Certified forest management and conservation of medium- and large-sized mammals: biodiversity, trampling, browsing and seed removal in the Argentine Austral Yungas

Alveira Mariela[a]

de Bustos Soledad[b]

Tálamo Andrés[c]

[a] Facultad de Ciencias Naturales, Universidad Nacional de Salta, Av. Bolivia 5150, 4400 Salta, Argentina. marialveira@hotmail.com

[b] Secretaría de Ambiente y Desarrollo Sustentable de Salta, Santiago del Estero 2246, Edificio B, 4400 Salta, Argentina. soledadddebustos@yahoo.com.ar

[c] Laboratorio de Ecología Aplicada a la Conservación (LEAC), Instituto de Bio y Geociencias del NOA (IBIGEO), Universidad Nacional de Salta, Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Avenida 9 de julio 14, CP 4405 Rosario de Lerma, Salta, Argentina. atalamo@unsa.edu.ar

Corresponding author: Soledad de Bustos soledadddebustos@yahoo.com.ar

Abstract

Timber extraction is one of the most widespread land uses in forested environments, and subsequent environmental degradation and impacts on wildlife have been largely mentioned. Reduced-impact logging (RIL) under certification standards could help to reconcile forest production with biodiversity conservation standards. However, whether this is a convenient strategy for the conservation of the medium-large mammal

assemblage of the Argentine Austral Yungas remains unknown. Here, we compare the richness, frequency of signs and identities of medium-large mammal species, as well as three mammal-plant interactions (seedling trampling, plant browsing and fruit removal) between an area under forestry certification and a similar area without forestry use (control). Our approach showed that the native medium-large mammal assemblage was not quantitatively affected by forestry activity under the international forest certification management guidelines (FSC), after 3-4 years of forestry use. This was evidenced by detected species richness and frequency of signs, as well as by grouping species by size classes and trophic groups (with the exception of carnivores). Seedling trampling and plant browsing in the lower strata (< 1 m height) did not differ among sites, although results were less robust in the case of mammal species identity, fruit removal and plant browsing above one meter height. Although in our study we found certain species-specific differences, with a predominance of generalist species and certain reduced biological interactions in the logged compared to the unlogged area, we propose that forest intervention under responsible management guidelines is convenient to conserve a significant proportion of medium-large mammal diversity of the Argentine Austral Yungas. Responsible forest management is an "intermediate path" between deforestation and strict conservation, for which environmental and governmental institutions should support and promote it.

Keywords: logging, forest management, mammals, Yungas.

1. Introduction

Timber extraction is one of the most widespread uses in forested environments (FAO and UNEP, 2020), and subsequent environmental degradation and impacts on wildlife associated to logging have been widely mentioned. In the midst of a global

environmental crisis, it is essential that this activity is regulated and carried out in a sustainable way to ensure biodiversity conservation and ecosystem functionality (Bicknell et al., 2014; Corlett and Primack, 2008; Fredericksen, 2021; Putz et al., 2012). In that sense, the inclusion of reduced-impact logging (RIL) has been proposed as an alternative for environmental responsibility, which successfully combines forestry production with biological conservation (Putz et al., 2012, 2008, 2001). Although some studies have evaluated the effects of logging on biodiversity, results are variable and depend on the biological group, logging intensity, and existing forest management guidelines (Bicknell et al., 2014; Burivalova et al., 2014; Putz et al., 2012).

Native medium-large mammals are an important component of ecosystems. Since they are part of multiple interspecific interactions, they can trigger trophic and non-trophic cascade effects (Berger et al., 2001; Crooks and Soulé, 1999; Kurten, 2013). In addition, they are usually considered to be good ecological indicators, since they are often affected by human impacts and habitat degradation (Barlow et al., 2007; Morrison et al., 2007). Some mammal species are commonly the first to disappear of a landscape after a sustained human disturbance (Laliberte and Ripple, 2004; Ochoa, 1997; Weaver et al., 1996). However, each species or group of species might respond differently to disturbance intensity (Vetter et al., 2011). Comparisons of medium-large mammal diversity in areas under different forms of forestry use respect to undisturbed areas show different results, from lack of differences to 50% of species richness reduction (Barlow et al., 2007; Brodie et al., 2015; Burivalova et al., 2014; Costantini et al., 2016; Herrera Flores et al., 2002; Putz et al., 2012; Roopsind et al., 2017; Tobler et al., 2018). This variability in the responses is mainly attributed to differences in logging intensity and to the different management techniques that are used (Bicknell et al., 2014; Burivalova et al., 2014).

Forest logging can modify mammal species assemblages and their abundances, and also trophic and non-trophic interactions between mammals and plants (Herrera Flores et al., 2002; Burivalova et al., 2014; Brodie et al., 2015; Laufer et al., 2016; Constantini et al., 2016). Changes in these interactions can thus lead to indirect effects on the structure and functionality of forest ecosystems. For example, arboreal species regeneration can be modified by seedling trampling caused by medium-large mammals. This physical damage caused by vertebrates is a consistent force throughout the tropics that has affected survival of artificial seedlings, and therefore changes in vertebrate abundance could alter forest regeneration (Clark and Clark, 1989; Rosin et al., 2017). On the other hand, low strata vegetation structure can be modified by changes in plant browsing rates. In the Mexican Maya forest, higher plant browsing was found in an area without forest logging due to the increase of one herbivore species (Gutiérrez-Granados and Dirzo, 2009). Finally, seed removal is an important additional interaction that can become affected by changes in mammal assemblages (Janzen, 1971), which can in turn lead to other indirect effects on forest regeneration. Forestry and hunting can alter this interaction, as has been shown in the Mexican Maya forest and in a humid forest of Cameroon (Gutiérrez-Granados and Dirzo, 2009; Wang et al., 2007). However, knowledge on the possible simultaneous impacts of forestry activity on different mammal-plant interactions is scarce.

The Argentine Austral Yungas has been a target of forest logging for decades throughout most of its range (Nanni et al., 2020; Politi and Rivera, 2019). In most of the areas under forestry use, logging is carried out in a conventional way, without applying management guidelines that ensure forest logging sustainability (Politi and Rivera, 2019). Timber extraction is widely selective and intense, and has led to the impoverishment and simplification of the forest community (Minetti et al., 2009).

Between 2008 and 2014, only two forestry activities in the native argentine forest carried out reduced impact logging (RIL) under an international certification scheme (Forest Stewardship Council), which endorses the implementation of sustainable practices and provides a certification of the practice being held under sustainability standards. Since in this type of forest management an area is assigned as forest reserve where human disturbances such as hunting and livestock grazing are controlled, we were able to assess the possible effects of RIL on the medium-large mammal assemblage and on certain interactions between plants and mammals at one site of the Argentine Austral Yungas. To that aim, we compared the richness, diversity, frequency of records and identities of medium-large mammal species, and studied three mammal-plant interactions (seedling trampling, plant browsing of arboreal saplings and seed removal) between an area where RIL took place, and a similar area without forest logging within the same forestry management unit (Río Seco farm). Under effective management guidelines, we expect the medium-large mammal assemblage to be similar compared to the control area. Likewise, we expect mammal-plant interactions not to be affected.

2. Methods

2.1. Study area

Northwest Argentina mountain forests, or Austral Yungas extend on the slopes of the sub -Andean mountain ranges, between 22° and 29° S, in an altitudinal gradient between 400 and 2500 m.a.s.l where vegetation is organized in altitudinal levels with distinctive physiognomic features (Brown et al., 2001). This study was carried out at "Unidad de Manejo Forestal de la Finca Río Seco", a forestry management area located in Tartagal hills, towards the north of Salta Province (22.495326°S / 63.924393°W; Fig.

105 1). This unit harbors 16000 hectares in a continuous mountain forest matrix with a
106 rugged relief. Dominant vegetation corresponds to that of the lowest altitudinal level
107 (Pedemontana forest), where deciduous tree species predominate. These include Pablo
108 blanco (*Calycophyllum multiflorum*), Palo amarillo (*Phyllostylon rhamnoides*), Lapacho
109 rosado (*Tabebuia avellanedae*), Cebil colorado (*Anadenanthera macrocarpa*), Quina
110 (*Myroxylon peruiferum*), Afata (*Cordia trichotoma*), Lanza blanca (*Patagonula*
111 *americana*), Urundel (*Astronium urundeuva*), Pacará (*Enterolobium contortisiliquum*)
112 and Roble (*Amburana cearensis*). The area exhibits a sharp climatic seasonality: mean
113 monthly temperature varies between 13º C and 35º C, and rainfall ranges from 500 to
114 900 mm during the humid period, and can be lower than 5 mm in the dry period.

115 At the time this study was carried out, native forestry use under RIL had been carried
116 out for 11 years. From 2008, native forestry use began to apply certification standards
117 of the Forest Stewardship Council (FSC). Some management strategies included
118 property zoning with the identification of harvest, recover and reserve areas; livestock
119 exclusion; hunting control; planned harvest cycles for 25 years; a minimum cutting
120 diameter of 40 cm dbh; identification of seed specimens; road planning and directional
121 felling, among others.

122 2.2. *Study Design*

123 This study was carried out between May and October 2011, in two areas subjected to
124 different forest management (Fig. 1). One of these areas had been used for forestry
125 between 2007 and 2008 using RIL, and subsequently abandoned for its recovery (Cert-
126 Logged). The other area was considered as the control, since for the last 40 years it has
127 not been subjected to forestry use (Unlogged). Our study only compares two forest
128 sectors with different management, therefore the inferences made from sampling cannot

129 be upscaled to both sites (Ramage et al., 2013). However, both areas are approximately
130 5 km apart from the other; exhibit very similar climatic, orographic and floristic
131 characteristics; and are immersed in a large continuous forest matrix (Fig. 1) where no
132 other uses (e.g., hunting, livestock grazing) occur. Therefore, we believe we can
133 cautiously extrapolate our results beyond the spatial domain of our study to address a
134 possible relation between forestry activity and the medium-large mammal assemblage.

135 Since there are no other forest sectors under RIL management in northwest Argentina
136 mountain forests, we were precluded to obtain replications to increase the spatial
137 domain of our study.

138 2.3. *Medium-large mammal species (> 1 kg) diversity*

139 In each area, we recorded signs (i.e., tracks, faeces) of species at five to six transects of
140 0.7 to 1 km, distanced from each other by at least 1 km (Wallace, 1999; Fig. 1). We
141 established the transects on stream banks, where the wet substrate allowed better
142 detection of tracks. The frequency of recorded signs was standardized at 1 km. We
143 calculated the diversity (see Data analysis) and frequency of signs of different trophic
144 groups (Carnivorous, Herbivorous, Omnivorous) and size classes (< 6 kg, 6-12 kg, >12
145 kg), and for each species (or group of similar species) of native medium-large
146 mammals.

147 2.4. *Seedling trampling*

148 We evaluated the physical alteration caused by native medium-large mammals using
149 artificial seedlings built with 0.1" thick and 40 cm long galvanized iron wire. We buried
150 the artificial seedlings in the ground and placed a flagging tape to allow its easier
151 visualization (Clark and Clark, 1989). At each area we established six transects with 40

artificial seedlings each, placed on the animal tracks (Fig. 1). Distance between transects was less than one km, and distance between seedlings was one meter. After 30 days, we recorded the percentage of seedlings that had been altered by trampling at each transect. We considered a given seedling as altered when it bent ≥ 45°.

2.5. Plant browsing

We delimited six 200 m long, 2 m wide transects in both areas, at which we recorded the frequency of plants browsed by native mammals at different height levels: < 0.5 m, entre 0.5 y 1 m and > 1 m (Fig. 1). We considered plant browsing as the situation where both leaves and branches had been consumed, sometimes with noticeable signs of teeth, which differentiated them from insect activity. We recorded the frequency of browsed plants within 400 m^2 for each height level.

2.6. Fruit removal

In each area, we established 12 stations offering fruits of *Gleditsia amorphoides*, a frequent species in the region, to evaluate removal performed by native medium-large mammals (Fig.1). This fruit is a 6-10 cm long indehiscent legume that is frequently consumed by native medium-large mammals. We collected ripe fruits in good condition from the ground, usually under the mother trees through occasional searching in both areas. Each removal station consisted on a cloth on the ground, where we set 20 fruits and placed a camera-trap to record the visitor species. We considered removal when at least 75% of the fruit was consumed. The experiment lasted 26 days on average, and when it ended, we recorded the percentage of removed fruits.

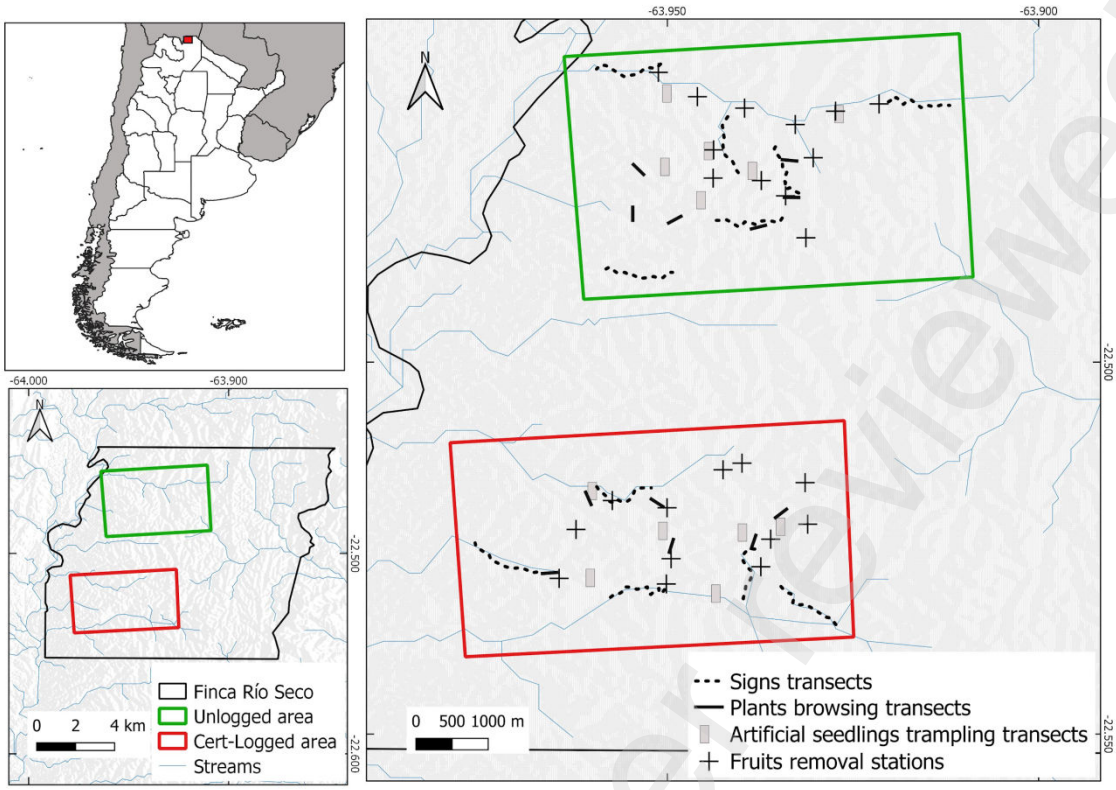


Fig. 1. Distribution of the signs transects, plant browsing transects, artificial seedling trampling transects and fruits removal stations in Unlogged and Cert- Logged areas of Finca Río Seco, Austral Yungas, northwest Argentina.

2.7. *Data analysis*

We compared species diversity through rank-abundance curves, which provide a visual representation of species richness (number of points), species relative abundance, the slope of the curve (equitativity) and the sequence of species (Feinsinger, 2004). In addition, we compared the mean diversity of each site at a given abundance level using the rarefaction technique based on individuals to calculate the Hill numbers (*i.e.*, the "effective number" of species) (Chao et al., 2014). We built the rarefaction curves with the ggiNEXT function of the iNEXT package (Hsieh et al., 2016). We analyzed the relationship between logging levels (Cert-logged vs. Unlogged) and response variables with generalized linear models in R software (R Core Team, 2018). We employed a

binomial error distribution and a logit link function to model the percentage of artificial seedlings trampled and percentage of removed fruits. We used a Poisson error distribution and a log link function to model the frequency of signs / km and the number of browsed plants / 400 m^2 (Zuur et al., 2009).

3. Results

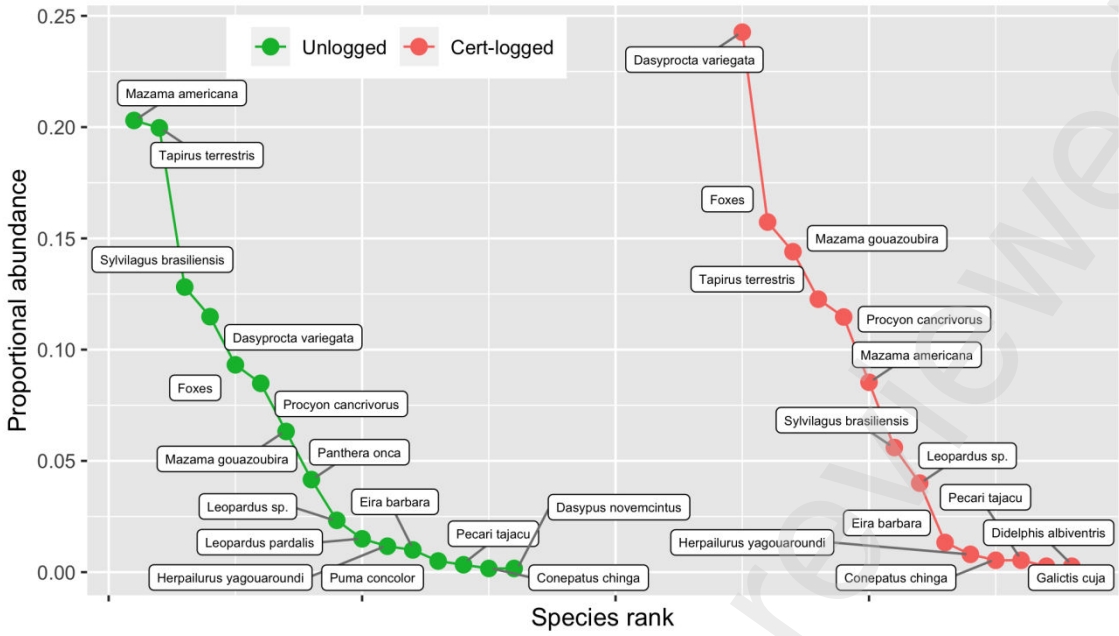
3.1. *Medium-large mammal diversity*

We recorded 18 native medium-large mammal species at the Finca Río Seco (Table 1). 16 species were detected in the unlogged area, and 15 in the cert-Logged area (Fig. 2). *Mazama americana, Tapirus terrestris, Sylvilagus brasiliensis, Dasyprocta variegata* and foxes were the dominant species in the unlogged area, while in the cert-logged area the dominant species were *D. variegata,* followed by foxes, *Mazama gouazoubira, T. terrestris* and *P. cancrivorus* (Fig. 2). We did not find evidences of changes in mean richness or Shannon and Simpson indices between the two areas (Fig. 3).

Table 1. Biological characteristics of the mammal species detected in areas with different forest management.

Species	**English name**	**Size ranges (kg)**	**Trophic group**
Didelphis albiventris	White-eared opossum	<5	Omnivore
Dasypus novemcinctus	Nine-banded armadillo	<5	Omnivore
Lycalopex gymnocercus	Pampas fox	5-12	Omnivore
Cerdocyon thous	Crab-eating fox	5-12	Omnivore
Eira barbara	Tayra	5-12	Carnivore

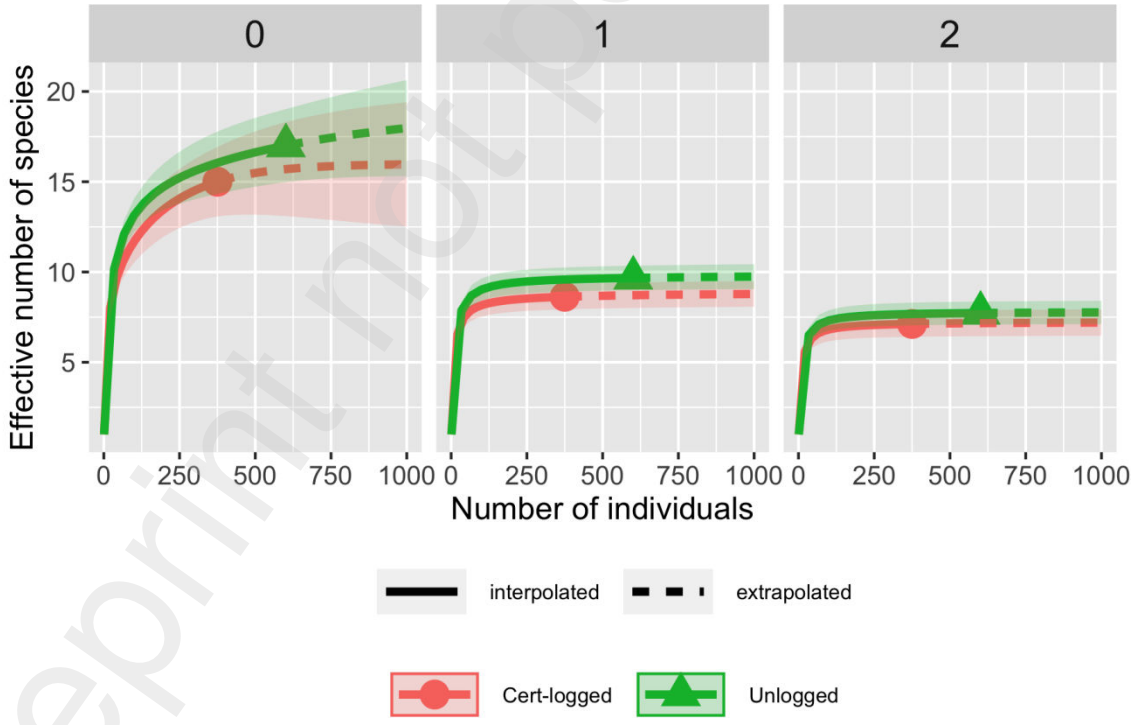
Galictis cuja	Lesser grison	<5	Carnivore
Conepatus chinga	Molina's hog-nosed skunk	<5	Omnivore
Procyon cancrivorus	Crab-eating raccoon	5-12	Omnivore
Panthera onca	Jaguar	>12	Carnivore
Puma concolor	Puma	>12	Carnivore
Leopardus pardalis	Ocelot	5-12	Carnivore
Leopardus sp.	Margay / Tirica	<5	Carnivore
Puma yagouaroundi	Jaguarundi	5-12	Carnivore
Tapirus terrestris	Lowland tapir	>12	Herbivore
Mazama americana	Red brocket	>12	Herbivore
Mazama gouazoubira	Gray brocket	>12	Herbivore
Pecari tajacu	Collared peccary	>12	Omnivore
Dasyprocta variegata	Agouti	<5	Herbivore
Sylvilagus brasiliensis	Brazilian rabbit	<5	Herbivore



202

203 Fig. 2. Rank-abundance curves of the species recorded in areas under different forestry

204 management in the austral Yungas of Argentina.



205

206 Fig. 3. Rarefaction curves showing the Hill diversity indices, expressed as the number

207 of effective species as a function of the number of individuals in areas under different

forestry management in the Austral Yungas of Argentina. q=0: species richness; q=1: Shannon index exponential; q=2: inverse Simpson index.

We did not find differences in the frequency of signs among different trophic groups or size classes between the unlogged and cert-logged areas (Fig. 4, 5) except for carnivores, whose signs were 2.11 more frequent in the unlogged area (Fig. 4). However, we found different species-specific responses (Fig. 6). The frequency of signs of *D. variegata* (b= 0.445, p= 0.004) *M. gouazoubira* (b= 0.701, p= 0.001) and *P. tajacu* (b= 1.435, p= 0.073) were 1.56, 2.02 and 4.2 times higher in the cert-logged compared to the unlogged area, respectively. On the other hand, the frequency of signs of *M. americana* (b= - 0.728, p= 8.4 x 10^{-6}), *S. brasiliensis* (b= -0.95, p= 1.51 x 10^{-5}) and *T. terrestris* (b= -0.394, p= 0.007) were 2.07, 2.59 and 1.48 times higher in the unlogged area compared to the cert-logged area, respectively. We did not obtain signs records of *Dasypus novemcinctus, Panthera onca* or *Leopardus pardalis* in the cert-logged area (thus we did not perform statistical tests), while *Didelphys albiventris* and *Galictis cuja* were only recorded under this forestry management (Fig. 6).

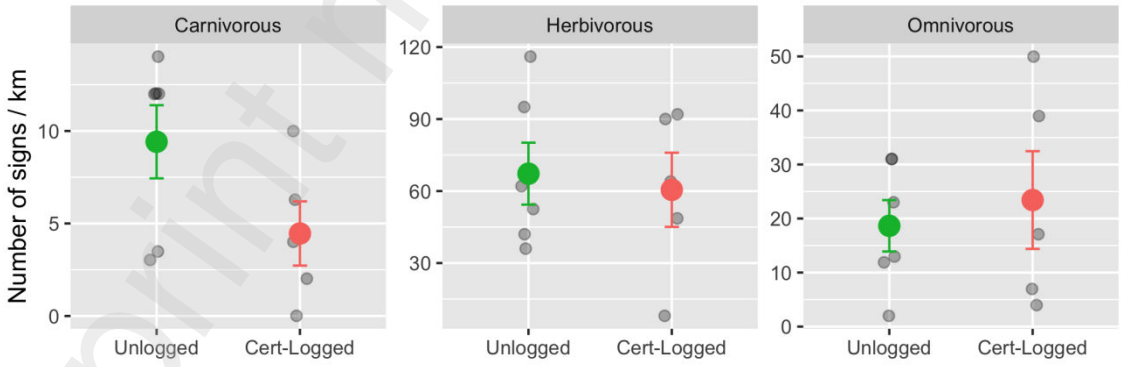
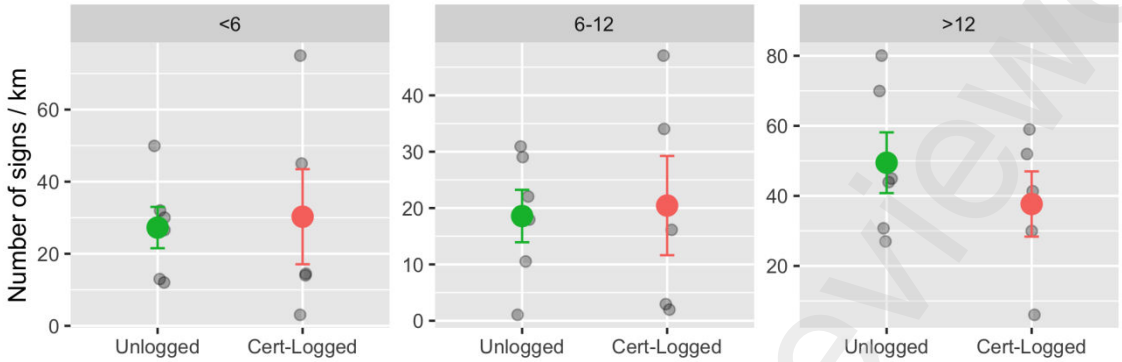


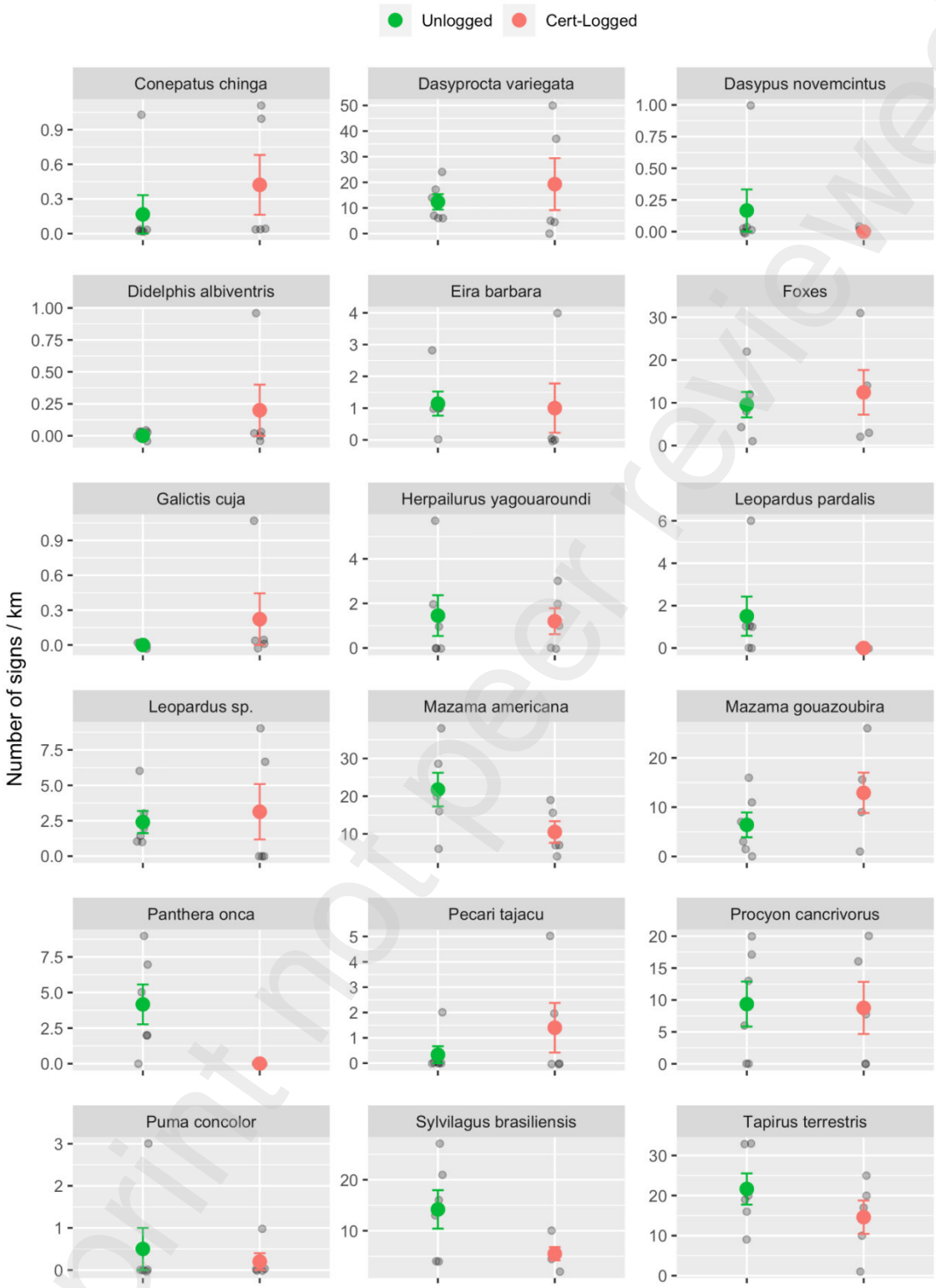
Fig. 4. Frequency of signs of medium-large mammals according to trophic groups in areas under different forestry management in the Austral Yungas of Argentina. Grey points indicate the frequencies of signs at each transect, and the colored circle indicates

227 the arithmetic mean (± Standard Error). The scales of axis Y vary for each trophic
228 group.



229

230 Fig. 5. Frequency of signs of medium-large mammals according to size classes (< 6 kg,
231 6-12 kg, > 12 kg) in areas under different forestry management in the Austral Yungas of
232 Argentina. Grey points indicate the frequencies of signs at each transect, and the colored
233 circle indicates the arithmetic mean (± Standard Error). The scales of axis Y vary for
234 each size class.



235

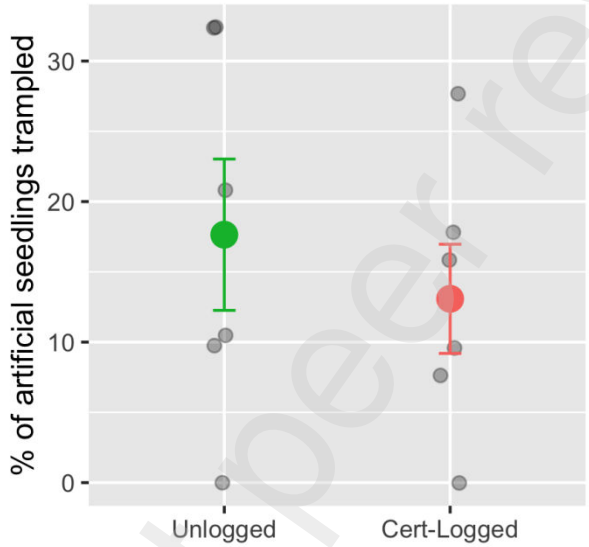
236 Fig. 6. Frequency of signs of each medium-large mammal species in areas under

237 different forestry management in the Austral Yungas of Argentina. Grey points indicate

238 the frequencies of signs at each transect, and the colored circle indicates the arithmetic
239 mean (± Standard Error). The scales of axis Y vary for each species.

240 3.2. *Seedling trampling*

241 We did not detect differences in the percentage of artificial seedlings trampled between
242 the two compared areas (b= -0.358; p= 0.163) (Fig. 7).



243

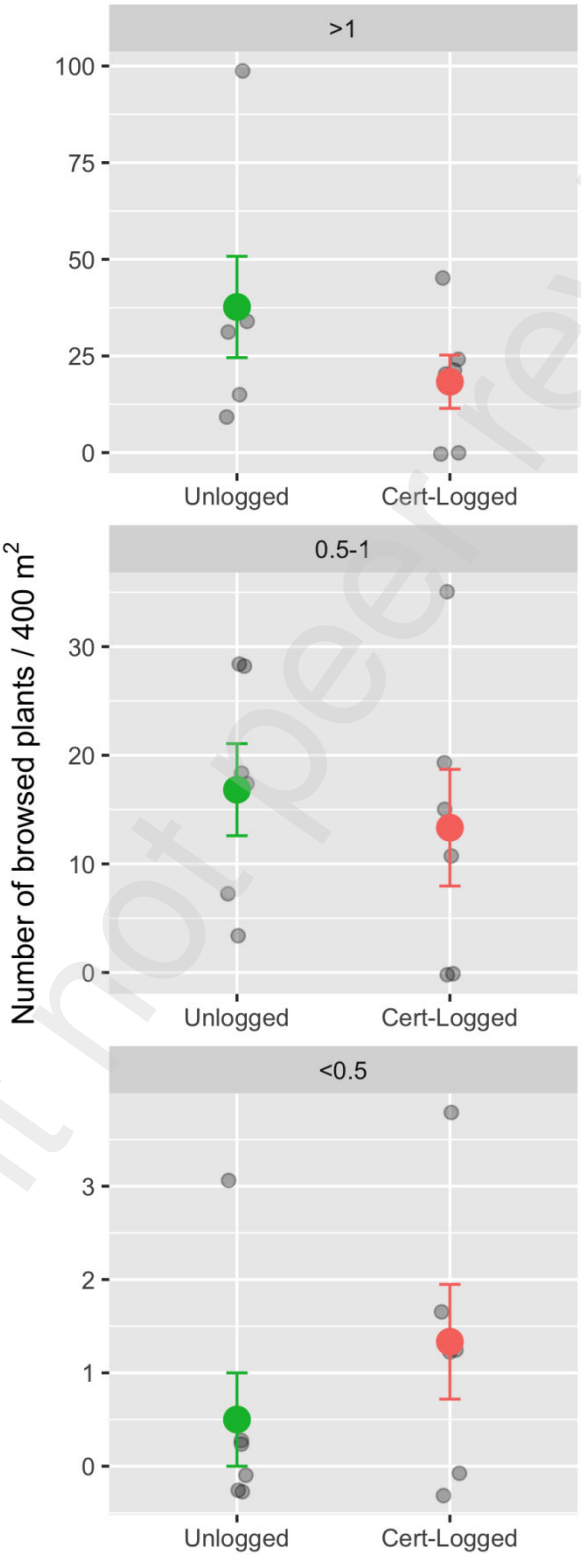
244 Fig. 7. Artificial seedling trampling by native medium-large mammals in areas under
245 different forestry management in the Austral Yungas of Argentina. Grey points indicate
246 the percentages at each transect, and the colored circle indicates the arithmetic mean (±
247 Standard Error).

248 *3.3. Plant browsing*

249 Differences in browsing rates between the two compared areas were conditioned by
250 vegetation height level (significant interaction, p= 0.002). Browsing rates for plants
251 below < 0.5 m were higher in the cert-Logged area (2.6 times, p= 0.14) compared to the
252 unlogged area. On the other hand, above 0.5 meters browsing rate was higher in the

253 unlogged area compared to the cert-logged area (0.5-1 m: 1.3 times, p= 0.11; > 1m: 2

254 times, p< 0.0001) (Fig. 8).

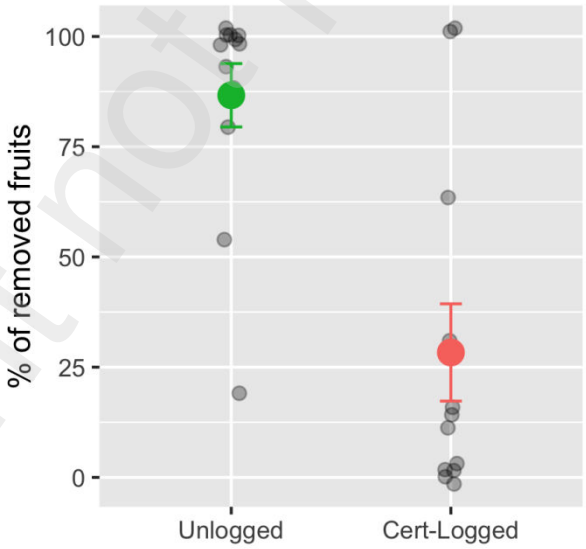


255

256 Fig. 8. Plant browsing by native medium-large mammals at different heights (> 1 m,
257 0.5-1 m, and < 0.5 m) in areas under different forestry management in the Austral
258 Yungas of Argentina. Grey points indicate the numbers of browsed plants at each
259 transect, and the colored circle indicates the arithmetic mean (± Standard Error). The
260 scales of the Y axis are different for each height level.

261 *3.4. Fruit removal*

262 \In the unlogged area, fruit removal percentage was 3.06 higher than in the cert-logged
263 area (b= -2.80; p= 5.5 x 10^{-32}) (Fig. 9). In the unlogged area, camera-traps showed that
264 the stations were mainly visited by *M. americana* and to a lesser extent by *P. tajacu, T.*
265 *terrestris* and *Cerdocyon thous.* On the other hand, the cert-logged area stations were
266 mainly visited by *M. gouazoubira, C. thous* and *D. variegata,* followed by *M.*
267 *americana* and *P. tajacu.*



268

269 Fig. 9. Fruit removal by medium-large mammals in areas under different forestry
270 management of the Austral Yungas of Argentina. Grey points indicate the percentages

of fruits removed at each removal station, and the colored circle indicates the arithmetic mean (± Standard Error).

4. Discussion

As expected in community studies that evaluate size and trophic group species richness and diversity, individual species and interactions, results do not show a clear, consistent pattern when comparing a certified forestry management sector with a sector with no forestry management in the Austral Yungas of northwest Argentina. Broadly, native medium-large mammal species composition and dominance were different between the two compared sites. Carnivores and six mammal species were more abundant in the unlogged area (with three exclusive species), while five species were more abundant in the cert-logged area (with two exclusive species). Finally, we observed a trend of higher trampling rates and lower browsing rates at medium and high height levels, and higher fruit removal in the unlogged area compared to the cert-logged area. The other analyzed variables (including the frequency of seven species) did not show significant differences between the compared areas. Thus, it is not possible to generalize the possible effects of forestry use on the medium-large mammal assemblages of the Austral Yungas of Argentina, since results depend on the analyzed variables.

Similar results regarding changes in medium-large mammal assemblages were observed in other tropical forests of the world after forestry use under adequate management guidelines (Azevedo-Ramos et al., 2006; Herrera Flores et al., 2002; Laufer et al., 2015; Putz et al., 2012; Samejima et al., 2012; Tobler et al., 2018). In forest exploited areas of Borneo tropical forests, species richness equaled that of unlogged forests after six years of recovery (Samejima et al., 2012). Our study was carried out three to four years after logging, for which mammal assemblage and their interactions might still be in a

recovery phase. A likely important limiting factor regarding forest recovery at the landscape scale is the proximity to well-preserved areas, which could act as sinks of large mammals capable of moving while the forest disturbance takes place. After the disturbance, they could act as population sources, thus it would be essential to preserve the original native mammal assemblage (Laufer et al., 2015; Lees and Peres, 2008, Iezzi et al., 2018). In our study, the cert-logged area is located around 5 km from the unlogged area, which is in turn part of an important well-preserved forest sector connected to protected areas, thus the conditions for the recovery of the unlogged area are suitable.

Animal populations differentially respond to disturbances, and forestry use changes the availability of shelter and food sources for certain species. This is a consequence of forest road opening for extraction and transportation, the accumulation of plant material in certain sectors, tree clearing, and the opening of the upper canopy and soil clearing. These become optimum habitats for the growth of fast-growing species, which in turn modify forest composition and structure. Ultimately, this could benefit species of generalist dietary habits, and affect resource specialists (Bicknell and Peres, 2010; Dirzo and Gutiérrez-Granados, 2006; Fredericksen and Fredericksen, 2002). While the vulnerability of carnivores to natural habitat degradation has been mentioned (Purvis et al., 2000), studies addressing the effects of forestry on this group show contrasting results (Brodie et al., 2015; Herrera Flores et al., 2002; Tobler et al., 2018). In our study, carnivores seem to have been negatively affected, since *P. onca* and *L. pardalis* were absent from the Cert-logged area. Both species have been associated to well-preserved forests (Cruz et al., 2018; De Angelo et al., 2011; de la Torre et al., 2017; de Matos Dias et al., 2019; Di Bitetti et al., 2010). Although *P. onca* was not detected in our signs transects, it was visually detected in the Cert-logged area by the logging company employees (Hugo Ortíz

obs. pers, 2010). On the other hand, degraded forests could constitute quality habitat for certain species groups, particularly those with higher dietary flexibility (Chazdon et al., 2009; Dunn, 2004; Parry et al., 2007; Wright and Muller-Landau, 2006). Previous findings regarding herbivores and omnivores in reduced-impact logging areas also show contrasting results (Herrera Flores et al., 2002; Heydon and Bulloh, 1997; Tobler et al., 2018). In our study, most of the species included in these groups and which have been frequently recorded in the Cert-logged area are generalists and can thus use degraded areas, such as *M. gouazoubira*, *P. tajacu*, *T. terrestris, C. thous, Lycalopex gymnocercus*, *Conepatus chinga, Procyon cancrivorus* y *Dasyprocta* sp. (Andrade-Núñez and Aide, 2010; de Matos Dias et al., 2019; Dotta and Verdade, 2007; Tejeda-Cruz et al., 2009; Tobler et al., 2018). Certain neotropical ungulates prefer to feed in relatively open forests or in forests under regeneration (Downer, 2001; Herrera Flores et al., 2002; Naranjo Piñera, 1995; Parry et al., 2007; Salas, 1996), since a higher density of palatable species (investing more resources in growth rather than structure formation) is usually found there. While we found this pattern in the case of *M. gouazoubira,* this was not the case for all herbivores or other individual species such as *T. terrestris, M. americana* or *S. brasiliensis*. It is likely that the relatively short time since the intervention was not enough for the recolonization of these herbivores. On the other hand, *G. cuja* and *D. albiventris* were only recorded in the logged area, which is aligned with findings of these species in modified areas such as plantations or even urbanized sectors (Dotta and Verdade, 2007; Fonseca et al., 1982).

In Neotropical forests, scarce studies have empirically evaluated the effects of logging on mammal-plant interactions, thus our work is a pioneer in the Austral Yungas. Many of the selective forces shaping forest plant communities are facilitated or hindered by these interactions. Herbivory is among the main influencing selection pressures on

neotropical forest vegetation dynamics, and can significantly plant community composition, structure and dynamics (Dirzo, 1987; Hawthorne and Parren, 2000; Olff and Ritchie, 1998; Price et al., 1991; Weisberg and Bugmann, 2003). In the Mayan Mexican area, a lower foliar damage was documented in logged areas compared to a reserve (Gutiérrez-Granados and Dirzo, 2009). This is consistent with our findings of higher browsing only in the upper strata of the understory, and we attribute this to the higher frequency of use of the unlogged forest by *T. terrestris* and *M. americana* (which browse at heights higher than one meter). In addition to herbivore consumption, plants can be damaged particularly by large mammals as a consequence of branch breakage and trampling, with alterations from growth to survival and consequent modifications of interspecific competition (Clark and Clark, 1989; Roldán and Simonetti, 2001). The lack of differences in trampling between the evaluated areas could be a consequence of similar animal stock independently of the identity of the detected mammals.

Fruit removal is a highly variable process attributed to many factors. These can be related to the involved plant species, the nutritional quality of fruits, or the physical characteristics, abundance or habitat type were they are placed. On the other hand, fruit removal could be associated to characteristics of the involved animal species, such as size, abundance and dietary specialization. Likewise, anthropic factors can also affect this biological process, either directly (e.g., hunting) or indirectly (e.g., habitat fragmentation) (Writght, 2003). Our studied fruits of *G. amorphoides* are very nutritious, woody and large, thus they might be better exploited by large herbivores. In fact, these fruits are used as optimum forage for large livestock. In that sense, the higher frequency of use by *T. terrestris* and *M. americana* in the unlogged area might be associated to the higher removal of these fruits, which was evidenced by the higher

number of photographs obtained in the camera-traps that were placed in front of the fruit stations, although this was not systematically quantified.

5. Conclusions and recommendations

In our study, we found certain species-specific differences, with a predominance of generalist species and certain reduced biological interactions in the cert-logged area compared to the unlogged area in a sector of the Argentine Austral Yungas. However, since many of the other quantified variables did not change among the compared sites, we suggest that forest intervention under responsible management guidelines can significantly conserve medium-large mammal diversity and broad features of the Austral Yungas of Argentina. The area under forest certification was found to provide habitat to national threatened species, such as *T. terrestris*, *M. americana* and *P. tajacu* (Camino et al., 2019; de Bustos et al., 2019; Varela et al., 2019).

Selective logging is the most widespread disturbance in the Neotropics, also it is less damaging that other practices carried out in these forests, such as deforestation, fires or defaunation associated to hunting. Thus, it can be considered as a reduced impact activity which could thus become an "intermediate path" between deforestation and strict protection total (Bicknell et al., 2014; Putz et al., 2012). For that reason, decision makers and governments should promote and support this practice, promoting benefits that compensate the major costs associated to the application of RIL and timber certification (Politi and Rivera, 2019), which in South America is scarcely valued by the general public.

6. Acknowledgements

We are grateful to Santa Bárbara S.A. Company and their staff, who made this study possible. We would also like to thank the students from Facultad de Ciencias Naturales who collaborated and participated in field work.

7. Funding

This work was partially supported by the Consejo de Investigación de la Universidad Nacional de Salta.

8. References

Andrade-Núñez, M.J., Aide, T., 2010. Effects of habitat and landscape characteristics on medium and large mammal species richness and composition in northern Uruguay. https://doi.org/10.1590/S1984-46702010000600012

Azevedo-Ramos, C., de Carvalho, O., do Amaral, B.D., 2006. Short-term effects of reduced-impact logging on eastern Amazon fauna. For. Ecol. Manag. 232, 26–35. https://doi.org/10.1016/j.foreco.2006.05.025

Barlow, J., Gardner, T.A., Araujo, I.S., Ávila-Pires, T.C., Bonaldo, A.B., Costa, J.E., Esposito, M.C., Ferreira, L.V., Hawes, J., Hernandez, M.I.M., Hoogmoed, M.S., Leite, R.N., Lo-Man-Hung, N.F., Malcolm, J.R., Martins, M.B., Mestre, L. a. M., Miranda-Santos, R., Nunes-Gutjahr, A.L., Overal, W.L., Parry, L., Peters, S.L., Ribeiro-Junior, M.A., Silva, M.N.F. da, Motta, C. da S., Peres, C.A., 2007. Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. Proc. Natl. Acad. Sci. 104, 18555–18560. https://doi.org/10.1073/pnas.0703333104

Berger, J., Stacey, P.B., Bellis, L., Johnson, M.P., 2001. A Mammalian Predator-Prey Imbalance: Grizzly Bear and Wolf Extinction Affect Avian Neotropical Migrants. Ecol.

413 Appl. 11, 947–960. https://doi.org/10.2307/3061004

414 Bicknell, J., Peres, C.A., 2010. Vertebrate population responses to reduced-impact
415 logging in a neotropical forest. For. Ecol. Manag. 259, 2267–2275.
416 https://doi.org/10.1016/j.foreco.2010.02.027

417 Bicknell, J.E., Struebig, M.J., Edwards, D.P., Davies, Z.G., 2014. Improved timber
418 harvest techniques maintain biodiversity in tropical forests. Curr. Biol. 24, R1119–
419 R1120. https://doi.org/10.1016/j.cub.2014.10.067

420 Brodie, J.F., Giordano, A.J., Ambu, L., 2015. Differential responses of large mammals
421 to logging and edge effects. Mamm. Biol. 80, 7–13.
422 https://doi.org/10.1016/j.mambio.2014.06.001

423 Brown, A.D., Grau, H.R., Malizia, L.R., Grau, A., 2001. Bosques nublados del
424 Neotrópico en Argentina, in: Bosques Nublados Del Neotrópico. IMBIO, Santo
425 Domingo de Heredia, Costa Rica, pp. 623–659.

426 Burivalova, Z., Şekercioğlu, Ç.H., Koh, L.P., 2014. Thresholds of Logging Intensity to
427 Maintain Tropical Forest Biodiversity. Curr. Biol. 24, 1893–1898.
428 https://doi.org/10.1016/j.cub.2014.06.065

429 Camino, M., Cirignoli, S., Varela, D., Barri, F., Aprile, G., Periago, M.E., de Bustos, S.,
430 Quiroga, V.A., Torres, R.M., Di Martino, S., 2019. Pecari tajacu (No. 215),
431 Categorización 2019 de los mamíferos de Argentina según su riesgo de extinción. Lista
432 Roja de los mamíferos de Argentina. SAyDS–SAREM.

433 Chao, A., Gotelli, N.J., Hsieh, T.C., Sander, E.L., Ma, K.H., Colwell, R.K., Ellison,
434 A.M., 2014. Rarefaction and extrapolation with Hill numbers: a framework for

435 sampling and estimation in species diversity studies. Ecol. Monogr. 84, 45–67.
436 https://doi.org/10.1890/13-0133.1

437 Chazdon, R.L., Peres, C.A., Dent, D., Sheil, D., Lugo, A.E., Lamb, D., Stork, N.E.,
438 Miller, S.E., 2009. The potential for species conservation in tropical secondary forests.
439 Conserv. Biol. J. Soc. Conserv. Biol. 23, 1406–1417. https://doi.org/10.1111/j.1523-
440 1739.2009.01338.x

441 Clark, D.B., Clark, D.A., 1989. The Role of Physical Damage in the Seedling Mortality
442 Regime of a Neotropical Rain Forest. Oikos 55, 225–230.
443 https://doi.org/10.2307/3565426

444 Corlett, R.T., Primack, R.B., 2008. Tropical Rainforest Conservation: A Global
445 Perspective.

446 Costantini, D., Edwards, D.P., Simons, M.J.P., 2016. Life after logging in tropical
447 forests of Borneo: A meta-analysis. Biol. Conserv. 196, 182–188.
448 https://doi.org/10.1016/j.biocon.2016.02.020

449 Crooks, K.R., Soulé, M.E., 1999. Mesopredator release and avifaunal extinctions in a
450 fragmented system. Nature 400, 563–566. https://doi.org/10.1038/23028

451 Cruz, P., Iezzi, M.E., Angelo, C.D., Varela, D., Bitetti, M.S.D., Paviolo, A., 2018.
452 Effects of human impacts on habitat use, activity patterns and ecological relationships
453 among medium and small felids of the Atlantic Forest. PLOS ONE 13, e0200806.
454 https://doi.org/10.1371/journal.pone.0200806

455 De Angelo, C., Paviolo, A., Di Bitetti, M., 2011. Differential impact of landscape
456 transformation on pumas (*Puma concolor*) and jaguars (*Panthera onca*) in the Upper

Paraná Atlantic Forest. Divers. Distrib. 17, 422–436. https://doi.org/10.1111/j.1472-4642.2011.00746.x

de Bustos, S., Varela, D., Lizarraga, L., Cirignoli, S., Quiroga, V.A., Chalukián, S., Giombini, M., Juliá, J.P., Quse, V., Giraudo, A.R., Di Martino, S., Camino, M., Perovic, P.G., Albanesi, S., 2019. *Tapirus terrestris* (No. 215), Categorización 2019 de los mamíferos de Argentina según su riesgo de extinción. Lista Roja de los mamíferos de Argentina. SAyDS–SAREM.

de la Torre, J.A., Núñez, J.M., Medellín, R.A., 2017. Spatial requirements of jaguars and pumas in Southern Mexico. Mamm. Biol. 84, 52–60. https://doi.org/10.1016/j.mambio.2017.01.006

de Matos Dias, D., Lima Massara, R., de Campos, C.B., Henrique Guimarães Rodrigues, F., 2019. Human activities influence the occupancy probability of mammalian carnivores in the Brazilian Caatinga. Biotropica 51, 253–265. https://doi.org/10.1111/btp.12628

Di Bitetti, M.S., De Angelo, C.D., Di Blanco, Y.E., Paviolo, A., 2010. Niche partitioning and species coexistence in a Neotropical felid assemblage. Acta Oecologica 36, 403–412. https://doi.org/10.1016/j.actao.2010.04.001

Dirzo, R., 1987. Studies on plant-herbivore interactions in Los Tuxtlas, Veracruz. Rev. Biol. Trop. 35, 119–131.

Dirzo, R., Gutiérrez-Granados, 2006. Análisis de los efectos ecológicos del aprovechamiento forestal en el Corredor Biológico Mesoamericano: mamíferos, plantas y sus interacciones.

Dotta, G., Verdade, L.M., 2007. Trophic categories in a mammal assemblage: diversity in an agricultural landscape. Biota Neotropica 7, 287–292. https://doi.org/10.1590/S1676-06032007000200031

Downer, C.C., 2001. Observations on the diet and habitat of the mountain tapir (*Tapirus pinchaque*). J. Zool. 254, 279–291. https://doi.org/10.1017/S0952836901000796

Dunn, R.R., 2004. Recovery of Faunal Communities During Tropical Forest Regeneration. Conserv. Biol. 18, 302–309. https://doi.org/10.1111/j.1523-1739.2004.00151.x

FAO and UNEP, 2020. The State of the World's Forests 2020: Forests, biodiversity and people, El estado de los bosques del mundo (SOFO). FAO and UNEP, Rome, Italy. https://doi.org/10.4060/ca8642en

Feinsinger, P., 2004. El diseño de estudios de campo para la conservación de la biodiversidad, 1a. ed. ed. FAN, Bolivia.

Fonseca, G.A.B., Redford, K.H., Pereira, L.A., 1982. Notes on *Didelphis albiventris* (Lund, 1841) of Central Brazil. Ciênc Cult 34, 1359–1362.

Fredericksen, N.J., Fredericksen, T.S., 2002. Terrestrial wildlife responses to logging and fire in a Bolivian tropical humid forest. Biodivers. Conserv. 11, 27–38. https://doi.org/10.1023/A:1014065510554

Fredericksen, T.S., 2021. Biodiversity Conservation in Managed Forests. Forests 12, 1054. https://doi.org/10.3390/f12081054

Gutiérrez-Granados, G., Dirzo, R., 2009. Remoción de semillas, herbivoría y

reclutamiento de plántulas de *Brosimum alicastrum* (Moraceae) en sitios con manejo forestal contrastante de la selva Maya, Quintana Roo, México. Bol. Soc. Botánica México 51–58.

Hawthorne, W.D., Parren, M.P.E., 2000. How important are forest elephants to the survival of woody plant species in Upper Guinean forests? J. Trop. Ecol. 16, 133–150. https://doi.org/10.1017/S0266467400001310

Herrera Flores, J.C., Fredericksen, T.S., Rumíz, D., 2002. Evaluación rápida de mamíferos en base a huellas para observar los impactos del manejo forestal. Ecol. En Boliv. 37, 3–13.

Heydon, M.J., Bulloh, P., 1997. Mousedeer Densities in a Tropical Rainforest: The Impact of Selective Logging. J. Appl. Ecol. 34, 484–496. https://doi.org/10.2307/2404892

Hsieh, T.C., Ma, K.H., Chao, A., 2016. iNEXT: an R package for rarefaction and extrapolation of species diversity (Hill numbers). Methods Ecol. Evol. 7, 1451–1456. https://doi.org/10.1111/2041-210X.12613

Janzen, D.H., 1971. Seed Predation by Animals. Annu. Rev. Ecol. Syst. 2, 465–492. https://doi.org/10.1146/annurev.es.02.110171.002341

Kurten, E.L., 2013. Cascading effects of contemporaneous defaunation on tropical forest communities. Biol. Conserv. 163, 22–32. https://doi.org/10.1016/j.biocon.2013.04.025

Laliberte, A.S., Ripple, W.J., 2004. Range Contractions of North American Carnivores and Ungulates. BioScience 54, 123–138. https://doi.org/10.1641/0006-

3568(2004)054[0123:RCONAC]2.0.CO;2

Laufer, J., Michalski, F., Peres, C.A., 2015. Effects of reduced-impact logging on medium and large-bodied forest vertebrates in eastern Amazonia. Biota Neotropica 15. https://doi.org/10.1590/1676-06032015013114

Lees, A.C., Peres, C.A., 2008. Conservation value of remnant riparian forest corridors of varying quality for amazonian birds and mammals. Conserv. Biol. J. Soc. Conserv. Biol. 22, 439–449. https://doi.org/10.1111/j.1523-1739.2007.00870.x

Minetti, J., Bessonart, S.J., Balducci, E.D., 2009. La actividad forestal en la Selva Pedemontana del Norte de Salta, in: Selva Pedemontana de Las Yungas. Historia Natural, Ecología y Manejo de Un Ecosistema En Peligro. Ediciones del Subtrópico, Tucumán, Argentina, p. 487.

Morrison, J.C., Sechrest, W., Dinerstein, E., Wilcove, D.S., Lamoreux, J.F., 2007. Persistence of Large Mammal Faunas as Indicators of Global Human Impacts. J. Mammal. 88, 1363–1380.

Nanni, A.S., Rodríguez, M.P., Rodríguez, D., Regueiro, M.N., Periago, M.E., Aguiar, S., Ballari, S., Blundo, C., Derlindati, E., Blanco, Y.D., Eljall, A., Grau, H.R., Herrera, L., Herrera, A.H., Izquierdo, A.E., Lescano, J.N., Macchi, L., Mazzini, F., Milkovic, M., Montti, L., Paviolo, A., Pereyra, M., Quintana, R., Quiroga, V., Renison, D., Beade, M.S., Schaaf, A., Gasparri, N.I., 2020. Presiones sobre la conservación asociadas al uso de la tierra en las ecorregiones terrestres de la Argentina. Ecol. Austral 30, 304–320. https://doi.org/10.25260/EA.20.30.2.0.1056

Naranjo Piñera, E.J., 1995. Abundancia y uso de hábitat del tapir (*Tapirus bairdii*) en

un bosque trópical humedo de Costa Rica. Vida Silv. Neotrópical 20–30.

Ochoa, J., 1997. Potential sensibilities of mammals in logged forests of the Venezuelan Guyana Region. INTERCIENCIA 22, 112+.

Olff, H., Ritchie, M.E., 1998. Effects of herbivores on grassland plant diversity. Trends Ecol. Evol. 13, 261–265. https://doi.org/10.1016/S0169-5347(98)01364-0

Parry, L., Barlow, J., Peres, C.A., 2007. Large-vertebrate assemblages of primary and secondary forests in the Brazilian Amazon. J. Trop. Ecol. 23, 653–662. https://doi.org/10.1017/S0266467407004506

Politi, N., Rivera, L., 2019. Limitantes y avances para alcanzar el manejo forestal sustentable en las Yungas Australes. Ecol. Austral 29, 138–145. https://doi.org/10.25260/EA.19.29.1.0.753

Price, P.W., Lewinsohn, T.M., Fernandes, G.W., Benson, W.W., 1991. Plant-Animal Interactions: Evolutionary Ecology in Tropical and Temperate Regions. Wiley.

Purvis, A., Gittleman, J.L., Cowlishaw, G., Mace, G.M., 2000. Predicting extinction risk in declining species. Proc. R. Soc. B Biol. Sci. 267, 1947–1952.

Putz, F.E., Blate, G.M., Redford, K.H., Fimbel, R., Robinson, J., 2001. Tropical forest management and conservation of biodiversity: an overview. Conserv. Biol. 15, 7–20. https://doi.org/10.1046/j.1523-1739.2001.00018.x

Putz, F.E., Sist, P., Fredericksen, T., Dykstra, D., 2008. Reduced-impact logging: Challenges and opportunities. For. Ecol. Manag. 256, 1427–1433. https://doi.org/10.1016/j.foreco.2008.03.036

565 Putz, F.E., Zuidema, P.A., Synnott, T., Pena-Claros, M., Pinard, M.A., Sheil, D.,
566 Vanclay, J.K., Sist, P., Gourlet-Fleury, S., Griscom, B., Palmer, J., Zagt, R., 2012.
567 Sustaining conservation values in selectively logged tropical forests: the attained and
568 the attainable. Conserv. Lett. 5, 296–303. https://doi.org/10.1111/j.1755-
569 263X.2012.00242.x

570 R Core Team, 2018. R: A language and environment for statistical computing. R
571 Foundation for Statistical Computing, Vienna.

572 Ramage, B.S., Sheil, D., Salim, H.M.W., Fletcher, C., Mustafa, N.-Z.A., Luruthusamay,
573 J.C., Harrison, R.D., Butod, E., Dzulkiply, A.D., Kassim, A.R., Potts, M.D., 2013.
574 Pseudoreplication in tropical forests and the resulting effects on biodiversity
575 conservation. Conserv. Biol. 27, 364–372. https://doi.org/10.1111/cobi.12004

576 Roldán, A.I., Simonetti, J.A., 2001. Plant-Mammal Interactions in Tropical Bolivian
577 Forests with Different Hunting Pressures. Conserv. Biol. 15, 617–623.

578 Roopsind, A., Caughlin, T.T., Sambhu, H., Fragoso, J.M.V., Putz, F.E., 2017. Logging
579 and indigenous hunting impacts on persistence of large Neotropical animals. Biotropica
580 49, 565–575. https://doi.org/10.1111/btp.12446

581 Rosin, C., Poulsen, J.R., Swamy, V., Granados, A., 2017. A pantropical assessment of
582 vertebrate physical damage to forest seedlings and the effects of defaunation. Glob.
583 Ecol. Conserv. 11, 188–195. https://doi.org/10.1016/j.gecco.2017.06.001

584 Salas, L.A., 1996. Habitat use by lowland tapirs (*Tapirus terrestris* L.) in the Tabaro
585 River valley, southern Venezuela. Can. J. Zool. 74, 1452–1458.
586 https://doi.org/10.1139/z96-160

587 Samejima, H., Ong, R., Lagan, P., Kitayama, K., 2012. Camera-trapping rates of
588 mammals and birds in a Bornean tropical rainforest under sustainable forest
589 management. For. Ecol. Manag. 270, 248–256.
590 https://doi.org/10.1016/j.foreco.2012.01.013

591 Tejeda-Cruz, C., Naranjo, E.J., Cuarón, A.D., Perales, H., Cruz-Burguete, J.L., 2009.
592 Habitat use of wild ungulates in fragmented landscapes of the Lacandon Forest,
593 Southern Mexico 73, 211–219. https://doi.org/10.1515/MAMM.2009.044

594 Tobler, M.W., Anleu, R.G., Carrillo-Percastegui, S.E., Santizo, G.P., Polisar, J.,
595 Hartley, A.Z., Goldstein, I., 2018. Do responsibly managed logging concessions
596 adequately protect jaguars and other large and medium-sized mammals? Two case
597 studies from Guatemala and Peru. Biol. Conserv. 220, 245–253.
598 https://doi.org/10.1016/j.biocon.2018.02.015

599 Varela, D., de Bustos, S., Di Bitetti, M.S., Cirignoli, S., 2019. *Mazama americana* (No.
600 215), Categorización 2019 de los mamíferos de Argentina según su riesgo de extinción.
601 Lista Roja de los mamíferos de Argentina. SAyDS–SAREM.

602 Vetter, D., Hansbauer, M.M., Végvári, Z., Storch, I., 2011. Predictors of forest
603 fragmentation sensitivity in Neotropical vertebrates: a quantitative review. Ecography
604 34, 1–8.

605 Wang, B.C., Sork, V.L., Leong, M.T., Smith, T.B., 2007. Hunting of Mammals
606 Reduces Seed Removal and Dispersal of the Afrotropical Tree *Antrocaryon klaineanum*
607 (Anacaridaceae). Biotropica 39, 340–347.

608 Weaver, J.L., Paquet, P.C., Ruggiero, L.F., 1996. Resilience and Conservation of Large

609 Carnivores in the Rocky Mountains. Conserv. Biol. 10, 964–976.

610 Weisberg, P.J., Bugmann, H., 2003. Forest dynamics and ungulate herbivory: from leaf
611 to landscape. For. Ecol. Manag., Forest Dynamics and Ungulate Herbivory : From Leaf
612 to Landscape 181, 1–12. https://doi.org/10.1016/S0378-1127(03)00123-3

613 Wright, S.J., Muller-Landau, H.C., 2006. The Future of Tropical Forest Species.
614 Biotropica 38, 287–301. https://doi.org/10.1111/j.1744-7429.2006.00154.x

615 Zuur, F.L., Ieno, A.F., Walker, N.J., Saveliev, A.A., Smith, G., 2009. Mixed Effects
616 Models and Extensions in Ecology with R. Springer, New York.

617 **CRediT author statement**

618 Mariela Alveira: Conceptualization, Investigation, Writing original draft, Funding
619 Acquisition. Soledad de Bustos: Conceptualization, Methodology, Resources, Project
620 administration, Writing-Reviewing and Editing, Funding Acquisition. Andrés Tálamo:
621 Methodology, Formal Analysis, Supervision, Writing-Reviewing and Editing, Funding
622 Acquisition.