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Survey of medium-sized and large mammals of Piedras Blancas National Park, Costa Rica

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Abstract
Piedras Blancas National Park, in southern Costa Rica, is an important component of two biological corridors connecting the Osa Peninsula (Corcovado National Park) and La Amistad International Park. Understanding the mammal community composition of Piedras Blancas will provide baseline data to evaluate the success of conservation efforts. We used camera traps and opportunistic observations to describe the medium-sized and large mammals of the park. We deployed camera traps for 1,440 trap nights (2016-2018). We detected 19 mammal species from seven orders and 13 families. Five species are globally threatened: *Leopardus wiedii* (Schinz, 1821), *Saimiri oerstedii* (Linnaeus, 1758), *Ateles geoffroyi* (Kuhl, 1820), *Alouatta palliata* (Gray, 1849), and *Tapirus bairdii* (Gill, 1865). We did not detect two locally threatened species, *Panthera onca* (Linnaeus, 1758) and *Tayassu pecari* (Link, 1795). Our research highlights a need for critical conservation work within the proposed biological corridor to support Costa Rica's most threatened wildlife.

Keywords
Baird's tapir, camera trap survey, conservation biology, endangered species, Osa Peninsula, Jaguar, wildlife monitoring.

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Introduction

Mesoamerica is considered one of Earth's important biodiversity hotspots, hosting an impressive number of biomes, life zones, and eco-regions (Rivera et al. 2002; Mittermeier et al. 2004). However, it has experienced relatively high rates of deforsestation in its western pacific lowland forests over the past century (Guppy 1984; Myers 1993; Mittermeier et al. 2004). Protected areas, such as national parks, have been shown to play an important role in conserving biodiversity and mitigating the impacts of human development and disturbance (Guppy 1984; Bruner et al. 2001; Sánchez-Azofeifa et al. 2003; Nepstad et al. 2006), although small or isolated areas are less effective. One way to enhance biodiversity conservation for small or isolated protected areas is by ensuring connectivity between multiple protected areas (Bennett 1998). Biological corridors

maintain connectivity between isolated habitats, ensuring genetic connectivity and maintenance of metapopulation dynamics.

Among Mesoamerican countries, Costa Rica is seen as a leader in conservation, largely due to its numerous protected areas which cover approximately 26% of the country (Gonzáles-Maya et al. 2016). Piedras Blancas National Park is located on the Pacific coast, at the base of the Osa Peninsula, in southern Costa Rica. Piedras Blancas is a relatively small protected area located at the junction of two biological corridors, the Osa and AMITOSA biological corridors, connecting Corcovado National Park and La Amistad International Park (Fig. 1).

Corcovado and La Amistad represent important local biodiversity hotspots. For example, Corcovado is considered a critical habitat for Jaguars within Costa Rica (SINAC 2018) and a stronghold for Costa Rica's most threatened megafauna (Carrillo et al. 2000; Foerster and Vaughan 2002; Fuller et al. 2002; Salom-Pérez et al. 2007). The persistence of one of the oldest wild Jaguars within Corcovado National Park, highlights the quality of habitat and its importance in Jaguar conservation (Olson et al. 2019). Corcovado, however, is relatively isolated and over the long-term cannot support its mammal community without adequate connectivity (González-Maya et al. 2016).

Similarly, La Amistad International Park, located in the central mountainous region of eastern Costa Rica, is known to support a large variety of terrestrial mammals, including populations of Jaguar and Baird's Tapir (González-Maya et al. 2008, 2009, 2012, 2015; SINAC 2018). Since the mid-20th century, however, areas adjacent to these parks have experienced rapid population growth and human development (Carrillo et al. 2000; Weissenhofer et al. 2008). Development of the lands between Corcovado and La Amistad has already contributed to the isolation of their mammal populations (Bennett 1998; Sánchez-Azofeifa et al. 2003; Gonzáles-Maya et al. 2016).

Given the context of human development on the Osa peninsula, the establishment of connectivity between Corcovado and La Amistad has been identified as critical for biodiversity conservation in the region (Bennet 1998; González-Maya et al. 2016). The functionality of this system of protected areas and biological corridors to connect populations of vulnerable mammal species could play an important role in the long-term persistence of these species in the Osa region (Shaffer 2010). Because Piedras Blancas sits at the crux of the system of protected areas and biological corridors, monitoring the mammal species in Piedras Blancas is a critical step in determining the efficacy of the proposed system

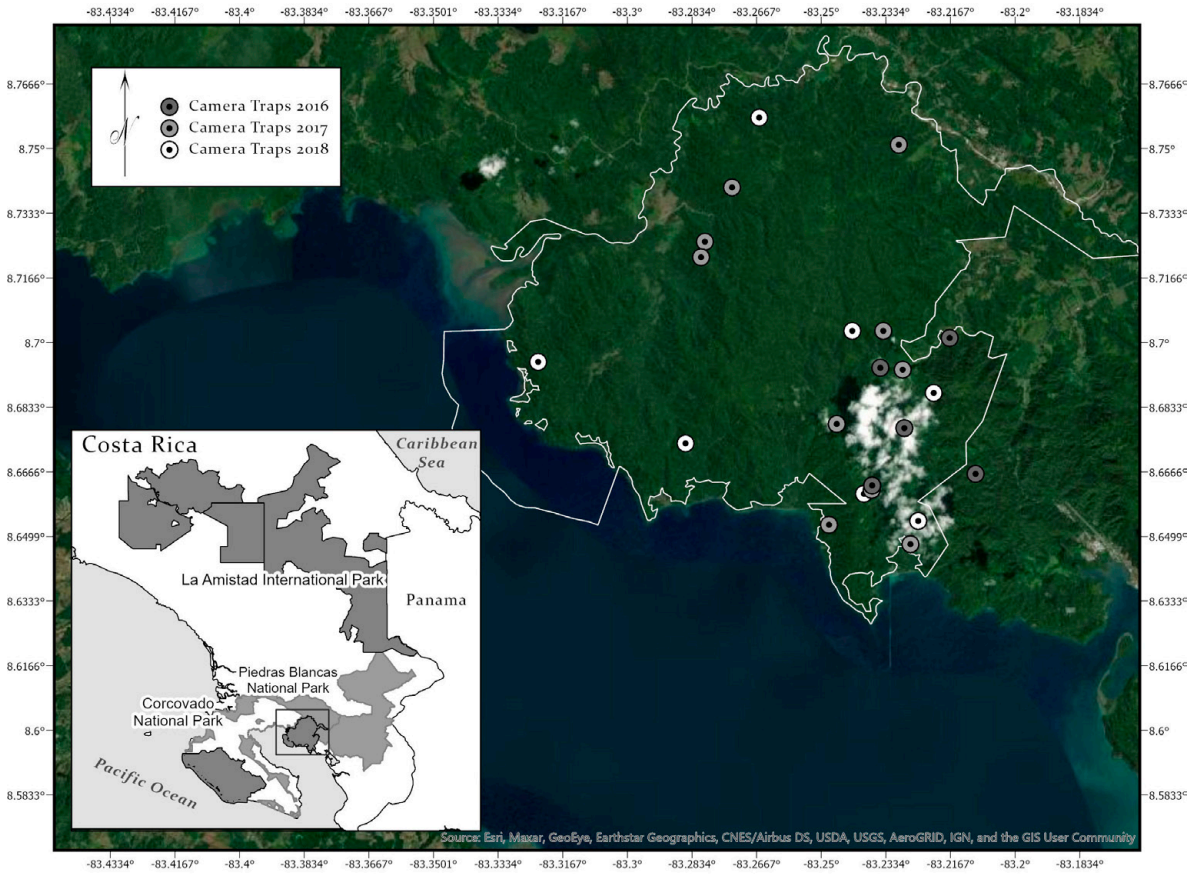

Figure 1. Camera trap station locations for 2016, 2017, and 2018 in Piedras Blancas National Park, Costa Rica. Inset map shows the location of Piedras Blancas National Park relative to La Amistad International Park and Corcovado National Park. The Osa and AMITOSA biological corridors are also displayed.

of biological corridors and assessing the effectiveness of conservation activities. Mammal records for Piedras Blancas are relatively limited but remain crucial for biodiversity conservation within the Osa region.

A preliminary list of mammal species for Piedras Blancas was created by Landmann et al. (2008) in 2004, using a combination of interviews with local experts, tracking, camera trap surveys, and live and kill trapping methods. Field data from this study, however, was mainly taken in a six km^2 area on the eastern edge of the park, and camera traps were only deployed for 155 trap nights and detected only seven medium-sized to large mammal species. The monitoring methods employed by Landmann et al. (2008) spanned a short period of time (28 days) and were primarily focused on small and medium-sized mammals.

Camera traps are known to be a precise and efficient method of detecting elusive and cryptic medium-sized and large mammals (Silveira et al. 2003; Lyra-Jorge et al. 2008). Therefore, expanding the geographic coverage and intensifying camera trapping efforts in Piedras Blancas has the potential to improve and update our understanding of the status of medium-sized and large mammals throughout the park; allowing conservationists the opportunity to better assess the efficacy and effectiveness of the biological corridors. Thus, we aimed to provide a list of medium-sized and large mammals in Piedras Blancas National Park.

Methods

Study area. Piedras Blancas National Park covers a 148 km^2 tract of land located near the town of Golfito, in the Puntarenas province of southern Costa Rica, between latitudes 8.6193 and 8.7756 and longitudes −083.1824 and −083.2380 (Fig. 1). The park is in the tropical wet forest life-zone, as defined by Holdridge et al. (1971), and stretches from sea level to 579 m of elevation at the top of Cerro Nicuesa (Gonzáles 1999). The nearby town of Golfito receives about 571 mm of rain in the wet season (May through mid-November) and 251 mm of rain in the dry season (mid-November through April) on average. Mean annual temperature is 26.6 °C and 27 °C in the wet and dry seasons, respectively (IMN 2016). A system of biological corridors connects Piedras Blancas to Corcovado National Park (~50 km to the southwest) and La Amistad International Park (~60 km to the north).

Data collection. We installed five to seven cameras for each sampling season, between April and November in 2016, 2017, and 2018. In 2017, all five cameras were subsequently moved to new locations after approximately 90 days to improve the spatial coverage of our survey. The number of cameras, brand, number of camera stations, and amount of time deployed varied from year-to-year (Table 1). We installed cameras in unpaired camera stations spaced between 1.6 and 3.4 km apart at roughly 1 m above ground, and adjacent to the trail (Fig. 1) (Olson et al. 2017, 2018, 2019). Depending on site layout, we angled cameras diagonally down the trail to increase capture rates for elusive or fast species. No bait or lures were used in this study.

Locally, we placed cameras in areas with relatively high abundance of wildlife sign. We programmed camera traps to record time, date, temperature, and moon phase for each photo. We also programmed them to take a burst of three photographs with a less than one second interval between each photograph, and no refractory period (i.e., rapid-fire) between events (Apps and McNutt 2018). We defined an event as any photo-series of a species, and we considered multiple photographs of the same individual(s) within 30 min to be the same event (O'Brien et al. 2003; Naing et al. 2015). Cameras operated 24 hours a day.

Geographic location of each camera trap was recorded with a Garmin eTrex® 20 Global Positioning System (GPS) unit (Schaffhausen, Switzerland). Because primarily arboreal species are difficult to detect using traditional terrestrial camera trapping methods (Olson et al. 2012), we also recorded all arboreal mammal observations while walking to camera stations in 2018. We recorded species, group size, distance, and angle when primates were encountered. Transects and primate sightings were recorded with a handheld GPS unit. We used these observations and other opportunistic observations of wildlife while doing fieldwork to further inform our species list.

Statistical analysis. Species were identified based on Wainwright and Arias 2007. We assessed the adequacy of our sampling effort to describe the mammal community of Piedras Blancas over time using species-effort curves for each year. Curves were created using the Vegan package (Oksanen et al. 2019) with R software (version 3.5.2; R Core Team 2018). We also calculated the frequency of occurrence for each species, which represents the proportion of camera stations, in that year, where a species was detected. Additionally, we calculated the relative abundance index (RAI) for all species as: RAI = $(E/TN) \times 1000$, where E is the number of events and TN is the total number of trap nights. We used *RAI* because it is considered an accurate index of

Table 1. Sample dates, camera types, and number of cameras and camera stations used in each sample year. Reconyx Hyperfire PC800s manufactured in Holmen, WI, USA. Bushnell Aggressor's Manufactured in Hebron, IL, USA.

Year	Installation date	Removal date	Camera type	No. of cameras	Camera stations	Trap nights
2016	16-Jun.	19-Sep.	Reconyx Hyperfire PC800	5	5	410
2017	22-Apr.	1-Sep.	Reconyx Hyperfire PC800	5	10	296
2018	18-Apr.	2-Nov.	Reconyx Hyperfire PC800, Bushnell Aggressor	7 (4,3)	7	734

abundance for some species (Parsons et al. 2017; Palmer et al. 2018). Finally, taxonomic data were used to qualitatively assess the functional diversity of Piedras Blancas and determine if any major functional groups were absent.

Results

Our methods resulted in a survey effort of 410, 296, and 734 trap nights for 2016, 2017, and 2018, respectively. The combined sampling effort resulted in 1440 trap-nights.

Table 2. Species list of medium- to large-sized mammals recorded in Piedras Blancas National Park, Costa Rica. Conservation status according to IUCN Red List (2019). Status Abbreviations: LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered, DD = Data Deficient.

Taxon	Common name	IUCN listing	No. of records
Artiodactyla			
Cervidae			
Mazama temama	Red Brocket Deer	DD	13
Tayassuidae			
Pecari tajacu	Collared Peccary	LC	194
Carnivora			
Felidae			
Herpailurus yagoroundi	Jaguarundi	LC	1
Leopardus pardalis	Ocelot	LC	29
Leopardus wiedii	Margay	NT	4
Puma concolor	Puma	LC	31
Mustelidae			
Eira barbara	Tayra	LC	36
Procyonidae			
Nasua narica	White-Nosed Coati	LC	83
Procyon lotor	Northern Raccoon	LC	5
Cingulata			
Dasypodidae			
Dasypus novemcinctus	Nine-Banded Armadillo	LC	35
Didelphimorphia			
Didelphidae			
Didelphis marsupialis	Common Opossum	LC	11
Perissodactyla			
Tapiridae			
Tapirus bairdii	Baird's Tapir	EN	1
Pilosa			
Myrmecophagidae			
Tamandua mexicana	Northern Tamandua	LC	15
Primates			
Atelidae			
Alouatta palliata	Mantled Howler Monkey	VU	1
Ateles geoffroyi	Geoffroy's Spider Monkey	EN	1
Cebidae			
Cebus capucinus	Central American White-faced Capuchin	LC	3
Saimiri oerstedii	Central American Squirrel Monkey	VU	3
Rodentia			
Cuniculidae			
Cuniculus paca	Lowland Paca	LC	52
Dasyproctidae			
Dasyprocta punctata	Central American Agouti	LC	486

We also recorded observations of primates over approximately 60 km during the 2018 field effort. We detected six groups of primates representing three species. Additionally, we incorporated two opportunistic observations of two species of wildlife, *Alouatta palliata* (Gray, 1849) and *Tapirus bairdii* (Gill, 1865), detected neither during our camera trap nor our primate surveys (J. Noguera pers. comm.). With this sampling effort, we identified 19 medium-sized and large mammal species belonging to seven orders and 13 families in Piedras Blancas National Park (Table 2, Fig. 2).

The richest order was Carnivora, with seven species, followed by Primates with four species, Artiodactyla and Rodentia with two, and Cingulata, Pilosa, Didelphimorphia, and Perissodactyla with one. Based on camera trap data alone, the species with the highest number of records for the three years surveyed were *Dasyprocta punctata* (Gray, 1842) with 486 records, and *Pecari tajacu* (Linnaeus, 1758) with 194 records (Fig. 3). In 2016, *D. punctata*, *P. tajacu*, *Eira barbara* (Linnaeus, 1758), *Nasua narica* (Linnaeus, 1766), and *Cuniculus paca* (Linnaeus, 1766) were recorded at all five camera stations (Fig. 3). In 2017 the highest frequency of occurrence was *D. punctata*, recorded at nine of the 10 camera stations, followed by *P. tajacu* recorded at six of the 10 camera stations (Fig. 3). We recorded *D. punctata*, *P. tajacu*, and *N. narica* at all seven camera stations in 2018 (Fig. 3).

Species accumulation curves began to reach an asymptote by the end of the sampling period, indicating that our sampling design was adequate for assessing the terrestrial, medium-sized and large mammal community in each year. However, the longer sampling period in 2018 (~ 200 days) resulted in a relatively more reliable assessment of the medium-sized to large mammal community. Additionally, both the combined species accumulation curve and the curves representing each of the three sampling years indicated that the community was adequately sampled after approximately 80 days (Fig. 4).

While most species were identified by camera trap images, the arboreal species, mainly primates, were primarily recorded visually while walking to camera stations. Roughly 60 km of transects were walked during the 2018 field effort. Six groups of primates were identified on these transects. These sightings included one instance of *Ateles geoffroyi* (Kuhl, 1820) (one group of two adults), two instances of *Cebus capucinus* (Thomas, 1903) (two groups, with three and five adults, respectively) and three instances of *Saimiri oerstedii* (Linnaeus, 1758) (three groups; group one = one adult, group two = two adults, group three = 10 adults and two juveniles). We did not detect *Alouatta palliata* during our observational transects in 2018, but *A. palliata* presence in Piedras Blancas was confirmed via opportunistic observation (J. Noguera pers. comm.). Additionally, presence of *Tapirus bairdii* in the park was confirmed via tracks (J. Noguera pers. comm.).

Five of the species recorded are threatened globally: *Alouatta palliata* (Vulnerable), *Saimiri oerstedii*

(Vulnerable), *Ateles geoffroyi* (Endangered), *Leopardus wiedii* (Near Threatened), and *Tapirus bairdii* (Endangered) (Cuaron et al. 2008; Wong et al. 2008; de Oliveira et al. 2015; Garcia et al. 2016; Cortes-Ortíz et al., 2020). *Mazama temama* is listed as Data Deficient by the International Union for the Conservation of Nature (IUCN) (Bello et al. 2016). All other species are listed as least concern (IUCN 2020).

Overall, Piedras Blancas appears to have a relatively high functional diversity. Several large and meso-predators were detected including: *Puma concolor* (Linnaeus, 1771), *Leopardus pardalis* (Linnaeus, 1758), *Leopardus wiedii* (Schinz, 1821), *Herpailurus yagouaroundi* (E. Geoffroy Saint-Hilaire, 1803), and *Eira barbara*. A diverse prey base was also present, including *Mazama temama* (Erxleben, 1777) and *Pecari tajacu*, and many smaller herbivores and omnivores such as *Dasyprocta punctata*, *Cuniculus paca*, *Nasua narica*, *Didelphis*

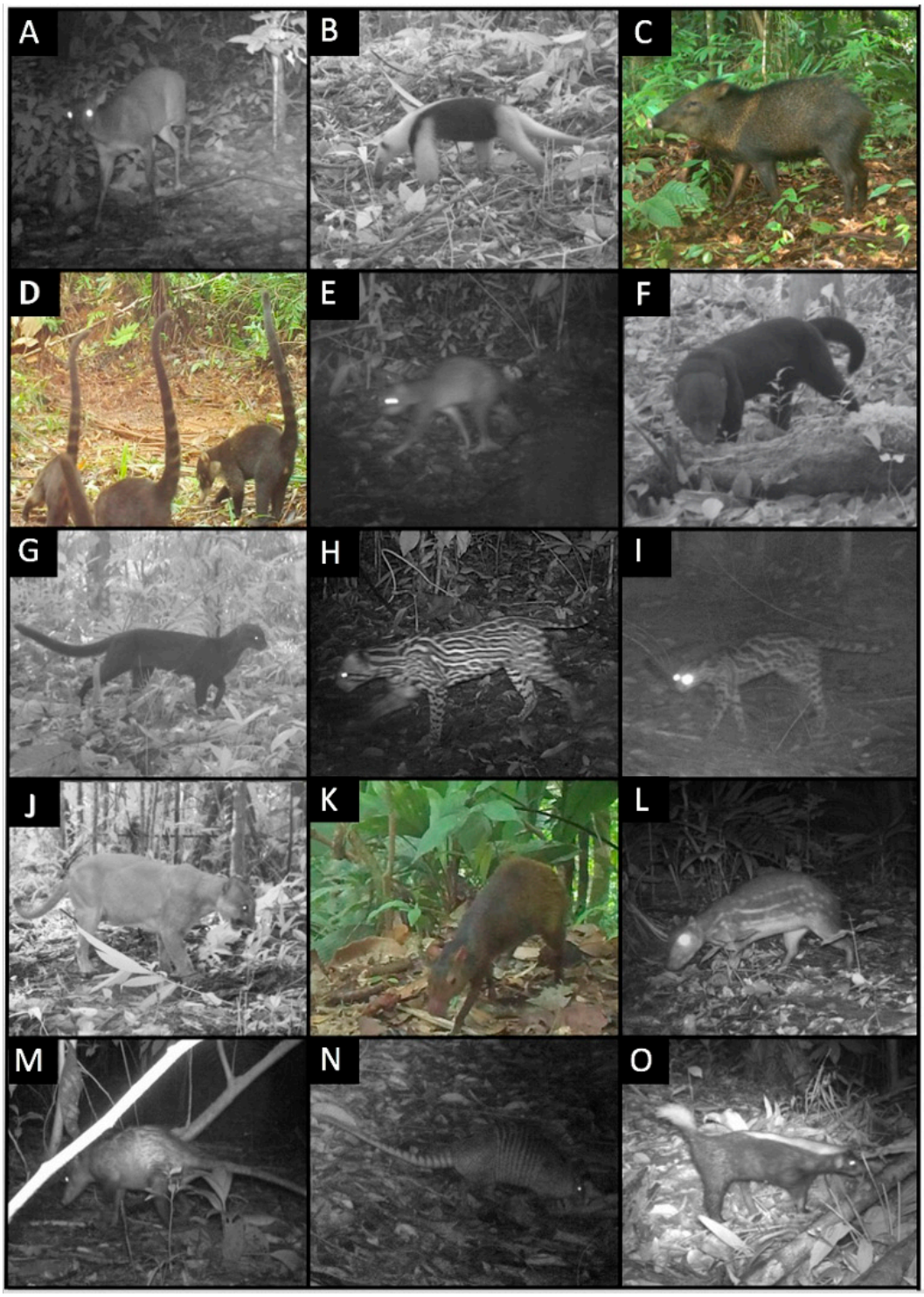

Figure 2. Photographic records of mammal species recorded with camera traps in Piedras Blancas National Park, Costa Rica. **A.** *Mazama temama*. **B.** *Tamandua mexicana*. **C.** *Pecari tajacu* **D.** *Nasua narica*. **E.** *Procyon lotor*. **F.** *Eira barbara*. **G.** *Herpailurus yagoroundi*. **H.** *Leopardus pardalis*. **I.** *Leopardus wiedii*. **J.** *Puma concolor*. **K.** *Dasyprocta punctata*. **L.** *Agouti paca*. **M.** *Didelphis marsupialis*. **N.** *Dasypus novemcinctus*. **O.** *Conepatus semistriatus*.

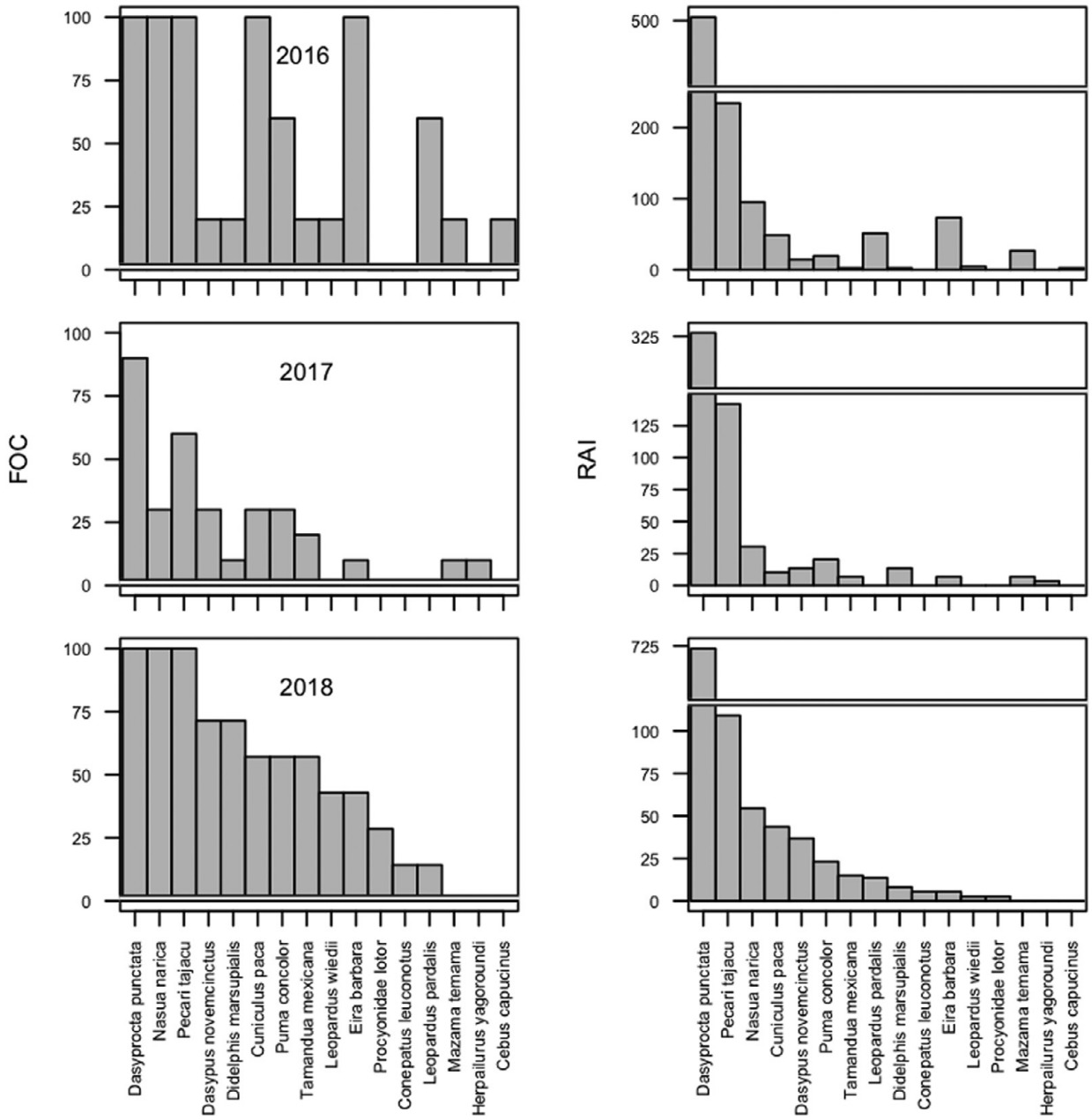

Figure 3. Frequency of occurrence (FOC) and relative abundance index (RAI) for medium-sized to large mammals of Piedras Blancas National Park of Costa Rica in 2016, 2017, and 2018.

marsupialis (Linnaeus, 1758), and *Tamandua mexicana* (Saussure, 1860).

Mazama temama (Erxleben, 1777)

Figure 2A

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; stations ID 1,15 (Table 3); first capture on 18 June 2016; camera trap photos.

Identification. The Central American Red Brocket is a small, reddish-brown deer. There are no markings present on the face (Wainwright and Arias 2007). May be confused with the White-tailed Deer (*Odocoileus virginianus* Zimmermann, 1780). *Mazama temama* is considerably smaller and lacks the facial markings of *O. virginianus*.

Tamandua mexicana (Saussure, 1860)

Figure 2B

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; stations ID 3–4, 13, 15–16, 18, 20 (Table 3); first capture on 9 July 2016; camera trap photos.

Identification. The Northern Tamandua is the only species of its genus in Central America (Hall 1981). It has a golden-brown coat and a prehensile tail. It folds claws of the forefeet inward when walking (Wainwright and Arias 2007).

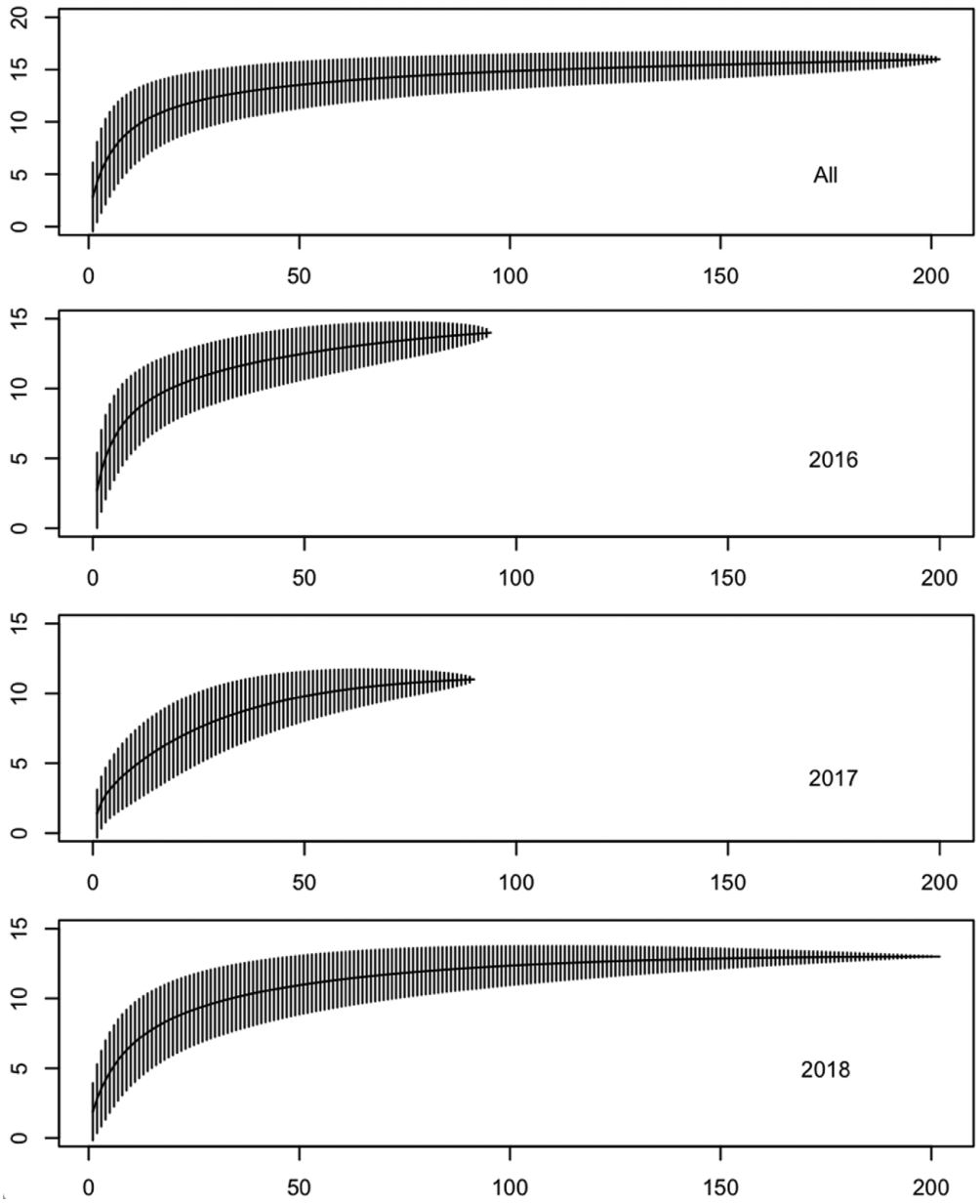

Figure 4. Species accumulation curves for medium-sized to large mammals in Piedras Blancas National Park, Costa Rica for all years, 2016, 2017, and 2018.

***Pecari tajacu* (Linnaeus, 1758)**
Figure 2C

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; stations ID 1–7, 10–13, 15–17, 19–22 (Table 3); first capture on 23 June 2016; camera trap photos.

Identification. The Collared Peccary is a medium-sized mammal with a dark gray coat, a large triangular head, and a pig-like snout. *Pecari tajacu* can be distinguished from the similar *Tayassu peccari* (Link, 1795) by its pale tan collar that stretches from the top of the shoulder to the back of the cheek (Wainwright and Arias 2007).

***Nasua narica* (Linnaeus, 1766)**
Figure 2D

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; stations ID 1–7, 12, 17, 19, 21–22 (Table 3); first capture on 18 June 2016; camera trap photos.

Identification. The White-nosed Coati has a dark coat overall with some light frosting on the shoulders. The most distinct features are the long muzzle and tail. The tail has a variable ring pattern and is often held vertically (Wainwright and Arias 2007). This is the only species of Coati in Costa Rica.

***Procyon lotor* (Linnaeus, 1758)**
Figure 2E

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; 08.701, −083.216; station ID 5 (Table 3); first capture on 11 Aug. 2016; camera trap photo.

Identification. The Northern Raccoon is predominantly dark brown with a short, banded, bushy tail, and pale

Table 3. Camera stations and geographic coordinates.

Station ID	Year	Latitude	Longitude	Installation Date
1	2016	08.678	−083.228	16 Jun.
2	2016	08.666	−083.209	16 Jun.
3	2016	08.662	−083.238	17 Jun.
4	2016	08.693	−083.234	17 Jun.
5	2016	08.701	−083.216	18 Jun.
6	2017	08.693	−083.229	22 Apr.
7	2017	08.662	−083.237	5 Jul.
8	2017	08.653	−083.248	19 Mar.
9	2017	08.751	−083.230	29 Mar.
10	2017	08.726	−083.280	15 Apr.
11	2017	08.703	−083.234	22 Jul.
12	2017	08.740	−083.273	27 Jul.
13	2017	08.679	−083.246	14 Jul.
14	2017	08.722	−083.281	26 Jul.
15	2017	08.648	−083.227	23 Jul.
16	2018	08.687	−083.221	30 May
17	2018	08.661	−083.239	31 May
18	2018	08.654	−083.225	22 May
19	2018	08.703	−083.242	24 May
20	2018	08.758	−083.266	21 Apr.
21	2018	08.674	−083.285	18 Apr.
22	2018	08.695	−083.323	18 Apr.

legs and feet. The black mask on its face is more extensive than the Crab-eating Raccoon, for which the Northern Raccoon can be easily mistaken (Wainwright and Arias 2007).

***Eira barbara* (Linnaeus, 1758)**
Figure 2F

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; stations ID 1–5, 11, 19–21 (Table 3); first capture on 20 June 2016; camera trap photos.

Identification. The Tayra is a large, long-legged mustelid, all dark except for a slightly paler head and a cream-colored patch on the throat. It is easily distinguished from similar species (Jaguarundi and Neotropical River Otter) by its dark bushy tail (Wainwright and Arias 2007).

***Herpailurus yagouaroundi* (E. Geoffroy Saint-Hilaire, 1803)**
Figure 2G

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; stations ID 12, 17 (Table 3); first capture on 31 July 2017; camera trap photos.

Identification. The Jaguarundi is a small, weasel-like felid that varies in color from black, to brownish-gray, to reddish-brown. The black Jaguarundi can look similar to *Eira barbara* but can be distinguished by the thin tail and lack of a white patch on the throat (Wainwright and Arias 2007). The only Jaguarundi found in this study was reddish-brown.

***Leopardus pardalis* (Linnaeus, 1758)**
Figure 2H

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; stations ID 1, 3, 5, 16–17, 19–21 (Table 3); first capture on 19 June 2016; camera trap photos.

Identification. The Ocelot is a medium-sized spotted cat. The only other species it may be confused with is *L. wiedii*, but *L. pardalis* is larger and has a proportionately shorter tail, roughly 45% of the head and body length (Wainwright and Arias 2007).

***Leopardus wiedii* (Schinz, 1821)**
Figure 2I

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; stations ID 3, 17, 20 (Table 3); first capture on 21 June 2016; camera trap photos.

Identification. The Margay is a small to medium-sized spotted cat. It may be confused with *L. pardalis* but can be distinguished by its proportionately longer tail (70% of head and body length) and muzzle. *Leopardus wiedii* also has proportionately larger eyes and forefeet, and is largely arboreal (Wainwright and Arias 2007).

***Puma concolor* (Linnaeus, 1771)**
Figure 2J

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; stations ID 2–4, 7, 11, 13,17, 19, 21 (Table 3); first capture on 16 July 2016; camera trap photos.

Identification. The Puma is a large cat that varies in color from pale to reddish brown. Puma often have black and white facial markings and a black tip on the tail (Wainwright and Arias 2007). It may be confused with the reddish-brown *Herpailurus yagouaroundi* but is considerably larger.

***Dasyprocta punctata* (Gray, 1842)**
Figure 2K

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; stations ID 1–7, 9–22 (Table 3); first capture on 18 June 2016; camera trap photos.

Identification. The Central American agouti is a medium-sized rodent that varies in color from reddish-brown to orangey-brown or yellowish-brown. Additionally, *D. punctata* have small ears and resemble ungulates when they move. They can be distinguished from *Cuniculus paca* (Linnaeus, 1766) by their lack of white spots and smaller size (Wainwright and Arias 2007).

***Cuniculus paca* (Linnaeus, 1766)**
Figure 2L

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; stations ID 1–5, 11,

13, 15, 17, 21, 22 (Table 3); first capture on 25 June 2016; camera trap photos.

Identification. The Paca is a large reddish-brown rodent with white spotting along the body. It is similar in morphology to *Dasyprocta punctata* but can be distinguished by both its size and the presence of white spotting (Wainwright and Arias 2007).

***Didelphis marsupialis* (Linnaeus, 1758)**
Figure 2M

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; stations ID 15, 17–19, 21 (Table 3); first capture on 4 July 2016; camera trap photos.

Identification. The Common Opossum is identified by its shaggy gray guard hairs and its pale underfur. Its cheeks are a dirty yellow color and its whiskers are black. The tail is black and white, the white portion often being longer than the black. The Virginia Opossum (*Didelphis virginiana* (Kerr, 1792) looks very similar to *D. marsupialis* but is not present in the southern portion of Costa Rica (Wainwright and Arias 2007).

***Dasypus novemcinctus* (Linnaeus, 1758)**
Figure 2N

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; stations ID 3, 6, 12, 13, 16, 17, 19–21 (Table 3); first capture on 26 June 2016; camera trap photos.

Identification. The Nine-banded Armadillo has an armored body with 8 or 9 scutes. It is distinguished from the Northern Armadillo (*Cabassous centralis* Miller, 1899) by its long snout, narrow ears, armored tail, and noticeably arched carapace (Wainwright and Arias 2007).

***Conepatus semistriatus* (Boddaer, 1785)**
Figure 2O

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; 08.703, −083.242; station ID 19 (Table 3); first capture on 6 April 2018; camera trap photo.

Identification. The Striped Hog-nosed Skunk is a small black skunk with a white, bushy tail and two distinctive white stripes that run along the top of the back, connecting on top of the head (Wainwright and Arias 2007). The white stripes easily distinguish this skunk species from the Spotted Skunk (*Spilogale putorius* Linnaeus, 1758).

***Cebus capucinus* (Thomas, 1903)**

Material examined. COSTA RICA • 3 adults; Puntarenas Province, Piedras Blancas National Park; 08.671, −083.234; first recorded on 22 May 2018; MRW Beal observation.

Identification. The White-throated Capuchin Monkey is a medium-sized primate with a pink face surrounded by cream colored fur on the chest and shoulders. The rest of the body is covered in black fur (Wainwright and Arias 2007). This species cannot be confused with other primate species in the region.

***Saimiri oerstedii* (Linnaeus, 1758)**

Materials Examined. COSTA RICA • 1 adult; Puntarenas Province; Piedras Blancas National Park; 08.708, −083.185; first recorded on 29 May 2018; MRW Beal observation.

Identification. The Central American Squirrel Monkey is a small primate easily distinguished from other primate species by its black cap, white face, and orange-brown fur. It does not have a prehensile tail and will often travel in groups of between 20 and 70 individuals (Wainwright and Arias 2007). This species is not easily confused with other primate species in the region.

***Ateles geoffroyi* (Kuhl, 1820)**

Material Examined. COSTA RICA • 2 adults; Puntarenas Province, Piedras Blancas National Park; 08.701, −083.231; first recorded on 29 May 2018; MRW Beal observation.

Identification. The Central American Spider Monkey is a medium-sized primate. It is distinguished from other species by its cream-reddish-black body with very long, darker-colored limbs and a proportionately small head. Additionally, a pinkish mask of skin can be seen around the eyes and muzzle (Wainwright and Arias 2007). This species is not easily confused with other primate species in the region.

***Alouatta palliata* (Gray, 1849)**

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; J. Noguera opportunistic observation.

Identification. The Mantled Howler Monkey is a medium-sized primate with dark fur and a reddish colored mantle on its sides. Males have white testicles, and both males and females have beards (Wainwright and Arias 2007).

***Tapirus bairdii* (Gill, 1865)**

Material examined. COSTA RICA • Puntarenas Province, Piedras Blancas National Park; J. Noguera opportunistic observation.

Identification. Baird's Tapir is a large mammal with a trunk-like nose and a short tail. Their tracks show three triangular toe prints. Young are striped and spotted (Wainwright and Arias, 2007).

Discussion

Our study recorded 19 species of medium-sized and large mammals in Piedras Blancas National Park. We identified four of the five felid species previously found on the Osa Peninsula, one of which (*Leopardus wiedii*) is categorized as Near Threatened by the IUCN (de Oliveira

et al. 2015). Additionally, we identified the Mantled Howler Monkey (*Alouatta palliata*), the Central American Squirrel Monkey (*Saimiri oerstedii*), the Central American Spider Monkey (*Ateles geoffroyi*), and Baird's Tapir (*Tapirus bairdii*) listed as Vulnerable, Vulnerable, Endangered, and Endangered by the IUCN, respectively (IUCN 2020). The presence of these species is encouraging given the proximity of human developments to the park including the relatively large, nearby city of Golfito, agricultural fields, and major highways surrounding the park.

Landmann et al. (2008) identified 34 mammal species in or near Piedras Blancas in 2004. Our study confirmed the presence of 17 of these mammal species and documented two additional species: Puma (*Puma concolor*) and Baird's Tapir. Landmann et al. (2008) also recorded the presence of a number of medium-sized and large mammals not identified in this study, including: Crab-eating Raccoon *(Procyon cancrivorus*) and White-lipped Peccary (*Tayassu pecari*).

A similar camera trap study implemented in Corcovado National Park from 2015–2018, identified 22 medium-sized and large mammal species (Olson et al. 2016, 2017, 2020). While the number of species found in each park is similar, Jaguar, White-lipped Peccary, and Baird's Tapir were recorded regularly in Corcovado, but were notably absent or, in the case of tapirs, were detected outside of the study period of this work.

White-lipped Peccary tend to be negatively affected by human disturbances (Thorton et al. 2020; Vargas et al. in preparation), while Collared Peccary (*Pecari tajacu*), although still negatively affected by higher levels of human disturbance, tend to be less affected by more moderate levels of human disturbance (Thorton et al. 2020; Vargas et al. in preparation). Thus, the absence of White-lipped Peccary and presence of Collared Peccary in Piedras Blancas National Park could be associated with the level of human disturbance in and around the park. However, in some cases, these two species have been shown to respond similarly to habitat covariates and avoid each other spatially as a function of niche partitioning (Ferreguetti et al. 2018). The documentation of White-lipped Peccary within Piedras Blancas by Landmann et al. (2008) was made prior to their fieldwork, based on what the authors considered to be a reliable observation made by a local. The absence of this species during their study and our study, suggests that White-lipped Peccaries occur rarely, if at all, within Piedras Blancas in recent years.

Similarly, it should be noted that we had only one opportunistic observation of Baird's Tapir and no camera trap pictures of this large mammal. Furthermore, this observation was made outside of our monitoring window and no direct or indirect observations were made during camera trap installation, maintenance, or removal. This may indicate that this individual was a transient, dispersing through the park. Yet, tapirs are relatively abundant in Corcovado National Park (Olson et al. 2016, 2017, 2020). Landmann et al. (2008) made no mention of Baird's Tapir and, we assume, found no evidence of it within the park.

Jaguars and tapirs have been observed in or near Piedras Blancas National Park at least once since 2014 (A. Artavia pers. comm.; H. Saladero pers. comm.; G. Saborío-R. pers. comm.). Landmann et al. (2008) also confirmed the presence of Jaguar through several sightings in 2004 and a single sighting in 2001. Yet, neither Landmann et al. (2008) nor this study documented Jaguar, White-lipped Peccary, or Baird's Tapir during scientific monitoring efforts, further indicating that these species may be transient or rare visitors of Piedras Blancas National Park in recent years.

While Piedras Blancas National Park supports a strong functional diversity and a number of globally threatened species, the apparent absence of a purported population of jaguars or White-lipped Peccaries in this park speaks to the current unmet conservation potential and its quality of habitat. Meyers et al. (2020) modeled the occupancy of nine large mammals along the Mesoamerican Biological Corridor in Panama, and found that Jaguar, White-lipped Peccary, and Baird's Tapir had the lowest levels of occupancy throughout their study area for the species assessed. Meyers et al. (2020) also found that jaguars were particularly sensitive to reductions in landscape-level connectivity. Thus, efforts to enhance connectivity and reduce human disturbance in and around protected areas may increase the probability of their occurrence. This only highlights the need for continued conservation efforts of the lands encompassing the system of biological corridors. The establishment of an effective biological corridor for medium-sized to large mammal species will rely heavily on Piedras Blancas to connect the Osa Peninsula to greater Costa Rica and Panama.

Conservation efforts focused on the protection of habitats within the biological corridors will encourage greater connectivity for populations of threatened species between the Osa Peninsula and greater Costa Rica in the coming years. Mammal inventories of Piedras Blancas are far from complete, but our study has provided an important baseline of the mammal community of this national park. We hope that the information presented in this paper will provide insight into some of the challenges facing Piedras Blancas National Park. We believe our results provide important baseline data that can be used to evaluate the effectiveness of conservation efforts and further implement an effective system of biological corridors in southeastern Costa Rica.

The diversity of mammal species we have documented is a sign of hope that the ecological needs of threatened mammal species may be met in the park and surrounding landscapes.

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Authors' Contributions

GS, EO, and PM developed the project; MB, JN, and PM collected data; MB and EO performed the analysis; MB, EO, and GS wrote the manuscript.

References

Apps PJ, McNutt JW (2018) How camera traps work and how to work them. African Journal of Ecology 56 (4): 702–709. https://doi.org/10.1111/aje.12563

Bello J, Reyna R, Schipper J (2016) *Mazama temama*. The IUCN Red List of threatened species 2016: e.T136290A22164644. https://doi.org/10.2305/iucn.uk.2016-2.rlts.t136290a22164644.en. Accessed on: 2020-7-21.

Bennett AF (1998) Linkages in the Landscape: the role of corridors and connectivity in wildlife conservation. IUCN, Gland, Switzerland, 254 pp.

Bruner AG, Gullison, RE, Rice RE, Da Fonseca GA (2001) Effectiveness of parks in protecting tropical biodiversity. Science 291 (5501): 125–128. https://doi.org/10.1126/science.291.5501.125

Carrillo E, Wong G, Cuarón AD (2000) Monitoring mammal populations in Costa Rican protected areas under different hunting restrictions. Conservation Biology 14 (6): 1580–1591. https://doi.org/10.1111/j.1523-1739.2000.99103.x

Cortes-Ortíz L, Canales Espinosa D, Cornejo FM, Guzman-Caro D, Link A, Moscoso P, Méndez-Carvajal P, Palacios E, Rodríguez V, Rosales-Meda M, Solano D, Williams-Guillén K, Cuarón AD, Morales A, Shedden A, Rodríguez-Luna E, de Grammont PC (2008) *Saimiri oerstedii*. The IUCN Red List of threatened species 2008: e.t19840a9023408. https://doi.org/10.2305/iucn.uk.2008.rlts.t19840A9023408.en. Accessed on: 2020-7-21.

de la Torre S (2020) *Alouatta palliata*. The IUCN Red List of threatened species 2020: e.T39960A17925090. https://doi.org/10.2305/iucn.uk.2020-2.rlts.t39960a17925090.en. Accessed on 2020-7-21.

de Oliveira T, Paviolo A, Schipper J, Bianchi R, Payan E, Carvajal SV (2015) *Leopardus wiedii*. The IUCN Red List of threatened species 2015: e.T11511A50654216. https://doi.org/10.2305/iucn.uk.2015-4.rlts.t11511a50654216.en. Accessed on 2020-7-21.

Ferreguetti AC, Davis CL, Tomas WM, Bergallo HG (2018) Using activity and occupancy to evaluate niche partitioning: the case of two peccary species in the Atlantic Rainforest, Brazil. Hystrix, the Italian Journal of Mammalogy 29 (2): 168–174. https://doi.org/10.4404/hystrix-00068-2018

Foerster CR, Vaughan C (2002) Home range, habitat use, and activity of Baird's Tapir in Costa Rica. Biotropica 34 (3): 423–437.

Fuller TK, Carrillo E, Saenz JC (2002) Survival of protected white-lipped peccaries in Costa Rica. Canadian Journal of Zoology 80 (3): 586–589. https://doi.org/10.1139/z02-020

Garcìa M, Jordan C, O'Farril G, Poot C, Meyer N, Estrada N, Leonardo R, Naranjo E, Simons Á, Herrera A, Urgilés C, Schank C, Boshoff L, Ruiz-Galeano M (2016) *Tapirus bairdii*. The IUCN Red List of threatened species 2016: e.T21471A45173340. https://doi.org/10.2305/iucn.uk.2016-1.rlts.t21471a45173340.en. Accessed on: 2020-7-21.

Gonzáles MG (1999) Abundance and population structure of some economically important trees of Piedras Blancas National Park, Costa Rica. Master's thesis, University of Montana, Missoula, 1464 pp.

González-Maya JF, Finegan B, Schipper J, Casanoves F (2008) Densidad absoluta y conservacion de jaguares en Talamanca, Costa Rica. Serie Técnica. The Nature Conservancy, San José, Costa Rica, 49 pp.

González-Maya JF, Schipper J, Rojas-Jimenez K (2009) Elevational distribution and abundance of Baird's Tapir (*Tapirus bairdii*) at different protection areas in Talamanca Region of Costa Rica. Tapir Conservation 18 (25): 29–35.

González-Maya JF, Schipper J, Polidoro B, Hoepker A, Zarrate-Charry D, Belant JL (2012) Baird's tapir density in high elevation forests of the Talamanca region of Costa Rica. Integrative Zoology 7 (4): 381–388. https://doi.org/10.1111/j.1749-4877.2012.00324.x

González-Maya JF, Víquez-R LR, Belant JL, Ceballos G (2015) Effectiveness of protected areas for representing species and populations of terrestrial mammals in Costa Rica. PLoS ONE 10 (5): e0124480. https://doi.org/10.1371/journal.pone.0124480

Gonzáles-Maya JF, Gómez-Hoyos DA, Gómez-Junco G, Schipper J, Zárrate-Charry DA (2016) Connecting felid populations between La Amistad and Osa priority conservation areas in Costa Rica. The Wild Felid Monitor 9 (2): 21–27.

Guppy N (1984) Tropical deforestation: a global view. Foreign Affairs 62 (4): 928–965.

Hall ER (1981) The mammals of North America. 2nd ed. John Wiley and Sons, New York, 717 pp.

Holdridge L, Grenke W, Hatheway W, Liang T, Tosi J (1971) Forest environments. In: Tropical life zones: a pilot study. Pergamon Press, New York, 747 pp.

Instituto Meteorológico Nacional de Costa Rica (IMN) (2016) Mapa de Costa Rica climatic data. https://www.imn.ac.cr/en/mapa. Accessed on: 2019-11-27.

IUCN (2020) The IUCN Red List of threatened species. Version 2020-2. https://www.iucnredlist.org. Accessed on 2020-7-21.

Landmann A, Walder C, Vorauer A, Emser T (2008) Mammals of the Piedras Blancas National Park, Costa Rica: species composition, habitat associations and efficiency of research methods—a preliminary overview. Stapfia 80: 409–422.

Lyra-Jorge MC, Ciocheti G, Pivello VR, Meirelles ST (2008) Comparing methods for sampling large-and medium-sized mammals: camera traps and track plots. European Journal of Wildlife Research 54 (4): 739–744. https://doi.org/10.1007/s10344-008-0205-8

Meyer NF, Moreno R, Reyna-Hurtado R, Signer J, Balkenhol N (2020). Towards the restoration of the Mesoamerican Biological Corridor for large mammals in Panama: comparing multi-species occupancy to movement models. Movement Ecology 8 (1): 1–14.

Mittermeier RA, Gil PR, Hoffman M, Pilgrim J, Brooks T, Mittermeier CG, Lamoreux J, Fonseca GAB, (2004) Hotspots revisited: earth's biologically richest and most endangered terrestrial ecoregions. Cemex, Mexico City, 390 pp.

Myers N (1993) Tropical forests: the main deforestation fronts. Environmental Conservation 20 (1): 9–16.

Naing H, Fuller TK, Sievert PR, Randhir TO, Tha Po SH, Maung M, Lynam AJ, Htun S, Thaw WN, Myint T (2015) Assessing large mammal and bird richness from camera-trap records in the Hukaung valley of northern Myanmar. Raffles Bulletin of Zoology 63: 376–388.

Nepstad D, Schwartzman S, Bamberger B, Santilli M, Ray D, Schlesinger P, Rolla A (2006) Inhibition of Amazon deforestation and fire by parks and indigenous lands. Conservation Biology 20 (1): 65–73. https://doi.org/10.1111/j.1523-1739.2006.00351.x

O'Brien TG, Kinnaird MF, Wibisono HT (2003) Crouching tigers, hidden prey: Sumatran Tiger and prey populations in a tropical forest landscape. Animal Conservation 6 (2): 131–139. https://doi.org/10.1017/S1367943003003172

Oksanen J, Blanchet G, Friendly M, Kindt R, Legendre P, McGlinn D, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Henry M, Stevens H, Szoecs E, Wagner H (2019). vegan: community ecology package. R package version 2.5-6. https://CRAN.R-project.org/package=vegan. Accessed on 2020-7-21.

Olson E, Beal MRW, Saborío-R G, Azofeifa A, Montes W (2018) Wildlife monitoring report for Corcovado National Park, Costa Rica – 2017. Technical report for the Ministerio de Ambiente y Energía – Sistema Nacional de Áreas de Conservación, Golfito, 29 pp.

Olson ER, Beal MRW, Saborío-R G, Azofeifa A, Olmos E, Fernandez WM (2020) Wildlife monitoring report for Corcovado National Park, Costa Rica – 2018. Technical report for the Ministerio de Ambiente y Energía – Sistema Nacional de Áreas de Conservación, Golfito, 28 pp. https://doi.org/10.13140/RG.2.2.28664.67845

Olson ER, Marsh RA, Bovard BN, Randrianarimanana HL, Ravaloharimanitra M, Ratsimbazafy JH, King T (2012) Arboreal camera trapping for the Critically Endangered Greater Bamboo Lemur *Prolemur simus*. Oryx 46 (4): 593–597.

Olson E, Matzinger P, Saborío-R G (2016) Wildlife monitoring report for Corcovado National Park, Costa Rica – 2015. Technical report for the Ministerio de Ambiente y Energía – Sistema Nacional de Áreas de Conservación, Golfito, 18 pp.

Olson E, Matzinger P, Saborío-R G, Azofeifa A, Montes W (2017) 2016 Wildlife monitoring report for Corcovado National Park, Costa Rica – 2016. Technical report for the Ministerio de Ambiente y Energía – Sistema Nacional de Áreas de Conservación, Golfito, 23 pp.

Olson ER, Matzinger PJ, Saborío G, Carazo-Salazar J (2019) Macho uno: a sign of hope for the Jaguars of Corcovado National Park, Costa Rica. CAT News 69: 1–3.

Palmer MS, Swanson A, Kosmala M, Arnold T, Packer C (2018) Evaluating relative abundance indices for terrestrial herbivores from large-scale camera trap surveys. African Journal of Ecology 56 (4): 791–803. https://doi.org/10.1111/aje.12566

Parsons AW, Forrester T, McShea WJ, Baker-Whatton MC, Millspaugh JJ, Kays R (2017) Do occupancy or detection rates from camera traps reflect deer density? Journal of Mammalogy 98 (6): 1547–1557. https://doi.org/10.1093/jmammal/gyx128

R Core Team (2018). R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/. Accessed on 2020-7-21.

Rivera VS, Cordero PM, Cruz IA, Borras MF (2002) Mesoamerican biological corridor and local participation. Parks 12 (2): 42–54.

Salom-Pérez R, Carrillo E, Sáenz JC, Mora JM (2007) Critical condition of the jaguar *Panthera onca* population in Corcovado National Park, Costa Rica. Oryx 41 (1): 51–56. https://doi.org/10.1017/s0030605307001615

Sánchez-Azofeifa GA, Daily GC, Pfaff ASP, Busch C (2003) Integrity and isolation of Costa Rica's national parks and biological reserves: examining the dynamics of land-cover change. Biological Conservation 109 (1): 123–135. https://doi.org/10.1016/S0006-3207(02)00145-3

Shaffer M (2010) Minimum viable populations: coping with uncertainty. In: Soulé M (Ed.) Viable populations for conservation. Cambridge University Press, Cambridge, 69–86. https://doi.org/10.1017/cbo9780511623400.006

Silveira L, Jácomo ATA, Diniz-Filho JAF (2003) Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114 (3): 351–355. https://doi.org/10.1016/S0006-3207(03)00063-6

Sistema Nacional de Áreas de Conservación (SINAC) (2018) Estado de conservación del jaguar (*Panthera onca*) en Costa Rica a través de la integración de datos de registros de la especie y modelaje del hábitat idóneo. Proyecto MAPCOBIO-SINAC-JICA-Santo Domingo de Heredia, Costa Rica, 84 pp.

Thornton D, Reyna R, Perera-Romero L, Radachowsky J, Hidalgo-Mihart MG, Garcia R, Moreira-Ramírez JF (2020) Precipitous decline of White-lipped Peccary populations in Mesoamerica. Biological Conservation 242: 108410. https://doi.org/10.1016/j.biocon.2020.108410

Wainwright M, Arias O (2007) The mammals of Costa Rica: a natural history and field guide. Comstock, New York, 155 pp.

Weissenhofer A, Huber W, Koukal T, Immitzer M, Schembra E, Sontag S, Zamora N, Weber A (2008) Ecosystem diversity in the Piedras Blancas National Park and adjacent areas (Costa Rica), with the first vegetation map of the area. Stapfia 88: 65–96.