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Four years of vertebrate monitoring on an upper Amazonian river

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Abstract Long-term monitoring of tropical forest animals lags far behind long-term monitoring of tropical forest plants, compromising ecologists' ability to identify parallel trends. On 257 occasions over 4 years, park guards in a newly protected lowland Amazonian forest in southeastern Peru tallied individuals of 31 reptile, bird, and mammal species sighted along a 47-km stretch of river. Each survey entailed ~3 h of observation from a motorized boat; total survey effort was 892 h and ~12,048 km. Our primary goals were descriptive: to establish baseline sighting rates for these species and to document trends over time and the influence of environmental and sampling factors on sightings. Our secondary goals were to identify the advantages and disadvantages of river-based monitoring and to assess how useful these data are for ecologists and protected areas managers. Over the 4 years of monitoring we observed 1.8 animals/km. More than 90% of recorded individuals belonged to seven common taxa: two reptiles, four birds, and one mammal. Season was the most frequent correlate of sighting frequency; sightings increased in dry season. For the majority of taxa common enough to analyze, sightings increased over the 4 years of monitoring; this is possibly a result of reduced hunting since the establishment of the protected area. Compared to forest-based surveys, river-based surveys were inefficient at recording most mammals. Results to date suggest that river-based surveys can be a valuable, inexpensive tool for monitoring some ecologically important Amazonian animals, and especially those in protected areas.

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Introduction

Ecologists have increasingly good data on how Amazonian plant communities change over time (e.g., Phillips et al. 2002, 2004; Laurance et al. 2004; Lewis et al. 2004a). The same cannot be said for Amazonian animal communities. In the 30 years that ecologists have been working in southwestern Amazonia—one of the richest and best-studied areas of the basin—fewer than five studies have tracked population dynamics of an animal species for more than 3 years (e.g., Goldizen et al. 1996; Groenendijk et al. 2001, 2005). In the absence of long-term monitoring, it was possible for the region's most abundant large vertebrate to vanish from an area larger than Costa Rica for 12 years with no more than anecdotal documentation by scientists (white-lipped peccaries in Madre de Dios, Peru, 1978–1990; Silman et al. 2003).

The peccaries' disappearance appears to have doubled the seedling density of a dominant tree species at one site (Silman et al. 2003); it likely produced other convulsions in the plant community across the region (Dirzo and Miranda 1991; Wright et al. 2000; Terborgh et al. 2001, 2008; Peres and Palacios 2007). Given the interdependence between vertebrate seed dispersers, canopy trees, and top predators in tropical forests, similar shifts in plant communities are likely taking place across Amazonia as hunting decimates vertebrate communities (e.g., Peres and Lake 2003). But since the dataset on global climate far outstrips the dataset on Amazonian vertebrate communities, many of these changes in plant communities may be attributed incorrectly to a changing climate (but see Lewis et al. 2004b).

The problem is compounded by the fact that the leading survey techniques for Amazonian vertebrates (e.g., line-transects, point counts, quadrat surveys, camera traps) tend to require trained experts or expensive equipment, making them expensive, time-consuming, and difficult to sustain over long time periods (Danielsen et al. 2005, 2008; Gardner et al. 2007). All of this makes it a high priority to investigate simple, low-cost methods by which local residents can collect monitoring data on Amazonian wildlife.

In this paper we describe results from 4 years of quantitative wildlife surveys by park guards along a river in western Amazonia, in part to determine whether this low-cost method might help supplement traditional monitoring efforts across the basin. We begin by asking:

(1) What are the baseline sighting rates for the 31 target taxa? Which species were commonly sighted and which were rare?
(2) How did sighting probability and the number of animals spotted vary over time, and how did they vary under different survey and environmental conditions?

Since tropical river surveys are becoming increasingly common in the scientific literature (e.g., Renton 2002; Davenport 2003; Karubian et al. 2005; Townsend et al. 2005; Cintra et al. 2007) and since little has been written about their effectiveness, we then ask:

(3) What are the biases of riparian monitoring, and what are the advantages? How do results from riparian monitoring compare with those from more traditional monitoring along forest transects?
(4) How useful are the data collected for ecologists, and which species are the most promising for future work? How useful are results to date for protected area managers?

Methods

Study area

Monitoring was carried out on the Los Amigos River, a tributary of the Madre de Dios River at the base of the Andes in southern Peru (Figs. 1, 2). The 353-km Los Amigos drains 4,415 km^2 of lowland Amazonian forest between 225 and 600 masl. A low-gradient whitewater river, the Los Amigos meanders through a 1–2 km-wide floodplain dotted with oxbow lakes and flanked by forested terraces 30–40 m high.

Data in this paper were collected on a 47-km section of the Los Amigos between the river's mouth (12.57S 70.06W, 225 masl) and its confluence with the Amiguillos River (12.44S 70.25W, 259 masl). The end points of this stretch of river are 24.3 km apart in a straight line. River width here varies seasonally as dropping water levels expose large sandy beaches, but the distance between the vegetation on opposite banks is 60–90 m year-round. The most common vegetation types on this stretch of river are primary successional forest and older floodplain forest (Terborgh and Petren 1991; Kalliola et al. 1992; Hamilton et al. 2007). What an observer traveling the river sees is a strip of sky overhead, a wall of vegetation to either side, and a curving expanse of water, snags, beaches, and riverbank (Fig. 2). The majority of animals sighted during monitoring were on beaches (most caimans, shorebirds, and terrestrial mammals), on snags in the river (most turtles), in the trees along the bank (most primates), or airborne (most macaws).

No towns or villages have existed in the Los Amigos watershed over the last century, and it has suffered no significant deforestation. Even so, during our study animal

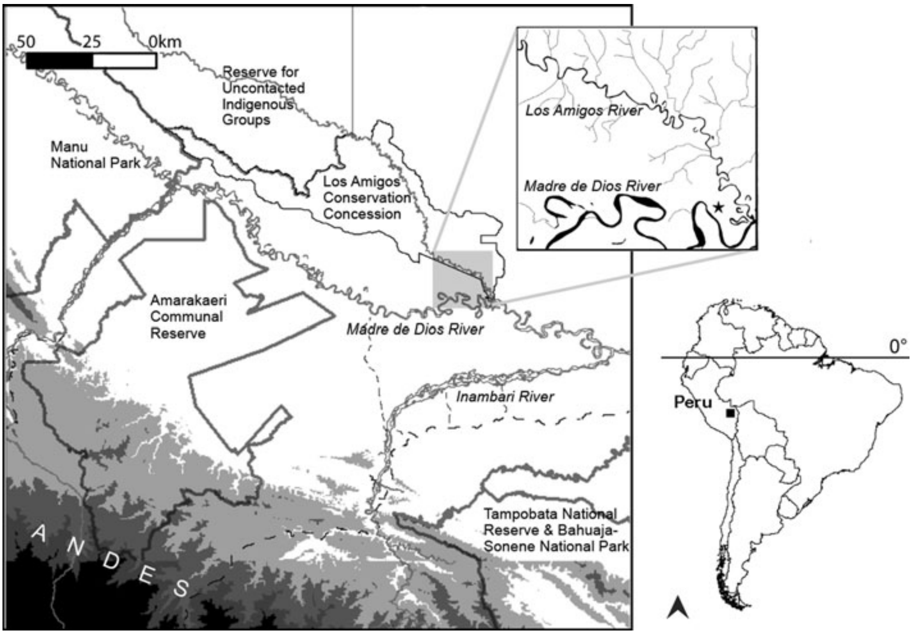

Fig. 1 A *map* of the study area in southeastern Peru. The *inset* shows the 47-km stretch of the Los Amigos River along which the study was carried out. A *star in the inset* indicates the location of the Los Amigos Biological Station. The *white portion of the map* is below 500 m elevation; *darker gradations* show 500-m intervals. *Dotted lines* represent roads. Several rivers have been omitted for clarity

Fig. 2 A dry-season photograph of a segment of the Los Amigos River monitored in this study. During much of the wet season, the sandbanks seen here are underwater. The distance between vegetation on the opposite banks is approximately 60 m. The logs littering the river are the result of natural erosion. Photo courtesy of Antonio Vizcaíno

communities were recovering from significant hunting pressure. The stretch of river we studied is inside the Los Amigos Conservation Concession (LACC), a 145,918-ha protected area managed by a Peruvian conservation organization since 2003 under the supervision of the Peruvian forest service. Prior to the LACC's establishment, dozens of logging camps were active inside the Los Amigos watershed and both hunting and turtle egg-collecting were common. Between May 2001 and March 2002, an average 1,000 loggers/day were estimated to be cutting scattered mahogany and tropical cedar trees inside the watershed. Although this only gives a population density of 0.22 persons/km^2, the absence of roads in the watershed concentrated hunting pressure (mostly shotguns) in a narrow band of forest along the river. Based on boat traffic data we collected at a point on the lower Amigos in 2003 (before the new reserve was implemented), we estimate for that period an average >5 boat trips per day with at least one hunter.

By the time our animal monitoring began in April 2004, all loggers had left the watershed. Boat traffic on the stretch of river we studied was reduced to an average <1 trip per day (mostly researchers and park guards), and both hunting and turtle-egg collecting were reduced to essentially 0. While the border of the protected area runs close to the south bank of the river for most of this stretch (Fig. 1), the adjacent lands (all logging concessions) are also closed canopy forest where impacts during the study were limited to selective logging several kilometers from the river and hunting was rare to absent. The monitoring we report on here was carried out by the LACC's park guards as part of their frequent patrols of the Los Amigos River.

Data collection

Between 27 April 2004 and 21 April 2008, we recorded the number of individuals of 31 vertebrate species (hereafter "target species") observed during 257 boat trips traversing the same 47-km stretch of the Los Amigos River, for a total of 12,047 km sampled (Table 1). Each upstream trip took 3–4 h; downstream trips took 2.5 h. Trips were not made on a

Table 1 Sampling effort, species diversity, and the number of individuals of reptiles, birds, and mammals sighted per km during 4 years of riparian monitoring on the Los Amigos River in Amazonian Peru

Monitoring year	Trip count (wet, dry)	Total trip distance (km)	Total species	Mean number of species per km	Mean individuals per km			
					All	Reptiles	Birds	Mammals
1	63 (24, 39)	2,953	21	0.11 (0.01–0.13)	0.93 (0.75–1.19)	0.33 (0.22–0.53)	0.41 (0.32–0.51)	0.07 (0.03–0.11)
2	73 (41, 32)	3,422	23	0.12 (0.01–0.13)	1.69 (1.37–2.07)	0.94 (0.70–1.25)	0.44 (0.34–0.61)	0.14 (0.08–0.24)
3	63 (30, 33)	2,953	22	0.14 (0.13–0.15)	2.38 (2.05–2.92)	1.40 (1.13–1.72)	0.72 (0.59–0.90)	0.22 (0.16–0.30)
4	58 (25, 33)	2,719	21	0.14 (0.13–0.15)	2.35 (1.87–2.92)	1.50 (1.08–2.07)	0.93 (0.72–1.24)	0.23 (0.18–0.30)
All years	257 (120, 137)	12,047	26	0.13 (0.12–0.15)	1.60 (1.37–1.94)	1.06 (0.79–1.47)	0.54 (0.42–0.68)	0.18 (0.11–0.26)

Means were estimated via a bootstrapping technique and are accompanied by 95% confidence levels in parentheses fixed schedule, but took advantage of the park guards' patrols. Park guards made an average of 5.4 trips per month (range 0–15). May and June had the highest mean number of trips, September and December the lowest.

All boat travel was in 12-m wooden boats powered by 16-hp engines with a 3-m driveshaft (locally known as *peque-peques*). Upstream velocity was 11–17 km/h; downstream velocity was 18–22 km/h. These motors are extremely noisy and can be heard from up to 4 km away; most animals were recorded by sight. The median number of observers per trip was two (range 1–5).

Data for each trip were recorded on a standardized paper form which included checklists of target species and space to record trip information and environmental observations (see form in Table 4—Appendix 1). Trip information included the names and number of observers, the date and time of departure and arrival, and the presence or absence of other boats on the same stretch of river the same day. Environmental data were qualitative observations of river level (high, medium, low) and sunshine (sunny or not). On each trip we recorded the total number of individuals observed of each target species.

The 31 target species included three aquatic reptiles (a turtle and two caimans), 16 mammals (seven primates, two mostly aquatic, and seven terrestrial), and 12 birds. These species were selected because: (1) they are species of conservation interest potentially recovering from past overharvesting in southeastern Peru (e.g., *Melanosuchus niger* [black caiman], *Podocnemis unifilis* [yellow-spotted river turtle], *Pteronura brasiliensis* [giant otter]), (2) because they reproduce in riparian areas and may be indicators of riverside impacts (e.g., *Rhynchops niger* [Black Skimmer], *Sterna superciliaris* [Yellow-billed Tern]), or (3) because their use of riverside habitat in Amazonia is poorly quantified (e.g., *Atelocynus microtis* [short-eared dog]). Five species are globally threatened: *Ateles chamek* (black-faced spider monkey, VU), *Lagothrix lagotricha* (common woolly monkey, VU), *P. unifilis* (VU), *P. brasiliensis* (EN), and *Tapirus terrestris* (South American tapir, VU; IUCN 2008).

Intensive inventories of reptiles, birds, and non-volant mammals at Los Amigos have tallied 74 reptile, 552 bird, and 66 non-volant mammal species (R. von May, J. Tobias, R. Leite Pitman and colleagues, pers. comm.). Thus the 31 target species in our monitoring program represent a tiny percentage of the total vertebrate fauna in the region, biased towards large, conspicuous, and threatened species.

The park guards who carried out the monitoring are long-time residents of Madre de Dios who grew up surrounded by forest and can identify target species with ease. Binoculars were not typically used. To minimize observer bias, park guards received a 1-h field-and-classroom training session in identifying the more difficult-to-distinguish target species, especially the smaller birds, before beginning the surveys. As a result of this meeting, as well as monthly meetings throughout the surveys, various identification problems were identified and resolved. For example, sightings of two macaw species (*Ara chloropterus* and *A. macao*) were aggregated because flying individuals cannot always be distinguished by sight alone (D. Brightsmith, pers. comm.).

Surveys conducted in October–March were classed as "wet season" and those in April–September as "dry season," based on seasonal rainfall patterns in southeastern Peru (Amazon Conservation Association, unpublished data). For each trip, we calculated total precipitation recorded in the 24 h preceding midday of the trip's date by a weather station at the Los Amigos Biological Station (12.56°S 70.10°W), 3.5 km from the mouth of the Los Amigos River (Fig. 1). The time effect (i.e., the moment in which each survey began during the four-year period) was modeled by creating a continuous variable ranging from 0 to 4; each trip during the 4 years of monitoring was assigned a value on this scale corresponding to its starting time and date.

In order to assess impacts of historical hunting on the survey results, we classified each target species as never hunted, occasionally hunted, or commonly hunted, based on personal observations around Los Amigos and data from elsewhere in Madre de Dios (e.g., Schulte-Herbrüggen 2003).

In order to compare river-based monitoring results with forest-based monitoring results, we used diurnal data from five permanent ~4-km transects in floodplain forest along or near this stretch of the Los Amigos River (Amazon Conservation Association, unpublished data). At monthly intervals between April 2005 and May 2008, two observers surveyed mammals along these transects a total of 134 times (reptiles and birds were not recorded). Each survey began at 6 a.m. and lasted for 4 h, following standard methods (Peres 1999). Total survey effort was 561.3 km and approximately the same amount in hours. Transect surveys were carried out by the same park guards who did riparian surveys.

Based on Danielsen et al.'s (2008) recent classification system for monitoring approaches, river-based and transect-based monitoring at Los Amigos in 2004–2008 qualified as Category 3 (Collaborative Monitoring with External Data Interpretation).

Cost of data collection

A full accounting of the cost of these river-based surveys would take into account park guard salaries, as well as training, gasoline, boat, and other expenses. However, because river-based surveys were incorporated into the guards' existing duties, monitoring itself incurred very few additional costs. The one exception was the paper forms used during the monitoring (Table 4—Appendix 1). Our estimate of the cost of forest transect-based surveys by the park guards included travel, work, and fuel costs.

Statistical analyses

In order to standardize sampling effort and data distribution to compare sighting rates between monitoring years, a resampling procedure was used to derive means and 95% confidence intervals of individuals/km values for each monitoring year. The data were resampled with replacement (Bootstrap) to create samples of 40 records for each year (20 from dry season and 20 from wet season) with 10,000 iterations to provide stable values. One outlier (a sighting of 200 peccaries) was replaced by 25, the mean number of peccaries oberved per sighting on other occasions.

For a subset of 11 relatively common species we used generalized linear mixed effects models to evaluate the influence of temporal, environmental and other factors on the survey results (Pinheiro and Bates 2000). The 11 species included three reptiles [*P. unifilis*, *M. niger*, and *Caiman crocodilus* (white caiman)], four birds [*A. ararauna* (Blue-and-yellow Macaw), *Anhima cornuta* (Horned Screamer), *Cairina moschata* (Muscovy Duck), and *Vanellus cayanus* (Pied Lapwing)], and four mammals [*Hydrochoerus hydrochaeris* (capybara), *Alouatta seniculus* (Colombian red howler monkey), *A. chamek* and *Saimiri boliviensis* (Bolivian squirrel monkey)]. Six of these were hunted in Los Amigos before 2002, and five were not (see Table 3). Resampled values were not used in the mixed effects models.

To model the number of individual animals seen on a given trip, counts were first square-root transformed to improve normality and reduce heteroscedascity. To model sighting probability on a given trip, individual counts were transformed to binary presence/absence data (binomial family). In both models we included observation time, season (wet or dry), trip starting period (categorical with three levels: morning, midday, afternoon), rainfall, sunshine, presence of other boats and direction of travel as fixed effects, and month in year, trip starting hour and observer as uncrossed random effects. We did not include interaction terms. Within the mixed effects model differences in the random effects are accounted for by taking account of their contribution to the variance in response as measured by a standard deviation in intercept and a standard deviation in slope (Crawley 2007). Modeling month within year as a random effect was used to account for the anticipated non-normal (autocorrelated) errors resulting from our irregular timeseries. Backwards selection was used to select the minimal adequate model for each species, based on AIC and BIC values.

P values for the full models and the individual effects were derived for an upper-bound *n* of denominator degrees of freedom computed as *n* of observations minus *n* of fixed effects. As these *P*-values are potentially anti-conservative, we generated confidence intervals from the posterior distribution of parameter estimates with Markov Chain Monte Carlo methods, using the mcmcsamp function in the lme4 package with default specifications (e.g., $n = 1{,}000$ samples; locally uniform priors for fixed effects; locally non-informative priors for random effects; Bates et al. 2008; Bolker et al. 2009; Baayen et al. 2008). Both procedures yielded the same results; we present those from the Markov Chain Monte Carlo methods.

We used analysis of variance (ANOVA) to test if there was any significant variation in the timing of trips between monitoring years (as surveys started in April, monitoring years were defined as the 12 months from April to March).

Results

Baseline sighting rates

In the 12,047 km of river surveyed from 2004 to 2008, we observed 21,641 animals belonging to 27 of the 31 target species (Table 5—Appendix 2): an overall sighting rate of 1.8 animals/km. Table 1 reports bootstrapped annual and overall sighting rates for reptiles, birds, and mammals, as well as the mean number of species sighted per km surveyed.

Two reptile, four bird, and one mammal species were recorded on most trips, and these seven taxa accounted for 90% of all individuals sighted (Table 2). Four target species known to occur in the area, all mammals, were never observed: *A. microtis*, *L. lagotricha*,

Table 2 The seven species recorded on ≥49% of trips during 4 years of monitoring on the Los Amigos River, Amazonian Peru

Species	Common name	Percentage of all trips recorded	Percentage of all individuals recorded	Overall individuals/km
Caiman crocodilus	White caiman	49	4	0.08
Podocnemis unifilis	Yellow-spotted river turtle	86	53	0.96
Ara chloropterus and A. macao	Red-and-green Macaw and Scarlet Macaw	71	8	0.14
Ara ararauna	Blue-and-yellow Macaw	73	16	0.29
Vanellus cayanus	Pied Lapwing	63	6	0.10
Hydrochoerus hydrochaeris	Capybara	50	3	0.05

These seven taxa accounted for 90% of all individuals recorded

Puma concolor (puma), and *S. venaticus* (bush dog). Two primate species are represented in the database by a single individual (*Pithecia irrorata* [Gray's bald-faced saki monkey] and *Cebus albifrons* [White-fronted capuchin monkey]), and three bird species were recorded three or fewer times (*Platalea ajaja* [Roseate Spoonbill], *Neochen jubata* [Orinoco Goose], and *Phaetusa simplex* [Large-billed Tern]).

Trends over time

The number of all animals recorded per km surveyed increased significantly from the first to the fourth year of monitoring (Table 1). This was also the case for reptiles (a fourfold increase), birds (a twofold increase), and mammals (a threefold increase; Fig. 3). In all three taxa, every new year of monitoring saw an increase in sighting frequency compared to the previous year. Annual increases were rarely significant, but variation between values separated by two or more years was always positive and statistically significant 78% of the time. The mean number of species recorded per km showed a steady but non-significant increase from the first to the fourth year of monitoring. We found no significant variation in the mean starting time of trips between monitoring years (ANOVA, $F_{3,253} = 0.185$, $P = 0.907$) so can reject the hypothesis that there was any systematic change in the timing of trips that could bias results over the four monitoring years.

The number of individuals recorded per trip increased over time for six of the eleven species common enough to model, and for five of the six most commonly sighted species (Table 3). Four species also showed a significant temporal trend in sighting probability. Three species (*C. crocodilus*, *H. hydrochaeris*, and *A. chamek*) showed a positive trend in both measures. Three species (*P. unifilis*, *A. ararauna*, and *V. cayanus*) showed a positive

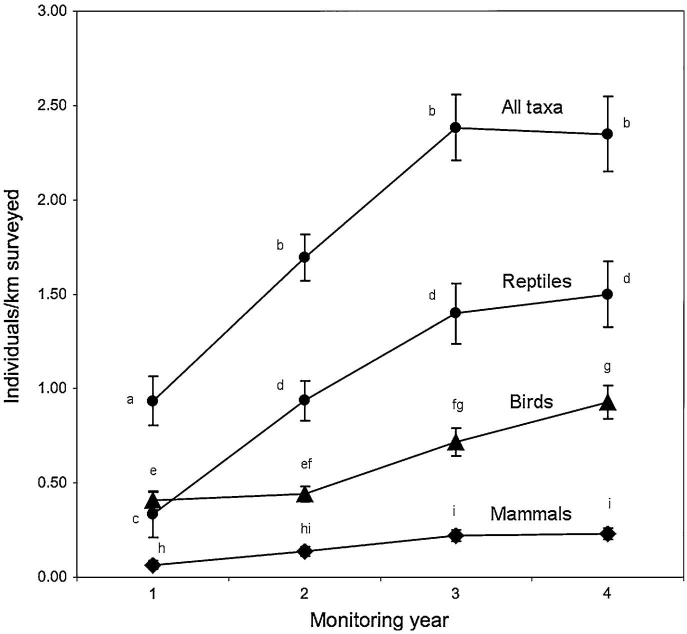

Fig. 3 Changes in mean annual sighting frequency of 31 species of reptiles, birds, and mammals over 4 years of riparian monitoring on the Los Amigos River, Amazonian Peru. Within a taxonomic group, means that share a *letter* are not significantly different

Table 3 Predictors of relative abundance for 11 common vertebrates on the Los Amigos River, Amazonian Peru

Species	No. trips sighted	Temporal trend no. individuals		Temporal trend sighting probability		Wet season no. individuals		Wet season sighting probability		Other correlations
Podocnemis unifilis§	222	0.73***	(0.18)			−2.30†	(0.41)			Rainfall (−), sun (+)
Melanosuchus niger	60					−0.36**	(0.08)	−1.8086†	(0.3783)	
Caiman crocodilus§	127	0.21*	(0.11)	0.3262*	(0.1362)	−1.61†	(0.25)	−2.4564†	(0.3190)	Boats (+)
Ara ararauna	187	0.51*	(0.21)					1.4465***	(0.4420)	Boats (−)
Anhima cornuta	121			−0.04329	(0.14036)	−0.29*	(0.12)	−0.38999	(0.31702)	
Cairina moschata§	83									Sun (−)
Vanellus cayanus	163	0.32**	(0.11)			−1.37†	(0.24)	−1.5180***	(0.4974)	Sun (+)
Hydrochoerus hydrochaeris§	129	0.43†	(0.07)	0.6091†	(0.1371)	−0.53**	(0.15)	−0.7386**	(0.3013)	Afternoon (+), upriver (+)
Alouatta seniculus§	38									Rainfall (+)
Ateles chamek§	42	0.14*	(0.05)	0.3630**	(0.1577)					
Saimiri boliviensis	39									Upriver (+)

Formerly hunted species are marked with § symbol. Significance symbols: * < 0.05, ** <0.01, *** <0.001, † <0.0001 trend in number of individuals sighted but no change in sighting probability. Just one of the 11 species showed a negative trend in either measure (*A. cornuta*, which showed a weak and insignificant decrease in sighting probability with time). Four species (*M. niger*, *C. moschata*, *A. seniculus* and *S. boliviensis*) showed no trend in either measure. No difference was found in the trends over the four-year study period between hunted and unhunted species.

Of the 12 species recorded in at least 10% of all trips, 11 had higher raw sighting rates (individuals/km) in the fourth wet season than in the first, and the median increase was 137%. The comparable numbers for the first and fourth dry seasons are 10 species and a median increase of 160% (Table 5—Appendix 2).

Sighting rates under varying conditions

After time, the most important fixed effect in the models was season. For five species, both the number of individuals sighted and sighting probability declined significantly in wet season (Table 3). Number of individuals sighted declined for one additional species. Four species showed no seasonal effect, while one species increased in sighting probability during the wet season (*A. ararauna*). Other correlations between abundance and fixed effects were scattered and mostly unsurprising (e.g., more turtles recorded in sunny weather; see Table 3).

Cost of data collection

Because the park guards collected these data in the course of other duties, taking advantage of time that was previously spent in unproductive boat travel, the cost of data collection was close to 0. Survey forms were photocopied for <\$10, giving a cost per km close to 0. Extra gasoline, salaries, and food required to survey 20 km of forest transects cost approximately \$140/km/year.

Discussion

River-based monitoring by park guards in Amazonian Peru proved capable of detecting significant temporal trends in faunal sighting rates at a cost more than two orders of magnitude lower than more traditional monitoring methods in Amazonia (Gardner et al. 2007). While the survey proved inappropriate for some species and the data it generated are not easily linked to population density, the method shows significant promise for tracking long-term trends in the world's most diverse animal communities and strengthens similar findings for participatory monitoring schemes elsewhere in the tropics (Danielsen et al. 2005, 2008).

Faunal rebound at our study site

The survey data from 2004 to 2008 suggest that the newly protected reptile, bird, and mammal populations on the Los Amigos River are rebounding following a recent history of logging, hunting, and egg collection (Fig. 3, Table 3). This conjecture relies, however, on the untested assumption that higher sighting rates are an indicator of higher population densities. Further studies are needed to distinguish this hypothesis from the alternative hypotheses that higher sighting rates mostly reflect decreasing wariness of animals following the departure of hunters, or the improving skills of observers over time. For the time being, we discount these hypotheses based on the observation that increasing sighting rates were documented for species with a broad range of behavior under hunting pressure and visual conspicuousness: noticeable animals, cryptic animals, animals that are spooked by boats and animals that are not.

The number of individuals sighted per trip increased for a majority of the 11 species common enough to analyze, but sighting rates of hunted species were no more likely to increase than those of unhunted species. For example, we recorded significant increases in sightings of the unhunted Pied Lapwing and Blue-and-yellow Macaw but not of the hunted Muscovy Duck and howler monkey. This was an unexpected result that deserves more study. In the meantime, it is worth repeating that the cessation of hunting in a large protected area surrounded by intact wilderness resulted in a rebound in sighting rates that is as significant for unhunted species as it is for hunted ones.

Commonly sighted taxa: reptiles

One turtle species (*P. unifilis*) accounted for more than half of all animal sightings. Our data suggest that the Los Amigos watershed may protect a viable population of this globally threatened species. To estimate the size of the watershed's turtle population, we divided the maximum number of turtles seen on a single trip (a conservative approximation of the number of individuals resident in the 47-km stretch of river) by the trip distance. This gives a mean population density of 7 individuals/km. Assuming a comparable density along the rest of the 353-km Los Amigos River, a simple extrapolation gives ~2,500 turtles living on the main river (i.e., not considering the several dozen tributaries and lakes). However, while turtle sightings have increased dramatically on the lower Los Amigos (Table 3; Table 5—Appendix 2), where harvests of the edible eggs ended in 2003, the same is not necessarily the case for the upper stretches of the river. Approximately 20 km upriver from the stretch of river we studied, researchers have found turtle nests dug up for food by uncontacted indigenous groups (A. Mansilla, pers. comm.).

Comparable published data on *P. unifilis* densities on other Amazonian rivers are few, but Townsend et al. (2005) report similar maximum numbers of turtles sighted per km for a rebounding population of *P. unifilis* along two rivers in eastern Ecuador. The key unanswered question about these populations is how much, and for how long, they will continue to grow. Given that early European explorers marveled at immense Amazonian turtle populations (e.g., Medina 1934), it may be that turtle populations in newly established parks will continue growing for decades.

The consistently higher sightings of *P. unifilis* in dry season (Table 2; Table 5—Appendix 2) reflect a combination of factors: more sunshine and sunning perches (exposed snags) in dry season, and migration to adjacent oxbow lakes in wet season (A. Mansilla, pers. comm.). Higher dry season sighting rates for many other reptiles, birds, and terrestrial mammals (Table 2) are mostly due to the fact that lower river levels in dry season expose large beaches on which animals are more easily observed.

Commonly sighted taxa: birds

Three macaw species were sighted on the Los Amigos River more frequently than any of the other nine birds monitored (Table 2; Table 5—Appendix 2). Blue-and-yellow Macaws (*A. ararauna*) were especially common, recorded more than twice as often as the other two species combined. The number of *A. ararauna* sighted increased dramatically over the 4 years, though the probability of sighting at least one individual during a trip did not change. We also observed that the *A. ararauna* sighting rate varied more strongly from one dry season to another than it did between wet seasons. While the highest dry season sighting rate on the Los Amigos (year 3) was nearly five times higher than the lowest (year 1), the difference between the highest and lowest wet season sighting rates was less than a factor of two. Given the species' large geographic range and its importance to the local economy (e.g., Trivedi et al. 2004; Brightsmith and Bravo 2005), the strong increase in sightings on the Los Amigos in 2004–2008 and the impressive variation in dry season sighting rates merit further study.

For all 4 years of monitoring, sighting rates of *A. ararauna* on the Los Amigos were more than 100% higher than those recorded in a similar survey on the nearby Manu River during the wet and dry seasons of 1989 (Renton 2002). [The Manu is 100 km W of our study site; to compare our data (individuals/km) to Renton's data (individuals/h), we transformed our data using the relationship 100 km = 6 h]. Like Renton, we found no difference in the numbers of individuals recorded in wet and dry season. However, we did find a consistently higher probability of observing at least one *A. ararauna* during trips in the wet season, which is when the species breeds in this region of Peru (Brightsmith and Bravo 2005).

Combined sighting rates for the other two macaw species (Scarlet and Red-and-green Macaws) were consistently lower on the Los Amigos than on the Manu (Renton 2002). The highest wet season sighting rate on the Los Amigos (individuals/h for year 4) is roughly a third of that recorded on the Manu in 1989; the lowest (year 1) was just 19%. Sightings of Scarlet Macaws alone on the Manu in 1989 exceeded sightings of both species in seven of eight seasons on the Los Amigos. Likewise, Red-and-green Macaws were more abundant on the Manu in the 1989 wet season than both species were on the Los Amigos in all four 2004–2008 wet seasons.

When all the Los Amigos macaw data are combined, they do not support Renton's (2002) finding of "a significant threefold decline in the number of large macaws encountered during the dry season compared to the rainy season." Dry season sighting rates at Los Amigos (7.5 individuals/h) were very similar to wet season rates (6.8 individuals/h). Monitoring underway on the nearby Manu and Tambopata rivers (A. Lee and C. Kirkby, pers. comm.) should soon describe this regional and seasonal variation in a more rigorous fashion.

Commonly sighted taxa: mammals

Capybaras (*H. hydrochaeris*), recorded on 50% of all trips, were the most commonly sighted mammal on the Los Amigos. The species also shows one of the most striking upward trends of all taxa studied (Table 3). In the first year of monitoring, observers sighted capybaras on 32% of trips. By the fourth year, this figure had risen to 80%. Likewise, the maximum number of individuals sighted on a single trip each year mounted steadily throughout the study: 5, 9, 12, 24. While capybaras are not especially sought-after by hunters in this area of Peru (Schulte-Herbrüggen 2003), local villagers confirmed that they were hunted for meat before the establishment of the conservation concession (F. Espinoza, pers. comm.). A map of all *H. hydrochaeris* sighting localities on the Los Amigos during this monitoring program suggests that during the first year capybaras were largely absent from the lower ~10 km of the Los Amigos—the portion of the river closest to the nearest village—and subsequently recolonized that stretch over the next 3 years.

Rare species and other survey techniques

Several animal species that were rarely seen in river-based monitoring are frequently recorded by other kinds of monitoring at Los Amigos. These include *C. albifrons* and

C. apella, two of the most commonly sighted primates along forest transects at Los Amigos; *T. pecari* and *P. tajacu*, peccaries commonly recorded in camera-trap studies at Los Amigos (Tobler et al. 2008); and *P. irrorata*, a primate that is not infrequent in forest transect data from Los Amigos.

Most mammal species were recorded far less frequently from motorized boats along the river than they were along permanent transects in the adjacent floodplain forest, suggesting that river-based monitoring of this kind will never be a practical substitute for monitoring many medium to large mammal species. There are exceptions, however. Howler monkeys (*A. seniculus*) and jaguars (*P. onca*) were recorded more frequently on the river than inside the forest, on a per-hour basis. A howler monkey was observed once every five hours on the river, on average, versus once every 14 h on forest transects. Jaguars were recorded twice as frequently on the river. Tapirs (*T. terrestris*), squirrel monkeys (*S. boliviensis*) and spider monkeys (*A. chamek*) were recorded approximately twice as frequently in the forest. Given that river-based monitoring by park guards was also less expensive than forest-transect monitoring, these results raise the possibility that river-based monitoring of these taxa—which make disproportionate contributions to predation, herbivory, and seed-dispersion in southeastern Peru (Terborgh et al. 2008; Tobler 2008)—may be more effective than land-based surveys.

Low riparian sighting rates of some other species appear to reflect genuinely low population sizes in the Los Amigos watershed. For example, puma (*P. concolor*) sightings are consistently rarer than jaguar sightings not only in our river-based monitoring, but also in camera trap studies (Tobler et al. 2008) and forest transects at Los Amigos (see also Emmons 1987). *S. venaticus*, never recorded in the river monitoring, has never been photographed by camera traps nor recorded in forest transect monitoring at Los Amigos, though it has been sighted at Los Amigos at least twice in the last 10 years (Tobler et al. 2008, R. Leite Pitman, pers. comm.). At our study site it seems unlikely that river-based monitoring of these very rare mammals, and of mammals which do not make regular use of riverine habitat, will ever result in enough sightings to make more than anecdotal contributions to science.

The rarity of many bird species in our dataset most likely reflects the paucity of optimal habitat along the Los Amigos River. Many of these birds (*J. mycteria*, *M. americana*, *N. jubata*, *P. ajaja*, *P. simplex*, and *S. superciliaris*) prefer large mudflats, large sandflats, large marshy river margins, and other habitats that are common along larger rivers in the region but rare to absent along the narrower Los Amigos (J. Tobias, pers. comm.). For some of these species, the Los Amigos may be a sink that is reliant on source populations along the larger Madre de Dios River. Effective tracking of these taxa will require monitoring on the Madre de Dios itself (J. Tobias, pers. comm.).

Advantages, disadvantages, biases, and usefulness of river-based sampling in Amazonia

A more complete discussion of the advantages, disadvantages, and possible biases of monitoring programs such as the one described here is provided by Danielsen et al. (2005, 2008). In our study, the principal advantages relative to other monitoring programs were a high data-to-cost ratio and a high potential for long-term continuation (because park guards will continue patrolling the protected area for the foreseeable future). While we observed few disadvantages to river-based monitoring per se, our simple sampling design posed some limitations to analysis and could be improved (Fletcher and Hutto 2006). Likewise, our river-based monitoring data was clearly biased against several species that are spooked by the noise of boats, inactive during daylight hours, not commonly present along large rivers, rare because appropriate habitat is absent, and/or hard to observe for other reasons.

The river-based monitoring program at Los Amigos is ongoing. The full dataset is regularly updated and freely available from the authors or at http://www.acca.org.pe/espanol/investigacion/programas/monitoreo.html, and the organization managing the conservation concession aims to continue the program for the duration of its 40-year management contract. One immediate benefit of the program is a boost in the morale of park guards, who actively keep tabs on wildlife rather than simply manning guard posts or patrolling borders, and see clear evidence that the work they do is helping wildlife (Danielsen et al. 2005). Given that hunting and deforestation are expected to accelerate in southeastern Peru in the near future (Killeen 2007), the accumulating data should also eventually provide baseline sighting frequencies against which future data from Los Amigos and neighboring areas can be compared.

Until then, park managers have several reasons to be skeptical about the data's usefulness for day-to-day operational decisions. First, sighting trends for some species may be a better indication of conditions outside the park, or of a scarcity of appropriate natural habitat inside the park, than of the quality of park management. Second, managers have few historical or geographical yardsticks against which to interpret current sighting rates and trends at Los Amigos. Third, day-to-day management of Peru's Amazonian parks tends to focus on keeping out loggers and hunters, a state of affairs that detailed data on animal populations are unlikely to change in the short term. Finally, until further research provides a better understanding of the relationship between sighting rates and population sizes, the autecology of the species being monitored, and the causes behind increases and declines, the appropriate management response to a given trend in sighting rates may not be obvious. It is worth noting, however, that most of these criticisms apply to other monitoring programs in the Amazon (e.g., Ferraz et al. 2007; Magnusson et al. 2008). It is also the case, in our opinion, that many of these problems reflect a general lack of basic biodiversity data for Amazonian protected areas—a shortcoming that itself may be partly overcome by tracking trends in wildlife populations via monitoring like that described here.

Several aspects of the data presented here require further research. Fruitful comparisons of monitoring data collected on different rivers (e.g., Davenport 2003) will require a better understanding of the effects of differing river conditions like size, flooding intensity, area of exposed beach, current speed, and the character of the floodplain landscape. Understanding how boat noise affects the sighting rates of target species is also a high priority. Likewise, more exacting survey techniques may permit more refined interpretations of sighting rate data (e.g., Fletcher and Hutto 2006).

In the meantime, hundreds of park guards and tourist boats travel rivers in the Amazon basin every day. With little added cost in time or money, they could easily collect data of the kind we describe here (e.g., Gray and Kalpers 2005; see costs in Table 1 of Danielsen et al. 2005). Given the ubiquity of rivers (Toivonen et al. 2007), the intensification of hunting (Peres and Lake 2003), and the large number of permanent tree plots being monitored across the basin (Lewis et al. 2004a), river-based animal monitoring programs in a few dozen protected areas and ecotourism operations have the potential to provide valuable data that are currently absent from the debate about ecological change in Amazonia.

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Appendix 1

See Table 4.

Table 4 Paper form filled out by data collectors for river-based monitoring on the Los Amigos River, Amazonian Peru

MONITOREO DE FAUNA EN EL RÍO LOS AMIGOS

Fecha:
Nombre:
Otros observadores:

Ruta:
del CM1 al CM2
del CM2 al CM1
del CM2 al Amigos
del Amigos al CM2
del CM2 al Amiguillos
del Amiguillos al CM2
....

Hora de salida:
Hora de llegada:

Clima (lluvia, sol, nublado, etc.):
Nivel del río (alto, bajo, mediano):

Movilidad:
peque-peque 55 hp 25 hp
....

Otros botes en la ruta hoy?:

TARICAYAS (#juv.): (#adul.):

CAIMANES NEGROS (#peq.): (#med.): (#grande):
CAIMANES BLANCOS (#peq.): (#med.): (#grande):

GUACAMAYOS
Ara chloroptera/macao (#):
Ara ararauna (#):

AVES DE PLAYA (indica ubicación en el mapa con las letras respectivas)
MA. *Mycteria americana* (#):
JM. *Jabiru mycteria* (#):
AA. *Ajaia ajaja* (#):
AC. *Anhima cornuta* (#):
NJ. *Neochen jubata* (#):
CM. *Cairina moschata* (#):
VC. *Vanellus cayanus* (#):
CC. *Charadrius collaris* (#):
PS. *Phaetusa simplex* (#):
ST. *Sterna superciliaris* (#):
RN. *Rynchops nigra* (#):
CR. *Chordeiles rupestris* (#):
GF. *Gymnoderus foetidus* (#):

PRIMATES (indica ubicación en el mapa con las letras respectivas)
CA. *Cebus apella* (#):
AS. *Alouatta seniculus* (#):
CL. *Cebus albifrons* (#):
PM. *Pithecia monachus* (#):
AP. *Ateles paniscus* (#):
SS. *Saimiri sciureus* (#):
LL. *Lagothrix lagothricha* (#):

LOBOS DE RÍO (indica ubicación en el mapa con la letra "L")
grupo 1 (#juveniles): (#adultos):
grupo 2 (#juveniles): (#adultos):

OTROS MAMÍFEROS IMPORTANTES (indica ubicación en el mapa con las letras respectivas)
TT. *Tapirus terrestris* (#):
HH. *H. hydrochaeris* (#):
AM. *Atelocynus microtis* (#):
TP o PT. Pecaríes (especie, #):
PO. *Panthera onca* (#):
SV. *Speothos venaticus* (#):
PC. Puma concolor (#):

Appendix 2

See Table 5.

Table 5 Raw sighting rates (individuals/100 km) and sighting probabilities (% of trips with at least one record) for the 27 species recorded over 4 years of riparian monitoring on the Los Amigos River, Amazonian Peru, classified by year and season

Year	1		2		3		4		All			Max
Season	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	All	
Podocnemis unifilis												
ind./100 km	85.215	17.154	119.321	51.871	172.523	88.382	147.055	71.502	129.107	58.145	95.973	333
% trips seen	89.7	62.5	93.8	80.5	100.0	93.3	87.9	76.0	92.7	79.2	86.4	
Melanosuchus niger												
ind./100 km	1.805	0.178	1.666	0.312	1.034	0.284	1.487	0.341	1.510	0.284	0.938	7
% trips seen	41.0	8.3	34.4	9.8	30.3	13.3	33.3	8.0	35.0	10.0	23.3	
Caiman crocodilus												
ind./100 km	6.727	0.356	16.798	1.041	12.475	1.138	20.232	1.109	13.717	0.942	7.752	47
% trips seen	59.0	12.5	78.1	17.1	72.7	26.7	84.8	36.0	73.0	22.5	49.4	
Ara chloropterus and *A. macao*												
ind./100 km	6.126	19.020	8.732	13.319	10.536	14.434	20.555	24.915	11.273	17.154	14.019	43
% trips seen	38.5	87.5	62.5	85.4	48.5	86.7	75.8	96.0	55.5	88.3	70.8	
Ara ararauna												
ind./100 km	13.400	24.886	20.598	14.984	65.351	27.517	38.073	31.655	33.538	23.571	28.884	98
% trips seen	43.6	91.7	59.4	82.9	78.8	90.0	63.6	84.0	60.6	86.7	72.8	
Mycteria americana												
ind./100 km	0.438	0.267	–	–	0.129	–	–	–	0.156	0.053	0.108	3
% trips seen	10.3	4.2	–	–	6.1	–	–	–	4.4	0.8	2.7	

Table 5 continued

Year	1		2		3		4		All			Max
Season	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	All	
Jabiru mycteria												
ind./100 km	2.571	–	0.533	–	1.228	1.351	–	0.085	1.152	0.356	0.780	17
% trips seen	35.9	–	6.3	–	9.1	6.7	–	4.0	13.9	2.5	8.6	
Platalea ajaja												
ind./100 km	0.055	–	–	–	–	–	0.517	–	0.140	–	0.075	7
% trips seen	2.6	–	–	–	–	–	6.1	–	2.2	–	1.2	
Anhima cornuta												
ind./100 km	4.047	1.955	2.400	1.197	3.426	2.204	2.780	1.877	3.207	1.742	2.523	8
% trips seen	56.4	45.8	46.9	34.1	51.5	50.0	48.5	44.0	51.1	42.5	47.1	
Neochen jubata												
ind./100 km	0.109	–	–	0.104	–	–	–	–	0.031	0.036	0.033	2
% trips seen	2.6	–	–	2.4	–	–	–	–	0.7	0.8	0.8	
Cairina moschata												
ind./100 km	1.696	1.244	1.733	0.989	0.388	1.351	4.008	3.498	1.946	1.653	1.809	15
% trips seen	35.9	29.2	37.5	19.5	15.2	33.3	54.5	36.0	35.8	28.3	32.3	
Vanellus cayanus												
ind./100 km	5.141	2.400	15.332	4.422	18.875	3.413	18.487	11.604	14.044	5.262	9.943	41
% trips seen	46.2	37.5	87.5	56.1	87.9	46.7	81.8	60.0	74.5	50.8	63.4	
Phaetusa simplex												
ind./100 km	0.273	–	–	–	–	–	–	–	0.078	–	0.042	3
% trips seen	5.1	–	–	–	–	–	–	–	1.5	–	0.8	
Sterna superciliaris												
ind./100 km	–	–	0.400	0.208	0.065	0.071	0.194	–	0.156	0.089	0.125	4
% trips seen	–	–	12.5	2.4	3.0	3.3	6.1	–	5.1	1.7	3.5	

Table 5 continued

Year	1		2		3		4		All			Max
Season	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	All	
Alouatta seniculus												
ind./100 km	0.875	0.089	1.133	1.561	1.745	1.280	1.293	1.621	1.246	1.209	1.228	8
% trips seen	7.7	4.2	12.5	14.6	18.2	23.3	15.2	24.0	13.1	16.7	14.8	
Ateles chamek												
ind./100 km	1.039	2.133	0.800	1.873	1.357	3.697	3.297	3.840	1.604	2.791	2.158	17
% trips seen	7.7	16.7	12.5	12.2	9.1	33.3	21.2	24.0	12.4	20.8	16.3	
Cebus apella												
ind./100 km	–	0.711	–	0.104	–	0.640	0.582	0.853	0.140	0.516	0.315	8
% trips seen	–	4.2	–	2.4	–	6.7	9.1	12.0	2.2	5.8	3.9	
Cebus albifrons												
ind./100 km	–	–	–	–	–	–	0.065	–	0.016	–	0.008	1
% trips seen	–	–	–	–	–	–	3.0	–	0.7	–	0.4	
Saimiri boliviensis												
ind./100 km	3.774	3.555	5.066	3.902	6.787	9.243	7.110	4.863	5.605	5.368	5.495	30
% trips seen	12.8	8.3	18.8	7.3	15.2	20.0	24.2	16.0	17.5	12.5	15.2	
Pithecia irrorata												
ind./100 km	–	0.089	–	–	–	–	–	–	–	0.018	0.008	1
% trips seen	–	4.2	–	–	–	–	–	–	–	0.8	0.4	
Pteronura brasiliensis												
ind./100 km	0.656	–	0.067	–	0.065	0.284	0.452	0.341	0.327	0.142	0.241	6
% trips seen	7.7	–	3.1	–	3.0	3.3	9.1	4.0	5.8	1.7	3.9	
Tapirus terrestris												
ind./100 km	0.328	0.089	0.200	0.156	0.388	0.213	0.129	–	0.265	0.124	0.199	2
% trips seen	15.4	4.2	6.3	7.3	12.1	6.7	6.1	–	10.2	5.0	7.8	

Table 5 continued

Year	1		2		3		4		All			Max
Season	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	All	
Hydrochoerus hydrochaeris												
ind./100 km	2.078	0.800	2.600	2.861	6.916	5.404	15.707	6.314	6.648	3.804	5.320	24
% trips seen	41.0	16.7	28.1	41.5	72.7	60.0	78.8	60.0	54.7	45.0	50.2	
Tayassu pecari												
ind./100 km	1.367	4.000	–	2.081	–	2.275	2.262	–	0.934	2.080	1.469	40
% trips seen	2.6	8.3	–	2.4	–	6.7	3.0	–	1.5	4.2	2.7	
Pecari tajacu												
ind./100 km	0.219	0.622	–	0.104	–	–	0.129	–	0.093	0.160	0.125	5
% trips seen	2.6	8.3	–	2.4	–	–	3.0	–	1.5	2.5	1.9	
Panthera onca												
ind./100 km	0.055	0.089	0.067	–	0.194	–	–	–	0.078	0.018	0.050	1
% trips seen	2.6	4.2	3.1	–	9.1	–	–	–	3.6	0.8	2.3	

The four target species that were never recorded are not included in the table (*Atelocynus microtis*, *Lagothrix lagotricha*, *Puma concolor*, *Speothos venaticus*). Dry season is April–September inclusive

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