Assessing the Effects of Tropical Land Use Change:

A Camera Trapping Study of Terrestrial Peruvian Mammals

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Abstract

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Previous research shows that most mammals are reduced in fragmented forests, particularly species averse to human-modified landscapes. Since felids are elusive, sometimes nocturnal, and usually inhabit interior forest away from human activity, they can be difficult to study through in-person field observations. One effective approach to study felids is through camera trapping, where the captured images can be used to identify individuals of certain tropical felid species by their spots and bot fly warbles. To better understand the impacts of forest fragmentation on felids, the presence and distribution of both felids and their prey species were studied across a modified tropical forest gradient in the Piedras region of Madre de Dios, Peru. The goal of this study was to compare and relate species abundance and species diversity data for captured Peruvian mammals in response to land use and land cover changes (LUCC), specifically for jaguar, puma, and ocelot. Jaguar home range, distribution, and density estimates were also made using the program Camera Base. Twenty-three terrestrial mammal species were identified and assigned capture frequencies ranging from .04 to 80.7 (number of photos/1000 camera stations nights). Density of jaguars was estimated using the 8 individuals identified and data analysis in both Camera Base and DENSITY. The Jackknife Mh estimator with MMDM (mean maximum distance moved) was used to estimate jaguar density at approximately 5.05 jaguars/100 sq km. Results of this research indicate healthy populations of jaguar and ocelot, and support the theory that felids are using human modified areas for movement, habitat, and hunting. In addition, seasonally used and minimally fragmented forests in the Piedras hold abundant biodiversity and can act as corridors between core habitat and protected areas for medium and large-sized mammals. Given the demonstrated diversity and vulnerability of the Piedras region, and that it represents one of the largest unprotected and largely intact tropical rainforests in Peru, this research shows both the importance of the region in supporting robust felid populations and the urgency needed to increase the protection of the region's species and forests. The vast majority of studies looking at felids occur in protected areas like national parks, so monitoring felids in unprotected areas as a comparison is also vital.

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Introduction

Background

The Amazon basin holds more than 50 percent of the earth's intact tropical forests, which are experiencing some of the world's highest rates of deforestation. More than 80 percent of logging activities in the Amazon are illegal, causing rapid habitat fragmentation with often unknown and adverse impacts on resident and threatened wildlife. The effects of fragmentation on threatened species and those living in remote areas of the Amazon are largely undocumented (Laurence et al., 2000; Michaelson et al. 2013). One of the largest unprotected and intact tropical rainforests in Peru, which has the second largest extent of rainforest in the Amazon, is the Piedras region of Madre de Dios. Despite facing increasing logging activities in recent years, the Piedras region is encompassed within a critical portion of the Tropical Andes biodiversity hotspot. The region is known worldwide for its diversity and abundance of fauna, including threatened species like the jaguar (*Panthera onca*), bush dog (*Speothos venaticus*), and lowland tapir (*Tapirus terrestris*).

It is well known that keystone species and large predators such as cats provide a stabilizing function within ecosystems and increase biodiversity through trophic effects (Laurence et al., 2000; Redford 1992; Terborgh et al. 1999). One of the main functions of a predatory felid is to directly control smaller mammals through consumption, particularly seed predators and rodents such as agouti, which when left unchecked, disturb natural ecosystem structure and function When rodents increase due to the absence of predators, the saplings of canopy trees decline significantly. Without predators like cats, primary producers become limited by herbivory, not just competition for resources (Estes et al. 2013; Laurence et al., 2000). Additionally, high trophic level species like carnivores are frequently more vulnerable to habitat fragmentation than species like herbivores, creating the potential to alter the entire structure and function of food webs (Crooks 2002; Colchero et al. 2011; Didham et al., 1998b; Fahrig 2003; Hatten et al. 2005; Haag et al. 2010; Terborgh et al. 2001; Zeilhofer et al. 2014).

Assessing the habitat preference and suitability of top predators like the jaguar can indicate overall ecosystem health and integrity. Although most research endeavors report jaguars as being a habitat generalists, there is little monitoring of their preferences in unprotected, changing environments. Habitat loss and fragmentation are serious threats to large carnivores, especially jaguars. However, recent research shows that jaguars will substitute their natural prey with domestic livestock if given the opportunity, which has led to increased human-wildlife conflict in areas of contact (Rabinowitz, 1986; Sanderson et al., 2002; Schaller & Crawshaw, 1980, Silveira et al., 2008; Zeilhofer et al., 2014). Assessing how these complex interactions will respond to growing human modified landscapes is essential for the future conservation of felids.

Camera trapping is a unique method for monitoring wildlife populations because it is non-invasive, requires low personnel demand, and allows unbiased indicator estimation in remote areas. Camera trapping can also identify individuals of a particular felid species by their spots and bot fly warbles (Estes et al, 2013). However, camera trapping has yet to be used as a method for monitoring mammal populations in response to human impacts.

Camera traps usually use infrared flash of around 800 nm, a spectral output not disruptive to most wildlife. This makes these cameras ideal for capturing authentic animal behaviors day and night, since most tropical mammals are diurnal or nocturnal. This method can be used in lieu of, or congruently, with common wildlife inventory methods including interviews with local people, direct observations, line transects, trapping and tagging, and identification of tracks and feces

(Haugaasen & Peres, 2005; Mendes Pontes, 2004; Tobler et al., 2008; Trolle, 2003a; Voss & Emmons, 1996; Voss, Lunde & Simmons, 2001).

This study was designed to survey a 150 square km site representative of a wide range of habitat and land use types in the Piedras region of Peru. Findings yielded estimates of species presence, richness, diversity, and density, all in relationship to several key variables. The study addressed species presence in relation to the following variables: human development gradient, habitat type, land use, concession type, method of movement, distance from water, and distance from human infrastructure.

Movement was aggregated based on the categories of trails, roads, rivers, and streams. The human development gradient was determined by human presence, activities, disturbance, and noise from nearby chakras (agricultural fields), research stations, housing, and roads. Land cover was characterized using a range from closed-canopy (primary) forest greater than 1km from human disturbances to settlement areas with high human activity. Those areas delineated as concessions were compared to true land use due to the high amount of illegal hunting and selective logging still occurring in ecotourism and conservation concessions. Density estimates of both jaguar (*Panthera onca*) and ocelot (*Leoparuds wiedii*) were also created to better relate these populations to prey abundance and distribution in the study site.

This project advances the collective goals of better understanding local felids and the impacts of regional land cover and land use change (LUCC) on local wildlife. It is important to note that a number of socioeconomic and political factors are involved in the management of LUCC in the Madre de Dios region at the local, regional, and national level. If this survey is successful in evaluating the influence of land use activities on mammals in the Piedras region, conservation policies could be improved, including using these results to delineate protected areas and wildlife corridors that would better enhance local populations by allowing dispersal, gene flow, and protection from hunting.

Project findings have provided an overview of mammal presence and preference, including rare and elusive mammals, in a landscape undergoing swift anthropogenic change. According to Matthias Tobler, "Despite years of research throughout the Amazon, there are few complete mammal inventories and our knowledge on the distributions of rare and elusive species is still poor" (2008, p. 169). In summary, the survey performed for this study will form a baseline for the regional conservation of threatened species, particularly cats, which is invaluable for the long-term monitoring of mammal abundance and diversity. There are no published studies on carnivores in the Piedras region, making this study both globally important and locally novel.

Study Region

The Piedras River Basin was the region of study (see Figure 1). This region holds the remaining frontier forests of the Peruvian Amazon and is a biodiversity hotspot. Flowing from its source far into Alto Purús National Park, the Las Piedras River stretches 621 kilometers before merging with the Madre de Dios River on its way into Bolivia and eventually the Amazon River. The Piedras River also travels through protected indigenous territories of several isolated tribes, which provide an important buffer between the expansion of human infrastructure and one of the most pristine rainforests left in the world. Little research has been conducted in these indigenous territories due to their isolation and the privacy sought by tribes, and these areas hold some of the last intact mahogany stands and endangered timber species. The Piedras River also passes through native communities including Monte Salvado and Puerto Nuevo before reaching the communities of Lucerna and Palma Real, two communities located within the boundaries of this survey’s study area.

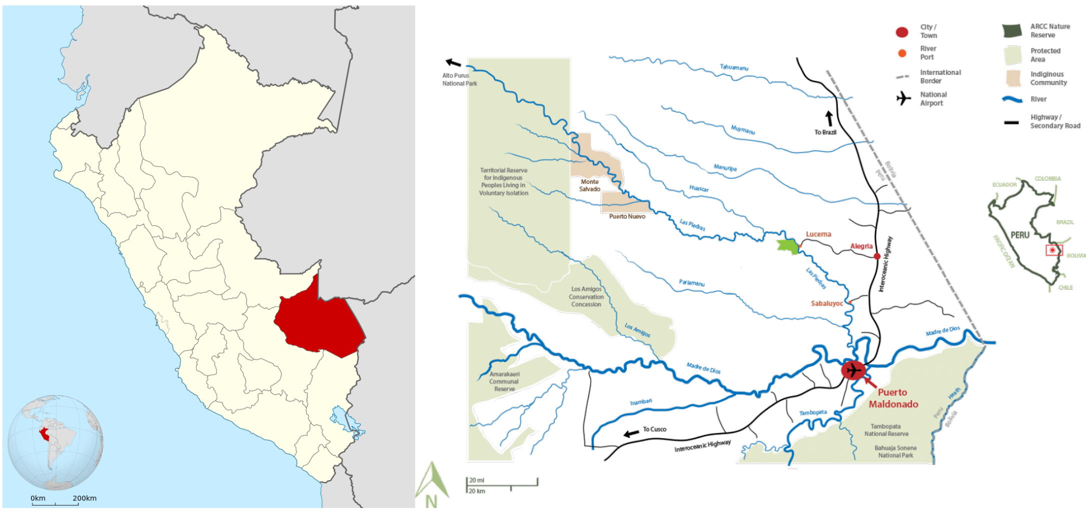


Figure 1. The state of Madre de Dios, Peru (left) and the study region of the Piedras (right)

Historical Land Use

According to Michaelsen et al., “more than 60 percent of deforestation in the Brazilian Amazon has occurred within 50 km of major paved highways” leading to rampant deforestation and carbon emissions contributing to climate change globally (2013, p. 132). Due to a lack of road networks, Peru’s intact forests have been only mildly disturbed, and over 55% of their national territory was forest cover. Intact, remote forests are converted and deforested due to resource demand; however, this process is facilitated by the creation of roads. The paving of roads has boosted local economies and stimulated regional growth primarily due to the reduction of transportation costs. It has also provided direct and easy access to forests that could not be reached otherwise- forests that are then cleared far beyond the need for basic subsistence production. Recent deforestation and encroachment into previously undisturbed forests over the last five years trends over the last five years can be explained by the construction of the Inter-

Oceanic Highway (IOH), a large, paved road connecting the ports of Peru to the ports of Brazil that was completed in 2011. The increased rate of deforestation seen in the Peruvian lowlands has occurred as a result of, and in close proximity to, the new road networks extending from the IOH (Michaelsen et al. 2013).

In many parts of the Amazon, including the Madre de Dios Region of Peru, "land tenure and resource boundaries of agricultural and mining areas, protected areas, timber and Brazil nut concessions have for long co-existed without proper enforcement of their legal boundaries, which has led to land invasions and unsustainable resource extraction" (Michaelsen et al., 2013. p. 133). Titling procedures and granting property rights are currently managed by the Commission for the Formalization of Informal Property (COFOPRI), but were previously managed by the Rural Cadastre Project (PETT) and the Ministry of Agriculture. These transitions, along with inconsistent deforestation estimates, have made titling procedures extremely unclear. The boundaries between concessions have been blurred as tenure overlaps, resulting in land use and land cover change (LUCC) being documented throughout even the more remote areas of the Peruvian Amazon. Although legal boundaries for concessions exist, they cannot be properly enforced, thus resulting in increased land invasions, infrastructure creation, and deforestation.

The town of Lucerna is a clear representation of land invasion in the Piedras Basin. Lucerna was founded nine years ago while Palma Real, a subdivision of Lucerna more focused on agricultural productivity, was founded in 2014. Although different presidents oversee them, the towns share many of the same community members who migrated from the Ayacucho region of the Andes Mountains. For the last nine years, families have fled from a conflicted area in Ayacucho known as VRAE (Valle del Rio Apurímac y Ene). This area is known primarily for its coca production and has recently experienced increasing instability, leading to more emigration from the area. Originally from the mountains, the community of almost 90 members speaks both Quechua and Spanish. A schoolhouse for all ages was recently built in the center of Lucerna next to their football (soccer) pitch and they have installed a solar panel in order to power a radio system that helps them keep in touch with Puerto Maldonado and other nearby towns. Both of these infrastructure improvements have helped Lucerna gain recognition from the government of Peru as permanent residents working the land instead of invaders of the land.

Traditionally agriculturalists from the mountains, the people of Lucerna have been practicing logging in the surrounding jungle and farming their "chakras," or fields, which have cleared the surrounding forest habitat. The rugged logging road connecting the town of Alegria on the highway to Lucerna has given better access to the intact forests of the Piedras. Prior to the construction of the IOH, much of the surrounding area was inaccessible by road and therefore escaped the high hunting and logging pressures of other major river basins in the area, such as the Madre de Dios and Tambopata River Basins. This is yet another example of the detrimental impacts of roads to both forests and biodiversity. While national parks and indigenous territories protect the northern reaches of the Las Piedras, the southern section remains forest management land or completely unprotected.

Study Site

The study was carried out in the State of Madre de Dios, Peru, at the Las Piedras Biodiversity Station (12°3'24.63"S, 69°31'42.63"W) along the Piedras River 70 km northwest of Puerto Maldonado. The study site (see Figure 2 below) included 150 square kilometers of lowland rainforest representative of diverse land cover and land use. This size was selected because jaguars have home ranges of up to 150 square km, as reported by Zeilhofer (2014) and

Silveira (2004). Cameras were deployed in late July and collected in early November during the dry season; camera cards were collected and replaced, along with stolen and malfunctioning cameras, throughout the duration of the study.

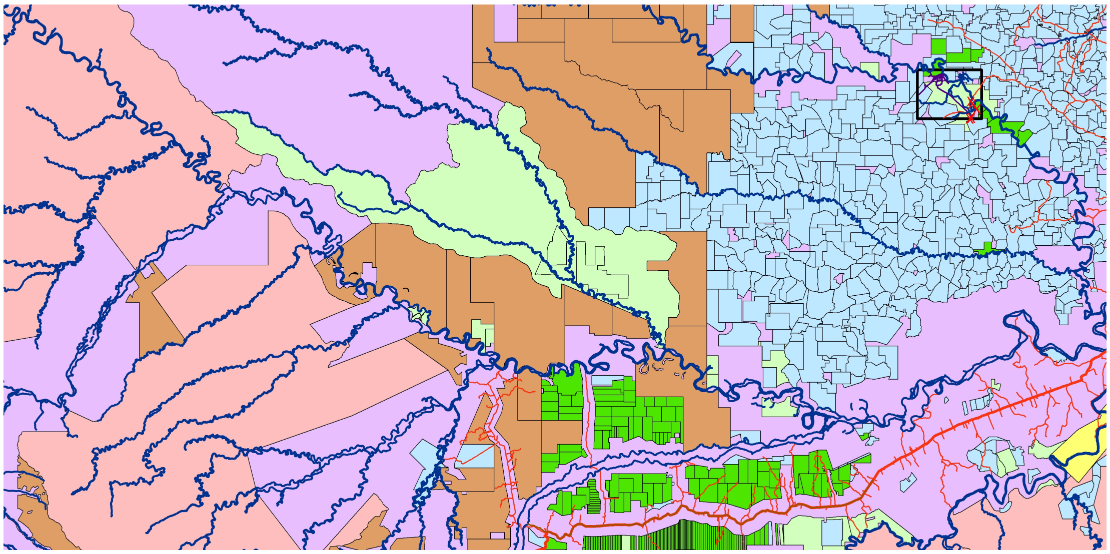


Figure 2. Location of the Piedras study site within the State of Madre de Dios, Peru, and the complex matric of concessions represented throughout the region

The Las Piedras Biodiversity Station is part of a 5 square km ecotourism concession bordering over 40 square km of conservation concession land. Other designated land use activities in the area include reforestation, timber extraction, and brazil nut harvesting; however, all five concessions are largely unregulated and therefore do not represent actual land use.

Three main habitat types including *terra firme* (upland) forest, floodplain forest, and palm swamps are represented at the study site. Cameras were not placed in palm swamps as they occupy a limited extent of the study area. Floodplain forest in this region does not become inundated until December in the wet season, so no inundation occurred during the weeks cameras were operational in the field. Due to selective logging irrespective of concession type over the years, little primary forest remains in the Piedras. However, closed-canopy forests can still be found within areas at least 2.5km from the nearest road.

Mean rainfall was between approximately 57mm and 201mm during study period of July- early November. Precipitation will range from a low of about 50mm in July to a high of 343mm during the wet season in January. The Piedras has a dry season from May-September and a wet or rainy season from December-March. In late October or early November the stream and river levels begin to rise marking the transition into the wet season, which will then transition back to the dry season in late March or early April. Average temperatures from July to early November ranged from 18C to 33C with lowest temperatures found in July and the highest in October (NOAA Climate Data).

Materials and Methods

Camera Trap Surveys

A grant written by the author to the University of Washington Student Technology Fee was accepted in January 2015, providing $44,650 to purchase tech equipment for the School of Environmental and Forest Sciences. This money was used to buy trail cameras, batteries, GPS units, SPOT units, and other field equipment necessary to complete the study. Approximately $2,500 was raised via crowd funding to support the primary author's travel, lodging, and food expenses in Peru.

The 2014 Browning Strike Force Sub Micro series trail camera, model #BTC-5, was used in this study (see Figure 3 below). It was chosen for its discrete size and color, excellent picture quality, quick recovery time, wide detection zone, and noteworthy night photos. The low-glow infrared flash at night and under closed canopy is less invasive than a white flash camera; it is very difficult for both animals and animals to detect. All cameras were in *trail cam*, or photo, operation mode, with the photo quality set at *ultra* 10MP, the picture delay set at 5 seconds, and the multi-shot mode set at *4-shot rapid fire*. Each camera lasted the entire study period on 6 AA lithium batteries.

Figure 3. The 2014 Browning Strike Force Sub Micro series trail camera, model #BTC-5

Cameras were operational from late July to early November excluding cases of site change or theft. The longest consecutive range of camera station nights was 105 (together 210 camera trap nights), and the average number of camera trap nights between all cameras was 108. Overall station nights totaled 2,539, while overall camera trap nights totaled 4,066.

Each camera station location was chosen based on extremely specific characteristics shown in Tables 1 and 2 below. Cameras were set up along trails, roads, rivers, and streams, covering a total area of 150 sq km spaced at least 1 km apart. Most cameras were about 50-60cm off of the ground. However, the height of several cameras was adjusted based on the location to make them more covert in areas of high human presence. Cameras were strapped securely to trees or posts inserted into the ground, and a shelter was built above each camera using natural forest materials that were replaced as cameras were checked and SD cards were collected.

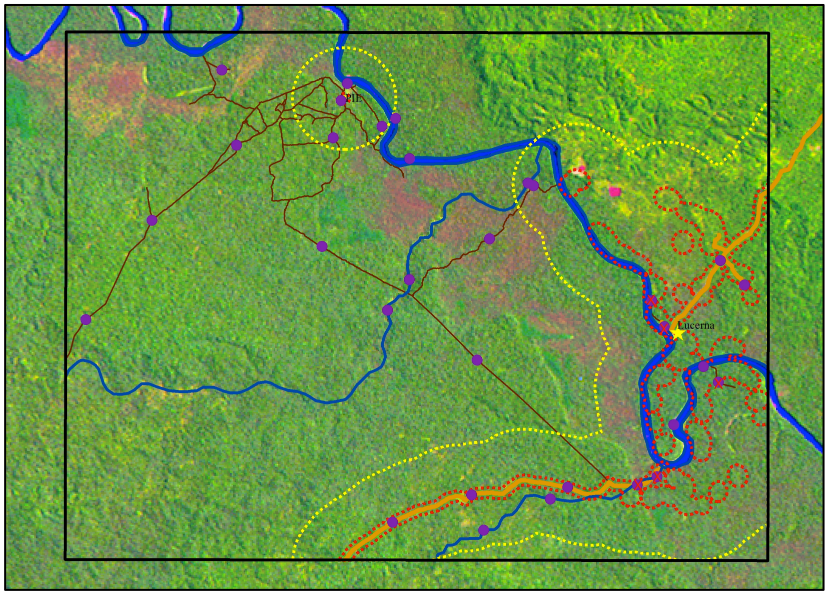


Figure 4. Study site showing camera stations and movement type with human infrastructure buffers

The study began with 30 stations, 60 total camera traps, 26 of which remained operational throughout the study and were included in the analyses. Figure 4 above shows the 30 original camera trap stations, the study site's trails, roads, rivers, and streams, and the 100m and 1km buffers around human infrastructure. One camera was lost due to a tree fall, two cameras died due to moisture, and five cameras were stolen from areas of high human presence and density. Two camera traps represented each station throughout the study site (Tobler et al., 2013); each pair faced the same direction, but cameras were staggered so as to avoid one another's infrared flash when dark.

Generally, both trail cameras captured all medium and large animals passing through each camera station. In some cases, such as those involving small animals or those not following the pathway being surveyed, animals were only captured on one camera. If caught on both cameras, only one "capture" was recorded for that individual. Only one capture was recorded within an hour period if the same species was captured at the same station more than once, unless individuals could be distinguished. Paired camera traps have been used to successfully identify individuals of a species, particularly cats, by their unique coats and botfly markings. This is a common way to make density estimates for a population with a large enough sample size.

Table 1. Tested environmental variables and their characteristics

Concession	Land Use	Land Cover	Habitat	Movement	Elevation (m)	Stream	Water	Infra.
The right to use land for a specified purpose	Management and modification of the natural environment	Physical land type	Land units used by wildlife with equivalent structure and function	Method of movement through the landscape	Height above sea level	Distance from streams	Distance from water sources	Distance from human infrastructure
ECOTOURISM	MIXED	PRIMARY	UPLAND	TRAIL	LOW<240	100M	100M	100M
REFORESTATION	CONS	INTACT	SECONDARY	RIVER	240<MED<270	1KM	1KM	1KM
BRAZILNUT		SECONDARY	FLOODPLAIN	STREAM	270<HIGH	1KM+	1KM+	1KM+
CONSERVATION		SETTLEMENT		ROAD				

Table 2. Camera Trap Stations and their Corresponding Characteristics

Camera	Concession	Land Use	Land Cover	Habitat	Movement	Elevation	Stream Dist.	Water Dist.	Infra. Dist.
1HNTTRL	CONSERVATION	CONS	INTACT	FLOOD	TRAIL	237.91	1KM	1KM	1KM
1STRAMAG	CONSERVATION	CONS	STREAM	FLOOD	STREAM	237.04	100M	100M	1KM
2HNTTRL	CONSERVATION	CONS	INTACT	FLOOD	TRAIL	232.79	1KM	1KM	1KM+
BNTRL1	ECOTOURISM	CONS	PRIMARY	UPLAND	TRAIL	266.66	1KM+	1KM+	1KM+
BNTRL2	BRAZILNUT	MIXED	INTACT	SECONDARY	TRAIL	279.62	1KM+	1KM+	1KM+
BNTRL3	BRAZILNUT	MIXED	INTACT	SECONDARY	TRAIL	302.08	1KM	1KM	1KM+
HS	REFORESTATION	MIXED	PRIMARY	FLOOD	TRAIL	238.01	1KM+	1KM	1KM+
LUCRD	CONSERVATION	MIXED	SETTLE	SECONDARY	ROAD	262.59	1KM+	1KM+	100M
NEPRIST	CONSERVATION	CONS	STREAM	UPLAND	STREAM	242.32	100M	100M	1KM+
NEWQUEBRA	BRAZILNUT	MIXED	STREAM	FLOOD	STREAM	223.58	100M	100M	1KM
NPRIMTRL	CONSERVATION	CONS	PRIMARY	UPLAND	TRAIL	252.20	1KM+	1KM+	1KM+
PIE100	ECOTOURISM	CONS	SECONDARY	UPLAND	TRAIL	256.02	1KM+	1KM	100M
PIE1KM	ECOTOURISM	CONS	PRIMARY	UPLAND	TRAIL	256.97	1KM+	1KM+	1KM
PIERVR	REFORESTATION	MIXED	RIVER	FLOOD	RIVER	237.14	1KM+	100M	1KM
PIERVRTRL	ECOTOURISM	CONS	PRIMARY	FLOOD	TRAIL	239.52	1KM+	1KM	1KM
RDCAM2	CONSERVATION	CONS	SECONDARY	SECONDARY	ROAD	265.66	1KM	1KM	100M
RDCAM3	BRAZILNUT	MIXED	SECONDARY	SECONDARY	ROAD	267.91	1KM	1KM	100M
RDCAM4	BRAZILNUT	MIXED	SECONDARY	SECONDARY	ROAD	287.18	1KM	1KM	100M
RVRAG	BRAZILNUT	MIXED	RIVER	FLOOD	RIVER	233.28	1KM+	100M	1KM+
RVRDB	CONSERVATION	MIXED	RIVER	SECONDARY	RIVER	236.16	1KM+	100M	1KM
RVRRONCHA	REFORESTATION	MIXED	RIVER	SECONDARY	RIVER	221.51	1KM+	100M	100M
SECRD	CONSERVATION	MIXED	SECONDARY	SECONDARY	ROAD	260.64	1KM+	1KM+	100M
SPRIMTRL	CONSERVATION	CONS	PRIMARY	UPLAND	TRAIL	269.32	1KM+	1KM+	1KM+
SPRIST	CONSERVATION	CONS	STREAM	UPLAND	STREAM	246.89	100M	100M	1KM+
STRM2	CONSERVATION	CONS	STREAM	SECONDARY	STREAM	253.49	100M	100M	1KM
STRM3	BRAZILNUT	MIXED	STREAM	SECONDARY	STREAM	262.24	100M	100M	1KM

Data Analyses

Roughly 15,000 images were sorted through for animal captures, and 1,716 entries were made in Microsoft Excel. Photos without animals were deleted, and those remaining were filtered to exclude photos of the same species at the same camera station within an hour period. This kept capture events independent, since some species like the pale-winged trumpeter (*Psophia leucoptera*) and the collared peccary (*Pecari tajacu*) would spend over an hour in front of one camera. For each capture, the camera station, camera, species, number of individuals, date, and time of day was recorded. A species code was generated for each animal, as well as a time code that split each day into six, four-hour periods.

Humans, domestic animals, non-terrestrial mammals, and birds were excluded from the data analyses, including small rodents, aquatic or riverine species, and primarily arboreal species. Capture frequencies were calculated for each animal captured throughout the study. Capture frequencies are equal to the number of photos per 1000 camera station days.

The characteristics of each tested environmental variable are listed in Table 2 above. Concessions within the study area included lands designated to conservation, ecotourism, brazil nut extraction, and reforestation. However, they are not representative of actual land use activities and land cover change. For instance, the lands classified as conservation and ecotourism are experiencing illegal selective logging and increased hunting pressure. The entire reforestation and conservation concessions on the east and southwest side of the river have been "invaded" and currently house over 100 agriculturalists and loggers; more than 60% of this land has been converted. Because of the disparity between title and use (see Figure 5 below), several new classifications were created to represent actual land use and land cover change within the study area.

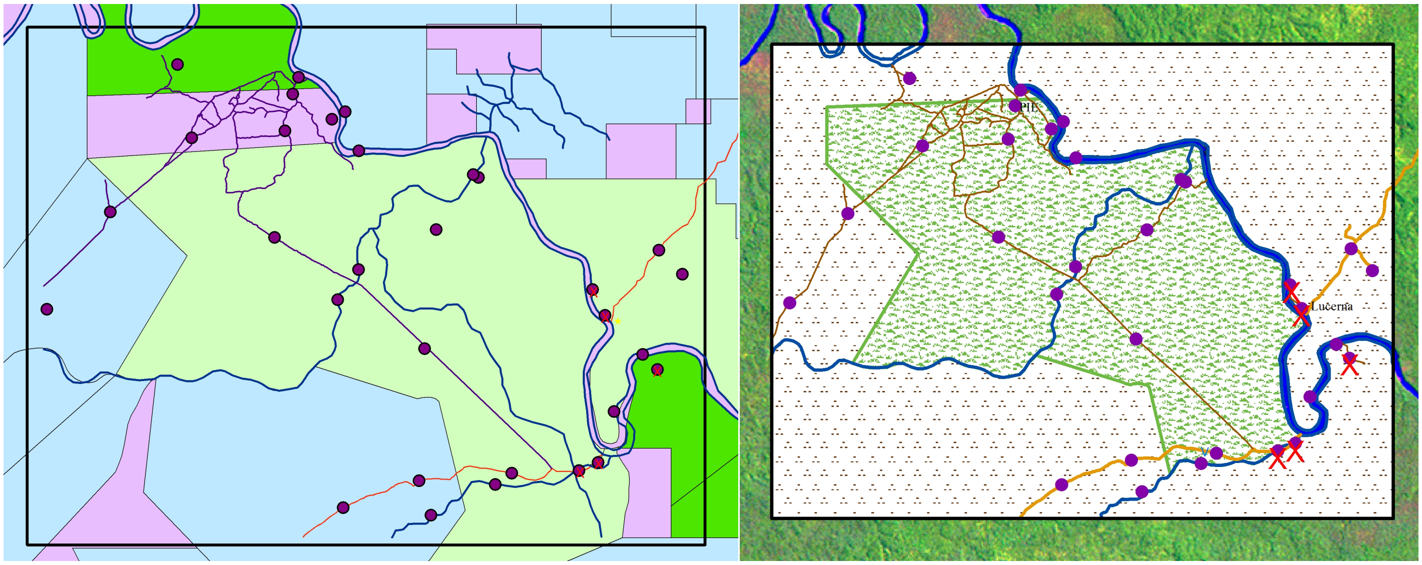


Figure 5. Comparison between a) concession type and b) true land use activity (conservation vs. mixed)

Land Use and Habitat Categories

The "Land Use" variable simply classified areas of the landscape as either conservation areas (CONS) or areas of mixed-use (MIXED). Conservation areas have low human presence, disturbance, and noise, and are being used primarily for research, ecotourism, or preservation purposes. Mixed-use areas are those with higher human presence and disturbance where activities including housing development, road development, farming, logging, and hunting are occurring. The "land cover" variable classified areas of the landscape according to their level of natural forest structure and composition. "Primary" forests represented healthy, closed-canopy forests with little to no historical selective logging. "Intact" forests were those that have been selectively logged in the past for their large, expensive hardwood trees such as Chihuahuaca and forest products are still extracted seasonally (i.e. brazil nuts). "Secondary" forests are those bordering human infrastructure that are currently experiencing selective logging and deforestation, in addition to increased human traffic. "settlement" areas are those irreversibly damaged or destroyed by conversion to agriculture, housing, or other infrastructure. Any cameras placed along main roads, in chakras, or other developed areas fell under this category. Finally, “river” and “stream” land cover types were excluded from analyses involving human impact or land cover because they do not accurately depict the presence of terrestrial mammals, the overall focal group of this study.

Habitat was categorized using in-situ observations and surveys as well as high-resolution aerial and satellite imagery. From the imagery, floodplain versus upland forests was easily identified, in addition to elevation data and changes in tree species composition. Cameras stations set up in forests that would be classified as “secondary” or “settlement” under the “land cover” variable were placed under the “secondary” habitat category to separate them from intact and primary upland or floodplain forests (areas of high habitat quality and diversity). The elevation of each camera was recorded and narrowed down to three categories for data analysis. Elevations lower than 240m were “low”, between 240m and 270m were “medium”, and above 271m were categorized as “high” elevations. The distance from human infrastructure (i.e. housing, roads, and chakras), streams, and all water sources (rivers and streams) was also calculated for each camera trap station and categorized as under 100m, between 101m and 1km, or over 1km.

Exploratory data analysis (EDA) methods and statistics were used to explore, analyze, and summarize the dataset of animal captures. One-way analysis of variance (ANOVA) was used to test the statistical significance among and between mammal groups and subsets, and the study’s key environmental variables. Tested groups included all mammals, all cats, big cats (jaguar and puma), jaguar, ocelot, all prey, IUCN threatened species, and threatened species of Peru. Linear regression ANOVA models were then used to analyze predator prey relationships amongst the environmental variables. All statistical models were run using the program R and RStudio.

In addition, all images and entries of felids were uploaded and entered into a program called Camera Base, an Access database designed by Matthias Tobler (2007) that manages camera trap survey data. The program can manage thousands of photos from different camera trap surveys and provide tools for a variety of data analyses including occupancy, diversity, density, activity patterns, and capture-recapture. The jaguar was the focal species of this study as a top predator, keystone, and indicator species in South America. Camera Base was used to generate an estimate for MMDM (mean maximum distance moved) and 1/2MMDM, which is the calculated average of the longest distance travelled by an individual jaguar. Inputs for the program DENSITY were also created using Camera Base. Texts files of capture data and station data were used to estimate jaguar densities using different buffer widths and estimators.

Results

Species Capture Frequencies

Out of the total 1,462 non-human animal captures made, 1,160 were included in the study, consisting of 23 medium and large-sized mammal species. The number of total captures and capture frequencies of all animals identified during the survey are shown in Table 3 below. Capture frequencies are equal to the number of photos per 1000 camera station days. Capture frequencies were also calculated for all identified small rodents, aquatic or riverine species, and primarily arboreal species excluded from the study, including spiny rat species (*Proechimys sp.*), mice (*Sigmodontinae sp.*), the tufted capuchin (*Cebus apella*), the Southern Amazonian red squirrel (*Sciurus spadiceus*), the capybara (*Hydrochoerus hydrochaeris*), and all listed bird species.

Table 3. Number of captures and capture frequency (number of photos/1000 camera station nights) for all species observed and their respective habitat (T, terrestrial; Ar, arboreal; Aq, aquatic). Species not included in the analysis[a]

Order/Family	Species	Common Name	Captures/Frequency	Habitat
Didelphimorphia Didelphidae	*Didelphis marsupialis*	Common opossum	99 (39.0)	T
Cingulata Dasypodidae	*Dasypus novemcinctus*	Nine-banded long-nosed armadillo	7 (2.8)	T
	Dasypus kappleri	Great long-nosed armadillo	1 (.4)	T
	Dasypus spp.	Long-nosed armadillo	2 (.8)	T
	Priodontes maximus	Giant Armadillo	8 (3.2)	T
Primates Cebidae	*Cebus apella*	Tufted capuchin	2 (.8)	Ar[a]
Carnivora Canidae	*Atelocynus microtis*	Short-eared dog	1 (.4)	T
	Speothos venaticus	Bush dog	3 (1.2)	T
Procyonidae	*Procyon cancrivorus*	Crab-eating raccoon	2 (.8)	T
Mustelidae	*Eira barbara*	Tayra	13 (5.1)	T
Felidae	*Puma yagouarundi*	Jaguarundi	2 (.8)	T
	Leopardus pardalis	Ocelot	135 (53.2)	T
	Leopardus wiedii	Margay	5 (2.0)	T, Ar
	Panthera onca	Jaguar	22 (8.7)	T
	Puma concolor	Puma	21 (8.3)	T
Perissodactyla Tapiridae	*Tapirus terrestris*	Lowland tapir	205 (80.7)	T
Artiodactyla Cervidae	*Mazama spp.*	Brocket deer	155 (61.0)	T
Tayassuidae	*Pecari tajacu*	Collared peccary	137 (54.0)	T
Rodentia Dasyproctidae	*Dasyprocta variegata*	Brown agouti	189 (74.4)	T
	Myoprocta pratti	Green acouchi	26 (10.2)	T
Sciuridae	*Sciurus spadiceus*	Southern Amazonian red squirrel	18 (7.1)	Ar[a]
Caviidae	*Hydrochoerus hydrochaeris*	Capybara	19 (7.5)	T, Aq[a]
Dinomyidae	*Dinomys branickii*	Pacarana	3 (1.2)	T
Cuniculidae	*Cuniculus paca*	Paca	103 (40.6)	T
Echimyidae	*Proechimys spp.*	Spiny rat	32 (12.6)	T[a]
Creditidae	*Sigmodontinae spp.*	Mouse	2 (.8)	T[a]
Lagomorpha Leporidae	*Sylvilagus brasiliensis*	Brazilian rabbit	1 (.4)	T
Class Aves	*Mitu tuberosa*	Razor-billed curassow	31 (12.2)	a
	Penelope jacquacu	Spix's guan	20 (7.9)	a
	Psophia leucoptera	Pale-winged trumpeter	155 (61.0)	a
	Ardea cocoi	Cocoi heron	6 (2.4)	a
	Buteogallus schistaceus	Slate-coloured hawk	1 (.4)	a
	Coragyps atratus	Black vulture	1 (.4)	a
	Harpia harpyja	Harpy eagle	1 (.4)	a

	Momotus momota	Blue-crowned motmot	3 (1.2)	a
	Ramphastos culminatus	Yellow-ridged Toucan	2 (.8)	a
	Tinamus major	Great tinamou	13 (5.1)	a
	Odontophorus spp.	Wood quail	7 (2.8)	a
	Monasa nigrifrons	Black-fronted nunbird	7 (2.8)	a
		Total Captures	1462	
		Included in Study	1160	
		All Mammals	25	
		Terrestrial Mammals	23	

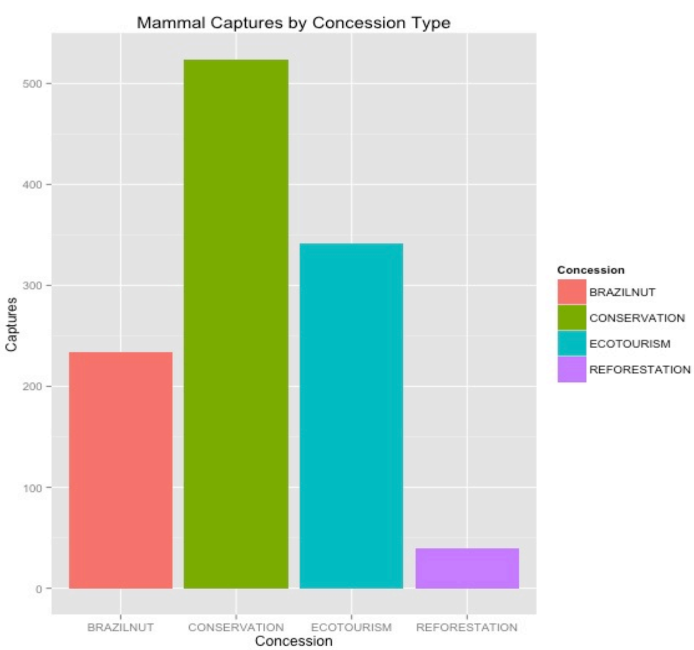
Environmental Characteristics Analysis

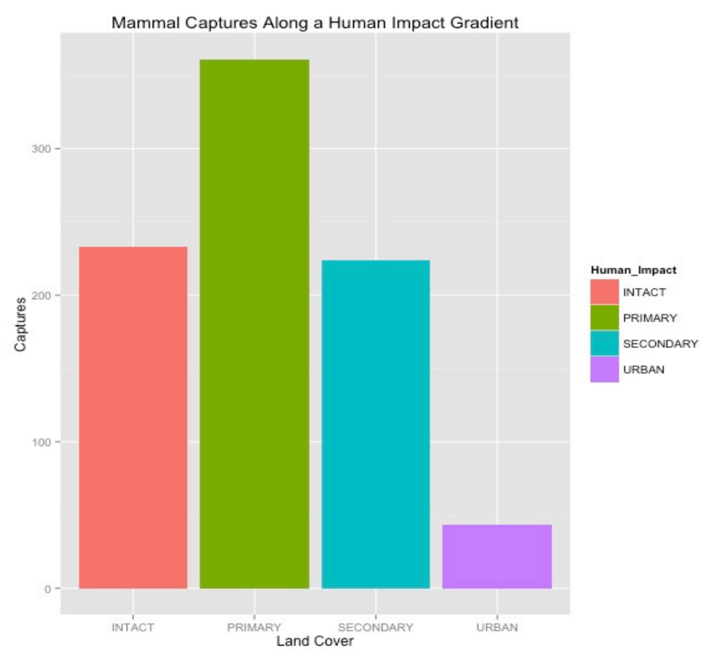
One-way analysis of variance (ANOVA) was used to test the statistical significance among and between mammal groups and subsets, and the study's key environmental variables. Tested groups included all mammals, all cats, big cats, jaguar, ocelot, all prey, IUCN threatened species, and threatened species of Peru. All non-felids were considered prey species to big cats (jaguar and puma), as they are diet generalists (Wallace et al. 2003; Zeilhofer et al. 2013). IUCN threatened species are those considered critically endangered, endangered, or vulnerable worldwide, and included the pacarana (*Dinomys branickii*), giant armadillo (*Priodontes maximus*), jaguar (*Panthera onca*), margay (*Leopardus wiedii*), short-eared dog (*Atelocynus microtis*), bush dog (*Speothos venaticus*), and lowland tapir (*Tapirus terrestris*). The list of threatened species in Peru differs only slightly; it includes all of the above IUCN threatened species plus the puma (*Puma concolor*) and ocelot (*Leopardus pardalis*). All environmental variables listed in Table 1 were tested against each group.

ANOVA test results (F- and p-values) are listed in Table 4. Out of the 80 tests ran in RStudio, 22 were found statistically significant, including the relationships between all mammals and concession type, land cover type, movement type, elevation, distance from streams, distance from water, and time of day, between all cats and elevation, between ocelot and elevation, between all prey and concession type, land use type, movement type, distance from streams, distance from water, and time of day, between IUCN threatened species and land use type, movement type, and distance from streams, and between the threatened species of Peru and both land use type and elevation. Graphs of the majority of statistically significant relationships can be found in Figures 6, 7, 8, 9, and 10 below.

Table 4. ANOVA F-values and p-value codes of significance from tested groups in relation to each environmental variable ('-' for not significant, '+' for 0.1, '*' for 0.01, '' for 0.001, and '***' for 0.0001)**

Group Tested	Concession		Land Use		Land Cover		Habitat		Movement		Elevation		Distance from Human Infrastructure		Distance from Streams		Distance from Water		Time of Day	
Value	F	p	F	p	F	p	F	p	F	p	F	p	F	p	F	p	F	p	F	p
All Mammals	3.13	*	2.69	+	7.15	***	1.05	-	2.63	*	5.84	**	0.86	-	7.08	***	2.37	*	4.97	***
All Cats	1.29	-	0.16	_	0.77	_	1.44	-	0.71	-	5.38	**	1.63	-	0.25	-	1.02	-	0.99	-
Big Cats	0.35	-	0.53	_	0.87	_	1.49	-	0.40	-	1.49	-	1.31	-	0.32	-	0.26	-	0.73	-
Jaguar	0.58	-	0.56	_	0.81	_	1.08	-	0.32	-	1.08	-	1.38	-	1.48	-	0.48	-	0.62	-
Ocelot	1.36	-	0.008	_	1.05	_	1.51	-	0.69	-	5.33	**	1.44	-	0.21	-	0.94	-	0.83	-
All Prey	2.65	*	3.63	*	6.60	***	1.65	-	2.48	*	4.88	**	0.50	-	8.86	***	2.50	*	4.59	***
IUCN Threatened	1.63	-	8.70	**	2.06	+	1.29	-	4.35	**	1.59	-	0.07	-	2.51	**	0.19	-	0.44	-
Threatened in Peru	1.86	-	5.50	*	0.07	-	0.69	-	1.73	-	3.15	*	0.67	-	2.15	-	0.10	-	0.55	-





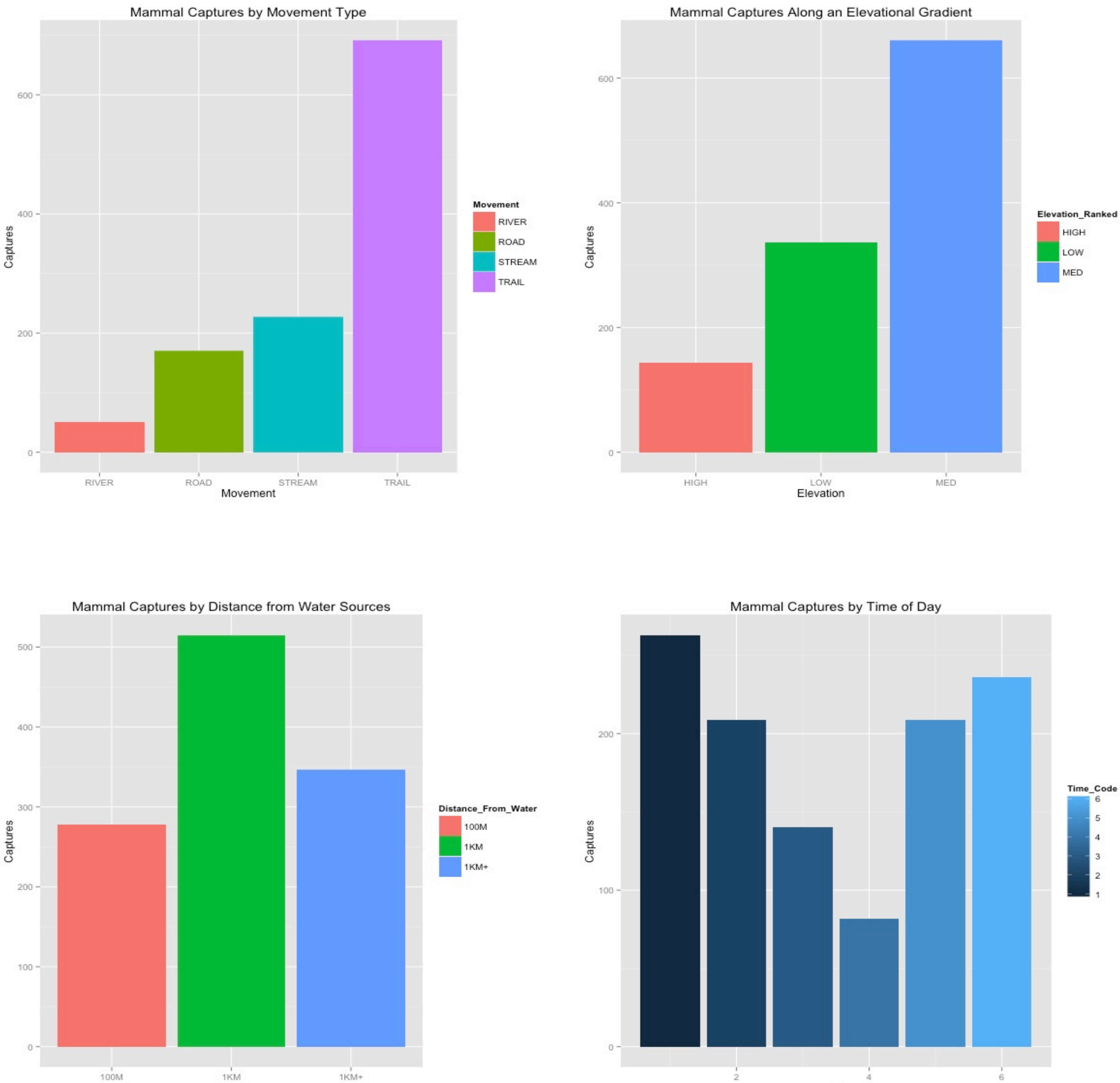


Figure 6. Statistically significant relationships between the number of mammal captures and a) concession type, b) land cover type, c) movement type, d) elevation, e) distance from water sources, and f) time of day

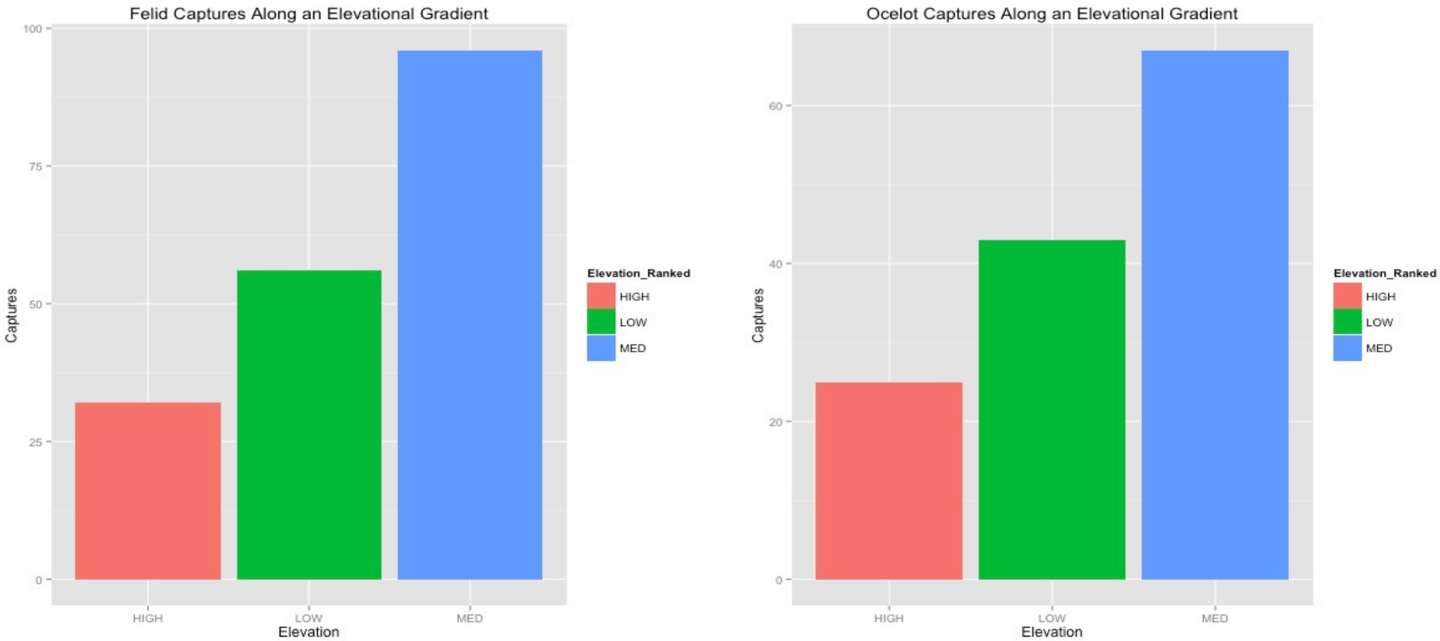
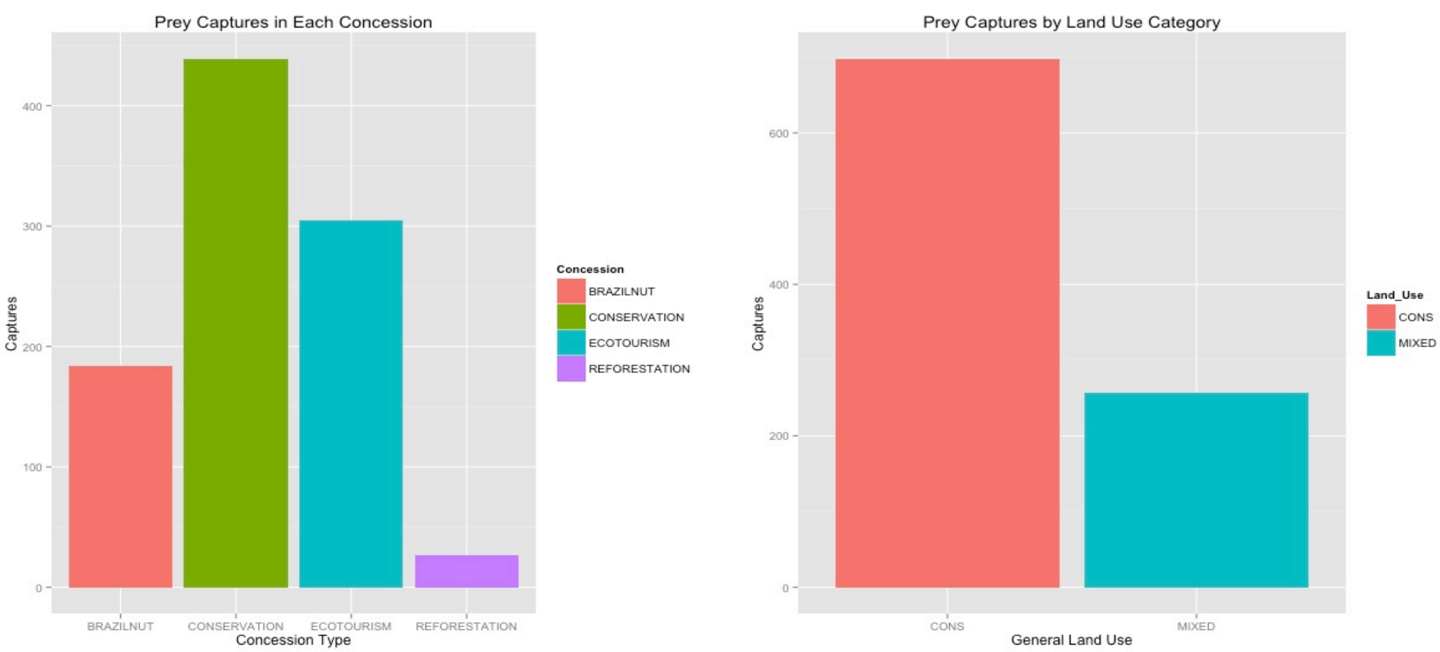


Figure 7. a) Felid captures and b) ocelot captures along a categorized elevational gradient



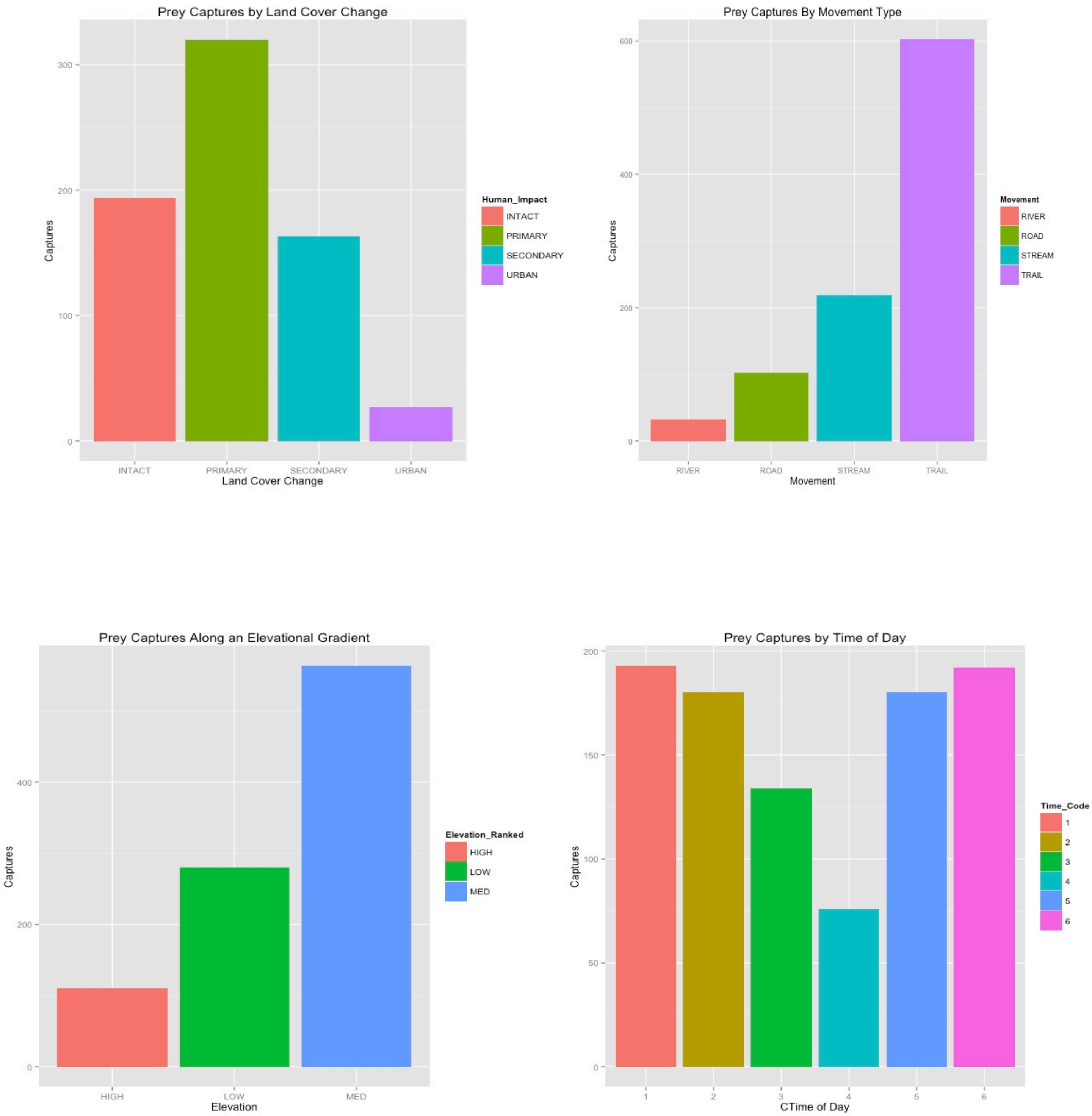


Figure 8. Statistically significant relationships between prey captures and a) concession type, b) general land uses, c) land cover type, d) movement type, e) elevation, and f) time of day

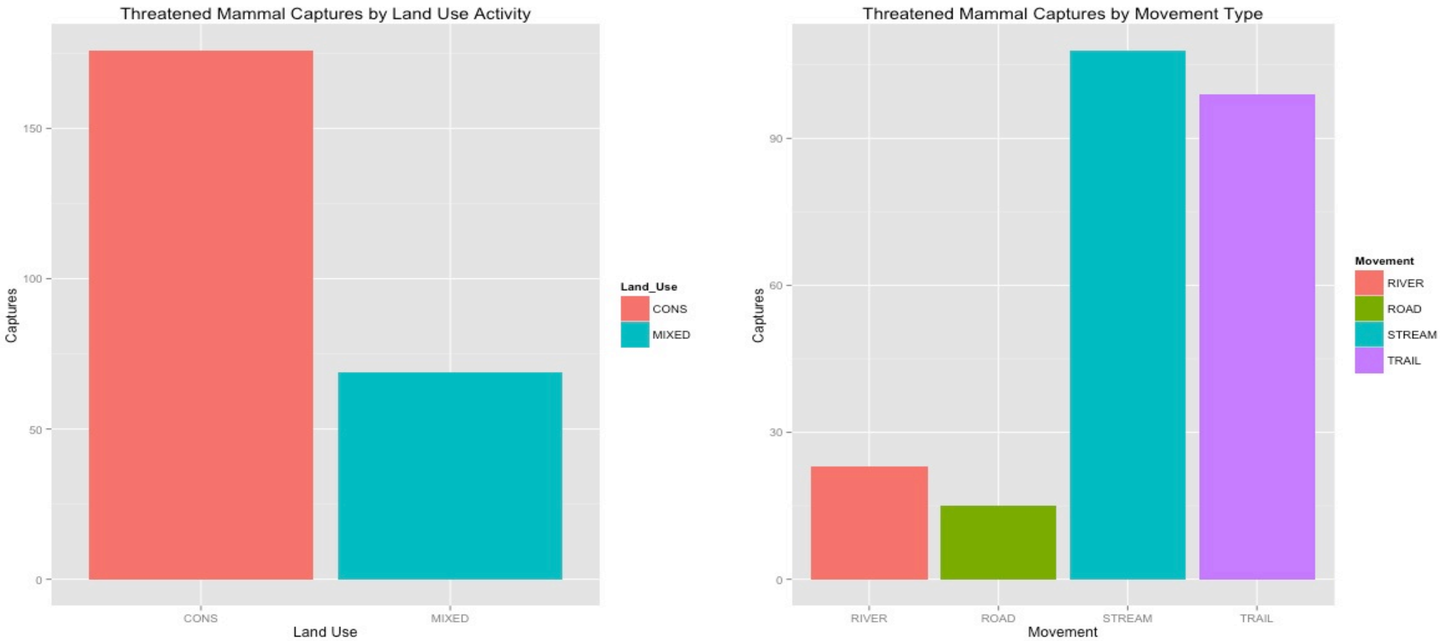


Figure 9. The relationship between IUCN globally threatened species and both a) general land use activity and b) movement type

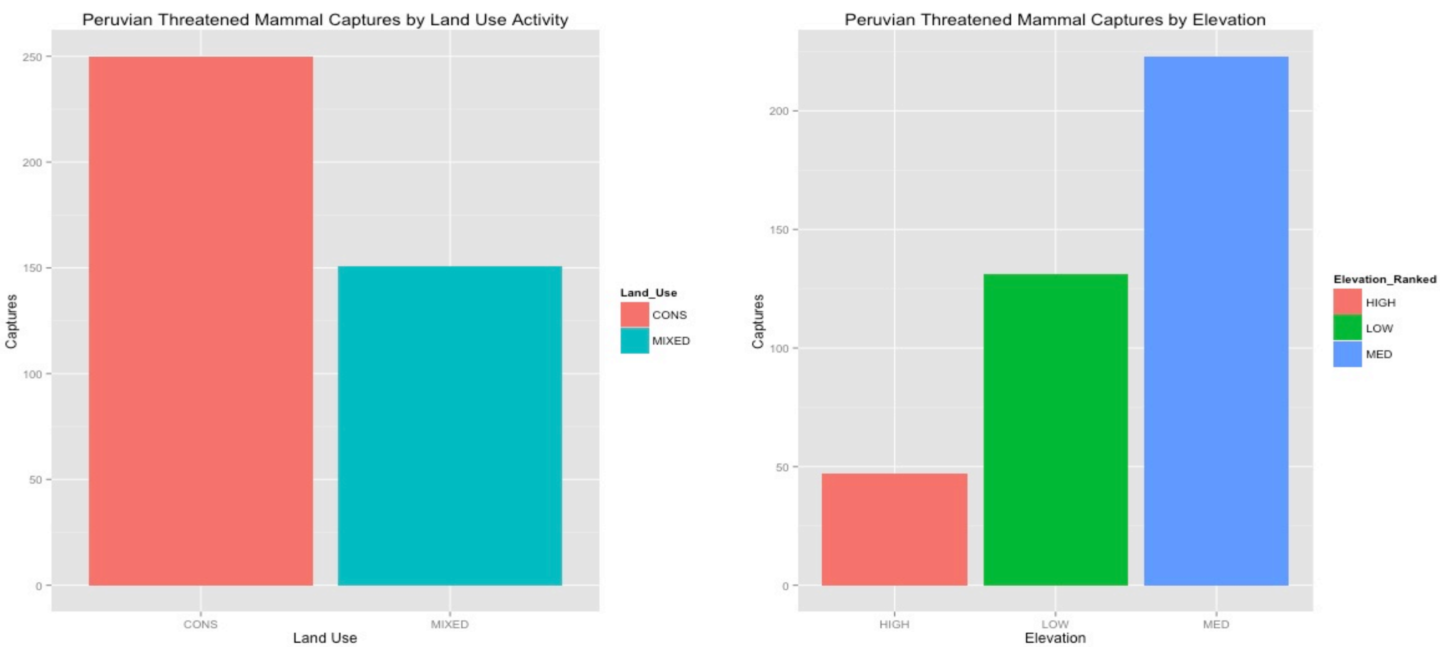


Figure 10. The relationship between threatened species of Peru and both a) general land use activity and b) categorized elevation

To assess the presence of predators in relation to their prey, the groups “big cats” and “all prey” were compared using a one-way ANOVA linear regression model. Captures of “big cats” was used as the dependent variable, while the independent or predictor variables were “all prey” plus each environmental characteristic. Testing aggregated captures by camera trap station of both predators and prey yielded the counts in Table 5 below. Figure 11 below shows the general negative correlation between big cat captures and prey captures.

Table 5. Aggregated counts of big cats (jaguar and puma) and prey species at each camera trap station and the corresponding environmental variable of each station

Camera	Big Cat Captures	Prey Captures	Concession	Land Use	Land Cover	Habitat	Movement	Elevation	Stream Dist.
1HNTTRL	6	53	CONSERVATION	CONS	INTACT	FLOOD	TRAIL	LOW	1KM
2HNTTRL	2	32	CONSERVATION	CONS	INTACT	FLOOD	TRAIL	LOW	1KM
BNTRL1	3	44	ECOTOURISM	CONS	PRIMARY	UPLAND	TRAIL	MED	1KM+
BNTRL2	2	40	BRAZILNUT	MIXED	INTACT	SECONDARY	TRAIL	HIGH	1KM+
BNTRL3	1	34	BRAZILNUT	MIXED	INTACT	SECONDARY	TRAIL	HIGH	1KM
LUCRD	1	26	CONSERVATION	MIXED	SETTLE	SECONDARY	ROAD	MED	1KM+
PIE1KM	2	62	ECOTOURISM	CONS	PRIMARY	UPLAND	TRAIL	MED	1KM+
PIERVRTRL	2	104	ECOTOURISM	CONS	PRIMARY	FLOOD	TRAIL	LOW	1KM+
RDCAM2	10	7	CONSERVATION	CONS	SECONDARY	SECONDARY	ROAD	MED	1KM
RDCAM3	3	31	BRAZILNUT	MIXED	SECONDARY	SECONDARY	ROAD	MED	1KM
RDCAM4	4	21	BRAZILNUT	MIXED	SECONDARY	SECONDARY	ROAD	HIGH	1KM
RVRAG	1	18	BRAZILNUT	MIXED	RIVER	FLOOD	RIVER	LOW	1KM+
SECRD	3	13	CONSERVATION	MIXED	SECONDARY	SECONDARY	ROAD	MED	1KM+
SPRIMTRL	1	40	CONSERVATION	CONS	PRIMARY	UPLAND	TRAIL	MED	1KM+
STRM2	2	94	CONSERVATION	CONS	STREAM	SECONDARY	STREAM	MED	100M

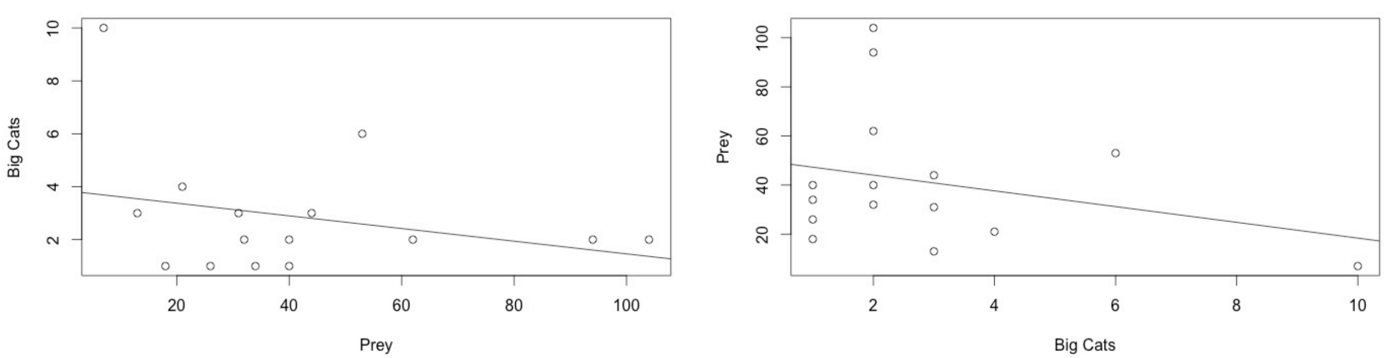


Figure 11. Negative linear relationship between the aggregated counts of big cats and prey by camera station

At an alpha equal to 0.1 and using an adjusted R-squared value, the linear model was found significant when relating predator presence to prey presence plus land use with a p-value of 0.0774, but this was the only statistically significant linear model. The results of these analyses are shown in Table 6 below. When switching the variables and using prey as the dependent variable, the analyses yielded overall smaller p-values with both linear models "big cats plus land use" and "big cats plus movement" being statistically significant ($p<0.1$). These values can be seen in Table 7 as compared to Table 6.

Table 6. Significance of one-way analysis of variance (ANOVA) comparing aggregated counts of big cats (dependent) to prey (independent) for each environmental variable

	R-squared	F-statistic	p-value
Concession	-0.048	0.786	0.527
Land Use	0.238	3.191	0.077
Land Cover	-0.113	0.763	0.619
Habitat	-0.145	0.408	0.750
Movement	-0.012	0.640	0.646
Elevation	-0.138	0.433	0.734
Stream Dist.	0.090	1.461	0.279

Table 7. Significance of one-way analysis of variance (ANOVA) comparing aggregated counts of prey (dependent) to big cats (independent) for each environmental variable

	R-squared	F-statistic	p-value
Concession	0.214	2.271	0.137
Land Use	0.400	5.675	0.018
Land Cover	0.351	2.623	0.115
Habitat	-0.072	0.685	0.580
Movement	0.454	3.910	0.037
Elevation	-0.079	0.657	0.595
Stream Dist.	-0.061	0.627	0.552

Density Estimates of Jaguar

Individual jaguars were identified using their unique coats. It was determined that the cameras captured eight different individual jaguars over the three-month survey. Two photos per capture were printed and compared visually, followed by closer examination using tools in Camera Base. Figure 12 shows the identification process and the different groups of individual jaguar photos created, while Table 8a provides a list of the eight jaguars captured and how many times they were captured. A mean maximum distance moved (MMDM), or home range diameter, of 3819 was generated by Camera Base, as well as a 1/2MMDM, or home range radius, of 1910 (Table 8b). Figure 13 shows an activity pattern graph for the jaguars with a focus on the individual named JAMESFRANCO.

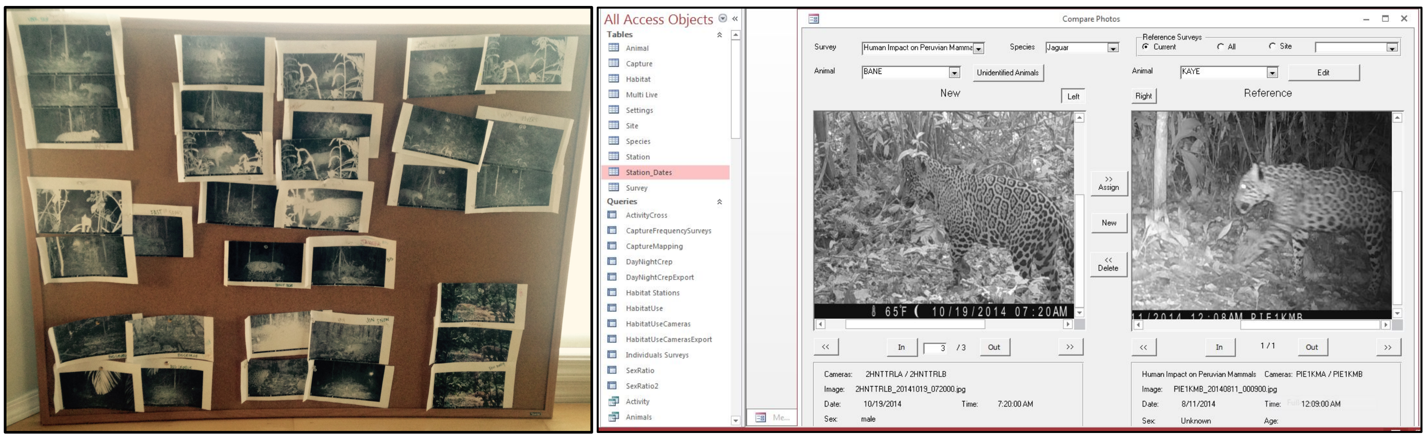


Figure 12. Comparison of jaguar photos a) from printed photos and b) in Camera Base to identify individuals

Table 8. a) Individually identified jaguars and their respective number of captures and b) MMDM and 1/2MMDM estimates generated from individual jaguar captures

Individual Jaguar	# of Captures
JAMESFRANCO	5
SEARS	4
BANE	3
MYERS	3
JONSNOW	2
KAYE	1
SKYLER	1
STEVENSON	1

Human Impact on Peruvian Mammals

Mean Maximum Distance Moved (MMDM) for Jaguar (Panthera onca)

Individual	Camera 1	Camera 2	X	Y
BANE	1HNTTRLA	1HNTTRLB	446127.1	8665427
BANE	2HNTTRLA	2HNTTRLB	445293.7	8664375
SKYLER	RDCAM4A	RDCAM4B	443435	8658812
MYERS	BNTRL1A	BNTRL1B	440394.9	8666218
MYERS	BNTRL2A	BNTRL2B	438767.7	8664726
JONSNOW	PIE1KMA	PIE1KMB	442252.3	8666369
JONSNOW	PIERVRTRLA	PIERVRTRLB	443204.7	8666591
JAMESFRANCO	BNTRL1A	BNTRL1B	440394.9	8666218
JAMESFRANCO	RDCAM2A	RDCAM2B	446795.2	8659487
JAMESFRANCO	RDCAM4A	RDCAM4B	443435	8658812
SEARS	LUCRDA	LUCRDB	449752.7	8663965
SEARS	RVRAGA	RVRAGB	445549.2	8665951
SEARS	SECRDA	SECRDB	450221.5	8663489
KAYE	PIE1KMA	PIE1KMB	442252.3	8666369
STEVENS	BNTRL1A	BNTRL1B	440394.9	8666218

Individual	N Stations	Max Distance
BANE	2	1342
SKYLER	1	0
MYERS	2	2208
JONSNOW	2	978
JAMESFRANCO	3	9288
SEARS	3	5281
KAYE	1	0
STEVENS	1	0

MMDM: 3819 S.E.: 1563
1/2 MMDM: 1910 S.E.: 781

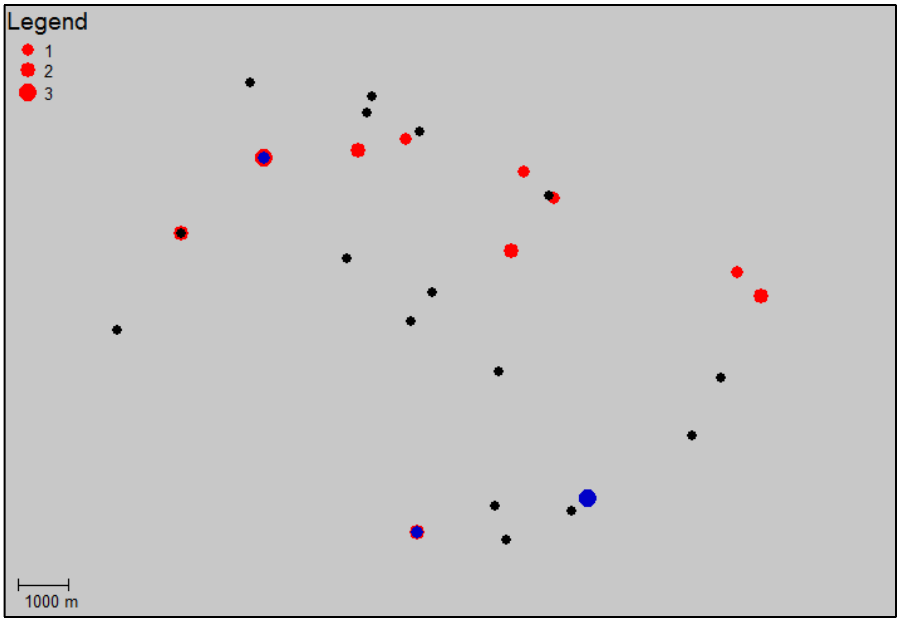


Figure 13. Activity pattern graph for jaguars with a focus on individual JAMESFRANCO

Spatially-explicit capture-recapture (SECR) is a newer method used for estimating density. It accounts for individual movement while using spatial information acquired from captures to estimate densities. A larger state-space is created that includes the grid or trapping area but allows for more realistic jaguar movements that are off-grid. SECR is then used to estimate the parameters related to the model of movement chosen and the number of activity centers within the state-space. These estimates are then translated into a density estimate.

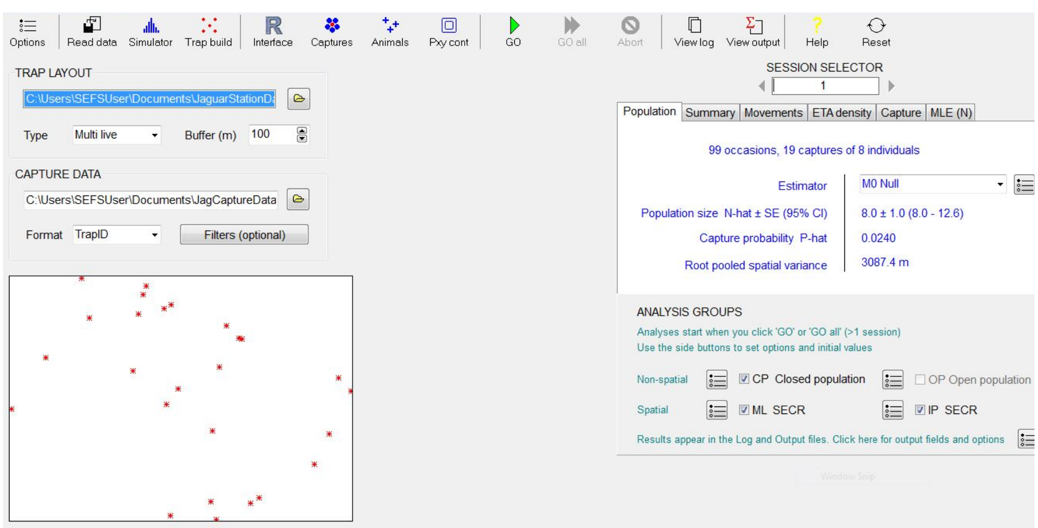


Figure 14. Screen capture of data analysis using the Windows program DENSITY

Capture data using the format TrapID and a trap layout using the multi live type and several buffer strips of different widths were used to estimate jaguar density in DENSITY (Efford, Dawson, & Robbins, 2004) (see Figure 14 above). Population data was recorded based on 99 occasions and 19 captures of 8 individual jaguars with a buffer width of either 100m or 3819m, a range that provided extremely different density estimates. In addition, using a conventional estimate versus a SECR method provided a range in jaguar density between 1.74 and 10.72 jaguars/sq km. An effective trapping area (ETA) of 242.387 sq km was used with a trap grid of 70.93 sq km.

Densities of jaguar were calculated using the software DENSITY with capture and data outputs created in Camera Base. Jaguar densities were heavily influenced by the boundary or buffer strip applied to the trapping area. The population data, irrespective of the buffer width chosen, was recorded, including the population size equation, capture probability, and root pooled spatial variance for each of the four estimators used.

Table 9 below describes each analysis group the estimators were paired with, two of which are spatially explicit. When using the MMDM of 3890 as the buffer width, density estimates were below 0.1 jaguars/sq km. However, when using a smaller buffer width of 100m, densities averaged 4 jaguars/sq km using conventional analysis (see Table 10 below) and approximately 10 jaguar/sq km using spatial analysis groups. The runs conducted using a 100m buffer width, all four estimators, and both spatial analysis groups (ML SECR and IP SECR) yielded the results in Table 11 below. Figure 15 shows the capture records and potential tracks of the recaptured jaguars with 1 km gridlines.

Table 9. Description of each analysis group tested

Analysis Group	Description
ETA Density	Conventional estimate of effective trap area by convex polygon and manual strip method
CP Closed population	Conventional closed population size
ML SECR	Closed population density estimated by maximum likelihood
IP SECR	Closed population density estimated by inverse prediction

Table 10. Conventional estimates of effective trapping area (ETA) and density using a convex polygon, MMDM, and a buffer width of 3819

Estimator	Density
# Caught	3.3
M0 Null	2.02-4.58
Mh Jackknife	1.74-5.05
Mh Chao	2.14-6.32
Mb Zippin	2.01-4.59

Table 11. Density estimates by estimator and analysis group using a buffer width of 100m

Estimator	Analysis Group	Density	g0	sigma
M0 Null	IP SECR	9.784	0.0023	2974.239
	ML SECR	10.714	0.0026	2778.635
Mh Jackknife	IP SECR	7.440	0.0030	3015.528
	ML SECR	10.712	0.0026	2799.067
Mh Chao	IP SECR	10.576	0.0020	2930.732
	ML SECR	10.713	0.0026	2778.635
Mb Zippin	IP SECR	20.823	-0.003	363.888
	ML SECR	10.711	0.0026	2802.386

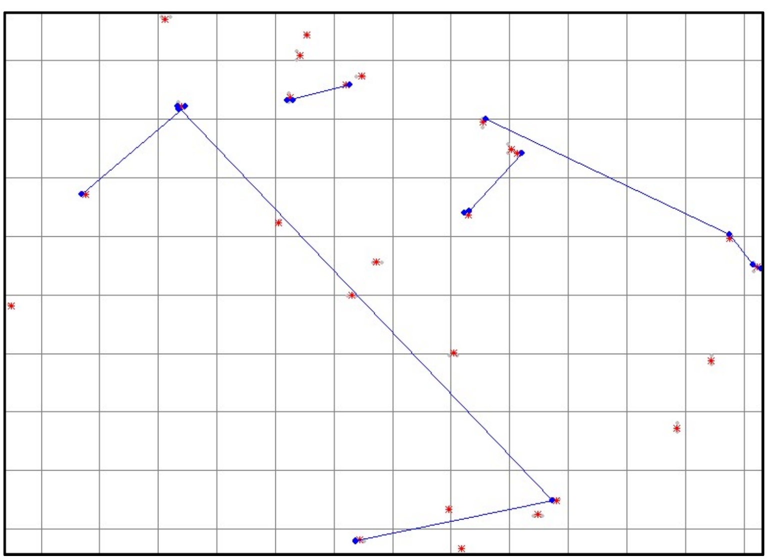


Figure 15. Capture records and potential tracks of recaptured jaguars with 1km grid lines generated in DENSITY

Discussion

Species Capture Frequencies

The camera trap survey captured 23 of 26 terrestrial mammal species known to occupy the study area, only excluding the coati (*Nasua nasua*), grison (*Galictis vittata*) and southern naked-tailed armadillo (*Cabassous unicinctus*). While the white-lipped peccary (*Tayassu pecari*) used to occur in the Piedras, the survey and a lack of in-situ observations over the past few years suggest they are now locally extinct. This species forms and travels in large herds, necessitating contiguous, extensive areas of habitat, without which local populations decrease and are overall more vulnerable to hunting (Cullen, Bodmer and Valladares-Padua 2000), suggesting that their local extinction may be a result of increased deforestation and hunting pressure. The giant anteater (*Myrmecophaga tridactyla*), now classified as vulnerable by the IUCN since 2010, has been absent from the Piedras Basin for several years. This is most likely due to the influx of people since Lucerna was established nine years ago, as giant anteaters are hunted for food, to make leather, as pests, for pets, or as part of the illegal wildlife trade (Ferreira *et al*. 2013). Primarily arboreal or aquatic species not captured during the survey included the collared anteater (*Tamandua tetradactyla*), Neotropical otter (*Lontra longicaudis*), Amazon weasel (*Mustela african*), and giant otter (*Pteronura brasiliensis*); the two otter species are known to now be locally extinct in many areas of the Amazon due to habitat destruction, water pollution, and continuous illegal hunting and trade (Alho *et al.* 1998; Duplaix et al. 2008).

Species with the highest number of captures and therefore the highest calculated capture frequency were the lowland tapir (*Tapirus terrestris)*, ocelot (*Leopardus pardalis)*, brocket deer (*Mazama sp.)*, collared peccary (*Pecari tajacu)*, and brown agouti (*Dasyprocta variegate)*. Rare and/or elusive species with very low capture frequencies (five or less captures) included the crab-eating raccoon (*Procyon cancrivorus),* Brazilian rabbit (*Sylvilagus brasiliensis*), jaguarondi (*Puma yagouarundi*), margay (*Leopardus wiedii*), pacarana (*Dinomys branickii*), and short-eared dog (*Atelocynus microtis)*, the latter three species of which are listed as vulnerable or near-threatened by the IUCN. Although not included in this study, the threatened and rarely seen harpy eagle (*Harpia harpyja*) was also captured along an intact forest stream (see Appendix A).

Overall, this camera trapping survey registered 88.5% of species known to occupy the study area. The coati (*Nasua nasua*), grison (*Galictis vittata*) and southern naked-tailed armadillo (*Cabassous unicinctus*) are all extremely rare and only known to be present by very few sightings over the past few years. The majority of camera trapping studies register between 57-86% of species; however, many had less camera trap nights than ours (Silveira et al., 2003; Srbek-Araujo & Garcia, 2005; Tobler et al., 2008). This study shows that it takes a substantial amount of camera trap nights to capture the rare and elusive species with low capture frequencies. The number of species captured is positively correlated with survey efforts, but in many cases levels off and extremely rare species sightings are not expected. Due to this, it is highly likely that 2,000 camera trap nights, rather than 2,539, would have been sufficient to capture all 23 terrestrial mammals.

Environmental Characteristics Analysis

The one-way analysis of variance (ANOVA) results comparing terrestrial mammals and mammal subsets to each key environmental variable illustrate which species and subsets are adapting to human-modified areas of the landscape and those that are rarely found outside of the higher quality, less disturbed habitat farther from human disturbance and activity.

When looking at all terrestrial mammals, 70.1% of captures were made in areas with land use activities falling under “conservation” as compared to “mixed”, 77.1% were in conservation and ecotourism concessions, 68.1% were in closed-canopy and intact forests as compared to secondary forests and settlement areas, 59.3% were along trails as compared to roads, rivers, and streams, 59.3% were at medium elevation (240m>medium<270m), 69.5% were within 1KM of a water source, and 75.7% were captured more than 1KM away from human infrastructure.

The only statistically significant relationship found for the subset "all cats" was in comparison to elevation (p=0.00542). As shown by Figure 7a, the majority of cat captures, 52.5%, were in areas of medium elevation, similar to the results of the entire dataset. Figure 7b shows a significant relationship between the ocelot subset and elevation as well, yielding a p-value of 0.00602 because 50% of ocelot captures were made in areas of medium elevation.

Eight statistically significant relationships were found for the prey subset, more than any group tested. Of total prey captures, 74.1% of captures were made in areas with land use activities falling under "conservation" as compared to "mixed", 79.1% in were in conservation and ecotourism concessions, 72.1% were in closed-canopy and intact forests as compared to secondary forests and settlement areas, 61.7% were along trails as compared to roads, rivers, and streams, 60.7% were at medium elevation, 70.6% were within 1KM of a water source, and 60.4% were captured between the hours of 8pm and 8am.

The last two subsets, IUCN threatened species and threatened species in the country of Peru, had important, statistically significant relationships considering both groups include the majority of, or all of, the cats species found in this region that have shown to use all parts of the landscape. Of total IUCN threatened species captures, 73.6% of captures were made in areas with land use activities falling under "conservation" as compared to "mixed", 84.5% were in closed-canopy and intact forests as compared to secondary forests and settlement areas, 66.0% were within 1KM of a stream, and 86.0% were along trails or streams as compared to roads and rivers. With the inclusion of puma and especially ocelot in the "threatened species of Peru" subset, less significant relationships were seen. Of all captures, 63.5% of captures were made in areas with land use activities falling under "conservation" as compared to "mixed", and 56.5% were at medium elevation.

In addition to the ANOVA results, several observations were made about threatened species in the region or species that are known to be rare and elusive. Of 35 captures of rare and elusive species, 24 (68.6%) were made in "conservation" lands, and only 8 captures (22.9%) were made in areas of settlement or secondary land cover. Of the 401 total captures of rare, elusive and/or threatened species (including cats), 256 (63.8%) were made in "conservation" lands, and only 85 captures (21.2%) were made in areas of settlement or secondary land cover with a higher human impact. All captures of the crab-eating raccoon, Brazilian rabbit, bush dog, jaguarondi, harpy eagle, and giant armadillo were made solely in areas with land use activities falling under the "conservation" category. All captures of the bush dog, short-eared dog, pacarana, crab-eating raccoon, and harpy eagle were made at least 1KM from human infrastructure and activity, solely in either intact or primary rainforest habitat.

Density Estimates of Jaguar

Accurate jaguar density estimates remain scarce despite several published studies over the last ten years. This is mainly due to an overall lack of understanding of jaguar ecology and behavior, but also due to a lack of funds and resources necessary to carry out camera trapping studies that are comprehensive enough. Previous studies by Soisalo and Cavalcanti (2006) and Tobler and Powell (2013) explain in detail the variability and problems that can occur when using camera trap data to estimate jaguar densities. Some problems include camera failure, small study area size, small sample sizes, low capture probabilities, and the misidentification of individual cats (Foster and Harmsen, 2012; Tobler and Powell, 2013). The size of the study area, number of camera trap stations, and identification of individual jaguars plays a huge role in creating the DENSITY inputs, as well as the boundary or buffer strip.

Many studies have an insufficient number of camera trap stations and studies areas that are too small to fully encompass the home range of local jaguars, which is necessary to calculate the jaguar density of that region. In addition, correctly identifying each jaguar is crucial, as their individual movements directly create the MMDM and 1/2MMDM values used as buffers during analysis. This study was designed to gather data on the presence and abundance of all terrestrial mammals in a variety of habitats at varying levels of human impact. It was not designed with solely density estimation in mind. To accurately estimate jaguar density, the study site would be approximately 300 sq km, with 100 camera stations placed in a grid 1-2 km apart along trails and roads. This size and number of cameras would result in more jaguar captures and more accurate density estimates.

Considering the layout of this camera trap survey, the suggested estimator Jackknife Mh was was the best fit model and Finding 8 individual jaguars in a 150 sq km site that is undergoing increasing human impact and modification is promising.

Conclusion

The Piedras River Basin represents a mosaic of habitat patches at several levels. Land cover is diverse and heterogeneous across the landscape, and is under constant transformation due to seasonality changes and land use activities. It was assumed that forest structure and composition as well as the scale of human impact would affect terrestrial mammal presence and movement across the landscape, especially considering that animal spacing and movement is heavily influenced by resource distribution (Mitchell and Powell 2004; Ostfeld 1990). This camera trapping survey confirmed that environmental variables such as land use activities, distance from human infrastructure, and habitat type and quality have a significant influence on terrestrial mammal diversity, occupancy and movement, especially threatened species or those considered as prey. In order to predict the effects of habitat and land use change on faunal distributions, understanding how animals move through and use an environment is a crucial step.

The statistical analyses of all four felid subsets including “all cats”, “big cats”, “jaguar”, and “ocelot” suggest that felids are not as affected by human disturbance and land cover change. This was an expected outcome given that cats, especially jaguar, are known as diet and habitat generalists, occupying a variety of habitats including tropical forest, tropical savannas, dry scrub forests, montane forests, cerrado regions, and mangroves and preying upon any animal within its range (Wallace et al. 2003; Zeilhofer et al. 2014). In addition, studies have shown that the percentage of natural vegetation lost cannot accurately predict habitat suitability for carnivores. According to Carvalho (2009) and Zeilhofer (2014), it is the type and intensity of land use that has a complex impact on carnivore presence in deforested landscapes. For instance, felid species in the Piedras are consistently found traveling logging roads and through chakras, and are known to prey upon domestic livestock such as chickens. In Brazil, domestic livestock predation is a common occurrence that increases the human-wildlife conflict and persecution of jaguar, and is an issue requiring active management and conservation methods in these areas (Silveira et al. 2008).

Perhaps the most influential results were those of the IUCN Red List of Threatened Species and those species most threatened in Peru. Even with the inclusion of adaptive generalists like the jaguar, the subset of IUCN listed species was primarily captured in conservation lands, and avoided secondary forests and infrastructure like roads, mainly traveling through the landscape via trails and streams. The pacarana in particular, a rarely seen species listed as vulnerable by the IUCN, was captured twice in a stream and once in the intact forests of the brazil nut concession, rendering both necessary habitat to preserve this species in the Piedras.

The global decline in earth's biodiversity of flora and fauna has many causes, but deforestation and fragmentation are universal and rapidly increasing. For South American mammals, habitat loss and degradation is the largest threat, followed by direct persecution (Kelt and Meserve 2014). The Amazon's lowland tropical rainforests is rich in flora and fauna biodiversity, home to over 400 species of mammals, 170 of which are endemic to the Amazon rainforest (Mares 1992; Alho, Reis & Seixas 2002; Robles Gil et al. 2002). The Piedras River Basin is especially unique given its species richness and diversity, but also its position and conservation potential in the region. It is located between Manú National Park, Tambopata National Reserve, and Alto Purus National Park, three famous and well-protected biodiversity hotspots (see Figure 17 below).

Figure 16. The Piedras study region, situated between three protected biodiversity hotspots

Based on the diversity, abundance, and density of wildlife shown by this camera trapping survey, it is clear that the larger mammals such as jaguar are moving between the parks using the Piedras as somewhat of a corridor. The viability and quality of this corridor over time, however, is not secure. As road networks are created and people continue to immigrate farther into the lowland rainforests, the future of a protected corridor or park becomes less feasible and less necessary as wildlife populations decrease.

This study provides a terrestrial mammal inventory and respective capture frequencies for the unprotected lower Piedras region. Although initial density estimates of jaguar were made, further research aimed solely at obtaining accurate density measurements of felids is still needed. With current research and information about wildlife populations and vulnerability, local governments are more likely to take an interest in conservation management and the enforced protection of forests. Sustainability through subsistence agriculture and the strategic extraction of forest products is achievable, and it is mutually beneficial for both the wildlife and local communities of the Piedras that the forests and soils remain healthy and intact. In conclusion, improving local livelihoods and ecosystem integrity concurrently to prevent irreversible destruction in the Piedras would serve as a global example for sustainable land management and the natural resource conservation.

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Appendix A

Tayra (*Eira Barbara)*

Harpy Eagle (*Harpia harpyja*)

Lowland Tapir (*Tapirus terrestris)*

Short-eared Dog (*Atelocynus microtis)*

Puma (*Puma concolor*)

Ocelot (*Leopardus pardalis)*

Jaguarondi (*Puma yagouarundi)*

Jaguar (*Panthera onca*)

Capybara (*Hydrochoerus hydrochaeris)*

Razor-billed curassow (*Mitu tuberosa)*

Bush Dog (*Speothos venaticus*)

Giant Armadillo (*Priodontes maximus)*