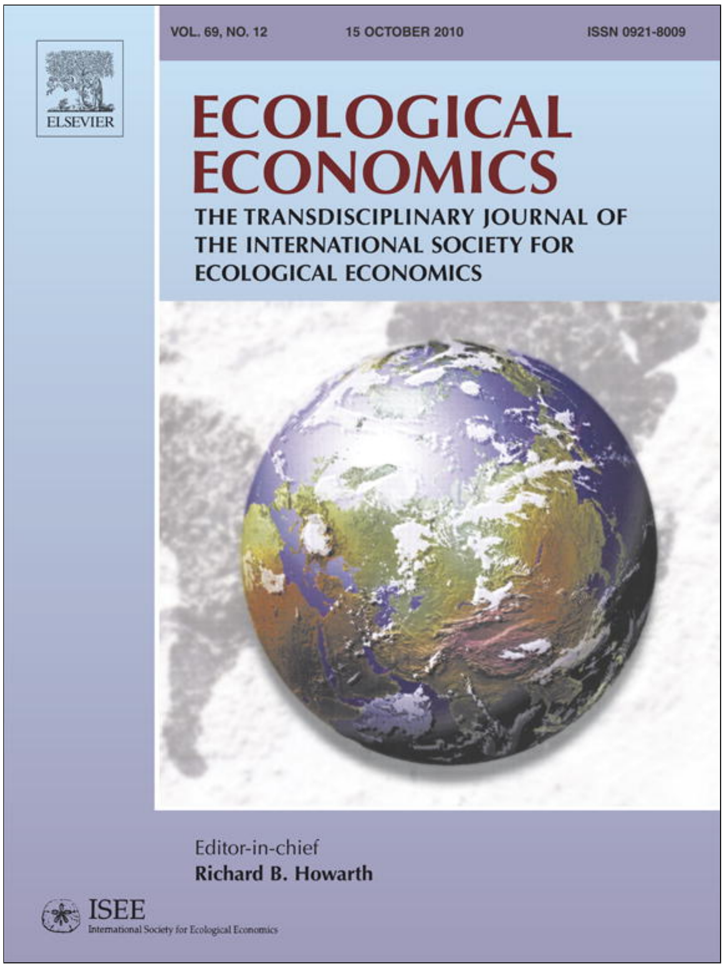
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Analysis

Protecting endangered species: When are shoot-on-sight policies the only viable option to stop poaching?

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ABSTRACT

Protecting endangered species that offer poachers from low-income countries high economic benefits remains a policy challenge. A broadly applicable economic model of poaching shows why CITES international bans have not always been successful, especially in situations where black markets exist and nonpoaching wages are low. In these situations, poachers may have nothing left to lose, since low nonpoaching wages impose a practical cap on the potential economic costs of fines and imprisonment. Thus, the model suggests "shoot-on-sight" policies as the only viable option. Trends in animal populations appear to support the efficacy of the shoot-on-sight policies, which also suggests an inherent value of life traditionally not captured in Value of a Statistical Life estimates.

1. Introduction

Illegal poaching continues to threaten endangered species throughout the world, especially in developing countries. Recently, the World Wildlife Fund reported a reduction from seventy-nine to three one-horn rhinos (*Rhinoceros unicornis*) in Nepal's Bardia National Park because of a two-year absence of anti-poaching patrols after Maoist rebels took over the wildlife parks. In the 1980s, an estimated 675,000 African elephants (*Loxodonta africana*) were poached (Barbier et al., 1990) and as the population of large bull elephants decreased, poachers began hunting female and adolescent elephants. Thus, obtaining one ton of ivory required poaching twice as many elephants (Chadwick, 1991). In the 1980s, poaching reduced African black rhino (*Diceros bicornis*) populations by 96%, to 2600, and only four African countries still have viable wild rhino populations (Brown and Layton, 2001; Emslie, 1996; Milliken et al., 1993). These examples illustrate the vulnerability of endangered species that provide large economic benefits for poachers living in low-income countries.

In these situations, traditional anti-poaching policies, such as raising the amount of fines and lengthening jail terms, appear to have only minimally reduced poaching. Historically, increases in poaching activity paralleled increases in the price of ivory and rhino horns. While published estimates vary widely, there is little debate that the prices offered for these items increased significantly in the 1980s. Using constant-dollar prices for uncarved elephant tusks, several studies found that the price of ivory rose from $3 to $41 per kilogram between 1969 and the late 1980s (Kremer and Morcom, 2000; The Economist, 1991) and some estimates put the price as high as $150 per kilogram. Since tusks can weigh ten kilograms each the income a poacher received for two elephant tusks could exceed the income from a year of nonpoaching work (The Economist, 1989). To bolster elephant protection, the Convention on International Trade in Endangered Species (CITES) banned international trading of ivory in 1989. Bulte and van Kooten (1999a) attribute subsequent reductions in elephant poaching to that ban, in part due to the drop in demand from consumers in developed countries and the corresponding fall in the price of ivory received by potential poachers. In a related article (Bulte and van Kooten, 1999b), these authors argue that a first-best approach is to have strict and efficient law enforcement to prevent poaching, but that a realistic second-base approach is to retain the CITES ban on the ivory trade.

CITES imposed a similar ban on international trading of rhino horns in 1977 but there is no evidence that this ban significantly slowed poaching activity. One possible explanation is that the demand for rhino horns, which are used for medicines in Asia and dagger handles in Yemen, is more inelastic than the demand for ivory. Brown and Layton (2001) estimated the wholesale price of rhino horns at $350 per kilogram in

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1998 dollars and calculated that a poacher would receive approximately 40% of this value, or \$140 per kilogram. Other estimates of the price of rhino horn have ranged from \$168 to \$1351 per kilogram, depending on location and time (Leader-Williams, 1992). Even at a price of \$140 per kilogram, a poacher would receive between \$420 and \$840 for each rhino horn. Since elephants and rhinos can sometimes be hunted simultaneously, one successful hunt could yield an income estimated to be greater than twelve years of nonpoaching work (Chadwick, 1991).

This paper builds upon a number of other studies published in *Ecological Economics* that have looked at the issues of incentives of poachers, elephant and rhino preservation, the effects of CITES bans, and the interactions between human and large mammals around protected park areas (see, for instance, Skonhoft, 2007; Heltberg, 2001; Bulte and Van Kooten, 1999b, and Burton, 1999). This paper also contributes to the literature by developing an economic model of crime that explicitly includes the Value of a Statistical Life (VSL) and highlights how low wages impose practical caps on the potential economic costs of fines and imprisonment. These factors have not been fully accounted for in other models related to protecting endangered species from poaching. This model can be applied broadly to a variety of endangered species and illegal poaching contexts. The model suggests that the only effective anti-poaching policy in situations where nonpoaching wages are low and the economic benefits of poaching are high may be to institute extreme enforcement measures—specifically to be willing to shoot poachers on sight. Trends in animal populations in countries that have used shoot-on-sight policies are discussed and how their apparent success challenges the traditional VSL estimation techniques by suggesting the existence of an inherent value of life not traditionally included in VSL estimates in developing countries.

2. An Economic Model of Crime and Policy Implications

The potential efficacy of shoot-on-sight policies can be examined by a model of the poacher's decision regarding how much time to spend hunting. In the style of Becker's (1968) model of the economics of crime, a generalized model is developed where the poacher chooses how much time, if any, should be spent hunting, t_h, for a high-value, endangered species. The model is developed to better understand the decision of the poacher and how potential poachers may respond to various policy options. As such, the model is not a bio-economic model.[1] In the model presented here, a risk-neutral poacher seeks to maximize his/her utility from consumption (C) and leisure (t_l) given the risk of death per unit of time spent hunting, $r_d(G_s)$, which is an increasing function of government expenditures on shoot-on-sight enforcement policies, G_s, so $r'_d>0$. Expected utility is defined as:

$$EU = [1-r_d(G_s)t_h]U(C,t_l). \tag{1}$$

Eq. (2) is the budget constraint that includes, w, the per unit income from nonpoaching wage labor; t_w, the hours of nonpoaching work; $Q(t_h)$, the number of animals poached, as a function of the time spent hunting, where $Q'>0$; P, the price for the poached animal[2]; and the poacher's budget constraint on consumption. Likewise, the equation involves, $r_f(G_f)$, the probability of being caught (incidents/time), as a function of government enforcement (G_f), where $r'_f>0$; and F, the amount of the fine per incident which also includes the economic cost to the poacher of imprisonment. The time constraint (Eq. (3)) includes, t_h, the time spent on hunting; nonpoaching work for wages; and, leisure, t_l.

$$wt_w + PQ(t_h) - r_f(G_f)Ft_h - C = 0. \tag{2}$$

$$T = t_h + t_w + t_l. \tag{3}$$

As shown in the Appendix A, one can derive from the first-order conditions an equation describing the poacher's choice regarding how much time, if any, to spend hunting. Thus, the expected costs of hunting (left-hand side) are set equal to the marginal benefits of hunting (right-hand side):

$$PQ'(t_h) = w + r_f(G_f)F + r_d(G_s)VSL \tag{4}$$

where $0<r_f(G_f)<1$ and $0<r_d(G_s)<1$.

Note that this condition thus depends on estimates of the VSL for the poacher. In Eq. (4), the VSL is given by $\dfrac{U(C^*,t_l^*)}{\partial U(\cdot)/\partial C[1-r_d(G_s)t_h]}$ and is multiplied by the risk of death, $r_d(G_s)$, to obtain the marginal cost to the poacher of a shoot-on-sight policy. Thus, the amount of time spent hunting, t_h, is a decreasing function of the relative cost of time spent hunting:

$$t_h = Q'^{-1}\left[\frac{w + r_f(G_f)F + r_d(G_s)VSL}{P}\right]. \tag{5}$$

The solution for t_h directly suggests three anti-poaching policies: 1) reduce the price received by the poacher, 2) raise nonpoaching wages for potential poachers, and 3) increase the economic costs to poachers through tougher anti-poaching efforts.[3]

In Eq. (5) the benefits from poaching are captured by P. One of the key objectives in the CITES bans on international trade is to lower the price of the valued good to zero by reducing consumer demand.[4] In this case, the time spent hunting would also go to zero. However, this outcome is reasonable only so far as a black market does not arise after the implementation of the CITES ban, which frequently happens in situations where the demand for the good is inelastic. For example, with ivory this can be especially difficult since the CITES ban only applies to 'raw' uncarved ivory and not to the trade of ivory that has been already carved into a consumer product (Glennon, 1990). If a black market does arise, then there are no assurances that the price received by the poacher will be sufficiently low to discourage poaching effort.

Market-based approaches have also been proposed to lower the price of ivory (Kremer and Morcom, 2000) and rhino horn (Brown and Layton, 2001). These approaches advocate for international trade and require that the CITES bans be lifted. Since ivory is storable, Kremer and Morcom recommend that countries with elephant populations increase their stockpiles of ivory by collecting it from elephants who die from natural causes or are culled due to insufficient carrying capacity at protected parks, and then threaten to flood the market if elephant populations fall. They argue that this market-based

[1] For examples of bio-economic and other models related to poaching, see Milner-Gulland and Leader-Williams (1992), Leader-Williams and Milner-Gulland (1993), Messer (2000) and Heltberg (2001), and Damania et al. (2005).

[2] The incentives to poach that arise from the interactions between human and large mammals can also be incorporated into this model. Elephants frequently cause significant economic damage to agricultural activities located near protected areas. This problem can grow with an increase in the population as additional elephants move beyond park boundaries (see Skonhoft (2007) and Skonhoft and Armstrong (2005) for detailed models of these types of interactions). The killing of these 'nuisance' elephants therefore can bring additional expected benefits to the potential poacher. To account for these situations in this model, P could be constructed to reflect *both* the price of the ivory and also the expected benefits from avoiding the damage to agricultural activities. The overall impact of including this factor is simply to increase the economic benefits of poaching and thus make it even more difficult for traditional law enforcement efforts to stop poaching.

[3] Inspection of Eq. (5) also reveals that reducing the number of animals is another way of reducing time spent hunting, a policy, however, that goes directly against the objective of preserving the endangered species.

[4] See Heltberg (2001) and Swanson (1994) for good theoretical treatments of how a CITES ban likely affect the demand side of the international ivory trade. Additionally, this decrease in demand as a results of a CITES ban can have impacts on other animal species as both hunters and consumers seek substitutes (Carpenter et al., 2005).

policy would keep the price of ivory depressed and thereby decrease illegal poaching. They suggest that credible governments can eliminate extinction equilibria by committing to enforcing strict anti-poaching policies if the elephant population falls below a set threshold. Brown and Layton recommend that countries with rhino populations should treat rhino horns as a renewable resource and actively harvest and sell the horns in an effort to depress prices and diminish illegal poaching. A major obstacle to both of these market-based approaches is the international conservation community's reluctance to lift trade bans.

This reluctance to lift CITES bans is often articulated by international conservation organizations as a concern that consumer demand might increase when the goods are longer deemed illegal, thereby raising the market price received by potential poachers. Another concern frequently articulated with regard to the ivory trade is that some countries, especially those in the south of Africa, would make the hunting of elephants legal, within certain restrictions, while other countries would continue to make all forms of hunting illegal. With the introduction of 'legal' ivory into the international market, it may be difficult and/or overly costly to distinguishing between 'legal' and 'illegal' ivory as traders will seek to launder the illegal ivory (Bulte and van Kooten, 1999b). The end results would be an increase in the market prices received by poachers in countries where hunting elephants remains illegal.

A second policy option relates to improvement of the standard of living of poachers and is captured by the nonpoaching wage rate, w. This rate represents the opportunity cost for a poacher. Raising wage rates in developing countries is a slow process. So raising the wages of all potential poachers likely would not happen quickly enough to prevent widespread killing and even extinction of the species. As shown stylistically in Fig. 1, in the absence of any costs, the poacher would spend considerable time hunting. As costs such as the prevailing nonpoaching wage, w, are factored in, the amount of time spent hunting declines to t_h^* (point A on Fig. 1). To stop illegal hunting, the wage rate would have to rise to the level where, combined with other costs of poaching, the poacher would not spend any time hunting (point C on Fig. 1).

The model suggests a third policy option of increasing economic costs to poachers through tougher anti-poaching efforts. This could be accomplished by increasing the amount of fines imposed and the length of terms of imprisonment, which are captured in F, and the risk of detection, r_f. As shown in Fig. 1, increases in fines and the risk of detection would cause the poacher to spend less time hunting. However, the true cost of the fines and imprisonment ultimately depends on the nonpoaching wage rate since low wages mean that a fine of $100,000 is as infeasible to pay as a fine of $100 million. Consequently, low wages serve as a practical cap on the size of fines that can be collected and the economic consequences of imprisonment. This wage-dependent cap on the economic costs involved with poaching is represented as Point B in Fig. 1, where some positive level of poaching continues to occur.[5] Therefore, poachers may find that, when the economic situation is bleak, they have little left to lose from spending time poaching.[6]

Consequently, it may be the case that the only way that a government can impose a large enough cost on poachers to effectively reduce poaching is to authorize lethal law enforcement. By including

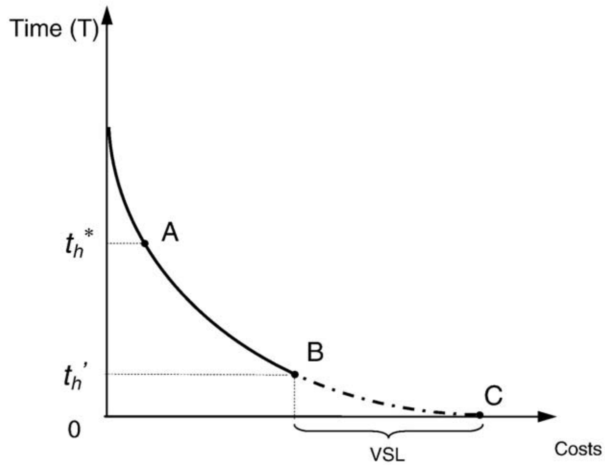

Fig. 1. Time spent hunting and the costs of poaching (stylistic).

the risk of death as an economic cost for the poacher, the costs of time spent hunting can outweigh its benefits (thereby moving from point B to point C in Fig. 1). Note that, for a shoot-on-sight policy, an important element is the perceived and real probability of detection. Psychologists and behavioral economists have shown that the expected utility model frequently does not accurately predict the behavior of people who face risks with less than 10% probability of occurring since humans tend to put undue weight on low probability events (Edwards, 1962; Kahneman and Tversky, 1979; Machina, 1983). As a result, a poacher's estimation of the risk of detection may not be much different when the odds of detection are 5% versus 1% but the government may have to spend significantly more to increase the probability of detection to 5%. Therefore, successful implementation of shoot-on-sight policies may be possible without killing many people or incurring large enforcement costs.[7]

3. Trends in Animal Populations in Countries That Have Used Shoot-on-Sight Policies

When considering the potential validity of the model, it is helpful to consider examples where shoot-on-sight policies have been applied. In countries where shoot-on-sight policies have been instituted for a number of years, general trends in the animal populations suggest that they have been successful. Ironically, in light of its recent problems with illegal poaching once anti-poaching patrols stopped, Nepal was one of the countries that had implemented shoot-on-sight policies. After the policy was introduced, Nepal's rhino population rebounded from 96 in 1968 to 600 in 2002 (Martin and Vigne, 1996; The Economist, 2002). Zimbabwe instituted "Operation Stronghold" in 1984. In the decade afterward, anti-poaching forces killed 167 poachers (Milliken et al., 1993), while its elephant population increased by nearly 50%—from approximately 44,000 to more than 65,000. Kenya initiated a shoot-on-sight policy in 1989. In the 1970s and 1980s, poaching had reduced its elephant population

[5] As pointed out by a reviewer, whether point B is problematic for the eventual survival of the endangered species is dependent upon the population dynamics of the species and the specific geography. In the case of rapidly reproducing species, some levels of illegal poaching may not be problematic. However, for species with slower growth rates this level of poaching may be unsustainable.

[6] Note that the model suggests that shoot-on-sight policies would not be necessary to stop illegal poaching in high-income countries, since traditional law enforcement efforts, such as passing anti-hunting laws with sufficient fines and prison terms and enforcing these laws without the influence of corruption, would be sufficient to offset the economic benefits that can accrue from poaching.

[7] As with any law enforcement policy, a policy's success is dependent upon being free of corruption (Glennon, 1990). If poachers can offer game wardens and anti-poaching patrols sufficient bribes to prevent the application of shoot-on-sight policies, then these policies too will be unsuccessful at protecting endangered species. However, one potential benefit of these policies is that they involve a more limited number of individuals who could susceptible to corruption, as the effectiveness of the policy depends primarily upon the integrity of the anti-poaching patrols. In contrast, traditional enforcements efforts not only are subject to potential corruption in the anti-poaching patrols, but also corruption in the judicial system which determines the final level of potential fines and imprisonment.

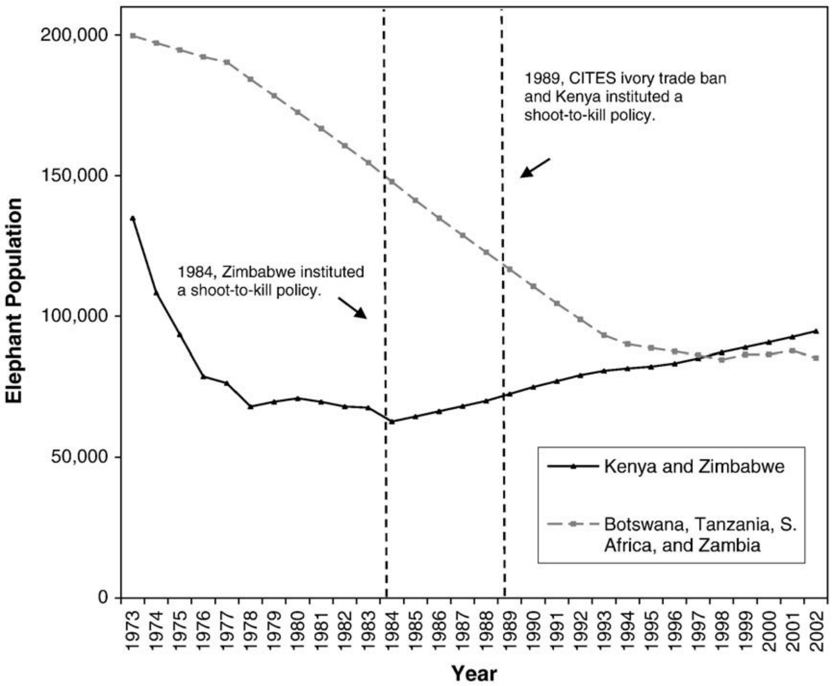

Fig. 2. Elephant populations in countries with and without shoot-on-sight policies.

from 167,000 to 17,000 and the rhino population from 20,000 to less than 400. During the first two years of implementation, more than 100 poachers were killed (Chadwick, 1991). Between 1989 and 2000, Kenya's elephant population grew to 26,000 (The Economist, 2000). Similarly, Kenya's rhino population had also increased, to 500 by 2003 (African Wildlife Federation, 2003).

Fig. 2 shows a marked difference in elephant population trends for four African countries that did not impose shoot-on-sight policies—Botswana, South Africa, Tanzania, and Zambia—and the two that did—Kenya and Zimbabwe. A country's elephant population was calculated based on the 230 published elephant population estimates from the sixty parks as listed in Table 1 (Blanc et al., 2002; Barnes et al., 1999; Douglas-Hamilton, 1987; Said et al., 1995).[8] Both sets of countries reported relatively large elephant populations in 1973. But elephant populations, particularly in Kenya, declined rapidly in the 1970s and early 1980s. By 1984, when "Operation Stronghold" began in Zimbabwe, elephant populations in Kenya and Zimbabwe had fallen by more than 50%, while populations in Botswana, South Africa, Tanzania, and Zambia had fallen by 25%. After 1984, Kenya and Zimbabwe's combined populations increased and by 1998 they surpassed those of Botswana, South Africa, Tanzania, and Zambia despite having 100,000 fewer elephants than those countries in the late 1970s.

While these population trends are suggestive, they mask variations in the trend for each country. For instance, the elephant population in Krueger and Addo National Parks in South Africa was estimated at 8026 elephants in 1973—twenty years later, the parks were home to almost exactly the same number, 8029, in large part due to the management practice of culling elephants due to their overabundance. In contrast, during the same time period the number of elephants in Tanzania's national parks declined from 113,033 to just 60,406. Ideally, a meta-analysis of the park-specific elephant populations would be conducted where the impact of the CITES ban, the initiation of countries' shoot-on-sight policies, the impact of country-specific development programs, such as Zimbabwe's CAMPFIRE program could be properly specified in the model. Unfortunately, critical to this analysis is an accurate estimate of the price of ivory received by the poachers in different countries for the different years but, as with other models of criminal activity in a black market, such information is not available (Heltberg, 2001). Furthermore, estimates of government anti-poaching expenses for each park are not publicly available.

4. Discussion

While these examples appear to support the model's implication that shoot-on-sight polices will be effective, several ethical concerns regarding their use naturally arise. For instance, they appear to violate the "principle of proportionality" that asserts that the severity of a punishment should correspond to the severity of the harm done by the crime. In humanistic philosophical traditions, animals are not given equivalent moral standing as humans, and therefore, killing poachers to protect an elephant or rhino, even if endangered, may not be considered ethical. Similarly, as mentioned previously, large mammals, such as elephants, often cause economic damage to human agricultural activities. Therefore, killing poachers who are dealing with animals that are causing direct harm to humans may be difficult to justify. Furthermore, since shoot-on-sight policies would only be necessary to deal with illegal poachers who are too poor to be effectively countered by traditional law enforcement methods, the only time shoot-on-sight policies would be used is when the poachers have few other economic opportunities. Therefore, the use of these policies will be closely correlated to conditions of extreme poverty.

On the other hand, the non-use benefits provided by charismatic mammals that accrue to a large number of people worldwide, while likely individually small, when aggregated are likely greater than the large individual costs imposed upon a relatively small group of poachers, traders, and consumers of these animals. Furthermore,

[8] Since population estimates were not available for each park for each year, linear approximations were made from published estimates with the closest dates for each park. This assumption is most reasonable when the change in population is slow. Since an elephant population, undisturbed, typically increases by approximately 5% each year, this means the dates associated with increases in populations are likely to be accurate than decreases in population.

Table 1
Date and source of elephant population estimates by National Park.

	Douglas-Hamilton, 1987	Said et al., 1995	Barnes et al., 1999	Blanc et al., 2002
Botswana				
Tuli Block	1983	1994		2001
Kenya				
Aberdare	1979	1994	1990, 1998	
Isiolo	1973, 1977			
Kilifi	1973, 1977, 1978, 1980, 1983	1993		
Kitul	1983	1993		2002
Kwale	1973, 1983			
Laikpia	1973, 1977, 1978, 1981, 1982		1996	
Lamu Garissa	1973, 1976, 1977, 1978, 1983	1988	1996	2001
Marsabit	1973, 1977, 1978, 1981, 1983	1993	1998	
Mt. Elgon	1979		1991, 1996	1999
Mt. Kenya	1979		1991, 1998	2001
Narok	1973, 1977, 1978, 1980, 1983			
Samburu	1973, 1977, 1981		1992, 1996	2002
Tana River	1973, 1974, 1977, 1978, 1980, 1983			2002
Turukana	1977		1997	
Wajir	1973, 1978			
South Africa				
Addo	1972, 1974, 1976, 1979, 1980, 1981, 1984		1995, 1998	2002
Krueger	1972, 1973, 1974, 1975, 1976, 1977, 1978, 1980, 1981, 1985		1995, 1998	2002
Tanzania				
Kilimanjaro	1972		1990	
Kilombero	1976, 1986	1994		2002
Manyara	1967, 1975, 1981, 1984, 1985		1990	
Mkomazi	1978	1994	1996	2002
Ngorongoro	1980		1992	
Ruaha	1972, 1977, 1983	1993	1996	2002
Rukwa	1977		1991	2002
Rungwa	1977, 1983	1993	1996	2002
Selous	1971	1994		
Serengeti	1970, 1977	1994	1998	2000
Tarangire	1980	1994	1998, 1999	
Zambia				
Chiawa	1984	1991	1996	
Chisomo	1984	1994	1996	1999
Isangano	1984		1993	
Kafinde	1984	1991		
Kafue	1984	1991	1997	2001
Kasanka	1984	1991		
Kasonso-Busanga	1984		1997	
Lavushi Manda	1984	1991		
Lower Zambezi	1984	1991	1996	
Luambe and Lumimba South	1984	1994	1996	
Luano	1984		1996	
Lukusuzi	1984	1994		
Lumimba North	1984			2001
Lunga-Luwishi	1984	1991	1997	
Lupande	1984	1993	1996	2002
Mosi-oa-Tunya	1984	1991		
Mumbwa	1984		1997	
Zambia				
Musalangu	1984	1991	1996	2001
Namwala West	1984		1997	2000
North Luangwa	1985		1996	2001
Nsumbu	1984		1998	
Mulobezi/Sichifula	1984	1991	1997	
Sioma Ngwezi	1984	1991		
South Luangwa	1985		1996	2002
West Lunga	1984	1991	1996	
West Petauke	1984	1994	1996	1999
Zimbabwe				
Hwange	1971, 1973, 1974, 1977, 1979, 1983, 1984	1994	1997	
Gona Re Zhou	1985		1997	2001
Matetsi Complex	1985	1994	1995, 1997	
Sebungwe	1985	1993		
Zambezi Valley	1985	1993	1995	2001

poachers tend to be well armed—often better than the game wardens—and can pose a direct and lethal threat to game wardens when they try to make an arrest. Thus, in some circumstances lethal action in self-defense may occur as a result of traditional law enforcement.

While a consensus among major humanistic and naturalistic ethical traditions likely does not exist,[9] it is interesting to note that shoot-on-sight policies have been used without significant outcry from the international community. In fact, shoot-on-sight policies have received public support from a number of sources. As director of the Kenyan Wildlife Service (1989–1994), Dr. Richard Leakey raised more than $153 million to rebuild park infrastructure and arm anti-poaching units at a time when Kenya's shoot-on-sight policies were well known. Likewise, more than twenty organizations, including the World Wide Fund for Nature and the United States Agency for International Development, provided aid worth millions of U.S. dollars to Zimbabwe's anti-poaching efforts. A number of international conservation organizations, including Care for the Wildlife International, the Born Free Foundation, and the International Fund for Animal Welfare, openly publicize their support for shoot-on-sight policies. Even news articles, such as *Africa News* (2002), have used the word "massacre" to describe the killing of elephants and not the killing of suspected poachers. This public support (or at least lack of public outcry) may stem from the fact that these policies are being used to protect large, charismatic mammals in situations when great efforts have already been made to protect them over a number of years. In light of the failure of many of these efforts, in certain circumstances, the defenders of these valued animals appear to have come to accept to the use of shoot-on-sight policies as a last resort.

As previously shown, the model depends on estimates of the VSL for a poacher. The VSL is the amount people will pay to reduce the risk of a fatality with the expectation of saving one life. One approach for determining the VSL is to estimate an individual's willingness to accept a marginal change in his/her probability of survival (Schelling, 1968; Mishan, 1971). Viscusi (1993) reported that studies in the United States have generally estimated the VSL at between $3.8 and $9.0 million. Viscusi and Aldy (2002) found that the median estimated VSL from thirty studies in the United States was $7 million. For developing countries, only a handful of studies have estimated VSLs. In general, these estimates tend to be smaller as mortality risks tend to be several times higher in developing countries than in developed countries and wage rates are several times lower. Examples of estimated VSLs (in 2000 dollars) in developing countries include: $0.8 million for South Korea (Kim and Fishback, 1999), $1.0 to $4.0 million for India (Shanmugam, 1996, 2000, 2001), $0.2 to

[9] For reviews of different ethical and philosophical traditions and how they can be applied to economic welfare conditions, see Kneese and Schulze (1985) and Sen and Williams (1982).

\$0.9 million for Taiwan (Liu et al., 1997; Liu and Hammitt, 1999), and \$1.7 million for Hong Kong (Siebert and Wei, 1998).

The potential success of shoot-on-sight polices also has implications for traditional estimates of VSLs in developing countries. These estimates depend on an individual's willingness to accept a marginal change in her probability of survival and the implicit income elasticity of the VSL is traditionally 1.0 (Viscusi, 1993; Viscusi and Aldy, 2002; Shanmugam, 1996; Liu et al., 1997).[10] Since, a critical component of most VSL estimates is an individual's foregone earnings, which are derived primarily from current annual income, in situations where the nonpoaching wage rate is very low, VSLs can approach zero—thereby implying essentially no *inherent* economic value of life. If VSLs truly are zero, then the model of poaching suggests that the low nonpoaching wages should also provide a practical cap on the efficacy of shoot-on-sight policies. However, the examples of the apparent success of shoot-on-sight policies suggest the opposite. This implies the existence of some inherent economic value of life that should be factored into VSL estimations.

5. Conclusion

The proper response to poaching of economically valuable endangered species in low-income countries is a difficult economic and ethical question. Unfortunately, most existing policies are fraught with problems. An economic model of poaching that includes the Value of a Statistical Life (VSL) and accounts for the practical cap that low wages put on the economic costs of fines and imprisonment suggests that in certain situations the only way to protect endangered species is to dramatically raise the cost of poaching by being willing to shoot suspected poachers on sight. Examples suggest that these policies can be highly effective. This apparent success further suggests an inherent value of life that is not traditionally measured in VSL studies in developing counties.

The results of this model are likely to be controversial and reasonable people are likely to disagree with its implications. The intent of this paper is to help structure the debate around this important and complex issue and to help guide future theoretical and empirical work that might provide greater insight into this matter. For example, empirical studies could examine situations where different parks in one country have used different enforcement strategies, where all of the needed data are available, so that the model could be directly tested. Additionally, the model could also be expanded to include factors related to community engagement and social institutions to evaluate whether these factors can do a better job at reducing poaching than central anti-poaching policy and enforcement efforts. Finally, the model could be used to analyze why certain CITES bans have been successful and others have failed to protect endangered species.

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[10] Some VSL studies have estimated income elasticities as much less than 1.0. In a meta-analysis of more than forty-nine studies from ten countries, Viscusi and Aldy (2002) estimated that the income elasticity was about 0.5 to 0.6. In other words, every 10% increase in per capita income increases the VSL by 5–6%. This lower estimate suggests that people derive more utility from life than can be measured by market consumption. These estimates are particularly relevant to the situations of people in developing countries (and also the elderly and children in developed countries), thereby suggesting that the actual VSL is significantly larger than the one that is estimated using a foregone-earnings approach.

Appendix A. Derivation of the Model

The poacher's expected utility problem can be described as follows:

$$\begin{aligned}
&\text{Max}\, EU = [1-r_d(G_s)t_h]U(C,t_l)\\
&\text{St. } wt_w + PQ(t_h)-r_f(G_f)Ft_h-C = 0\\
&T = t_h + t_w + t_l.
\end{aligned}$$

Therefore, the Lagrangian is:

$$\begin{aligned}
L = {} & [1-r_d(G_s)t_h]U(C,t_l) + \lambda[wt_w + PQ(t_h)-r_f(G_f)Ft_h-C]\\
& + \mu[T-t_h-t_w-t_l].
\end{aligned}$$

This yields four first-order conditions:

$$\begin{aligned}
&\frac{\partial L}{\partial t_h} = -r_d(G_s)U(\cdot) + \lambda\left[PQ'(t_h)-r_f(G_f)F\right]-\mu\\
&\text{or}\quad \mu = \lambda PQ'(t_h)-\lambda r_f(G_f)F + r_d(G_s)U(\cdot),
\end{aligned} \tag{A1}$$

$$\begin{aligned}
&\frac{\partial L}{\partial C} = [1-r_d(G_s)t_h]\frac{\partial U(\cdot)}{\partial C}-\lambda\\
&\text{or}\quad \lambda = [1-r_d(G_s)t_h]\frac{\partial U(\cdot)}{\partial C},
\end{aligned} \tag{A2}$$

$$\begin{aligned}
&\frac{\partial L}{\partial t_w} = \lambda w-\mu\\
&\text{or}\quad w = \frac{\mu}{\lambda},
\end{aligned} \tag{A3}$$

and

$$\begin{aligned}
&\frac{\partial L}{\partial t_l} = [1-r_d(G_s)t_h]\frac{\partial U(\cdot)}{\partial t_l}-\mu\\
&\text{or}\quad \mu = [1-r_d(G_s)t_h]\frac{\partial U(\cdot)}{\partial t_l}.
\end{aligned} \tag{A4}$$

In Eq. (A1), substitute for λ (Eq. (A2)) and set equal to Eq. (A4). Solving for $\frac{\partial U(\cdot)}{\partial t_l}$ yields:

$$\frac{\partial U(\cdot)}{\partial t_l} = \frac{\partial U(\cdot)}{\partial C}\left[PQ'(t_h)-r_f(G_f)F\right]-\frac{r_d(G_s)U(\cdot)}{[1-r_d(G_s)t_h]} \tag{A5}$$

From Eq. (A3), w can be derived by dividing Eq. (A4) by Eq. (A2):

$$\begin{aligned}
&w = \frac{\mu}{\lambda} = \frac{[1-r_d(G_s)t_h]\frac{\partial U(\cdot)}{\partial t_l}}{[1-r_d(G_s)t_h]\frac{\partial U(\cdot)}{\partial C}}\\
&\text{or}\quad w = \frac{\frac{\partial U(\cdot)}{\partial t_l}}{\frac{\partial U(\cdot)}{\partial C}}.
\end{aligned} \tag{A6}$$

By rearranging Eq. (A5) and substituting in w from Eq. (A6), the result is Eq. (A7):

$$PQ'(t_h) = w + r_f(G_f)F + \frac{r_d(G_s)U(\cdot)}{\frac{\partial U(\cdot)}{\partial C}[1 - r_d(G_s)t_h]}$$

$$\text{or} \quad PQ'(t_h) = w + r_f(G_f)F + r_d(G_s)VSL \tag{A7}$$

$$\text{where} \quad VSL = \frac{U(c^*, t_l^*)}{\frac{\partial U(\cdot)}{\partial C}[1 - r_d(G_s)t_h]}.$$

Finally, we solve for t_h:

$$t_h = Q'^{-1}\left[\frac{w + r_f(G_f)F + r_d(G_s)VSL}{P}\right]. \tag{A8}$$

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