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Forest land-cover trends in the Monarch Butterfly Biosphere Reserve in Mexico, 1994–2017

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Summary

The hibernation sites of the monarch butterfly (*Danaus plexippus*, L.) were discovered in central Mexico in 1975 and, following the decree of a protected area in 1986, processes of deforestation and forest degradation were triggered on the socially owned land in question. Further deterioration has occurred since the expansion and designation of the area as the Monarch Butterfly Biosphere Reserve in 2000. An innovative programme of economic incentives was established to compensate the affected properties in the core zone for curtailment of their forest use and to pay for environmental services; however, some of the agrarian communities were in disagreement with this programme. Orthophotographs from 1994 were compared with high-resolution satellite images from 2017 in order to determine forest-cover trends in the areas incentivized by Payment for Environmental Services to avoid deforestation and those areas that were not incentivized. The results show an overall recovery of 2% in forest area between 1994 and 2017, while a 5% increase in the deforested area is notable in the core zone. The findings indicate that, for the establishment of an effective protected area on social property lands, consensus must be achieved across all of the communities in order to avoid subsequent forest loss.

Introduction

Despite the importance of protecting forests, their loss has increased in recent decades worldwide: the planet has lost 178 million ha of forests since 1990 (FAO 2020). More specifically, from 2001 to 2018, 12.0% of the global forest area and 4.1% of the forest area under protection have been lost (Wade et al. 2020). Despite these discouraging figures, global deforestation is actually in decline, having gone from 16 million ha/year in the 1990s to 15 million ha/year during 2000–2010 and 11 million ha/year between 2010 and 2020 (FAO 2020). As a result, the annual net change in forest area decreased from a reduction of 8 million ha/year in the 1990s to a reduction of 5.2 million ha/year during 2000–2010 and a reduction of 4.7 million ha/year during 2020–2010 (FAO 2020). Slowing of deforestation and increased forest recovery are evident worldwide.

Protected areas (PAs) currently represent almost 15% of the Earth's land surface and serve to protect 5% of global tree cover (Wade et al. 2020). An estimated 726 million ha of forest are included in PAs around the world, with an increase of 5% observed from the 1990s to 2020 (FAO 2020). This increase is a consequence of the commitment made by the signatory countries of the Convention on Biological Diversity (2010), which had the protection of 17% of the Earth's surface by 2020 as one of its stated goals (CBD 2011).

In 1990, the forests of Mexico covered an area of 70.59 million ha, with net annual changes of –221.0 ha/year from 1990 to 2000, –143.8 ha/year from 2000 to 2010 and –125.1 ha/year from 2010 to 2020, reflecting annual deforestation rates of 0.32%, 0.21% and 0.19%, respectively. These rates left 65.69 million ha of forest remaining in 2020 (FAO 2020). It should be noted that the terrestrial PAs of Mexico cover a total area of *c.* 21.5 million ha, representing 11% of the Mexican territory.

Data from Mexico's periodic national forest inventories for 1994 and 2000 suggest an annual overall deforestation rate of 1.3%, with a rate of 1.2% for temperate forests alone (Velázquez et al. 2003). Another study calculated a deforestation rate of 0.25% in temperate forests (Mas et al. 2004). At monarch butterfly (*Danaus plexippus*, L.) hibernation sites, where temperate forests predominate, deforestation rates have been calculated as 0.1% from 1971 to 2000 (Ramírez et al. 2003), 3.8% from 1999 to 2009 (López-García 2011), 4.9% from 1999 to 2013 (López-García & Navarro-Cerrillo 2019) and 1.6% from 1993 to 2006 (Navarrete et al. 2011), while forest degradation rates have been calculated as 1.3% from 1971 to 2000 (Ramírez et al. 2003),

1.7% from 1971 to 1984, 2.4% from 1984 to 1999 (Brower et al. 2002) and 0.5% from 1999 to 2009 (López-García 2011).

In developing countries, land tenure is essential for the application of effective forest management and the maintenance of low deforestation rates. It is estimated that 80% of Mexico's forests are currently under social property regimes known as *ejidos* or Indigenous communities (Bray et al. 2003). The social property of the forests where the monarch butterfly hibernates was not an impediment for the Mexican government to decree them as a Protected Natural Area in 1986 (DOF 1986), with no consideration given to the needs of the communities present in the area, no dialogue with the owners, no warning and few instances of local consultation (Chapela & Barkin 1995, Merino 1999).

Hostility and enduring problems typically ensue when PAs are created without proper consultation on boundary locations (Brandon 2002). The agrarian communities present in the area are recognized groups with communal property titles (*ejidos* or Indigenous communities) and are highly dependent on natural resources as a source of subsistence, a dependency that was directly affected by the PA declaration.

The historical marginalization of communities with forested lands and the antagonistic relationship they have with the State explain why these communities reacted violently to the restrictions imposed with the creation of the PA (Klooster 2003, Boyer 2005, Bray et al. 2005). During the first 5 years of the 1990s, they demanded the restructuring of the PA boundaries (Chapela & Barkin 1995, Hoth et al. 1999). In order to minimize the impact on the economic income of local populations, some researchers had recommended reducing the no-cut areas and promoting community forestry (Merino 1995).

The process of decision-making regarding PAs has been dominated by national and international conservationist interests (Tucker 2004), relegating the participation of the local populations concerned. However, successful PA management ultimately depends on the cooperation and support of local people (Wells & Brandon 1993). This aspect was not taken into account in the designation of the PA, since the strategy was developed with no adequate understanding of the local socioeconomic context (Wells & Brandon 1993).

Creation of the PA restricted the legal economic activities in a region that offered few viable alternatives for livelihoods and employment. Most of the communities with lands in the PA were dependent on logging and subsistence farming (Toledo 1999). The agrarian communities affected by the 1986 decree were unaware of the limits of the PA and its implications, such as the limitations being applied to their rights to use the forest. This translated into clear discontent and excessive responses, such as the felling and burning of the forests of the community of San Cristóbal, for example. The forests of the Chivatí-Huacal hills were cleared, in part, for fear of their expropriation (Merino 1995, Honey-Rosés 2009a). In such social property, the highest authority of the agrarian communities is the *ejido* or communal assembly, which ultimately determines the mechanisms of economic and social organization.

In 1997, as a strategy by which to resolve the conflicts provoked by the 1986 decree, the North American Conference on the Monarch Butterfly was held in Mexico (Hoth et al. 1999) and was attended by academics, farmers, professors and journalists. The agrarian communities that were affected by the decree demonstrated against it, but their demands were not met, and this prevented a consensus being reached in terms of signing the Monarch Butterfly Conservation Fund (MBCF) agreement. Representatives of the *ejidos* and Indigenous communities reported that they had been affected by the decree and were opposed to the PA. The conference was attended by 73 *ejidatarios*, including 16 *ejido* commissioners, 10 members of the Indigenous communities and 2 municipal presidents. A total of 48 agrarian communities and 1 small property were represented.

From the conservationist perspective, the limits imposed by the PA were still inadequate. In response, and more than a decade after its initial constitution as a PA, the Mexican government agreed to a review (Hoth et al. 1999). The World Wildlife Fund (WWF) of Mexico was invited to organize the scientific community and to propose new limits based on biological criteria (Missrie 2004). This reformulation of the PA involved intense negotiation and consultation with the affected communities between June and October of 2000 (Missrie 2004). Regardless of the fact that this process failed to convince all of the affected agrarian communities, the expansion and recategorization of the PA as the Monarch Butterfly Biosphere Reserve (MBBR) was subsequently decreed in November 2000 (DOF 2000). This action evidently had a political purpose, taking place as it did 1 month before the end of the mandate of president Ernesto Zedillo.

With the designation of the MBBR, WWF-Mexico, the David and Lucile Packard Foundation and the Mexican Fund for the Conservation of Nature created the MBCF in order to support the communities included within the new limits of the Reserve, especially those that had been forced to relinquish their exploitation rights (Missrie 2004, Honey-Rosés 2005). This fund created a programme of economic incentives to compensate the affected properties in the core zone with two types of payments: first, payment for non-use, aimed at owners who had lost their previously authorized use rights; and second, payment for conservation services. However, only 31 of the 38 agrarian communities signed the agreement, and thus the problem remained unresolved. Dissident groups conducted clandestine logging on their properties, possibly in collusion with organized gangs (Honey-Rosés 2009b, Vidal et al. 2014). This triggered considerable disturbance of the forests and the disappearance of several colonies of monarch butterflies, the protection of which had been the original goal of the legislation (Vidal et al. 2014).

In 2003, Mexico launched an innovative Payment for Hydrological Environmental Services (PHES) programme to help landowners protect forest watersheds in critical areas of the country (CONAFOR 2012). Since 82% of the MBBR area is included in the Cutzamala basin, which supplies 24% of the water consumed by Mexico City (CONAGUA & World Bank Group 2015), this represented a complement to the payments made by the MBCF. Although programmes such as Payment for Environmental Services (PES) are insufficient alone to ensure sustainable forest management, they remain crucial components of efficient policy formulation (Muñoz-Piña et al. 2008, Pérez-Verdín et al. 2011).

As part of the impact of PA establishment, it is necessary to consider not only the acceptance and adaptation of the communities present in the area, but also the impact that such establishment has in terms of disturbance of forest dynamics, the recovery of which can require several decades. Thus, the effectiveness of such community-based natural resource management depends on available incentives, consideration of legal rights and the inherent capacities of local resource managers (Brechin et al. 2007). Some key actions can make a significant difference to the effectiveness with which a PA can promote biodiversity conservation (Brandon 2002). The agrarian communities that were affected by the 1986 decree were unaware of the limits of the PA and its

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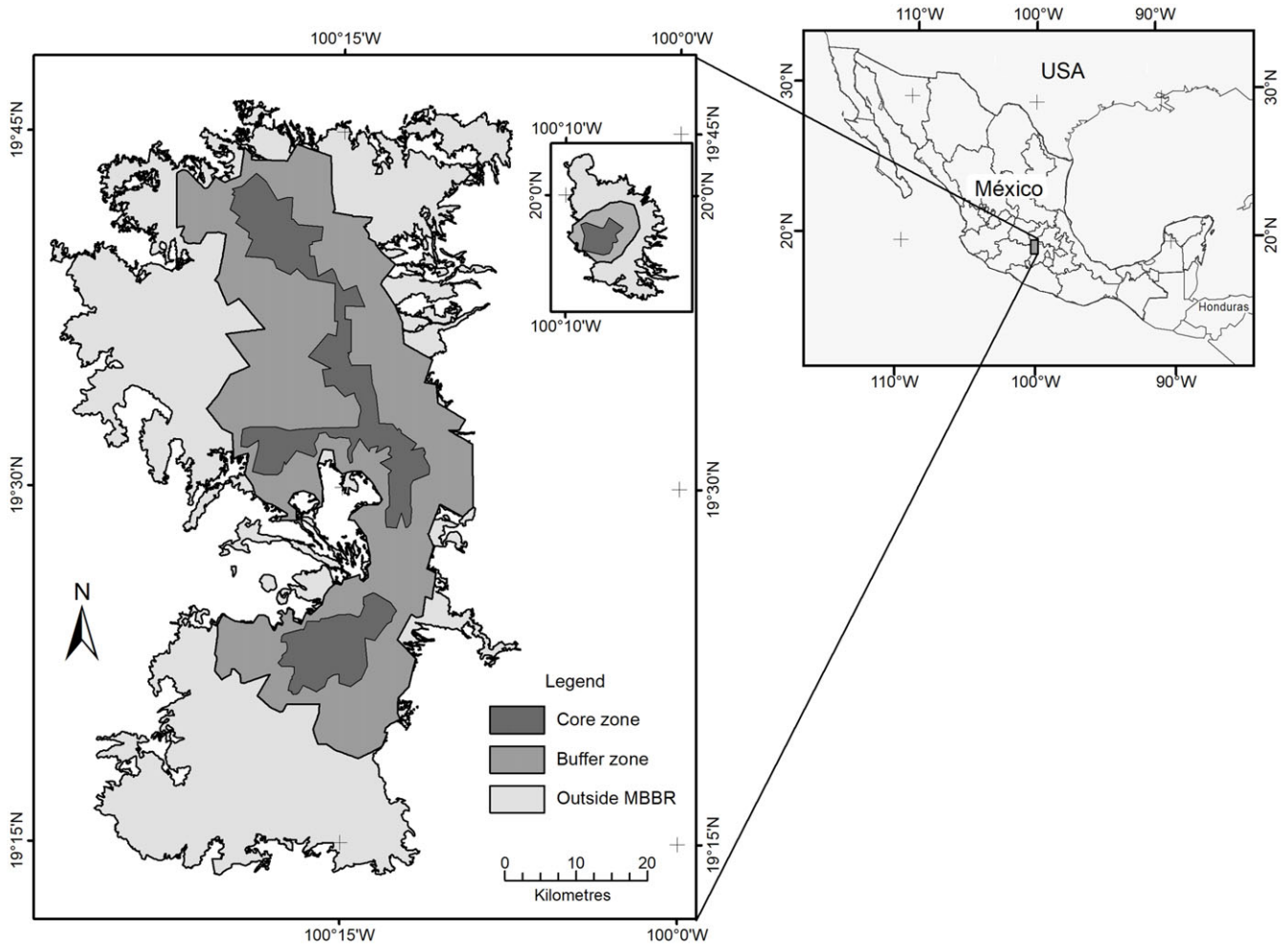

Fig. 1. Study area, encompassing the Monarch Butterfly Biosphere Reserve (MBBR).

implications, which acted to limit their rights to use the forest. In contrast, clear boundaries are consistently associated with successful resource management (Dietz et al. 2003).

This contribution aims to provide an overview of the forest-cover trends in areas incentivized by PES in order to avoid deforestation, as well as in those areas that were not incentivized both inside and outside of the MBBR.

Materials and methods

Study area

The study area comprises a continuum of temperate forests on mountainous terrain with an overall area of 122 350 ha, spread over 56 259 ha within the MBBR (comprising the core zone of 13 555 ha and the buffer zone of 42 704 ha) and 66 091 ha outside the limits of the Reserve (Fig. 1). It includes the headwaters of two important basins: Cutzamala and Lerma.

Monarch butterflies hibernate and reproduce mainly in fir (*Abies religiosa* Kunth Schltdl. et Cham.) forests that grow at an elevation of 2900–3600 m above sea level; below these forests are communities of pine and, on the lowest slopes, of oak.

This area involves parts of 17 municipalities, with Ocampo and Angangueo fully included within it. According to the National Agrarian Registry, the area is made up of *ejidos* (66.29%), Indigenous communities (14.35%), private property (7.72%), national property (0.58%), sites in litigation (0.21%) and sites for which no information is available (10.85%).

Preparation of material

The assessment used 14 orthophotographs from February 1994 with a resolution of 2 m/pixel (from the National Institute of Statistics, Geography, and Informatics) and two SPOT 7 panchromatic images from February 2017 with a resolution of 1.5 m/pixel (México Nueva Generación, Ermex). Both of these products were co-registered with Universal Transverse Mercator (UTM) projection, with Datum WGS84, zone 14 N.

The images were co-recorded using ground control points and a digital terrain model with contour lines every 20 m, supported by 30 control points on smooth terrain and 40 control points on rough terrain.

Evaluation of the change in forest cover

Visual interpretation of the images considered tone, texture, shape, design and the relationship with other objects (Horning 2004).

Classification of forest-cover density was based on five categories of tree density: >75% as closed cover, 51–75% as semi-closed cover, 26–50% as semi-open cover, 10–25% as open cover (López-García 2009) and <10% as deforested (FAO 2010). Other land uses

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Table 1. Matrix of changes in forest-cover density (%) in the Monarch Butterfly Biosphere Reserve and its area of influence between 1994 and 2017.

		2017						
	Categories	Closed	Semi-closed	Semi-open	Open	Deforested	No forest	Total 1994
1994	Closed	55.22	2.21	1.04	0.71	1.96	0.31	61.45
	Semi-closed	2.04	1.91	0.26	0.15	0.45	0.06	4.88
	Semi-open	0.95	0.46	1.01	0.15	0.29	0.04	2.89
	Open	0.83	0.55	0.19	0.52	0.36	0.05	2.51
	Deforested	1.98	0.39	0.22	0.25	4.91	0.00	7.75
	No forest	0.55	0.10	0.10	2.22	0.00	17.56	20.53
	Total 2017	61.57	5.63	2.82	3.99	7.98	18.01	100.00

(agricultural, grassland and infrastructure) were grouped into the 'non-forest' category.

Visual interpretation was carried out at a scale of 1:5000 and the minimum mappable area was 625 m^2 for deforested areas and non-forest use (López-García et al. 2016). For the different densities of forest cover, the minimum mappable area was 5000 m^2, according to the definition of a forest (FAO 2010).

A coverage density map was obtained from the orthophotographs from 1994 and another from the SPOT 7 images from 2017. The two were combined to obtain the mapped polygons and attribute table, from which was created the matrix of forest-cover density changes between 1994 and 2017.

Determination of change processes

The coverage maps from 1994 and 2017 were combined to indicate the changes that occurred in this period both inside (core zone and buffer zone) and outside of the MBBR. This process identified six different processes of change during the 23-year period. Three of these were negative changes: (1) forest degradation (decrease in density of forest cover leading to a change of cover category, such as closed to semi-closed cover); (2) deforestation (reduction of the density of cover to <10%); and (3) land-use change, which refers to the transformation from forest to another use. The other three were positive processes of recovery: (1) forest improvement (increase in density of forest cover, such as from open to semi-closed cover); (2) reforestation (change from a deforested area to forest with a cover density >10% and trees >5 m in height and with a diameter >10 cm); and (3) afforestation (transformation of agricultural land or pastures into forest).

Rates of change in forest cover

Rates of change in forest cover were calculated (FAO 1995) using the equation $\delta n = (S_2/S_1)1/n - 1$, where δ is the rate of change (multiplied by 100 to express this as a percentage), S_1 is the area on date 1, S_2 is the area on date 2 and n is the number of years between these two dates.

Conservation policies

Through the transparency law of Mexico, the national-scale databases of the PHES from between 2003 and 2017 were obtained. The information corresponding to the study area was extracted and, together with the payments for conservation services made by the MBCF to the agrarian communities of the core zone between 2000 and 2017, was correlated with the changes in forest cover found in the areas analysed in order to determine how the PES influenced the processes of change in forest cover in terms of whether recovery or disturbance occurred in the core zone, buffer zone or outside the Reserve.

Results

Change of coverage at a general level

The forest-cover density analysis determined that the forests of this region are generally found to present cover values greater than 50%, an increase in forest area between 1994 and 2017 of 1% (1071 ha), a slight increase in the deforested land (mainly in the core zone) and a considerable decrease in non-forest surfaces (3%) due to the conversion of agricultural land to forest through afforestation (Table 1). Together, these values suggest a trend of recovery in the forests of this region. A total of 81% of the area remained with no apparent changes, and 72% of the forest in 1994 had increased by 2% in 2017.

Change by PA status

The forest cover in the core zone presented the most negative changes. In the forest dynamics in this region, 64% of the core zone remained unchanged in this period, followed by the buffer zone at 72% and, finally, the forests outside the Reserve at 90% (Table 2). In the period from 1994 to 2017, forest cover levels >50% in the core zone decreased by 3% and the deforested area increased by 5%. In the buffer zone, the forest area increased slightly and there was no evident deforestation. Outside the Reserve, there was an increase in forest cover levels >50% of 2%, a decrease in deforestation and a reduction in agricultural areas (4%) due to afforestation programmes applied on unused agricultural land (Fig. 2 & Table 2).

After 23 years, changes were found in a total of 23 094 ha (19%), of which 73% occurred within the MBBR, with disturbance being greater than recovery. Outside the Reserve, recovery processes predominated. Regarding the proportional gains for each zone, the core zone presented the highest gain (16%), mainly due to the suppression of grazing, followed by the buffer zone (13%) and, finally, the zone outside the Reserve offering lower levels of profit (8%). In terms of losses, the most considerable negative changes occurred in the core zone (21%) as a result of clandestine logging, then in the buffer zone (14%) and, finally, outside the Reserve, where negative changes were minimal (1%) compared to the positive forest trends (8%).

Change by PES participation

Total negative forest trends of 8% were observed, compared to total positive forest trends of 11%. It therefore appears that the incentive offered by the PES has had a positive influence, since the positive forest processes prevailed. However, negative forest trends in the core zone were at 21% as a result of illegal logging, compared to the positive forest trends in the core zone of 16%, mainly due to non-grazing. The gains were slightly higher without PES than with

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Table 2. Matrix of changes in forest-cover density between 1994 and 2017. Numbers on the diagonal (grey background) = no change. Numbers above the diagonal = losses. Numbers below the diagonal = gains. Outside the diagonal, numbers in normal font indicate changes in the core zones, numbers in italics indicate changes in the buffer zones and numbers in bold indicate changes outside the Monarch Butterfly Biosphere Reserve.

		2017						
	Categories	Closed	Semi-closed	Semi-open	Open	Deforested	No forest	Total 1994
1994	Closed	54.70	5.78	2.23	1.48	6.62	0.01	70.81
		45.64	*3.86*	*2.18*	*1.23*	*3.49*	*0.76*	*57.16*
		61.51	**0.42**	**0.07**	**0.21**	**0.02**	**0.08**	**62.30**
	Semi-closed	4.54	1.25	0.44	0.37	1.28	0.00	7.89
		2.62	*0.73*	*0.44*	*0.24*	*0.47*	*0.13*	*4.62*
		1.16	**2.81**	**0.11**	**0.05**	**0.28**	**0.03**	**4.42**
	Semi-open	2.39	0.95	0.44	0.18	0.94	0.00	4.90
		1.31	*0.49*	*0.38*	*0.25*	*0.46*	*0.11*	*3.01*
		0.42	**0.33**	**1.53**	**0.07**	**0.05**	**0.00**	**2.40**
	Open	1.58	0.74	0.25	0.41	1.20	0.00	4.18
		1.81	*0.36*	*0.27*	*0.38*	*0.65*	*0.12*	*3.59*
		0.05	**0.64**	**0.13**	**0.64**	**0.00**	**0.01**	**1.47**
	Deforested	2.88	0.81	0.69	0.59	3.40	0.00	8.37
		3.65	*0.67*	*0.41*	*0.35*	*2.60*	*0.00*	*7.68*
		0.71	**0.13**	**0.00**	**0.11**	**6.72**	**0.00**	**7.67**
	No forest	0.33	0.03	0.03	0.00	0.00	3.47	3.85
		1.05	*0.20*	*0.08*	*0.10*	*0.00*	*22.51*	*23.95*
		0.28	**0.05**	**0.12**	**4.05**	**0.00**	**17.25**	**21.74**
	Total 2017	66.42	9.55	4.08	3.03	13.45	3.47	100.00
		56.08	*6.32*	*3.76*	*2.54*	*7.67*	*23.63*	*100.00*
		64.12	**4.38**	**1.95**	**5.12**	**7.06**	**17.37**	**100.00**

PES, while losses were more noticeable without PES. The overall balance of change was negative inside the Reserve but positive outside it (Table 3).

Similarly, negative forest trends outside the Reserve were 1% compared to the positive forest trends outside the Reserve of 8% (Table 3). This shows that local consensus (rather than external imposition) and incentives were better for forest conservation.

The analysed area presented greater recovery than disturbance, which was proportionally higher in the farms that did not receive PES than those that did. In the MBBR, there was more disturbance than recovery in plots without PES but more recovery than disturbance in plots with PES. The core zone presented much more disturbance than recovery in the farms without PES and slightly more disturbance than recovery in those with PES; the zones excluded from PES presented 7% deforestation compared to 3% reforestation. In contrast, in the buffer zone, deforestation was slightly (1%) higher than reforestation (Fig. 3 & Table 3).

Within the Reserve, there was a net decrease in forest area since deforestation exceeded reforestation, mainly in the core zone and specifically due to logging on properties that did not participate in the PES. Similarly, forest degradation exceeded forest improvement in the buffer zone due to forest exploitation and, to a lesser extent, clandestine logging. Outside the MBBR, afforestation largely acted to offset forest loss due to land-use change (agricultural activities such as avocado cultivation), producing a net increase in forest cover and an overall increase that far exceeded the decline accounted for within the PA. This fact can be attributed to the abandonment of agricultural areas in the region and subsequent afforestation programmes applied on this unused agricultural land (Table 4). The greater forest degradation and deforestation in the MBBR are explained by the discontent of the owners of the properties that did not participate in the PES programme and the opportunism of organized groups in terms of felling trees. The greater deforestation and forest degradation of the PA therefore leads us to conclude that this situation was a direct result of the area being decreed as a PA. From 1994 to 2017, the processes of disturbance and recovery modified the appearance of this forested region, although 61% remained unchanged with coverage greater than 50%, there was recovery in 6% of the area, and 41% of the area received PES (75% of the core zone, 51% of the buffer zone and 27% outside the Reserve; Fig. 3).

Rates of change in forest cover

The region under study presented a rate of change of 0.14% for forest cover >10% and a rate of change of –1.64% for forest loss (deforestation and non-forest), indicating a trend of slight recovery in forest cover and a decrease in land without forest cover, which became forest through afforestation. However, at the MBBR level, these rates were –0.05% and 0.14%, respectively, with a tendency towards a slight loss of forest cover and an increase in the area of land without forest cover. This did not occur in the core zone, where the deforestation rate was 2.06%, partly due to the presence of properties that did not participate in the MBCF, compared to the core zone, which showed a decrease in deforested areas (Table 4).

Changes in forest cover by agrarian communities

During this period, the core zone presented a disturbance rate of 42% and the buffer zone of 27%, with deforestation rates of 21% and 10%, respectively. Finally, outside the Reserve, there was a disturbance rate of 2% and a deforestation rate of 1%, showing that the forests of the core zone were those most affected by clandestine logging.

Considering only the properties with land in both the core and buffer zones, a forest degradation rate of 14% and a deforestation rate of 11% were recorded, corresponding to 10% in the core zone and 8% in the buffer zone. This indicates that, on these properties, the people preferred to cut down trees in the core zone rather than in the buffer zone. The Indigenous communities with land in all three zones presented a disturbance rate of 8% in the core zone, 4% in the buffer zone and almost 0% outside the Reserve. These

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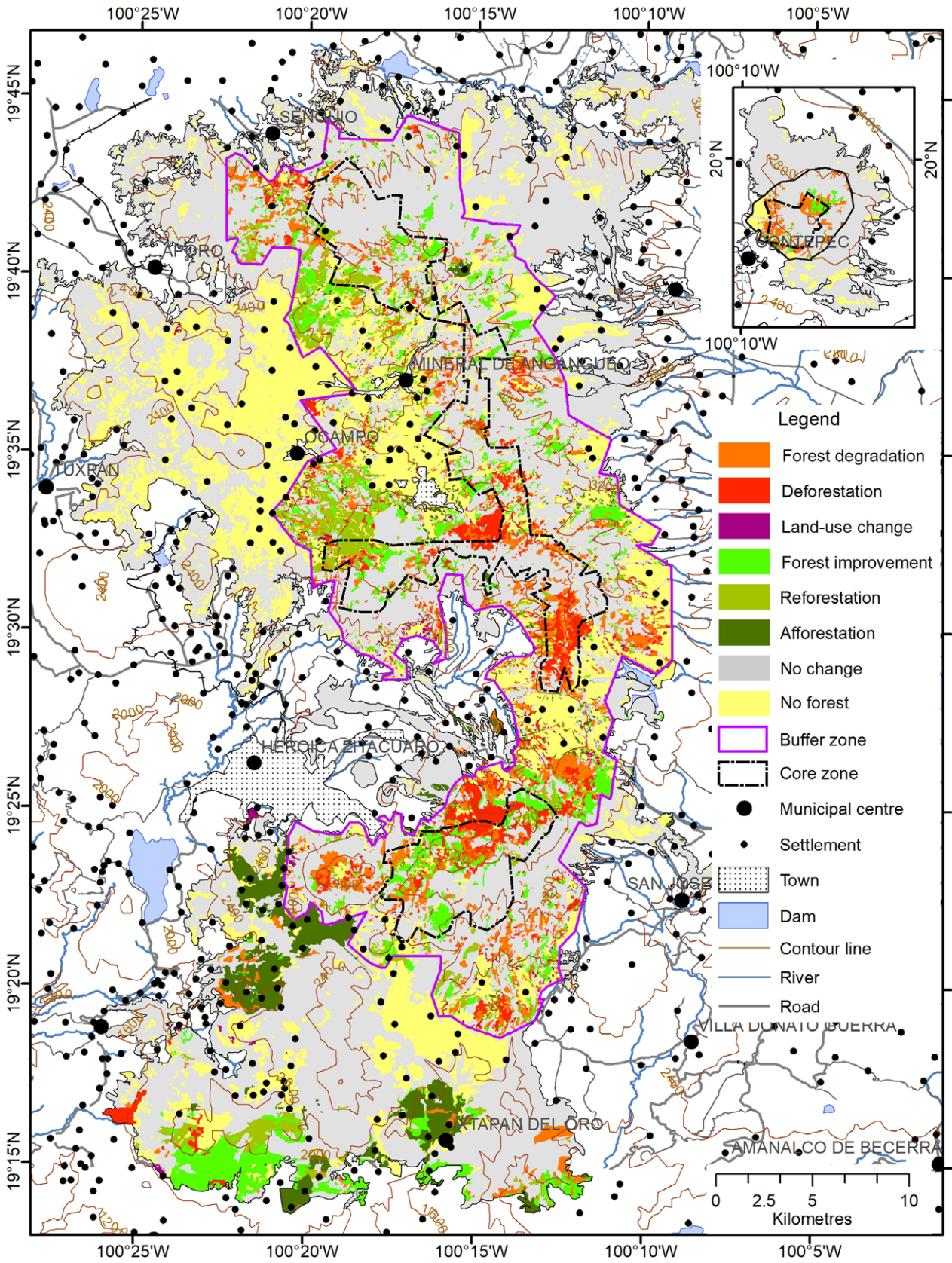

Fig. 2. Processes of change in the study area: 2017 compared with 1994.

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Table 3. Percentages (relative to each zone) of forest-cover change processes in the core and buffer zones and outside the Monarch Butterfly Biosphere Reserve (MBBR) with and without Payment for Ecosystem Services (PES).

		Core zone			Buffer zone			MBBR			Outside MBBR			All areas		
		With PES	No PES	Total	With PES	No PES	Total	With PES	No PES	Total	With PES	No PES	Total	With PES	No PES	Total
Change processes	Forest degradation	5.07	5.40	10.47	3.14	5.04	8.19	3.61	5.13	8.74	0.21	0.71	0.92	1.77	2.74	4.52
	Deforestation	2.54	7.50	10.05	1.40	3.67	5.07	1.68	4.59	6.27	0.01	0.33	0.34	0.78	2.29	3.07
	Land-use change	0.01	0.00	0.01	0.22	0.91	1.12	0.17	0.69	0.86	0.01	0.11	0.11	0.08	0.38	0.46
	Disturbance	7.62	12.91	20.53	4.76	9.62	14.38	5.45	10.41	15.86	0.23	1.15	1.38	2.63	5.41	8.04
	Forest improvement	5.72	4.73	10.46	3.36	3.51	6.86	3.93	3.80	7.73	0.22	2.51	2.73	1.92	3.11	5.03
	Reforestation	1.69	3.28	4.97	2.54	2.53	5.08	2.34	2.71	5.05	0.46	0.50	0.95	1.32	1.51	2.84
	Afforestation	0.11	0.27	0.39	0.16	1.28	1.44	0.15	1.04	1.19	0.04	4.45	4.49	0.09	2.88	2.97
	Recovery	7.53	8.29	15.81	6.07	7.32	13.38	6.42	7.55	13.97	0.72	7.45	8.17	3.34	7.50	10.84
	Total change	15.15	21.19	36.34	10.83	16.94	27.77	11.87	17.96	29.83	0.95	8.60	9.55	5.97	12.91	18.88

data suggest a deliberate response to an evident disagreement with the implementation of the PA (Table 5).

The two Indigenous communities that did not participate in the MBCF programme were responsible for 14% of the forest degradation and 19% of the deforestation in the core zone. They were also responsible for 9% of the forest degradation and 11% of the deforestation in the buffer zone, a disturbance that could have been avoided if inclusion in the PES had been successfully negotiated with these communities and their demands met.

The Indigenous communities with land in the three zones cover 30% of the core zone, 25% of the buffer zone and 9% outside the Reserve. The Indigenous communities that did not participate with the MBCF – Crescencio Morales and San Cristóbal – were more reluctant to accept the declaration of the PA and expressed their disagreement by cutting down 18% of the forest in the core zone.

Discussion

From this detailed analysis through visual interpretation it is clear that the trends and patterns of recovery and loss of forest both inside and outside the MBBR between 1994 and 2017 are, in general, directed towards an increase in forest cover, a slight increase in deforestation and a decrease in non-forest surfaces that were converted to forest. Between 1994 and 2017, 4009 ha were deforested or changed to non-forest use in the MBBR, with a forest loss of 174 ha/year, including 1824 ha in the core zone (79 ha/year), which is consistent with the previous findings of several authors (Brower et al. 2002, López-García 2011, Navarrete et al. 2011, Champo-Jiménez et al. 2012, Vidal et al. 2014), although these focused on different periods, study areas, analysis methods (photographic interpretation, satellite images, visual interpretation) and different spatial resolutions of analysis (1–30 m/pixel) and zones under analysis (in some cases only the core zone, in others the entire MBBR). There were also studies that considered both the Reserve and its area of influence. In any case, they all concur that the greatest disturbance has occurred inside the PA, which could have been avoided through successful negotiation with the agrarian communities that disagreed with participation in the MBBR project instead of imposing a declaration that was clearly doomed to failure.

Although disturbance has decreased since 2012 (Vidal et al. 2014, López-García & Navarro-Cerrillo 2019), it is estimated that, as of 2018, with the inclusion in the PES of the communities that had no initial desire to participate (De la Vega et al. 2021) and were responsible for disturbance of 6.81% of the core zone following 20 years of the MBBR's existence, the observed trend is one of forest recovery. The four main drivers of this forest recovery have been reduction of grazing activities, decreases in logging, recovery after fire and reforestation (Honey-Rosés et al. 2018). In 2018, 97% of the farms in the core zone were included in the MBCF PES programme, and only one *ejido* and three private properties still remained to sign an agreement with the MBCF. The continuing trend is therefore expected to be one of improvement in forest recovery.

Agricultural abandonment has given rise to active afforestation through reforestation programmes for unused agricultural land. Reduced grazing activities and felling and recovery after fire have been the drivers of passive reforestation, giving rise to forest improvement processes (forest densification) on land with intense degradation. Most of the forest recovery has taken place in degraded forests rather than on abandoned agricultural land (Honey-Rosés et al. 2018). The results of this analysis show three

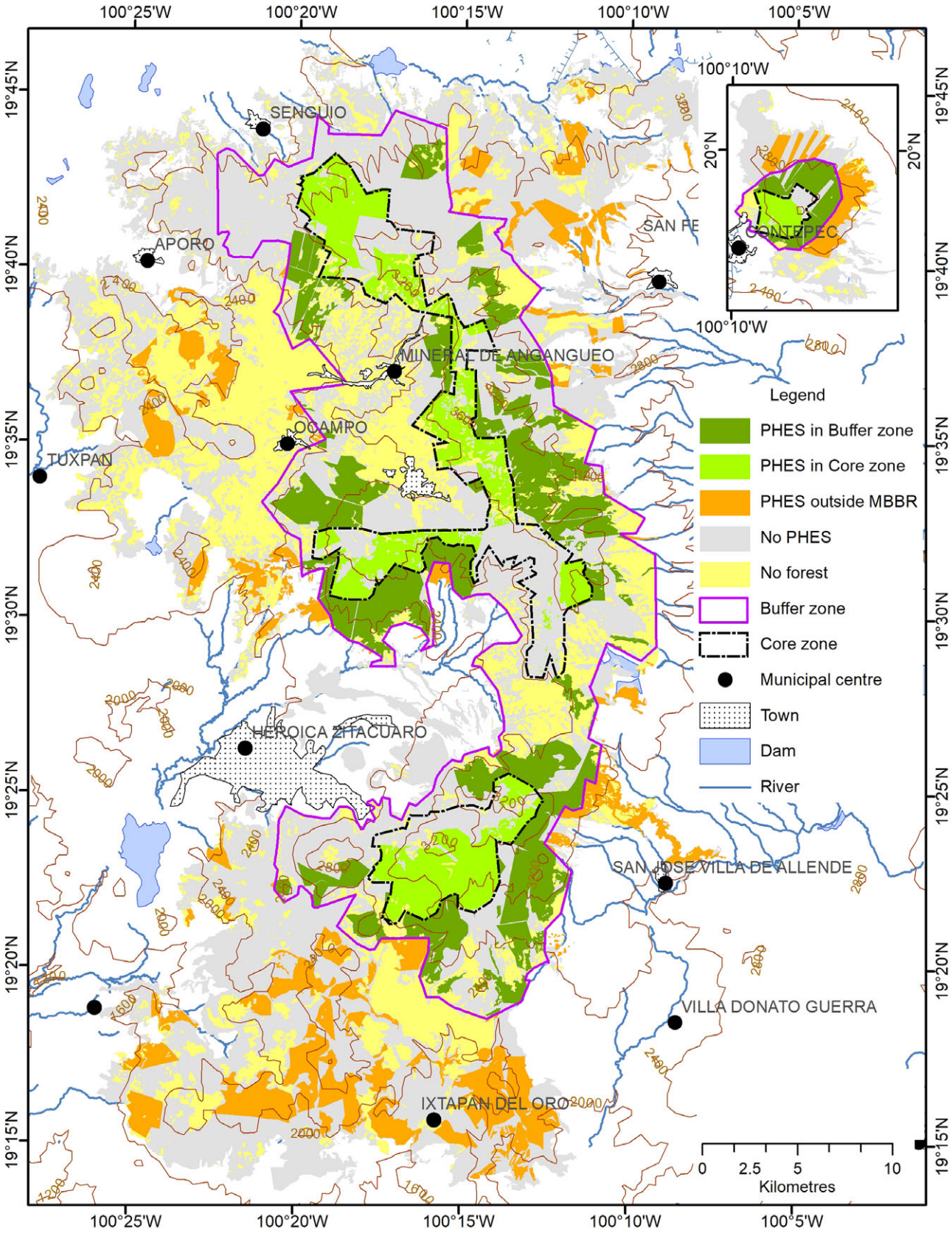

Fig. 3. Payments for Hydrological Environmental Services (PHES) in the Monarch Butterfly Biosphere Reserve (MBBR) and in the forests within its area of influence (2000–2017).

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Table 4. Rates of forest-cover change in the various zones analysed between 1994 and 2017.

Categories	Core zone	Buffer zone	MBBR	Outside MBBR	All areas
Forest cover >50%	−0.15	0.04	-0.01	0.11	0.06
Forest cover 10–50%	−1.06	−0.20	-0.45	2.67	1.02
Forest cover >10%	−0.24	0.02	-0.05	0.30	0.14
Deforested	2.06	−0.28	0.63	−0.42	0.01
No forest	−0.37	0.03	-0.08	−0.95	−0.51
Deforested and no forest	1.42	−0.04	0.14	−0.80	−1.64

MBBR = Monarch Butterfly Biosphere Reserve.

Table 5. Percentage of forest degradation and deforestation, distributed by property and zone, proportional to the properties analysed in each zone.

		Core zone 11.08%		Buffer zone 34.90%		Outside MBBR 54.02%	
Type of property		Forest degradation	Deforestation	Forest degradation	Deforestation	Forest degradation	Deforestation
Properties in core zone, buffer zone and outside MBBR 23.24%	IC (10)	3.25	4.46	2.48	2.00	0.07	
	Ej (10)	1.86	0.31	0.45	0.05		
	Total	5.12	4.76	2.93	2.06	0.07	
Properties in MBBR (core zone and buffer zone) 8.69%	Ej (16)	4.07	0.03	0.09	0.04		
	PP (4)	0.03	3.29	1.09	0.43		
	FP (1)	0.30	0.31				
	Total	4.40	3.63	1.18	0.47		
Properties in buffer zone and outside MBBR 22.09%	IC (3)			0.49	0.28	0.06	
	Ej (26)			1.75	0.82		
	PP (5)			0.83	0.54		
	Total			3.07	1.63		
Properties only in core zone 1.53%	Ej (2)	0.59	1.60				
	PP (4)	0.30	0.18				
	SP (1)	0.06	0.11				
	Total	0.95	1.89				
Properties only in buffer zone 4.54%	Ej (15)			0.61	0.81		
	PP (8)			0.41	0.11		
	Total			1.01	0.91		
Properties only outside MBBR 23.19%	IC (1)						
	Ej (68)					0.38	0.33
	PP (20)						
	Total					0.38	0.33
Undefined properties 16.72%						0.40	0.01
Total		20.94	20.56	16.38	10.14	1.37	0.67

Ej = *ejido*; FP = federal property; IC = Indigenous communities; MBBR = Monarch Butterfly Biosphere Reserve; PP = private property; SP = state property.

types of recovery: through forest improvement (5.03%) that takes place on previously degraded land; through reforestation (2.84%), found in previously deforested land, where passive reforestation should dominate; and through afforestation (2.97%) that occurs on land used for agriculture or grazing, evidently as active reforestation. Problems among the agrarian communities have also decreased and productive activities have increased, which have obviously improved the quality of life of the populations that have found themselves in the MBBR and thus reduced the pressure on the forest.

It can thus be affirmed that, as of 1986, the communities lost social control of the land through conversion of the common goods regulated by the *ejidos* and the Indigenous communities into a PA, which created conflicts due to the manner in which the PA acted to transform the commons (Merino-Pérez & Hernández-Apolinar 2004, Honey-Rosés et al. 2009). Assets were commercially exploited through community-managed forestry companies that equitably distributed income among each member of the *ejido* or community, except for the *avecindados*, who live there but do not own land (Bray et al. 2003, Merino 2003). These conflicts prompted the Indigenous communities of San Cristóbal (1049 ha) and Crescencio Morales (6945 ha) not to sign the agreement with the MBCF. The former community felled and burned its forests in response to the 1986 decree (WWF 2004), while the latter community cut down its forests between 2005 and 2007 (López-García 2009). Social conflicts in the Indigenous community of Crescencio Morales finally ended with the formation of the Crescencio Morales *ejido* in 2008, leaving the community with 5220 ha and the *ejido* with 1725 ha.

The PES scheme of the MBCF commodified the land that was once managed as a common forest (González-Duarte 2021), leading to conflicts as the Reserve transformed the common goods that were socially regulated by *ejidos* and Indigenous communities (Merino-Pérez & Hernández-Apolinar 2004, Honey-Rosés et al. 2009). While the PES programme has alleviated some of the economic losses associated with the ban on communal forestry, it has also brought about social conflict (González-Duarte 2021). Therefore, neither the legal protection nor the PES programme was associated with the maintenance of forest cover (Honey-Rosés et al. 2011).

Some authors have estimated the forest loss (disturbance and deforestation) avoided in the MBBR and its area of influence by comparing forest cover on protected and unprotected lands that were similar in terms of accessibility, governance and forest type

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(Honey-Rosés et al. 2011). Others understand that the core and buffer zones present similar conditions and can thus be compared, but they consider that such a comparison should be treated with some caution because these zones have different types of soils (Mas 2005). In the present study, changes in the properties that were in the core zone, the buffer zone and outside the Reserve were compared under the assumption that they would experience the same management, since the assembly of each *ejido* or Indigenous community is the highest authority and determines the management that is conducted in each property. if they were managed by an *ejido* or Indigenous community. The results show that the communities cut down more trees in the core zone. Changes per farm were also compared between those located within the core zone and those in the buffer zone, and the result was the same, indicating that this is a consequence of the social discontent produced following declaration of the PA. It should be noted that 86% of the area of the core zone corresponds to properties with land in both zones (core and buffer). This confirms the notion that clandestine logging is closely related to the disagreement with the PA declaration. From 1971 to 1999, 44% of the 1986 PA forests were degraded by illegal logging (Brower et al. 2002). As a result, several monarch butterfly colonies disappeared completely or their numbers of butterflies decreased considerably (Vidal et al. 2014). This was the case with the colonies in Cerro Pelón (Ramírez et al. 2008), Sierra Campanario (Brower et al. 2008), Cerro Altamirano, Rosario and Sierra Chincua (Brower et al. 2011). Felling of the fir forests shows that these communities wanted to eliminate the monarch butterfly colonies from their land in order to demonstrate their disagreement with the PA. The most affected forests were those of the colonies of Crescencio Morales, El Rosario, Nicolás Romero, La Mesa, Cerro Prieto and San Juan Xoconusco (Vidal & Rendón-Salinas 2014). In 2009, the Indigenous communities of San Cristóbal and Crescencio Morales signed an agreement with the MBCF and, in 2018, the *ejido* Crescencio Morales also signed an agreement with the MBCF (De la Vega et al. 2021).

Conclusion

In regions with social property regimes, such as Mexico, establishment of a PA requires the consensus of all of the relevant communities in order to achieve effective conservation. The lack of involvement of some *ejidos* and the Indigenous communities and small landowners of the core zone in the creation of the MBBR, without the application of programmes that promote productive activities in the buffer zone and compensate the communities for the lack of use of the forest, has had adverse consequences for the conservation of forests and protection of monarch butterfly hibernation sites. Forty-five years after the monarch butterfly hibernation sites were identified, 35 years after the decree that prompted defiant logging in this region and almost two decades after its expansion and designation as the MBBR, disturbance has outpaced forest recovery. Outside the Reserve, however, recovery has exceeded disturbance. It took nearly two decades of negotiation to include the communities that were initially reluctant to participate in the monarch butterfly conservation programme. The consequent loss of forest and impact on monarch butterfly colonies could have been avoided by negotiating for the participation of all of the agrarian communities prior to decreeing the PA and thus avoiding the collateral impacts that the PA brought with it. The disturbance suffered in the MBBR not only affected the forests and the monarch butterfly colonies, but also altered the water balance and reduced the environmental services that these forests can provide to society.

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