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LED flashlight technology facilitates wild meat extraction across the tropics

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|-------------------------------|---|
| Journal: | <i>Frontiers in Ecology and the Environment</i> |
| Manuscript ID | FEE18-0292.R3 |
| Wiley - Manuscript type: | Research Communications |
| Date Submitted by the Author: | n/a |
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| Substantive Area: | Conservation < Population Ecology < Substantive Area, Resource Management (Wildlife, Fisheries, Range, Other) < Ecosystems < Substantive Area, Endangered Species < Management < Substantive Area, Resource Management < Management < Substantive Area |
| Organism: | Mammals < Vertebrates < Animals |
| Habitat: | Terrestrial < Habitat, Tropical Zone < Terrestrial < Habitat |
| Geographic Area: | South America < Geographic Area, Africa < Geographic Area |
| Additional Keywords: | hunting, flashlight, technology, community conservation |
| 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, |

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|--|--|
| | <p>nocturnal hunting has been limited. However, brighter, more efficient 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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1 LED flashlight technology facilitates wild meat extraction 2 across the tropics

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27

28 Abstract

29 Hunting for wild meat in the tropics provides subsistence and income for millions
30 of people. Methods have remained relatively unchanged since the introduction of

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

42

43 **Introduction**

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

59 Powerful, white light-emitting diodes (LEDs) are increasingly replacing
60 incandescent bulbs in flashlights. LED flashlights are brighter and approximately 10-20
61 times more efficient than incandescent lightbulbs (Pimputkar, *et al.* 2009). Although

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

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

73

74 **Methods**

75 *Hunter interviews*

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

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

93

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

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

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

117

118 **Results**119 *Q1. Do you use LED flashlights, and if so, when did you switch to these?*

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

124

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

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

134

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

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

145

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

148 In Brazil and Peru, hunters most commonly listed paca, brocket deer (*Mazama*
149 *spp.*), armadillos (*Dasypus spp.*) and tapir as nocturnally-hunted species (Figure 2). In
150 Gabon, Brush-tailed porcupines (*Atherurus africanus*) and duiker (*Cephalophus spp.*
151 and *Philantomba monticola*) were most commonly listed (WebTable 1). In all regions,
152 most LED-using hunters (69% across regions) reported killing more of the nocturnally-
153 hunted species that they mentioned than when they used incandescent lights (Figure
154 1c).

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

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

160 The proportion of hunts made during the night compared to during the day increased
161 around the time LED lights came into use at ASDR (20.6% vs 39.8%, $\chi^2 = 50.64$, p
162 <0.001 . Figure 3a. Similarly, the proportion of kills made during the night compared to
163 during the day increased at the same time (19.3% vs 37.3%, $\chi^2 = 73.45$, $p <0.001$
164 Figure 3b). This reflects an increase in the proportions of nocturnal species taken, but
165 also an increase in the proportion of nocturnal kills for species that can be hunted both
166 at night and in daytime. After the uptake of LED flashlights in ASDR, tapir hunting
167 switched from exclusively diurnal to predominantly nocturnal (0% vs 83.3%, $\chi^2 = 25.71$,
168 $p <0.001$ (Figure 4), with hunters confirming that LED flashlights facilitated this change.

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

175

176 **Discussion**

177 *New technology and hunting in the tropics*

178 Our interviews with hunters show that LED flashlights are perceived to have
179 increased the efficiency of nocturnal hunting in tropical sites in three different countries,
180 and that local people now hunt at night more, killing more nocturnal animals. Hunting
181 registers in Brazil are consistent with these hunters' perceptions, showing increases in
182 the proportions of nocturnal hunting and kills. The only explanation put forward by the
183 hunters themselves for these changes in the registers is that the use of LED lights
184 facilitates hunting at night. While we are unable to establish cause and effect from the
185 harvest data, the hunters' testimonials are compelling. Hunters have detailed knowledge

186 of their local areas and are the best sources of information on their hunting methods
187 and behavior. Furthermore, due to the legal and community-imposed restrictions on
188 hunting in place at our study sites, any tendency to misreport is likely to downplay any
189 increases in harvest. Even in Gabon, where the strongest restrictions on hunting are in
190 force, most hunters reported harvesting more nocturnal species since acquiring LED
191 flashlights, while others declined to answer or gave ambiguous responses. Given that
192 harsh penalties for illegal commercial hunting may result in under-reporting of nocturnal
193 hunting in Gabon, we regard this as strong evidence for an increase in the hunting of
194 nocturnal animals resulting from LEDs.

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

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

210

211 *Implications for wildlife populations*

212 How gains in hunting efficiency manifest themselves in wild meat harvests
213 depends greatly on the culture and economics of hunting communities, and the
214 demography of the hunted species. While improved efficiency does not necessarily
215 translate to higher offtake, commercial hunting occurs widely across Amazonia (van
216 Vliet, *et al.* 2014), and it is likely that some harvests have increased with the advent of

217 LED lights. For example, tapir hunting in the ASDR shifted from day to night, and
218 hunters confirmed that LED flashlights facilitated this change. It is likely that tapir
219 hunting has increased across Amazonia. Prior to the introduction of LED flashlights, the
220 CPUE of the Lowland paca in the ASDR was declining as a result of overharvesting
221 (Valsecchi, *et al.* 2014). The abrupt increase in CPUE for the paca, at around the time
222 of the introduction of the new lights, is likely to have been repeated across Amazonia,
223 which may have a substantial impact on subsistence and markets. Pacas are widely
224 commercialized in urban markets and restaurants (Mayor, *et al.* 2019), and although
225 they are generally considered resilient to hunting (Bodmer, *et al.* 1997), they reproduce
226 relatively slowly, and can be locally extirpated (El Bizri, *et al.* 2018). CPUE in the ASDR
227 appears to decline again after the initial increase, perhaps indicating a further decline in
228 paca densities. Although pacas are likely to be resilient to hunting in remote areas, they
229 may become scarcer around population centers, making extraction more costly in the
230 longer term.

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

241

242 *LED flashlights and the implications for wildlife management*

243 It is unlikely that use of LEDs in hunting can be controlled in practice. Other kinds
244 of flashlights are now difficult to find in markets and hunters will select the best light
245 source. Laws restricting hunting equipment would have to forbid nocturnal hunting with
246 any light source. Wildlife laws in Gabon do prohibit this practice (République Gabonaise
247 2001), but the law is not enforced, and hunting with flashlights is common. Other

248 management strategies could counter shifts in harvests, particularly where rural
249 communities depend on wildlife for subsistence and risk overharvesting their resources.
250 The establishment of no-take areas, changes in harvest quotas, or restrictions on
251 hunting vulnerable species, are measures that are already commonly employed with
252 varying degrees of success (Campos-Silva, *et al.* 2017). Efforts could be focused on
253 ecologically sensitive areas like mineral licks, water sources, or game trails that attract
254 animals (Becker, *et al.* 2013). However, such measures, like bans on spotlighting, will
255 fail if hunters do not comply, so local management is likely to be necessary.

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

269 A common feature of community management programs is monitoring animal
270 populations through CPUE (Rist, *et al.* 2010), especially where the budgets of
271 supporting organizations do not permit labor-intensive wildlife surveys, although in
272 practice, measures of effort and catch are prone to bias (Rist, *et al.* 2008). Our results
273 suggest that co-management groups may find increases in CPUE when new hunting or
274 transport technologies emerge. Managers must be careful not to interpret these as
275 increases in wildlife abundance. Similarly, declines in abundance may be masked by
276 the same increases in hunting efficiency that cause the declines. Changes to CPUE are
277 also open to misinterpretation unless communities record spatial and temporal
278 measures of hunts and kills in enough detail. The hunting equipment and methods

279 should also be registered, including the use of dogs, game calls or recordings, while
280 travel methods and the use of mineral licks or other landscape features, will also affect
281 CPUE.

282

283 *Conclusions*

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

294

295 **Acknowledgements**

296 We thank all the participating hunters in our focal communities in Peru, Brazil and
297 Gabon. We thank two anonymous reviewers and the editors for their constructive
298 comments on this manuscript.

299

300

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360

For Review Only

361 **Figure Legends**

362

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

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

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

368

369 Figure 2. Animals' eyeshine and their response of freezing in a spotlight makes them
370 vulnerable to hunting with flashlights: a) lowland tapir (*Tapirus terrestris*) with eyeshine,
371 b) lowland paca (*Cuniculus paca*) with eyeshine. Picture Credits: a) James Warwick, b)
372 Hani El Bizri.

373

374 Figure 3. The proportion of a) hunts and b) kills made at night in the Amanã Sustainable
375 Development Reserve, Brazil, showing an increase in nocturnal hunting at around the
376 time of the introduction of LED lights.

377

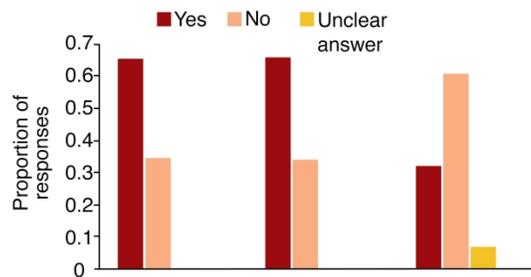
378 Figure 4. Day versus night kills for lowland tapir (*Tapirus terrestris*) (n=27) in the Amanã
379 Sustainable Development Reserve, Brazilian Amazon, before and after the uptake of
380 LED flashlights. Numbers next to bars are sample sizes.

381

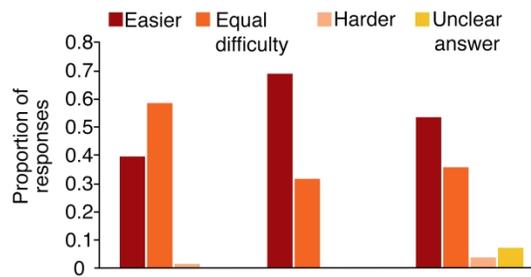
382 Figure 5. Catch Per Unit Effort (CPUE) kg hunter⁻¹ hour⁻¹ for the lowland paca
383 (*Cuniculus paca*) in the Amanã Sustainable Development Reserve, Brazilian Amazon. A
384 breakpoint analysis detected a structural change between 2010 and 2011 and a
385 subsequent regression analysis showed that both the intercept and slope change at that
386 point (without change: $R_2=0.18$, $F=3.91$, $p=0.07$, with change: $R_2=0.89$, $F=26.6$,
387 $p<0.001$). Lines show linear regressions and 95% confidence intervals.

388

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?†

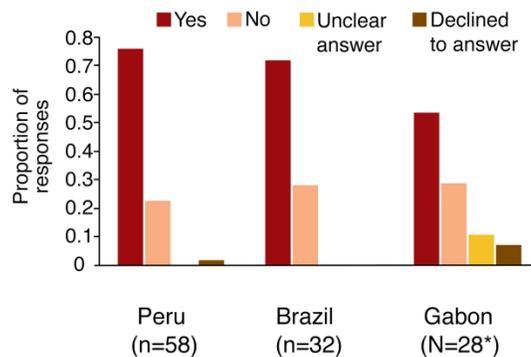


Figure 1. Responses of hunters asked about changes in their hunting behavior since starting to use LED flashlights in Peru, Brazil and Gabon.

*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?"



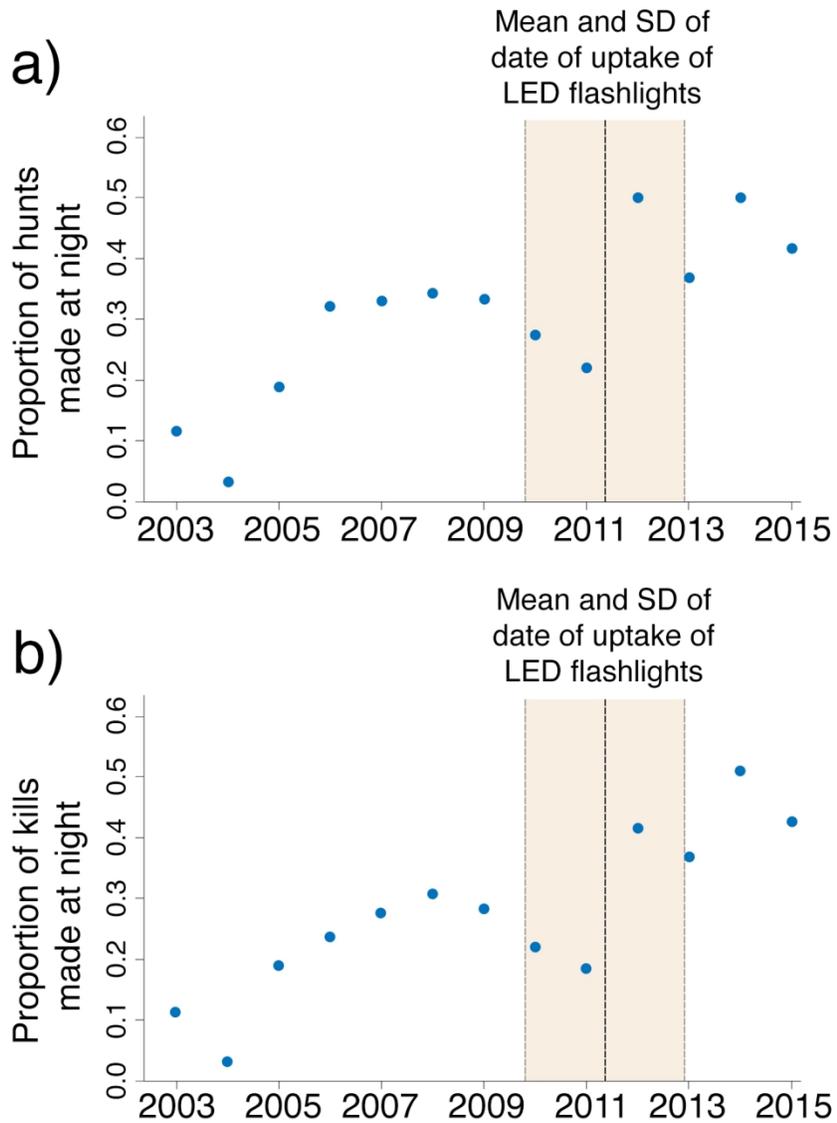
Animals' eyeshine and their response of freezing in a spotlight makes them vulnerable to hunting with flashlights: a) Lowland tapir (*Tapirus terrestris*) with eyeshine, b) Lowland paca (*Cuniculus paca*) with eyeshine. Picture Credits: a) James Warwick, b) Hani El Bizri.

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)



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.

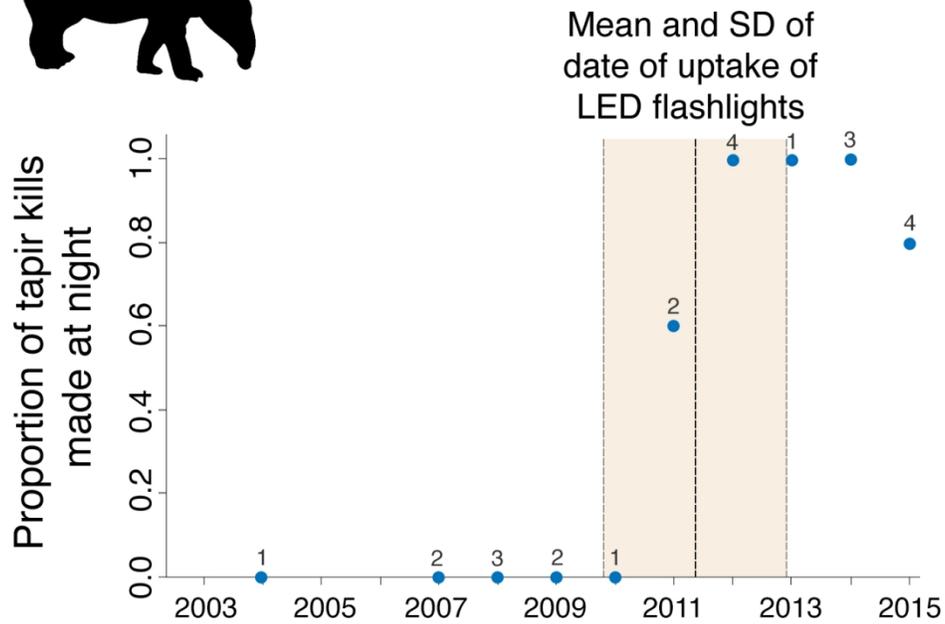


Figure 4. Day versus night kills for lowland tapir (*Tapirus terrestris*) (n=27) in the Amanã Sustainable Development Reserve, Brazilian Amazon, before and after the uptake of LED flashlights. Numbers next to bars are sample sizes.

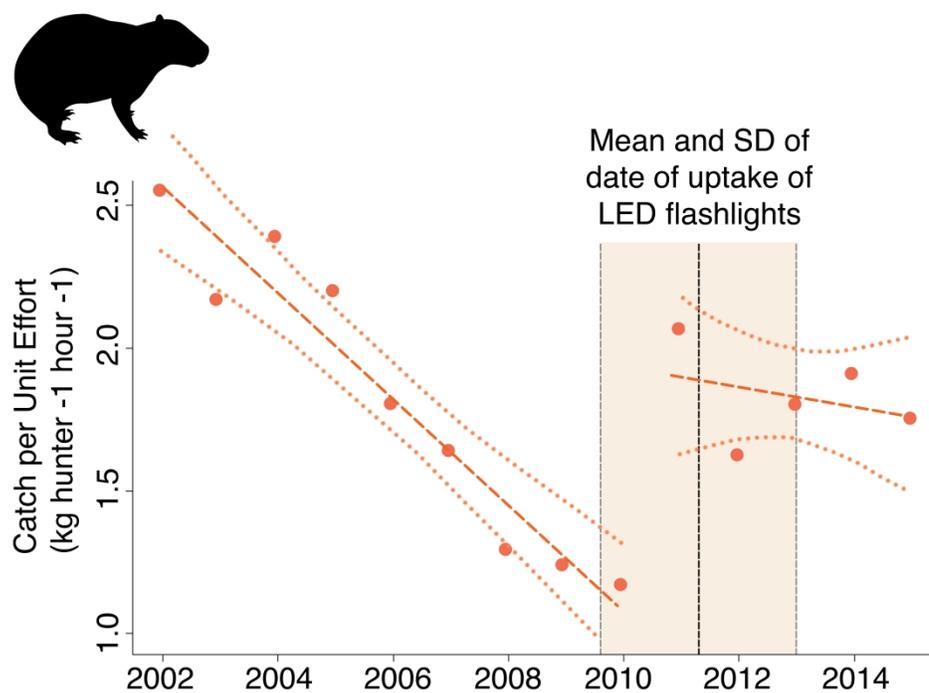


Figure 5. Catch Per Unit Effort (CPUE) kg hunter⁻¹ hour⁻¹ for the lowland paca (*Cuniculus paca*) in the Amanã Sustainable Development Reserve, Brazilian Amazon. A breakpoint analysis detected a structural change between 2010 and 2011 and a subsequent regression analysis showed that both the intercept and slope change at that point (without change: $R^2=0.18$, $F=3.91$, $p=0.07$, with change: $R^2=0.89$, $F=26.6$, $p<0.001$). 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. and Cricetomys sp.</i> | 2 | 6.7% | Nocturnal | 1 |
| Pangolin | <i>Phataginus tricuspis and 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, Bdeogale nigripes, 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-Percestequi, 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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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 increased
161 around the time LED lights came into use at [Amanã-ASDR](#) (20.6% vs 39.8%, $\chi^2_{2} =$
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%, $\chi^2_{2} =$
164 73.45, $p < 0.001$ Figure 3b). This reflects an increase in the proportions of nocturnal
165 species taken, but also an increase in the proportion of nocturnal kills for species that
166 can be hunted both at night and in daytime. After the uptake of LED flashlights in
167 [Amanã-ASDR](#), tapir hunting switched from exclusively diurnal to predominantly nocturnal
168 (0% vs 83.3%, $\chi^2_{2} = 25.71$, $p < 0.001$ (Figure 4), with hunters confirming that LED
169 flashlights facilitated this change.

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

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

297 **Acknowledgements**

298 We thank all the participating hunters in our focal communities in Peru, Brazil and
299 Gabon. We thank two anonymous reviewers and the editors for their constructive
300 comments on this manuscript.

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368 Figure Legends

369

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

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

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

375

376 Figure 2. Animals' eyeshine and their response of freezing in a spotlight makes them
377 vulnerable to hunting with flashlights: a) Lowland tapir (*Tapirus terrestris*) with eyeshine,

378 b) Lowland paca (*Cuniculus paca*) with eyeshine ~~c) Paca are hunted predominantly by~~

379 ~~spotlighting from canoe d) Hunters report that using LED flashlights increases hunting~~

380 ~~efficiency. LEDs are attached to the head to free up the hands and to increase the~~

381 ~~pickup of animals' eyeshine. Picture Credits: a) James Warwick, b) Hani El Bizri, c)~~

382 ~~Mark Bowler, d) Seberino Rios.~~

383

384 Figure 3. ~~a) The proportion of a) hunts and b) kills~~ made at night in the Amanã

385 Sustainable Development Reserve, Brazil, showing an increase in nocturnal hunting at

386 around the time of the introduction of LED lights. ~~b) The proportion of kills made at night~~

387 ~~in the Amanã Sustainable Development Reserve, Brazil, showing an increase in~~

388 ~~nocturnal kills at around the time of the introduction of LED lights.~~

389

390 Figure 4. Day versus night kills for tapir (n=27) in the Amanã Sustainable Development

391 Reserve, Brazilian Amazon, before and after the uptake of LED flashlights. Numbers

392 next to bars are sample sizes.

393

394 Figure 5. Catch Per Unit Effort (CPUE) kg hunter⁻¹ hour⁻¹ for the lowland paca

395 (*Cuniculus paca*) in the Amanã Sustainable Development Reserve, Brazilian Amazon. A

396 breakpoint analysis detected a structural change between 2010 and 2011 and a

397 subsequent regression analysis showed that both the intercept and slope change at that

398 point (without change: $R_2=0.183$, $F=3.91$, $p=0.07$, with change: $R_2=0.88889$, $F=26.6$,
399 $p<0.001$). Lines show linear regressions and 95% confidence intervals.

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