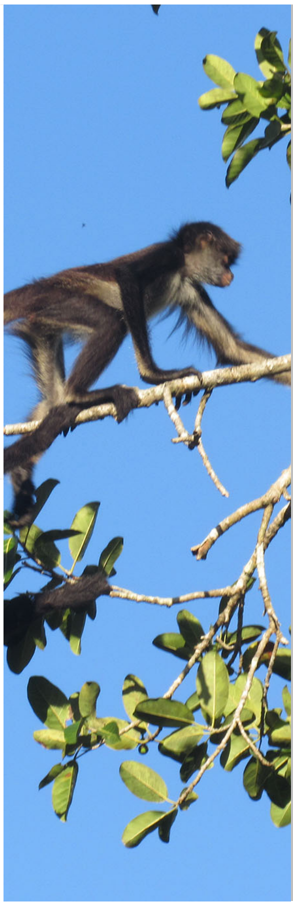


THE IMPACT OF THE ESTABLISHMENT OF OTOCH MA'AX YETEL KOOH PROTECTED AREA (YUCATÁN, MEXICO) ON POPULATIONS OF TWO NEOTROPICAL PRIMATES

Denise Spaan[1,2,3,*], Gabriel Ramos-Fernández[2,4,5], Martha Bonilla-Moheno[6], Colleen M. Schaffner[2,7] and Filippo Aureli[1,2,8.*]

Corresponding authors: dspaan@uv.mx; faureli@uv.mx

[1]Instituto de Neuroetología, Universidad Veracruzana, Xalapa, 91190 Veracruz, Mexico
[2]ConMonoMaya, A.C., Km 5.4 carretera Chemax-Coba, Chemax, 97770 Yucatan, Mexico
[3]Instituto de Investigaciones sobre los Recursos Naturales, Universidad Michoacana San Nicolás de Hidalgo, Morelia, 58330 Michoacan, Mexico
[4]Instituto de Investigaciones en Matemáticas Aplicadas y en Sistemas, Universidad Nacional Autónoma de Mexico, 04510, Mexico City, Mexico
[5]Unidad Interdisciplinaria en Ingeniería y Tecnologías Avanzadas, Instituto Politécnico Nacional, La Laguna Ticoman, 07340, Mexico City, Mexico
[6]Red de Ambiente y Sustentabilidad, Instituto de Ecología A.C., El Haya, Xalapa, 91073, Veracruz, México
[7]Psychology Department, Adams State University, Alamosa, CO 81101, USA
[8]Research Centre in Evolutionary Anthropology and Palaeoecology, Liverpool John Moores University, Liverpool L3 3AF, UK

ABSTRACT
In 2002, Otoch Ma'ax Yetel Kooh (OMYK) was decreed a federal Flora and Fauna Protected Area in the state of Yucatán, Mexico, resulting in bans on hunting, logging and slash-and-burn agriculture within its limits. Our aim was to evaluate the influence of the establishment of the protected area on local primate populations. We compared relative abundances of Geoffroy's Spider Monkeys (*Ateles geoffroyi*) and Black Howler Monkeys (*Alouatta pigra*) in mature and secondary forest before OMYK was established (in 1998) and 13 years after (in 2015). In both years, the relative abundance of Spider Monkeys was higher in mature than in secondary forest and Howler Monkeys were found exclusively in mature forest. The overall similarity in Spider and Howler Monkey relative abundances over time when mature and secondary forests are considered together is likely because the primates were not hunted and logging was not carried out prior to the establishment of the protected area. Benefits to wildlife of banning slash-and -burn agriculture take longer to become apparent. Still, the legal status of the protected area is critical to defend this site from future land-use changes and it allows the secondary forests to age, thereby increasing habitat for the primate populations.

Key words: *Ateles*, *Alouatta*, conservation, population monitoring, Mexico, reserve

INTRODUCTION
Evaluating the effectiveness of protected areas in maintaining stable wildlife populations is particularly relevant in light of Aichi Biodiversity Target 11, which aimed to protect 17 per cent of the Earth's terrestrial surface and inland waters by the year 2020 (CBD, 2010). Protected areas tend to maintain stable populations of birds and mammals (Geldmann et al., 2013), but these trends are associated with the development level of each country and animal body mass and therefore vary across countries and taxa (Barnes et al., 2016). Commonly, studies compare either animal abundance or species richness of protected areas to areas without protection (often adjacent to the protected areas; Gray et al., 2016), or monitor changes in population size within already established protected areas (Barnes et al., 2016; Brown et al., 2019; Kiffner et al., 2020). Although comparisons of population size of mammal species before and after the establishment of protected areas are uncommon (Wegge et al., 2009), they can provide critical information regarding trends of change, which is particularly relevant in the context of endangered species, and/or aiding in the recovery of highly endangered species (e.g. the Hainan Gibbon (*Nomascus hainanus*), Zhang et al., 2020).

In tropical regions, protected areas are often mosaics of different types of land cover including forests in differing stages of regeneration, savanna grasslands and woodlands (Arroyo-Mora et al., 2005; DeClerck et al., 2010). This heterogeneous landscape can influence the effectiveness of protected areas in maintaining species populations as they vary per land cover depending on their habitat requirements. This is particularly relevant for many primate species that have highly specialised diets because food availability varies across the landscape (Clink et al., 2017). Evaluation of the success of protected areas in sustaining mammal populations should therefore be assessed per land cover type.

Secondary forests (i.e. forest regenerating after clearance or disturbance; Guariguata & Ostertag, 2001), for instance, differ greatly from mature forests in terms of their structure and species composition, even though some characteristics of older secondary forests may resemble mature forests. Once a plot that was farmed using traditional techniques (e.g. slash-and-burn agriculture) is abandoned, structural complexity may be reestablished within 40–95 years if abandoned agricultural plots are well connected and surrounded by large tracts of mature forest from which seed dispersal is high (Aide et al., 2000; Chazdon, 2003; Read & Lawrence, 2003; Chazdon et al., 2009; Dupuy et al., 2012). Although tree species composition of secondary forests may take hundreds of years to resemble that of mature forests (Aide et al., 2000; Chazdon, 2003), leading to differences in feeding tree availability between mature and secondary forests (Sorensen & Fedigan, 2000; Ramos-Fernández & Ayala-Orozco, 2003), primates are widely reported to use secondary forests (Galán-Acedo et al., 2019).

The benefits to wildlife associated with prohibitions implemented by protected areas with regards to traditional farming techniques (e.g. banning slash-and-burn agriculture) may be slow and indirect, only detectable as the secondary forest reaches late stages of regeneration. Understanding the effects of forest regeneration on primate populations in protected areas therefore requires long-term monitoring. Contrastingly, the benefits of banning extractive activities that directly threaten wildlife abundance (e.g. hunting) or tree species composition (e.g. logging) will directly and rapidly benefit wildlife if well enforced (Harrison, 2011). The aim of our study was to determine the effectiveness of the protected area Otoch Ma'ax Yetel Kooh (OMYK; "the house of the spider monkey and the puma" in Yucatec Maya), located on the Yucatan Peninsula, Mexico, in maintaining stable populations of Geoffroy's Spider Monkeys (*Ateles geoffroyi*) and Black Howler Monkeys (*Alouatta pigra*) by comparing their relative abundance in mature and secondary forests before OMYK was decreed and 13 years after. Both primates are listed as Endangered on the IUCN Red List (Cortes-Ortíz et al., 2020a,b) and Geoffroy's Spider Monkey is one of the 25 most endangered primate species (Méndez -Carvajal et al., 2019).

METHODS

Study area

Otoch Ma'ax Yetel Kooh (5,367 ha; 20°38' N, 87°38' W; 14 m elevation) was decreed as a Flora and Fauna protected area in 2002. Unlike many other federal protected areas in Mexico, OMYK developed out of a community-based initiative, led by members of the local community of Punta Laguna (García-Frapolli et al., 2009). The decree banned hunting, logging and slash-and-burn agriculture (CONANP, 2006). The ban on slash-and-burn agriculture allowed converted forests to regenerate naturally, thereby increasing available habitats for canopy dwelling species as the forest aged (Ramos-Fernández et al., 2018). Neither species of monkey was hunted nor were large trees logged in the mature forest bordering the lake prior to the protected area's establishment.

The protected area consists of patches of semi-deciduous forest surrounded by forest in different stages of regeneration. The area where the primate surveys were performed consisted of 90.1 per cent and 93.4 per cent regenerating forest and 2.2 per cent and 2.6 per cent mature forest in 2003 and 2015, respectively (Bonilla-Moheno et al., in review). OMYK is highly seasonal, with a rainy season from May to October and a dry season from November to April (SMN, 2020). Mean temperatures range from 20.1 °C in January to 26.9 °C in August (SMN, 2020).

Study design

We carried out population surveys of Geoffroy's Spider Monkeys and Black Howler Monkeys in 1997–1998 (hereafter 1998; before the protected area was established) and 2015 (after the protected area was established) in the southern section of OMYK (Figure 1). We surveyed four transects in 1998 and three transects in 2015. The three transects surveyed in 2015 were in approximately the same location as the transects surveyed in 1998. The total length of all transects was 19.6 km in 1998 and 12.5 km in 2015. Most of the transect lengths were in secondary forest: 13.2 km in 1998 (67 per cent) and 7.9 km in 2015 (63 per cent). Each transect was walked between 9 and 31 times (mean ± standard deviation: 19.8 ± 8.4) in 1998 and between 9 and 15 times (11.3 ± 2.6) in 2015.

DATA COLLECTION

For both survey periods (1998 and 2015) we walked transects between 7:00 and 11:00 and between 13:00

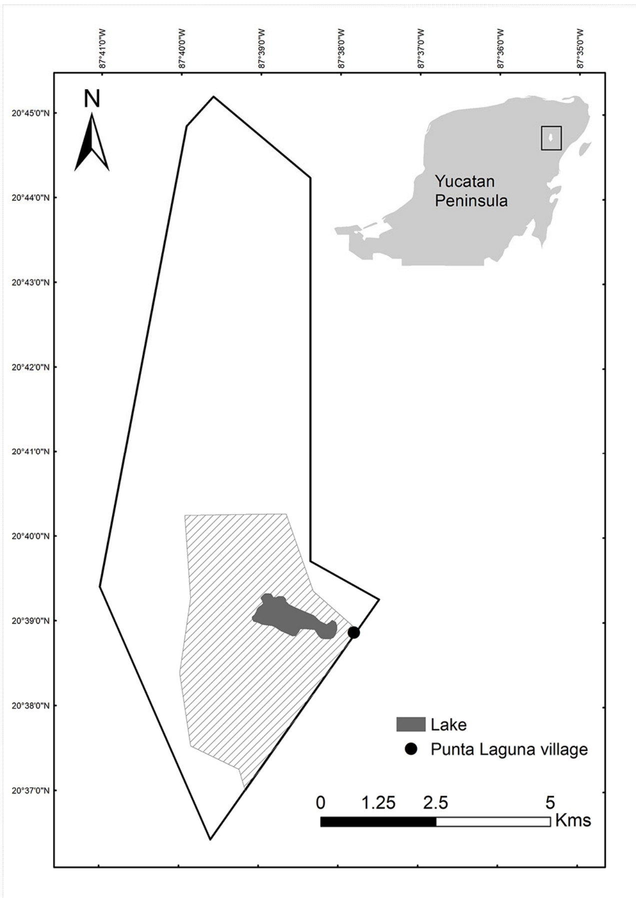


Figure 1. OMYK location. The perimeter of the protected area is represented by the solid black line. The hatched polygon represents the area where surveys were carried out in 1998 and 2015.

and 18:00 at a speed of 1.25–2.0 km per hour. We scheduled transect walks evenly between the morning and afternoon over a full year. On sighting monkeys, we counted all independently moving individuals and marked the location of the sighting using a hand-held GPS device.

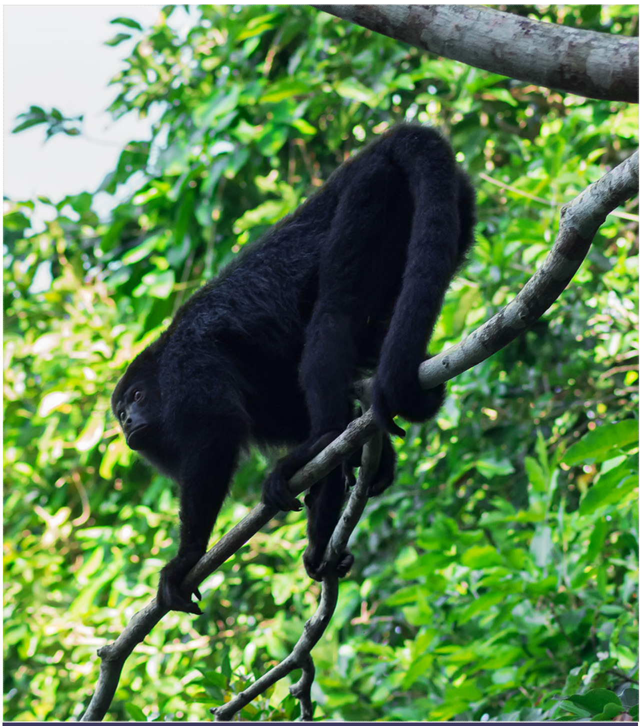
Data analysis

We used the encounter rate as a measure of relative abundance (Mitani et al., 2000; Matsuda et al., 2016; Chapman et al., 2018). We calculated the encounter rate by dividing the total number of individuals sighted during surveys by survey effort (total kilometres walked). Instances where monkeys were heard but not seen during transect walks were not considered in the analyses. We calculated encounter rates for the secondary and the mature forest in 1998 and 2015 for each species. We calculated 95 per cent confidence intervals following Meyler et al. (2012) to compare encounter rates of the same species between years and vegetation types. We were unable to calculate 95 per cent confidence intervals for mature forest in 1998 as only one transect included mature forest. Encounter rates are a useful tool for long-term monitoring as they lack the assumptions that may limit the use of population density estimates (Chapman et al., 2018). Encounter rates do not account for the different probabilities of detecting primates due to differences in visibility between secondary and mature forest or differences in observers' ability to detect primates (Chapman et al., 2018). The observers were different individuals between the 1998 and 2015 surveys, but variance in observers' ability to detect primates is usually low (e.g. Chapman et al., 2000).

RESULTS

We walked a similar percentage of transect length in mature forest during each survey period (33.2 per cent in 1998 and 33.3 per cent in 2015). We saw 128 and 83 Spider Monkeys during the 1998 and 2015 surveys, respectively (Table 1). The encounter rate in mature forest for Spider Monkeys in 1998 fell within the 95 per cent confidence interval for 2015 (Table 1). For the secondary forest, the 95 per cent confidence intervals of Spider Monkey 1998 and 2015 encounter rates overlapped (Table 1). Spider Monkey encounter rates in mature forest were above the 95 per cent confidence intervals for regenerating forest in both survey periods (Table 1).

We sighted 37 and 12 Howler Monkeys during the 1998 and 2015 surveys, respectively (Table 2). The encounter



Black Howler Monkey (*Alouatta pigra*) © Fabrizio Dell'Anna

Table 1. Spider Monkey encounter rate (number of individuals per km walked) and 95 per cent confidence intervals (CI) per vegetation type for the 1998 and 2015 surveys.

	1998				2015			
Vegetation type	Distance walked (km)	Number of individuals sighted	Individual encounter rate	95% CI	Distance walked (km)	Number of individuals sighted	Individual encounter rate	95% CI
Mature forest	72.9	102	1.40		42.8	76	1.78	0.51 – 2.11
Secondary forest	146.8	26	0.18	0.04 – 0.31	85.7	7	0.08	-0.05 – 0.15
Total	219.7	128	0.58	-0.13 – 1.09	128.5	83	0.65	0.02 – 1.34

Table 2. Howler Monkey encounter rate (number of individuals per km walked) per vegetation type for the 1998 and 2015 surveys.

	1998			2015			
Vegetation type	Distance walked (km)	Number of individuals sighted	Individual encounter rate	Distance walked (km)	Number of individuals sighted	Individual encounter rate	95% CI
Mature forest	72.9	37	0.5	42.8	12	0.28	-0.12 – 0.38
Secondary forest	146.8	0	0	85.7	0	0	
Total	219.7	37	0.17	128.5	12	0.09	-0.06 – 0.21

rate for Howler Monkeys in mature forest in 1998 was above the 95 per cent confidence interval of the corresponding 2015 encounter rates (Table 2). No Howler Monkeys were seen in secondary forest. When considering both types of forest, the encounter rate for Howler Monkeys in 1998 fell within the 95 per cent confidence interval for 2015 (Table 2).

DISCUSSION

Few studies have compared animal populations before and after the establishment of a protected area (Gormley et al., 2012). Hence, our findings contribute to this important line of research. We found that Spider Monkey relative abundance in mature forest and both Spider and Howler Monkey overall relative abundances (combining mature and secondary forest) were similar before and after the establishment of the protected area. Howler Monkey relative abundance in mature forest was slightly lower in 2015 than in 1998, but only one group of Howler Monkeys was repeatedly detected during the two survey periods.

The stability in overall relative abundances (i.e. when mature and secondary forests are considered together) of both monkey species suggests that OMYK's establishment contributed to the maintenance of these primate populations. It is likely that the 17-year gap between our two surveys is not sufficient to document changes in relative abundances as these species have slow life cycles (Di Fiore et al., 2010). The hunting and logging bans put in place upon the decree of the protected area are unlikely to have affected the Howler and Spider Monkey populations in OMYK because the local community did not hunt monkeys for food or to be kept or sold as pets and did not log trees important to the monkey diets long before the creation of the protected area. Still, the establishment of the protected area had beneficial consequences for the monkeys and other wildlife by providing legal impediments to large-scale developments linked to mass tourism. The legal status of protected areas enables forests to regrow or regenerate in areas that would remain unforested without protection (Andam et al., 2013), thereby contributing to the conservation of wildlife populations that can use these areas. After the decree of OMYK, mature forest and secondary forest > 15 years of age increased in the southern section of the protected area (Bonilla-Moheno et al., in revision), potentially increasing the available Spider Monkey food sources and resting sites as the forest aged (cf. Sorensen & Fedigan, 2000). It is therefore plausible that the overall number of Spider Monkeys will increase over time as forests regenerate naturally, supporting the slower and indirect benefits of banning slash-and-burn agriculture and of protecting areas for biodiversity.

Part of the success of OMYK in protecting primate populations might be due to its origins, in particular the

Geoffroy's Spider Monkeys (*Ateles geoffroyi*) © Denise Spaan

involvement of the local Mayan population (García-Frapolli et al., 2009), which is recognised as a vital component to ensure that protected areas' rules and policies are complied with (Andrade & Rhodes, 2012). For several decades preceding the decree of the protected area, members of the Punta Laguna community profited from a small-scale ecotourism project focused on the Spider Monkeys living in the area (García-Frapolli et al., 2009). After OMYK's establishment in 2003, they formed the cooperative Najil Tucha (the house of the Spider Monkeys), thereby managing ecotourism in a more structured manner (Garcia-Frapolli et al., 2013). As a result, traditional slash-and-burn agriculture was not only abandoned within the protected area, but it was also greatly reduced in the buffer zone surrounding the protected area between 2003 and 2015 (Bonilla-Moheno et al., in revision). This means that areas surrounding the protected area were left to regenerate naturally, increasing the overall habitat available for Spider Monkeys and potentially improving structural connectivity between mature forest patches within and outside of OMYK.

The similarity in overall relative abundances of the two monkey species before and after the protected area's establishment suggests that small-scale slash-and-burn agriculture carried out by the local people within and around the protected area before its decree did not jeopardise primate populations. This is plausible as the Mayan people have practised slash-and-burn agriculture for thousands of years (Jones, 1994) with primate populations living alongside them in many areas. Traditionally, slash-and-burn agriculture practised by Mayan communities surrounding OMYK involved fallow periods of 20–30 years. This way of practising slash-and -burn agriculture may not greatly impact primate populations as Spider and Howler monkeys mostly use mature and secondary forest older than 30 years (Ramos-Fernández et al., 2013). Slash-and-burn agriculture was performed on a relatively small scale in the years preceding the decree of OMYK (Bonilla-Moheno et al., in revision), thereby supporting the view that its impact on primate populations was sustainable. The ban on slash-and-burn agriculture put in place after the protected area's establishment will have long-term impacts on the primate and other wildlife populations by providing more suitable habitat as the forest ages.

Spider Monkeys were sighted in both mature and secondary forests although they were found at higher relative abundances in mature forest compared to secondary forest in both 1998 and 2015. Spider Monkeys living in heterogeneous landscapes therefore use secondary forests, provided there is sufficient mature forest available. The differences we report between

Spider and Howler Monkey relative abundances in mature and secondary forests clearly show the importance of understanding how individual species use the landscape within protected areas over time. Studies like ours focusing on individual species per land-cover type are critical for protected area management to make informed decisions and thereby ensure the maintenance of stable populations.

It may take substantial time for protected areas to have a measurable impact on the abundance of species with slow life cycles, especially when hunting and logging are not the main threats. However, the legal status of the area is likely to have an immediate positive effect by protecting wildlife from negative land-use changes and thus maintaining their populations. Our research also contributes to a growing body of evidence that secondary forests play an important role in mammal conservation and that preserving these forests within and outside of protected areas is vital in protecting populations of arboreal mammal. This can be facilitated when there is community support for protected areas to ensure their long-term success in preserving biodiversity.

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ABOUT THE AUTHORS

Denise Spaan has a BSc in Zoology (University of Leeds), MSc in Primate Conservation (Oxford Brookes University) and a PhD in Neuroethology (Universidad Veracruzana). She undertook a postdoctoral fellowship at the Universidad Michoacana de San Nicolas de Hidalgo and she is currently a researcher in the Institute of Neuroethology at the Universidad Veracruzana. She coordinates primate population monitoring for the Mexican NGO ConMonoMaya. Her research focuses on understanding threats facing primates and improving methods used to survey their populations.

Gabriel Ramos-Fernández has a BSc in Basic Biomedical Research (National Autonomous University of Mexico (UNAM)) and a PhD in Biology (University of Pennsylvania). He was academic advisor for Pronatura Península de Yucatán and a Professor at the National Polytechnic Institute in Mexico and is now associate professor at UNAM. His interests lie in social complexity, social behaviour in animals and social network modelling, as well as in strategies for biodiversity conservation and socio-ecosystems. He is a founding member of the NGO ConMonoMaya.

Martha Bonilla-Moheno is a Researcher at the Instituto de Ecología in Xalapa, Mexico. She has a BSc in Biology (UNAM), and a PhD in Environmental Studies (University of California, Santa Cruz). She was a postdoctoral scholar at the University of Puerto Rico. Her research topics include land use change, restoration ecology and the effect of productive activities on the landscape.

Colleen M. Schaffner has a BA degree in Psychology (George Washington University), a Master's degree in Animal Behaviour (Bucknell University) and a PhD in Biological Psychology (University of Nebraska). She was professor in the Psychology Department and Director of the Graduate School for the University of Chester before moving to Mexico as a professor at Universidad Veracruzana. Currently, she is at Adams State University in southern Colorado where she is Director of the School of Humanities and Social Sciences. Since 2000, Colleen has studied all things Spider Monkeys and is a founding member of the NGO ConMonoMaya.

Filippo Aureli has a BSc in Biological Sciences (University of Rome "La Sapienza") and a PhD in Ethology (University of Utrecht). He was a postdoctoral fellow at Emory University and a Professor of Animal Behaviour at Liverpool John Moores University. He is currently a Professor at Universidad Veracruzana. He has researched primates for 35 years, focusing on social relationships, conflict management and fission-fusion dynamics. Over the past 20 years, he has devoted himself to the socioecology and conservation of Spider Monkeys in their natural habitat and is a founding member of the NGO ConMonoMaya.

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RESUMEN

En 2002, la reserva Otoch Ma'ax Yetel Kooh (OMYK, por sus siglas en inglés) fue declarada como Área de Protección de Flora y Fauna federal en el estado de Yucatán, México, lo que supuso la prohibición de la caza, la tala y la agricultura de roza y quema dentro de sus límites. Nuestro objetivo era evaluar la influencia del establecimiento del área protegida en las poblaciones locales de primates. Comparamos la abundancia relativa de los monos araña de Geoffroy (*Ateles geoffroyi*) y los monos aulladores negros (*Alouatta pigra*) en el bosque maduro y secundario antes del establecimiento de OMYK (en 1998) y 13 años después (en 2015). En ambos años, la abundancia relativa de monos araña fue mayor en el bosque maduro que en el secundario y los monos aulladores se encontraron exclusivamente en el bosque maduro. La similitud general de la abundancia relativa de los monos araña y los monos aulladores a lo largo del tiempo al considerar en conjunto los bosques maduros y los secundarios, se debe probablemente a que los primates no eran cazados y a que la tala de árboles no se llevaba a cabo antes del establecimiento del área protegida. Los beneficios para la fauna silvestre de la prohibición de la agricultura de tala y quema tardan más en hacerse evidentes. Aun así, la condición legal del área protegida es fundamental para defender este sitio de futuros cambios en el uso de la tierra y permitir que los bosques secundarios envejezcan, con el consiguiente aumento del hábitat de las poblaciones de primates.

RÉSUMÉ

En 2002, Otoch Ma'ax Yetel Kooh (OMYK) a été décrété aire fédérale protégée de la flore et de la faune dans l'État du Yucatán, au Mexique, ce qui a entraîné l'interdiction de la chasse, de l'exploitation forestière et de la culture sur brûlis dans cette zone. Notre objectif était d'évaluer l'influence de la création de cette aire protégée sur les populations locales de primates. Nous avons comparé les abondances relatives des singes araignées de Geoffroy (*Ateles geoffroyi*) et des singes hurleurs noirs (*Alouatta pigra*) dans la forêt mature et secondaire avant la création de l'OMYK (en 1998) et 13 ans après (en 2015). Au cours de ces deux années, l'abondance relative des singes araignées était plus élevée dans la forêt mature que dans la forêt secondaire, et les singes hurleurs ont été trouvés exclusivement dans la forêt mature. La similitude générale dans les abondances relatives de singes araignées et de singes hurleurs, lorsque les forêts matures et secondaires sont considérées ensemble, s'explique probablement par le fait que ni la chasse aux primates ni l'exploitation forestière n'avaient lieu avant l'établissement de l'aire protégée. Mais les avantages pour la faune de l'interdiction de l'agriculture sur brûlis mettent plus de temps à se manifester. Néanmoins, le statut juridique d'aire protégée est essentiel pour défendre ce site contre les changements futurs d'utilisation des terres, perme