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LED flashlight technology facilitates wild meat extraction across the tropics

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Abstract:	Hunting for wild meat in the tropics provides subsistence and income for millions of people. Methods have remained relatively unchanged since the introduction of shotguns and battery-powered incandescent flashlights, but due to the short life of batteries in such flashlights, nocturnal hunting has been limited. However, brighter, more efficient

	<p>light-emitting diode (LED) flashlights, have recently been adopted by hunters. Brighter spotlights increase the freezing response of many species, and greater battery life allows hunters to pursue game for longer and more frequently. Hunters interviewed in African and South American forests, disclosed that LEDs increase the frequency and efficiency of nocturnal hunting, and the number of kills made. These changes were reflected in harvest data in Brazil. The drastic change in efficiency brought about by LEDs, well known to hunters around the world, poses a significant threat to wildlife. We consider the implications for communities, governments, wildlife managers and conservationists.</p>

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26

27 Abstract

28 Hunting for wild meat in the tropics provides subsistence and income for millions
29 of people. Methods have remained relatively unchanged since the introduction of
30 shotguns and battery-powered incandescent flashlights, but due to the short life of

31 batteries in such flashlights, nocturnal hunting has been limited. However, brighter,
32 more efficient light-emitting diode (LED) flashlights, have recently been adopted by
33 hunters. Brighter spotlights increase the freezing response of many species, and
34 greater battery life allows hunters to pursue game for longer and more frequently.
35 Hunters interviewed in African and South American forests, disclosed that LEDs
36 increase the frequency and efficiency of nocturnal hunting, and the number of kills
37 made. These changes were reflected in harvest data in Brazil. The drastic change in
38 efficiency brought about by LEDs, well known to hunters around the world, poses a
39 significant threat to wildlife. We consider the implications for communities, governments,
40 wildlife managers and conservationists.

41

42 **Introduction**

43 Wild vertebrates are a source of food and income for millions of people
44 throughout the tropics. However, overhunting is a major concern, causing the decline of
45 large-bodied animal species and driving some to extinction (Benítez-López, *et al.* 2017,
46 Maxwell, *et al.* 2016, Ripple, *et al.* 2016). Unsustainable hunting threatens the food
47 security of rural populations that depend on wild meat (Cawthorn and Hoffman 2015,
48 Nasi, *et al.* 2011). Wild animals in tropical forests are hunted with a variety of methods,
49 both traditional (e.g. bow and arrow) and modern (e.g. firearms) (Fa and Brown 2009).
50 Methods have improved incrementally through time, through the use of metal wire for
51 the manufacture of snares and traps in Africa, cheaper guns, and the availability of
52 incandescent battery-powered flashlights for hunting at night (Alvard 1995, Hames
53 1979, Levi, *et al.* 2009, Redford and Robinson 1987). Flashlights are used to locate
54 animals using the eyeshine that many species exhibit, a method known as spotlighting
55 or lamping (Hames 1979). Many animals are temporarily immobilized by the lights,
56 appearing to see the light as non-threatening. Hunters can then carefully approach to
57 within a short distance of the animals to greatly improve their chances of making a kill.

58 Powerful, white light-emitting diodes (LEDs) are increasingly replacing
59 incandescent bulbs in flashlights. LED flashlights are brighter and approximately 10-20
60 times more efficient than incandescent lightbulbs (Pimputkar, *et al.* 2009). Although
61 LEDs existed for decades as low-power indicator lights, and high-power white-light

62 emitters have been produced since 1999, this technology remained prohibitively
63 expensive for hunters in developing countries for many years. Our collaborative
64 research groups observed that LED flashlight prices became comparable to
65 incandescent flashlights around 2012 and are now available in rural markets throughout
66 the tropics, and widely employed in nocturnal hunting in Latin America, Africa and Asia.

67 We investigated the impact of LED flashlights in increasing wild mammal offtake
68 by hunters in tropical forests, using interviews with commercial and subsistence hunters
69 in Peru, Brazil and Gabon. We support this with data from hunting events monitored for
70 13 years in the Brazilian Amazon comparing hunting returns before and after the
71 introduction of LED lights.

72

73 **Methods**

74 *Hunter interviews*

75 During 2016 and 2017, we administered semi-structured questionnaires to 120
76 shotgun hunters in three countries (Peru, Brazil and Gabon). In Peru, we interviewed 58
77 subsistence and commercial hunters from three dispersed communities - *Nueva*
78 *Esperanza* on the Rio Yavari, *Tahuayo* on the Rio Tahuayo, and *Sucusari*, on the Rio
79 Napo, in Western Amazonia. In Brazil, we questioned 32 subsistence hunters in the *Boa*
80 *Esperança* and *Bom Jesus do Baré* communities in the Amanã Sustainable
81 Development Reserve (ASDR), between the Japurá and Negro Rivers, in Central
82 Amazonia. In Gabon, we interviewed 30 principally commercial hunters from 18 villages
83 within the rural Ogooué-Ivindo Province.

84 In each country, researchers familiar with the study areas and hunters, and
85 experienced in communicating with local communities, administered interviews
86 translated from an original text in Spanish. We asked each hunter the following
87 questions, in Spanish, Portuguese or French; Q1. Do you use LED flashlights, and if so,
88 when did you switch to these?; Q2. Do you hunt more frequently at night since you
89 started using LEDs; Q3. Do LED lights make hunting easier or harder, and why? Q4.
90 What species do you hunt at night? And do you kill more, or less of these species since
91 using LEDs?

92

93 *Pre- and Post-LED hunting success in Brazil*

94 As part of a long-term hunting study in five communities within the ASDR, Brazil,
95 hunting registers were kept continuously for 13 years between 2003 and 2015 (n=1373
96 hunts; 1999 kills). Lowland paca (*Cuniculus paca*), the most frequently hunted species
97 in Amazonia (El Bizri, *et al.* 2019), are targeted specifically on nocturnal canoe forays,
98 which were recorded separately between 2002 and 2015. Hunters recorded the start
99 and end of each hunt, species hunted, and the time of all kills. Because the identities of
100 hunters are kept anonymous, the number of hunts each hunter recorded is unknown.
101 Hunting in Brazil is forbidden by law, except by necessity for subsistence within the
102 family. Hunting is therefore tolerated in small isolated communities such as those in the
103 ASDR, and hunters are generally comfortable reporting catches. This is especially true
104 in the ASDR where participatory monitoring has been in place for over 10 years. There
105 is no specific independent verification of the data, but researchers participate in the data
106 collection and train hunters annually.

107 Catch per unit effort (CPUE) ($\text{kg hunter}^{-1} \text{hour}^{-1}$) (Rist, *et al.* 2010) is the usual
108 metric to show changes in hunting efficiency, but among the nocturnal species recorded
109 in hunting registers, sample sizes were sufficient to calculate CPUE annually only for
110 the paca (n=309 nocturnal hunts; 501 nocturnal kills). For all hunted species collectively,
111 we calculated the proportion of diurnal versus nocturnal hunts and kills annually, and for
112 the lowland tapir (*Tapirus terrestris*), a nocturnal species for which hunting occurs both
113 diurnally and nocturnally, we calculated the proportion of nocturnal versus diurnal kills
114 each year (n=27 kills). These metrics were compared before and after the uptake of
115 LED flashlights by the hunters in the reserve.

116

117 **Results**

118 *Q1. Do you use LED flashlights, and if so, when did you switch to these?*

119 LED flashlights were used by all interviewed hunters in Peru and Brazil and by
120 almost all hunters (93%) in Gabon. In Peru (n=58) and Brazil (n=32), hunters estimated
121 that they started using LEDs around 2011, and in Gabon (n=28) reported uptake was
122 around 2015.

123

124 Q2. *Do you hunt more frequently at night since you started using LEDs?*

125 In Peru and Brazil, most hunters (66% at both sites) said that they hunted more
126 at night now that they had LED flashlights (Figure 1a). In Gabon, where hunting with a
127 light source is illegal, just 32% said they hunted more frequently with LED lights. The
128 remaining hunters did not indicate if they hunted less, or at the same frequency. In all
129 regions, hunters mentioned that LEDs were more efficient than incandescent flashlights.
130 Many hunters also said that because incandescent flashlights used batteries quickly,
131 this made their use prohibitively expensive, thus limiting nocturnal hunting, whereas
132 LEDs allowed hunting for several nights on a single pair of batteries.

133

134 Q3. *Do LED lights make hunting easier or harder, and why?*

135 Over three-quarters of all hunters (75% in Brazil, 77% in Peru and 82% in
136 Gabon) reported that LED flashlights had increased brightness and range over
137 incandescent lights; only hunters that used lower-powered LED flashlights disagreed.
138 More than half of the hunters from each site (69% in Brazil, 40% in Peru, 54% in
139 Gabon) suggested that animals were easier to hunt with LEDs, with most of the
140 remainder saying that there was no change in the ease of hunting (Figure 1b). Those
141 that found hunting easier suggested that this was due to the increased range or
142 brightness of flashlights, and because a higher proportion of animals 'froze in the
143 spotlight'.

144

145 Q4. *What species do you hunt at night? Do you kill more, or less of these species since*
146 *using LEDs?*

147 In Brazil and Peru, hunters most commonly listed paca, brocket deer (*Mazama*
148 spp.), armadillos (*Dasypus* spp.) and tapir as nocturnally-hunted species (Figure 2). In
149 Gabon, Brush-tailed porcupines (*Atherurus africanus*) and duiker (*Cephalophus* spp.
150 and *Philantomba monticola*) were most commonly listed (WebTable 1). In all regions,
151 most LED-using hunters (69% across regions) reported killing more of the nocturnally-
152 hunted species that they mentioned than when they used incandescent lights (Figure
153 1c).

154 Hunters may have underreported the frequency or ease of hunting, or the relative
155 frequency of nocturnal animal kills wherever commercial hunting is illegal or strictly
156 managed. This may have been particularly pronounced in Gabon where commercial
157 hunting and hunting with flashlights are both illegal (République Gabonaise 2001).

158

159 *Pre- and Post-LED hunting success in Brazil*

160 The proportion of hunts made during the night compared to during the day
161 increased around the time LED lights came into use at Amanã (20.6% vs 39.8%, $\text{Chi}_2 =$
162 50.64, $p < 0.001$. Figure 3a. Similarly, the proportion of kills made during the night
163 compared to during the day increased at the same time (19.3% vs 37.3%, $\text{Chi}_2 = 73.45$,
164 $p < 0.001$ Figure 3b). This reflects an increase in the proportions of nocturnal species
165 taken, but also an increase in the proportion of nocturnal kills for species that can be
166 hunted both at night and in daytime. After the uptake of LED flashlights in Amanã, tapir
167 hunting switched from exclusively diurnal to predominantly nocturnal (0% vs 83.3%, Chi
168 $_2 = 25.71$, $p < 0.001$ (Figure 4), with hunters confirming that LED flashlights facilitated
169 this change.

170 Between 2002 and 2010, the catch per unit effort for the lowland paca was in
171 steep decline, but after the widespread adoption of LEDs around 2011, the CPUE close
172 to doubled, before showing signs of declining again (Figure 5). A breakpoint analysis
173 (Bai and Perron 2003) detected a structural change between 2010 and 2011 and a
174 subsequent regression analysis showed that both the intercept and slope change at that
175 point (without change: $R^2=0.183$, $F=3.91$, $p=0.07$, with change: $R^2=0.888$, $F=26.6$,
176 $p < 0.001$).

177

178 **Discussion**

179 *New technology and hunting in the tropics*

180 Our interviews with hunters show that LED flashlights are perceived to have
181 increased the efficiency of nocturnal hunting in tropical sites in three different countries,
182 and that local people now hunt at night more, killing more nocturnal animals. Hunting
183 registers in Brazil are consistent with these hunters' perceptions, showing increases in
184 the proportions of nocturnal hunting and kills. The only explanation put forward by the

185 hunters themselves for these changes in the registers is that the use of LED lights
186 facilitates hunting at night. While we are unable to establish cause and effect from the
187 harvest data, the hunters' testimonials are compelling. Hunters have detailed knowledge
188 of their local areas and are the best sources of information on their hunting methods
189 and behavior. Furthermore, due to the legal and community-imposed restrictions on
190 hunting in place at our study sites, any tendency to misreport is likely to downplay any
191 increases in harvest. Even in Gabon, where the strongest restrictions on hunting are in
192 force, most hunters reported harvesting more nocturnal species since acquiring LED
193 flashlights, while others declined to answer or gave ambiguous responses. Given that
194 harsh penalties for illegal commercial hunting may result in under-reporting of nocturnal
195 hunting in Gabon, we regard this as strong evidence for an increase in the hunting of
196 nocturnal animals resulting from LEDs.

197 Although we do not have figures on the uptake of LEDs in different countries, we
198 suspect that most hunters in tropical countries now use LEDs. LEDs have generally
199 replaced incandescent lights to the point that the older technology is hard to find in our
200 study regions and reductions in costs and waste will benefit rural communities globally.
201 Based on our results and the now-ubiquitous use of LEDs, we suspect that wild meat
202 offtake will have increased across the tropics.

203 In addition to advances in LED technology, the increasing provision of solar
204 power and rechargeable batteries, and the arrival of other technologies, such as
205 refrigeration, mobile phones and cheap, efficient motors, is modernizing hunting in
206 tropical forests. While new technologies tend to be expensive, prices inevitably fall and
207 LED lights are predicted to get ever brighter and more efficient (Pimputkar, *et al.* 2009).
208 More expensive models are already capable of floodlighting large areas of forest, while
209 infrared LEDs and night vision equipment is already commonly employed by hunters in
210 developed countries (Manning 2014), and may eventually be available in the tropics,
211 where they will enable the increasingly rapid extraction of wild meat.

212

213 *Implications for wildlife populations*

214 How gains in hunting efficiency manifest themselves in wild meat harvests
215 depends greatly on the culture and economics of hunting communities, and the

216 demography of the hunted species. While improved efficiency does not necessarily
217 translate to higher offtake, commercial hunting occurs widely across Amazonia (van
218 Vliet, *et al.* 2014), and it is likely that some harvests have increased with the advent of
219 LED lights. For example, tapir hunting in the ASDR shifted from day to night, and
220 hunters confirmed that LED flashlights facilitated this change. It is likely that tapir
221 hunting has increased across Amazonia. Prior to the introduction of LED flashlights, the
222 CPUE of the Lowland paca in the ASDR was declining as a result of overharvesting
223 (Valsecchi, *et al.* 2014). The abrupt increase in CPUE for the paca, at around the time
224 of the introduction of the new lights, is likely to have been repeated across Amazonia,
225 which may have a substantial impact on subsistence and markets. Pacas are widely
226 commercialized in urban markets and restaurants (Mayor, *et al.* 2019), and although
227 they are generally considered resilient to hunting (Bodmer, *et al.* 1997), they reproduce
228 relatively slowly, and can be locally extirpated (El Bizri, *et al.* 2018). CPUE in the ASDR
229 appears to decline again after the initial increase, perhaps indicating a further decline in
230 paca densities. Although pacas are likely to be resilient to hunting in remote areas, they
231 may become scarcer around population centers, making extraction more costly in the
232 longer term.

233 As human populations and demand for wild meat grows throughout sub-Saharan
234 Africa, any increase in nocturnal offtake is unlikely to result in the alleviation of hunting
235 pressure on diurnal species. The most commonly targeted species across Central
236 Africa, brush-tailed porcupines (*Atherurus africanus*) and blue duikers (*Philantomba*
237 *monticola*), are considered locally abundant and resilient to hunting, but 30% of
238 respondents in Gabon reported hunting indiscriminately at night and targeting species of
239 conservation concern like the pangolins (*Smutsia gigantean*, *Phataginus tricuspis* and
240 *Phataginus tetradactyla*), bay duiker (*Cephalophus dorsalis*), white-bellied duiker
241 (*Cephalophus leucogaster*), and yellow-backed duiker (*Cephalophus silvicultor*), for
242 which immediate conservation attention is required.

243

244 *LED flashlights and the implications for wildlife management*

245 It is unlikely that use of LEDs in hunting can be controlled in practice. Other kinds
246 of flashlights are now difficult to find in markets and hunters will select the best light

247 source. Laws restricting hunting equipment would have to forbid nocturnal hunting with
248 any light source. Wildlife laws in Gabon do prohibit this practice (République Gabonaise
249 2001), but the law is not enforced, and hunting with flashlights is common. Other
250 management strategies could counter shifts in harvests, particularly where rural
251 communities depend on wildlife for subsistence and risk overharvesting their resources.
252 The establishment of no-take areas, changes in harvest quotas, or restrictions on
253 hunting vulnerable species, are measures that are already commonly employed with
254 varying degrees of success (Campos-Silva, *et al.* 2017). Efforts could be focused on
255 ecologically sensitive areas like mineral licks, water sources, or game trails that attract
256 animals (Becker, *et al.* 2013). However, such measures, like bans on spotlighting, will
257 fail if hunters do not comply, so local management is likely to be necessary.

258 Although challenging at many sites, community-based co-management, in which
259 local people make management decisions and implement conservation with the
260 technical support of 'co-managers' in government, NGOs or academic institutions has
261 had localized success across Amazonia (Campos-Silva, *et al.* 2017), and is a key
262 principle in several African countries, especially those in southern and eastern areas
263 (Baghai, *et al.* 2018). Because hunters make their own rules and are invested in the
264 outcomes of the interventions, the actions they impose are likely to be widely accepted
265 and implemented. In Peru, this system of management has proven successful at
266 several sites and has been adopted by the government's National Service for Natural
267 Protected Areas (SERNANP) which acts as the co-manager to communities living in
268 and around Natural Protected Areas (Bodmer, *et al.* 2009). Thus, community co-
269 management has been shown to be a scalable management strategy that can be widely
270 implemented.

271 A common feature of community management programs is monitoring animal
272 populations through CPUE (Rist, *et al.* 2010), especially where the budgets of
273 supporting organizations do not permit labor-intensive wildlife surveys, although in
274 practice, measures of effort and catch are prone to bias (Rist, *et al.* 2008). Our results
275 suggest that co-management groups may find increases in CPUE when new hunting or
276 transport technologies emerge. Managers must be careful not to interpret these as
277 increases in wildlife abundance. Similarly, declines in abundance may be masked by

278 the same increases in hunting efficiency that cause the declines. Changes to CPUE are
279 also open to misinterpretation unless communities record spatial and temporal
280 measures of hunts and kills in enough detail. The hunting equipment and methods
281 should also be registered, including the use of dogs, game calls or recordings, while
282 travel methods and the use of mineral licks or other landscape features, will also affect
283 CPUE.

284

285 *Conclusions*

286 We highlight the likely effects of the introduction of LED lights, an otherwise
287 highly beneficial development, on the efficiency of nocturnal hunting. These findings
288 should alert management groups to the potential of increased harvest rates of selected
289 species at the time of introduction, and highlights the limitation of using the CPUE of
290 harvested species to monitor their abundance; a common practice where community
291 co-management is employed (Rist, *et al.* 2010). Managers should be aware that other
292 new technologies may have similar effects on CPUE. Alternative measures of wildlife
293 abundance could be sought, and caution should be employed when interpreting CPUE
294 unless sufficient detail is recorded. Managers must also take changes in technology into
295 account when implementing conservation strategies.

296

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301

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For Review Only

363 Figure Legends

364

365 Figure 1. Responses of hunters asked about changes in their hunting behavior since
366 starting to use LED flashlights in Peru, Brazil and Gabon.

367 *sample size excludes two interviewees who had not switched to LED flashlights

368 †This question was asked as “What species do you hunt at night? Do you kill more of
369 the species you hunt at night since using LEDs?”

370

371 Figure 2. Animals' eyeshine and their response of freezing in a spotlight makes them
372 vulnerable to hunting with flashlights: a) Lowland tapir (*Tapirus terrestris*) with eyeshine,
373 b) Lowland paca (*Cuniculus paca*) with eyeshine c) Paca are hunted predominantly by
374 spotlighting from canoe d) Hunters report that using LED flashlights increases hunting
375 efficiency. LEDs are attached to the head to free up the hands and to increase the
376 pickup of animals' eyeshine. Picture Credits: a) James Warwick, b) Hani El Bizri, c)
377 Mark Bowler, d) Seberino Rios.

378

379 Figure 3. a) The proportion of hunts made at night in the Amanã Sustainable
380 Development Reserve, Brazil, showing an increase in nocturnal hunting at around the
381 time of the introduction of LED lights. b) The proportion of kills made at night in the
382 Amanã Sustainable Development Reserve, Brazil, showing an increase in nocturnal kills
383 at around the time of the introduction of LED lights.

384

385 Figure 4. Day versus night kills for tapir (n=27) in the Amanã Sustainable Development
386 Reserve, Brazilian Amazon, before and after the uptake of LED flashlights.

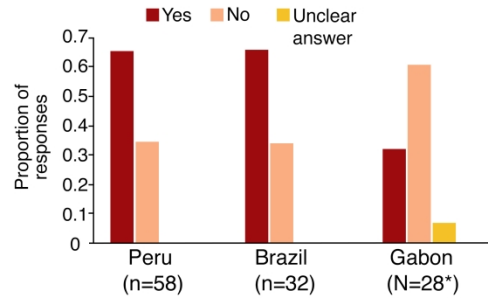
387

388 Figure 5. Catch Per Unit Effort (CPUE) kg hunter⁻¹ hour⁻¹ for the lowland paca
389 (*Cuniculus paca*) in the Amanã Sustainable Development Reserve, Brazilian Amazon. A
390 breakpoint analysis detected a structural change between 2010 and 2011 and a
391 subsequent regression analysis showed that both the intercept and slope change at that
392 point (without change: R²=0.183, F=3.91, p=0.07, with change: R²=0.888, F=26.6,
393 p<0.001). Lines show linear regressions and 95% confidence intervals.

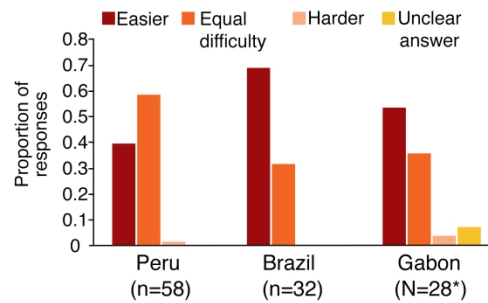
394

For Review Only

a) Q2. Do you hunt more frequently at night since you started using LED lights?



b) Q3. Do LED lights make hunting easier or harder?



c) Q4. Do you kill more of the species you hunt at night using LED lights?†

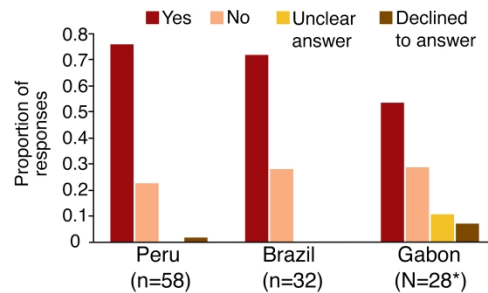


Figure 1. Responses of hunters asked about changes in their hunting behavior since starting to use LED flashlights in Peru, Brazil and Gabon.

*sample size excludes two interviewees who had not switched to LED flashlights

†This question was asked as “What species do you hunt at night? Do you kill more of the species you hunt at night since using LEDs?”



Animals' eyeshine and their response of freezing in a spotlight makes them vulnerable to hunting with flashlights: a) Lowland tapir (*Tapirus terrestris*) with eyeshine, b) Lowland paca (*Cuniculus paca*) with eyeshine. Picture Credits: a) James Warwick, b) Hani El Bizri.

317x473mm (300 x 300 DPI)



Animals' eyeshine and their response of freezing in a spotlight makes them vulnerable to hunting with flashlights: a) Lowland tapir (*Tapirus terrestris*) with eyeshine, b) Lowland paca (*Cuniculus paca*) with eyeshine. Picture Credits: a) James Warwick, b) Hani El Bizri.

564x423mm (180 x 180 DPI)



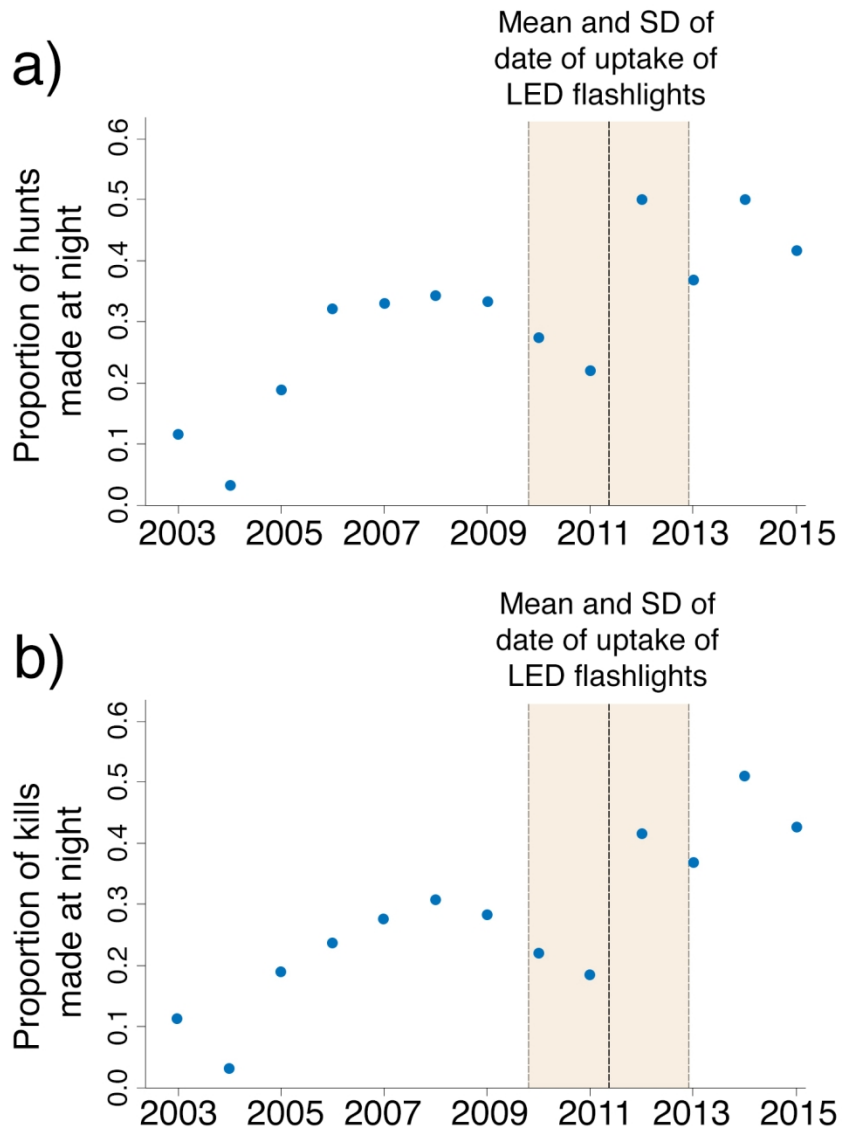
Figure 2. Animals' eyeshine and their response of freezing in a spotlight makes them vulnerable to hunting with flashlights: a) Lowland tapir (*Tapirus terrestris*) with eyeshine, b) Lowland paca (*Cuniculus paca*) with eyeshine c) Paca are hunted predominantly by spotlighting from canoe d) Hunters report that using LED flashlights increases hunting efficiency. LEDs are attached to the head to free up the hands and to increase the pickup of animals' eyeshine. Picture Credits: a) James Warwick, b) Hani El Bizri, c) Mark Bowler, d) Seberino Rios.

140x211mm (240 x 240 DPI)



Figure 2. Animals' eyeshine and their response of freezing in a spotlight makes them vulnerable to hunting with flashlights: a) Lowland tapir (*Tapirus terrestris*) with eyeshine, b) Lowland paca (*Cuniculus paca*) with eyeshine c) Paca are hunted predominantly by spotlighting from canoe d) Hunters report that using LED flashlights increases hunting efficiency. LEDs are attached to the head to free up the hands and to increase the pickup of animals' eyeshine. Picture Credits: a) James Warwick, b) Hani El Bizri, c) Mark Bowler, d) Seberino Rios.

352x264mm (300 x 300 DPI)



The proportion of a) hunts and b) kills made at night in the Amanã Sustainable Development Reserve, Brazil, showing an increase in nocturnal hunting at around the time of the introduction of LED lights.

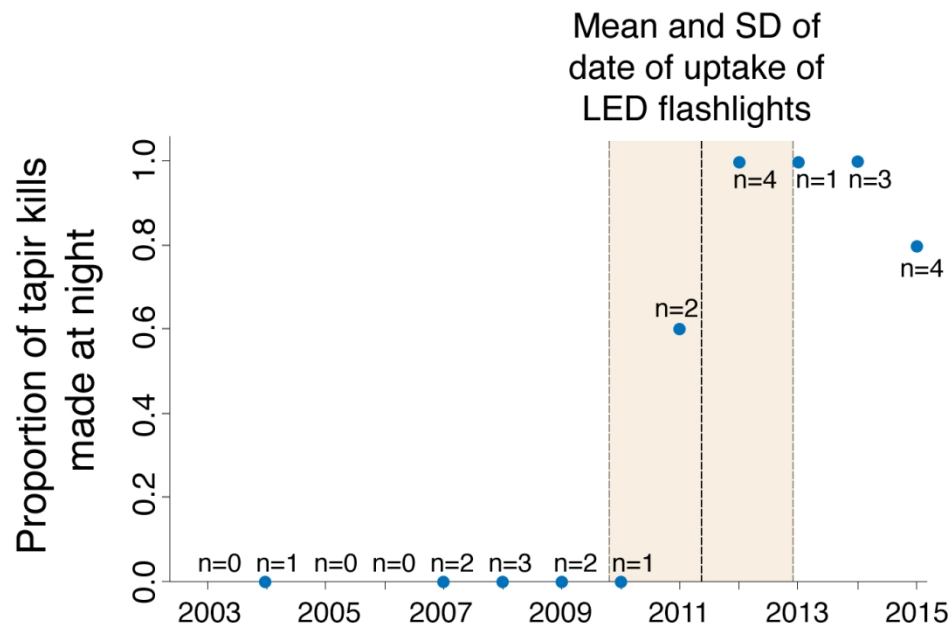


Figure 4. Day versus night kills for tapir ($n=27$) in the Amanã Sustainable Development Reserve, Brazilian Amazon, before and after the uptake of LED flashlights.

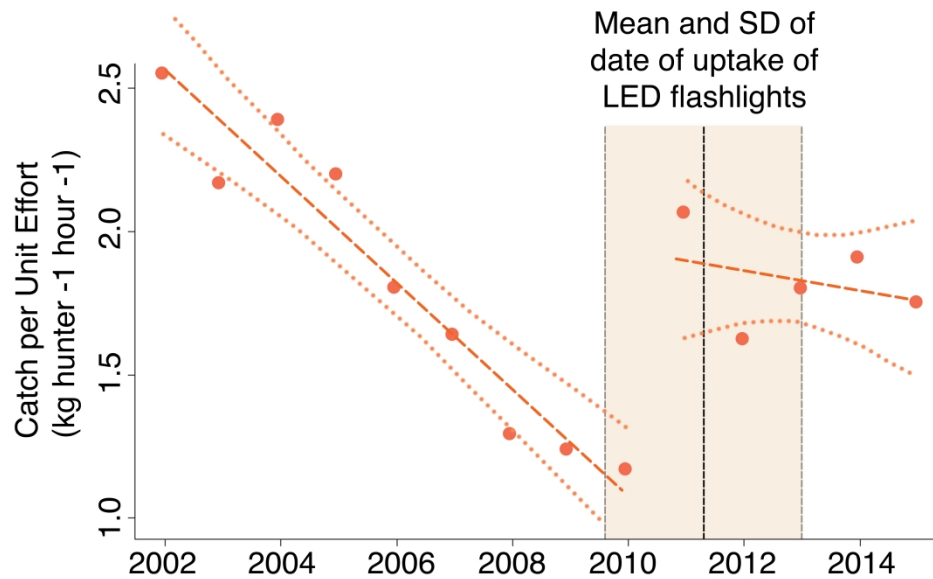


Figure 4. Day versus night kills for tapir ($n=27$) in the Amanã Sustainable Development Reserve, Brazilian Amazon, before and after the uptake of LED flashlights.

Figure 5. Catch Per Unit Effort (CPUE) kg hunter⁻¹ hour⁻¹ for the lowland paca (*Cuniculus paca*) in the Amanã Sustainable Development Reserve, Brazilian Amazon. A breakpoint analysis detected a structural change between 2010 and 2011 and a subsequent regression analysis showed that both the intercept and slope change at that point (without change: $R^2=0.183$, $F=3.91$, $p=0.07$, with change: $R^2=0.888$, $F=26.6$, $p<0.001$). Lines show linear regressions and 95% confidence intervals.

Supplemental Information

WebTable 1. Species and taxonomic groups mentioned by interviewees as hunted at night by hunters in Peru - Rio Yavari, Rio Tahuayo, Rio Napo, Brazil - the Amanã Sustainable Development Reserve, and Gabon, Ogooué-Ivindo Province.

Common name	Species	Number of interviewees mentioning the species		Activity pattern	
Gabon					
African brush-tailed porcupine	<i>Atherurus africanus</i>	20	66.7%	Nocturnal	1
Duikers	<i>Cephalophus spp.</i>	16	53.3%	<i>Cephalophus dorsalis</i> Nocturnal; <i>Cephalophus leucogaster</i> Diurnal; <i>Cephalophus silvicultor</i> Cathemeral	2
Blue duiker	<i>Philantomba monticola</i>	20	66.7%	Diurnal	1
Red river hog	<i>Potamochoerus porcus</i>	5	16.7%	Primarily nocturnal or crepuscular	1
African Palm Civet	<i>Nandinia binotata</i>	3	10.0%	Nocturnal	1
Rats	<i>cf. Thryonomys sp.</i> and <i>Cricetomys sp.</i>	2	6.7%	Nocturnal	1
Pangolin	<i>Phataginus tricuspis</i> and <i>Phataginus tetradactyla</i>	2	6.7%		1
Giant pangolin	<i>Smutsia gigantea</i>	1	3.3%		1
Crocodile	<i>Mecistops cataphractus</i>	1	3.3%	No data	
Mongoose	<i>Atilax paludinosus</i> , <i>Bdeogale nigripes</i> , <i>Herpestes naso</i>	1	3.3%	Primarily nocturnal or crepuscular	1
Brazil					
Lowland paca	<i>Cuniculus paca</i>	32	100.0%	Nocturnal	3
Brocket deer	<i>Mazama spp.</i>	25	78.1%	Crepuscular	4
Lowland tapir	<i>Tapirus terrestris</i>	25	78.1%	Predominantly nocturnal	4
Armadillo	<i>Dasybus spp.</i>	22	68.8%	Nocturnal	3
Jaguar	<i>Panthera onca</i>	4	12.5%	Cathemeral	3
Agouti	<i>Dasyprocta spp.</i>	3	9.4%	Diurnal	3
Collared Peccary	<i>Pecari tajacu</i>	1	3.1%	Diurnal	4
Capybara	<i>Hydrochoerus hydrochaeris</i>	1	3.1%	Cathemeral	5
Ocelot	<i>Leopardus pardalis</i>	1	3.1%	Predominantly nocturnal	6
Peru					
Lowland paca	<i>Cuniculus paca</i>	41	70.7%	Nocturnal	3
Brocket deer	<i>Mazama spp.</i>	23	39.7%	<i>M. americana</i> Crepuscular; <i>M. gouazoubira</i> Diurnal	4
Armadillo	<i>Dasybus spp.</i>	19	32.8%	Nocturnal	3
Lowland tapir	<i>Tapirus terrestris</i>	9	15.5%	Predominantly nocturnal	4
Kinkajou	<i>Potos flavis</i>	3	5.2%	Nocturnal	7

¹Kingdon, J.; Happold, D.; Hoffmann, M.; Butynski, T.; Happold, M.; Kalina, J. (2013). Mammals of Africa. London, UK: Bloomsbury; ²Newing, H., 2001. Bushmeat hunting and management: implications of duiker ecology and interspecific competition. *Biodiversity & Conservation*, 10(1), pp.99-118; ³Blake, J.G., Mosquera, D., Loisel, B.A., Swing, K., Guerra, J. and Romo, D., 2012. Temporal activity patterns of terrestrial mammals in lowland rainforest of eastern Ecuador. *Ecotropica*, 18(2), pp.137-146; ⁴Tobler, M.W., Carrillo-Percastegui, S.E. and Powell, G., 2009. Habitat use, activity patterns and use of mineral licks by five species of ungulate in south-eastern Peru. *Journal of Tropical Ecology*, 25(3), pp.261-270; ⁵Gómez, H., Wallace, R.B., Ayala, G. and Tejada, R., 2005. Dry season activity periods of some Amazonian mammals. *Studies on Neotropical Fauna and Environment*, 40(2), pp.91-95; ⁶Salvador, J. and Espinosa, S., 2016. Density and activity patterns of ocelot populations in Yasuní National Park, Ecuador. *Mammalia*, 80(4), pp.395-403; ⁷Kays, R.W., 2000. The behavior and ecology of olingos (*Bassaricyon gabbii*) and their competition with kinkajous (*Potos flavus*) in central Panama. *Mammalia*, 64(1), pp.1-10.

1 LED flashlight technology facilitates wild meat extraction 2 across the tropics

3
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27

28

29 Abstract

30 Hunting for wild meat in the tropics provides subsistence and income for millions
31 of people. Methods have remained relatively unchanged since the introduction of
32 shotguns and battery-powered incandescent flashlights, but due to the short life of
33 batteries in such flashlights, nocturnal hunting has been limited. However, ~~with the~~
34 ~~recent availability of~~ brighter, more efficient light-emitting diode (LED) flashlights, ~~have~~
35 ~~recently been adopted by~~ hunters, ~~can find and kill prey more easily~~. Brighter spotlights
36 increase the freezing response of many species, and greater battery life allows hunters
37 to pursue game for longer and more frequently. ~~Hunters interviewed~~ ~~Through interviews~~
38 ~~and hunting registers~~ in African and South American forests, ~~disclosed~~ ~~we show~~ that ~~the~~
39 ~~use of~~ LEDs ~~can~~ increase the ~~frequency and efficiency~~ ~~kill rates~~ of nocturnal ~~hunting,~~
40 ~~and the number of kills made. These changes were reflected in harvest data in~~
41 ~~Brazil, species and overall harvests~~. The drastic change in efficiency brought about by
42 LEDs, well known to hunters around the world, poses a significant threat to wildlife. We
43 consider the implications for communities, governments, wildlife managers and
44 conservationists.

45

46 Introduction

47 Wild vertebrates are a source of food and income for millions of people
48 throughout the tropics. However, overhunting is a major ~~source of~~ concern, ~~causing~~
49 ~~since it causes~~ the decline ~~offer~~ large-bodied animal species and ~~driving~~ ~~drives~~ some ~~of~~
50 ~~these~~ to extinction (Benítez-López, *et al.* 2017, Maxwell, *et al.* 2016, Ripple, *et al.* 2016).
51 Unsustainable hunting ~~also~~ threatens the food security of rural populations that
52 ~~depend~~ ~~are dependent~~ on wild meat (Cawthorn and Hoffman 2015, Nasi, *et al.* 2011).
53 Wild animals in tropical forests are hunted with a variety of ~~methods, both~~ traditional
54 ~~(e.g. bow~~ ~~methods~~ and ~~arrow)~~ ~~and more~~ modern ~~(e.g. ones like~~ firearms) (Fa and Brown
55 2009). ~~Methods~~ ~~Hunting methods~~ have improved incrementally through time, through the
56 use of metal wire for the manufacture of snares and traps in Africa, cheaper guns, and
57 the availability of incandescent battery-powered flashlights for hunting at night (Alvard
58 1995, Hames 1979, Levi, *et al.* 2009, Redford and Robinson 1987). Flashlights are used

59 to locate animals using the eyeshine that many species exhibit, a method known as
60 spotlighting or lamping (Hames 1979). Many animals are temporarily immobilized by the
61 lights, appearing to see the light as non-threatening. Hunters can then carefully
62 approach to within a short distance of the animals to greatly improve their chances of
63 making a kill.

64

65 Powerful, white light-emitting diodes (LEDs) are increasingly replacing
66 incandescent bulbs in flashlights. LED flashlights are brighter and approximately 10-20
67 times more efficient than incandescent lightbulbs (Pimputkar, *et al.* 2009). Although
68 LEDs existed for decades as low-power indicator lights, and high-power white-light
69 emitters have been produced since 1999, this technology remained prohibitively
70 expensive for hunters in developing countries for many years. Our collaborative
71 research groups observed that LED flashlight prices became comparable to
72 incandescent flashlights around 2012 and ~~LED lights~~ are now ~~commonly~~ available in
73 rural markets throughout the tropics, and ~~are~~ widely employed in nocturnal hunting in
74 Latin America, Africa and Asia.

75

76 We investigated the impact of ~~the use of~~ LED flashlights in increasing wild
77 mammal offtake by hunters in tropical forests, ~~using~~ ~~We use~~ interviews with commercial
78 and subsistence hunters in Peru, Brazil and Gabon. We ~~support this with also use~~ data
79 from hunting events monitored for ~~1317~~ years in the Brazilian Amazon ~~comparing to~~
80 ~~compare~~ hunting returns before and after the introduction of LED lights.

81

82 **Methods**

83 *Hunter interviews*

84 During 2016 and 2017, we administered semi-structured questionnaires to 120
85 shotgun hunters in three countries (Peru, Brazil and Gabon). In Peru, we interviewed 58
86 subsistence and commercial hunters from three ~~dispersed~~ communities - *Nueva*
87 *Esperanza* on the Rio Yavari, *Tahuayo* on the Rio Tahuayo, ~~south of the Amazon River,~~
88 and *Sucusari*, on the Rio Napo, in Western Amazonia. In Brazil, we questioned 32
89 subsistence hunters in the *Boa Esperança* and *Bom Jesus do Baré* communities in the

90 Amanã Sustainable Development Reserve (ASDR), between the Japurá and Negro
91 Rivers, in Central Amazonia. In Gabon, we interviewed 30 principally commercial
92 hunters from 18 villages within the rural Ogooué-Ivindo Province.

93 In each country, researchers familiar with the study areas and hunters, and
94 experienced in communicating with local communities, administered interviews
95 translated from an original text in Spanish. We asked each hunter the following
96 questions, in Spanish, Portuguese or French; Q1. Do you use LED flashlights, and if so,
97 when did you switch to these?; Q2. Do you hunt more frequently at night since you
98 started using LEDs; Q3. Do LED lights make hunting easier or harder, and why? Q4.
99 What species do you hunt at night? And do you kill more, or less of these species
100 since using LEDs?

101

102 *Pre- and Post-LED hunting success in Brazil*

103 As part of a long-term hunting study in five communities within the Amanã
104 Sustainable Development Reserve (ASDR), Brazil, hunting registers were kept
105 continuously for 1317 years between 2003 and 2015 (n=1373 hunts; 1999 kills).
106 Lowland paca (*Cuniculus paca*), the most frequently hunted species in Amazonia (EI
107 Bizri, et al. 2019), are targeted specifically at Amanã on nocturnal canoe forays distinct
108 from other hunts, which were recorded separately between 2002 and 2015. Hunters
109 recorded the start and end of each hunt, species hunted, and the time of all kills.
110 Because the identities of hunters are kept anonymous, the number of hunters and the
111 proportion of hunts each hunter recorded is unknown. Hunting in Brazil is forbidden by
112 law, except by necessity for subsistence within the family. Hunting is therefore tolerated
113 in small isolated communities such as those in the ASDR, and hunters are generally
114 comfortable reporting catches. This is especially true in the ASDR where participatory
115 monitoring has been in place for over 10 years. There is no specific independent
116 verification of the data, but researchers participate in the data collection and train
117 hunters annually.

118 Catch per unit effort (CPUE) ($\text{kg hunter}^{-1} \text{hour}^{-1}$) (Rist, et al. 2010) is the
119 usual ideal metric to show changes in hunting efficiency, but among ~~Among~~ the
120 nocturnal species recorded in hunting registers, sample sizes were sufficient for us to

121 calculate CPUE this annually only for the paca (n=309 nocturnal hunts; 501 nocturnal
122 kills). ~~For all hunted. For all~~ species collectively, we calculated the proportion of diurnal
123 versus nocturnal hunts and kills annually, and for the lowland tapir
124 (*Tapirus terrestris*), a nocturnal species for which hunting occurs both diurnally and
125 nocturnally, we calculated the proportion of nocturnal versus diurnal kills each year
126 (n=27 kills). These metrics were compared before and after the uptake of LED
127 flashlights by the hunters in the reserve.

128
129

130 Results

131 *Q1. Do you use LED flashlights, and if so, when did you switch to these?*

132 LED flashlights were used by all interviewed hunters in Peru and Brazil and by
133 almost all hunters (93%) in Gabon. In Peru (n=58) and Brazil (n=32), hunters
134 estimated that they started using LEDs around 2011, and in Gabon (n=28) 2011 but
135 reported uptake was ~~later, around 2015 in Gabon.~~ around 2015.

136

137 ~~Q2. Whereas LEDs allowed hunting for several nights on a single pair of batteries. Q2.~~

138 *Do you hunt more frequently at night since you started using LEDs?*

139 In Peru and Brazil, most hunters (66% at both sites) said that they hunted more
140 at night now that they had LED flashlights (Figure [1a](#)). In Gabon, where hunting with a
141 light source is illegal, just 32% said they hunted more frequently with LED lights. The
142 remaining hunters did not indicate if they hunted less, or at the same frequency. In all
143 regions, hunters mentioned that LEDs were more efficient than incandescent flashlights.
144 Many hunters also said that because incandescent flashlights used batteries quickly,
145 this made their use prohibitively expensive, thus limiting nocturnal hunting, whereas
146 LEDs allowed hunting for several nights on a single pair of batteries.

147

148 *Q3. Do LED lights make hunting easier or harder, and why?*

149 Over three-quarters of all hunters (75% in Brazil, 77% in Peru and 82% in
150 Gabon) reported that LED flashlights had increased brightness and range over
151 incandescent lights; only hunters that used lower-powered LED flashlights disagreed.

152 More than half of the hunters from each site (69% in Brazil, 40% in Peru, 54% in
 153 Gabon) suggested that animals were easier to hunt with LEDs, with most of the
 154 remainder saying that there was no change in the ease of hunting (Figure 1b4B). Those
 155 that found hunting easier suggested that this was due to the increased range or
 156 brightness of flashlights, and because a higher proportion of animals 'froze in the
 157 spotlight'.

158

159 *Q4. What species do you hunt at night? Do you kill more, or less of these species since*
 160 *using LEDs?*

161 ~~In Brazil and Peru, hunters~~Hunters most commonly listed ~~lowland~~ paca, brocket deer
 162 (*Mazama* spp.), armadillos (*Dasypus* spp.) and tapir as nocturnally-hunted species. ~~In~~
 163 ~~Gabon, in Brazil and Peru, and~~ Brush-tailed porcupines (*Atherurus africanus*) and
 164 duiker (*Cephalophus* spp. and *Philantomba monticola*) ~~were most commonly listed~~
 165 ~~(WebTable 1).in Gabon (Supplementary material S1).~~ In all regions, most LED-using
 166 hunters (69% across regions) reported killing more of ~~the~~these nocturnally-hunted
 167 species ~~that they mentioned~~ than when they used incandescent lights (Figure 1c).1C).

168

169 ~~Hunters~~At all sites, ~~hunters~~ may have underreported the frequency ~~or,~~ ease of
 170 hunting, or the relative frequency of ~~hunting~~nocturnal ~~animal kills wherever~~animals
 171 ~~because~~ commercial hunting is illegal or strictly managed. ~~at the site in which they~~
 172 ~~operate.~~ This may have been particularly pronounced in Gabon where commercial
 173 hunting and hunting with flashlights are both illegal (République Gabonaise 2001).

174

175

176 *Pre- and Post-LED hunting success in Brazil*

177

178 ~~Day X Night Hunts Intentional:~~The ~~proportion of hunts made during the night~~
 179 ~~compared to during the day increased around the time LED lights came into use at~~
 180 ~~Amanã (20.6% vs 39.8%, $\chi^2 =$ chi-square statistic is 50.64,6381. The $p <$ -value is~~
 181 ~~1.1107E-12 (<0.001. Figure 3a. Similarly, the proportion of kills made during the night~~
 182 ~~compared to during the day increased at the same time (19.3% vs 37.3%, $\chi^2 =$)~~

183
184 ~~Day X Night Kills Intentional: The chi-square statistic is 73.45,4513. The p <-~~
185 ~~value is 1.03152E-17 (<0.001 Figure 3b). This reflects an increase in the proportions of~~
186 ~~nocturnal species taken, but also an increase in the proportion of nocturnal kills for~~
187 ~~species that can be hunted both at night and in daytime.)~~

188
189 After the uptake of LED flashlights in Amanã Brazil, tapir hunting switched from
190 exclusively diurnal to predominantly nocturnal (0% vs 83.3%, $\text{Chi}_2 = 25.71$, $p < 0.001$
191 (Figure 42), with hunters confirming that LED flashlights facilitated this change.

192 Between 2002 and 2010, the catch per unit effort for the lowland paca was in
193 steep decline, but after the widespread adoption of LEDs around 2011, the CPUE close
194 to doubled, before showing signs of declining again (Figure 5). A breakpoint analysis
195 (Bai and Perron 2003) detected a structural change between 2010 and 2011 and a
196 subsequent regression analysis showed that both the intercept and slope change at that
197 point (without change: $R^2=0.183$, $F=3.91$, $p=0.07$, with change: $R^2=0.888$, $F=26.6$,
198 $p<0.001$).

199 ~~Tapir Intentional: The chi-square statistic is 25.714. The p-value is 3.95886E-07~~
200 ~~(<0.001)~~

201
202 ~~Paca CPUE (I did an ANCOVA here): Difference of mean CPUE between~~
203 ~~periods: $F(1, 10)=7.3700$, $p=.02175$; Difference between slopes/between trends of the~~
204 ~~periods: $F(1,10)=7.42644$, $p = 0.021371$.~~

209 Discussion

210 ~~New technologyThe size of harvests of wild animals is primarily affected by variations in~~
211 ~~game abundance and changing market forces, but also by innovations in hunting in the~~
212 ~~tropics~~

213 ~~equipment.~~ Our interviews with hunters show that LED flashlights are perceived
214 to ~~have increased~~ ~~increase~~ the efficiency of nocturnal hunting in tropical sites in three
215 different countries, and that local people now hunt at night more, killing more nocturnal
216 animals. Hunting registers in Brazil are consistent with these hunters' perceptions,
217 showing increases in the proportions of nocturnal hunting and kills. The only explanation
218 put forward by the hunters themselves for these changes in the registers is ~~that~~ ~~due to~~
219 the use of LED lights facilitates hunting at night. While ~~we are~~ ~~the offtake of any one~~
220 ~~species is not independent of harvests of other species, and we are therefore~~ unable to
221 establish cause and effect from the harvest data, the hunters' testimonials are
222 compelling. Hunters have detailed knowledge of their local areas and are the best
223 sources of information on their hunting methods and behavior. Furthermore, due to the
224 legal and community-imposed restrictions on hunting ~~that are~~ in place at our study sites,
225 any tendency to misreport ~~hunting~~ is likely to downplay any increases in harvest. Even
226 in Gabon, where the strongest restrictions on hunting are in force, most hunters
227 reported harvesting more nocturnal species since acquiring LED flashlights, while
228 others declined to answer or gave ambiguous responses. Given that harsh penalties for
229 illegal commercial hunting may result in under-reporting of nocturnal hunting in Gabon,
230 we regard this as strong evidence for an increase in the hunting of nocturnal animals
231 resulting from LEDs.

232 Although we do not have figures on the uptake of LEDs in different countries, we
233 ~~suspect~~ ~~infer from our results~~ that most hunters in tropical countries now use ~~or have~~
234 ~~access to~~ LEDs. LEDs have generally replaced incandescent lights to the point ~~This~~
235 ~~means~~ that the older technology ~~there~~ is hardbound to ~~find~~ ~~have been a significant~~
236 ~~increase~~ in our study regions and reductions in costs and waste will benefit rural
237 communities globally. Based on our results and the now-ubiquitous use of LEDs, we
238 suspect that wild meat offtake will have increased ~~offtake of wild meat~~ across the tropics.

239 In addition to advances in LED technology, the increasing provision of solar
240 power and rechargeable batteries, ~~due to the introduction of this technology~~ and the
241 arrival of other technologies, such as refrigeration, mobile phones and cheap, efficient
242 motors, is modernizing hunting in tropical forests. While new technologies tend to be
243 expensive, prices inevitably fall and LED lights are predicted to get ever brighter and

244 more efficient (Pimputkar, *et al.* 2009). More expensive models are already capable of
245 floodlighting large areas of forest, while infrared LEDs and night vision equipment is
246 already commonly employed by hunters in developed countries ([Manning 2014](#)), and
247 may eventually be available in the tropics, where they will enable the increasingly rapid
248 extraction of wild meat.

249

250 *Implications LED flashlights and the implications for wildlife populations*

251 ~~LED flashlights are now ubiquitous and have generally replaced incandescent~~
252 ~~lights to the point that the older technology is hard to find. The availability of batteries no~~
253 ~~longer limits nocturnal hunting to the degree that it did prior to the arrival of this~~
254 ~~technology, and reductions in costs and waste further benefit rural communities.. Given~~
255 ~~the effectiveness of nocturnal hunting for large mammal species, it is not surprising that~~
256 ~~hunters perceive a large shift in their hunting activity towards nighttime. How gains in~~
257 ~~hunting ease and efficiency manifest themselves in wild meat harvests depends greatly~~
258 ~~on the culture and economics of hunting communities, and as well as the demography of~~
259 ~~the hunted species. species in question. Hunting lowland tapir, a large-bodied slow-~~
260 ~~reproducing species considered vulnerable to overhunting (Tobler, *et al.* 2014), has~~
261 ~~shifted overwhelmingly from day to night (Figure 2.), with hunters confirming that LED~~
262 ~~flashlights facilitated this change. Tapirs are frequent visitors to mineral licks, traveling~~
263 ~~long distances from their territories to eat mineral-rich soils (Tobler, *et al.* 2009),~~
264 ~~therefore tapir could be efficiently extirpated from large tracts of forest if hunters target~~
265 ~~mineral licks at night. While improved increases in efficiency does not necessarily~~
266 ~~translate to higher an increase in offtake, commercial hunting occurs widely across~~
267 ~~Amazonia (van Vliet, *et al.* 2014), and it is likely that some tapirs harvests have~~
268 ~~increased with the advent of LED lights. For example, tapir hunting in the ASDR shifted~~
269 ~~from day to night, and hunters confirmed that LED flashlights facilitated this change. It is~~
270 ~~likely that tapir hunting has increased across Amazonia.~~

271

272 Prior to the introduction of LED flashlights, the CPUE of the Lowland ~~paca~~ *Paca* in
273 ~~the ASDR~~ *Amara* was declining as a result of overharvesting ([Valsecchi, *et al.* 2014](#)). ([El](#)
274 [Bizri, *et al.* 2019](#)). The abrupt increase in CPUE for the lowland *paca* in the ASDR, at

275 around the time of the introduction of the new lights, is likely to have been repeated
276 across Amazonia, which may have a substantial impact on subsistence and markets.
277 Pacas are widely commercialized in urban markets and restaurants (Mayor, *et al.* 2019),
278 and although they ~~are generally considered~~ ~~were previously thought to be~~ resilient to
279 hunting ~~and touted as an alternative prey to more vulnerable species~~ (Bodmer, *et al.*
280 1997), they reproduce relatively slowly, and can be locally extirpated (El Bizri, *et al.*
281 2018). CPUE ~~in the ASDRat Amana~~ appears to decline again after the initial increase,
282 perhaps indicating a further decline in paca densities. ~~Although pacas~~ Pacas are likely
283 to be resilient to hunting ~~in remote areas, they across Amazonia but~~ may become
284 scarcer around population centers, making extraction more costly in the longer term.
285

286 As human populations and demand for wild meat grows throughout sub-Saharan
287 Africa, any increase in nocturnal offtake is unlikely to result in the alleviation of hunting
288 pressure on diurnal species. The most commonly targeted species across Central
289 Africa, brush-tailed porcupines (*Atherurus africanus*) and blue duikers (*Philantomba*
290 *monticola*), are considered locally abundant and resilient to hunting, ~~but 30% of~~
291 ~~respondents in Gabon~~ (Poulsen, *et al.* 2009), ~~but 30% of respondents~~ reported hunting
292 indiscriminately at night and targeting species of conservation concern like the
293 pangolins (*Smutsia gigantea*, *Phataginus tricuspis* and *Phataginus tetradactyla*), bay
294 duiker (*Cephalophus dorsalis*), white-bellied duiker (*Cephalophus leucogaster*), and
295 yellow-backed duiker (*Cephalophus silvicultor*), for which immediate conservation
296 attention is required.

297 *New technology and hunting in the tropics*

298 ~~In addition to advances in LED technology, the increasing provision of solar power and~~
299 ~~rechargeable batteries~~ (Andrade, *et al.* 2011), (Manning 2014). ~~Similar equipment will~~
300 ~~eventually be available in the tropics, where they will enable the increasingly rapid~~
301 ~~extraction of wild meat. The conservation of tropical species and maintenance of game~~
302 ~~for rural livelihoods depends on understanding the rapid evolution of technological and~~
303 ~~cultural changes alongside parameters like game abundance and human demography.~~
304 ~~Wildlife managers and conservationists must now reassess the threats to wildlife and~~
305

306 ~~adapt management plans to account for this and other emerging technologies. Hunters~~
307 ~~are often aware of species declines, just as they are aware of the changes in hunting~~
308 ~~efficiency, but some changes to wildlife populations will go unnoticed unless~~
309 ~~communities keep coordinated registers that record spatial and temporal measures of~~
310 ~~hunts and kills in enough detail to pick up any changes in CPUE. While this approach~~
311 ~~has challenges in areas where hunting is controlled or illegal, it is a widely used~~
312 ~~monitoring tool in tropical regions. The hunting equipment and methods should be~~
313 ~~registered, including the use of dogs, game calls or recordings, while travel methods~~
314 ~~and the use of mineral licks or other landscape features, will also affect CPUE.~~

315

316 *LED flashlights and the implications for wildlife management*

317 It is unlikely that use of LEDs in hunting can be controlled in practice. Other kinds
318 of flashlights are now difficult to find in markets and hunters will select the best light
319 source. ~~Laws~~ Because outlawing LED flashlights is not an option, laws restricting
320 hunting equipment would have to forbid nocturnal hunting with any light source. Wildlife
321 laws in Gabon do prohibit this practice (République Gabonaise 2001), but the law is not
322 enforced, and hunting with flashlights is common. Other hunters regularly engage in
323 nocturnal hunting with flashlights. While enforcing bans on nocturnal hunting may be
324 difficult and resource intensive, efforts could be focused on ecologically sensitive areas
325 like mineral licks, water sources, or game trails that regularly attract high numbers of
326 animals (Becker, et al. 2013). National laws must be coupled with other management
327 strategies could counter shifts in harvests, particularly where rural communities that
328 depend on wildlife for subsistence and are at risk of overharvesting their resources.
329 The resource. Local strategies could include a temporary or permanent ban on
330 hunting of vulnerable species, the establishment of no-take areas, changes or a change
331 in harvest quotas, or restrictions on hunting vulnerable for a species, are; measures that
332 are already commonly employed with varying degrees of success (Campos-Silva, et al.
333 2017). Efforts could be focused on ecologically sensitive areas like mineral licks, water
334 sources, or game trails that attract animals (Becker, et al. 2013). However, such These
335 measures, like bans on spotlighting, will also fail if hunters do not comply, so ; therefore,
336 the key to managing wildlife is likely local management is likely to be necessary.

337 ~~Although challenging at many sites, , which can encourage buy-in by~~ community
338 ~~members and enforcement of rules, laws, and norms.~~

339 ~~Community-based co-wildlife management, in which initiatives have had~~
340 ~~localized success across Amazonia where~~ local people make management decisions
341 and implement conservation with the technical support of 'co-managers' in government,
342 NGOs or academic institutions ~~has had localized success across Amazonia~~ (Campos-
343 Silva, *et al.* 2017), ~~and is a key principle in several African countries, especially those in~~
344 ~~southern and eastern areas (Baghai, et al. 2018).~~ Because hunters make their own
345 rules and are invested in the outcomes of the interventions, the actions they impose are
346 likely to be widely accepted and implemented. In Peru, this system of management has
347 proven successful at several sites and has been adopted by the government's National
348 Service for Natural Protected Areas (SERNANP) which acts as the co-manager to
349 communities living in and around Natural Protected Areas (Bodmer, *et al.* 2009). Thus,
350 community co-management has been shown to be a scalable management strategy
351 that can be widely implemented. ~~Our reported increases in hunting efficiency at night~~
352 ~~further motivate the expansion of community management programs to promote~~
353 ~~sustainable hunting.~~

354 ~~A common feature of community management programs is monitoring animal~~
355 ~~populations through CPUE (Rist, et al. 2010), especially where the budgets of~~
356 ~~supporting organizations do not permit labor-intensive wildlife surveys, although in~~
357 ~~practice, measures of effort and catch are prone to bias (Rist, et al. 2008). Our results~~
358 ~~suggest that co-management groups may find increases in CPUE when new hunting or~~
359 ~~transport technologies emerge. Managers must be careful not to interpret these as~~
360 ~~increases in wildlife abundance. Similarly, declines in abundance may be masked by~~
361 ~~the same increases in hunting efficiency that cause the declines. Changes to CPUE are~~
362 ~~also open to misinterpretation unless communities record spatial and temporal~~
363 ~~measures of hunts and kills in enough detail. The hunting equipment and methods~~
364 ~~should also be registered, including the use of dogs, game calls or recordings, while~~
365 ~~travel methods and the use of mineral licks or other landscape features, will also affect~~
366 ~~CPUE.~~

367

368 Although community co-management has seen success in parts of Peru and
369 Brazil (Campos-Silva, *et al.* 2017), most areas in the tropics lack wildlife management.
370 At some sites, community management is highly challenging. While community co-
371 management is a key principle in several African countries, especially those in southern
372 and eastern areas (Baghai, *et al.* 2018), in many forested west African countries, large
373 and growing human populations, particularly in urban areas, generate a commercial
374 demand for wild meat that greatly exceeds estimates of sustainability, and some
375 countries lack the political structure or will to introduce community co-management. In
376 these cases, our observations hasten the already desperate need for designing,
377 implementing and enforcing new conservation strategies, whether that is in finding
378 alternative protein sources, restricting markets or changing public opinion and consumer
379 behavior.

380

381 *Conclusions*

382 We highlight the likely effects of the introduction of LED lights, an otherwise
383 highly beneficial development, on the efficiency of nocturnal hunting. These findings
384 should alert management groups to the potential of increased harvest rates of selected
385 species at the time of introduction, and highlights the limitation of using the CPUE of
386 harvested species to monitor their abundance; a common practice where community
387 co-management is employed

388 Finally, we highlight the likely effects of a new hunting technology on the CPUE of a
389 commercially hunted species. CPUE is commonly used as a metric for monitoring
390 wildlife populations where community management is employed [cite]. Managers must
391 take changes in technology into account when making management decisions, and
392 specifically, managers should expect an increase in CPUE at the introduction of this
393 particular LED technology.

394 (Rist, *et al.* 2010). Managers should be aware that other new technologies may
395 have similar effects on CPUE. Alternative measures of wildlife abundance could be
396 sought, and caution should be employed when interpreting CPUE unless sufficient
397 detail is recorded. Managers must also take changes in technology into account when
398 implementing conservation strategies.

399

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477 Figure Legends

478

479 Figure 1. Responses of hunters asked about changes in their hunting behavior since
480 starting to use LED flashlights in Peru—~~Rio Yavari, Rio Tahuayo, Rio Napo~~, Brazil ~~—the~~
481 ~~Amanã Sustainable Development Reserve~~, and Gabon, ~~Ogooué-Ivindo Province~~.

482 *sample size excludes two interviewees who had not switched to LED flashlights

483 †This question was asked as “What species do you hunt at night? Do you kill more of
484 the species you hunt at night since using LEDs?”

485

486 Figure 2. Animals' eyeshine and their response of freezing in a spotlight makes them
487 vulnerable to hunting with flashlights: a) Lowland tapir (*Tapirus terrestris*) with eyeshine,
488 b) Lowland paca (*Cuniculus paca*) with eyeshine c) Paca are hunted predominantly by
489 spotlighting from canoe d) Hunters report that using LED flashlights increases hunting
490 efficiency. LEDs are attached to the head to free up the hands and to increase the
491 pickup of animals' eyeshine. Picture Credits: a) James Warwick, b) Hani El Bizri, c)
492 Mark Bowler, d) Seberino Rios.~~Figure 2. Day X Night Hunts Intentional: The chi-square~~
493 ~~statistic is 50.6381. The p-value is 1.1107E-12 (<0.001)~~

494

495 ~~Figure 3. Day X Night Kills Intentional: The chi-square statistic is 73.4513. The p-value~~
496 ~~is 1.03152E-17 (<0.001)~~

497 a) The proportion of hunts made at night in the Amanã Sustainable Development
498 Reserve, Brazil, showing an increase in nocturnal hunting at around the time of the
499 introduction of LED lights. b) The proportion of kills made at night in the Amanã
500 Sustainable Development Reserve, Brazil, showing an increase in nocturnal kills at
501 around the time of the introduction of LED lights.

502

503 Figure 4. Day versus night kills for tapir (n=27) ~~across five communities hunting for~~
504 ~~subsistence only~~ in the Amanã Sustainable Development Reserve, Brazilian Amazon,
505 before and after the uptake of LED flashlights. ~~The proportion of nocturnal kills was~~
506 ~~significantly higher after the mean year of uptake of LED flashlights: The chi-square~~
507 ~~statistic is 25.714. The p-value is 3.95886E-07 (<0.001).~~

508

509 Figure 5. Catch Per Unit Effort (CPUE) $\text{kg}/\text{hunter}^{-1} \text{hour}^{-1}$ for the lowland paca
510 (*Cuniculus paca*) ~~across five communities hunting for subsistence only~~ in the Amanã
511 Sustainable Development Reserve, Brazilian Amazon. A breakpoint analysis detected a
512 structural change between 2010 and 2011 and a subsequent regression analysis
513 showed that bothThe CPUE for paca was significantly higher after the intercept and
514 slope change at that point (without change: $R^2=0.183$, mean year of uptake of LED
515 flashlights: ANCOVA here: $F=3.91(1, 10)=7.3700$, $p=0.07$, with change:
516 $R^2=0.888$, $=.02175$; Difference between slopes/between trends of the periods:
517 $F=26.6(1,10)=7.42644$, $p<0.001$). Lines show linear regressions and 95% confidence
518 intervals. $= 0.021371$.

519

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