



**Manchester  
Metropolitan  
University**

---

El Bizri, HR and Fa, J and Bowler, M and Valsecchi, J and Bodmer, R and Mayor, P (2018) Breeding seasonality in the lowland paca (*Cuniculus paca*) in Amazonia: interactions with rainfall, fruiting, and sustainable hunting. *Journal of Mammalogy*, 99 (5). ISSN 1545-1542

---

**Downloaded from:** <http://e-space.mmu.ac.uk/621439/>

**Version:** Accepted Version

**Publisher:** Oxford University Press (OUP)

**DOI:** <https://doi.org/10.1093/jmammal/gyy102>

Please cite the published version

<https://e-space.mmu.ac.uk>

1 Published in **Journal of Mammalogy**

2 **Running Header:** Seasonal reproduction and hunting of pacas

3

4 **Breeding seasonality in the lowland paca (*Cuniculus paca*) in Amazonia: interactions**

5 **with rainfall, fruiting, and sustainable hunting**

6

7 Hani Rocha El Bizri, John E. Fa, Mark Bowler, João Valsecchi, Richard Bodmer, and Pedro

8 Mayor

9

10 *Grupo de Pesquisa em Ecologia de Vertebrados Terrestres, Instituto de Desenvolvimento*

11 *Sustentável Mamirauá (IDSM), Estrada do Bexiga 2584, Fonte Boa, CEP 69553-225, Tefé,*

12 *Amazonas – Brazil (HREB, JV).*

13 *ComFauna, Comunidad de Manejo de Fauna Silvestre en la Amazonía y en*

14 *Latinoamérica, 332 Malecon Tarapaca, Iquitos – Peru (HREB, JV, RB, PM)*

15 *School of Science and the Environment, Manchester Metropolitan University. Oxford Road,*

16 *M15 6BH, Manchester – United Kingdom (HREB, JEF).*

17 *Center for International Forestry Research (CIFOR), Jalan Cifor Rawajaha, Situ Gede,*

18 *Bogor Barat, Kota Bogor, Jawa Barat 16115 - Indonesia (JEF)*

19 *School of Science, Technology and Engineering, University of Suffolk, Waterfront Building,*

20 *Neptune Quay, Ipswich, IP4 1QJ – United Kingdom (MB)*

21 *San Diego Zoo Global Institute for Conservation Research, Escondido, California, CA*

22 *92027-9614 - USA (MB)*

23 *FundAmazonia, Malecón Tarapacá n° 332, Iquitos, Loreto – Peru (RB, PM).*

24 *Departament de Sanitat i Anatomia Animals, Universitat Autònoma de Barcelona, Bellaterra,*

25 *E-08193, Barcelona – Spain (PM).*

26 *Programa de Pós-Graduação em Saúde e Produção Animal na Amazônia, Universidade*  
27 *Federal Rural da Amazônia (UFRA), Av. Presidente Tancredo Neves 2501, Terra Firme,*  
28 *Postal Code 66077-830, Belém, Pará – Brazil (PM).*

29

30 \*Correspondent: hanibiz@gmail.com

31

32 The resilience of a given species to hunting is conditioned by the effect of potential threats  
33 upon the more sensitive periods in its life history, such as when animals are breeding. We  
34 investigated the environmental drivers of breeding seasonality in the lowland paca (*Cuniculus*  
35 *paca*), and the potential impact of hunting on the species. As part of a participative study with  
36 hunters in 2 Amazonian sites, we obtained reproductive organs of pacas as well as  
37 information on the hunters' daily wild meat extraction. Using data on rainfall, river water  
38 level, and fruiting phenology from the 2 study sites, we applied generalized additive models  
39 (GAMLSS) to examine the effect of climatic and environmental factors on paca reproduction.  
40 Forest fruiting was directly linked to higher pregnancy rates in pacas, and when lactation and  
41 weaning of offspring mostly occurred. Hunting was highly seasonal in all studied years and  
42 positively correlated with higher levels of river water. The coincidence between hunting  
43 patterns and paca reproductive cycles during the wet season resulted in more pregnant  
44 females being harvested. In addition to the known slow reproductive rate of pacas, the  
45 disproportionate offtake of pregnant females may affect the long-term sustainability of  
46 hunting of this species. Reducing hunting during the flooded season may not be feasible  
47 because the lowland paca provides most of wild meat consumed by thousands of rural  
48 Amazonians during this period. However, options to offset the negative effects of killing of  
49 pregnant females could include the zoning of hunting areas or encouraging hunters to target  
50 primarily males. Our results indicate that strategies for the sustainable harvest of paca and

51 other heavily hunted Amazonian mammals should consider the interaction between the  
52 species' reproductive cycles and hunting by local people in order to enhance conservation  
53 and management efforts.

54

55 Key words: conception dates, forest phenology, game species, hunter participation,  
56 management, pregnancy rates, rainfall patterns, reproduction, Rodentia, wildlife

57

58 A resiliência de uma espécie à caça é condicionada pela sua capacidade reprodutiva  
59 intrínseca e pelo efeito de potenciais ameaças durante os períodos mais sensíveis de sua  
60 história de vida, como o período reprodutivo. Neste trabalho, nós investigamos os fatores  
61 ambientais que determinam a sazonalidade reprodutiva da paca (*Cuniculus paca*) e o  
62 potencial impacto da caça sobre espécie. Em um estudo participativo de 15 anos em duas  
63 áreas da Amazônia, obtivemos órgãos reprodutivos de pacas doados voluntariamente por  
64 caçadores, bem como informações sobre seus padrões diários de caça. Usando informações  
65 sobre precipitação, nível d'água dos rios e fenologia de frutificação, nós aplicamos modelos  
66 aditivos generalizados (GAMLSS) para examinar o efeito de fatores climáticos e ambientais  
67 na reprodução da paca. A precipitação esteve positivamente ligada a uma maior frutificação,  
68 que por sua vez foi correlacionada com maiores taxas de prenhes da paca e com os períodos  
69 de lactação e desmame da prole. A caça de paca foi altamente cíclica ao longo dos anos e  
70 positivamente associada aos níveis d'água mais elevados. A convergência entre os padrões de  
71 caça e os ciclos reprodutivos de paca resulta na extração de um grande número de fêmeas  
72 grávidas. Juntamente com a lenta taxa de reprodução da espécie, a captura desproporcional de  
73 fêmeas grávidas pode afetar a sustentabilidade do uso da paca. Reduzir a caça durante os  
74 períodos de inundação pode não ser viável, pois a paca é a espécie responsável por fornecer  
75 grande parte da carne silvestre consumida por milhares de moradores rurais da Amazônia

76 neste período. No entanto, ações para compensar os efeitos negativos da extração de pacas  
77 grávidas poderiam incluir o zoneamento de áreas de caça ou o incentivo aos caçadores em  
78 abater preferencialmente machos. Nossos resultados indicam que estratégias para a extração  
79 sustentável da paca e outras espécies cinegéticas amazônicas devem considerar a interação  
80 entre a reprodução e a caça pela população local, a fim de melhorar as ações de conservação e  
81 manejo no bioma.

82

83 Palavras-chave: datas de concepção, fenologia florestal, espécies cinegéticas, coleta  
84 participativa, manejo, taxas de prenhes, padrões de chuva, reprodução, Rodentia, vida  
85 silvestre

86

87 In high latitudes, where climatic variability between seasons is greatest, most species produce  
88 a large number of offspring in a short period of time, most of which do not survive (Bronson  
89 1985). By contrast, in more stable environments with less seasonal variation, such as tropical  
90 forest regions, species generally produce a constant, low number of offspring over the year  
91 (McNaughton 1975). However, in the Amazon basin, the extreme variation in river levels,  
92 caused by seasonal meltwater in the Andes or rainfall, affects food availability (particularly  
93 tree fruits) to such an extent that frugivorous mammals may exhibit a greater than expected  
94 reproductive seasonality for this environment (Dubost et al. 2005). Seasonal patterns in water  
95 levels also determine patterns of hunting and fishing by humans (Endo et al. 2016).

96 Animal populations are regulated by factors that impact mortality and recruitment  
97 (Caughley 1977). Understanding the population dynamics of exploited species is essential to  
98 determine sustainable harvest rates for wildlife populations. Harvesting individuals can have  
99 direct effects on the growth rate of a population by increasing mortality rates. There is  
100 increasing evidence that harvesting can also have indirect effects on population growth. For

101 instance, harvest can disrupt the sex and age structure of a population, which can in turn  
102 affect fecundity rates (Milner et al. 2007; Bunnefeld et al. 2009). Furthermore, sex-skewed  
103 harvesting can have potentially deleterious effects on long-term fecundity (defined as the  
104 number of young born) and lead to population collapse, as shown for ungulates (Ginsberg  
105 and Milner-Gulland 1994; Freeman et al. 2014). In addition, overhunting of females in  
106 seasonally breeding animals, during periods when more females are pregnant, may negatively  
107 influence the population dynamics of the species.

108         In this paper, we evaluate how hunting may affect the population dynamics of the  
109 lowland paca (*Cuniculus paca*). The paca is a large, frugivorous caviomorph rodent that  
110 occurs throughout the Neotropics, inhabiting primarily broadleaf forests from east-central  
111 Mexico to northern Argentina. (Collet 1981; Pérez 1992; Aquino et al. 2009; Goulart et al.  
112 2009). Studies to date, in primary broadleaf forest, suggest that pacas occupy relatively small  
113 home ranges (Marcus 1984; Beck-King et al. 1999), and are patchily distributed in mosaic  
114 landscapes with scattered resources (Marcus 1984; Beck-King et al. 1999; Ulloa et al. 1999).  
115 Pacas feed mostly on fruits and seeds, and occasionally consume leaves and flowers (Beck-  
116 King et al. 1999; Dubost 2017).

117         Pacas are of conservation and management interest throughout their geographic range,  
118 as a popular game species for people (e.g., Read et al. 2010; El Bizri et al. 2015, 2016;  
119 Gutiérrez-Granados 2015; Mayor et al. 2015), an important prey of large carnivores, and as  
120 seed dispersers (Dubost and Henry 2006; Aquino et al. 2009; Foster et al. 2016). However,  
121 there is concern that current levels of hunting may be unsustainable, as observed in several  
122 Amazonian sites (e.g., Zapata-Ríos et al. 2009; Valsecchi et al. 2014). Given the importance  
123 of the paca as a source of protein to human residents of tropical forests, identifying the  
124 factors that may affect paca numbers remains fundamental.

125 Here, in 2 sites in Amazonian Peru and Brazil, we first assess how environmental  
126 factors such as rainfall patterns affect fruit availability, and in turn show how this correlates  
127 with the reproductive seasonality of pacas. We then assess the impact of hunting rates during  
128 the different phases of the reproductive cycle of pacas using data gathered from a 15-year  
129 participatory hunting study for the 2 study sites.

130

131

## MATERIALS AND METHODS

132 *Study sites.*— The Yavarí-Mirín River (YMR; 04°19'53" S, 71°57'33" W) is located  
133 in the western Peruvian Amazon, encompassing 107,000 ha of continuous upland forests  
134 containing a single indigenous community of 307 inhabitants (Fig. 1). The Amanã  
135 Sustainable Development Reserve (ASDR; 01°54'00" S, 64°22'00" W) is a 2,313,000-ha  
136 reserve of predominantly upland forests in the central Brazilian Amazon, between the Negro  
137 and Japurá rivers. Approximately 4,000 riverine people inhabit 23 communities and some  
138 isolated settlements within this reserve (Fig. 1). In both study sites, local communities rely on  
139 agriculture for income and on hunting and fishing for subsistence. River water levels at both  
140 sites change seasonally, varying up to 12 m between the dry and flood peaks (Ramalho et al.  
141 2009). Climate in both study sites is typically equatorial with annual temperatures ranging  
142 between 22°C and 36°C, relative humidity of 80%, and an annual rainfall of 1,500 – 3,000  
143 mm.

144 *Water level and rainfall.*— For the YMR, we calculated monthly average river water  
145 level (as meters above sea level – m.a.s.l.) and rainfall (in mm) on the Yavarí River, from  
146 data provided by a Brazilian National Water Agency hydrological station, c. 50 km from the  
147 study site (HidroWeb, Estirão do Repouso station, rainfall: 1962 – 1999, water level: 1980 –  
148 2017, <http://www.snirh.gov.br/hidroweb/>). In the ASDR, we used data on average rainfall  
149 (mm) for the Tefé municipality, c. 90 km from the study area, from information also provided

150 by the Brazilian National Water Agency (HidroWeb, Tefé station, 2005 – 2017,  
151 <http://www.snirh.gov.br/hidroweb/>). We used data on river water levels from the Mamirauá  
152 Sustainable Development Institute for the Amanã Lake station inside the ASDR (1990 –  
153 2018, [https://mamiraua.org.br/pt-br/pesquisa-e-  
154 monitoramento/monitoramento/fluviometrico/](https://mamiraua.org.br/pt-br/pesquisa-e-monitoramento/monitoramento/fluviometrico/)).

155 *Ripe fruit availability.*— We determined annual changes in ripe fruit availability, the  
156 main item in the diets of pacas (Dubost et al. 2005), by monitoring tree fruit abundance in 3  
157 transects between March 2004 and February 2005. Two transects, started at random points,  
158 were in upland forests in the YMR, and a third transect was located in *aguajal*, upland swamp  
159 forest dominated by palms. All transects were 5 m wide except one in the upland forest,  
160 which was 20 m wide (Pitman et al. 2003). We tagged and identified every tree of a diameter  
161 at breast height (DBH) >10 cm, as well as every vine or liana of DBH >7 cm (Ayres 1986).  
162 We marked plants until the rate of discovery of new species plateaued (Sutherland 2000),  
163 which determined the length and area of each transect. Starting mid-month, we observed the  
164 canopy of each tagged tree or vine once per month with binoculars and a small telescope,  
165 recording the presence or absence of ripe fruits in each sampled individual plant. Because  
166 fruits of the moriche palm (*Mauritia flexuosa*) constitute an important part of the diet of  
167 pacas (Mendieta-Aguilar et al. 2015), we also obtained more detailed fruiting data from the  
168 38 individuals found within the transects and analyzed it independently.

169 *Paca reproduction and hunting.*— We trained local hunters in the YMR community  
170 and in 5 ASDR communities to remove all abdominal and pelvic organs from hunted  
171 specimens and to store these materials in buffered 4% formaldehyde solution (v/v). From  
172 2000 to 2015, local hunters collected and voluntarily donated genitalia from 300 female pacas  
173 (212 in the YMR and 88 in the ASDR), each labeled with the hunting date. Since hunters do  
174 not consume these organs, we avoided encouraging additional mortality to supply our study.



175 In parallel, between 2000 and 2015 in the YMR, and between 2002 and 2015 in the ASDR,  
176 hunters recorded all hunted pacas, including sex and hunting date. In each monitored  
177 community in YMR and ASDR, local hunters were provided with datasheets in which they  
178 voluntarily recorded information on their daily hunting events. To ensure data were  
179 accurately collected, we conducted regular workshops and meetings (at least once per year)  
180 with all data providers and members of the participating communities. In this study, we only  
181 used the data for hunted females.

182 *Data analysis.*— We removed the conceptuses from all pregnant females. Using a  
183 metal caliper (maximum 300 mm) and a tape measure (1.0 mm accuracy), we measured the  
184 crown-rump length and longitudinal length of each embryo or fetus, from rostral edge of nose  
185 to distal portion of the tail. Conception dates were determined by backdating the date of  
186 collection each embryo or fetus from their estimated age, using the age formula for paca  
187 fetuses in El Bizri et al. (2017). Predicted parturition dates were estimated by summing a  
188 standard gestation length of 149 days (Guimarães et al. 2008) to the derived conception dates.  
189 We then calculated the monthly number and percentage of conceptions and parturitions  
190 during the study period. Hunting data on females collected by local people were also used to  
191 calculate the monthly percentage of female pacas hunted in each site within each monitored  
192 year (hereafter known as hunting rates). Additionally, we estimated the pregnancy period  
193 (from conception to parturition dates) for each paca, and summed the cumulative number of  
194 pregnant pacas per month to obtain a monthly percentage of pregnant females among all  
195 collected samples in a year (hereafter known as pregnancy rate). We also estimated the  
196 monthly percentage of weaned offspring by summing a standard lactation length of 21 days  
197 to the parturition dates, which correspond to the period after which the offspring, although  
198 still suckling, starts eating solid food (Collett 1981). In addition, we calculated the average  
199 longitudinal length of the embryos or fetuses per month in each locality.

200           We applied generalized additive models for location, scale, and shape (GAMLSS)  
201 (Stasinopoulos and Rigby 2007) to assess the relationship between climate, fruiting, paca  
202 reproductive events, and hunting. By using GAMLSS, it is possible to test across a wide set  
203 of distribution families, ensuring the best fit to the data is selected. Analyses were conducted  
204 in 3 sets using a theoretical framework of likely direct relationships between the variables. In  
205 set (1), we evaluated the relationship between monthly rainfall (predictor variable) and  
206 monthly fruiting percentage in the 3 YMR environments. In set (2), we evaluated the  
207 relationship between monthly fruiting percentage in the 3 environments (predictor variables)  
208 and paca reproductive events (percentage of conceptions, parturitions, and weaning, and  
209 pregnancy rates) for the YMR; in this second set, we also tested rainfall as a predictor  
210 variable for conceptions in both areas (YMR and ASDR), since this factor has been reported  
211 as a possible cue for conceptions in several mammal species. In set (3), we evaluated the  
212 relationship between river water level and paca reproductive events (predictor variables) with  
213 hunting rates. For the latter, we calculated the monthly percentage of hunted females in each  
214 year in both areas and related these values with the monthly average water level and  
215 percentage reproductive events, which were considered constants among months,  
216 independently of the year.

217           We tested all combinations of predictor variables in each set in linear or non-linear  
218 forms using different distribution families. Final models were selected based on  $\Delta$ AIC values,  
219 i.e., the difference between the value of Akaike's information criterion (AIC) for the model  
220 being evaluated and the model with the lowest AIC value (Burnham and Anderson 2004);  
221  $\Delta$ AIC values smaller than 2 indicated models with good support. Among these models, we  
222 chose the simplest one as final, i.e., the model with fewest degrees of freedom and with  
223 fewest predictor variables in the model. We used R 3.3.3 software (R Core Team 2017) for

224 all statistical analyses. GAMLSS were run using the *gamlss* R-package. Values are expressed  
225 as the mean  $\pm$  standard deviation ( $\bar{X} \pm SD$ ).

226 *Compliance.*— All research followed guidelines of the American Society of  
227 Mammalogists for the ethical use of wild animals in research (Sikes et al. 2016) and was  
228 conducted in compliance with the research protocol approved by the Research Ethics  
229 Committee for Experimentation in Wildlife at the Dirección General de Flora y Fauna  
230 Silvestre from Peru (License 0229-2011-DGFFS-DGEFFS), by the Instituto Chico Mendes  
231 for Biodiversity Conservation from Brazil (License SISBIO No 29092-1), and by the  
232 Committee on Ethics in Research with Animals of the Federal Rural University of the  
233 Amazon (UFRA CEUA protocol 007/2016).

234

## 235 RESULTS

236 *Ripe fruit availability.*— We sampled 589 trees and vines in 8,970 m<sup>2</sup> of upland  
237 forests, and 386 trees and vines in 5,150 m<sup>2</sup> of swamp forests. Fruiting patterns in the YMR  
238 varied according to habitat type. In upland forests, fruiting trees were present throughout the  
239 year, with peaks in March (6.62% plants fruiting) and December (4.68% plants fruiting; Fig.  
240 2). In swamp forests, fruiting peaked between February and May ( $6.12 \pm 0.83\%$  plants  
241 fruiting), with no trees fruiting in September and October. *Mauritia flexuosa* showed marked  
242 fruiting during the low rainfall period (May - August), with the highest number of fruiting  
243 trees recorded in June (34.21%); no fruits were observed during the remaining months of the  
244 year (Fig. 2). Upland forest fruiting was positively correlated with rainfall (Fig. 3, Table 1),  
245 but there was no correlation between *M. flexuosa* fruiting and rainfall in swamp forest (Table  
246 1).

247 *Paca reproductive seasonality.*— There were 157 (52.3%) pregnant pacas among all  
248 sampled females, 100 (47.2%) in the YMR and 57 (64.8%) in ASDR (Fig. 4). Average fetal

249 length was  $11.30 \pm 10.58$  cm in the YMR and  $17.43 \pm 9.74$  cm in the ASDR, with a  
250 significant difference between sites ( $t_{155} = 3.59$ ,  $P < 0.01$ ). Paca reproductive events occurred  
251 during different periods of the year in the 2 study sites. In YMR, conceptions occurred  
252 mainly between October and January (50.0%), while parturitions primarily took place  
253 between March and June (49.0%). In ASDR, most conceptions occurred between March and  
254 June (45.6%), while most parturitions happened between August and November (42.1 %; Fig.  
255 5). Nevertheless, conceptions and parturitions occurred throughout the year in both sites.  
256 There was a positive relationship between conceptions and rainfall in both study sites (Figs.  
257 6A and B), but there was a negative relationship between conceptions and fruiting in upland  
258 forests in the YMR (Fig. 6C; Table 1). Pregnancy rates were positively associated with  
259 fruiting in upland forest (Fig. 6D), while the higher weaning rates were related to higher  
260 fruiting periods in swamp forest (Fig. 6E) and of *M. flexuosa* (Fig. 6F, Table 1). On the other  
261 hand, there was no relationship between parturition and fruiting in any environment (Table  
262 1).

263 *Hunting vulnerability of pregnant pacas.*— A total of 803 hunted paca females were  
264 recorded in the communities, 288 in the YMR and 515 in the ASDR. Hunting rates varied  
265 between months, which were cyclical along the years (Figs. 7A and B) and showed a positive  
266 relationship with the river water level in both study sites (Figs. 7C and D, Table 1). A strong  
267 positive relationship between hunting rates and pregnancy rates was observed (Figs. 7F and  
268 G, Table 1). There were no relationships between conceptions, parturitions, and weaned  
269 offspring and hunting rates (Table 1).

270

271

## DISCUSSION

272

273

*Paca reproductive seasonality and fruit availability.*— Although pregnant females were present year-round in our study sites, most pregnancies occurred during periods of

274 greater fruit availability in upland forests, when rainfall was highest. The greater food supply  
275 during this period can sustain larger numbers of pregnant females. When most females are in  
276 their last third of gestation, a period of greatest absolute fetal growth and when pregnant  
277 individuals demand more energy, fruit availability is, in fact, at its peak. A similar pattern has  
278 been observed for the ring-tailed coati (*Nasua nasua*) where the gestation period,  
279 concentrated between November and March, coincided with greater fruit availability in  
280 upland and swamp forests in the YMR (Mayor et al. 2013a). However, mammals with less  
281 selective diets are aseasonal breeders, as in the case of the white-lipped peccary (*Tayassu*  
282 *pecari*), collared peccary (*Pecari tajacu*), and the red brocket deer (*Mazama americana*)  
283 (Mayor et al. 2009, 2010, 2011), because these species consume green leaves, insects, and  
284 small vertebrates when fruit is less available (Dubost and Henry 2017). This pattern has also  
285 been confirmed by Dubost and Henry (2017) in French Guiana, who showed that mammals  
286 that consume more fruits were highly seasonal breeders.

287 *Changing energy demands and seasonality in food supply.*— There is evidence from  
288 Amazonia that a seasonal increase in rainfall triggers fruit maturation in several habitat types,  
289 including non-flooded forests (Haugaasen and Peres 2005). Since rainfall and river water  
290 levels vary in different regions of the Amazon, reproductive events of the paca occur at  
291 different phases of the year in each of our studied sites, according to local variations in  
292 climate and fruit production. Paca reproduction is therefore plastic and opportunistically  
293 seasonal (Mayor et al. 2013b). Thus, for fruit-dependent species, rainfall, in contrast to  
294 photoperiod, may drive conceptions to take place some months prior to fruit ripening, and  
295 pregnancies and births will coincide with the period of higher fruit abundance. The  
296 observation made by Dubost and Henry (2006) that non-pregnant pacas consumed less seeds  
297 than pregnant animals also suggests that conceptions occur during periods of low food  
298 availability so that pregnancies mostly occur during periods of higher fruit and seed

299 availability. Our results also show that the greatest number of conceptions occurred when  
300 fruit availability in upland forests was low; pregnant pacas could take advantage of the  
301 subsequent periods of greater food supply. Similarly, in free-ranging, provisioned rhesus  
302 macaques (*Macaca mulatta*) on islands in Puerto Rico, more conceptions occurred during the  
303 spring rainfall period, just before the main tree-fruiting season (Rawlins and Kessler 1985).

304         In Amazonia, swamp forest species and *M. flexuosa* in particular (the most important  
305 source of food during the drought period) play a major role in sustaining lactating females  
306 and their young, which start weaning during the low-water period. Since during lactation  
307 females consume up to 5 times more food than before pregnancy (Randolph et al. 1977), the  
308 availability of ripe fruits during this period is of extreme importance. For several species of  
309 flying foxes (*Pteropus* spp.), O'Brien (1993) showed that lactation and offspring weaning  
310 occur during periods when fruit supply is at its peak. In addition, Lee et al. (2017) showed  
311 that giraffe (*Giraffa camelopardalis*) calves born during the dry season in Tanzania had a  
312 higher survival probability due to the greater energy reserves accumulated by mothers during  
313 the rainy season as well as the higher protein concentration of available browse during the  
314 late dry-season rains.

315         *Hunting and reproduction in quarry species.*— Different prey can cope with human  
316 harvest according to their population dynamics and biological capacity (Cardillo et al. 2005),  
317 but their patterns of reproduction reflect their response to environmental and human  
318 disturbance. Predator–prey systems often co-evolve slowly through generations by the action  
319 of natural selection, with the appearance of phenotypical and behavioral traits in prey species  
320 that avoid their extinction (Kooijman and Lika 2014). However, the current reproductive  
321 strategies in wild species are not adapted to the typically more intensive levels of human  
322 predation, especially when hunting is directly impacting pregnant females and affecting the  
323 species' recruitment potential.

324 Water levels and hunting rates were shown to have a similar cyclical pattern over the  
325 period of 15 years for which data were available. Other studies in the Amazon basin have  
326 also demonstrated that hunters maximize their captures by taking into account seasonal water  
327 level changes (Kvist et al. 2001; Endo et al. 2016). This temporal convergence between  
328 heavier hunting and pregnancies in pacas is thus likely to adversely impact the species'  
329 population dynamics. A probable indication that hunting of pregnant paca females during  
330 high-water periods may affect populations of the species is available for the ASDR, where  
331 Valsecchi et al. (2014) demonstrated that paca hunting is unsustainable and the species'  
332 abundance at this site significantly dropped over an 8-year period.

333 *Management implications.*— Pacas provide the largest proportion of wild meat  
334 consumed by local populations and even urban dwellers in the Amazon (Bodmer and Lozano  
335 2001; Suárez et al. 2009; van Vliet et al. 2015). However, the species has a relatively low  
336 reproductive output, in which females only produce 1 young per pregnancy (Mayor et al.  
337 2013b; El Bizri et al. 2017). The results presented here highlights the necessity for  
338 developing sustainable harvest strategies that are compatible with the target species' life  
339 history and their reproductive patterns. These strategies could include focusing hunting  
340 efforts on males or reducing hunting during the pregnancy season. However, avoiding  
341 hunting pacas during high water levels may not be possible for hunters. During the flooded  
342 period, fishing becomes difficult and hunting becomes the main source of meat supply during  
343 this period (Valsecchi et al. 2014; Endo et al. 2016), thus making it unlikely for a shift away  
344 from hunting pacas during the wet season. On the other hand, since male pacas can fertilize  
345 several females, hunting males exclusively during the high-water period, when pregnant  
346 females are more common, is feasible since rural Amazonian hunters pursue pacas by  
347 “spotlighting” (Valsecchi et al. 2014), thus permitting the identification of the sex of the  
348 animal and even the pregnancy stage of females (H. R. El Bizri, pers. obs.).

349 Another strategy to improve the state of hunted paca populations is to encourage the  
350 use of rotating hunting areas over the years or to protect areas during the hunting season that  
351 could act as refugia for females. This strategy would create a source-sink system where  
352 protected grounds would function as sources of individuals to repopulate areas depleted by  
353 hunting. This strategy has already been advocated as efficient to conserve species such as the  
354 culpeo fox (*Pseudalopex culpaeus*) in the Argentine Patagonia (Novaro et al. 2005) as well as  
355 ungulates in the Neotropics (Naranjo et al. 2001; Naranjo and Bodmer 2007). A similar  
356 approach was effectively applied to recover giant Arapaima (*Arapaima gigas*) populations by  
357 encouraging community-based source-sink schemes; this system is now successfully applied  
358 throughout the Amazon (Campos-Silva et al. 2017). Here, we argue that source-sink systems  
359 could be equally applied for pacas. However, as all systems, these also need to be  
360 continuously monitored and adapted especially because the demand for paca meat is likely to  
361 increase in line with human population growth. Thus, additional measures such as setting  
362 quotas of the paca population that can be harvested per family, hunter, or community may be  
363 needed. Finally, since palm species are essential for pacas, and probably other Amazonian  
364 species, to achieve their highest reproductive potential, actions focused on conservation of  
365 swamp forest palm species, which are largely exploited by humans (Peters et al. 1989; Rull  
366 and Montoya 2014), are also critical.

367 Due to the fact that most hunting in Amazonia is determined by the annual variation  
368 in river water level, we argue that the impact we have observed in pacas could be mirrored in  
369 other species, and hence might affect the sustainability of wild meat, so vital for numerous  
370 inhabitants. Accordingly, strategies that ensure the sustainability of hunted Amazonian  
371 species must be based on reproductive information to minimize the impact on their  
372 populations when they are most vulnerable.

373



374  
375  
376  
377  
378  
379  
380  
381  
382  
383  
384  
385  
386  
387  
388  
389  
390  
391  
392  
393  
394  
395  
396  
397  
398

#### ACKNOWLEDGMENTS

We sincerely thank the people from the Yavari-Mirin River and the Amanã Sustainable Development Reserve, without whom this work would not be possible. We also thank J. R. Gonçalves for making the map, and T.Q. Morcatty for aid in the statistical analysis. This work was supported by the Gordon and Betty Moore Foundation, the National Council of Technological and Scientific Development (CNPq) [grant numbers 300005/2013-0; 452908/2016-7; 201475/2017-0], the IVITA (Instituto Veterinario de Investigaciones de Tropico y de Altura), the Museo de la Universidad Nacional de la Amazonía Peruana, the Earthwatch Institute and the Fundacion Autonoma Solidaria.

#### LITERATURE CITED

AYRES, J. M. 1986. The white Uakaris and the Amazonian flooded forests. PhD dissertation, University of Cambridge, UK.

BECK-KING, H., HELVERSEN, O., AND BECK-KING, R. 1999. Home Range, population density, and food resources of *Agouti paca* (Rodentia: Agoutidae) in Costa Rica: A study using alternative methods. *Biotropica* 31 (4): 675-685.

BODMER, R. E., AND LOZANO, E. P. 2001. Rural development and sustainable wildlife use in Peru. *Conserv. Biol.* 15: 1163-1170.

BRONSON, F.H. 1985. Mammalian reproduction: an ecological perspective. *Biol. Reprod.* 32: 1-26.

BURNHAM, K.P., AND ANDERSON, D.R. 2004. Multimodel inference: understanding AIC and BIC in model selection. *Sociological Methods & Research* 33:261-304.

BUNNEFELD, N., BAINES, D., NEWBORN, D., AND MILNER-GULLAND, E.J. 2009. Factors affecting unintentional harvesting selectivity in a monomorphic species. *Journal of Animal Ecology* 78, 485-492.

399 CAMPOS-SILVA, J.V., PERES, C.A., ANTUNES, A.P., VALSECCHI J., PEZZUTI, J. 2017.  
400 Community-based population recovery of overexploited Amazonian wildlife.  
401 Perspectives in Ecology and Conservation 15: 266-270.

402 CARDILLO, M., MACE, G. M., JONES, K. E., BIELBY, J., BININDA-EMONDS, O. R. P., SECHREST,  
403 W., ORME, C.D.L., AND PURVIS, A. 2005. Multiple causes of high extinction risk in large  
404 mammal species. Science, 309(5738), 1239-1241.

405 CAUGHLEY, G. 1977. Analysis of Vertebrate Populations. John Wiley & Sons, London.

406 COLLET, S.F. 1981. Population characteristics of *Agouti paca* (Rodentia) in Colombia.  
407 Michigan: Michigan State University.

408 DUBOST, G., HENRY, O., AND COMIZZOLI, P. 2005. Seasonality of reproduction in the three  
409 largest terrestrial rodents of French Guiana forest. Mammalian Biology 70: 93-109.

410 DUBOST, G., AND HENRY, O. 2006. Comparison of diets of the acouchy, agouti and paca, the  
411 three largest terrestrial rodents of French Guianan forests. Journal of Tropical  
412 Ecology 22: 641-651.

413 DUBOST, G., AND HENRY, O. 2017. Seasonal reproduction in Neotropical rainforest mammals.  
414 Zoological Studies 56: 2.

415 EL BIZRI, H., MORCATTY, T., LIMA, J., AND VALSECCHI, J. 2015. The thrill of the chase:  
416 uncovering illegal sport hunting in Brazil through YouTube™ posts. Ecology and  
417 Society 20: 30.

418 EL BIZRI, H. R., DA SILVA ARAÚJO, L. W., DA SILVA ARAÚJO, W., MARANHÃO, L., AND  
419 VALSECCHI, J. 2016. Turning the game around for conservation: using traditional hunting  
420 knowledge to improve the capture efficiency of Amazon lowland pacas. Wildlife  
421 Biology 22: 1-6.

422 EL BIZRI, H. R., MONTEIRO, F. O. B., DE ANDRADE, R. S., VALSECCHI, J., GUIMARÃES, D. A.  
423 A., AND MAYOR, P. 2017. Embryonic and fetal morphology in the lowland paca  
424 (*Cuniculus paca*): A precocial hystricomorph rodent. *Theriogenology* 104: 7-17.

425 ENDO, W., PERES, C. A., AND HAUGAASEN, T. 2016. Flood pulse dynamics affects  
426 exploitation of both aquatic and terrestrial prey by Amazonian floodplain  
427 settlements. *Biological Conservation* 201: 129-136.

428 FLOWERDEW, J.R. 1987. MAMMALS: THEIR REPRODUCTIVE BIOLOGY AND POPULATION  
429 ECOLOGY. LONDON: EDWARD ARNOLD.

430 FREEMAN, E.D., LARSEN, R.T., PETERSON, M.E., ANDERSON JR., C.R., HERSEY K.R. AND  
431 MCMILLAN, B.R. 2014. Effects of male-biased harvest on mule deer: implications for  
432 rates of pregnancy, synchrony, and timing of parturition. *Wildlife Society Bulletin*, 38,  
433 806-811.

434 GINSBERG, J. R., MILNER-GULLAND, E. J. 1994. Sex-biased harvesting and population  
435 dynamics in ungulates: implications for conservation and sustainable use. *Conservation*  
436 *Biology* 8, 157-166.

437 GUIMARÃES, D.A.A., BASTOS, L.V., FERREIRA, A.C.S., LUZ-RAMOS, R.S., OHASHI, O.M., AND  
438 RIBEIRO, H.L. 2008. Características reprodutivas da paca fêmea (*Agouti paca*) criada em  
439 cativeiro. *Acta Amazonica* 38:531-538.

440 HAUGAASEN, T., AND PERES, C. A. 2005. Primate assemblage structure in Amazonian flooded  
441 and unflooded forests. *American Journal of Primatology* 67: 243-258.

442 KOOIJMAN, S. A., & LIKA, K. 2014. Resource allocation to reproduction in  
443 animals. *Biological Reviews* 89: 849-859.

444 KVIST, L. P., GRAM, S., AND ORE, I. 2001. Socio-economy of flood plain households in the  
445 Peruvian Amazon. *Forest Ecology and Management* 150: 175-186.

- 446 LEE, D. E., BOND, M. L., AND BOLGER, D. T. 2017. Season of birth affects juvenile survival of  
447 giraffe. *Population Ecology* 59: 45-54.
- 448 MAYOR, P., BODMER, R. E., AND LOPEZ-BEJAR, M. 2009. Reproductive performance of the  
449 wild white-lipped peccary (*Tayassu pecari*) female in the Peruvian Amazon. *European*  
450 *Journal of Wildlife Research* 55: 631-634.
- 451 MAYOR, P. G., BODMER, R. E., AND BEJAR, M. L. 2010. Reproductive performance of the wild  
452 collared peccary (*Tayassu tajacu*) female in the Peruvian Amazon. *European Journal of*  
453 *Wildlife Research* 56: 681-684.
- 454 MAYOR, P., BODMER, R. E., LOPEZ-BEJAR, M., AND LÓPEZ-PLANA, C. 2011. Reproductive  
455 biology of the wild red brocket deer (*Mazama americana*) female in the Peruvian  
456 Amazon. *Animal Reproduction Science* 128: 123-128.
- 457 MAYOR, P., MONTES, D., AND LÓPEZ-PLANA, C. 2013a. Functional morphology of the female  
458 genital organs in the wild ring-tailed coati (*Nasua nasua*) in the northeastern Peruvian  
459 Amazon. *Canadian Journal of Zoology* 91: 496-504.
- 460 MAYOR, P., GUIMARÃES, D. A., AND LÓPEZ, C. 2013b. Functional morphology of the genital  
461 organs in the wild paca (*Cuniculus paca*) female. *Animal Reproduction Science* 140:  
462 206-215.
- 463 MAYOR, P., PÉREZ-PEÑA, P., BOWLER, M., PUERTAS, P., KIRKLAND, M., AND BODMER, R.  
464 2015. Effects of selective logging on large mammal populations in a remote indigenous  
465 territory in the northern Peruvian Amazon. *Ecology and Society* 20: 36.
- 466 MAYOR, P., EL BIZRI, H., BODMER, R. E. AND BOWLER, M. 2017. Assessment of mammal  
467 reproduction for hunting sustainability through community-based sampling of species in  
468 the wild. *Conservation Biology* 31: 912–923.
- 469 MCNAUGHTON, S. 1975. r-and K-selection in *Typha*. *The American Naturalist* 109: 251-261.

470 MENDIETA-AGUILAR, G., PACHECO, L. F., AND ROLDÁN, A. I. 2015. Dispersión de semillas de  
471 *Mauritia flexuosa* (Arecaceae) por frugívoros terrestres en Laguna Azul, Beni,  
472 Bolivia. *Acta Amazonica* 45: 45-56.

473 MILNER, J.M., NILSEN, E.B., ANDREASSEN, H.P. 2007. Demographic side effects of selective  
474 hunting in ungulates and carnivores: review. *Conservation Biology* 21, 36–47  
475 (doi:10.1111/j.1523-1739.2006.00591.x) [PubMed]

476 NARANJO, E.J, BODMER, R.E. 2007. Source–sink systems and conservation of hunted  
477 ungulates in the Lacandon Forest, Mexico. *Biological Conservation* 138: 412-420.

478 NOVARO, A.J., REDFORD, K.H., BODMER, R.E. 2001. Effect of Hunting in Source-Sink  
479 Systems in the Neotropics. *Conservation Biology* 14: 713-721.

480 NOVARO, A. J., FUNES, M. C., AND WALKER, R. S. 2005. An empirical test of source–sink  
481 dynamics induced by hunting. *Journal of Applied Ecology* 42: 910-920.

482 PITMAN, N., VRIESENDORP, C., AND MOSKOVITS, D. 2003. Peru: Yavari. Rapid Biological  
483 Inventories Report 11. Chicago: The Field Museum.

484 PERES, C. A. 2000. Effects of subsistence hunting on vertebrate community structure in  
485 Amazonian forests. *Conservation Biology* 14:240-253.

486 PETERS, C. M., BALICK, M. J., KAHN, F., AND ANDERSON, A. B. 1989. Oligarchic forests of  
487 economic plants in Amazonia: utilization and conservation of an important tropical  
488 resource. *Conservation Biology* 3: 341-349.

489 O'BRIEN, G. M. 1993. Seasonal reproduction in flying foxes, reviewed in the context of other  
490 tropical mammals. *Reproduction, Fertility and Development* 5: 499-521.

491 R CORE TEAM. 2017. R: A language and environment for statistical computing. R Foundation  
492 for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.

- 493 RAMALHO, E. E., MACEDO, J., VIEIRA, T. M., VALSECCHI, J., MARMONTEL, M., AND QUEIROZ,  
494 H. L. 2010. Ciclo hidrológico nos ambientes de várzea da Reserva de Desenvolvimento  
495 Sustentável Mamirauá – médio rio Solimões, período de 1990 a 2008. UAKARI 5: 61-87.
- 496 RANDOLPH, P. A., RANDOLPH, J. C., MATTINGLY, K. AND FOSTER, M. M. 1977. Energy costs  
497 of reproduction in the cotton rat *Sigmodon hispidus*. Ecology 58:31-45.
- 498 RAWLINS, R. G., AND KESSLER, M. J. 1985. Climate and seasonal reproduction in the Cayo  
499 Santiago macaques. American Journal of Primatology 9: 87-99.
- 500 RULL, V., AND MONTOYA, E. 2014. *Mauritia flexuosa* palm swamp communities: natural or  
501 human-made? A palynological study of the Gran Sabana region (northern South  
502 America) within a Neotropical context. Quaternary Science Reviews 99: 17-33.
- 503 SIKES, R. S., AND THE ANIMAL CARE AND USE COMMITTEE OF THE AMERICAN SOCIETY OF  
504 MAMMALOGISTS. 2016. 2016 Guidelines of the American Society of Mammalogists for  
505 the use of wild mammals in research and education. Journal of Mammalogy 97:663–688.
- 506 STASINOPOULOS, D.M., RIGBY, R.A. 2007. Generalized additive models for location, scale  
507 and 491 shape (GAMLSS) in R. Journal of Statistical Software 23(7):1-46.
- 508 SUTHERLAND, W. J. 2000. The conservation handbook: Techniques in research, management  
509 and policy. Oxford: Blackwell Science.
- 510 SUAREZ, E., ET AL., 2009. Oil industry, wild meat trade and roads: indirect effects of oil  
511 extraction activities in a protected area in north-eastern Ecuador. Animal Conservation  
512 12: 364-373.
- 513 VALSECCHI, J., EL BIZRI, H. R., AND FIGUEIRA, J. E. C. 2014. Subsistence hunting of  
514 *Cuniculus paca* in the middle of the Solimões River, Amazonas, Brazil. Brazilian Journal  
515 of Biology 74: 560-568.
- 516 VAN VLIET, N., QUICENO-MESA, M. P., CRUZ-ANTIA, D., TELLEZ, L., MARTINS, C., HAIDEN,  
517 E., OLIVEIRA, M. R., ADAMS, C., MORSELLO, C., VALENCIA, L., BONILLA, T., YAGÜE, B.,

- 518 AND NASI, R. 2015. From fish and bushmeat to chicken nuggets: the nutrition transition  
519 in a continuum from rural to urban settings in the Tri frontier Amazon region. *Ethnobiol*  
520 *Conserv* 4: 1-12.
- 521 ZAPATA-RÍOS, G., URGILÉS, C., AND SUÁREZ, E. 2009. Mammal hunting by the Shuar of the  
522 Ecuadorian Amazon: is it sustainable? *Oryx* 43: 375-385.

## FIGURE LEGENDS

FIGURE 1. Location of the 2 study sites (YMR: Yavari-Mirín River, ASDR: Amanã Sustainable Development Reserve) in Amazonia and the communities participating in the monitoring of hunting and collection of biological material on lowland pacas (*Cuniculus paca*).

FIGURE 2. Trends in (A) rainfall (dashed line) and percentage of trees bearing fruits in upland forests (solid line) and swamp forest (solid line); and (B) rainfall (dashed line) and percentage of *M. flexuosa* trees bearing fruits (solid line) along the year in the Yavari-Mirín River, western Amazonia.

FIGURE 3. Relationship between rainfall (mm) and percentage of trees bearing fruits in upland forests in the Yavari-Mirín River, western Amazonia. The gray area represents 95% confidence intervals. The response variable is plotted on the y-axis in a scale of variation around the mean ( $\mu = 0$ ) calculated from the original data used to build the model.

FIGURE 4. Number and percentage of lowland paca (*Cuniculus paca*) samples that included a uterus showing signs of pregnancy, collected in each month over the monitoring years in the Amanã Sustainable Development Reserve (ASDR) and Yavari-Mirín River (YMR), Amazonia.

FIGURE 5. Trends in (A, B) the percentage of paca conceptions (dashed gray lines) and parturitions (solid black lines); and (C, D) average river water level (dashed lines) and percentage of pregnant female pacas (solid lines) along the year in the Amanã Sustainable Development Reserve (ASDR) and Yavari-Mirín River (YMR), Amazonia.



FIGURE 6. Relationship between (A) rainfall and the percentage of paca conceptions in the Amanã Sustainable Development Reserve, central Amazonia; (B) rainfall and percentage of paca conceptions in the Yavari-Mirín River, western Amazonia; (C) percentage of trees bearing fruits in upland forest and percentage of paca conceptions in the Yavari-Mirín River, western Amazonia; (D) percentage of trees bearing fruits in upland forest and pregnancy rate in the Yavari-Mirín River, western Amazonia; (E) percentage of trees bearing fruits in swamp forest and percentage of weaned offspring, and (F) percentage of *M. flexuosa* trees bearing fruits and percentage of weaned offspring in the Yavari-Mirín River, western Amazonia. The gray area represents 95% confidence intervals. Response variables are plotted on the y-axis in a scale of variation around the mean ( $\mu = 0$ ) calculated from the original data for models with a single predictor variable, and from partial residuals for models including more than 1 predictor variable.

FIGURE 7. Temporal trends of the river water level and hunting rates (monthly percentage of hunted females within each year) in the (A) Amanã Sustainable Development Reserve, and (B) Yavari-Mirín River, in Amazonia. Relationship between river water level and hunting rates in the (C) Amanã Sustainable Development Reserve and (D) Yavari-Mirín River, in Amazonia. Relationship between pregnancy rate and hunting rates in the (E) Amanã Sustainable Development Reserve and (F) Yavari-Mirín River, in Amazonia. The gray area represents 95% confidence intervals. Response variables are plotted on the y-axis in a scale of variation around the mean ( $\mu = 0$ ) calculated from partial residuals of the models.

## TABLES

**Table 1.** Details of the best-fit models using GAMLSS for each response variable, with the family of distribution,  $\Delta$ AIC in relation to the null model ( $\Delta$ AIC null), and generalized  $R^2$ . Non-linear effects were fit using cubic spline (*cs*) functions provided by gamlss R-package. Families of distributions are represented by log-Normal (LOGNO), Normal (NO), Zero-Adjusted Gamma (ZAGA), Gamma (GA), Box-Cox t (BCTo), inverse Gaussian (IG), Gumbel (GU), and Inverse Gamma (IGAMMA). Generalized  $R^2$  were calculated using the function Rsq of the gamlss package. Null models are indicated by 1.

Best fitted model <sup>a</sup>		Estimate	P-value	Family of distribution	$\Delta$ AIC null	Generalized $R^2$
Response variables	Predictor variables					
Yavari-Mirin River						
Fruiting						
% plants fruiting U.F.	<i>cs</i> (rainfall)	0.0068		LOGNO	5.45	62
% plants fruiting S.F.	1	-		NO	1.23	
% plants fruiting <i>M.f.</i>	1	-		ZAGA	0.87	
Paca reproductive events						
% conceptions	rainfall	0.0083	0.011	LOGNO	3.97	48.5
	% plants fruiting U.F.	-0.2147	0.027			
% parturitions	1			IG	1.22	
% weaned offspring	% plants fruiting S.F.	0.6945	0.009	GU	11.95	73.5
	% plants fruiting <i>M.f.</i>	0.0972	0.041			
pregnancy rate	<i>cs</i> (plants fruiting U.F.)	0.0734	0.007	IGAMMA	5.6	67
Paca hunting						
hunting rates	water level	0.0541	0.033	ZAGA	6.02	6.73
	pregnancy rate	0.2239	0.003			
Amanã Reserve						
Paca reproductive events						
% conceptions	<i>cs</i> (rainfall)	0.0333	0.001	RG	3.97	53.6
Paca hunting						
hunting rates	water level	0.102	<0.001	ZAGA	7.22	29.1
	pregnancy rate	0.2223	<0.001			

<sup>a</sup>abbreviations for plants fruiting – U.F.: upland forest; S.F.: swamp forest; *M.f.*: *Mauritia flexuosa*.

## FIGURE LEGENDS

FIGURE 1. A map showing the location of the two study sites (YMR: Yavarí-Mirín River, ASDR: Amanã Sustainable Development Reserve) in Amazonia and the communities participating in the hunting monitoring and biological material collection on lowland pacas (*Cuniculus paca*).

FIGURE 2. Trends in (A) rainfall (dashed dark blue line) and percentage of fruiting trees in upland forest (solid green line) and swamp forest (solid orange line); and (B) rainfall (dashed dark blue line) and percentage of *M. flexuosa* fruiting trees (solid brown line) along the year in the Yavarí-Mirín River, Western Amazonia.

FIGURE 3. Relationship between rainfall (mm) and percentage of fruiting trees in upland forests (U.F.) in the Yavarí-Mirín River, Western Amazonia.

FIGURE 4. Trends in (A, B) the percentage of paca conceptions (dashed grey lines) and parturitions (solid black lines); and (C, D) river water level (dashed blue lines) and percentage of pregnant paca females (solid red line) along the year in the Amanã Sustainable Development Reserve (ASDR) and Yavarí-Mirín River (YMR), in Amazonia.

FIGURE 5. Relationship between (A) rainfall and the percentage of paca conceptions in the Amanã Sustainable Development Reserve, Central Amazonia; (B) rainfall and percentage of paca conceptions, (C) percentage of fruiting trees in upland forest (U.F) and percentage of paca conceptions, (D) percentage of fruiting trees in upland forest (U.F) and pregnancy rate, (E) percentage of fruiting trees in swamp forest (S.F) and percentage of weaned offspring,

and (C) percentage of fruiting trees of *M. flexuosa* (M.f) and percentage of weaned offspring in the Yavarí-Mirín River, Western Amazonia.

FIGURE 6. Temporal trends of the river water level and monthly percentage of hunted females along the years in the (A) Amanã Sustainable Development Reserve, and (B) Yavarí-Mirín River, in Amazonia. Relationship between river water level and monthly percentage of hunted females in the (C) Amanã Sustainable Development Reserve and (D) Yavarí-Mirín River, in Amazonia. Relationship between pregnancy rate and monthly percentage of hunted females in the (E) Amanã Sustainable Development Reserve and (F) Yavarí-Mirín River, in Amazonia.

Fig. 1

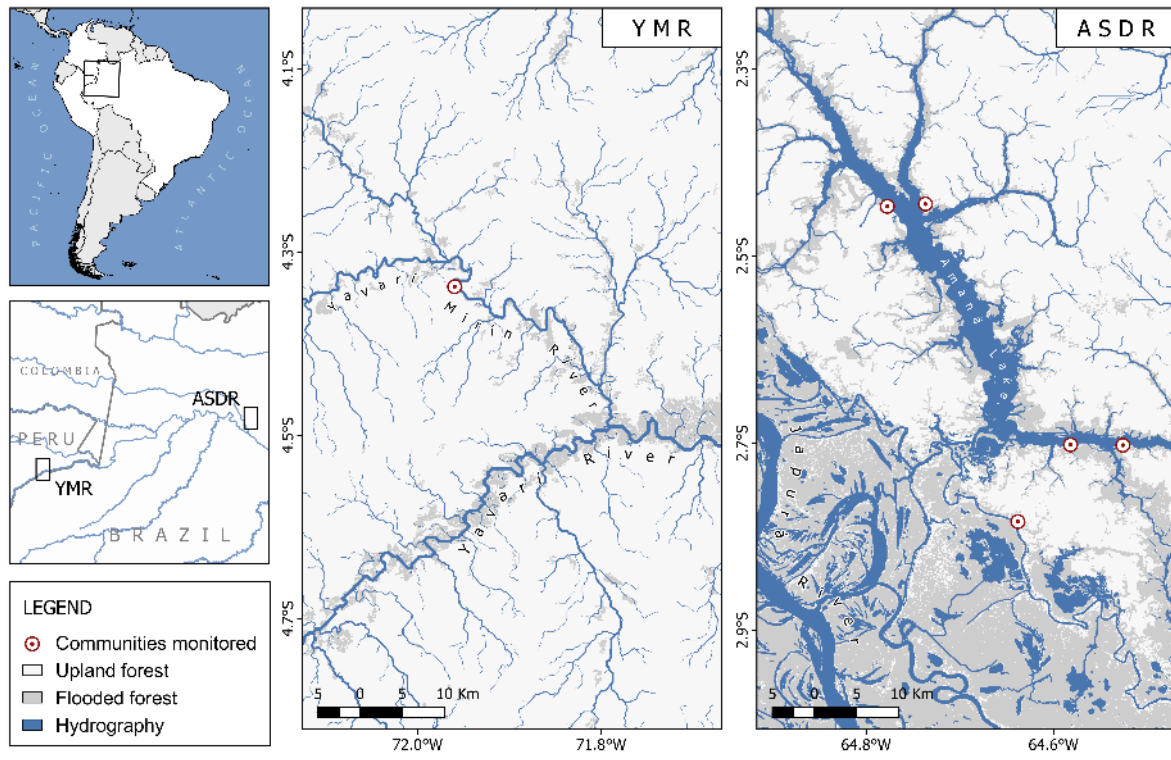


Fig. 2

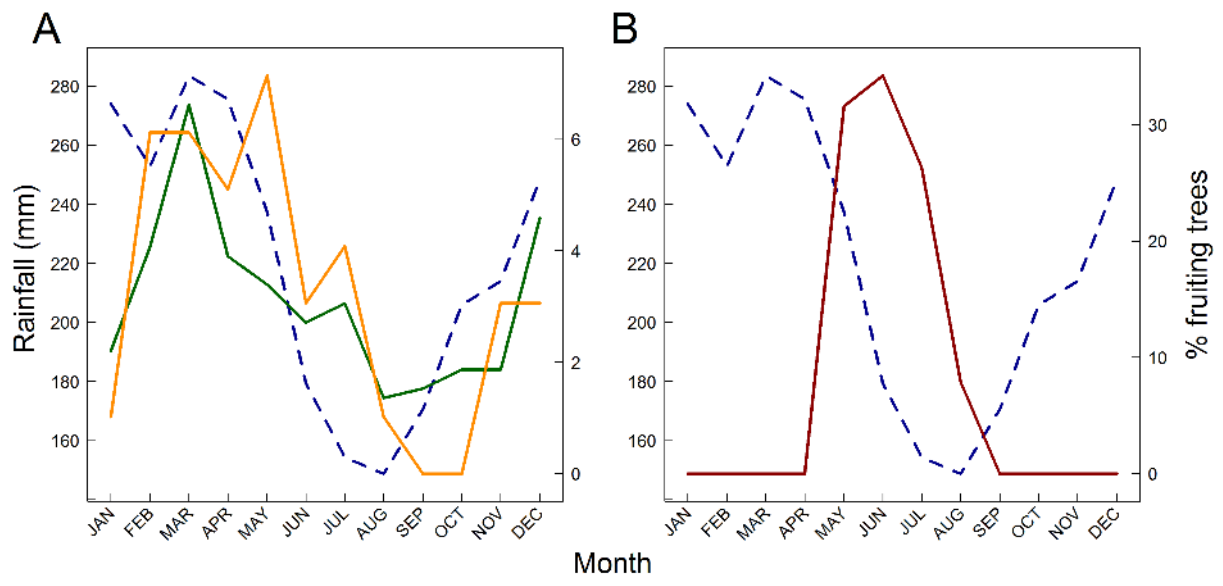


Fig. 3

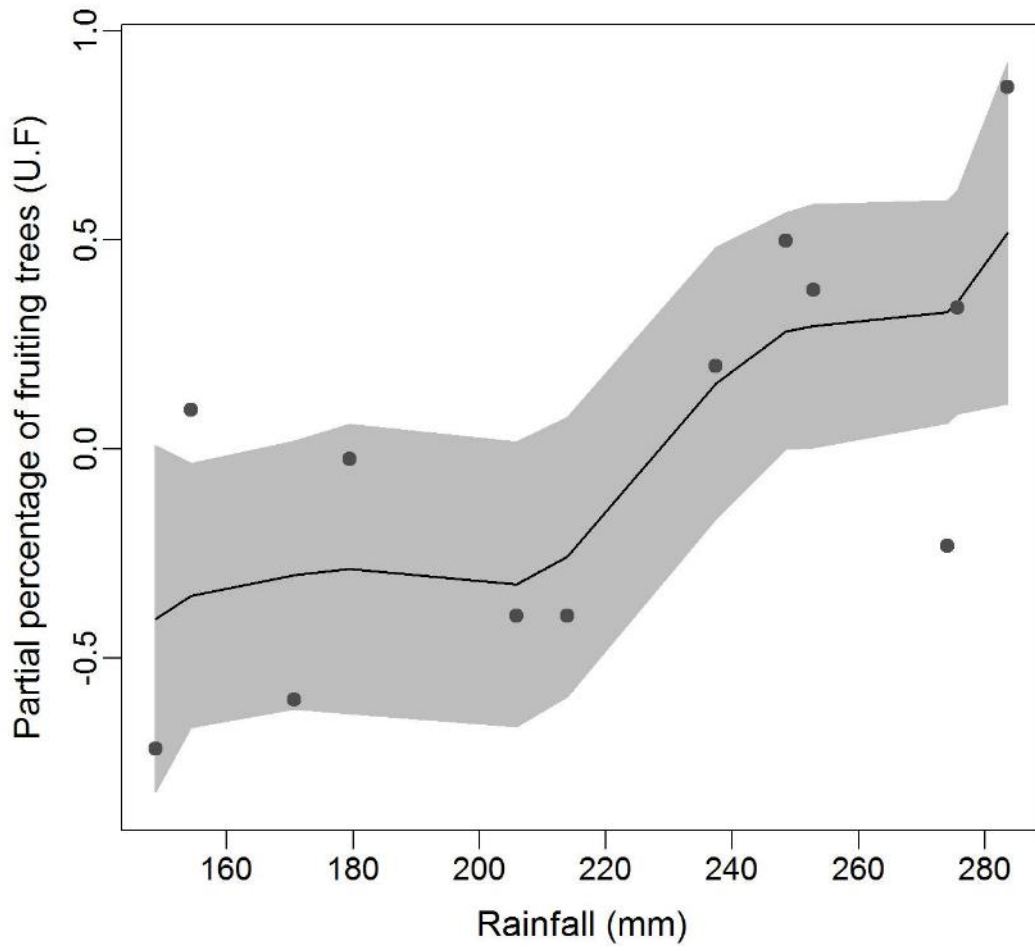


Fig. 4

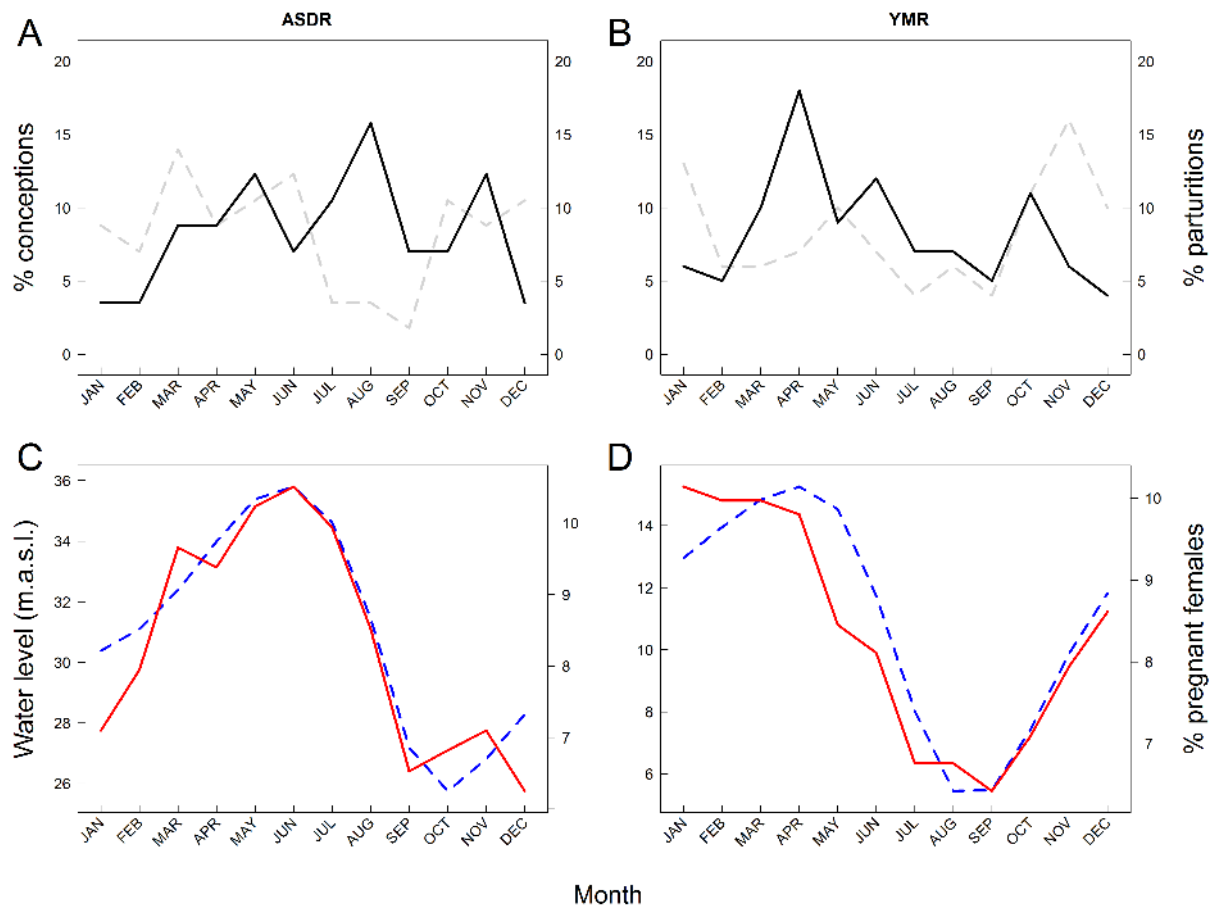




Fig. 5

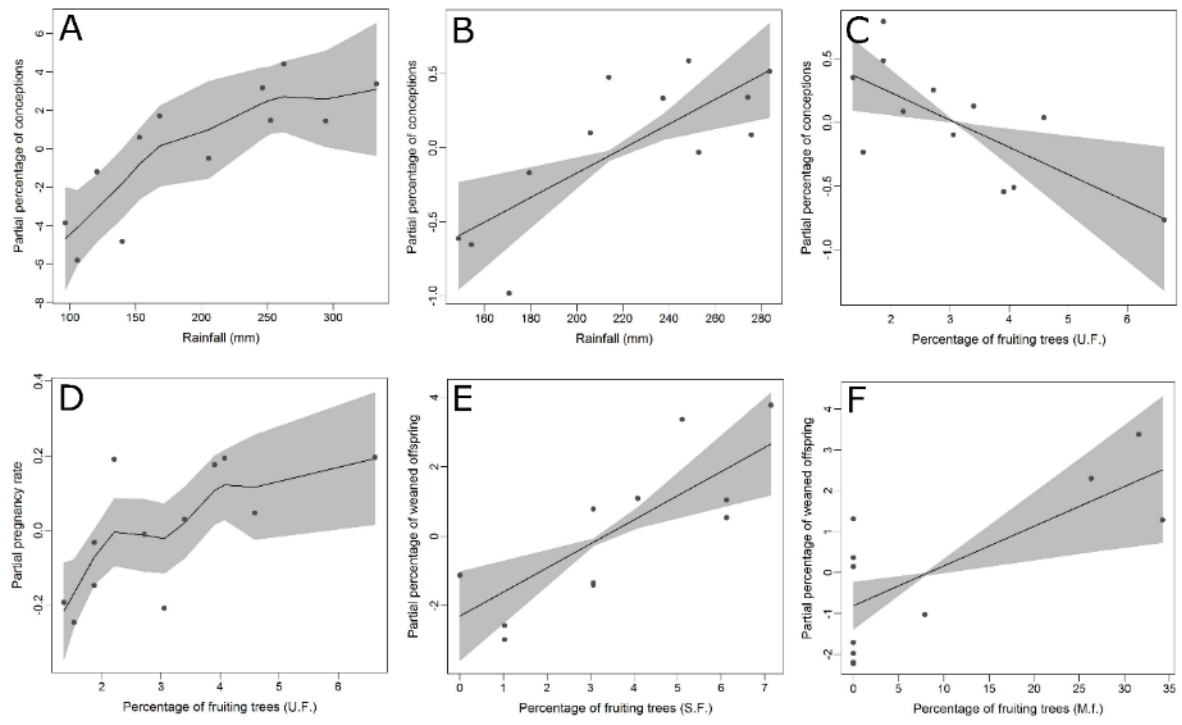


Fig. 6

