



Applying a conceptual framework to rhinoceros conservation on private lands in South Africa

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ABSTRACT: Although there is a large body of literature on rhinoceros ('rhino') conservation, a comprehensive analysis of the challenges inherent in rhino conservation is missing. In particular, the role of private landowners in rhino conservation has been insufficiently addressed, even though private landowners manage a third of the rhino population in South Africa. In this paper we apply a conceptual framework to the issue of rhino conservation on private lands in South Africa. The framework (1) visually illustrates the political and economic complexity of rhino conservation; (2) reveals how financial decision-making drives rhino conservation among private landowners; and (3) demonstrates how the costs that poaching imposes on private landowners (e.g. security costs) undermines their willingness to conserve rhinos on their land. We argue that current anti-poaching actions are insufficient to attain rhino conservation on private lands because these actions fail to address key components of the private landowners' decision-making process. New actions that incentivize rhino management and conservation on private lands are required. To safeguard their family, clients, employees and rhinos from armed poachers, landowners require access to improved, lower cost security systems and technologies. To offset the costs of rhino protection and management (including acquiring and managing sufficient habitat to support rhinos), landowners require a renewable income stream that is directly linked to rhino conservation. We consider how legal trade in rhino horn may attain this second objective.

KEY WORDS: Poaching · CITES · Wildlife policy · Illegal trade

THE RHINOCEROS POACHING CRISIS

Black rhinoceros *Diceros bicornis* and white rhinoceros *Ceratotherium simum* (hereafter referred to as 'rhinos') populations in southern Africa are threatened by poaching. Poaching is motivated by international demand for rhino horns for medicinal uses and as status symbols (Hubschle 2016). Rhino poaching first became a serious problem in the 1960s and early 1970s. A temporary lull in poaching from the mid-1990s to 2007 led many to believe the problem had been successfully contained ('t Sas-Rolfes 2011a). Only 120 rhinos were poached on private and public lands in South Africa between 2000 and 2007 (Hub-

schle 2016). However, poaching has since escalated, driven by increased illegal demand for rhino horn ('t Sas-Rolfes 2011a). A total of 6102 rhinos were poached between 2008 and 2016 in South Africa, the number poached rising from 83 rhinos in 2008 (Hubschle 2016) to 1054 rhinos in 2016 (Modise 2017).

South Africa plays a critical role in rhino conservation. As of 2010, South Africa was home to 95% (~19 000) of Africa's white rhino population and 40% (~1915) of its black rhino population (Emslie et al. 2016). Poaching levels in South Africa were sustainable until about 2014, when rhino deaths outpaced births (Hubschle 2016). The decline of rhino populations has resulted in global concern for the future

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existence of rhinos. This concern has generally manifested itself in pressure from developed countries and conservation interest groups not to lift the international ban on rhino horn trade and to increase penalties for poaching. Unfortunately, opponents of alternative policies and actions to attain rhino conservation are failing to recognize the complexity of rhino conservation, and the limitations of current rhino conservation strategies. If rhinos are to be conserved, it is important to consider how the decisions and actions of key stakeholders (including private landowners and poaching syndicates) are—or may be—altered by different policies or actions. A conceptual framework helps decision-makers to think through such a problem where there is limited research, and to consider what suite of policies and programs are required to attain conservation outcomes.

APPLYING A CONCEPTUAL FRAMEWORK TO RHINO CONSERVATION BY PRIVATE LANDOWNERS IN SOUTH AFRICA

Conservation practitioners often struggle to design and implement effective conservation practices and policies because they must deal with complex systems consisting of both natural ecosystems and human societies (Salafsky et al. 2002). To improve their understanding of these coupled natural–human systems, practitioners can develop and utilize conceptual frameworks that simplify complex conservation issues to cognitively accessible problems. Conceptual frameworks provide a foundation that can be used to explore how different management actions may potentially change the system (Salafsky et al. 2002), and whether these actions may have unintended consequences.

Salafsky et al. (2002) outlined a general framework that can be applied to conservation problems. The framework consists of identifying a conservation target, determining the threats affecting the target, and incorporating actions that may be used to reach the targeted goal (Salafsky et al. 2002). Conceptual frameworks have been applied to a range of conservation challenges, including human–wildlife conflicts (Treves et al. 2009); wildlife tourism and recreation (Duffus & Dearden 1990, Reynolds & Braithwaite 2001); and integrating human needs with biodiversity conservation (Salafsky & Wollenberg 2000). Our framework for understanding rhino conservation generally follows the framework suggested by Salafsky et al. (2002). To the best of our knowledge, this is the first

application of a conceptual framework to rhino conservation or the illegal rhino horn trade.

We explicitly focus on rhino conservation by private landowners in South Africa because approximately a third of South Africa's rhinos are found on private lands (Rademeyer 2016). Eighty percent of the land in South Africa is privately held and only 5% of land is publicly protected (Cousins et al. 2008), making private lands critical to long-term conservation and recovery of rhino populations in South Africa. Under South African law, private landowners may own the wildlife on their lands (Child et al. 2012, Taylor et al. 2015). Accordingly, South African landowners have a direct financial incentive to place land into wildlife management in order to generate wildlife-based income, including revenues from trophy hunting, meat hunting, game breeding, live animal sales, production of game byproducts, and photographic tourism. The general success of this system in attaining the conservation of game species is well documented (Reilly et al. 2003, van der Merwe et al. 2004, 2014, Bond & Cumming 2006, Child et al. 2012, Lindsey et al. 2013). Recent estimates suggest that there are approximately 9000 private game ranches in South Africa that encompass over 17 million ha of land (Taylor et al. 2015). It is within this context that private landowners in South Africa decide to own and manage rhinos. Ferreira et al. (2014b) estimated that approximately 2 million ha of private lands are currently managed for rhinos. It should be noted that the South African model of wildlife ownership is diametrically opposite to the preservationist approach to conservation, applied in other rhino range states such as Kenya (Kabiri 2010) and India (Mishra 2000), which seeks to minimize consumptive use.

Our conceptual model seeks to illustrate rhino conservation and the poaching crisis as a financial problem within South Africa's wildlife ownership model. In a system where private landowners manage wildlife as a financially viable land use, species that are a significant financial liability are likely to be removed from the land, even if landowners value their existence, because the costs outweigh the benefits (financial and non-financial) of managing those species. Our conceptual framework visually elucidates the complexity of rhino conservation on private lands in South Africa by (1) revealing how financial decision-making drives rhino conservation among private landowners; (2) assessing how poaching alters the financial viability of private rhino ownership, thus affecting how rhinos fit into the wildlife use paradigm of South Africa; and (3) showing the limitations of anti-poaching interventions.

We use this framework to examine how domestic and international policy hinders private sector conservation of rhinos by both increasing poaching pressures (by raising black market horn prices through the elimination of competition from a legal market), and stripping landowners of their ability to generate alternative income from their rhinos (which is necessary to offset the costs of rhino conservation and management). We further use the framework to investigate how current and potential conservation solutions affect rhino poaching and conservation. Two important findings emerge. First, current conservation actions only influence discrete portions of the framework, and so are limited in their scope for attaining rhino conservation on private lands. Second, new policies and actions that incentivize rhino management and conservation on private lands are required.

A CONCEPTUAL FRAMEWORK: VIEWING RHINO CONSERVATION AS A FINANCIAL COST-BENEFIT ANALYSIS

Target: rhino conservation

Our conceptual framework begins with the fundamental target of rhino conservation through private ownership (Fig. 1). We simplify the decision to own rhinos to a financial cost-benefit analysis (see Tieten-

berg & Lewis 2009), based on the notion that ownership is desirable if the benefits outweigh the costs. Although we recognize that there are non-financial costs (e.g. safety concerns for family and employees) and benefits (e.g. passion for the conservation of threatened and endangered species) associated with rhino ownership, we simplify the complex problem of rhino conservation to a purely financial decision as a first key step towards understanding the challenges of rhino conservation.

Because we are framing private rhino ownership as a financial cost-benefit analysis, the 2 factors contributing to the decision to own rhinos are the revenues generated by rhinos and the costs of rhino ownership (Fig. 1). When the revenue from rhinos exceeds the cost of owning and managing them, game ranchers are more likely to invest in rhinos and consider them an asset to their wildlife operations (resulting in increased rhino conservation). When the costs of ownership exceed the revenues generated from rhinos, ranchers will view rhinos as a financial liability and are more likely to disinvest, resulting in less private land available as rhino habitat and likely also reduced rhino populations on private lands.

Financial revenue from rhinos

Currently, the only legal revenues that can be generated from rhinos are revenues from photographic

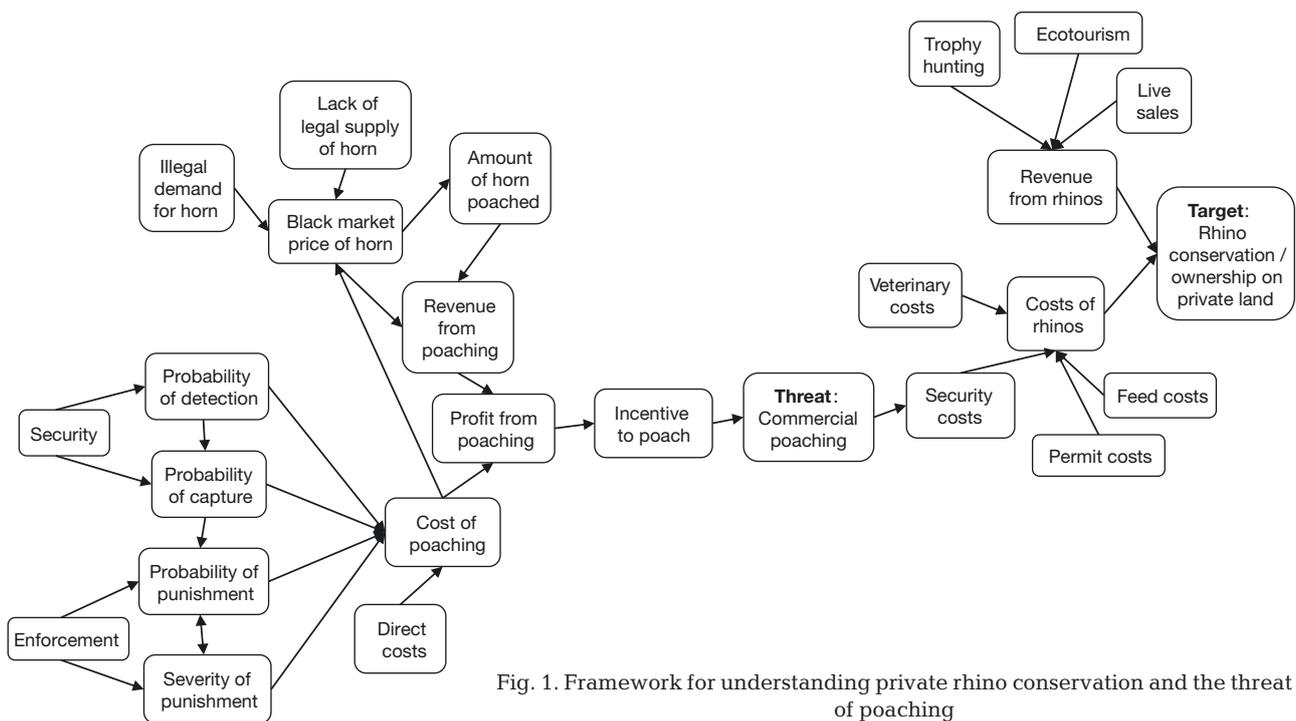


Fig. 1. Framework for understanding private rhino conservation and the threat of poaching

tourism (ecotourism), trophy hunting, and live sales (Fig. 1) (Child 2012). Estimates of the photographic tourism value of rhinos on private lands are scarce in the literature. Spenceley & Barnes (2005) attempted to value the presence of rhinos on one South African and one Namibian private reserve. While guides at the reserves indicated that guests were interested in viewing rhinos, Spenceley & Barnes (2005) were unable to estimate the proportion of tourism revenues that were attributable to rhinos on these reserves. However, using data from a Namibian communal conservancy, they estimated that 7% of the tourism value of the area could be attributed to the presence of rhinos (Spenceley & Barnes 2005). Recent research suggests that the photographic tourism revenues generated by Kruger National Park's rhino population between 2011 and 2013 ranged from 5.9 to 14.9 million US\$ per year (Saayman & Saayman 2017). Inferring a similar value for photographic tourism on private lands may be misleading, however, because photographic tourism is generally not feasible on the marginal, unattractive lands of many game ranches. Large operations with scenic appeal and charismatic fauna are better suited to photographic tourism (Hutton & Leader-Williams 2003).

The advent of rhino hunting provided a financial incentive for the private sector to invest in rhinos ('t Sas-Rolfes 2011a). Saayman & Saayman (2017) documented that 331 white rhinos and two black rhinos were hunted between 2010 and 2012. The average price to hunt a white rhino increased by 31% from 65 000 US\$ in 2010 to 85 000 US\$ in 2012. The average price to hunt a black rhino increased by 28% from 235 000 US\$ in 2010 to 300 000 US\$ in 2012. Between 2010 and 2012 over 26 million US\$ in revenues were generated by rhino hunting (~8.7 million US\$ annually) (Saayman & Saayman 2017).

In general, higher trophy hunting prices translate into increased live sale prices for wildlife. Landowners bid to invest in trophy hunting species, and expected hunting returns from a species are reflected in the species' purchase price at auction. Despite increasing trophy hunting prices, auction data from 2001 through 2016 show that the number of rhinos sold and the average price per rhino have fluctuated since a market trough in 2005 (see Wildlife Auctions 2017, <http://wildlifeauctions.co.za/getHistory.php>). This may be due

to landowner uncertainties regarding poaching threats and/or whether rhino horn trade will be legalized. These fluctuations indicate that revenues from live rhino sales are unstable, thereby increasing financial risks for rhino owners. Based on available information, hunting currently appears to be the most profitable use of rhinos on private lands.

Financial costs of rhinos

Hall (2012) documents several financial costs of rhino ownership, including the initial land purchase, fencing, infrastructure, veterinary services, maintenance costs, and labor costs. Similar costs apply to a game ranch with virtually any wildlife species, depending on the intensity of the management system (Taylor et al. 2015). For the purpose of this framework, we assume that landowners have already invested in land and rhinos, and their property functions as a private game ranch. Only those costs that are specific to managing rhinos are encompassed in our conceptual framework, including rhino veterinary costs, supplemental feed costs, anti-poaching enforcement, and the costs of permits (Fig. 1).

Rhino ownership results in significant additional anti-poaching security costs to private game ranchers (Fig. 1) (Martin 2011, Ferreira et al. 2014b, Collins et al. 2016). These costs encompass investment in both labor (e.g. highly trained security guards who are willing to engage with armed poachers) and anti-poaching technology and infrastructure (e.g. drones, helicopters, security towers; Table 1). Anti-poaching security forces and poachers have become locked in a conservation-related arms race, where each side must continue to become more militarized, techno-

Table 1. Examples of anti-poaching security costs. Adapted from Collins et al. (2016)

Anti-poaching expenditure	Price in ZAR (price in 2016 USD)
Rhino dehorning	R6000–R10 000 per rhino (~\$423–\$706)
Fitting rhino with transmitter devices	R8000–R10 000 per rhino (~\$564–\$706)
Entry level personnel	R4000 per month (~\$282)
Experienced/weapons-trained personnel	R6000 per month (~\$423)
Vehicle operation	R6000 per month (~\$423)
Helicopter support	R400 per flight hour (~\$28)
Handheld thermal imagery cameras	R68 000 per camera (~\$4798)
Bullet-proof vest	R4000 per vest (~\$282)
Night vision binoculars	R17 000 per pair (~\$1200)

logically sophisticated, and strategic (Lunstrum 2014) – which in turn has resulted in escalating risks and anti-poaching costs for private landowners. Besides trying to kill rhinos, poachers now carry a range of weapons meant for targeting anti-poaching units, including AK-47s and rocket grenades (Lunstrum 2014). In contrast to public lands, private game ranchers do not receive government or NGO subsidies to offset their anti-poaching security expenses, so they must shoulder these considerable costs themselves (Child 2012).

Threat: commercial poaching

Understanding what drives commercial poaching is critical to planning suitable and successful rhino conservation actions. Rhino poaching has quickly evolved from a haphazard activity to a well-structured and organized criminal venture (Lunstrum 2014). Poaching syndicates operate multinationally, and there is evidence that organized cartels that trade rhino horn are linked to the illegal trade of other natural resources (e.g. abalone and ivory), as well as other illicit activities (e.g. drug smuggling and vehicle theft) (Montesh 2013).

Local men from South Africa and Mozambique are contracted by crime syndicates to poach rhinos. These poachers usually only receive 1000 to 9000 US\$ kg⁻¹ horn (compared to an estimated 65 000 kg⁻¹ for end-users), but there are always willing participants. Ground-level poachers are generally poor, and they rarely have access to job opportunities that provide comparable earnings (Lunstrum 2014). These poachers are at greatest risk of capture, injury, or death (Lunstrum 2014), which appears to be of little concern to the international poaching syndicates. Syndicates can easily replace and recruit ground-level poachers because of their ample supply (Martin 2011).

South African middlemen collect horns from the ground-level poachers, as well as from members of the private sector who are engaged in illegal trade (e.g. game ranchers who sell horn from dehorning or professional hunters who acquire horn through the guise of trophy hunting) (Montesh 2013). At the highest level of the supply chain are leaders of the crime syndicates who control the movement of horn from South Africa to Asian consumer markets (Montesh 2013).

While the individuals involved in the illegal rhino horn trade are heterogeneous, we assume that they are all profit-maximizers (see also 't Sas-Rolfes 2012,

Collins et al. 2016). The correlation between the increasing price of horn and the increase in the frequency of poaching (Hubschle 2016, Saayman & Saayman 2017) supports this assumption. For the remainder of this paper, we will focus primarily on ground-level poachers because we are most interested in poaching activity that directly affects private rhino owners. However, we will discuss other members of the illegal supply chain when relevant to rhino conservation by private landowners. Assuming profit-maximizing behavior, we argue that poachers are incentivized by high potential profits. The profit from poaching equals the revenue from poaching less the costs of poaching (Fig. 1).

Revenue from poaching

Revenues from poaching depend on both the amount of horn poached and the price of the horn, although prices received are different for on-the-ground poachers versus high-level syndicate members dealing with the end market (Fig. 1). The (inherently black market) price of rhino horn is a reflection of the demand for horn and the lack of competition from a legal market (Fig. 1). We postulate that the price of horn stimulates poaching activity (Hubschle 2016, Saayman & Saayman 2017), although the link between the black market price for horn and the quantity of horn poached has not been explicitly tested.

Demand for rhino horn has existed for thousands of years (Martin 2011). Asian markets dominate the demand (Hubschle 2016), particularly Vietnam and China (Ferreira et al. 2014b). The horn is used in traditional medicine to treat a spectrum of ailments ranging from insomnia to paralysis (Cheung 1995). It is also viewed as a status symbol and is used as criminal currency (Hubschle 2016).

The absence of competition from a legal market has allowed criminal syndicates to create an oligopoly in rhino horn trade and charge inflated prices ('t Sas-Rolfes 2012). Increasing scarcity of rhino horn as the rhino population declines or anti-poaching enforcement improves should further increase the price of horn, *ceteris paribus*¹. Despite these high prices and the fact that rhino horn is contraband, the Asian market for rhino horn persists, suggesting that

¹*Ceteris paribus* is a Latin phrase that is used by economists to denote 'all other things being equal' or 'other things held constant'.

the demand for horn is *price inelastic* or insensitive to price changes² ('t Sas-Rolfes 2012; see also Crookes & Blignaut 2015).

Price inelasticity of rhino horn demand means that the percentage decrease in demand for rhino horn will be less than the percentage increase in prices as horn becomes more scarce. However, price inelasticity of demand should also mean that a decrease in the price of rhino horn (e.g. owing to competition from legal trade) should not greatly stimulate demand for horn. This is an important point. If opposition to the legal trade in rhino horn is based on the assumption that lowering the price of rhino horn will substantially increase demand for horn, then better understanding of the price elasticity of rhino horn demand is required. The income elasticity of rhino horn demand also needs to be better understood. Crookes & Blignaut (2015) recently confirmed Milner-Gulland's (1993) finding that rhino horn is a luxury good, which suggests that demand for rhino horn is income elastic³. However, there is insufficient evidence on the elasticity of the demand for rhino horn. This means that we cannot determine the degree to which demand for rhino horn will change as the price of horn or the incomes of end consumers change.

Despite an imperfect understanding of the demand for rhino horn, price data demonstrates that rhino horn is currently worth more than gold, diamonds, or cocaine per kilogram (Biggs et al. 2013). Hubschle's (2016) fieldwork in Vietnam indicated that rhino horn could sell for as much as 65 000 kg⁻¹ US\$ to the end-users. At that price, the horn on a single white rhino is worth nearly 500 000 US\$ (Hubschle 2016). Other estimates place the price as high as 100 000 kg⁻¹ US\$ to end-users (Saayman & Saayman 2017). At these prices, it is unsurprising that poaching has escalated and that professional organized syndicates have

entered the market ('t Sas-Rolfes 2011a). Poaching syndicates can profit even more by stockpiling poached horn in expectation of higher prices in the future as horn becomes scarcer (Brown & Layton 2001, Mason et al. 2012).

Cost of poaching

The cost of poaching consists of direct costs (e.g. vehicles, weapons), as well as the risk cost (Fig. 1). Risk cost is a function of the probability of detection, capture, and punishment, and the severity of the punishment (Fig. 1) ('t Sas-Rolfes 2011b). Anti-poaching security on private lands has a direct impact on the probabilities of detection and capture of on-the-ground poachers (Fig. 1). The probability and severity of punishment are consequences of the legal system's enforcement post-capture (Fig. 1). The 4 components of the risk cost function are interdependent (Fig. 1). The probability of capture would be slim if there were no probability of detection. Punishment would be impossible without capture. In South Africa, the probability of punishment and the severity of punishment are jointly linked because stronger evidence is required to prosecute cases that carry heavier fines and prison sentences ('t Sas-Rolfes 2012). Therefore, as the severity of punishment for poachers increases, the probability of prosecution declines. We explore the implications of this inverse relationship between the severity and probability of punishment later in this paper. We postulate that the cost of poaching is likely capitalized into the black market price of horn (Fig. 1).

RHINO CONSERVATION AS GOVERNMENT AND MARKET FAILURES

Even in its simplified form, the conceptual framework illustrates that rhino conservation is a multifaceted problem. Another important insight from the conceptual framework is that financial decision-making drives rhino conservation among private landowners. Cost-benefit analysis suggests that rhino conservation on private lands depends on the revenues from rhinos outweighing the costs. This is a cause for concern, since currently the costs to private landowners from managing rhinos significantly outweigh the revenues generated by rhinos – in large part owing to the costs of anti-poaching measures.

Before examining some of the solutions intended to enhance rhino conservation on private lands, it is

²Price elasticity of demand measures how demand for a good changes as the price of the good changes, *ceteris paribus*. Demand for a good is price inelastic when a 1% increase in the price of a good results in less than 1% decrease in demand for the good. Similarly, a 1% decrease in the price of the good will increase demand by less than 1%

³Income elasticity of demand measures how demand for a good changes as the income of consumers increases, *ceteris paribus*. It is calculated as the ratio of the percentage change in quantity demanded to the percentage change in consumers' income. For most goods, a 1% increase in income results in less than a 1% increase in demand for the good, i.e. the income elasticity of demand is less than 1. However, the income elasticity of demand for a luxury good is greater than 1, i.e. a 1% increase in income results in greater than 1% increase in demand for the good.

critical to understand the policy context in which the conceptual framework lies. The Convention on International Trade in Endangered Species (CITES) banned the international trade of rhinos and rhino parts in the mid-1970s (De Alessi 2000), which has had unintended, perverse consequences for rhino conservation, which we explore below.

The CITES trade ban as a government failure

Poorly structured policies create perverse incentives that result in sub-optimal outcomes (Tietenberg & Lewis 2009). The CITES trade ban is based on the assumption that making the trade of rhino horn illegal will stop people from trading horn, but this does not hold in practice. Not only has the trade ban proven to be unsuccessful in reducing poaching, its implementation has actually created a problematic feedback loop for rhino conservation by ignoring the ban's perverse role in incentivizing poaching.

By restricting the legal supply of rhino horn (and associated supply-side competition), the CITES trade ban may have increased the black market price of horn, thereby increasing the financial incentive to poach (Biggs et al. 2013). Increased enforcement and higher penalties may also fail to raise the costs of poaching to the point that there is reduced incentive to poach. Given the price inelastic demand for horn, syndicates may pass on the costs of poaching (in the form of increased risks) to end consumers by increasing the price of rhino horn. Increased black market horn prices enhance revenues from poaching and generate an even greater financial incentive to poach rhinos (Fig. 1) (Biggs et al. 2013).

The CITES trade ban as a market failure

The current CITES trade ban on global rhino horn trade has created a significant market failure that jeopardizes rhino conservation on private lands by limiting legal revenues to be earned from rhinos. Well-defined property rights are (1) exclusive, where all benefits and costs from a resource accrue only to the owner; (2) transferable, so that all property rights can be voluntarily transferred from one owner to another; (3) secure, so that other people, firms, or the government cannot involuntarily seize one's resources; and (4) comprehensively assigned, where all assets of a resource are owned (Hanley et al. 2007). Strong, well-defined property rights result in the incentive for the owner of a resource to use, improve,

and conserve the resource under his or her control (Hanley et al. 2007, Tietenberg & Lewis 2009).

The rhino horn trade ban has created a market failure of incomplete property rights. Rights are not comprehensively assigned because landowners are not permitted to earn income from the horns of their rhinos. As such, the trade ban artificially reduces the value of rhinos on the legal market, distorting economic signals (Child 2012). Incomplete property rights are directly linked to another market failure—missing (legal) markets (Krug 2001). High black market horn prices solely benefit actors within the illegal supply chain. Conversely, law-abiding game ranchers do not capture full benefits of rhino conservation, but carry the entire financial burden of rhino ownership (Child 2012). If landowners do not receive all the benefits or potential financial returns associated with rhino conservation, they will engage in lower levels of conservation than is optimal (i.e. the number of rhinos conserved on private lands, and the amount of habitat managed for rhinos will be lower than if landowners are able to earn higher payments for their conservation efforts).

The conservation impacts of these failures: poaching and rhino disinvestment

When the costs of protecting rhinos were low, the benefits from photographic tourism, hunting, and live sales covered the costs of ownership (Child 2012). These income streams are now insufficient to offset the costs of security needed to protect rhinos from poaching threats. As a result, many private landowners are opting out of rhino conservation (Knight 2011, Ferreira et al. 2014b). It is estimated that as of 2016, 70 of the approximate 400 private rhino owners in South Africa have removed rhinos from their lands, amounting to a loss of about 200 000 ha of land available for rhino conservation (CITES Management Authority 2016). Disinvestment at this scale will likely lead to a lower carrying capacity for surplus rhinos that need to be moved from public lands (Knight 2011, Ferreira et al. 2014b).

ADDING ACTIONS: POTENTIAL SOLUTIONS

Several conservation actions have been tested in an attempt to increase rhino protection and reduce poaching, but with little demonstrated success. Fig. 2 illustrates how current and potential conservation actions fit into the framework of rhino conservation

majority of the horn and leaving a stub on the animal—which does not adversely affect the rhino (Fig. 2). However, even the horn stub is valuable enough to attract poachers (Lindsey & Taylor 2011), which undermines the effectiveness of this strategy. Dehorned rhinos may also be poached (1) to increase the price of stockpiled horn, (2) as a message to rhino owners that dehorning is ineffective, or (3) so poachers can avoid tracking the same animal again (De Alessi 2000). Dehorning in the absence of effective anti-poaching security has failed to reduce poaching (Lindsey & Taylor 2011).

Poisoning rhino horn

Poisoning rhino horn, or infusing the horn with an anti-tick treatment and dye, has been suggested as a way to decrease the revenue associated with poaching. The logic is that by poisoning the horn, it will become harmful to humans, thereby rendering the horn worthless on the black market (Fig. 2) (Ferreira et al. 2014a). In addition to multiple technical and practical issues associated with injecting the treatment and dye into the horn of a live animal (see Ferreira et al. 2014a), the greatest problem with this strategy is that poachers are not the end-users of rhino horn. Unless poachers are concerned about the health and safety of consumers (which seems highly unlikely), they will simply sell the treated horn, especially if the dye is not visible (Ferreira et al. 2014a). Not only has this method been ineffective in its ability to alter the horn in any significant way that would deter poaching (see Ferreira et al. 2014a), the morality of poisoning horns potentially destined for human consumption is questionable.

Improving anti-poaching technology to increase security

Several current conservation actions focus on increasing the cost of poaching by influencing different aspects of the risk cost function (Fig. 2). Evidence suggests that on-the-ground poachers focus on immediate potential profits and heavily discount the future ('t Sas-Rolfes 2012). As a result, increasing the probability of detecting and capturing poachers before they kill a rhino is the risk cost factor that is most likely to alter a poacher's perception of expected profit (Milner-Gulland & Leader-Williams 1992, 't Sas-Rolfes 2012). Measures that preemptively detect poachers are a better deterrent to poaching

and are also more beneficial as they actually protect rhinos while they are still alive (Martin 2011, 't Sas-Rolfes 2011b, 2012).

Improved technology can ultimately lead to increased probabilities of detection and capture of on-the-ground poachers (although it does not directly affect other players in the illegal supply chain) (Fig. 2). Increased security through improved anti-poaching technology should result in increased costs for poachers—whether in time, effort, or risk associated with poaching—which may reduce their incentives to poach. However, the incentive to poach will likely not be eliminated if on-the-ground poachers have minimal or no access to comparable income earning opportunities (Fig. 2). As technology improves, it may become cheaper, potentially leading to decreased security costs for private landowners (Fig. 2). Decreasing the costs associated with improved anti-poaching technology should result in better *in situ* rhino protection.

New advances such as remotely piloted aircraft systems and heat sensing planes can be used to detect animals and humans on the ground, and mobile biological sensors can detect abnormalities in rhino movements (Mukwazvure & Magadza 2014). Acoustic traps can monitor areas for unusual sounds, and radio collars that transmit GPS data are common for rhino protection (UNEP 2014). Technologies also empower the public. New mobile phone applications encourage the public to report illegal wildlife activities (UNEP 2014). However, it is important to remember that as anti-poaching security forces seek to improve technology, so do syndicate-backed poachers, resulting in a continuous arms race (Lunstrum 2014).

Increasing enforcement through heavier sentences, shoot-to-kill policies, and increased prosecution rates

Conservation actions also target the remaining 2 aspects of poachers' risk cost functions by increasing the likelihood and severity of punishment if poachers are arrested (Fig. 2). However, these components appear not to significantly alter poachers' decision-making. Middlemen have been known to pay the fines imposed on ground-level poachers, so increased fines do not serve as a deterrent to ground-level poachers ('t Sas-Rolfes 2011b). Long prison sentences, the death penalty and shoot-to-kill policies are insufficient to deter poaching because of how highly impoverished ground-level poachers discount

the future ('t Sas-Rolfes 2012). Sanctioned killing of poachers also raises moral issues in terms of placing animal lives above human lives, punishing the impoverished, and lack of due process. For example, relations between Kruger National Park and nearby South African and Mozambican villages are strained because villagers view rangers as killers who value rhinos more highly than humans (Rademeyer 2016).

Although seeking heavier sentences in court may reduce the probability of a conviction in South Africa ('t Sas-Rolfes 2012), the greater problem seems to be that poaching-related arrests have not increased at the same rate as poaching incidents (Collins et al. 2016). In addition, in 2015, 83% of the poaching-related arrests in South Africa were not prosecuted (Verwoerd 2016).

Unlike increasing the probability of detection, these reactionary and punitive enforcement strategies are suboptimal because a rhino was poached before the 'success' of punishing the poacher was attained (Martin 2011). Additionally, catching or killing poachers does not actually end the threat. Ground-level poachers are replaceable within the syndicate (Martin 2011). The enforcement system has also been undermined by pervasive bribery and corruption (Martin 2011, 't Sas-Rolfes 2011b, Rademeyer 2016).

If local, impoverished communities are engaging in poaching because they have limited means to meet their survival needs, then poverty alleviation programs may be more effective in reducing poaching than punitive actions (see Douglas & Alie 2014, Haas & Ferreira 2016). Wildlife management in South Africa is highly lucrative, and may have generated a 'resource curse' in terms of socioeconomic inequality, corruption, and social conflict (Douglas & Alie 2014). Policies and programs that promote poverty alleviation should be combined with anti-poaching enforcement and efforts to dismantle criminal syndicate networks (Haas & Ferreira 2016).

Subsidizing security costs

One potential conservation action that has not been implemented to date is to establish government subsidies to defray security costs associated with rhino conservation (Fig. 2) (Child 2012). Just as the US government offers programs that provide financial assistance to individuals engaged in conservation efforts on private lands (Sorice et al. 2011), government subsidies to offset security costs may provide South African private landowners with an incentive to invest in rhino conservation.

Realistically, however, it is unlikely that the South African government is able to provide this support to private landowners because public conservation lands already suffer from inadequate funding and declining budgets (Krug 2001). Other public spending programs (such as health and education) may also take priority over rhino conservation (Rademeyer 2016). Finally, government programs that undermine the self-sufficiency of ranchers (who currently must generate sufficient revenues to cover the costs of their land management) may generate perverse outcomes in terms of landowner reliance on government subsidies, and reduced efficiency in their land management practices.

Legalizing horn trade

Legalizing the horn trade would help to correct the market failures associated with the CITES trade ban. Legalizing horn trade would permit the sale of horns from dehorned rhinos and horn stockpiles that have been generated from natural deaths of rhinos on private and state lands (Ferreira et al. 2014b). Several authors discuss the advantages and disadvantages of this potential conservation action in detail (see Martin 2011, 't Sas-Rolfes 2012, Biggs et al. 2013, Ferreira et al. 2014b, Collins et al. 2016), and we will only summarize some of the main arguments.

Proponents of legalizing rhino horn trade commonly point to 2 significant potential conservation outcomes of this action. First, legal trade would increase the supply of horn available on the market, creating competition for the black market and removing the black market's ability to charge inflated prices ('t Sas-Rolfes 2012). Decreased black market profits may reduce the incentive to poach, *ceteris paribus* (Fig. 2) ('t Sas-Rolfes 2012, Biggs et al. 2013, Ferreira et al. 2014b), although it should be recognized that illegal trade exists for items with legal markets. Nonetheless, population increases of crocodiles, ostriches, and vicuna are cited as evidence that legalized trade reduces poaching pressures (Eustace 2012). Similar arguments have been made when considering the creation of a legal market for cocaine, heroin, and other illicit drugs (Miron 2003).

A legal market would also allow for monitoring of consumer demand, which is currently extremely challenging because all trade takes place illegally ('t Sas-Rolfes 2012). While it is likely that black market trade would still occur even if a legal market were established, the legal market may attract consumers away from the black market, especially if the legal

product is cheaper, of guaranteed quality, and/or lower risk than the illegal product (Martin 2011, Biggs et al. 2013).

The second key argument for legalization of horn trade is that it would provide an additional, renewable source of income for rhino owners, increasing the revenue of live rhinos and thereby incentivizing rhino ownership and long-term conservation on private lands (Fig. 2) (Child 2012, 't Sas-Rolfes 2012, Biggs et al. 2013). This new revenue stream could be reinvested in anti-poaching security ('t Sas-Rolfes 2012), which should reduce the amount of horn available to poachers (Fig. 2).

Arguments against legal trade in rhino horn center on ethical concerns about commercially exploiting wildlife ('t Sas-Rolfes 2012) and the uncertain consequences of removing the CITES trade ban (Ferreira et al. 2014b). Of particular concern is the potential of a 'reverse stigma effect', where demand increases because previously law-abiding consumers now enter the market ('t Sas-Rolfes 2012). The counter argument is that an increase in demand for rhino horn would translate into a long-run increase in the number of rhinos conserved on private lands to meet this demand (Biggs et al. 2013), i.e. private landowners will invest in valuable rhinos.

There is significant debate surrounding regulated trade as a conservation strategy that extends beyond rhino conservation to include many endangered species that are poached and trafficked (Fischer 2010, Santos et al. 2011, Conrad 2012). Some authors assert that 'naïve' models that do not realistically capture markets for wildlife are common in pro-trade literature (Fischer 2004, Bulte & Damania 2005). However, more complex models also generate uncertain predictions regarding the success of trade bans versus regulated trade. The model predictions depend on which assumptions are made about market competition (Bulte & Damania 2005) and the presence of illegal horn laundering (Fischer 2004).

Although our conceptual framework suggests that legal trade is a necessary component of rhino conservation on private lands in South Africa, the fact remains that policymakers should be careful when implementing legal trade (Bulte & Damania 2005) in order to ensure that a legal market has a net positive conservation effect. This is not inconsistent with South Africa's game ranching system. Landowners are required to fence their land in accordance with government regulations in order to be allowed to earn hunting revenues throughout the year (Taylor et al. 2015). Landowners are also required to obtain permits related to wildlife on their land, and in order

to move or transport wildlife to other locations (Taylor et al. 2015). The permit system provides an opportunity to require that landowners manage sufficient habitat to support rhinos before they would be allowed to engage in legal trade.

Significant effort will be required to create a well-regulated horn market (Biggs et al. 2013, Ferreira et al. 2014b, Collins et al. 2016). There is now urgent need to determine how legal rhino horn trade should be structured. In February 2017, South Africa's Minister of Environmental Affairs published a government gazette, 'Draft Regulations for the Domestic Trade in Rhinoceros Horn, or a Part, Product or Derivative of Rhinoceros Horn' (DEA 2017). As a result, the Private Rhino Owners Association (PROA) of South Africa has been drafting a domestic trade proposal (PROA 2017).

Current indications are that a central selling organization (CSO) will be instituted to regulate and monitor the legal rhino horn trade within South Africa. The CSO would be the only authority that could legally sell horns to registered buyers. It has also been suggested that the CSO would use technology (e.g. microchips) to track individual horns through the legal selling chain to the end consumer (Biggs et al. 2013). By regulating the supply chain, a CSO could effectively minimize the risk of corruption and speculation through rhino horn stockpiling (Biggs et al. 2013). Additionally, a CSO may stop the legal trade of rhino horn if the legal market proves ineffective in incentivizing rhino conservation (Martin 2011, Biggs et al. 2013).

It is important to note that the draft regulation is for domestic horn trade only and the export of horn is permitted only for personal (i.e. non-commercial) use. Because the demand for rhino horn is driven by Asian consumers, in the absence of legal exports of rhino horn for commercial purposes, it is likely that the draft regulations will still restrict potential profits from rhino horn trade. This will limit financial incentives for rhino conservation by private landowners.

DISCUSSION

Our conceptual model demonstrates 2 important points. First, each current rhino conservation action is targeted at only one part of the larger problem of protecting rhinos (with the exception of improving anti-poaching technology). Practitioners need to use multiple tools to counter different and diverse rhino conservation threats (Salafsky et al. 2002). Although all the current strategies to conserve rhinos likely

play a role in reducing rhino poaching, there is mounting evidence that they are insufficient to ensure the conservation and recovery of the rhino. After nearly a decade of drastic and increasing poaching pressure, a more comprehensive strategy (or set of strategies) that targets multiple threats to rhino conservation (including rhino disinvestment by private landowners) is needed.

The second insight from the conceptual framework is that current conservation actions completely overlook half of private landowners' cost-benefit function. Not a single strategy focuses on increasing legal revenues from rhinos, which would directly benefit landowners and allow them to cover the costs of managing and protecting rhinos. Instead, the vast majority of conservation actions are dedicated to altering poachers' cost-benefit functions, which may reduce poaching pressures but does not directly influence the benefits that private landowners derive from rhino management. A truly comprehensive strategy should increase revenues from rhinos because financial benefits are central to the South African wildlife use model. Direct, transparent incentives to own and protect rhinos (in the form of sustainable revenues from harvesting horn) may increase rhino conservation on private lands.

While economic solutions are needed to conserve rhinos on private lands, we recognize that care should be taken in implementing a legal market for rhino horn. Research underpinned by an adaptive management approach (see Salafsky et al. 2002) should be conducted to ensure the market attains conservation outcomes. First, rigorous initial research regarding the design and structure of the market is needed to prevent perverse or unintended outcomes. As noted by Collins et al. (2013), there is little understanding about how the legal horn market should be structured or regulated. Research into different market structures (including a CSO) and how they may influence the legal price and supply of rhino horn is vital to increasing rhino conservation on private lands.

In the event that a legal market is created, the impacts of legal trade should be monitored to assess whether (1) rhino owners have the ability to meet horn demand, (2) legal trade stimulates demand for horn, and (3) legal trade reduces black market prices for horn ('t Sas-Rolfes 2012, Collins et al. 2013, Ferreira et al. 2014b). Research into how legal trade affects poaching activities will also be needed ('t Sas-Rolfes 2012, Biggs et al. 2013, Ferreira et al. 2014b) and whether measures are needed to prevent laundering of illegal horn into the legal supply (see Fischer 2004).

Conservationists are so alarmed by the state of rhino poaching in South Africa that plans are underway to transport rhinos to Australia (Hayward et al. 2017) and Texas, USA (Forsyth 2015) for safekeeping. Hayward et al. (2017) catalog a series of concerns related to projects aimed at establishing extralimital populations, including the fact that they divert funding and expertise from *in situ* conservation efforts, may result in unknown ecological consequences, and exploit Africa's resources by removing biological assets. Despite the fact that efforts are already being taken to remove rhinos from their natural habitat in the name of conservation, conservationists have yet to fully explore all available options that may improve *in situ* conservation. While some conservationists question the morality of horn trade legalization and commoditizing wildlife, the morality of shipping rhinos out of Africa is also debatable. It seems prudent to exhaust all potential strategies that may promote *in situ* conservation of rhinos before they are sent to other continents to be protected.

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