LED flashlight technology facilitates wild meat extraction across the tropics

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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 the short battery life of such flashlights has limited nocturnal hunting. However, hunters in many countries throughout the tropics have recently begun to switch to brighter and more efficient light-emitting diode (LED) flashlights. Such brighter spotlights stimulate the freeze response of many species, and improved battery life allows hunters to pursue game more often and for longer periods of time. Interviews with hunters in African and South American tropical forests revealed that LEDs increase the frequency and efficiency of nocturnal hunting, and subsequently the number of kills made. In Brazil, these findings were supported by harvest data. The marked change in efficiency brought about by LEDs, well known to hunters around the world, poses a major threat to wildlife. Here we consider the implications of the increasing use of LED lights in hunting for communities, governments, wildlife managers, and conservationists.

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Wild vertebrates are a source of food and income for millions of people throughout the tropics. However, overhunting is a major concern, causing the decline of large-bodied animal species and even driving some to extinction (Maxwell *et al.* 2016; Ripple *et al.* 2016; Benítez-López *et al.* 2017). Unsustainable hunting threatens the food security of rural human populations that depend on wild meat (Nasi *et al.* 2011; Cawthorn and Hoffman 2015). In tropical forests, wild animals are hunted with a variety of methods, involving both traditional (eg bow and arrow) and modern (eg firearms) weapons (Fa and Brown 2009). Methods have improved incrementally over time, through the use of metal wire for the manufacture of snares and traps in Africa, cheaper guns, and the availability of incandescent battery-powered flashlights for hunting at night (Hames 1979; Redford and Robinson 1987; Alvard 1995). Flashlights are used to locate animals using the eyeshine that many species exhibit, a method known as "spotlighting" or "lamping" (Hames 1979). Bright lights at night temporarily immobilize many animals, which appear to perceive the light as non-threatening; this behavior allows hunters to approach within a short distance of the targeted animals, thereby greatly improving their chances of making a kill.

Powerful, white light-emitting diodes (LEDs) are increasingly replacing incandescent bulbs in flashlights. LED flashlights are brighter and approximately 10–20 times more efficient than incandescent bulbs (Pimputkar *et al.* 2009). Although LEDs have existed for decades as low-power indicator lights, and high-power white-light emitters have been in production since 1999, this technology has remained prohibitively expensive for hunters in developing countries for many years. Based on observations made by our collaborative research groups, LED flashlight prices became competitive with those of incandescent flashlights around 2012, and LED flashlights are now available in rural markets throughout tropical Latin America, Africa, and Asia, where they are commonly used in nocturnal hunting.

We investigated the impact of LED flashlights in increasing wild mammal offtake by hunters in tropical forests through interviews with commercial and subsistence hunters in Peru, Brazil, and Gabon. We support our qualitative analysis with data from hunting events monitored for 13 years in the Brazilian Amazon, which allow for the comparison of hunting returns before and after the introduction of LED lights.

Methods

Hunter interviews

Semi-structured questionnaires were administered to 120 shotgun hunters in three countries (Peru, Brazil, and Gabon)

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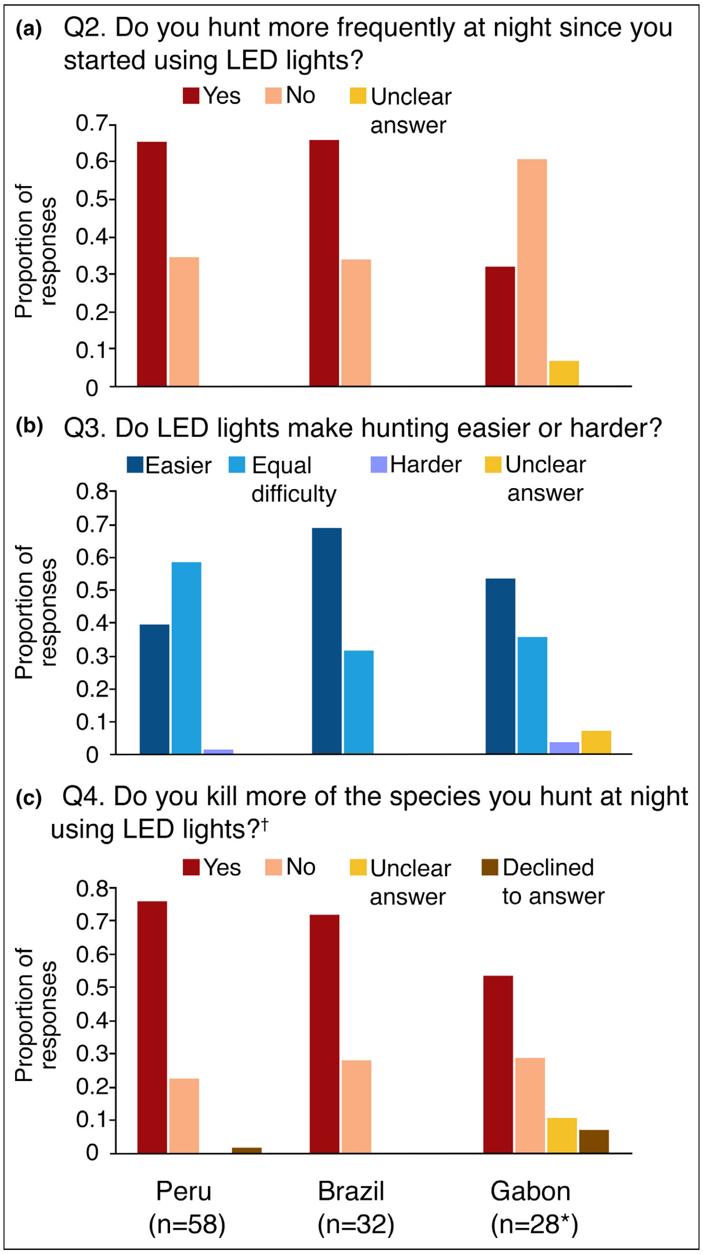

Figure 1. Responses of hunters in Peru, Brazil, and Gabon to selected questions about changes in their hunting behavior after they began using light-emitting diode (LED) flashlights. *Sample size excludes two interviewees who had not switched to LED flashlights; †question 4 is shortened here but was asked as "what species do you hunt at night? And do you kill more, or fewer, of the species you hunt at night since using LEDs?".

in 2016 and 2017. In Peru, we interviewed 58 subsistence and commercial hunters from three dispersed communities: *Nueva Esperanza* on the Rio Yavari, *Tahuayo* on the Rio Tahuayo, and *Sucusari* on the Rio Napo, all in Western Amazonia. In Brazil, we questioned 32 subsistence hunters in the *Boa Esperança* and *Bom Jesus do Baré* communities in the Amanã Sustainable Development Reserve (ASDR), between the Japurá and Negro rivers, in Central Amazonia. In Gabon, we interviewed 30 primarily commercial hunters from 18 villages in the rural Ogooué-Ivindo Province.

In each country, researchers familiar with the study areas and hunters, and experienced in communicating with local communities, conducted interviews translated from an original text in Spanish. We asked each hunter – depending on their country of origin – the following questions in either Spanish, Portuguese, or French: (1) do you use LED flashlights, and if so, when did you switch to these?; (2) do you hunt more frequently at night since you started using LEDs?; (3) do LED lights make hunting easier or harder, and why?; and (4) what species do you hunt at night, and do you kill more, or fewer, of these species since using LEDs?

Pre- and post-LED hunting success in Brazil

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

Catch per unit effort (CPUE, expressed as kilograms of hunted animals per hunter per hour [kg hunter^{-1} hr^{-1}]; Rist *et al.* 2010) is the metric usually used to note changes in hunting efficiency, but among the nocturnal species recorded in hunting registers, sample sizes were sufficient to calculate CPUE annually only for the lowland paca (n = 309 nocturnal hunts, 501 nocturnal kills). For all hunted species collectively, we calculated the proportion of diurnal versus nocturnal hunts and kills annually; in addition, for the lowland tapir (*Tapirus terrestris*), a nocturnal species for which hunting occurs both diurnally and nocturnally, we calculated the proportion of nocturnal versus diurnal kills each year (n = 23 total kills). These metrics were compared before and after the adoption of LED flashlights by hunters in the reserve.

Results

Do you use LED flashlights, and if so, when did you switch to these?

LED flashlights were used by all interviewed hunters in Peru and Brazil and by almost all hunters (93%) in Gabon. Hunters in Peru (n = 58) and Brazil (n = 32) estimated that they began using LED flashlights around 2011, whereas hunters in Gabon (n = 28) first began using LED flashlights around 2015.

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

Most hunters in Peru and Brazil (66% in both countries) said that they hunted more at night now that they had LED flashlights (Figure 1a). In Gabon, where hunting with a light source is illegal, just 32% said they hunted more frequently with LED lights. The remaining hunters did not indicate if they hunted less often or at the same frequency. In all three countries, hunters mentioned that LEDs were more efficient than incandescent flashlights. Many hunters also reported that the short battery life of incandescent flashlights made their use prohibitively expensive, thereby limiting nocturnal hunting, whereas LEDs permitted hunting for several nights on a single pair of batteries.

Do LED lights make hunting easier or harder, and why?

Over three-quarters of all hunters (75% in Brazil, 77% in Peru, and 82% in Gabon) reported that LED flashlights had increased brightness and range relative to incandescent lights; only hunters that used lower-powered LED flashlights disagreed. More than one-half of the hunters in two of the three countries (69% in Brazil, 40% in Peru, and 54% in Gabon) suggested that animals were easier to hunt with LEDs, with most of the remainder in all three countries saying that there was no change in the ease of hunting (Figure 1b). Those that found hunting easier suggested that this was due to the increased brightness or range of the LED flashlights, and because a higher proportion of animals tended to remain motionless when exposed to these lights (ie "frozen in the spotlight").

What species do you hunt at night? And do you kill more, or fewer, of these species since using LEDs?

Hunters in Brazil and Peru identified lowland paca, brocket deer (*Mazama* spp), armadillo (*Dasypus* spp), and lowland tapir as the most common species hunted at night (Figure 2). In Gabon, brush-tailed porcupine (*Atherurus africanus*) and numerous species of duikers (*Cephalophus* spp), including blue duiker (*Philantomba monticola*), were most commonly listed (WebTable 1). In all three countries, most hunters who use LED flashlights (69% across countries) reported killing more of the nocturnally hunted species that they mentioned than when they used incandescent lights (Figure 1c).

Wherever commercial hunting is illegal or strictly managed, hunters may have underreported the frequency of hunting, the ease of hunting, or the relative frequency of nocturnal animal kills. This outcome may have been particularly pronounced in Gabon, where both commercial hunting and hunting with flashlights are illegal (Gabonese Republic 2001).

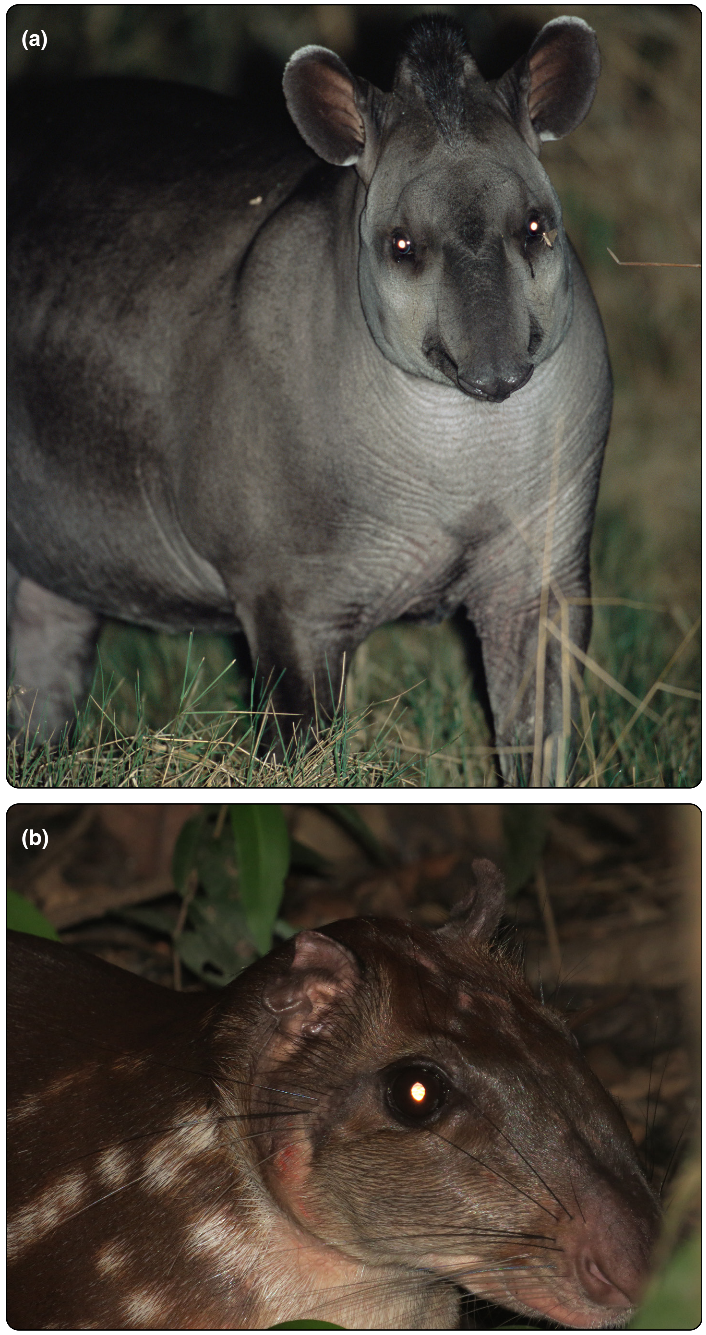

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Figure 2. Animals' eyeshine and their tendency to freeze in place when exposed to light at night increase their vulnerability to nocturnal hunters using flashlights. (a) Lowland tapir (*Tapirus terrestris*) and (b) lowland paca (*Cuniculus paca*).

Pre- and post-LED hunting success in Brazil

The proportion of night hunts relative to day hunts began to increase around the time that LED lights came into use at ASDR (20.6% versus 39.8%, respectively; χ^2 = 50.64, $P < 0.001$; Figure 3a). Similarly, the proportion of kills made during the night as compared to during the day increased at about the same time (19.3% versus 37.3%, respectively;

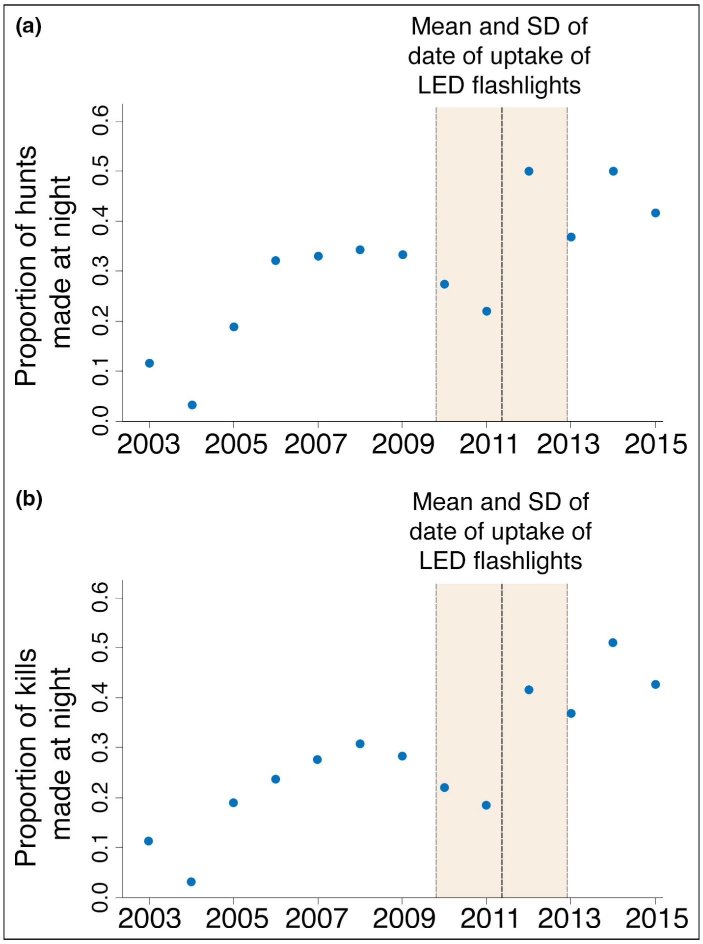

Figure 3. The proportion of (a) hunts and (b) kills made at night in the Amanã Sustainable Development Reserve (ASDR), Brazilian Amazon, showing an increase in nocturnal hunting around the time LED lights were introduced. SD = standard deviation. Mean and SDs are depicted by the dashed black and gray lines, respectively.

$\chi^2 = 73.45$, $P < 0.001$; Figure 3b). This reflects not only an increase in the proportions of nocturnal species taken, but also an increase in the proportion of nocturnal kills for species that can be hunted both at night and during the day. After the uptake of LED flashlights in ASDR, hunting of lowland tapir shifted from exclusively diurnal to predominantly nocturnal (0% versus 83.3%, respectively; $\chi^2 = 25.71$, $P < 0.001$; Figure 4), with hunters confirming that LED flashlights facilitated this change.

Between 2002 and 2010, the CPUE for the lowland paca was in steep decline, but nearly doubled after the widespread adoption of LEDs around 2011, although it has shown signs of once again declining (Figure 5). Using a breakpoint analysis (following the methods of Bai and Perron [2003]), we detected that a change in the trend observed in the data, known as a "breakpoint", occurred between 2010 and 2011; a subsequent regression analysis revealed that both the intercept and slope of CPUE for lowland paca changed at that point (linear regression: $R^2 = 0.183$, $F = 3.91$, $P = 0.07$; segmented regression with breakpoint: $R^2 = 0.888$, $F = 26.6$, $P < 0.001$).

Discussion

New technology and hunting in the tropics

Our interviews with hunters revealed that LED flashlights are perceived to have increased the efficiency of nocturnal hunting in tropical sites in three different countries, and that local people now hunt at night more often and kill greater numbers of nocturnal animals. Hunting registers in Brazil are consistent with hunters' perceptions, given that they show clear increases in the proportions of nocturnal hunting and kills. As for the reason behind these changes, the only explanation suggested in the registers by the hunters themselves is that the use of LED lights facilitates hunting at night. While we were unable to establish direct cause and effect from the harvest data, the hunters' testimonials are compelling.

Hunters have detailed knowledge of their local areas and are the best sources of information on local hunting methods and hunter behavior. Furthermore, due to the legal and community-imposed restrictions on hunting in place at our study sites, any tendency to misreport is likely to downplay any increases in harvest. Even in Gabon, where the strongest restrictions on hunting are in force, most hunters reported harvesting greater numbers of nocturnal species since acquiring LED flashlights, while other hunters declined to answer or gave ambiguous responses. Given that harsh penalties for illegal commercial hunting may result in underreporting of nocturnal hunting in Gabon, we regard this observation as strong evidence for an increase in the hunting of nocturnal animals resulting from LEDs.

Although we do not have figures on the uptake of LEDs in different nations, we suspect that most hunters in tropical countries now use LEDs. LEDs have generally replaced incandescent lights to such an extent that the older technology is hard to find in our study regions, and reductions in costs and waste will benefit rural communities globally. On the basis of our results and the now-ubiquitous use of LEDs, we suspect that wild meat offtake will have increased across the tropics.

In addition to advances in LED technology, the increasing provision of solar power and rechargeable batteries, as well as the arrival of other technologies (eg refrigeration, mobile phones, inexpensive and efficient motors), are helping to modernize hunting throughout the tropics. Although new technologies tend to be expensive, prices inevitably fall; advances in LED technology, for instance, will lead to the development of brighter and more efficient flashlights (Pimputkar *et al.* 2009). More expensive models are already capable of floodlighting large areas of forest, while infrared LEDs and night-vision equipment are already commonly used by hunters in developed countries (Manning 2014), and may eventually be available in the tropics, where they will facilitate the increasingly rapid extraction of wild meat.

Implications for wildlife populations

How gains in hunting efficiency manifest themselves in wild meat harvests depends greatly on the culture and economics of hunting communities, and on the demography of the hunted species. While improved hunting efficiency does not necessarily translate to higher offtake, commercial hunting occurs widely across Amazonia (van Vliet *et al.* 2014), and some harvests have likely increased with the advent of LED lights. For example, lowland tapir hunting in the ASDR has largely shifted from day to night, and hunters confirmed that LED flashlights facilitated this change. Lowland tapir hunting has likely increased across Amazonia. Prior to the introduction of LED flashlights, the CPUE of hunting lowland paca in the ASDR was declining as a result of overharvesting (Valsecchi *et al.* 2014). The abrupt increase in CPUE for the lowland paca, which occurred around the time that LED flashlights were introduced to the region, is likely to have been repeated across Amazonia, and may have a substantial impact on subsistence and markets. Lowland pacas are widely commercialized in urban markets and restaurants (Mayor *et al.* 2019), and while they are generally considered resilient to hunting (Bodmer *et al.* 1997), their reproductive rate is relatively slow; populations can therefore be at greater risk to extirpation (local extinction) (El Bizri *et al.* 2018). CPUE in the ASDR appeared to fall again after the initial increase, perhaps indicating a further decline in lowland paca densities. Although likely to be resilient to hunting in remote areas, lowland pacas may become more scarce around human population centers, making extraction more costly in the longer term.

As human populations and demand for wild meat grow throughout sub-Saharan Africa, any increase in nocturnal offtake is unlikely to alleviate hunting pressure on diurnal species. The most commonly targeted species across Central Africa, brush-tailed porcupines and blue duikers, are considered locally abundant and resilient to hunting, but 30% of respondents in Gabon reported hunting indiscriminately at night and targeting species of conservation concern, including giant pangolin (*Smutsia gigantea*), tree pangolin (*Phataginus tricuspis*), long-tailed pangolin (*Phataginus tetradactyla*), bay duiker (*Cephalophus dorsalis*), white-bellied duiker (*Cephalophus leucogaster*), and yellow-backed duiker (*Cephalophus silvicultor*), for which immediate conservation attention is required.

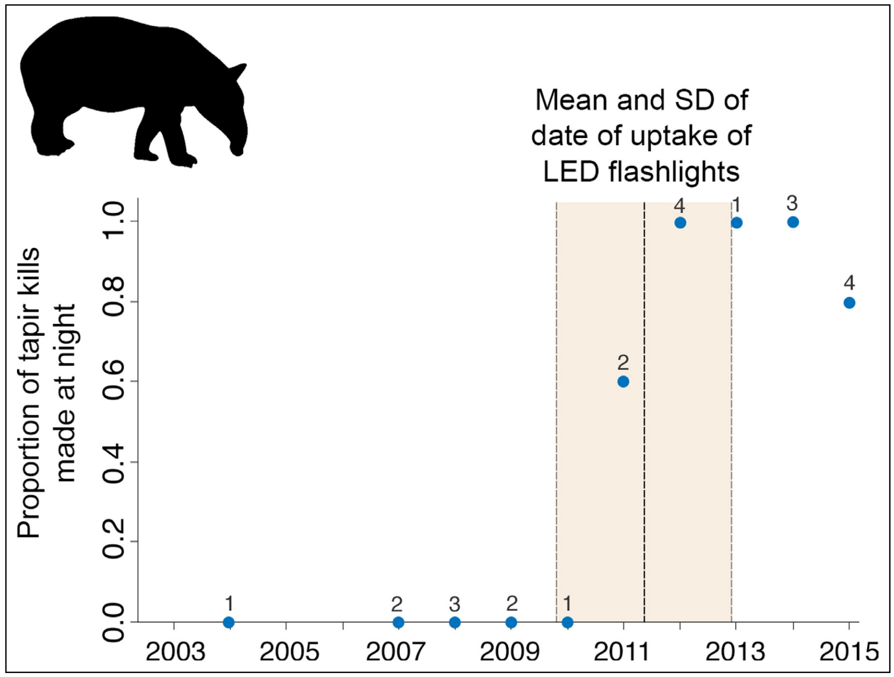

Figure 4. Day versus night kills of lowland tapir ($n = 23$) in the ASDR before and after the uptake of LED flashlights. Values above circles represent sample sizes (number of tapir kills reported).

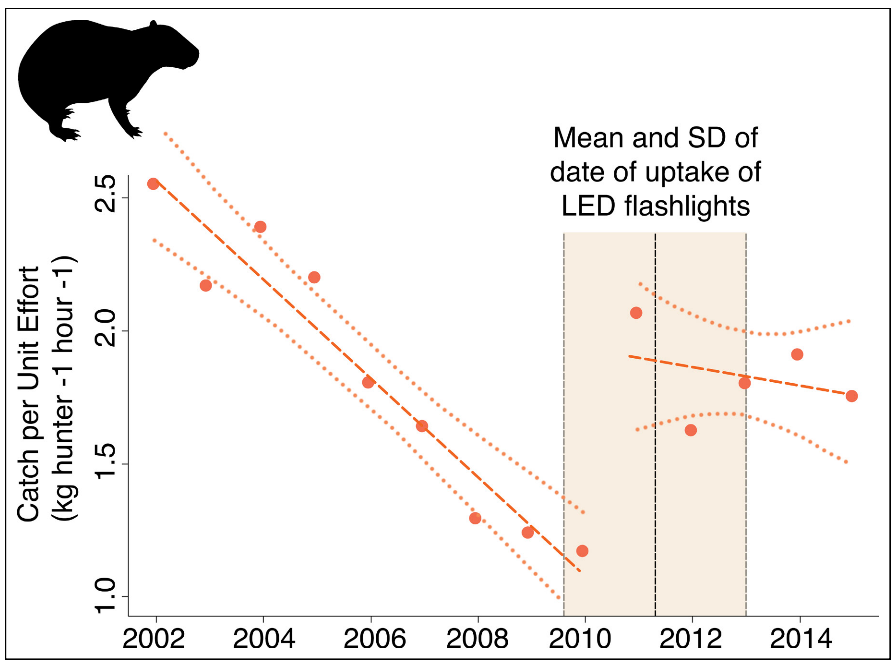

Figure 5. Catch per unit effort (CPUE; expressed as kilograms of hunted animals per hunter per hour [kg hunter^{-1} hr^{-1}]) for the lowland paca in the ASDR. A breakpoint analysis detected a structural change between 2010 and 2011, and a subsequent regression analysis showed that both the intercept and slope change at that point (without change: $R^2 = 0.18$, $F = 3.91$, $P = 0.07$; with change: $R^2 = 0.89$, $F = 26.6$, $P < 0.001$). Dashed and dotted orange lines show linear regressions and 95% confidence intervals, respectively.

LED flashlights and implications for wildlife management

It is unlikely that use of LEDs in hunting can be controlled in practice. Other kinds of flashlights are now difficult to find in markets, and hunters will select the best light source. Laws restricting hunting equipment would have to essentially ban nocturnal hunting with any light source. Although wildlife laws in Gabon already prohibit this practice (Gabonese

Republic 2001), the law is not enforced, and hunting with flashlights is common. Other management strategies could counter shifts in harvests, especially in areas where rural communities depend on wildlife for subsistence and risk overharvesting their resources. The establishment of no-take areas, changes in harvest quotas, and restrictions on hunting vulnerable species are a few measures commonly employed, with varying degrees of success (Campos-Silva *et al.* 2017). Efforts could be focused on protecting ecologically sensitive areas like mineral licks, water sources, or game trails that attract animals (Becker *et al.* 2013). However, such measures, like bans on spotlighting, will fail if hunters do not comply, and therefore local management is likely to be necessary.

Although challenging to put into action at many sites, community-based co-management – in which local people make management decisions and implement conservation efforts with the technical support of "co-managers" in government, non-governmental organizations, or academic institutions – has had success across a small number of sites in Amazonia (Campos-Silva *et al.* 2017), and is a key principle in several African countries, especially those in southern and eastern areas (Baghai *et al.* 2018). Because hunters make their own rules and are invested in intervention outcomes, the actions that are imposed by co-management schemes are likely to be widely accepted and implemented by hunters. In Peru, this system of management has proven successful at several sites and has been adopted by the government's National Service for Natural Protected Areas (SERNANP), which acts as the co-manager to communities located in and around the country's system of Natural Protected Areas (Bodmer *et al.* 2009). Thus, community co-management is a scalable management strategy that can be widely implemented.

A common feature of community management programs is monitoring animal populations based on CPUE (Rist *et al.* 2010), especially where the budgets of supporting organizations do not permit labor-intensive wildlife surveys. In practice, however, measures of effort and catch are prone to bias (Rist *et al.* 2008). Our results suggest that co-management groups may detect increases in CPUE when new hunting or transport technologies emerge. Managers must be careful not to interpret these as increases in wildlife abundance. Furthermore, declines in abundance may be masked by the same increases in hunting efficiency that cause the declines. Changes to CPUE are also open to misinterpretation unless communities record spatial and temporal measures of hunts and kills in sufficient detail. Hunting equipment and methods employed should also be registered, including the use of dogs, game calls, or recordings, while travel methods and the use of mineral licks or other landscape features will also affect CPUE.

Conclusions

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

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Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.2242/suppinfo

FrontiersEcoPics

Fog basking by Namib Desert weevils

Namib Desert darkling beetles (*Onymacris unguicularis*) capture water droplets from fog using a highly specialized behavior called "fog basking". This has applications in biomimetics (the study of biology-inspired technology, which can be utilized to solve complex human problems). In short, synthetic surfaces that mimic the external texture of fog-dependent organisms can be used to extract water from the atmosphere, thereby helping to address the critical and growing human demand for water in arid regions.

In April 2019, my colleagues and I visited a site within the Namib Sand Sea approximately 18.7 km due east of the Atlantic seaboard, near Walvis Bay. At the time, heavy fog was being carried over the dunes by a westerly breeze. Near the base of a large sand dune, we encountered several clumps of dune grass (*Stipagrostis sabulicola*) and observed many Namib Desert weevils (*Leptostethus marginatus*) clinging head-down about halfway up the grass stems. All of the weevils had drops of water collecting within the pits on their wing cases and thoraxes from the fog.

The surface architecture of the weevils, characterized by concave impressions of pits and grooves, is nearly opposite from that of the darkling beetles, distinguished by bumpy convex features. This observation could stimulate biomimetic research and further advances in developing artificial surfaces that can capture water from atmospheric sources.

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