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LETTER

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Increase anti-poaching law-enforcement or reduce demand for wildlife products? A framework to guide strategic conservation investments

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Abstract

Donors, NGOs, and governments increasingly invest in campaigns to reduce consumer demand for wildlife products in an attempt to prevent the decline of overexploited and poached species. We provide a novel framework to aid these investment decisions based on a demand reduction campaign's return on investment compared to antipoaching law enforcement. A resulting decision rule shows that the relative effectiveness of demand reduction compared to increased enforcement depends entirely on social and economic uncertainties rather than ecological ones. Illustrative case studies on bushmeat and ivory reveal that campaigning to reduce demand may be more cost-effective than antipoaching enforcement if demand reduction campaigns drive modest price reductions. The outputs from this framework can link targeted monitoring of wildlife product prices to management decisions that protect species threatened by harvest and trade.

KEYWORDS

bushmeat, conservation marketing, demand reduction, enforcement, illegal wildlife trade, ivory, Loxodonta, overexploitation, poaching, social-ecological systems

1 | INTRODUCTION

The illegal harvest of wildlife is one of the greatest threats to biodiversity (Maxwell, Fuller, Brooks, & Watson, 2016). The problem is so urgent that from 2010 to 2016, foreign governments and NGOs donated over 1.3 billion $US toward antipoaching measures across Africa and Asia (World Bank Group, 2016). This money has largely gone toward law enforcement that targets poachers, smugglers, and dealers (Challender, Harrop, & MacMillan, 2015). To this day, proponents of enforcement argue that an additional 600 million $US/year, Africa-wide, antipoaching initiative could achieve positive economic returns just from the value of increased elephant populations alone (Gray & Gauntlett, 2017). However, alternative antipoaching interventions are increasingly gaining donor and government support—ones that attempt to indirectly curtail poaching by reducing consumer demand for wildlife products (Sato & Hough, 2016; Veríssimo & Wan, 2018). From educational and advertising material (Chaves et al., 2018; Veríssimo & Wan, 2018) to the public destruction of ivory and rhino horn (Biggs, Holden, Braczkowski, & Possingham, 2016; Braczkowski et al., 2018), these actions aim to stigmatize consumer purchases as part of multipronged demand reduction campaigns. Despite organizations moving forward with these interventions, and scientists exploring drivers of demand (Gao & Clark, 2014; Hanley, Sheremet, Bozzola, & MacMillan, 2017; Olmedo et al., 2017), there has yet to be any rigorous study on the effectiveness of demand reduction campaigns for securing populations of poached species compared to enforcement.

Where there is little empirical information, dynamic models linking species' population dynamics to poacher and consumer behavior can inform investment decisions between demand reduction and other management interventions. For example, consider two species, species one, for which poaching is difficult to police and species two, for which enforcement is mostly absent, but would be effective if it could be deployed. For species one, a demand reduction campaign may be the best investment because the alternative investment is not very effective, while species two might be better protected by increasing antipoaching patrols. Models allow us to quantify this logic to inform management decisions. Although previous studies have used models to increase the cost-effectiveness of enforcement (Byers & Noonburg, 2007; Messer, 2010), we suggest applying cost-effectiveness thinking to aid demand reduction investments as well. As a first step, we should ask, "How effective do demand reduction efforts have to be in order to generate a positive return on investment compared to enforcement measures?"

We propose a simple decision framework to assess the cost-efficacy of demand reduction campaigns and increased antipoaching enforcement for species threatened by illegal harvest and trade (Figure 1). The output of our approach is a threshold for demand reduction efficacy that can aid stakeholder-funding allocations toward the two strategies. We illustrate the framework using a simple dynamic model, widely used to study predation (Kot, 2003) and harvest (Bjørndal & Conrad, 1987). We then apply the framework and model to two case studies, African elephants threatened by poaching for ivory (Wittemyer et al., 2014) and poaching for bushmeat in Serengeti National Park, Tanzania (Knapp, 2012). For both examples, we assume poachers are profit seeking (Byers & Noonburg, 2007; Messer, 2010), despite the fact that antipoaching compliance is complex, involving personal norms, cognitive biases, community support of enforcement, and other factors (Arias, 2015; Brown et al., 2018; Gezelius & Hauck, 2011; Keane, Jones, Edwards-Jones, & Milner-Gulland, 2008). Incorporating such complications, within our framework, should be a priority for future research.

2 | METHODS

Our framework requires a management objective and a model to predict the effects of demand reduction and increased enforcement (Figure 1). We illustrate the framework with a simple, well-studied model of population and poacher dynamics and an objective of maximizing equilibrium population density. In the model, population and poacher density, N and E, respectively, change at rates

$$\frac{dN}{dt} = rN\,(1 - N/k) - qEN \tag{1}$$

$$\frac{dE}{dt} = \delta\,(pqEN - cE), \tag{2}$$

with intrinsic population growth rate (r), carrying capacity (k), catchability of individuals by poachers (q), price per poached individual received by poachers (p), and cost of poaching per unit effort (c). Equation (2) says poachers increase effort when poaching is profitable and decrease effort when it is unprofitable, where δ controls how fast poachers adjust effort. It is a well-studied model with a stable equilibrium population density of $N = c/(pq)$ if $c/(pq) < k$. If $c/(pq) > k$, poaching declines and population density approaches carrying capacity. Note, equilibrium population density is inversely proportional to the price poachers receive and directly proportional to the cost of poaching. Therefore, management interventions that affect poaching costs, such as antipoaching enforcement, have different effects on population densities than actions that reduce price, such as demand reduction campaigns.

The simplest way to model the expected cost of poachers being caught is to assume antipoaching patrols encounter poachers at a rate proportional to the product of patrol and

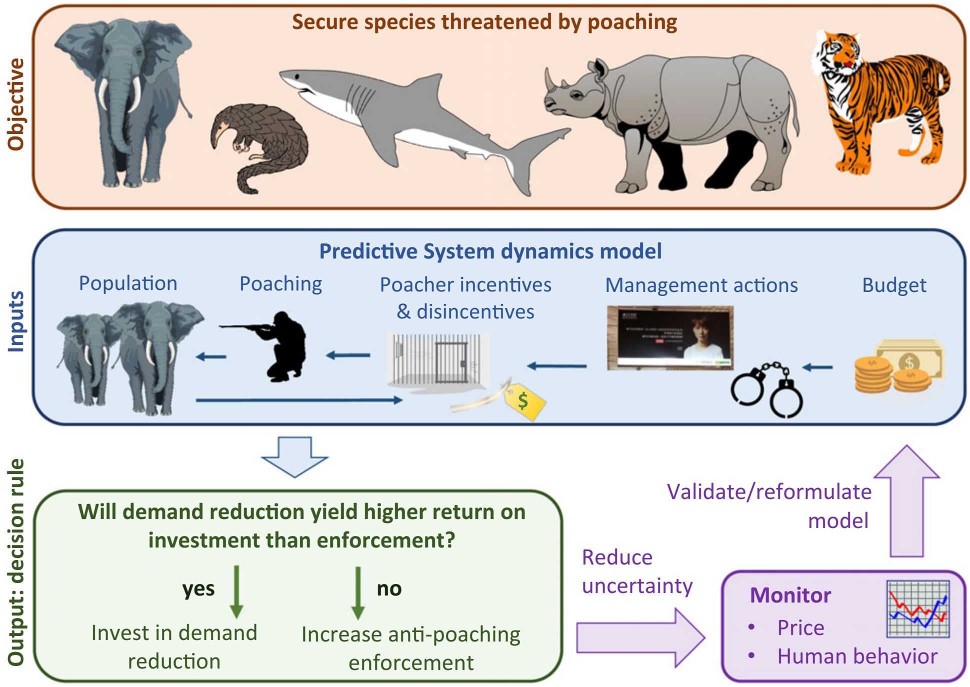

FIGURE 1 Decision support framework for strategic investment in demand reduction campaigns and antipoaching enforcement interventions. It requires a quantifiable objective related to securing poached populations (e.g., maximizing equilibrium population size, minimizing extinction risk, etc.), and a model that predicts the population's response to management interventions in order to calculate return on investment. This generates a decision rule to aid investment. Then, monitoring the effects of the decision in a way that can elucidate causal mechanisms is required to reduce uncertainty and revise (or validate) the model to improve future decision-making

poacher densities. This is reasonable because patrol handling time, arresting poachers, is small compared to search time. With this assumption, the cost of poaching c is $c_p + c_c s$, where c_p is the cost of poaching under no enforcement (e.g., alternative income lost) and c_c is the expected cost of getting punished (the penalty multiplied by the rate of getting caught and punished, per-unit antipoaching patrol density [s]). In the case where an added enforcement investment is chosen, we let $s = s_0 + s_a$, where s_0 is status-quo patrol density and s_a is the additional patrol density from the investment. The cost of both increased enforcement and a demand reduction campaign are incorporated through s_a. We assume a fixed budget equal to the cost of a demand reduction campaign. Then, we let s_a be the increased patrol density resulting from alternatively spending that budget on enforcement.

Using the above, we derive a condition for selecting the most cost-effective management action, a demand reduction campaign or increased enforcement. Here, we define "most cost effective" as the action that produces the highest equilibrium population density per dollar spent.

2.1 | Case study 1: African elephant poaching for ivory

We applied the framework to provide context for deterring elephant-poaching. Table 1 summarizes the parameterization, with details in the supplement. To parameterize, s_a, we must know the cost of a typical ivory demand reduction campaign, which includes the cost of print, electronic, and social media advertisements to target consumers globally. Unfortunately, there is no publically available information on the typical cost of such campaigns. Therefore, we consider two baseline scenarios, 4 and 54 million \$US investments. The World Bank reported that between 2010–2016, foreign governments and NGOs invested approximately 8 million \$US annually toward illegal wildlife trade "awareness and communication" of African species (World Bank Group, 2016). Given the financial interest in conserving elephants (Biggs et al., 2017), for the first scenario, we assumed that half of this money went toward ivory demand reduction. For the second scenario, we used a 2014 US Center for Disease Control and Prevention antismoking drive cost estimate for a 3-month, high-intensity, television and billboard education campaign of 54 million \$US (McAfee, Davis, Alexander, Pechacek, & Bunnell, 2013).

2.2 | Case study 2: Poaching for bushmeat in Serengeti, Tanzania

We used data from bushmeat poacher surveys in the Western Serengeti, which recorded self-reported poaching frequency, arrest frequency, punishments, and alternative

TABLE 1 Case study parameters

Parameter	Description	Value	Assumptions and source(s)
c_p	Poacher opportunity cost ($US/day)	Bushmeat 0.7 Elephant 2.1	**Bushmeat**: Average daily Serengeti income (Knapp, 2012). **Elephant**: Rural sub-Saharan Africa average (Lakner & Milanovic, 2016)
c_c	Expected punishment cost ($US /day/[patrol/km^2])	Bushmeat 28 Elephant 5,341*	**Bushmeat**: 39 $US fine, 0.0007 capture probability/poaching-day (at patrol density s_0), 0.56 conviction probability (Knapp, 2012)**. Elephant**: 2 years lost income from jail sentence, 0.35 discount rate (Mastrobuoni & Rivers, 2016), average capture rate per unit patrol density, Luangwa Valley (Leader-Williams et al., 1990) and Serengeti (Hilborn et al., 2006), 0.86 conviction probability (Leader-Williams et al., 1990).
s_0	Initial patrol density (patrols/km^2)	Bushmeat 0.0005 Elephant 0.00065	**Bushmeat**: Reports from the Serengeti (Hilborn et al., 2006). **Elephant**: Average patrol density in Luangwa Valley (Leader-Williams et al., 1990; Milner-gulland & Leader-Williams, 1992) and Serengeti (Hilborn et al., 2006)
s_a	Increased patrol density from budget (patrols/km^2)	Bushmeat 0.0001 Elephant 0.00002, 0.0003	150 $US/patrol-day, Selous-Game Reserve (see supplement) **Elephant**: Budget of 4 & 54 million $US/year and Elephant habitat of 3.3 million km^2. **Bushmeat**: 44,935 $US/year increased enforcement budget, and 14,750 km^2 Serengeti habitat.

*Note c_c may appear high, but only because the units are per unit of patrol density. One patrol per km^2 is very high. The expected punishment cost at a patrol density s_0 is s_0 times c_c, which is 3.5 $US/day.

income (Knapp, 2012) to estimate c_c and c_p. We then used a demand reduction campaign cost of 44,935 $US, which was the cost of a campaign to reduce wild meat consumption in the town of Tapauá, Central Brazilian Amazon (Chaves et al., 2018), including visual media, radio, print media, community outreach and education, giveaways, coupons, and labor (Chaves et al., 2018). See the supplement for the detailed itemized budget.

For both case studies, we performed a sensitivity analysis to assess each parameter's importance for decision-making.

3 | RESULTS

Given the model, a demand reduction campaign is more cost effective than increasing enforcement if the campaign can reduce price by more than a critical threshold proportion (p_R^*) given by

$$p_R^* = \frac{c_C\ s_a}{c_C(s_0 + s_a) + c_p}. \quad (3)$$

This says that the proportional reduction in price must be greater than the proportional reduction in poacher costs that would occur if an additional enforcement investment were redirected toward a demand reduction campaign (see supplement for derivation).

Some key insights are apparent from this formula. First, it does not depend on any ecological parameters or the initial wildlife product price. It is only dependent on socioeconomic factors relating to the management interventions. Second, for large values of the expected cost of getting caught and punished (c_c), the price reduction threshold is approximately equal to $s_a/(s_0 + s_a)$. This means that the proportion of total enforcement resulting from the increased investment bounds the required threshold price reduction. Third, high poacher opportunity cost favors demand reduction campaigns compared to enforcement, because c_p only appears in the denominator. This means interventions that improve alternative livelihoods of poachers (Wright et al., 2016) work more synergistically with demand reduction than increased enforcement. Lastly, for small, initial, patrol densities, increasing patrol density is more beneficial. If patrol intensity is already high, demand reduction is more likely to be cost effective than additional patrols. This is evident because s_0 is only in the denominator.

3.1 | Case study 1: African elephant poaching for ivory

In our baseline scenario, increasing the annual Africa-wide budget for antipoaching patrols by 4 and 54 million $US was as effective as reducing ivory price by 2 and 22%, respectively. Although there are major uncertainties in the parameter values, the threshold is not sensitive to all of them

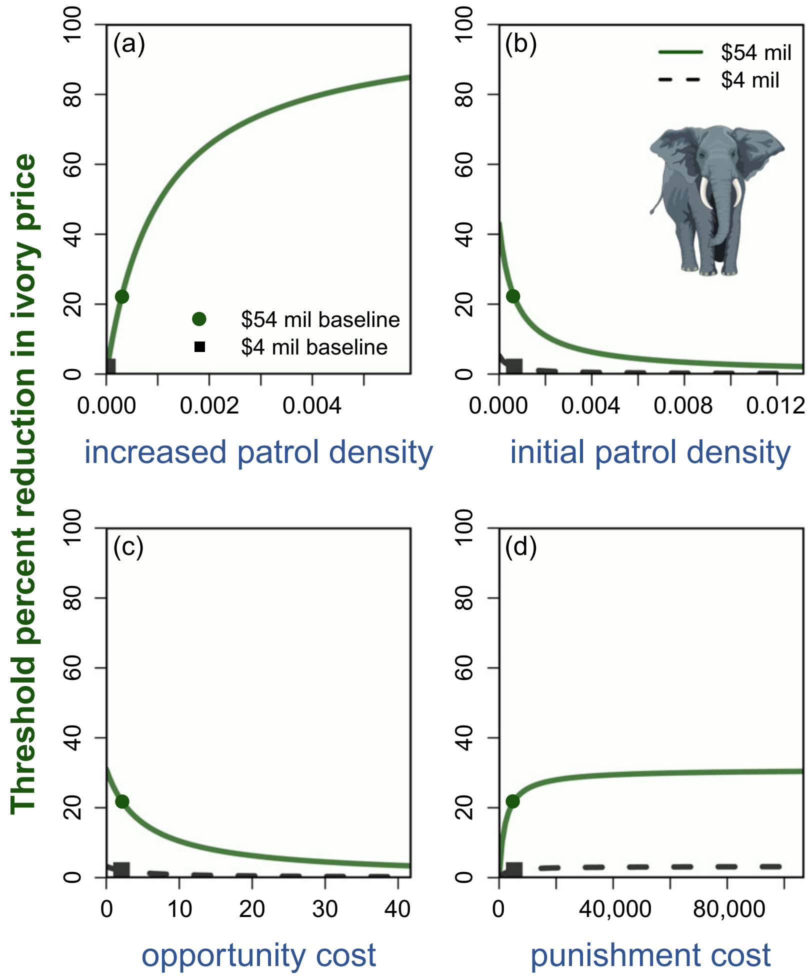

FIGURE 2 Sensitivity of ivory price reduction threshold to parameters: (a) increased patrol density (s_a; patrols/km^2), from spending a demand reduction campaign budget on patrols instead, (b) current patrol density (s_0; patrols/km^2), (c) poacher opportunity cost (c_p; $US/day poaching), and (d) expected cost of getting caught and punished, per patrol/km^2 enforcement density (c_c). Circle/solid line and square/dashed line represent the 4 and 54 $US million budget baselines

(Figure 2). The most important uncertainty for accurately determining the price threshold is the increased patrol density that would result from an investment equal to the demand reduction campaign budget (Figure 2a). This is why a more expensive demand reduction campaign of 54 $US million must be more effective than a 4 million $US one (compare solid curves and circle to dashed curves and square in Figure 2).

Other uncertainties had little effect on the price reduction threshold. For example, increasing the expected cost of getting caught and punished, even by a factor of 10, only increases the required price reduction to 35% (Figure 2d). This parameter is the most uncertain in our baseline scenario because old peer-reviewed studies do not incorporate improved patrol efficacy due to improvements in governance or technology (Nguyen et al., 2016; Plumptre et al., 2014) and the value also does not account for high variability in poacher penalties. Fortunately, the price threshold is relatively unaffected by these knowledge gaps.

The lack of sensitivity of the critical price reduction threshold to patrol efficacy (Figure 2d) is not the same as saying patrol efficacy is unimportant. Increasing patrol efficacy improves the efficacy of new patrols and status-quo patrols that would continue under a demand reduction campaign. Therefore, the degree to which improved patrol quality benefits new patrols over demand reduction is dependent on how many new patrols can be purchased relative to current patrol density.

3.2 | Case study 2: Poaching for bushmeat in Serengeti, Tanzania

In the baseline parameterization, a hypothetical 44,935 $US bushmeat demand reduction campaign in western Serengeti, 2006, would have had to reduce price by 0.2% to be more effective than investing the budget toward additional patrols. Although there is some sensitivity of the estimate to parameter uncertainties, the price reduction threshold is always below 10% (Figure 3). The threshold is much lower than for ivory because the small budget cannot meaningfully increase patrol density and because poaching punishments for bushmeat are nearly 200 times less costly than for elephants. Like ivory, the threshold is most sensitive to the costs of patrols and the demand reduction campaign (Figure 3a). However, unlike ivory, the threshold is sensitive to punishment costs

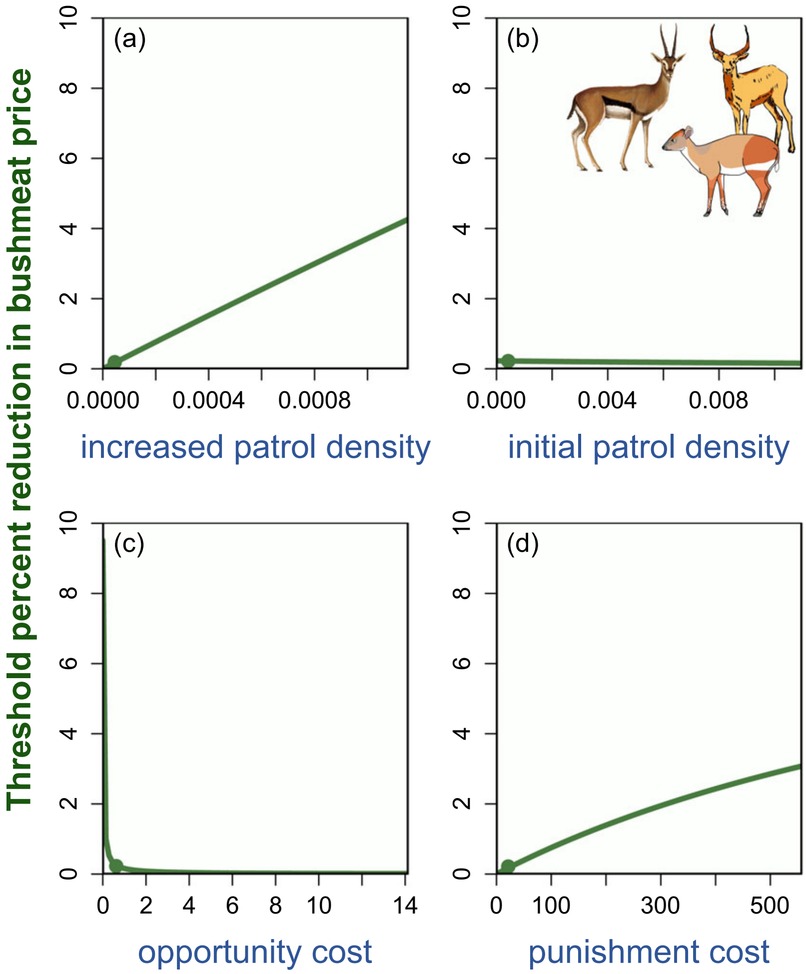

FIGURE 3 Sensitivity of bushmeat price reduction threshold to parameters: (a) increased patrol density (s_a), from spending a demand reduction campaign budget on patrols instead, (b) current patrol density (s_0), (c) the direct opportunity cost of poaching (c_p), (d) expected cost of getting caught and punished, per patrol/km^2 enforcement density (c_c). Circle is the baseline parameterization, which produces a price reduction threshold of 0.2%

(Figure 3d) and insensitive to the current patrol density (Figure 3b), because bushmeat fines are low.

4 | DISCUSSION

We introduced a general framework to aid strategic investment decisions between demand reduction campaigns and antipoaching enforcement. Illustrating the framework with a simple model, we found that demand reduction campaigns are likely the better investment when managers receive small budget increases and patrol efficacy or poaching penalties are low. A small increase in patrols, giving out minor penalties, does not reduce the economic incentive to poach. In these scenarios, if a demand reduction campaign could reduce price by any amount, the campaign would be the best investment. This situation is likely common for bushmeat hunting in many areas of the world. However, for species that attract multimillion dollar budgets, and for which poaching penalties are high (e.g., rhinos and elephants), campaigns have to reduce price by more meaningful percentages, roughly 1–40%, for the campaigns to be the better option.

Funding toward demand reduction campaigns has accelerated over the past 5 years (Veríssimo & Wan, 2018), especially for ivory, coinciding with a nearly 66% price decline since 2014 (Gao & Clark, 2014; Vigne & Martin, 2017). A 66% price drop is considerably higher than the critical threshold in our elephant case study. However, we cannot conclude campaigns are more cost-effective than increased antipoaching enforcement, because the ivory price decline cannot causally be attributed to campaigns, due to confounding factors (such as trade bans and financial crises). Therefore, it is essential to supplement monitoring with controlled experiments or techniques from causal inference (Baylis et al., 2016; Veríssimo & Wan, 2018). For bushmeat, the efficacy of demand reduction campaigns has been mixed. In Tapauá, Brazil, media and community engagement reduced demand for wild, Amazonian meat (Chaves et al., 2018), but a radio program in Tanzania did not generate statistically significant changes in self-reported bushmeat consumption (Veríssimo & Wan, 2018). Our results suggest that even small, potentially even statistically undetectable, responses to bushmeat demand reduction campaigns would likely make campaigns more effective than using the same budget to increase antipoaching patrols.

Because the purpose of this paper was to introduce a general framework, we used a simple model to maximize generality, transparency, and clarity. For species and area-specific policies, managers can use more complex models agreed upon by stakeholders (Biggs et al., 2017). Additional complexities worth exploring include market dynamics (Fischer, 2004), consumers hoarding wildlife products as speculative investments (Mason, Bulte, & Horan, 2012), spatial heterogeneity (Bulte, Damania, Lindsey, & Lindsay, 2004), time-varying consumer incomes (Crookes & Blignaut, 2015), uncertainty and stochastic dynamics (Weitzman, 2002), and noneconomic values of poachers and consumers.

We assumed that demand reduction campaigns proportionally reduce price by some fixed amount. However, if reliable transaction data were available, one could develop detailed models of supply and demand, as commonly applied to legally harvested resources (Burgess, Costello et al., 2017; Frey, Chamberlain, & Prestemon, 2018; Fryxell et al., 2017). Demand reduction could then be modelled as a demand curve transformation. The unimportance of ecological parameters for selecting between demand reduction and enforcement may not hold in this formulation. When demand declines with increasing price, ecological parameters affect equilibrium abundance (Burgess, Fredston-Hermann, Pinsky, Gaines, & Tilman, 2017), but for poached species, uncertainties in socioeconomic parameters are still much higher than ecological ones, and therefore resolving economic uncertainty will still likely be more important for management decisions. Most importantly, it is difficult for managers to monitor demand for illegal products, and therefore the price reduction formulation is likely more pragmatic without better data.

We used an equilibrium approach. However, transient population declines can occur in harvest models (Auger, Mchich, Raïssi, & Kooi, 2010; Burgess, Costello et al., 2017; Conrad & Lopes, 2017; Holden & McDonald-Madden, 2017; Ly, Auger, & Balde, 2014). This is a valid concern for long lived, slow growing species, where poaching and reproduction happen on vastly different time scales. In such cases, a manager could use a time-dependent objective within our framework.

The biggest caveat is that our model assumes poachers change effort proportional to expected profit. Profit-motivated poaching is a reasonable assumption in our case studies. For example, 86% of bushmeat poachers in the Serengeti said they were driven by profit, while only 7% by cultural heritage (Knapp, 2012). For other species and locations though, noneconomic incentives may strongly influence poachers, including social norms (Carter et al., 2017; St John, Edwards-Jones, & Jones, 2010), personal food security (Damania, Milner-Gulland, & Crookes, 2005), perceived legitimacy of regulations (Kahler & Gore, 2012; Kuperan & Sutinen, 1998; Rohe, Aswani, Schlüter, & Ferse, 2017; von Essen & Allen, 2017), and opportunistic encounters between harvesters and individual organisms in space and time (Branch, Lobo, & Purcell, 2013; Carter et al., 2017; Kurland et al., 2017; Pires & Clarke, 2012). Even poachers solely motivated by profits operate with cognitive biases and limited sets of past experiences (Keane et al., 2008). Like nearly all bioeconomic models, our study does not incorporate these complications, and projecting the effect of social and psychological aspects of compliance on poached species is an open area of research.

We assumed maintained yearly investments in enforcement and demand reduction. While sustained investment is likely required for effective enforcement, it seems plausible that demand reduction campaigns might only require diminishing reinvestments to maintain the reduced price. Therefore, our reported price reduction thresholds are likely conservative overestimates given the model.

Our model considers only two out of several potential interventions. Other strategies include increasing enforcement efficiency (Gholami et al., 2018), legalizing trade to fund conservation (Smith, Biggs, St. John, 't Sas-Rolfes, & Barrington, 2015), and livelihood-focused interventions for communities affected by poaching (Wright et al., 2016). A combination of these approaches, including demand reduction campaigns and enforcement, might be beneficial (Salazar, Mills, & Veríssimo, 2018), but certain combinations will pair better than others. For example, we showed that improving alternative livelihoods of poachers works more synergistically with demand reduction campaigns than increased enforcement. These types of insights make simple models powerful for aiding stakeholder dialogue and strategically guiding antipoaching investments.

Overexploitation, poaching, and illegal wildlife trade are issues of global concern that rally governments and conservationists to action (World Bank Group, 2016). However, knowing how best to respond requires an understanding of the effectiveness and costs of management interventions. Otherwise, we risk spending scarce resources on ineffective strategies and may fail to stem population declines. Our work proposes a framework to aid investment decisions between two key approaches associated with species protection, demand reduction and antipoaching enforcement. Illustrating the framework, we showed that demand reduction campaigns offer promise for the cost-effective use of conservation resources to protect threatened species.

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AUTHOR CONTRIBUTIONS

All authors designed the research. M.H.H. developed the framework and model, performed the analysis, and wrote the first draft of the paper. All authors discussed the results and revised the manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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