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Changes in the Socio-Ecological System of a Protected Area in the Yucatan Peninsula: A Case Study on Land-Use, Vegetation Cover, and Household Management Strategies

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Abstract: Protected areas (PA) are effective means for protecting biodiversity, but less is known about their effect on the social-ecological system (SES). Using a semi-experimental approach and a descriptive case study based evaluation, we analyzed the effect of a PA in the Yucatan Peninsula on land-cover and household resource management strategies in time and space (before and after the PA establishment; inside and outside its limits). To assess the changes of land-use practices in the areas surrounding the communities inside and outside the PA, and their change over time (from 2003 to 2015), we used remote sensing analysis and semi-structured interviews. Our results show that after the PA was established, the forest increased and agricultural plots decreased inside and to a lesser extent outside the PA. However, fires reduced the area of old-growth forest and increased young secondary forest, highlighting the system's vulnerability to uncommon events. Resource management strategies were also affected: while inside the PA households tended toward specializing on tourism, outside the PA household strategies implied a diversification of productive activities. Overall, the establishment of the PA proved to be an effective tool to promote forest recovery and prevent deforestation in the regions surrounding the communities both inside and outside the PA.

Keywords: land cover; milpa agriculture; productive activities; remote sensing; descriptive case study-based evaluation; Yucatan Peninsula

1. Introduction

Social-ecological systems (SES *sensu* Berkes and Folke [1]) are complex, open, and dynamic systems where humans and nature are coupled. In these systems, the local use of resources shapes the ecosystem leading to continuous cycles of perturbation and

adaptation, ultimately determined by the resilience of the system [1]. Although SES can remain in the same state for a long time, they are not immune to new disturbances. Joint social and ecological approaches are useful to understand and predict their change and resilience, which will ultimately determine how humans appropriate natural resources, including during periods of unpredictable disturbances.

Protected Areas (PAs) are institutions that regulate the use of natural resources in bounded geographic regions [2] and can be defined at different spatial, temporal, and organizational scales [3]. PAs are also a prominent policy tool for the conservation of biodiversity [4], expected to reduce deforestation, maintain the ecological integrity of ecosystems, and mitigate impacts from climate change [5,6]. Common ways to assess PAs conservation effectiveness include monitoring the preservation and recovery of biodiversity, mostly through species richness and indicator species, and evaluating rates of land conversion, mostly through remote sensing analysis (e.g., [7–9]). However, as the regulations on the use of resources apply only within the PA boundaries, the pressure on resources is often spatially displaced but not eliminated (e.g., [10–13]), raising questions on their overall conservation role at a larger scale.

In addition to reducing deforestation and maintaining the ecological integrity of ecosystems, there has been a paradigm shift in how PAs should operate: from the island approach or “fencing nature” where the use of resources is spatially restricted, to the social-ecological approach or creating “networks of nature” that transcend the PAs boundaries [14,15]. Under the latter vision, PAs should acknowledge the complexity of social–ecological interactions and conserve resources for the benefit of people and nature, and integrate local interests and participation in conservation projects [16]. As Mertz and Mertens argue [17], this paradigm shift is part of the debate on whether spared landscapes without any human interference (island approach) are better at conserving natural forests and habitats for endangered species than shared landscapes (social-ecological approach), where agriculture and forests are both present and interact, such as shifting cultivation or other agroforestry systems in the tropics.

Recent calls for evidence-based conservation and management policy design have highlighted the need to identify the specific factors that contribute to the success of PAs, both in ecological and social terms (e.g., [18–20]). The SES framework has been proposed as a useful tool for this, as it allows to identify trade-offs between the ecological and social components of a system (such as biodiversity vs. livelihood priorities), and formulate achievable goals [21,22]. According to McShane et al. [23], ‘in conservation and development, trade-offs are the norm.’ Assessing the integrated effects of PAs through a SES approach can provide robust information on the long-term conservation of ecosystems, while shedding light on the drivers that promote the resilience and thresholds in the system dynamics [3,14]. In this sense, case studies that incorporate data at different scales, including village or household level, can serve to evaluate different ways in which PAs shape the dynamics of the SES [24,25]. As Kovács et al. [26] argue, we have to be conscious that in many cases PAs lead to land-use change, which consequently causes trade-offs between the ecological and the social systems. These trade-offs result in changes in the beneficiaries, which might lead to conflicts between certain stakeholder groups.

One way to determine the overall role of PAs in the dynamics of the SES is by estimating the change in ecological and social indicators at different temporal and spatial dimensions. For this, we conducted a study in a PA in the Yucatan Peninsula that has two decades of being officially decreed as protected. People living in the area are indigenous Yucatec Maya, and most preserve many of their ancient cultural traditions, such as language, religious ceremonies, and traditional natural resource management. As it has been widely documented [27,28], Yucatec Mayas have historically managed biodiversity through a diversified strategy of natural resource use. Within this strategy, producers take advantage of the simultaneous development of various productive activities both for self-sufficiency and the market while ensuring food security and subsistence. Diversification reduces the risks associated with external socioeconomic shocks (e.g., changes in prices or lower demand)

or ecological events (e.g., hurricanes or droughts) [28,29]. Yucatec Maya natural resource management involves a lower output per unit of land compared with specialized resource management. However, the Yucatec Maya natural resource management strategy has great value because the permanent, dynamic system is based on the benefits of diversity [27,28]. Therefore, instead of maximizing areas of monoculture or specializing in one economic activity, the strategy maintains diversity through the utilization of many land-use units available for different economic activities.

The natural resources management in the PA we studied involves the management of different land-use units (milpa plot, home gardens, secondary forest, old-growth forest, and water-swamp vegetation), and within those units a number of economic activities, either subsistence and/or market-oriented, are implemented with the objective of maximizing the number of available options. Some economic activities are traditional (e.g., milpa agriculture, beekeeping, home gardening, gathering, and hunting), while others have been recently incorporated to their management strategy (e.g., ecotourism, handcraft production, and charcoal production). Not all households manage all the different land-use units or implement all the economic activities. That depends on the availability of household labor, their income level, how bilingual are the members of the household, among other variables. This management strategy is based on local ecological knowledge and it is constantly adapting to social, economic, and ecological changes.

Once the PA was established, one of the main regulations on land use prohibited milpas, as they were perceived by conservation authorities as the main threat to old-growth forest conservation [29,30]. This regulation reproduces dichotomies, such as the spatial segregation of conservation and agricultural activities, promoted by the land-sparing paradigm [31]. Given that scenario, García-Frapolli et al. [29] developed models to predict possible trajectories of land-use and cover change within the reserve, hypothesizing that in the short- and mid-term, the rate at which milpa agriculture was being carried out would not affect the cover of old-growth forest, as the practice was regulated by local institutions. The same authors also predicted that land-use regulations would intensify the agricultural activity outside the limits of the PA and would disrupt the local productive system that was based on traditional activities and traditional knowledge [29]. In the present study, through a descriptive case study, we analyze the effects that restrictions on land-use associated with the establishment of the PA had on the local SES in terms of changes in (1) vegetation and land cover and (2) household management strategies. To do so, we evaluated these changes over time, before (2003) and after (2015) the PA establishment, and over space, exploring the differences between communities located inside and outside of the PA.

There is still a limited understanding of the conditions that contribute to PAs effectiveness, as well as their overall effect on the dynamics of SES in the context of rural communities. Our study contributes to understanding the effects that PAs have on land cover and households' resource management strategies through time, within and surrounding their limits. This approach is relevant because many studies have analyzed only what happens inside PAs (e.g., [32,33]). In addition, it underscores the importance of the changes that PAs impose beyond its boundaries, providing more elements for evaluating whether these conservation tools can contribute to sustainable SES.

2. Materials and Methods

2.1. Study Site

Otoch Ma'ax Yetel Kooh (OMYK) is a "Flora and Fauna Protection Area" (IUCN Category VI) and is also included in a list of wetland sites of international importance under the Ramsar Convention. OMYK is located in the northeastern region of the Yucatan Peninsula (Figure 1). Its vegetation is semi-evergreen forest in different stages of succession (from recently abandoned milpas to forest older than 50 yrs). Despite its relatively small area (5367 ha), OMYK harbors a high biodiversity: at least 215 bird, 22 mammal, and more than 200 plant species [34]. One of the most salient features of the site is a healthy population of

spider monkeys [35], which prompted the inclusion of the PA among the priority sites for primate conservation in Mexico [36].

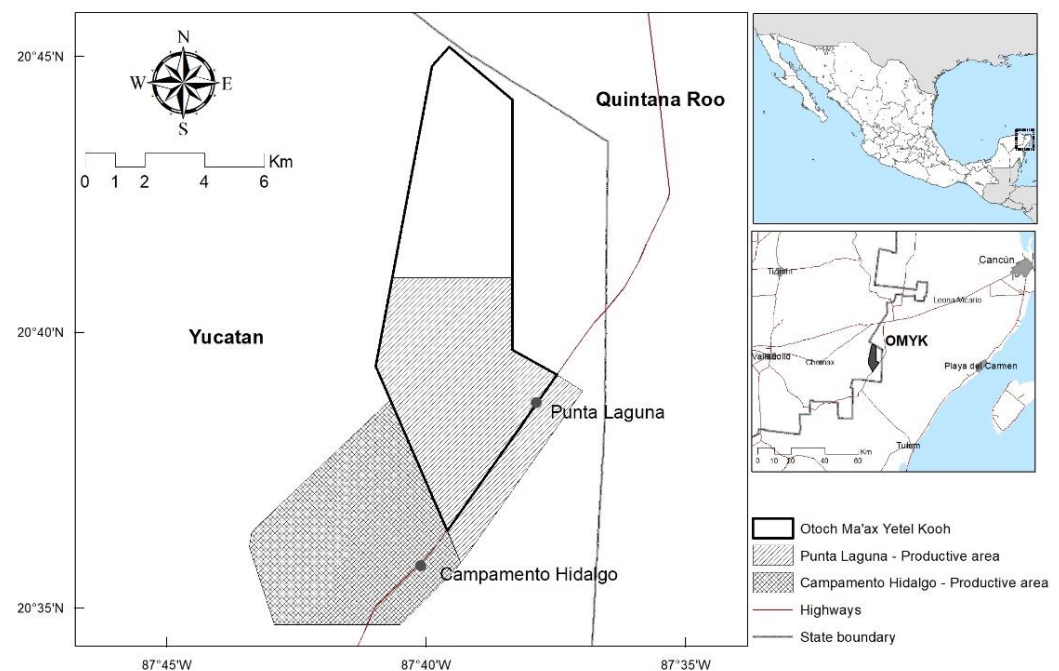


Figure 1. Location of Otoch Ma'ax Yetel Kooch (OMYK). Dashed areas represent the focal area of interest around the communities of Punta Laguna and Campamento Hidalgo where households implemented productive activities.

Local conservation efforts started in the 1980s as a community-based initiative with the support of researchers and a local NGO, leading to the decree of the PA in 2002 [37]. For the community, the PA decree was instrumental for the promotion of tourism activities and thus increased the flow of tourists to the community. At the time of the PA establishment, Punta Laguna (hereafter PL) and Yodzonot were the two communities settled within the PA, whereas nine communities were located within the buffer zone being Campamento Hidalgo (hereafter CH), the largest and closest to the PA (Figure 1, [34]). However, after the PA establishment, people from Yodzonot migrated to PL.

2.2. Data Collection and Analysis

To determine whether land regulations associated to the establishment of the PA, particularly the banning of milpa agriculture, promoted the change in land covers, and land-use practices, we used a semi-experimental approach [38,39] to estimate the changes in land cover extent and in the number of productive activities by households at two different dimensions: (1) temporal, considering before and after OMYK's establishment; (2) spatial, considering inside and in the surrounding area of OMYK. Our study provides a descriptive, rather than a statistical evaluation, of the effects of a PA on land cover and productive activities.

2.3. Land-Cover Change Inside Otoch Ma'ax Yetel Kooch

For the temporal analysis of land-cover change within the PA limits, we used a 2003 cover classification as a baseline, created from a SPOT image (5 m) (Appendix A). For this classification we interpreted and digitized following differences in colors, patterns, and textures (IDRISI Kilimanjaro GIS software, Newton, MA, USA). The 2015 classification was created from a Rapid Eye image (6.5 m), which was classified using the supervised method of maximum likelihood (ENVI 5.3 GIS software). Both images (2003 and 2015) were from February (dry season, <15% cloud cover) and were geometrically and atmo-

spherically corrected under the Mercator Transversal coordinate system WGS84 Zone 16N. For both classifications, we relied on aerial photographs and field control points (400) assisted by local guides, experts on the history of local vegetation and land use [29,40]. Six land-cover classes were defined: (1) old-growth forest (woody vegetation >50 years old; mature forest or without apparent disturbance); (2) medium secondary forests (woody vegetation 16–50 years old; forest in medium stages of succession); (3) young secondary forest (woody vegetation < 15 years old; forest in early stages of succession); (4) agriculture (milpa); (5) urban areas (human settlements or paved roads); (6) water. To improve the accuracy of both classifications, we applied a post-classification process by interpreting and manually digitizing images based on color, shape, and texture using as reference either aerial photographs (1:15,000, for the 2003 classification) or GeoEye Satellite images (for the 2015 classification). For the 2003 classification, 90% of 128 verified sites within the PA were correctly assigned [29]. For the 2015 classification, we used 100 verification points to calculate the confusion matrix and Cohen's Kappa statistic. The overall accuracy was 83% with a Kappa index of 0.79. For both classifications, we calculated the surface (area and percentage) of cover categories using the AREA tool (IDRISI 17.0 Taiga).

We estimated changes in land cover and vegetation during the study period using the Land Change Modeler (LCM) extension in IDRISI 17.0 Taiga (Clark Labs, 2009). With this information we (1) constructed a transition matrix; (2) estimated gain, loss, swap, persistence, and net and total change for each class; (3) mapped the spatial distribution of woody vegetation persistence, gains and losses.

Additionally, due to a series of fires that occurred between 2006 and 2011 in the northern part of the PA (see Results section), we ran an additional analysis excluding this area (ERASE tool; IDRISI 17.0 Taiga) and calculated the surface of the old growth, medium secondary, and young secondary forests without the effect of the fire using the AREA tool (IDRISI 17.0 Taiga).

2.4. Land-Use Change within and Outside Otoch Ma'ax Yetel Kooch

To evaluate the temporal and spatial cover change within and outside OMYK, we estimated the cover change in the areas surrounding the communities inside (PL) and outside (CH) the PA, and compared their land-cover area before (2003) and after (2015) the establishment of the PA (Figure 1). To determine the surrounding areas for each village, we delimited a 1 km² buffer around the largest concentration of households as the focal area. We determined this buffer based on the average distance that locals reported to walk to their milpas [29] and our knowledge on the locations used for productive activities and confirming it did not include areas used by other communities. These focal delimitations around communities made possible having equivalent comparisons between the “productive areas” of the both communities, where most changes would be detected.

We estimated land-use and vegetation cover at both sites using the SPOT (2003) and Rapid Eye (2015) images (Appendix A), following the same procedure described in Section 2.3. However, for this analysis we were mostly interested in determining milpa and forest cover change and categorized four cover classes: forest (which included all three woody vegetation categories, from recently abandoned to old growth forests), milpa, urban area, and water bodies. We only used these cover classes because we were mostly interested in documenting their change (particularly of milpa and forest covers), within the focal areas. We calculated the surface (area and percentage) of each class (AREA tool; IDRISI 17.0 Taiga).

2.5. Household Land-Use Practices and Management Strategies

To evaluate the temporal and spatial change of land-use practices and natural resource management strategies at the household level, we used quantitative information collected through semi-structured interviews. We obtained this information at household level from the community inside the PA (PL) and outside the PA (CH), in 2004 and 2015.

Field work included visits to the households and to the sites where productive activities were conducted (e.g., milpas, orchards, beehives, charcoal). For the semi-structured interviews, we used the typology of natural resource management strategies defined by [29] where, according to their context (e.g., economic, social, location, access to resources), households implement the strategy that best suits their needs. The productive activities within each management strategy range from self-sufficiency to income oriented. These management strategies included: (1) *Traditional*, where households are dedicated mainly to milpa agriculture; (2) *Service-oriented*, where households are dedicated mainly to tourism, assistance to researchers or work outside the community; (3) *Traditional/service-oriented*, including households combining traditional agriculture and services. In 2004, we conducted a total of 36 interviews (22 in PL and 14 in CH; [29]). In 2015, we conducted 43 interviews (22 in PL and 21 in CH). This sample represented 92% of the households in PL during both years, and 67% and 100% in CH in 2004 and 2015, respectively. Questions covered topics related to the implementation of economic activities, time dedicated to each activity, yields obtained, characteristics of milpa plots (size, distance, number of crops), labor allocation, and incentives. The obtained information allowed to configure the different typologies of natural resource management strategies at the household level.

We built four databases, one for each community (PL and CH) for each year (2004 and 2015; before and after PA establishment). We compiled the information at the household level for each community and compared the data within and between communities to determine the temporal and spatial change in economic activities. We used descriptive statistics and calculated the percentages of households dedicated to different activities per community given the number of times respondents reported on the different items.

3. Results

3.1. Land-Cover Change Inside Otoch Ma'ax Yetel Kooh

During both years, the medium secondary forest was the most extensive vegetation (over 70%; Table 1, Figure 2) and the cover with the largest persistence throughout the studied period (89%; Table S1). After the establishment of the reserve, the young secondary forest was the only cover experiencing a net increment in area (almost 300 ha). Remaining covers showed a reduction from their original area, with milpa showing the largest decrease, followed by the medium secondary and old forests (Table 1). Although all land-covers experienced changes, the vast majority of the area remained unchanged (71.7%; Table S1).

Table 1. Cover classes in area (ha) and percentage (in parenthesis) within OMKY before (2003) and after (2015) the PA establishment.

Land Cover	2003	2015	Net Change
Milpa	150.8 (2.8%)	2.1 (0.04%)	−148.8 (−2.8%)
Young secondary forest (<15 years)	686.6 (12.8%)	983.6 (18.3%)	297.0 (5.5%)
Medium secondary forest (16–50 years)	4096.6 (76.3%)	4028.2 (75.0%)	−68.4 (−1.3%)
Old growth forest (>50 years)	212.3 (4.0%)	149.4 (2.8%)	−62.9 (−1.2%)
Urban	11.3 (0.2%)	5.2 (0.1%)	−6.1 (−0.1%)
Water-Swamp vegetation	212.1 (3.9%)	201.3 (3.7%)	−10.8 (−0.2%)
Total	5369.8	5369.8	

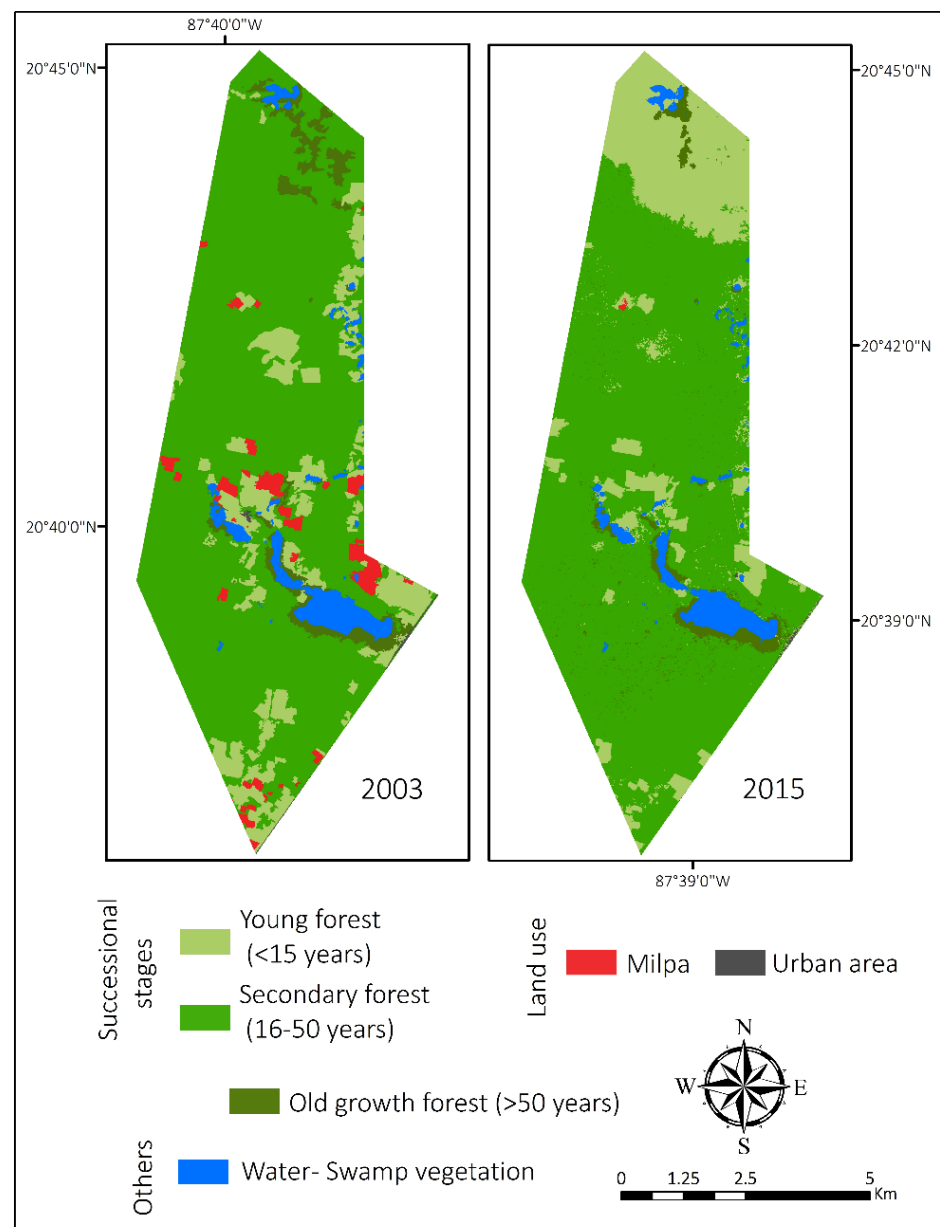


Figure 2. Land cover in OMKY before (2003) and after (2015) the PA establishment.

After the establishment of the reserve, land covers related to human activities decreased (Table 1; Figure 2). Milpas showed the greatest reduction (almost 150 ha). When milpas were no longer allowed inside the PA, active milpas were abandoned and became young secondary forests. Milpa cover almost completely disappeared by 2015. Urban cover lost almost half of the original extent, due to the abandonment of the Yokdzonot village. By 2015, the combined area of milpa and urban area occupied less than 1% of OMYK's surface, indicating anthropogenic covers had become almost undetectable inside the PA.

The gain in young secondary forest was the result of natural regeneration explained partially by the abandoning of milpas, but mostly by the loss of over 750 ha of medium secondary and old-growth forests, due to two fires that occurred between 2006 and 2011 in the northern part of the PA (Figure 3; Table S1). No reforestation planting practices have been conducted in the area.

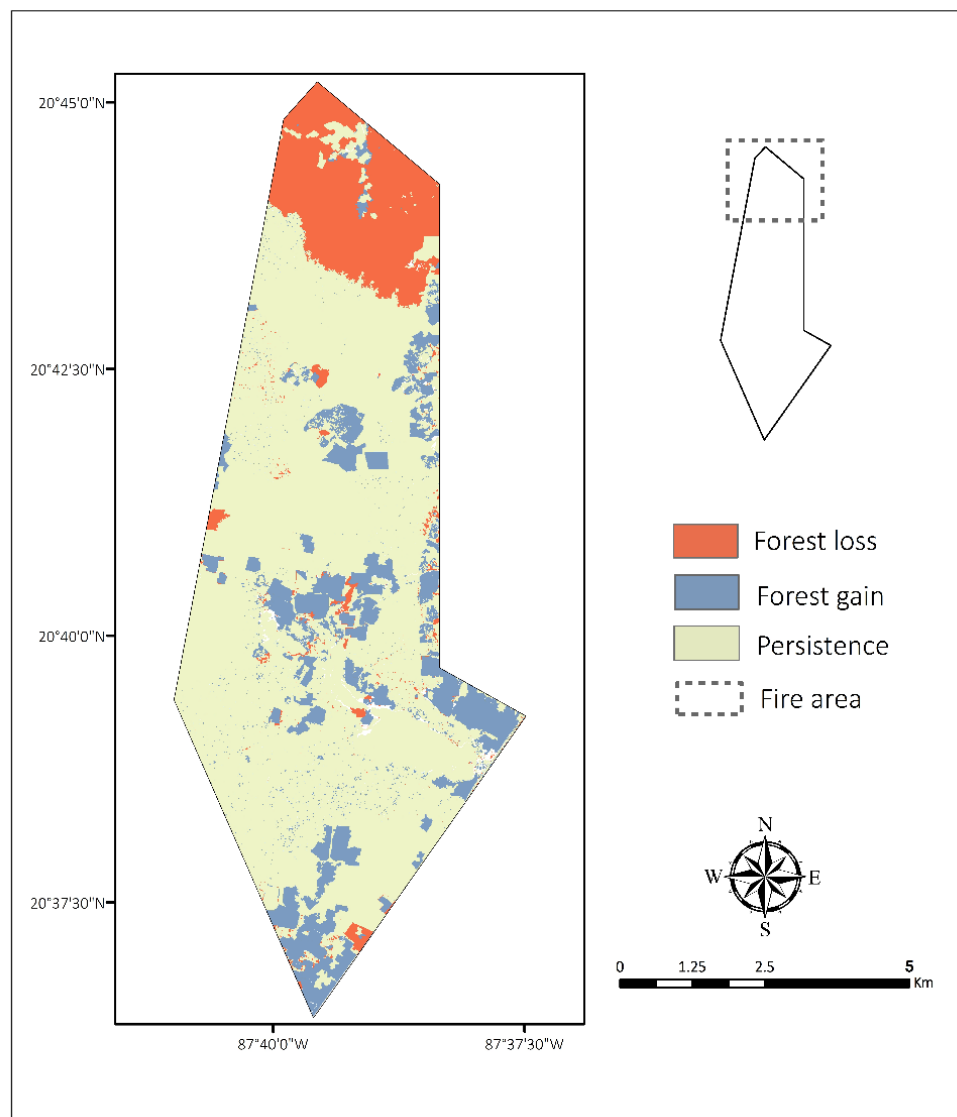


Figure 3. Spatial distribution of forest change (gain and loss), and persistence between 2003 and 2015. Forest refers to the three categories (young secondary, medium secondary, and old forest). Gains mostly include the transition from milpas to young secondary forest and from young secondary forest to medium secondary forest.

Excluding the region affected by the fires, the land-cover change showed an opposite trend: the old-growth and medium secondary forests increased (from 104.1 to 119.6 ha; and from 3535.8 to 4024.5, respectively), while the young secondary forest decreased (from 655.3 to 316.6 ha; Figure 3, Table 2). In addition, the major cover persistence (mostly from medium secondary forest), was homogeneously distributed across the PA (Figure 3).

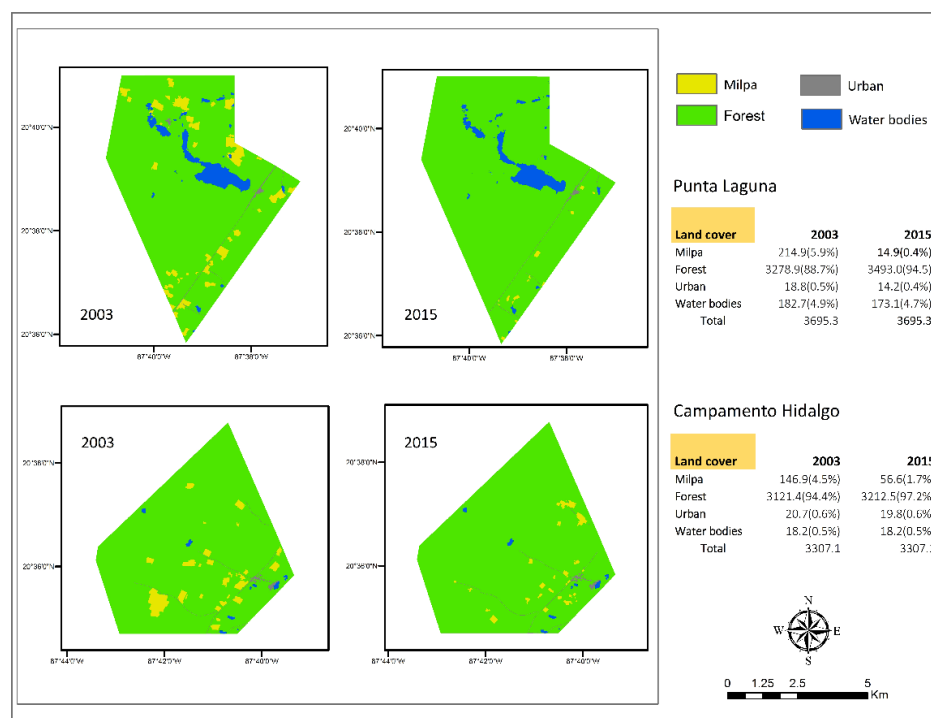
Table 2. Cover classes in area (ha) and percentage (in parenthesis) within OMKY before (2003) and after (2015) the PA establishment excluding the area affected by fires.

Land Cover	2003	2015	Net Change
Milpa	150.4 (3.2%)	2.1 (0%)	−148.3 (−3.2%)
Young secondary forest (<15 years)	655.3 (14.1%)	316.6 (6.8%)	−338.7 (−7.3%)
Medium secondary forest (16–50 years)	3535.8 (76.0%)	4024.5 (86.6%)	488.7 (10.5%)
Old-growth forest (>50 years)	104.1 (2.2%)	119.6 (2.6%)	15.5 (0.3%)
Urban	11.3 (0.2%)	5.2 (0.1%)	−6.1 (−0.1)
Water-Swamp vegetation	192.5 (4.1)	181.4 (3.9%)	−11.1 (−0.2%)
Total	4649.4	4649.4	

3.2. Land-Use Change within and Outside Otoch Ma'ax Yetel Kooch

Analysis of changes in the main land covers from focal areas within and outside the PA during the period before and after its establishment, showed similar trends: forest remained the dominant cover and milpa decreased its extension.

Inside the PA, in PL, forest cover increased (214.1 ha), mostly due to the decrease in milpa agriculture (200 ha). Forest cover increased about 5% (from 88.7 to 94.5% of the focal area), remaining the dominant cover in the focal area, whereas milpa lost a similar percentage (from 5.9% to 0.4%), practically disappearing and only remaining on the other side of the road that limited the reserve. Urban areas did not show substantial changes (Figure 4).

**Figure 4.** Land-cover change in the focal areas surrounding the communities inside (PL) and outside the PA (CH), before (2003) and after (2015) its establishment. Surface area (ha) and percentages (in parenthesis) of cover classes are shown for each area.

Outside the PA, in CH, forest cover increased (91.1 ha), whereas milpa decreased about the same amount (90.3 ha). These changes represented almost 3% of both covers (94.4% to 97.2% for forest and 4.5% to 1.7% for milpa). Remaining milpas were spatially distributed throughout the focal area in a similar way to before the reserve. Urban areas showed a slight reduction (ca. 1 ha; Figure 4).

3.3. Changes in Land-Use Practices and Management Strategies

Households from both communities changed their resource management strategies as well as the number of productive activities they carried out (Figure 5). Before the reserve restrictions were enforced, 45% of households inside the PA based their strategy on the traditional management of natural resources, but by 2015 only 9% of households reported this as their main strategy. The number of households that reported a mixed strategy increased from 15% to 50%; while those with a service-oriented strategy remained similar (40% and 41%).

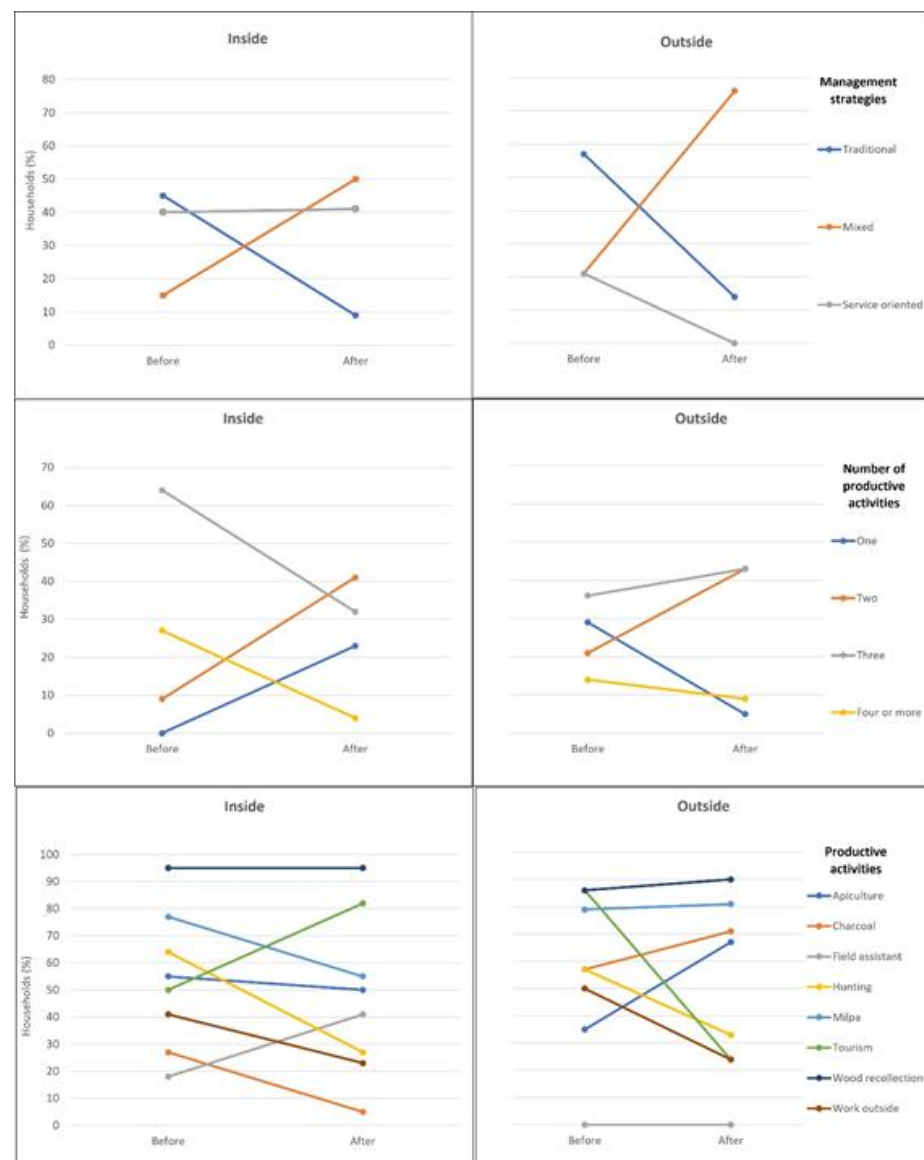


Figure 5. Trends in management strategies (traditional, mixed, or service-oriented); number of activities per household (one, two, three, four or more); type of productive activities in the communities inside the PA (Punta Laguna) and outside the PA (Campamento Hidalgo), before (2004) and after (2015) its establishment. Values are percentages of total households in each community.

Outside the PA, the number of households that reported a traditional management strategy also decreased after the establishment of the PA (from 57% to 14%), whereas households with a mixed strategy tripled (from 21% to 76%). Meanwhile, the number of households reporting a service-oriented strategy dramatically decreased from 21% to 0% (Figure 5).

In terms of the number of productive activities reported by households inside the PA, before its establishment, a high proportion implemented three (64%) or more (27%) as part of their management strategy, and none reported only one activity. In contrast, after the establishment of the PA the number of households that reported three or more activities decreased to 32% and 4%, respectively, and those that implemented a single activity increased to 23% (Figure 5). These results represent a decrease in the diversity of productive activities per household during the study period. In contrast, outside the PA the percent of households that focused on a single activity dropped from 29% to 5%, whereas the percent of households implementing two or three activities as part of their management strategy increased, implying a diversification in productive activities (Figure 5).

After the establishment of the PA, the set of main productive activities in both communities changed (Figure 5). Except from wood recollection, which remained the most prominent activity inside and outside the PA (over 86% of households in all cases), there were relevant changes in the number of households conducting other activities. Inside the PA, the number of households that implemented milpa agriculture decreased (from 77% to 55%), while tourism-related activities increased (50% to 82%), becoming the second most common activity. Outside the PA, tourism-related activities showed the reverse pattern, going from 86% to 24%, while milpa slightly increased (79% to 81%).

Inside and outside the PA, hunting and working outside the community, which before the PA establishment were very important activities, decreased substantially. Being a field assistant became more common inside the PA, whereas it continued to be absent from livelihood strategies outside the PA. Apiculture (based on *Apis mellifera* and *Melipona beecheii*) remained a common activity inside the PA with about half of households engaging in it, whereas outside the PA this activity doubled. The production of charcoal decreased inside (from 27% to 5%), whereas it increased outside (from 57% to 71%; Figure 5).

Results from the change in production indicate that even when producers inside and outside the PA continue to have their milpas at the same distance from their household (2 km average) as before the PA establishment, the average time they cultivated on the same plot doubled (from 3 to 6 years), while the plot size decreased in both communities (Table 3). In addition, in both communities after the PA establishment, the annual production of honey decreased while the number of beehives increased. In contrast, households from both communities decreased their charcoal production; this reduction was especially prominent inside the PA, in PL (from 12 to 4 times a year). In addition, the average number of charcoal bags produced also decreased for PL, whereas it slightly increased for CH (Table 3).

Table 3. Change in production from households inside (PL) and outside the PA (CH), in 2004 and 2015.

Productive activities	Punta Laguna		Campamento Hidalgo	
	2004	2015	2004	2015
Milpa (mean values)				
Area (ha)	4	2	4	3
Distance to milpa (km)	2	2	2	2
Number of crops	5	5	5	5
Time on the same plot (yrs)	3	6	3	6

Table 3. Cont.

	Punta Laguna		Campamento Hidalgo	
	Apiculture			
No. beehives (mean)	5	12	5	20
Honey annual production (kg)	780	272	727	339
	Charcoal			
Annual frequency	12	4	2–4	1–2
Annual production (bags)	65	50	48	54
Price by bag (USD)	1.05	2	1.05	2

4. Discussion

Much has been discussed on the role of PAs in biodiversity maintenance [4,41,42]; however, less is known about their general effect on the local SES [21]. Case studies that provide detailed information at the household level from before and after PAs establishment can significantly contribute to assess their effectiveness from a SES perspective, particularly in terms of trade-offs between biodiversity conservation and livelihoods. To contribute to this goal, we conducted detailed analyses on the role of OMYK establishment on land use, land cover, and household management strategies inside and outside its limits.

Excluding the area affected by fires, our results indicate that since its establishment, OMYK has experienced a loss of milpas and young secondary forest, and an increase in medium secondary forest. This is explained by two main processes: the minimum land-use conversion of older forest classes and the succession of abandoned milpas into younger forest covers and from younger forests into medium secondary forest. These results support previous studies in Mexico (e.g., [43,44]) and worldwide (e.g., [42,45,46]) that suggest that even when factors such as management capacity, funding, level of protection, size, and location are important drivers of PAs effectiveness, in general, they reduce deforestation and promote vegetation regrowth, benefiting local biodiversity. As an example, the overall relative abundance of the two monkey species inhabiting OMYK (*Ateles geoffroyi* and *Alouatta pigra*) was stable from before the PA establishment to 2015 and increased in old-growth forest, indicating that the PA has been effective in maintaining primate populations [47]. Hence, from a conservation perspective, land-use regulations associated to the establishment of OMYK have been an effective strategy to maintain biodiversity and prevent forest conversion. Figueroa and Sánchez-Cordero [32] showed that Flora and Fauna Protected Areas in Mexico, along with Biosphere Reserves, are the most effective categories for avoiding land use and cover transformation.

The protection of forests through a land-sparing approach [31] has been proposed as an effective way to sustain environmental services, ecological interactions, and to maintain habitat for endemic and threatened species (e.g., [47,48]). This strategy is particularly important in regions where land is scarce, intensively used, or where natural ecosystems have been replaced. However, land sparing restricts the access to natural resources and should be more effective in areas where livelihoods do not depend on the use of natural resources, or in sparsely populated areas where productive activities do not compromise the resilience of the ecosystem. In fact, there is evidence that allowing the use of resources at a small scale may be more effective in reducing deforestation and increasing socio-economic benefits than enforcing strict forest protection [46,49]. Additionally, it is doubtful that a strict conservation approach singularly based on the protected area model is the solution to the biodiversity crises. This is not a minor issue, given that in the international context, programs such as the half-earth proposal [50–52] or the Aichi targets [53,54] seek to drastically increase conservation coverage in the protected areas scheme. In the case of PL, even before the PA establishment, the rate and fallow time at which milpa agriculture was produced, coupled with local land-use agreements, did not jeopardize the extent of

old growth forest [29]. These results already suggested that a land-sharing model could be a valid conservation approach for this region.

Although the reduction of milpa agriculture in OMYK was reflected in the increase of young secondary forests, older classes of forests experienced a negative trend due to a series of fires during the study period. These fires occurred in the northern part of the reserve, where there still existed large patches of old-growth forest, a region far from PL and CH, but closer to remote communities without road access. According to the National Commission for Natural Protected Areas (CONANP), the institution in charge of managing the PA, the fires were caused by charcoal production activities in one of those communities. These fires, in synergy with the excess of woody biomass accumulated in the area due to hurricanes Emily and Wilma (2005), and drier years generated the conditions for these unusually large forest fires. For OMYK these events highlight the vulnerability that the natural system, particularly the old-growth forest, has in the face of more recent, less traditional activities and the lack of resources to respond to uncommon events.

We expected that land-use regulations would intensify the agricultural activity outside the limits of the PA. However, the establishment of OMYK did not promote deforestation spillovers, i.e., it did not encourage forest-to-milpa transition in CH. In fact, during the study period, land-cover trajectories were consistent within and outside the reserve: milpa cover decreased (virtually disappearing inside the reserve), while forest cover increased, contradicting our original prediction. For Mexico, this trend is highly dependent on the region, but in general PAs in the Yucatan Peninsula have shown a reduction in deforestation inside and around the PA [44]. These trends suggest that PAs have a general positive effect in forest cover, not only in the area that they are legally protecting, but also in the surrounding areas probably due to a change in the local economy, itself a consequence of the increase in ecotourism, coupled with a change in the local perception regarding land use. However, inside and outside the reserve, the number of households that only followed a traditional strategy decrease, while those that implemented a mixed strategy (combining traditional and service oriented) increased. Interestingly, in CH the number of households reporting doing milpas did not change, while tourism was drastically reduced, suggesting other mechanisms are responsible for the observed land-cover trend. It is possible that the reduction of milpa size, coupled with the intensification of its use (i.e., longer time using the same land plot) are inducing shorter fallow periods. In the long run, it would be necessary to analyze the impact these changes are having on the milpa practice and productivity, the ecosystem services (such as carbon stocks; [55]), and local wellbeing.

Following the original prediction from models of land-cover change as a consequence of PA regulations [29], we confirm that trends of secondary and old-growth forest increased after the PA establishment. Still, our results suggest that the PA did promote important changes in the natural-resource management strategies carried out by the households of both studied communities. This effect of the PA could be seen in the context of the increase in tourism that the region has experienced in past decades. At the time of the PA establishment, natural resource management in PL and CH followed a diversified management strategy, which involved the implementation of multiple productive activities for each household, that occurred in different land use units (e.g., young or medium secondary forest). During this time, milpas, the essential activity at the core of the Yucatec Mayan identity, constituted their main economic activity [29], and tourism was a complementary activity, mostly benefiting some members of the community [56]. However, as tourism became a prominent activity in the region [57], it extended to small communities advertising them as “environmental attractions”. This is happening in several regions of Mexico [58,59], but also worldwide as globalized tourism has gained interest in rural communities [60,61]. As PL gained a reputation as a “monkey reserve” and more households engaged in a market economy, CH experienced the opposite trend with tourism agencies reducing their presence, prompting households to diversify their activities, including novel ones, for example charcoal production. Besides milpa agriculture, the activities mostly abandoned inside the reserve were charcoal production, hunting, and migrating for temporal jobs. In contrast,

tourism and work as field assistants considerably increased inside the reserve. As a result, households inside the reserve became more specialized (reducing their activities from more than four to one or two dominant ones), while outside they diversified, incorporating at least one or two new activities to their management strategy. For PL, this trend towards productive specialization allows higher earnings, but could have in the long term potential repercussions in the mechanisms to cope with vulnerability [62], particularly if considering that the diversification of rural livelihood strategies has been identified as an important aspect to increase livelihood security and reduce vulnerability (e.g., [63–66]). However, this situation is not unique to PL. Campos-Silva et al. [67] show how, in Brazil, those households within PA that are economically specialized in one activity tend to have higher income levels compared to those households that have a higher diversity of livelihoods portfolio.

Our study demonstrates the importance of conducting an integrated analysis of the SES [1], including its social, economic, and ecological aspects. This approach not only makes it possible to understand the impact of institutions, such as PAs, on land cover and vegetation, but it also identifies the trade-offs and dynamics of the system [62,68]. Emphasizing trade-offs is also key to challenging the win-win discourse in conservation and human well-being [23]. In the field of conservation, for many decades there has been an attempt to build an argument around conservation policy options that generate a positive scenario for all stakeholders. First it was with the integrated conservation and development programs (ICDP) in the 1990s. Then, 10 years later, the same argument was built around the application of payments for ecosystem services (PES). For households in PL there was a clear trade-off between traditional and service-oriented management strategies, while in the case of CH households still needed to maintain a diversity of options. At the same time, the specialization registered in PL on a single productive activity that is temporal and variable, limits households' economic options and self-sufficient sources which in the face of disturbance events, can increase the system's vulnerability (i.e., [69–71]). If large, accidental fires such as those that occurred in the northern region of the PA, were to affect the area where tourism activities are conducted, it is likely that households would not have alternatives to cope with the fire consequences [62]. Additionally, unforeseen natural events such as hurricanes or the travel bans imposed by the COVID-19 pandemic can greatly reduce the number of tourists in the PA [56], and therefore the local income of those households relying solely on the service-oriented strategy.

Our results have clear implications for government programs related to land use and conservation. By identifying the specific threats that jeopardize forest cover at the landscape level and the diversified strategy of natural-resource management, it is possible to suggest strategies for conservation and local livelihoods. Government programs that promote specialization and support only the short-term monetary income could threaten traditional activities and the diversity of natural resources management strategies [72]. Instead, these programs should focus more broadly on incorporating new economic activities, including tourism, while strengthening local institutions that maintain a diversity of activities linked to sustainable development, as a buffer to face the consequences of unpredictable events such as hurricanes, fires, or the sudden decrease in tourism.

5. Conclusions

The establishment of OMYK proved to be an effective tool to promote forest recovery and prevent deforestation in the regions surrounding the communities both inside and outside the PA, where milpa agriculture sharply decreased. Although land trajectories were similar between the community inside and the community outside the PA, local characteristics and the presence of institutions, determined the direction of management strategies. In PL while tourism has positively contributed to the local income, it has also encouraged economic specialization, since nowadays almost 75% of households only carry out one or two economic activities and discouraged the diversification in their management strategy, particularly the abandonment of traditional activities. This economic

specialization can pose risks towards control of their livelihoods and increase dependency on external agents, such as the tourist industry.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/land10111147/s1>, Table S1: Gain, loss, swap, net change, total change, and persistence for each land-cover class in OMYK from 2003 to 2015.

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Appendix A

Image classification: The 2003 SPOT satellite image was classified using interpretation and digitalization according to differences in colors, patterns, and textures (IDRISI Kilimanjaro GIS software). The 2015 Rapid Eye satellite image was classified using the supervised method of maximum likelihood (ENVI 5.3 GIS software). Both images (2003 and 2015) were from February (dry season, <15% cloud cover) and were geometrically and atmospherically corrected under the Mercator Transversal coordinate system WGS84 Zone 16N. To improve the accuracy of both classifications, we applied a post-classification process by interpreting and manually digitizing images based on color, shape, and texture using as reference either aerial photographs (1:15,000, for the 2003 classification) or GeoEye Satellite images (for the 2015 classification). For the 2003 classification, 90% of 128 verified sites within the PA were correctly assigned (García-Frapolli et al., 2007). For the 2015 classification, we used 100 verification points to calculate the confusion matrix and Cohen’s Kappa statistic. The overall accuracy was 83% with a Kappa index of 0.79. For both classifications, we calculated the surface (area and percentage) of cover categories using the AREA tool (IDRISI 17.0 Taiga).

We estimated changes in land cover and vegetation during the study period using the Land Change Modeler (LCM) extension in IDRISI 17.0 Taiga (Clark Labs, 2009). With this information we (1) constructed a transition matrix; (2) estimated gain, loss, interchange, persistence, and net and total change for each class; (3) mapped the spatial distribution of woody vegetation persistence, gains, and losses.

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