellite imagery may overlook significant socioecological dynamics and histories. For example, by obscuring use, such as selective logging or afforestation, satellite imagery has the potential to make illegible the people and communities that depend on forest resources. As a result, people may be unintentionally removed from satellite imagery based maps even as conservation science has sought to incorporate human inhabitation and resource use into its assessment activities. This is compounded when cultural features, such as roads and villages, are not indicated on maps, and when planning is done at regional, national, and international scales with minimal fieldwork. As a result, inhabited and utilized areas may be unintentional targets of strict preservation or nonuse zones. Satellite imagery may thus be a threat to effective conservation planning, as well as the ally that it is commonly understood to be.

Satellite imagery may encourage a people–nature dichotomy as a result of how data are displayed. Even with hyperspatial sensors, such as IKONOS and QuickBird, satellite image derived maps are usually displayed in the two ways shown in Figure 3—as true color images or as classified vegetation cover types. Although they may have been made to illustrate other patterns, the impression one gets from areas classified as mature forest, is of peopleless mature forest. This implication is apparent in Panama's recent forest cover map (Autoridad Nacional del Ambiente 2002). In that map, the heavily fragmented areas throughout the country are obvious by their beige colors and extreme heterogeneity, and one assumes human inhabitation and use. But, the expanses of forested green, including the Majé region, have an implication of peopleless nature. This map is both reinforced by and reinforces the popular perception of pristine biodiversity in eastern Panama. As such, the use of satellite images suggests Jim Scott's (1998) idea of legibility, the process, historically by the state, of simplifying and translating complex traditions so that they are more manipulable. Scott found that such simplifications did not successfully represent the actual activity of the society they depicted, but rather only the portion that interested the official observer. When combined with state power such simplifications enabled the remaking of much of the reality they depicted (Scott 1998).

The use of satellite imagery based maps may also impact conservation policy and practice. This may be illustrated in the use of satellite imagery analyses to target

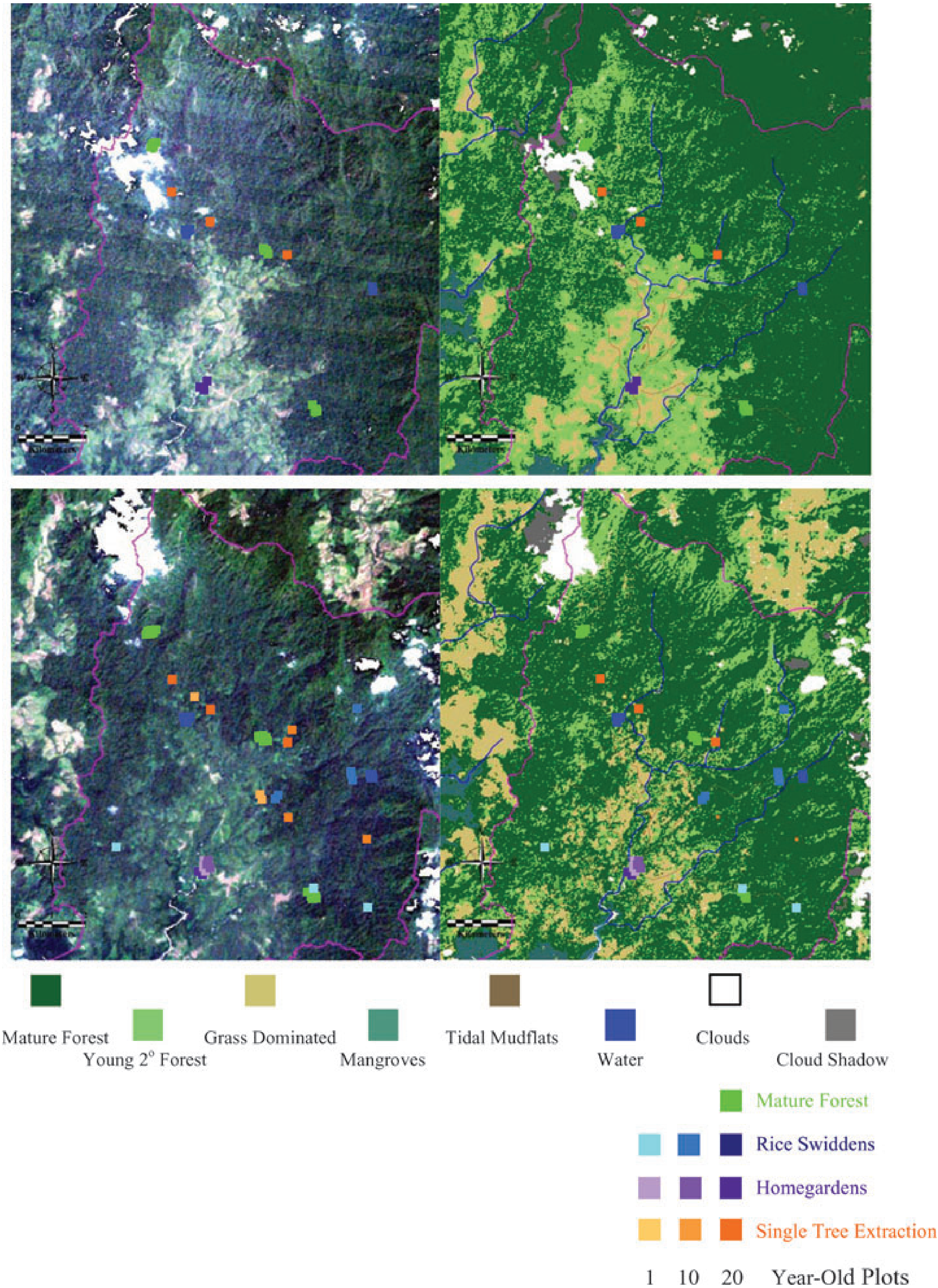

Figure 3 Majé landscape in 1985 (upper) and 2002 (lower). Left: display in true color 321-RGB. Right: land covers as per supervised classification. Based on Landsat TM image from 07 February 1985 and Landsat ETM image from 31 December 2002.

Table 4 Plot characteristics

Land-use type	Age class (in 2003)	Site and plot ID	Pixel classification from supervised classification
Multi-use mature forest	NA	10A	Mature forest
Multi-use mature forest	NA	10B	Mature forest
Multi-use mature forest	NA	10C	Mature forest
Multi-use mature forest	NA	10D	Mature forest
Multi-use mature forest	NA	15A	Mature forest
Multi-use mature forest	NA	15B	Mature forest
Multi-use mature forest	NA	15C	Mature forest
Multi-use mature forest	NA	15D	Mature forest
Multi-use mature forest	NA	19A	Mature forest
Multi-use mature forest	NA	19B	Mature forest
Multi-use mature forest	NA	19C	Mature forest
Multi-use mature forest	NA	19D	Mature forest
Rice Swidden	20	3A	Mature forest
Rice Swidden	20	3B	Young secondary forest
Rice Swidden	20	3C	Young secondary forest
Rice Swidden	20	3D	Young secondary forest
Rice Swidden	20	2A	Mature forest
Rice Swidden	20	2B	Mature forest
Rice Swidden	10	6A	Mature forest
Rice Swidden	10	8A	Mature forest
Rice Swidden	10	8B	Mature forest
Rice Swidden	10	8C	Mature forest
Rice Swidden	10	5A	Mature forest
Rice Swidden	10	5B	Mature forest
Rice Swidden	1	4A	Mature forest
Rice Swidden	1	7A	Mature forest
Rice Swidden	1	9A	Mature forest
Homegarden	20	30A	Grass-dominated
Homegarden	20	29A	Grass-dominated
Homegarden	20	28A	Grass dominated
Homegarden	10	27A	Grass-dominated
Homegarden	10	26A	Grass-dominated
Homegarden	10	25A	Grass-dominated
Homegarden	1	24A	Mature forest
Homegarden	1	23A	Grass-dominated
Homegarden	1	22A	Grass-dominated
Single tree extraction	20	11A	Mature forest
Single tree extraction	20	14A	Mature forest
Single tree extraction	20	21A	Mature forest
Single tree extraction	10	12A	Mature forest
Single tree extraction	10	13A	Mature forest
Single tree extraction	10	1A	Mature forest
Single tree extraction	1	16A	Young secondary forest
Single tree extraction	1	17A	Mature forest
Single tree extraction	1	18A	Mature forest

areas for both conservation and use. In Panama, all mature forest is property of the state and may not be titled without a forest management plan. In the last 5 years, the government has analyzed satellite imagery for vegetation, making visible vast land cover patterns. These analyses have allowed the environmental agency to pinpoint sites for new protected areas as well as for use via forestry concessions. In 2005, the environmental agency placed a forestry concession on Majé lands given its mature forest and lack of land title. This, together with diminishing indigenous rights via changes to the environmental law, has undermined rights and fueled social conflict. The stakes in getting analyses wrong include not only misreading the landscape (sensu Fairhead & Leach 1996), or the need to replan conservation activities, but also local peoples' loss of their lands.

This research highlights some of the real-world implications of shifting technologies for making sense of the world and acting in it. Clearly, there is a loss of resolution in the move from more hands-on to more remote technologies for conservation and landscape assessments. Yet, the very intelligibility of satellite image-derived maps is what makes them so seductive. They represent what Scott (1998) has termed high modernist ideology, that is, elements of an uncritical faith in the objectivity of technology. As tools such as Google Earth become increasingly common there seems to be an increasing tendency to understand satellite images as photographic truth rather than analyzed data. As a result, satellite imagery may further conservation's privileging of the visual, biophysical world, with less consideration for history, economics, culture, and power.

We are not implying that satellite imagery should be avoided; rather we suggest the use of multiple methods to make assessments, the active questioning of data and analyses, and significant discussion on the possible implications of analytic choices. We encourage the use of satellite imagery with mixed methods, in which different methods are used to study the same facet of research, especially over multiple temporal and spatial scales (Robbins & Maddock 2000; Turner 2003). Such methods can repeople a landscape, see communities, households, and livelihoods, but also see forests as part of larger landscapes. For example, during interviews and participant observation of forest use and history in Majé we learned that nonforest income generating activities, such as commercial shrimping and clamming, decreased the need to earn income via swiddening, thereby conserving forests. It is a multiplicity of methods, not necessarily laborious plots, but also multi-scalar sampling design, expert interviews, participatory mapping, repeat photography, and collaborative studies, together with satellite image analysis that can strengthen research and conservation by allowing researchers to understand landscapes differently, if not necessarily better. In addition, conservationists should critically assess methods, data, and analyses. This is particularly important given the increasing use of satellite imagery in advocacy (Mather 2005; Baker &

Williamson 2006) and monitoring legal compliance, such as deforestation limits on private parcels in Brazil and those receiving environmental services subsidies in Mexico. We simultaneously recognize that conservation cannot be paralyzed by inevitably imperfect or incomplete knowledge, and therefore suggest that significant attention is paid to the possible implications of methods and analytical choices.

Conclusion

We found that swiddens, single tree extraction, homegardens, and mature forests used by Wounaan could be discerned by the structure and floristics of chronosequences of vegetation plots. However, these forest uses were largely invisible in analyses of the same plots in Landsat satellite imagery. Our research underscored some of the limitations of utilizing satellite images, particularly at regional or landscape scales, in the absence of additional local data. We use our results to examine the increasing role of satellite image analyses in conservation work, questioning the presumed objectivity of satellite image based maps. In this study, the use of multiple methods and scales allowed us to understand the complexities of our data. To prevent the obscuring potential of satellite image analyses, we encourage the use of mixed methods at multiple temporal and spatial scales, as well as the critical reflection of our use of satellite image derived maps.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1 Descriptions of land use

Appendix S2 Diameter at breast height (DBH) distributions by land-use type

Appendix S3 1985 and 2002 Landsat images with cloud and cloud shadow masked with maximum likelihood supervised classification displayed in true color 321-RGB

Appendix S4 Additional nonplot results of satellite image analyses

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