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	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.

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 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.

Introduction

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 driving some to extinction (Benítez-López*, et al.* 2017, Maxwell*, et al.* 2016, Ripple*, et al.* 2016). Unsustainable hunting threatens the food security of rural populations that depend on wild meat (Cawthorn and Hoffman 2015, Nasi*, et al.* 2011). Wild animals in tropical forests are hunted with a variety of methods, both traditional (e.g. bow and arrow) and modern (e.g. firearms) (Fa and Brown 2009). Methods have improved incrementally through 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 (Alvard 1995, Hames 1979, Levi*, et al.* 2009, Redford and Robinson 1987). Flashlights are used to locate animals using the eyeshine that many species exhibit, a method known as spotlighting or lamping (Hames 1979). Many animals are temporarily immobilized by the lights, appearing to see the light as non-threatening. Hunters can then carefully approach to within a short distance of the animals to greatly improve 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 lightbulbs (Pimputkar*, et al.* 2009). Although LEDs existed for decades as low-power indicator lights, and high-power white-light emitters have been produced since 1999, this technology remained prohibitively expensive for hunters in developing countries for many years. Our collaborative research groups observed that LED flashlight prices became comparable to incandescent flashlights around 2012 and are now available in rural markets throughout the tropics, and widely employed in nocturnal hunting in Latin America, Africa and Asia.

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

Methods

Hunter interviews

During 2016 and 2017, we administered semi-structured questionnaires to 120 shotgun hunters in three countries (Peru, Brazil and Gabon). 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, 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 principally commercial hunters from 18 villages within the rural Ogooué-Ivindo Province.

In each country, researchers familiar with the study areas and hunters, and experienced in communicating with local communities, administered interviews translated from an original text in Spanish. We asked each hunter the following questions, in Spanish, Portuguese or French; Q1. Do you use LED flashlights, and if so, when did you switch to these?; Q2. Do you hunt more frequently at night since you started using LEDs; Q3. Do LED lights make hunting easier or harder, and why? Q4. What species do you hunt at night? And do you kill more, or less 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, Brazil, hunting registers were kept continuously for 13 years between 2003 and 2015 (n=1373 hunts; 1999 kills). Lowland paca (*Cuniculus paca*), the most frequently hunted species in Amazonia (El Bizri*, et al.* 2019), are targeted specifically on nocturnal canoe forays, which were recorded separately between 2002 and 2015. Hunters recorded the start and end of each hunt, 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. Hunting is therefore tolerated 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) (kg $hunter^{-1}$ $hour^{-1}$) (Rist*, et al.* 2010) is the usual metric to show changes in hunting efficiency, but among the nocturnal species recorded in hunting registers, sample sizes were sufficient to calculate CPUE annually only for the 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, and 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=27 kills). These metrics were compared before and after the uptake of LED flashlights by the hunters in the reserve.

Results

Q1. 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. In Peru (n=58) and Brazil (n=32), hunters estimated that they started using LEDs around 2011, and in Gabon (n=28) reported uptake was around 2015.

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

In Peru and Brazil, most hunters (66% at both sites) 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, or at the same frequency. In all regions, hunters mentioned that LEDs were more efficient than incandescent flashlights. Many hunters also said that because incandescent flashlights used batteries quickly, this made their use prohibitively expensive, thus limiting nocturnal hunting, whereas LEDs allowed hunting for several nights on a single pair of batteries.

Q3. 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 over incandescent lights; only hunters that used lower-powered LED flashlights disagreed. More than half of the hunters from each site (69% in Brazil, 40% in Peru, 54% in Gabon) suggested that animals were easier to hunt with LEDs, with most of the remainder 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 range or brightness of flashlights, and because a higher proportion of animals 'froze in the spotlight'.

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

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

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

Pre- and Post-LED hunting success in Brazil

The proportion of hunts made during the night compared to during the day increased around the time LED lights came into use at Amanã (20.6% vs 39.8%, Chi_2 = 50.64, $p < 0.001$. Figure 3a. Similarly, the proportion of kills made during the night compared to during the day increased at the same time (19.3% vs 37.3%, Chi_2 = 73.45, $p < 0.001$ Figure 3b). This reflects 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 in daytime. After the uptake of LED flashlights in Amanã, tapir hunting switched from exclusively diurnal to predominantly nocturnal (0% vs 83.3%, Chi_2 = 25.71, $p < 0.001$ (Figure 4), with hunters confirming that LED flashlights facilitated this change.

Between 2002 and 2010, the catch per unit effort for the lowland paca was in steep decline, but after the widespread adoption of LEDs around 2011, the CPUE close to doubled, before showing signs of declining again (Figure 5). A breakpoint analysis (Bai and Perron 2003) 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).

Discussion

New technology and hunting in the tropics

Our interviews with hunters show 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, killing more nocturnal animals. Hunting registers in Brazil are consistent with these hunters' perceptions, showing increases in the proportions of nocturnal hunting and kills. The only explanation put forward by the hunters themselves for these changes in the registers is that the use of LED lights facilitates hunting at night. While we are unable to establish 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 their hunting methods and 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 more nocturnal species since acquiring LED flashlights, while others declined to answer or gave ambiguous responses. Given that harsh penalties for illegal commercial hunting may result in under-reporting of nocturnal hunting in Gabon, we regard this 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 countries, we suspect that most hunters in tropical countries now use LEDs. LEDs have generally replaced incandescent lights to the point that the older technology is hard to find in our study regions and reductions in costs and waste will benefit rural communities globally. Based on 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, and the arrival of other technologies, such as refrigeration, mobile phones and cheap, efficient motors, is modernizing hunting in tropical forests. While new technologies tend to be expensive, prices inevitably fall and LED lights are predicted to get ever brighter and more efficient (Pimputkar*, et al.* 2009). More expensive models are already capable of floodlighting large areas of forest, while infrared LEDs and night vision equipment is already commonly employed by hunters in developed countries (Manning 2014), and may eventually be available in the tropics, where they will enable 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 the demography of the hunted species. While improved efficiency does not necessarily translate to higher offtake, commercial hunting occurs widely across Amazonia (van Vliet, *et al.* 2014), and it is likely that some harvests have increased with the advent of LED lights. For example, tapir hunting in the ASDR shifted from day to night, and hunters confirmed that LED flashlights facilitated this change. It is likely that tapir hunting has increased across Amazonia. Prior to the introduction of LED flashlights, the CPUE of the Lowland paca in the ASDR was declining as a result of overharvesting (Valsecchi, *et al.* 2014). The abrupt increase in CPUE for the paca, at around the time of the introduction of the new lights, is likely to have been repeated across Amazonia, which may have a substantial impact on subsistence and markets. Pacas are widely commercialized in urban markets and restaurants (Mayor, *et al.* 2019), and although they are generally considered resilient to hunting (Bodmer, *et al.* 1997), they reproduce relatively slowly, and can be locally extirpated (El Bizri, *et al.* 2018). CPUE in the ASDR appears to decline again after the initial increase, perhaps indicating a further decline in paca densities. Although pacas are likely to be resilient to hunting in remote areas, they may become scarcer around population centers, making extraction more costly in the longer term.

As human populations and demand for wild meat grows throughout sub-Saharan Africa, any increase in nocturnal offtake is unlikely to result in the alleviation of hunting pressure on diurnal species. The most commonly targeted species across Central Africa, brush-tailed porcupines (*Atherurus africanus*) and blue duikers (*Philantomba monticola*), 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 like the pangolins (*Smutsia gigantean*, *Phataginus tricuspis* and *Phataginus tetradactyla*), bay duiker (*Cephalophus dorsalis*), white-bellied duiker (*Cephalophus leucogaster*), and yellow-backed duiker (*Cephalophus silvicultor*), for which immediate conservation attention is required.

LED flashlights and the 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 forbid nocturnal hunting with any light source. Wildlife laws in Gabon do prohibit this practice (République Gabonaise 2001), but the law is not enforced, and hunting with flashlights is common. Other management strategies could counter shifts in harvests, particularly where rural communities depend on wildlife for subsistence and risk overharvesting their resources. The establishment of no-take areas, changes in harvest quotas, or restrictions on hunting vulnerable species, are measures that are already commonly employed with varying degrees of success (Campos-Silva*, et al.* 2017). Efforts could be focused on 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, so local management is likely to be necessary.

Although challenging at many sites, community-based co-management, in which local people make management decisions and implement conservation with the technical support of 'co-managers' in government, NGOs or academic institutions has had localized success across 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 the outcomes of the interventions, the actions they impose are likely to be widely accepted and implemented. 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 living in and around Natural Protected Areas (Bodmer*, et al.* 2009). Thus, community co-management has been shown to be a scalable management strategy that can be widely implemented.

A common feature of community management programs is monitoring animal populations through CPUE (Rist*, et al.* 2010), especially where the budgets of supporting organizations do not permit labor-intensive wildlife surveys, although in practice, measures of effort and catch are prone to bias (Rist*, et al.* 2008). Our results suggest that co-management groups may find increases in CPUE when new hunting or transport technologies emerge. Managers must be careful not to interpret these as increases in wildlife abundance. Similarly, 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 enough detail. The hunting equipment and methods 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. These findings should alert management groups to the potential of increased harvest rates of selected species at the time of introduction, and highlights 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 may 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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Figure Legends

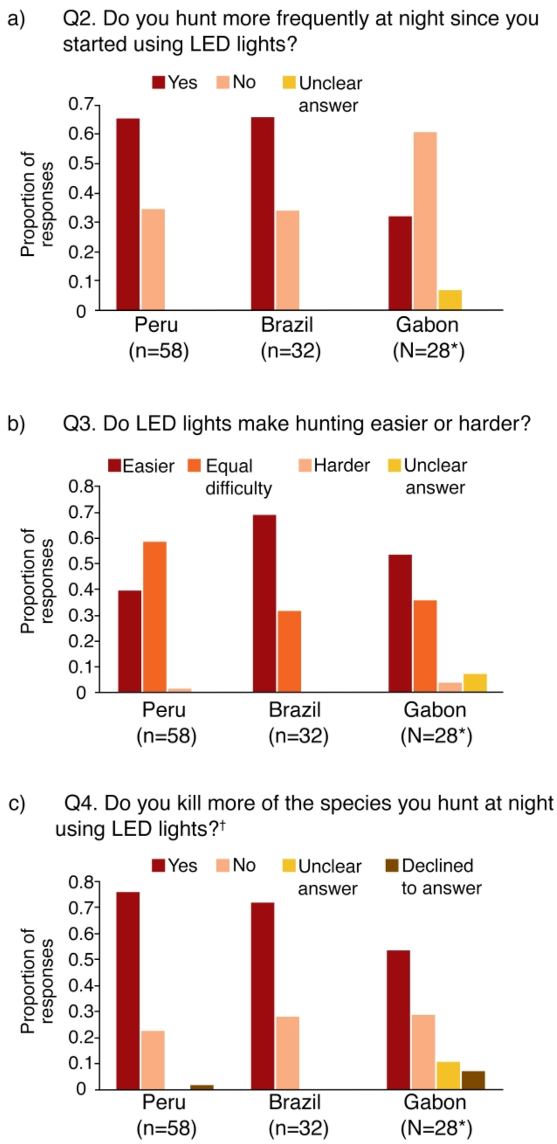
Figure 1. Responses of hunters asked about changes in their hunting behavior since starting to use LED flashlights in Peru, Brazil and Gabon.
*sample size excludes two interviewees who had not switched to LED flashlights
†This question was asked as "What species do you hunt at night? Do you kill more of the species you hunt at night since using LEDs?"

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.

Figure 3. a) The proportion of hunts 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. b) The proportion of kills made at night in the Amanã Sustainable Development Reserve, Brazil, showing an increase in nocturnal kills 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 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: $R2=0.183$, $F=3.91$, $p=0.07$, with change: $R2=0.888$, $F=26.6$, $p<0.001$). Lines show linear regressions and 95% confidence intervals.



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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.

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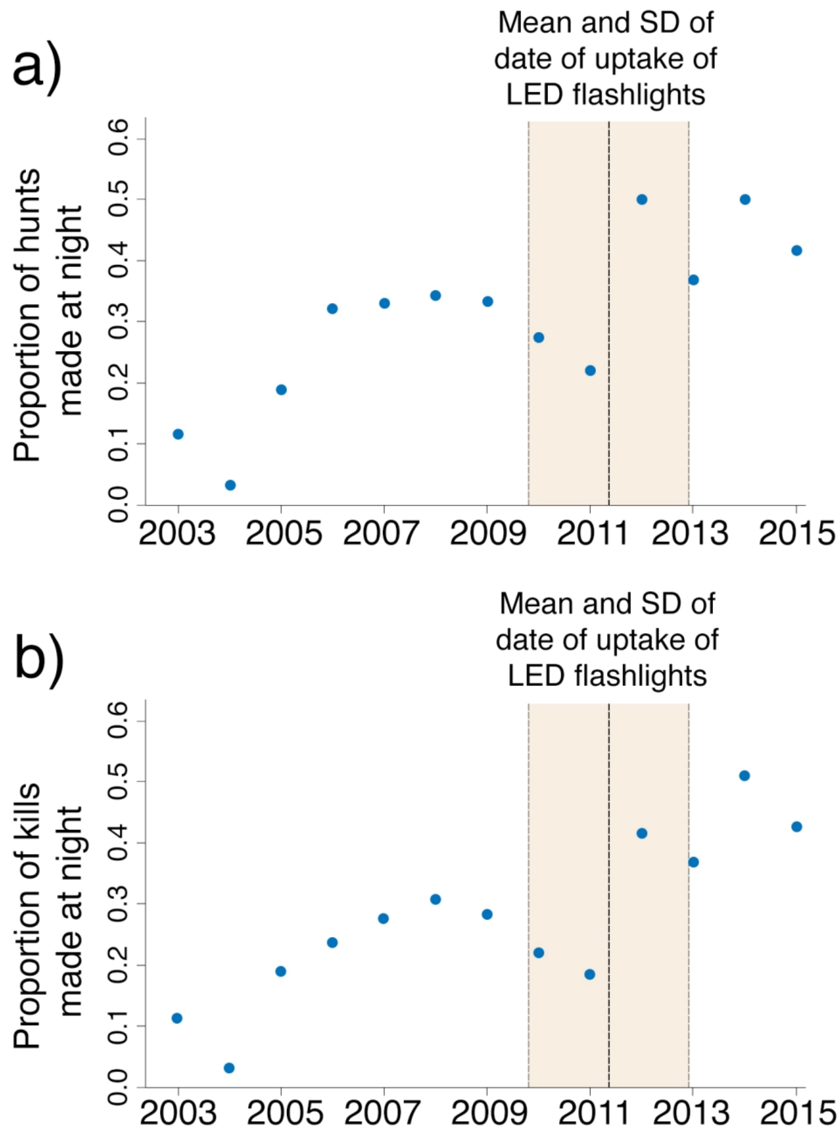

The proportion of a) hunts and b) kills made at night in the Amanã Sustainable Development Reserve, Brazil, showing an increase in nocturnal hunting at around the time of the introduction of LED lights.

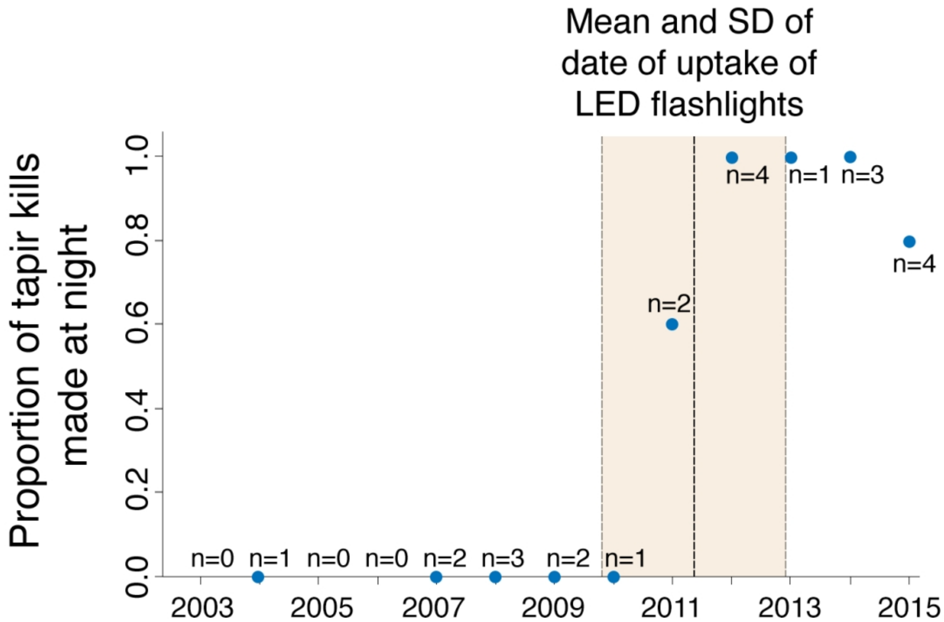

Figure 4. Day versus night kills for tapir (n=27) in the Amanã Sustainable Development Reserve, Brazilian Amazon, before and after the uptake of LED flashlights.

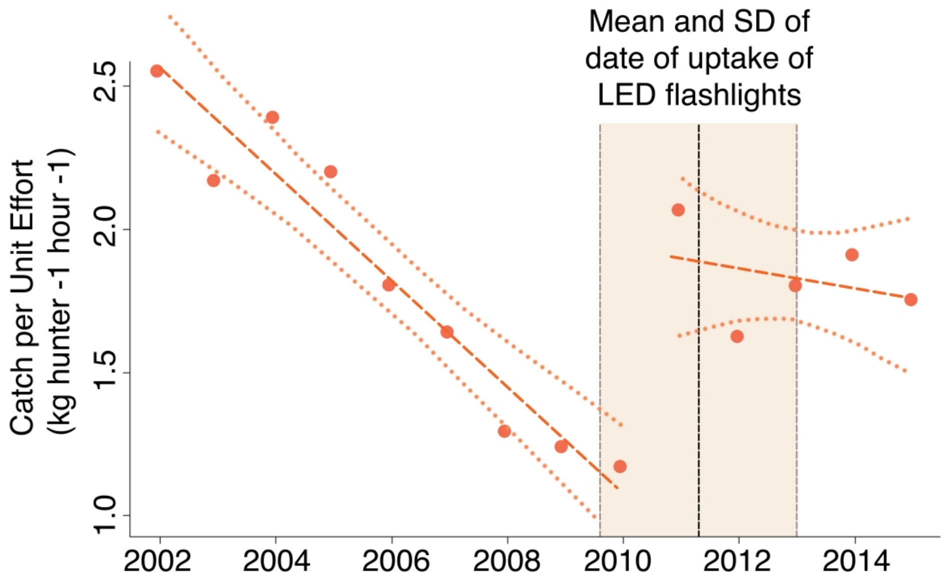

Figure 4. Day versus night kills for tapir (n=27) in the Amanã Sustainable Development Reserve, Brazilian Amazon, before and after the uptake of LED flashlights.

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: $R2=0.183$, $F=3.91$, $p=0.07$, with change: $R2=0.888$, $F=26.6$, $p<0.001$). 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	*Atherurus africanus*	20	66.7%	Nocturnal	1
Duikers	*Cephalophus spp.*	16	53.3%	*Cephalophus dorsalis* Nocturnal; Cephalophus *leucogaster* Diurnal; *Cephalophus silvicultor* Cathemeral	2
Blue duiker	*Philantomba monticola*	20	66.7%	Diurnal	1
Red river hog	*Potamochoerus porcus*	5	16.7%	Primarily nocturnal or crepuscular	1
African Palm Civet	*Nandinia binotata*	3	10.0%	Nocturnal	1
Rats	*cf. Thryonomys* sp. and *Cricetomys sp.*	2	6.7%	Nocturnal	1
Pangolin	*Phataginus tricuspis and Phataginus tetradactyla*	2	6.7%		1
Giant pangolin	*Smutsia gigantean*	1	3.3%		1
Crocodile	*Mecistops cataphractus*	1	3.3%	No data	
Mongoose	*Atilax paludinosus, Bdeogale nigripes, Herpestes naso*	1	3.3%	Primarily nocturnal or crepuscular	1
Brazil					
Lowland paca	*Cuniculus paca*	32	100.0%	Nocturnal	3
Brocket deer	*Mazama* spp.	25	78.1%	Crepuscular	4
Lowland tapir	*Tapirus terrestris*	25	78.1%	Predominantly nocturnal	4
Armadillo	*Dasypus* spp.	22	68.8%	Nocturnal	3
Jaguar	*Panthera onca*	4	12.5%	Cathemeral	3
Agouti	*Dasyprocta* spp.	3	9.4%	Diurnal	3
Collared Peccary	*Pecari tajacu*	1	3.1%	Diurnal	4
Capybara	*Hydrochoerus hydrochaeris*	1	3.1%	Cathemeral	5
Ocelot	*Leopardus pardalis*	1	3.1%	Predominantly nocturnal	6
Peru					
Lowland paca	*Cuniculus paca*	41	70.7%	Nocturnal	3
Brocket deer	*Mazama* spp.	23	39.7%	*M. americana* Crepuscular; *M. gouazoubira* Diurnal	4
Armadillo	*Dasypus* spp.	19	32.8%	Nocturnal	3
Lowland tapir	*Tapirus terrestris*	9	15.5%	Predominantly nocturnal	4
Kinkajou	*Potus flavis*	3	5.2%	Nocturnal	7

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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,~~ with the recent availability of~~ brighter, more efficient light-emitting diode (LED) flashlights, have recently been adopted by hunters.~~ can find and kill prey more easily.~~ 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~~Through interviews and hunting registers~~ in African and South American forests, disclosed~~we show~~ that ~~the use of~~ LEDs ~~can~~ increase the frequency and efficiency~~kill rates~~ of nocturnal hunting, and the number of kills made. These changes were reflected in harvest data in Brazil.~~species and overall harvests.~~ 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.

Introduction

Wild vertebrates are a source of food and income for millions of people throughout the tropics. However, overhunting is a major ~~source of~~ concern, causing ~~since it causes~~ the decline of~~for~~ large-bodied animal species and driving~~drives~~ some ~~of these~~ to extinction (Benítez-López*, et al.* 2017, Maxwell*, et al.* 2016, Ripple*, et al.* 2016). Unsustainable hunting ~~also~~ threatens the food security of rural populations that depend~~are dependent~~ on wild meat (Cawthorn and Hoffman 2015, Nasi*, et al.* 2011). Wild animals in tropical forests are hunted with a variety of methods, both traditional (e.g. bow~~methods~~ and arrow) and~~more~~ modern (e.g.~~ones like~~ firearms) (Fa and Brown 2009). Methods~~Hunting methods~~ have improved incrementally through 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 (Alvard 1995, Hames 1979, Levi*, et al.* 2009, Redford and Robinson 1987). Flashlights are used to locate animals using the eyeshine that many species exhibit, a method known as spotlighting or lamping (Hames 1979). Many animals are temporarily immobilized by the lights, appearing to see the light as non-threatening. Hunters can then carefully approach to within a short distance of the animals to greatly improve 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 lightbulbs (Pimputkar*, et al.* 2009). Although LEDs existed for decades as low-power indicator lights, and high-power white-light emitters have been produced since 1999, this technology remained prohibitively expensive for hunters in developing countries for many years. Our collaborative research groups observed that LED flashlight prices became comparable to incandescent flashlights around 2012 and ~~LED lights~~ are now~~ commonly~~ available in rural markets throughout the tropics, and ~~are~~ widely employed in nocturnal hunting in Latin America, Africa and Asia.

We investigated the impact of ~~the use of~~ LED flashlights in increasing wild mammal offtake by hunters in tropical forests, using~~. We use~~ interviews with commercial and subsistence hunters in Peru, Brazil and Gabon. We support this with~~also use~~ data from hunting events monitored for 13~~17~~ years in the Brazilian Amazon comparing~~to compare~~ hunting returns before and after the introduction of LED lights.

Methods

Hunter interviews

During 2016 and 2017, we administered semi-structured questionnaires to 120 shotgun hunters in three countries (Peru, Brazil and Gabon). In Peru, we interviewed 58 subsistence and commercial hunters from three dispersed communities - *Nueva Esperanza* on the Rio Yavari, *Tahuayo* on the Rio Tahuayo, ~~south of the Amazon River,~~ and *Sucusari*, on the Rio Napo, 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 principally commercial hunters from 18 villages within the rural Ogooué-Ivindo Province.

In each country, researchers familiar with the study areas and hunters, and experienced in communicating with local communities, administered interviews translated from an original text in Spanish. We asked each hunter the following questions, in Spanish, Portuguese or French; Q1. Do you use LED flashlights, and if so, when did you switch to these?; Q2. Do you hunt more frequently at night since you started using LEDs; Q3. Do LED lights make hunting easier or harder, and why? Q4. What species do you hunt at night? And do~~Do~~ you kill more, or less 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 ~~Amanã Sustainable Development Reserve (~~ASDR,~~),~~ Brazil, hunting registers were kept continuously for 13~~17~~ years between 2003 and 2015 (n=1373 hunts; 1999 kills).~~.~~ Lowland paca (*Cuniculus paca*), the most frequently hunted species in Amazonia (El Bizri, *et al.* 2019), are targeted specifically ~~at Amana~~ on nocturnal canoe forays ~~distinct from other hunts~~, which were recorded separately between 2002 and 2015. Hunters recorded the start and end of each hunt, species hunted, and the time of all kills. Because the identities of hunters are kept anonymous, the number of ~~hunters and the proportion of~~ hunts each hunter recorded is unknown. Hunting in Brazil is forbidden by law, except by necessity for subsistence within the family. Hunting is therefore tolerated 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) (kg hunter^{-1} hour^{-1}) (Rist*, et al.* 2010) is the usual~~ideal~~ metric to show changes in hunting efficiency, but among~~. Among~~ the nocturnal species recorded in hunting registers, sample sizes were sufficient ~~for us~~ to calculate CPUE~~this~~ annually only for the paca (n=309 nocturnal hunts; 501 nocturnal kills). For all hunted~~. For all~~ species collectively, we calculated the proportion of diurnal versus nocturnal hunts and kills annually~~anually~~, and for the lowland~~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=27 kills).~~.~~ These metrics were compared before and after the uptake of LED flashlights by the hunters in the reserve.

Results

Q1. 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. In Peru (n=58) and Brazil (n=32),~~,~~ hunters estimated that they started using LEDs around 2011, and in Gabon (n=28)~~2011but~~ reported uptake was ~~later, around2015 in Gabon.~~ around 2015.

Q2.~~. Whereas LEDs allowed hunting for several nights on a single pair of batteries. Q2.~~ Do you hunt more frequently at night since you started using LEDs?

In Peru and Brazil, most hunters (66% at both sites) 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, or at the same frequency. In all regions, hunters mentioned that LEDs were more efficient than incandescent flashlights. Many hunters also said that because incandescent flashlights used batteries quickly, this made their use prohibitively expensive, thus limiting nocturnal hunting, whereas LEDs allowed hunting for several nights on a single pair of batteries.

Q3. 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 over incandescent lights; only hunters that used lower-powered LED flashlights disagreed.

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

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

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

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

Pre- and Post-LED hunting success in Brazil

~~Day X Night Hunts Intentional:~~ The proportion of hunts made during the night compared to during the day increased around the time LED lights came into use at Amanã (20.6% vs 39.8%, Chi$_2$ =~~chi-square statistic is~~ 50.64,~~6381. The~~ p <~~-value is 1.1107E-12 (<~~0.001. Figure 3a. Similarly, the proportion of kills made during the night compared to during the day increased at the same time (19.3% vs 37.3%, Chi$_2$ =~~)~~

Day X Night Kills Intentional: The chi-square statistic is 73.45,4513. The p <-value is 1.03152E-17 (<0.001 Figure 3b). This reflects 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 in daytime.)

After the uptake of LED flashlights in AmanãBrazil, tapir hunting switched from exclusively diurnal to predominantly nocturnal (0% vs 83.3%, Chi$_2$ = 25.71, p <0.001 (Figure 42), with hunters confirming that LED flashlights facilitated this change.

Between 2002 and 2010, the catch per unit effort for the lowland paca was in steep decline, but after the widespread adoption of LEDs around 2011, the CPUE close to doubled, before showing signs of declining again (Figure 5). A breakpoint analysis (Bai and Perron 2003) 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).

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

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

Discussion

*New technology*The size of harvests of wild animals is primarily affected by variations in game abundance *and* changing market forces, but also by innovations in *hunting* *in the tropics* equipment. Our interviews with hunters show that LED flashlights are perceived to have increasedincrease the efficiency of nocturnal hunting in tropical sites in three different countries, and that local people now hunt at night more, killing more nocturnal animals. Hunting registers in Brazil are consistent with these hunters' perceptions, showing increases in the proportions of nocturnal hunting and kills. The only explanation put forward by the hunters themselves for these changes in the registers is thatdue to the use of LED lights facilitates hunting at night.. While we arethe offtake of any one species is not independent of harvests of other species, and we are therefore unable to establish 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 their hunting methods and behavior. Furthermore, due to the legal and community-imposed restrictions on hunting that are in place at our study sites, any tendency to misreport hunting is likely to downplay any increases in harvest. Even in Gabon, where the strongest restrictions on hunting are in force, most hunters reported harvesting more nocturnal species since acquiring LED flashlights, while others declined to answer or gave ambiguous responses. Given that harsh penalties for illegal commercial hunting may result in under-reporting of nocturnal hunting in Gabon, we regard this 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 countries, we suspect infer from our results that most hunters in tropical countries now use or have access to LEDs. LEDs have generally replaced incandescent lights to the pointThis means that the older technologythere is hardbound to findhave been a significant increase in our study regions and reductions in costs and waste will benefit rural communities globally. Based on our results and the now-ubiquitous use of LEDs, we suspect that wild meat offtake will have increasedofftake of wild meat across the tropics.

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

ImplicationsLED flashlights and the implications for wildlife populations

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

Prior to the introduction of LED flashlights, the CPUE of the Lowland pacaPaca in the ASDRAmana was declining as a result of overharvesting (Valsecchi*, et al.* 2014).(El Bizri*, et al.* 2019). The abrupt increase in CPUE for the lowland paca in the ASDR, at around the time of the introduction of the new lights, is likely to have been repeated across Amazonia, which may -have a substantial impact on subsistence and markets. Pacas are widely commercialized in urban markets and restaurants (Mayor, *et al.* 2019), and although they are generally consideredwere previously thought to be resilient to hunting and touted as an alternative prey to more vulnerable species (Bodmer*, et al.* 1997), they reproduce relatively slowly, and can be locally extirpated (El Bizri*, et al.* 2018).. . CPUE in the ASDRat Amana appears to decline again after the initial increase, perhaps indicating a further decline in paca densities. Although pacas . Pacas are likely to be resilient to hunting in remote areas, theyacross Amazonia but may become scarcer around population centers, making extraction more costly in the longer term.

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

New technology and hunting in the tropics

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

~~adapt management plans to account for this and other emerging technologies. Hunters are often aware of species declines, just as they are aware of the changes in hunting efficiency, but some changes to wildlife populations will go unnoticed unless communities keep coordinated registers that record spatial and temporal measures of hunts and kills in enough detail to pick up any changes in CPUE. While this approach has challenges in areas where hunting is controlled or illegal, it is a widely-used monitoring tool in tropical regions.The hunting equipment and methods should 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.~~

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

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

~~Community~~-based co-~~wildlife~~ management, in which ~~initiatives have had localized success across Amazonia where~~ local people make management decisions and implement conservation with the technical support of 'co-managers' in government, NGOs or academic institutions has had localized success across 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 the outcomes of the interventions, the actions they impose are likely to be widely accepted and implemented. 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 living in and around Natural Protected Areas (Bodmer*, et al.* 2009). Thus, community co-management has been shown to be a scalable management strategy that can be widely implemented. ~~Our reported increases in hunting efficiency at night further motivate the expansion of community management programs to promote sustainable hunting.~~

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

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

Conclusions

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

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

(Rist*, et al.* 2010). Managers should be aware that other new technologies may 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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Figure Legends

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

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.~~Figure 2. Day X Night Hunts Intentional: The chi-square statistic is 50.6381. The p-value is 1.1107E-12 (<0.001)~~

~~Figure 3. Day X Night Kills Intentional: The chi-square statistic is 73.4513. The p-value is 1.03152E-17 (<0.001)~~
a) The proportion of hunts 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. b) The proportion of kills made at night in the Amanã Sustainable Development Reserve, Brazil, showing an increase in nocturnal kills at around the time of the introduction of LED lights.

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

Figure 5. Catch Per Unit Effort (CPUE) kg ~~/~~hunter^{-1} hour^{-1} for the lowland paca (*Cuniculus paca*) ~~across five communities hunting for subsistence only~~ 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 CPUE for paca was significantly higher after~~ the intercept and slope change at that point (without change: R2=0.183,~~mean year of uptake of LED flashlights:ANCOVA here:~~ F=3.91~~(1, 10)=7.3700~~, p=0.07, with change: R2=0.888,~~=.02175; Difference between slopes/between trends of the periods:~~ F=26.6~~(1,10)=7.42644~~, p<0.001). Lines show linear regressions and 95% confidence intervals.~~ = 0.021371.~~