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Research Article

Protecting wildlife in a heavily hunted biodiversity hotspot: a case study from the Atlantic Forest of Bahia, Brazil

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Abstract

Hunting is one of the principal causes of wildlife declines throughout the tropics. Even with an increase in the number of reserves, protecting wildlife has proven difficult and many reserves remain little different from unprotected areas. In Brazil, private landowners are being encouraged by federal and state governments and non-governmental organizations to participate in a national conservation strategy by setting aside land for preservation. However, due to chronic hunting pressure, the role that private reserves might play remains to be determined. In this study we analyze the potential of private reserves through a case study of the Reserva Ecológica Michelin in Bahia, Brazil. We measured the relative abundances of medium and large mammals before and after the implementation of guard patrols, to determine the efficacy of this management strategy for protecting wildlife. The relative abundance of the fauna increased by 72.6 % after the initiation of guard patrols, from 5.07 to 8.68 encounters/10 km, with preferred game species (*Dasypus novemcinctus*, *Cuniculus paca, Pecari tajacu,* and *Mazama americana*) increasing by 146.7-300%. Similarities between the relative abundances of preferred game species at our site after the initiation of the guard patrols and those of other protected Neotropical reserves indicate that the Michelin reserve is now being effectively protected. Although the cost of $9.4/ha to protect the reserve is high, this study shows that the private reserve initiative can be an effective component of the national conservation strategy.

Keywords: Atlantic Forest; hunting; mammals; private reserve; protection

Resumo

A caça é uma das principais causas do declínio da vida silvestre nos trópicos. Mesmo com o aumento do número de reservas, a proteção da vida silvestre tem sido difícil e muitas reservas apresentam pouca diferença a áreas não protegidas. No Brasil os proprietários privados estão sendo incentivados pelos governos federal, estaduais e organizações não governamentais a participar de uma estratégia nacional de conservação salvaguardando terras para proteção. Contudo, devido à crônica pressão de caça, o papel que as reservas particulares podem desempenhar permanece indeterminado. No presente estudo, analisamos o potencial de reservas privadas nesta estratégia de conservação usando o estudo de caso da Reserva Ecológica Michelin na Bahia, Brasil. Medimos a abundância relativa dos mamíferos de médio e grande porte antes e depois da implementação de um sistema fiscalização para determinar se a estratégia de manejo adotada foi eficaz na proteção da vida selvagem. A abundância relativa da fauna amostrada aumentou 72,6% entre os períodos de estudo, de 5,07 a 8,68 detecções /10 km, com espécies preferencialmente caçadas (*Dasypus novemcinctus*, *Cuniculus paca*, *Pecari tajacu* e *Mazama americana*) aumentando entre 146,7-300%. Semelhanças nas abundâncias relativas das espécies preferencialmente caçadas de nosso área de pesquisa após a implementação do sistema de fiscalização com as de reservas protegidas do neotropico indicam que a reserva da Michelin está sendo efetivamente protegida. Embora o custo de US$ 9,4/ha para proteger a reserva é elevado, este estudo mostra que a inclusão de reservas privadas pode ser um componente eficaz na estratégia nacional de conservação.

Palavras-chave: Floresta Atlântica, caça, mamíferos, reserva privada, proteção

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Introduction

The precipitous decline of wildlife throughout the tropics due to hunting and habitat loss, degradation and fragmentation presents a major conservation challenge [1-5]. The crisis is especially acute in "biodiversity hotspots," where a disproportionate number of the world's species tenuously survive in human-dominated landscapes [6]. Human population densities tend to be high in the hotspots and the pressure on land and wildlife resources intense [7,8], and it is likely that if allowed open access, people will continue to colonize the remaining forests until no undisturbed areas remain [9]. Research indicates that even in the best of situations it is unlikely that the agricultural and pastoral habitats typical of these biomes will be able to support the full compliment of forest species [10-12]. Therefore, creating an effectively protected reserve network must be the foundation of any biome-level conservation strategy [3,13].

The number of conservation areas designated as full protection reserves (IUCN categories I and II) has increased in the tropics in recent decades [14-17], but local people continue to exploit resources in these areas, and most declared reserves are little different from unprotected areas [18]. Effectively protecting reserves is especially complex where hunting traditions are strong, because people often continue to hunt in order to maintain their traditions, for commercial purposes, and/or because they find hunting enjoyable even when they no longer depend on wildlife to meet their protein needs [19-26]. However, for full protection reserves to fulfill their mandate, hunting must be eliminated, not only because these are often the last refuges for endangered wildlife, but also because robust wildlife populations are essential for maintaining the integrity of the ecosystem [18, 27-30]. With so few forests remaining in the biodiversity hotspots, it is essential to keep some areas free from human exploitation if we are to preserve examples of natural habitats where human actions are not a principal influence on the ecosystem.

The Atlantic Forest of Brazil is similar to other tropical biodiversity hotspots: forest cover is reduced to 16% of its original area and forests continue to be cleared, fragmented and degraded; forest remnants are small with high edge/interior ratios; hunting is rampant; and wildlife populations have declined drastically [16, 31-34]. Although the number of protected areas has increased in recent decades, most reserves are small and inadequately protected, and the reserve network accounts for only 9% of the remaining forest cover [16,33]. Creating new federal and state reserves is complicated because most land is privately owned and the government lacks funds to pay compensation for appropriated land as required by law [14,35,36].

In order to overcome this impasse, the Brazilian government launched an initiative to include private landholders in the reserve network by offering land tax relief (Law 9.393/96 created in 1996 provides tax exemption for all lands set aside for preservation) to property owners who register areas as Private Natural Heritage Reserves (full protection reserves known as RPPNs – *Reserva Particular de Patrimônio Natural*) or as legal reserves (*Reserva Legal* – the 20% of each property that is required by federal law to be kept under natural vegetative cover in the Atlantic Forest biome) [35,37]. The result of these initiatives is that the private reserve system has expanded considerably, and there are now 730 RPPN reserves in the Atlantic Forest, tentatively protecting 1,368 km² [38]. While the creation of these private reserves is a positive step forward, there are no mechanisms in place to guarantee their protection, as the state and federal governments lack the resources and landowners often lack the experience and financial means to do so [36]. The potential role of private reserves as integral components of the reserve network depends on determining what is required for private landowners to effectively protect their areas.

We investigated a private company's attempt to protect a reserve in a heavily hunted landscape. Our aim was to learn what is required for a private landowner to provide such protection, and the implications for conservation efforts at sites suffering similar threats elsewhere. One of our principal goals was to discover how much effective protection costs, as the lack of funding is cited as one of the principal impediments to protecting reserves in the tropics [36, 39-43]. To address these issues we studied the Reserva Ecológica Michelin (REM). The reserve is located in coastal Bahia in one of the most species-rich parts of the biome [32,44] in a landscape that suffers threats typical of other Atlantic Forest areas, such as rampant hunting, timber felling, firewood collecting, forest clearing, and a high human population density [45]. To determine whether the reserve is being effectively protected, we evaluated changes in the abundances of medium and large mammals, using census data collected before and after the initiation of a guard patrol system [46].

Methods

Study Area

The study site was the 3,096 ha Reserva Ecológica Michelin located on the Bahian coast in the municipalities of Ituberá and Igrapiúna (13º50'S, 39º10'W). The reserve contains 1,800 ha of lowland evergreen hill forest distributed in three main fragments: Vila 5/Pancada Grande fragment with 625 ha, the 140 ha Luis Inácio forest, and the 550 ha Pacangê forest, which is contiguous with a 13,000 ha forest (Fig. 1a and 1b). All of the forests have a long history of human use, and after centuries of manioc farming and decades of intensive logging, most of the forest is secondary forest in various stages of development with small patches of more intact forest on the steepest slopes and ridge tops. The remainder of the reserve consists of wetlands, small forest fragments, and rubber (*Hevea brasiliensis*) groves enriched with native forest trees. Rainfall averages 2000 mm/year with no distinct dry season, and average temperatures are 21-28˚C (REM unpub. data). The landscape to the east of the reserve consists of rubber/cacao/banana groves; to the south, southwest and north are smallholder properties of mixed tree crops and small forest fragments; and to the northwest is the largest forest fragment in the region. The greater landscape (1,000 km²) has 40% forest cover and highly diverse agroforestry systems with more than 60 tree crops planted [45]. The human population density is 52/km², with people living throughout the landscape and no place in the forest is >2 km from a road. The rural economy is depressed, and most people live on less than two minimum wages per month (approximately US$700).

The history of hunting and protection

People have hunted in these coastal forests for thousands of years [47-49], but it was not until the 19th century that the first wildlife species were extirpated. The red and green macaw *(Ara chloropterus*) and lowland tapir (*Tapirus terrestris)* were the first to be shot out, followed by the white-lipped peccary (*Tayassu pecari)* and giant armadillo *(Priodontes maximus)* in the early 20th century, and the jaguar (*Panthera onca*) and brown howler monkey (*Alouatta guariba*) in the 1950s. With the increase in the human population that accompanied an intensive agricultural expansion between 1950 and 1970, hunting pressure increased dramatically, and by the end of the 1970s most of the medium and large mammals had become scarce [45]. Until the 1970s, people's principal motive for hunting was subsistence, but thereafter, hunting became a leisure activity with groups of friends pursuing game on weekends for the pleasure of the hunt and of eating game meat while consuming alcohol. A small number of men hunt commercially, selling the game in town to wealthy clients or small restaurants that clandestinely sell the meat as a specialty. Even though there are fewer people hunting today than in the past and evidence indicates that this trend will continue, hunting pressure is still intense and wildlife scarce in most forests [45].

The situation in the REM was similar to the other regional forests. When we began our work there in 1997, there were no forest guards and hunting was rampant, with hunters using all parts of the forest [45]. The REM was created with the purpose of protecting the forest from all illegal activities, including hunting (law 5.197). In order to do so, four men were hired from the local community to work as forest guards. They worked six days/week, patrolling mostly in the morning (6 – 13 h), but also in the afternoon (13 – 18 h) and occasionally at night (sunset to 23 h). Law enforcement in the region is weak and as the guards patrolled unarmed and did not possess the power to arrest, they did not patrol with the intent of apprehending hunters. Instead the objective was to try to frustrate hunters by destroying their traps and hides, chasing off dogs, and persuading hunters (mostly acquaintances from neighboring properties) to stop entering the reserve [50]. The only coercive power they possessed was the inherent threat of denouncing the hunters to the authorities.

Measuring "effective" protection

As the principal objective of the study was to determine whether the reserve is being effectively protected, it is necessary to define effectiveness, which could have various meanings depending on the type of assessment being made [51,52]. Here we define effective as a condition in which wildlife abundances are not primarily determined by hunting pressure. The lack of replication (only one reserve sampled) or a control site precluded the use of inferential statistics to address the principal research question [53,54]. Instead we organize our analysis of "effectiveness" on the basis of three questions to assess whether the observed changes are significant according to the management goals of the reserve.

1. Did wildlife abundances increase after the initiation of the guard patrols?

We used census data collected before and after the initiation of the guard patrol system to determine whether the presence of forest guards affected the relative abundance of medium and large mammals. The wildlife community sampled included 31 medium and large mammals and two small mammals, all of which can be sampled with the methods used [55]. We used five trail circuits (25 km of trails) distributed in the reserve's three principal forest fragments to census wildlife, with the trails designed to sample all of the existing forest types [56].

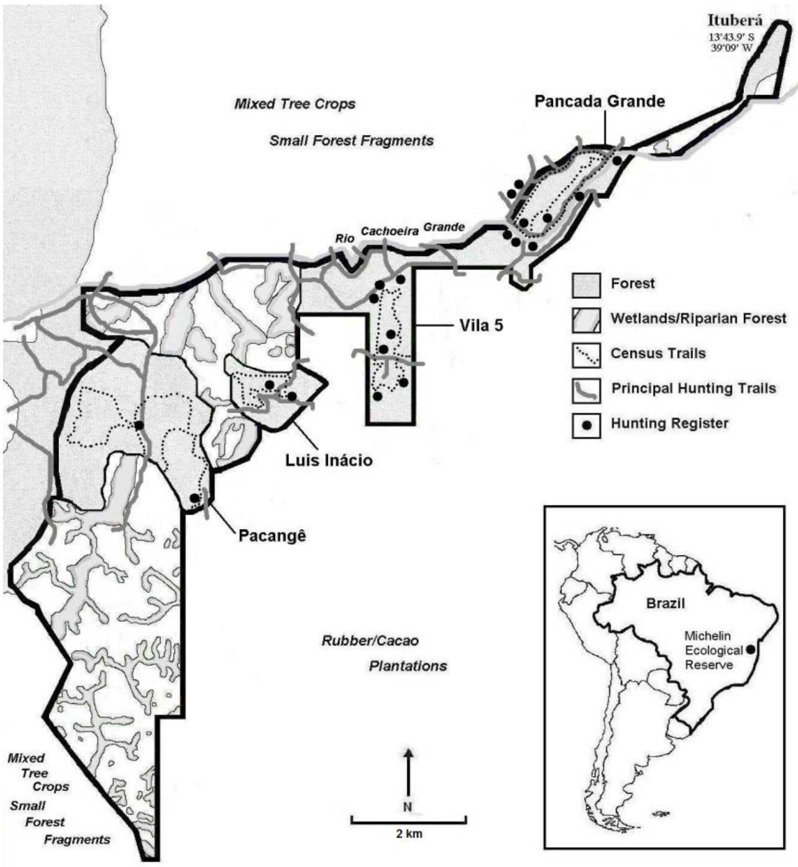

Fig. 1a. Hunting registers period 1, Reserva Ecológica Michelin, Bahia, Brazil

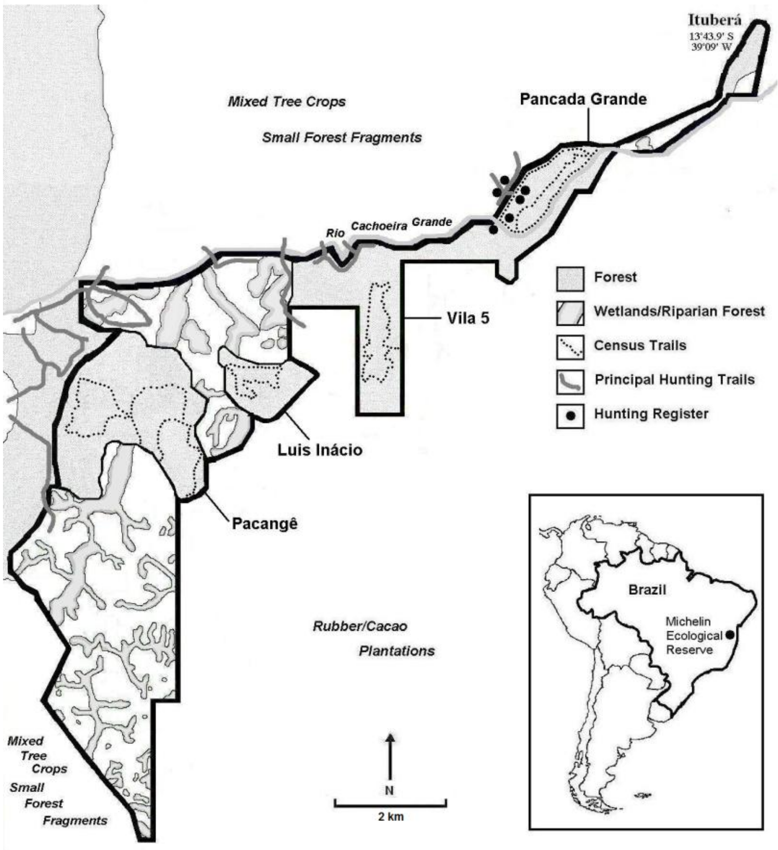

Fig. 1b. Hunting registers period 2, Reserva Ecológica Michelin, Bahia, Brazil.

To census wildlife, a lone observer walked slowly (1-1.2 km/hour) along cleared forest trails (3.4-5.1 km long), scanning all strata and pausing every 50 m to listen for animal sounds, using binoculars and a headlamp at night to help detect the animals. Day censuses began within the first hour after sunrise and night censuses began within the first hour after sunset. Wildlife was sampled throughout the year in order to avoid possible biases created by seasonal movements and range shifts characteristic of certain species [57]. For each wildlife encounter we registered the species, the number of animals, habitat and strata used, the location and the time. Encounters included sightings as well as vocalizations and flight sounds when the species were clearly identifiable and within 50 m of the census trails.

The pre-guard patrol census (P1) was conducted between May 1997 and August 2004, and the post-guard patrol census (P2) was conducted between October 2007 and November 2008. We walked 233 km of transects during each period (466 km total), with 133 km by day and 100 km by night. We used the same trails during both census periods with only minor changes where trails were improved. The study landscape remained stable between sampling periods without any changes that are likely to have influenced wildlife abundances. We use descriptive statistics for comparing the two census periods, measuring the percent change in the number of wildlife encounters per 10 km walked for the four census areas and for all areas combined.

2. Did the most hunted game species attain relative abundances similar to protected neotropical reserves elsewhere?

Because there are no control sites without hunting pressure to use as baseline data for comparison in our region, we compare the abundances of the four preferred game species during P2 at our site to those at protected neotropical sites elsewhere. We use these data as proxy measures to determine whether the wildlife populations in the REM have reached "natural" levels. We consider the fauna effectively protected if the relative abundances of the most procured game species at the REM attain levels similar to other protected or lightly hunted sites. Our reasoning is that if they have, it is likely that hunting pressure is not the principal factor influencing wildlife abundances.

3. Were the guard patrols effective at eliminating hunters from the reserve?

Hunting is illegal, and as people associated us with law enforcement officials, information about hunting behavior collected through direct interviews with hunters was not an option [58-60]. Instead we used a qualitative measure to assess hunting pressure based on evidence of hunters collected along the census trails [61,62], including hides, traps, rifle shots and campfires, but our assessment was mainly based on the frequency and abundance of human and dog tracks found along the trails. During each census walk we registered the presence of any of these indicators. We classify each forest using four qualitative categories of hunting pressure (none, low, moderate, and heavy; Table 1).

Table 1. Census sites, census effort, and hunting assessment at the Reserva Ecológica Michelin, Bahia, Brazil.

Forest and Census Effort	Hunting Pressure P 1ª	Hunting Pressure P 2
Pacangê 550 ha 8.6 km of trails Times walked: 17 (10 D, 7 N) Census km: 67 (41 D, 26 N)	Low <1 person using trail/week Human and dog tracks: Rare 0 traps/hides 0 new hunting trails 0 camp fires 2 gunshots heard	None 0 using trail/week[b] Human and dog tracks: None 0 traps/hides 0 new hunting trails 0 camp fires 0 gunshots heard
Vila 5 190 ha 4.5 km of trails Time walked: 26 (15 D, 11 N) Census km: 103 (60 D, 43 N)	Heavy >10 people using trail/week Human and dog tracks: Always 7 traps/hides 2 new hunting trails 1 camp fire 1 gunshot heard	None <1 person using trail/week Human and dog tracks: None 0 traps/hides 0 new hunting trails 0 camp fires 0 gunshots heard
Pancada Grande 170 ha 5.1 km of trails Times walked: 8 (3 D, 5 N) Census km: 31 (13 D, 18 N)	Heavy >10 people using trail/week Human and dog tracks: Always 3 traps/hides 0 new hunting trails 6 camp fires 0 gunshots heard	Low <10 people using trail/week[c] Human and dog tracks: Rare 4 traps/hides 0 new hunting trails 2 camp fires 0 gunshots heard
Luis Inácio 140 ha 3.4 km of trails Times walked: 10 (6 D, 4 N) Census km: 32 (19 D, 13 N)	Moderate <10 people using trail /week Human and dog tracks: Frequent 1 traps/hides 0 new hunting trails 0 camp fires 1 gunshot heard	None <1 person using trail/week Human and dog tracks: None 0 traps 0 new hunting trails 0 camp fires 0 gunshots heard

ª Only hunting sign found along the census trails is used for the assessment.
[b] All trails being used by forest guards, but no outsiders using the forest and no dog tracks found.
[c] These were mostly tourists using the first km of the river trail above the waterfall, and there were no indications of hunting pressure except along a segment of the trail that passes by the reserve boundary.

To measure changes in the distribution of hunting pressure, we mapped the location of all hunting registers on and off the census trails whenever they were encountered throughout both study periods (Fig. 1a and 1b). Although we visited all sections of these forests during the course of each year, systematic searches for hunting sign only began in 2005 (P2), so it was not possible to make a quantitative assessment of these changes. However, the changes were so dramatic that we include the data to help illustrate the effect of the forest guards' presence on the spatial distribution of hunting pressure in the reserve.

Measuring costs

We had access to all of the financial details of the guard patrol system and use the reserve accounting records to estimate costs.

Results

Changes in wildlife abundances

Relative abundances increased 72.6% between periods 1 and 2, with 117 encounters in the first and 202 in the second, respectively. Relative abundances increased from 5.07 (CI ± 0.24) to 8.68 (CI ± 0.50) encounters/10 km walked. Increases in abundance were more marked in the two forests with the greatest hunting pressure during the first period (Vila 5 and Pancada Grande) (Table 2). The increases in the relative abundances of the four preferred game species were more pronounced than in the overall community, with an average increase of 206.5% (range 146.7-300%)(Table 3). We detected 15 and 17 species in the first and second periods, respectively, but when including species registered off the census walks, the total was 31 species for both periods.

A comparison of the relative abundances of the four preferred game species recorded during the second sampling period with those found at un-hunted/lightly hunted sites shows that the abundances of these species at our site fall within the range of those found at un-hunted/lightly hunted sites (Table 4). The nine-banded armadillo (*Dasypus novemcinctus*) at our site reached higher relative abundances than at the other un-hunted sites, and the paca (*Cuniculus paca*) and red brocket deer (*Mazama americana*) were more abundant at our site than at all but one of the other sites. Collared peccary (*Pecari tajacu*) abundances at the REM were higher than those at four sites, but substantially lower than those found at three other sites.

Changes in hunting pressure and behavior

Hunting pressure decreased in all of the forests between the study periods, with 24 registers along the census trails in P1 and 6 during P2 (Table 1). Other than four hides and two campfires found along the boundary and river trails of the Pancada Grande forest, there were no indications of hunting along the census trails during P2. Whereas people used trails on a weekly basis in all except the Pacangê forest during the first census period, they largely stopped using the trails after the initiation of the guard patrols in 2005. There were still people using the Pancada Grande forest river trail during the second sampling period, but these were mostly tourists.

Table 2. Changes in wildlife encounters between the two census periods at the Reserva Ecológica Michelin, Bahia, Brazil.

Species	**PA1ª**	**PA2**	**V1**	**V2**	**PG1**	**PG2**	**L1**	**L2**
Dasypus novemcinctus	11	14	1	11	-	3	3	9
Bradypus torquatus	-	-	1	-	-	-	-	-
Tamandua tetradactyla	-	1	-	1	-	1	-	-
Didelphis aurita	-	2	8	7	-	3	-	-
Callithrix penicillata	2	4	19	7	2	2	2	-
Callicebus melanochir	1	6	9	21	1	5	2	2
Sapajus xanthosternos	4	4	-	-	-	-	-	-
Cerdocyon thous	1	-	-	-	-	-	-	-
Nasua nasua	3	1	1	1	-	-	2	-
Potos flavus	1	-	-	6	1	2	1	3
Eira barbara	1	2	1	-	-	-	-	-
Leopardus wiedii	-	1	1	-	-	-	-	-
Leopardus sp.	-	-	-	1	-	-	-	-
Mazama americana	1	2	2	10	-	4	2	4
Pecari tajacu	-	1	-	2	-	-	-	-
Dasyprocta leporina	4	8	7	6	-	1	5	3
Cuniculus paca	8	8	1	13	2	10	-	4
Sciurus aestuans	1	2	3	3	1	-	-	-
Chaetomys subspinosus	-	-	-	-	1	-	-	-
Sphiggurus insidiosus	-	1	-	-	-	-	-	-
Encounters/Forest	38	57	54	89	8	31	17	25
Encounters/10 km	5.67	8.51	5.24	8.64	2.58	10.00	5.31	7.81
% Increase		50%		64.8%		287.5%		47.1%
Encounters All Forests			Period 1 = 117		Period 2 = 202			
Sum Encounters/10 km			Period 1 = 5.03		Period 2 = 8.68			
Total % increase				72.6%				

ª Forest name abbreviations: PA = Pacangê, V = Vila 5, PG = Pancada Grande, L = Luis Inácio.

Hunters adapted their hunting strategies to deal with the challenge presented by the guard patrols. Chase hunting with dogs was common in the reserve before 2005 [45], but hunters largely stopped using this technique after the guard patrols began. After 2005, hunters mostly used traps and hides, which allow them to capture game quietly from set locations and to sit in the hides and check traps during hours when the guards are unlikely to be in the forest. When guards found their hides and traps, the hunters lost their invested effort but were not caught or identified.

The spatial distribution of hunting pressure also changed between sampling periods. Whereas hunters used the entire forest during the first census period, after 2005 all hunting sign was found within 100 m of the reserve boundary. The results of the change in the spatial distribution of hunting pressure were that hunting was largely restricted to the reserve boundary and that large sections of the forest became hunting-free zones, with at most sporadic and ephemeral hunting pressure.

The cost of protection

The annual cost for protecting the reserve is $29,124 or $9.4/ha., of which 58% is for guard salaries, 20% for equipment, 18% for other staff costs, and 4% for training courses (Table 5).

Table 3. Changes in the number of encounters and relative abundances of four preferred game species, Reserva Ecológica Michelin, Bahia, Brazil.

Species	P1 N	P1 N/10 km	P2 N	P2 N/10 km	% Increase
*Cuniculus paca*ª	11	1.1	35	3.5	218.18
*Dasypus novemcinctus*ª	15	1.5	37	3.7	146.67
Pecari tajacu[b]	0	0.0	3	0.23	-
*Mazama americana*ª	5	0.5	20	2.0	300
Total[c]	31	1.33	95	4.08	206.45

ª Only nocturnal census used (= 100 km)
[b] Only diurnal census used (= 133 km)
[c] Both diurnal and nocturnal census used (= 233 km)

Discussion

Wildlife abundances showed a marked increase after the initiation of the guard patrols, suggesting that hunting had been suppressing wildlife abundances in P1. The 146.7-300% increase in the abundances of four of the most procured game species was more pronounced than that of the overall fauna, providing further evidence that hunting was likely the principal cause driving population abundances during P1. The relative abundances of the principal game species reached levels comparable to other protected neotropical sites, in some cases with abundances surpassing these sites. This might indicate that hunting is no longer the principal determinant of these species abundances. However, the fact that the relative abundances of three of most procured game species (*C. paca*, *D. novemcinctus*, and *M. americana*) during P1 were higher than those registered at several protected Neotropical sites shows that comparing geographically dispersed sites to determine if the fauna had reached "natural" levels is not a reliable proxy measure [59]. Unfortunately, there are so few effectively protected sites in the Atlantic Forest that we have no control sites to use for baseline data for most regions in the biome. Only continued protection and monitoring at the REM will allow us to establish the carrying capacity of the reserve for these species.

Other evidence collected during and after the second study period corroborated our conclusion that the guard patrols were effectively controlling hunting pressure. Several of the study species and other monitored wildlife expanded their ranges after the initiation of the guard patrols, re-colonizing forests where they had been extirpated decades earlier and entering agricultural habitats were they had never occurred. Collared peccary, puma (*Puma concolor*), rusty-margined guan (*Penelope superciliaris*) and red-billed curassow (*Crax blumenbachii*) expanded their ranges >12 km, re-colonizing the Luis Inácio, Vila 5 and Pancada Grande forests where they had not been recorded for more than 30 years. Pumas and collared peccaries now include rubber monocultures and rubber/cacao groves in their home ranges. Yellow-breasted capuchin monkeys (*Sapajus xanthosternos*) and coatimundi

(*Nasua nasua*) started using the rubber and rubber/cacao groves and pupunha palm (*Bactris gasipaes*) plantations up to 500 m and 2 km from the forest edge, respectively. Capybara (*Hydrochoeris hydrochaeris*) and the broad-snouted caiman (*Caiman latirostris*) expanded their ranges into wetlands were they were previously absent. In addition to our direct sightings, people working in the reserve landscape reported increases in wildlife sightings, and since 2005 it has become increasingly common to see animals in the rubber groves far from the forest edge (K. Flesher, unpubl. data). This evidence coupled with that of the census walks suggests that the guard patrols have been effective at reducing hunting pressure so that it is no longer the principal driver of wildlife abundances.

Table 4. Comparison of the relative abundances of the four preferred game species at the REM after the initiation of the guard patrols with those at neotropical with no or low hunting pressure.

Species	REM P2 Encounters 10 km	Protected neotropical Reserves Encounters 10 km	Study
Cuniculus paca	3.50	0.16	[75]
		0.80	[56]
		1.32	[21]
		4.50	[76]
Dasypus novemcinctus	3.70	0.08	[75]
		0.12	[21]
		0.25	[77]
		0.30-0.40	[56]
		3.50	[76]
Pecari tajacu	0.23	0.00	[21]
		0.06	[58]
		0.16	[75]
		0.24-0.57	[78]
		0.81-1.06	[57]
		0.90-3.60	[20]
		4.40-6.0	[77]
Mazama americana	2.00	0.19	[75]
		0.20	[56]
		0.22	[77][a]
		0.22-0.69	[78]
		0.35	[58]
		0.40-1.50	[20]
		1.80	[76]
		2.50	[21]

[a] Abundances of two species of *Mazama* combined

Is protection too costly?

The cost of $940/km² for effective protection spent by Michelin is closer to the cost of protecting areas in the developed world (estimates: $1090-2768/km²) than that in the developing world (estimates: $52-376/ km²) [39,40,42,63]. This is not surprising, given the high labor costs in Brazil compared to most tropical countries. For a company with the capital of Michelin, $29,124/year is not an exorbitant expense given that it is necessary for the success of the reserve program. However, many agricultural firms and private landholders in the region are struggling to remain solvent due to the witches' broom fungus (*Crinipellis perniciosa*) [64] and South American leaf blight (*Microcyclus ulei*) that affect cacao and rubber production, respectively. This makes it difficult for many reserve owners to allocate money for conservation purposes.

Table 5. Annual cost of the reserve protection system, Reserva Ecológica Michelin, Bahia, Brazil.

Type of Expenditure	Annual Cost US $ª	Comments
Salaries for 4 forest guards with federally guaranteed benefits	$16,852	
Field supervisor: salary with federally guaranteed benefits	$2,224	15% of full time job[b]
Office administrative costs	$3,118	12% of full time job[b]
Training courses	$1,177	
Cell phones, clothes, backpacks, boots, machetes	$1,394	
Vehicle[c], gasoline, maintenance	$4,000	Initial investment: $20,000
Chainsaw[c]	$77	Initial investment: $765
GPS[c]	$282	Initial investment: $1,412
Total	$29,124	
Annual cost per hectare	$9.40	

ª The exchange rate was calculated as R$ 1.70 = US$ 1

[b] The costs of the supervisor and administrator are calculated based on the % of their work time dedicated to reserve protection related affairs

[c] The costs of the vehicle, chainsaw, and GPS are divided over the life expectancy of the product for the calculation of yearly expenditures, although in practice the expenditure for this equipment would be paid in the year that the equipment was purchased

We suggest that one possible solution to the financial shortfall is to link private reserve creation with agricultural development, so that enough land is planted to cover the cost of protecting the reserve in perpetuity [65]. The quantity of land necessary to set aside for agricultural production will vary depending on the profitability of the crops suitable to the region and on commodity price fluctuations. The potential profits from rubber monocultures and cacao/rubber plantations from our region demonstrate how this scheme might work. After paying workers' salaries and benefits, agro-chemical and other inputs, and taxes, the net profit per ha/year from a rubber monoculture is $294/ha at low rubber prices and $1177/ha at high prices (Eric Cavaloc pers. com.). Using the low figure, a landowner would need to set aside approximately 100 ha in order to guarantee the funds for protecting a 3000 ha reserve. At low commodity prices this is a ratio of 1 ha of agricultural land for 30 ha of forest, and at high commodity prices the ratio would be 1:120. Even less land is needed if cacao and rubber are double-cropped. At low prices $1177/ha with a ratio of 1 ha of agricultural land for 120 ha of forest, and at high commodity prices for both crops the net profit can reach $1618/ha with a ratio of 1 ha of agricultural land for 170 ha of forest (Paulo Bomfim pers. com.). Assuming low commodity prices, a landowner would need to set aside 25 ha of land planted in cacao/rubber groves to sustain a 3000 ha reserve. In years of high commodity prices, the surplus money could be used to invest in the reserve or for other purposes.

We are not advocating that forest be felled to plant crops, but that degraded or abandoned agricultural land already existing on the property should be brought into production. Most private reserves in Bahia are established on lands that were at least partially used for agriculture in the past. However, these lands are frequently left to revert to forest as part of the reserve management philosophy, and the owners come to depend on external funding to sustain their reserves. If instead these lands were cultivated, the profits could pay for the reserve protection without a need for substantial outside funding. Willingness to adopt this strategy will depend on a change in the management philosophy of conservationists who believe that agricultural development is contrary to forest protection and on the availability of land for planting on the property in question.

Lessons and challenges

The management approach for protecting the reserve evolved as Michelin learned through experience what worked best. During the first years, they applied an ad hoc approach in which the guards were assigned an area and allowed to patrol as they saw fit, reporting hunting incidents during periodic meetings. With little supervision, several of the guards stopped patrolling in the more difficult sections of their areas and in one case stopped patrolling altogether. Also, under this management system, hunting data were not systematically collected, so it was not possible to track hunting pressure adequately. After realizing that this approach was inefficient and led to apathy among the guards, it was decided to assign fixed rounds with each guard reporting hunting incidents daily [60,66]. Instead of each guard being assigned a particular part of the reserve, they now patrolled the entire reserve each month, working as a team and frequently patrolling in pairs. The supervisor and administrator periodically accompanied the men to evaluate their work, and meetings were held more frequently. Proactive leadership, increased interaction with the guards, more defined responsibilities, and varied patrol routes improved the management scheme considerably and increased the guards' morale [63,66].

Four guards were sufficient to patrol the area (ratio of 1 guard/1000 ha – the guards also patrolled 1000 ha of Michelin rubber groves outside of the reserve). They were able to patrol each area several times per month and patrolled problem areas at least once each week, in order to destroy traps and hides soon after their construction, which reduced the probability of animals being killed.

Patrolling on foot was essential for detecting hunting sign, as hunters were experts in covering their tracks. Only by carefully investigating any sign of human activity were the guards able to find the traps and hides. Initially the guards also patrolled by mule, but they complained that this was less efficient and the management ended this practice.

Employing men from the surrounding communities to work as forest guards was an essential part of the strategy to protect the reserve [68]. The guards have extended networks of family and friends, and even though many of these people hunt, they stopped hunting in the reserve out of consideration for the guards. The guards know who the hunters are, who is likely to be persuaded to stop hunting, and who will cause problems. This allows a more effective allocation of enforcement effort, with patrols more frequent in the areas used by the more recalcitrant hunters. It also permits the guards to adapt their strategies for dealing with each hunter according to the character of the individual. For example, they always patrolled in pairs or trios in the areas where they knew the hunters were aggressive.

Finding and maintaining men qualified to work as forest guards is a challenge. Most men who are interested in walking in the forest are hunters who could not be trusted as forest guards. Finding candidates is becoming more difficult as men with experience in the forest grow old and rural youth lose interest in the forest. Hunting has mostly become a leisure activity and young men today prefer town life for leisure. With each passing generation there are fewer people with knowledge of the forest and consequently fewer people qualified or willing to do this type of work. Low pay and the relatively arduous conditions further dissuade people from applying for and staying at the job. It took five to six months to replace guards who left the REM, and we suspect that it will become increasingly difficult to find qualified people if the tradition of walking in the forest continues to decline. Performance-based salary increases would provide an economic incentive for the guards and should be instituted in order to secure their commitment to the reserve.

The experience in the REM shows that hunters adapt their strategies to meet the challenges presented by guard patrols [67,68,69]. Therefore, the guard patrol strategies must also be adapted to the changes in the hunters' behavior [66]. Initially the guards patrolled mostly along the principal forest trails and exclusively during the day, making it easy for the hunters to avoid them. After realizing this, the guards were assigned varied patrol routes that ensured that the entire reserve was patrolled each month, including areas far from the trails and roads, and nocturnal patrols were initiated. After the data collection was systematized, it became easy to identify who the principal hunters were and which areas needed to be more intensively patrolled. With these changes the number of hunting incidents has fallen significantly from a high of >40/month before the reforms to an average of 9/month (range 0-20/month) thereafter (K. Flesher, unpubl. data). This experience indicates that patrol systems in tropical reserves need to be flexible and that patrol strategies are likely to change over space and time according to the variable challenges presented by hunters. Systematic monitoring that includes collecting data on the location, frequency and type of hunting behavior should be a central part of reserve protection strategies [60,63,66]. Only with precise data on hunters' behavior will it be possible to adapt patrol strategies to respond to changes in hunter strategies.

Completely eliminating hunting from the reserve is probably not an attainable goal given the regional hunting tradition, the long history of open access resource use, the high rural population in the landscape, and the apparent lack of a conservation ethic that includes protecting wildlife. However, the changes in hunting pressure in the REM indicate that it is possible to reduce hunting pressure and restrict the areas it affects [67]. In the case of the

REM this has been sufficient to allow for the wildlife populations to recover to levels acceptable to the management goals of the reserve.

Finally, this case study shows that private reserves can be an important component of the Atlantic Forest conservation strategy as they have been in other parts of the world [14,70]. The private reserve strategy is especially relevant in cultural contexts like that of Brazil, where individuals can legally hold exclusive property rights to land, there are laws that regulate the exploitation of natural habitats, and the government encourages private reserve creation. Corporations with large landholdings such as Michelin have a potentially important role to play as they can preserve large blocks of natural habitats and generally have the resources necessary to adequately manage their reserves [71,72]. Corporations frequently lack the technical expertise to manage natural areas, however, and it will be important for the scientific community to establish partnerships with these entities to help ensure that private reserves are effectively protected [73].

Implications for conservation

Wildlife populations recovered in the Michelin reserve after the initiation of a guard patrol system, showing that effective protection is possible in heavily hunted landscapes. Hiring local men to work as guards proved a good strategy as they are familiar with the forest, have an extensive network of family and friends in the surrounding landscape, and know who the problem hunters are. Regular interactions between administrators and guards kept the men interested in the work and the administrators well informed, which helped make the guard patrol system effective. However, protection is expensive, and while large corporations such as Michelin can afford to protect their forests, individual property owners are finding it difficult to do so. For the growing network of private reserves in Bahia to effectively protect the fauna, creative solutions are necessary. When outside funding is not available, reserve owners/directors must find ways to finance the protection of their reserves, such as by investing in agriculture. Beyond the problem of costs, the fundamental issue is that unless the local farmers change their inherent values concerning wildlife conservation, the existing tension between opposing visions of how wildlife resources should be used will remain. Reserve owners must therefore remain vigilant if they are to adequately protect their forests. The fact that many rural youth are loosing interest in hunting, coupled with the ongoing rural exodus in Brazil [74], gives hope that pressure on wildlife resources will continue to decline. Until then, it is essential that the forest guards continue their patrols.

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