Can a legal horn trade save rhinos?

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Abstract

The world's five rhinoceros species remain threatened with extinction in the wild despite a 40 year international trade ban on rhino products. Poachers kill rhinos for their horns, which are sought for medicinal and ornamental purposes i n Asia and command remarkably high prices in black markets. Recent attempts to restrict markets f or trophy hunts and rhino horn in South Africa were followed by unprecedented increases in poaching levels. This has prompted suggestions to investigate a legal trade alternative. We develop a model of rhino conservation that takes full account of contemporary conditions (markets, institutions, technology, and relevant biological parameters) and establish conditions under which an appropriately structured legal trading regime may prevent the extinction of the white rhino in South Africa. Taking advantage of existing data on rhino populations for calibration, we simulate the bioeconomic model to assess the effects of a legal trade regime. The results indicate that intensive management of rhinos, coupled with a legal outlet for verified horn, would increase rhino numbers while lowering the effective price for horn. Substantial expenditures for protecting live rhinos are required, despite which poaching persists at greatly reduced levels. These results are then brought to bear on the broader debate over rhino policy.

Keywords: endangered species, rhinoceros, poaching, wildlife property rights, illegal trade

JEL Codes: K42, Q19, Q21, Q27

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Note: This is personal work and does not reflect the official position of the US Council of Economic Advisers.

1 Introduction

Since 1977, international trade in all rhino products has been banned under the UN Convention on International Trade in Endangered Species (CITES). However, poaching has continued to decimate rhino populations, driven by the lucrative illegal trade in rhino horn. Although official price data are unavailable because of the clandestine nature of the market, undercover surveys by organizations such as the wildlife trade monitoring network TRAFFIC reveal that rhino horn prices have risen substantially over the last 36 years. At the time of writing, the retail value of rhino horn by weight in some Asian markets is reputed to be higher than that of gold (Graham-Rowe, 2011; Gwin, 2012). Circumstantial evidence indicates that persisting demand for rhino horn may be price inelastic and that continued efforts at enforcement simply drive up the black market price (Brown and Layton, 1997).

For some time, economists have proposed regulated legal trade as an alternative solution to the problem ('t Sas-Rolfes, 1995, 1997; Brown and Layton, 2001). More recently this idea has received broader support from scientists (Child, 2012; Biggs et al., 2013) and the South African government has announced its intention to investigate this further. This policy would be consistent with that recommended by Becker et al. (2006) for dealing with other goods with persistent inelastic demand characteristics such as drugs. Rhino horns are unusual among animal products regulated by CITES in that they can be harvested off live animals (by "dehorning") and they regrow, thus obviating the need to kill the animals to supply the market and thereby strengthening the rationale for legal trade. Poaching mortality is therefore a problem on two counts insofar as not only are the horns stolen, but the potential for future production is lost when the animal is killed.

Damania and Bulte (2007) sound a word of caution against unqualified acceptance of legal trade solutions to endangered species problems, and use a hypothetical model of African black rhino farming to illustrate their argument. However, as we demonstrate, neither of their two main concerns need apply to the South African white rhino situation, and the case for a

legal trade in horns harvested from white rhinos is more compelling than the simple supply-side approach that they critique. Because white rhinos' horns are acceptable substitutes for those of other more endangered species, a legal trade from South African rhinos also offers potential benefits to all of the world's rhino populations.

Although rhinos were close to extinct in South Africa by the year 1900, the population has rebounded to the point that the country now boasts the world's largest herd. Unlike most other rhino range states, South Africa has embraced market institutions as a conservation measure, allowing private ownership and trade of live animals as well as commercial trophy hunts and, until 2009, domestic trade in rhino horn. Unlike most rhino range states, South Africa has developed strong market institutions, such as private ownership of certain wild game species and independent/autonomous government conservation agencies that are allowed to retain and reinvest income from live game sales, nature tourism and related profitable activities. There is much evidence to suggest that these institutions account at least in part for South Africa's relative success with rhino conservation, as they create far stronger incentives to invest in protection, breeding and range expansion of rhino populations 't Sas-Rolfes (1990); Child (2012).

2 Background

2.1 Rhino Conservation and the Horn Trade

Humans have hunted rhinos for meat, hides, horn and other body parts throughout history, thereby gradually reducing rhinos' once extensive range to relatively few isolated areas in Africa and Asia. The fate of different species and subspecies has varied with time and geography, as tables 1 and 2 show. For example, the southern white rhino population has recovered from perhaps less than 50 individuals in South Africa in 1900 to more than 20,000 spread across nine countries today. By contrast, the population of the biologically similar northern subspecies has declined from an estimated 2,000 in 1970 to only two captive individuals and is now considered extinct

in the wild. Numbers of Indian rhinos were similarly low in 1900 and have recovered modestly compared to the southern white population.

Since the initial CITES ban, at least three rhino subspecies have become extinct in the wild, the Javan rhino population has remained stable and numbers of both black and Sumatran rhinos have declined. Africa's black rhino population, once abundant, declined precipitously until the mid-1990s, though it has since recovered somewhat. Whereas the decline of African rhinos can be mostly attributed to direct commercial exploitation, the Asian species are also severely impacted by habitat loss due to human land conversion.

CITES aims to conserve biodiversity by ensuring that no species of wild fauna or flora is subjected to unsustainable exploitation through international trade (Wijnstekers, 2011). To achieve this goal, the convention relies on a system of permits and restrictions. The signatory countries ("parties") decide on whether to list relevant species on one of three Appendices. Appendix 1 and 2 listings are the more significant, with the former imposing a complete ban on cross-border trade and the latter regulating trade by way of export and import permits.

Rhino conservation goals are set by the World Conservation Union (IUCN) through its Species Survival Commission, which has appointed two specialist groups (African and Asian) to deal specifically with rhino conservation issues and determine strategy and specific objectives. Broadly speaking, the IUCN rhino specialist groups aim to maintain genetically viable free-ranging populations of all rhino species and subspecies in their natural habitat within their former historical range. By this measure, rhinos are not performing well: out of thirteen distinct genetic varieties (species and subspecies) identified by biologists as extant in the early 20th century, five are now effectively extinct in the wild and a further six remain "critically endangered" (this includes three species). Five varieties (comprising three species) are considered to be increasing in numbers at the time of writing; the other three (comprising two species) are either stable or declining (see tables 1 and 2).

There is no clear evidence that implementing the CITES ban yielded any rhino conservation success before the mid-1990s, at which time several signif-

icant rhino horn consumer countries adopted domestic measures to restrict sale and consumption of rhino horn products. Prior to this, adoption and enforcement of CITES measures was piecemeal, varying erratically between countries and over time.

Destination markets for rhino horn have also varied over time. During the 1970s Yemen appears to have been one of the most significant markets, driven by demand for ornamental ceremonial dagger handles (Leader-Williams, 1992). Hong Kong constituted another key market during this time, apparently serving as an entrepôt for traditional medicinal markets in various East Asian countries. Wholesale prices for African rhino horn in several of these East Asian countries increased dramatically in the late 1970s following the initial CITES ban, although recorded prices in Yemen remained consistently higher through the early 1980s (Leader-Williams, 1992). However, by the early 1990s black market prices for African rhino horn in East Asia appeared to surpass those of Yemen, with Taiwan, South Korea and China emerging as the most significant markets.

The imposition of stricter domestic measures in those markets in the mid-1990s was followed by a lull in poaching activity during the late 1990s. However, during the early 2000s Vietnam emerged as a newly significant underground market with horn prices apparently far higher than those recorded in the early 1990s (Milliken and Shaw, 2012; Gwin, 2012).

The resurgence of the rhino horn market is indicated by data on poaching, trophy hunting, and live horn sales in Africa over the last decade. Figure 1 illustrates the changes. In 2002 and 2003, poaching incidents in South Africa and Zimbabwe increased before declining in 2004. At this time, Vietnamese nationals started visiting South Africa for the putative purpose of sport trophy hunting. Vietnam does not have a tradition of such sport hunting, but CITES exempts the export and import of rhino trophies from South Africa, and this provided a means for Vietnamese traders to acquire horns for export without contravening the international trade ban. It was also around this time that legal domestic sales of private horn stocks (collected from dehorning and collections) started to increase.

Concerned about the Vietnamese hunts and the fact that domestically-

sold horn appeared to be leaking illegally onto international markets in contravention of CITES, the South African government imposed tighter regulations on all aspects of the private rhino industry; these took effect from early 2008. Almost immediately following this, poaching levels increased dramatically. Since then the government has added further restrictions (including a moratorium on domestic trade in horn from 2009) and significantly stepped up enforcement efforts (ranging from increased expenditure on policing to harsher penalties for offenders). An increasing number of poachers and traders have been arrested, convicted and punished, but significant poaching levels persist at the time of writing. The cost of increased protection and enforcement is placing a substantial financial burden on South African rhino owners and custodians, as well as various sectors of government.

Environmental groups are now paying increased attention to consumer countries, especially Vietnam, whom they accuse of lax law enforcement. Recent studies by TRAFFIC reveal a vibrant and multi-faceted consumer market in Vietnam, with rhino horn rarity and prestige acting as driving factors alongside beliefs in medical efficacy (Nowell, 2012; Milliken and Shaw, 2012).

The current challenge for policy-makers is whether to continue pursuing enforcement of the ban along with attempts at "demand reduction" through consumer awareness campaigns, or whether to heed the increasing calls from South African rhino owners to pursue the alternative option of legal trade. Given that the leakage of non-lethal supplies of horn onto international markets during the period 2004–2007 appears superficially to have had a dampening effect on poaching, the legal trade option appears worthy of further consideration, as the subsequent implementation of CITES-related measures appears to have stimulated poaching activity rather than reduced it.

2.2 Previous Literature

Although CITES is widely considered as a successful conservation treaty (Rivalan et al., 2007; Wijnstekers, 2011) this success is less evident with

certain large and charismatic terrestrial mammals such as elephants, rhinos, tigers and bears ('t Sas-Rolfes, 2000). These examples share three important characteristics: first, the species concerned yield products that are highly valued in East Asian markets; second, they are icons for the fund-raising efforts of non-profit environmental groups; third, conserving genetically viable wild populations implies relatively high opportunity costs (these animals typically occupy large ranges and are considered dangerous to humans). Consequently, they are the subject of much debate on how to manage these competing forces. CITES and the IUCN endorse the principle of sustainable use of wildlife (Wijnstekers, 2011) and should thus approve international legal trade in those products if such trade does not threaten the species in question.

Legal trade proponents argue that sales of ivory stockpiles collected from naturally deceased elephants can provide much-needed conservation revenue (Kremer and Morcom, 2000) and that captive breeding and sustainable harvests of bears, tigers and rhinos can be employed as a means to satisfy consumer demand for traditional medicinal products (Jiang et al., 2007). However, these views are not shared by influential international environmental organizations, which mostly appear to support a continued policy of trade restrictions and law enforcement backed up by "demand reduction" campaigns (Graham-Rowe, 2011).

Swanson (1994) presents a revised economic theory of extinction and, after specifically analyzing the issue of elephant conservation, cautions against the demand reduction approach. He argues that "diverse resources must be accorded very substantial values, including market values, if they are to receive the investments that they require for their survival. The policy of 'demand destruction' is at odds with the fundamental solution concept to the problem of endangered species and biodiversity decline." Barbier and Schulz (1997) make a similar point and, in a later report for CITES, Bulte et al. (2003a) argue that strict restrictions may work as a short-term measure, but that establishing strong property rights and markets creates superior long-term incentives for conservation.

Trade bans are not only questionable as long-term conservation measures

7

but may also create short-term problems. For example, Courchamp et al. (2006) note that bans can increase rarity value (and therefore market prices) of species products and Rivalan et al. (2007) cite empirical evidence that CITES Appendix 1 listings have resulted in sudden spikes in commercial values and therefore increased levels of illegal harvesting and trade. Successful enforcement of trade bans and confiscations of illegal stocks amount to reductions in supply to the market and may therefore further exacerbate such price effects. Bergstrom (1990) discusses the issue of accumulated ivory and rhino horn stockpiles and explains the economic and conservation case for selling these rather than destroying them.

Barbier et al. (1990) also caution against the use of trade bans with reference to the example of elephant ivory. Notwithstanding this, the 1989 CITES ivory ban and associated destruction of ivory stockpiles appeared to be an initial success for elephant conservation as it was followed by an apparent reduction in demand, ivory prices and poaching (Brown and Layton, 2001). However, this success has not endured. Elephant range states such as South Africa, Zimbabwe, Botswana and Namibia still accumulate ivory stockpiles that they wish to sell, and demand in East Asian consumer countries appears to have risen in recent years along with reports of increased poaching and confiscations of illegal ivory (CITES Secretariat, 2012). Two one-off ivory sales approved by CITES (in 1999 and 2008) have had unclear effects on the market and the future of ivory trade remains the subject of much deliberation. For further discussions on ivory stockpiles, see Kremer and Morcom (2000, 2003) and Bulte et al. (2003b).

In a recent addition to the general discussion on stockpiles, Mason et al. (2012) demonstrate that, under certain conditions, speculators with monopoly power may have an incentive to contribute actively toward the extinction of a species in the wild, with the ultimate goal of achieving added monopoly rents from eventual sales of the harvested product. As a deterrent against this "banking on extinction" strategy, they recommend maintaining trade bans after a species becomes extinct. The authors analyze data on black rhino exploitation and assume that a single private stockpiler holds larger quantities of horn *ex situ* than wild stocks carry *in situ*, but do not provide

empirical evidence for this. Their assumption is almost certainly invalid and ignores the role of the white rhino horn market, as the authors themselves later acknowledge. The application of this model to the contemporary market for both black and white rhino horn (which appear to be near-perfect substitutes) is ambiguous, especially since all evidence indicates that horn stocks are dispersed among a wide range of owners, both public and private, in both range states and consumer countries.

Despite evidence that trade bans may fail to protect rhinos, elephants and tigers, the likely effects of lifting such bans continues to be hotly debated. Hypothetically, lifting a ban may have two countervailing effects on a market. The first is a substitution effect, whereby the new legal supply source competes with and crowds out the illegal supply market. The second is a possible expansion effect, whereby market demand may actually increase if previously abstinent, law-abiding consumers enter the market, resulting in an outward shift of the demand curve.

Fischer (2004) considers the effect of introducing certified ivory sales when some consumers are law-abiding and others not. She argues that introducing certified ivory at prices higher than the illegal market will satisfy the new legal markets but have no positive impact on the illegal markets. By contrast, introducing certified ivory at prices lower than the illegal market should ultimately reduce incentives for poaching. However, if legal and illegal markets are linked (through smuggling and laundering operations) and it is hard to distinguish legal products from those that were illegally harvested, then even lower-priced sales may exacerbate the poaching problem.

Damania and Bulte (2007) consider the potential effect of introducing a legal supply from wildlife farming when the illegal suppliers exercise a degree of market power. They argue that the success in deterring poaching may depend on how illegal traders respond to the new source of competition. If they respond by maintaining prices and restricting supply (Cournot competition) then poaching levels will drop. However, if they decide to respond by aggressively reducing prices (Bertrand competition) then poaching levels may increase.

In both instances, the concerns raised by Fischer and Damania and Bulte

only apply to the extent that illegal suppliers face lower costs than legal suppliers. This is an empirical issue. Damania and Bulte treat farmed and wild populations as completely separate and do not consider the possibility that profits from the sale of farmed products could be used to subsidize protection of wild populations. Abbott and van Kooten (2011) examine the case of tiger farming and argue that neither legitimizing trade in products from captive bred tigers nor increased enforcement alone is likely to prevent tigers from becoming extinct in the wild. They propose a cocktail of policies, including side payments from tiger farmers to pay for protection of wild tigers and their habitat. Abbott and van Kooten (2011) suggest that Bertrand competition is unlikely because both farmers and poachers do better by competing on the basis of quantity when wild and farmed products are substitutes.

A final concern relating to the supply of farmed products is that, despite them being substitutes, consumers may prefer products from wild-harvested animals. Meacham (1997) notes this possibility for tiger bones and Dutton et al. (2011) identify this problem in the case of bears. The latter authors argue that increasing the legal supply of bear bile from farmed bears may in fact increase the demand for wild-harvested bile.

In their review of the literature on renewable resources, Bulte and Barbier (2005) emphasize that the interplay of economic, ecological and institutional variables will determine whether trade is "good" or "bad" in any given situation. Similarly Fischer (2010) argues that "it is important to understand the full economic, ecological, and institutional context of the resource, or policies can indeed backfire." We agree with these authors and observe that, notwithstanding some common principles, the examples of elephants, rhinos, tigers and bears are all somewhat different contextually and we must exercise caution in distinguishing relevant similarities from differences. Furthermore, even within those examples we may find significant contextual differences: between species or subspecies, between different range states and even between individual populations.

2.3 Modern Rhinos

The literature to date misses certain important aspects that relate to the specific case of the contemporary rhino trade. Of critical importance is the institutional context, which is typically ignored or misspecified. For example, Damania and Bulte (2007) refer to "wild" rhino populations, implying an open access situation. However, in reality few if any surviving rhino populations exist under open access conditions: most are protected within state parks or on private land under relatively strong property rights regimes. In South Africa, rhino owners and custodians bear the costs of protection but are also entitled to retain any financial returns that rhinos may generate. This implies that, to the extent that rhino owners are able to raise income from their animals (e.g. by selling horn), they can re-invest the proceeds into protection, thereby effectively raising the costs of poaching.

Rhinos typically generate financial returns from five different sources: tourism viewing, trophy hunting, sales of live animals, sales of harvested products, and other captured values via donations and subsidies. A degree of incompatibility and conflict between certain uses complicates the rhino management decision. For example, dehorning live rhinos adversely affects their aesthetics and impacts upon trophy hunting and tourism viewing values. Swanson et al. (2004) also demonstrate that trophy hunting may negatively impact upon existence value and we can postulate that rhino dehorning and farming activities may do the same. We therefore recognize different types of rhino "owners."

The use of black rhino production data in a farming simulation (Brown and Layton, 2001; Damania and Bulte, 2007) is unrealistic in important ways. Black rhinos are still considered as critically endangered and their habits and habitat requirements render them as relatively inferior candidates for commercial free-range horn production (they are mostly solitary browsers and aggressive in nature). By contrast, white rhinos are far more abundant and considered the least threatened of all rhino species. They produce larger volumes of horn and their habits and habitat requirements render them as very good candidates for free-range horn production (they

11

are sociable grazers and typically docile in free-ranging conditions). The horns of white and black rhinos appear to be regarded as near-perfect substitutes by consumers.

The most recent (2016) official estimate of South Africa's white rhino population placed it at some 19,800 animals, with approximately 6,500 under private ownership. The balance was owned by the state, i.e., the South African National Parks authority (SANParks) and nine provincial agencies.

SANParks and the provincial agencies operate mostly as financially independent entities and are entitled to retain and reinvest income earned from their operations. They earn income from tourism and live sales of surplus animals and may also receive state subsidies. Most (if not all) of these agencies would be willing to sell stocks of rhino horns collected from naturally deceased animals and, between them, hold considerable old stocks of horn. However, most are also reluctant to dehorn their live animals mainly due to concerns over public perception and a potential negative impact on tourism (tourists are assumed to prefer rhinos with intact horns). SANParks does not allow commercial trophy hunting inside its parks, nor do most of the provincial agencies.

Among the private rhino owners we find diverse objectives. Rhinos are sought for the returns they can provide from tourism, trophy hunting and resale. Some owners pursue single objectives (e.g. tourism, trophy hunting or breeding) whereas others may pursue a combination of these. The existence of a robust resale market for live animals ensures an easy passage of rhinos between different forms of use.

In recent years, some private owners more focused on breeding have also showed increasing interest in the potential horn market. As a response to the increased threat of poaching, some have also experimented with higher stocking rates and supplementary feeding, combined with regular dehorning, as a means to secure and protect their stocks while maximising rates of reproduction and horn production. Under this management regime, owners can achieve average horn yields of 0.8 kg per year (and possibly more), harvesting at intervals of between 18 and 24 months. The harvested horn is

then securely stockpiled.[1]

Despite past calls from CITES parties for governments to destroy collected stockpiles of rhino horn, agents in South Africa (and other countries such as Namibia and Zimbabwe) have instead chosen to secure and store horns collected from natural mortalities, dehorning and confiscations from poachers and illegal traders (Milledge, 2002). In South Africa, recent legislation requires that all stockpiles be registered with the government and micro-chipped. Additionally, a DNA profile database is being established, which will allow all horns to be individually identified and traced to their source. The South African stockpile was conservatively estimated at 15 tons in 2009 (Milliken et al., 2009), although it is unclear how much of this could be sold at full market value because some of it has degenerated.

According to Rachlow and Berger (1997), free-ranging white rhino population annual growth rates vary between 6–11 percent. Growth rates may be affected by stocking rates, quality of habitat, and management considerations. Higher rates may be achieved with intensive and selective management of sex ratios. The science of rhino husbandry is still developing.

According to diverse sources, the average weight of horn on a white rhino is between four and seven kilograms. Protection costs of rhinos also vary significantly. Data on protection costs in state parks and protected areas are not available as state agencies typically do not account for rhino protection separately. Data from private areas are limited, and vary with factors such as geography and stocking intensity.

Dehorning is performed by tranquilizing the animal and removing most of the horn by cutting or shaving. To avoid harm to the animals, only a portion of the horn can be removed. In contrast, a poacher can also take the stump and root of the horn. The cost of dehorning can also vary substantially, depending on whether the rhino needs to be tracked with a helicopter or not. Intensive managers in open grassland areas are able to track rhinos on foot and are able to achieve dehorning at relatively low cost

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[1]A recent well-publicized theft of stockpiled rhino horn in South Africa underscores the perils of safeguarding any amount of valuable rhino horn, whether on the live animal or after the horn has been removed.

(with the most expensive item being the sedative).

Initial proposals for a legal trading regime envisage some type of centralized stock control and certification system, which could also be used to regulate the flow of legal horn to the market. Advances in DNA technology and the stockpile registration system provide decisive steps toward such a system. This system could provide a competitive advantage to legal horn sellers as there is apparently a high level of counterfeit horn in the illegal marketplace (Nowell, 2012).

3   A Model of Rhino Ranching and Horn Trade

Bringing to bear careful institutional analysis of contemporary rhino management in South Africa, we construct a model that represents market conditions and provides guidance on the likely effects of changing policy toward a legal trading regime.

We observe the emergence of two different rhino management strategies: extensive and intensive. Extensive management is the more traditional form, with rhinos retained under natural conditions—i.e. without supplementary feeding or genetic manipulation. Extensive managers may potentially earn income from tourism viewing, live sales, trophy hunts, collections of horn from deceased animals, and by capturing indirect values through donations or subsidies. Because many extensive managers are national or provincial parks, this last pathway is particularly important. Few extensive managers allow trophy hunting on their properties, but some sell live animals to private landowners. Those live animals may then enter the trophy market, or may augment existing intensive herds. If horns are collected from naturally deceased animals, at this time that product must be stockpiled because it may not legally be sold. In general extensive managers simply husband rhinos in a largely native state. The extent of management is typically to collect revenue where possible and to try to protect rhinos from poachers. As a last resort, extensive managers may temporarily employ dehorning as a security measure, but typically would avoid this as it may negatively impact tourism, trophy hunting, and other potentially valuable aspects of rhinos.

14

The emerging form of intensive management is characterized by higher stocking rates, supplementary feeding, and routine dehorning. The rhinos are still typically free-ranging, but some breeding manipulation may take place. In this sense intensively-managed rhinos are not entirely different from other range livestock or game ranching operations. Intensive managers may still derive income from tourism, but this is likely to be at a reduced rate. Similar discounts are likely for other indirect values that an owner may be able to capture. Live sales are still a possibility, depending on the extent to which horns may have been trimmed. As additional rhino farmers wish to enter the business, live animals from intensive managers are likely to be an important source for expanding herds.

The distinction between extensive and intensive management is significant in that conservation bodies such as the IUCN would not consider the latter practice to satisfy its conservation criteria. Accordingly, a principal conservation policy objective is to maintain a minimal viable population of extensively-managed rhinos (Eiswerth and van Kooten, 2009).

A key distinction of our model is the interaction between both types of management and poachers. We assume that managers are able to invest in protection, and that such protection is able to deter poachers by increasing the costs of poaching. The extent to which additional expenditures are able to prevent poaching is fundamentally an empirical question, but Leader-Williams and Albon (1988) provide some supporting evidence. While fences and armed guards come to mind immediately, less salient expenditures such as establishment location may also be important determinants of poaching prevention.

3.1 "Ownership" and Control of Rhinos

Consider two types of rhino "owners." *Intensive managers* potentially exploit multiple service streams of rhinos: viewing, sale of live animals, and regular harvesting of horn from live animals. *Extensive managers* do not collect horn from live animals and generally keep them in a more natural state. Potential sources of revenue include trophy hunting, viewing, and

collecting horn from natural mortality.

Despite distinctions that the IUCN might make between intensive and extensive stocks, we view both as free-ranging. Therefore the aggregate stock of rhinos is the sum of the intensive and extensive owner stocks.

$$s = s^I + s^E$$

The total harvest is a bit more complex because of the possibility of poaching from either type of owner. Designating legal harvest (live sales) as h and poached animals as z, we can summarize the total harvest of rhinos.

$$h = h^I + h^E + z^I + z^E$$

We assume a constant average horn yield function,[2] so the total amount of horn available to the market is given by:

$$y = y(s^I) + y(z^I + z^E)$$

There is therefore a legal stream of horn provided by intensive managers and illegal horn derived from poached animals. Both potentially satisfy the market demand. we make no attempt to segment the market demand into legal and illegal parts.

3.2 Basic Biological Representation

Represent the stock of white rhinos at time t as s_t. Rhinos are a biological resource that grows at a rate depending on the stock level, which can be represented with a concave growth function $f(s_t)$. More biological nuance could be added to this characterization, including asymmetry (skewness),

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[2]Consider that the yield of horn from a poached rhino is likely to differ from the stream of horn an intensive manager can realize from a given stock. In fact, poached rhinos may yield different amounts of horn depending on whether or not they have been previously dehorned (and how recently). These details are important in an empirical sense but subsumed into potentially different concave horn production functions. From the point of view of the poacher's problem, we can treat the revenue function as separable in dead rhinos from different sources.

Allee effects, or gender and age ratios. For the purposes of this discussion, the existence of a concave growth function is sufficient.

Rhinos are harvested by a number of means, including trophy hunting and poaching. The harvest of rhinos in any given time period is h_t. Combining the biological growth and harvest, we have a simple population transition equation that describes the change in rhino stocks over time. This biological representation is the same for all types of rhino owners.

$$s_{t+1} = f(s_t) - h_t$$

Rhinos are valuable for multiple reasons. Some value is derived from the presence of the stock—for example, wildlife viewing or pure existence values. These values depend on the stock of rhinos, s_t, as defined above. Value is also derived from removing an animal from the population. These harvests are included in h_t defined above. Finally, a vibrant black market in rhino horn exists. Consider a constant returns to scale production function for horn as a function of the stock of animals, where we can write $y(s_t)$ as the flow of horn from a stock of size s_t. We will consider the possibility of creating a legal market for horn and examine the implications.

3.3   Poaching

A great threat to rhinos is the possibility of poaching, primarily motivated by the valuable horn. Instead of removing horn as intensive managers do, poachers kill the rhino and harvest the horn from the dead animal. Poachers are stealing owners' rhinos with their clandestine kills. It is possible that they might steal from either type of owner, depending on the amount of protection and horn that a stock of rhinos has.[3] The poacher views stocks and prices as exogenous, and simply responds to stocks, protection, and punishment in a rational way. That is, in all time periods t the poacher

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[3]Bulte (2003) identified a similar type of switching by poachers (between rhinos and elephants) as they pursue the higher-value population.

chooses from which type of owner to steal rhinos (z):

$$\max_{z^I, z^E} R(z^I, z^E) - C(s^I, \rho^I, Z^I, s^E, \rho^E, z^E)$$

This implies that poachers equate the marginal return to poaching (price in the black market) with the marginal poaching costs (including expected probability of detection and prevention) across the intensive and extensive populations. Standard assumptions apply to the poaching cost function: more enforcement makes poaching more costly at a decreasing rate ($C_\rho > 0, C_{\rho\rho} < 0$); marginal costs are positive and increasing ($C_h, C_{hh} > 0$); and a larger stock of animals reduces the cost of poaching ($C_s, C_{hs} < 0$). The role of enforcement is important in that it operates through both the probability of detection and the penalty imposed. Our view is that both of these have the same effect on the cost function. However, we prefer to think about protective expenditures increasing the probability of detection and prevention of poaching because that has a more direct effect on poaching and rhinos. If the legal process does not punish apprehended poachers and they reenter the pool of potential thieves, we are interested in increasing the probability that they will be prevented from poaching again.

This simple model yields reasonable predictions: an increased horn price will increase poaching from both types of owners. Higher protective expenditures decrease poaching, and higher stocks increase the potential for poaching. We do not consider the possible strategic behavior of criminal syndicates.

3.4 Consumer Demand

A key distinction of this model from others is in how consumers view the legal and illegal products. Previous work has assumed that the poached product is superior (Damania and Bulte, 2007). However, as we mentioned above, DNA verification of authentic horn seems likely to reassure consumers in a market known to contain counterfeits. For the purposes of this model, we assume a stationary demand for viewing and hunting opportunities such that

all owners face a competitive price for these products. Although there are effectively two goods, which may be imperfect substitutes, we allow poached horn to be a perfect substitute and specify the inverse demand function as:

$$p_{horn} = \alpha - \beta \left(z^I + z^E + y(s^I) \right)$$

The intercept term α varies with the population and income level of potential rhino horn consumers.

4 Market Simulation

4.1 Simulation Procedure

A simulation study was conducted that describes the time path for populations of intensive and extensive rhinos, poaching of both types of rhinos, the price path for horn, and the protective investments that rhino owners are able to make from profits. The protective expenditures serve to deter poaching directly in the model. The model was calibrated using data on rhino population and horn growth from contemporary intensive and extensive rhino managers in South Africa.

4.2 Simulation Results

As a baseline, consider the likely trajectory of rhinos in the absence of intensive farming. Current trends of poaching are such that the slow-growing rhino populations cannot be sustained. The result of the system is depicted in figure 2. It is important to note that our simulations indicate that white rhinos will not completely disappear. The current stewards of rhinos work hard to protect their animals, and our model indicates that their efforts are likely to be somewhat successful. However, two important caveats must be noted. The first is that the expenditures necessary to protect these remaining rhinos far outstrips the immediate returns from doing so. In order to achieve such expenditures, large influxes of funding will be required from fatiguing donors or from fiscally-challenged governments. Without these

protections, the likely trajectory of rhino stocks is one much closer to extinction. Second, even with the benefit of protection, the reduced herd sizes would be susceptible to stochastic shocks. Such shocks could come in the form of disease, extreme weather or other types of habitat encroachment, or through shocks in the horn market that precipitate increased poaching. Poaching persists at positive levels in all of our simulation models.

Contrast with this outcome the result that obtains when intensive ranching is possible. The ability to legally sell harvested horn is critical to a stable intensive rhino industry because the horn is the primary source of value. The key to this strategy is to make live rhinos more valuable than dead ones. Because horn regenerates, over the course of a lifetime a live rhino can produce some eight times as much horn as one poached animal. Under these conditions a very different future unfolds. As depicted in figure 3, the number of rhinos grows steadily over time. The price of horn reacts strongly to the initial sale of horn. As additional sales from an ever-growing stock of intensive rhinos reach the market, the horn price falls. Poaching is not eliminated, but does decline due to the influx of protective expenditures.

This outcome is due in part thanks to large protective expenditures in the short term, as figure 4 demonstrates. The number of extensively-managed rhinos falls over time, through a combination of poaching and conversion to intensive stocks. Large expenditures are required to protect these extensive rhinos, though the requirement is relaxed over time. Intensive rhinos also require a large upfront investment in protection, though that declines over time as the number of rhinos increases and the horn price declines.

These results address concerns about the total number of rhinos, price of horn, and the amount of poaching. After an initial decline as extensive stocks continue to deplete while intensive stocks build up, the total population increases dramatically. The price falls steadily once the market is established and credible, though we expect prices to remain at high levels. It is important to note that in this model demand does not shift over the time period. Poaching is not totally eliminated in any time period, but as the marginal value of an additional rhino falls, so do optimal protective expenditures. This provides an opportunity for future poachers. Depending

20

on how the horn market is designed, it may be possible to limit the potential profits to poachers by creating non-price barriers such as verification standards. Some ideas along these lines are presented in the next section.

5   Policy Implications

To date, prohibitionist international trade policy has failed to provide enduring protection for free-ranging rhino populations. Despite increased attempts at enforcement and anti-trade publicity, the rate of poaching has increased each year since 2007. Our simulations suggest that most rhino populations will remain seriously threatened if poaching continues along the current trajectory.

Without significant and increasing external sources of funding, rhino managers and custodians seem unable to afford the substantial and increasing costs of field protection. The horns are simply too valuable in relation to all the other sources of revenue from rhinos. If the market can only acquire horns by illegally killing rhinos, it seems that wild populations are mostly doomed.

Unlike many other banned products from endangered species, rhino horn can potentially be supplied without endangering the population. There are substantial (and increasing) existing accumulated (legal) stockpiles from natural mortality and dehorning of live animals. In light of this important distinction, a revision of the prohibitionist policy seems appropriate.

Our model suggests that providing legal rhino owners the opportunity of raising their own funds through horn sales—and reinvesting such proceeds into additional protection—could provide significant protection against poachers. Furthermore, if such legally harvested horn was sold at competitive market prices, the ensuing competition with illegal suppliers has the potential to reduce black market prices over time. This is especially true if one takes account of the considerable additional capacity to supply horn through regular dehorning by intensive managers. Lower black market prices for horn reduce the incentives for poaching and other illegal activity.

An additional and steadily increasing supply source also potentially mit-

21

igates the "banking on extinction" risk identified by Mason et al. (2012). Whereas under the current trade ban it makes sense for speculators to stockpile horn on the expectation of future commercial extinction, sustained legal supply largely removes the scarcity rent that attracts speculators.

However, there are a few inter-related concerns relating to potential trade legalization. If the ultimate goal is one of *in situ* conservation, i.e., protection of extensively managed rhino populations, then we must be assured that such a policy shift would indeed reduce the poaching risk to them and not only to those that are intensively managed.

Opponents of trade legalization highlight the issues raised by Fischer (2004)—the risks that a legal trade might lower the cost of illegal supply and that the demand curve might initially shift so far outwards so as to raise prices (i.e., that the market expansion effect from legalization may be greater than the substitution effect from increased supply). These two concerns are most relevant to extensive managers, especially the latter one (commercial intensive managers may welcome higher prices). To succeed in gaining the approval for international legal trade through CITES any policy proposal would need to address these concerns effectively.

Previous authors have suggested establishing some type of cartel for the purposes of re-establishing a legal trade ('t Sas-Rolfes, 1995; Abbott and van Kooten, 2011; Biggs et al., 2013). As discussed above, a stock control system that employs DNA technology along with a registration and certification system could mitigate laundering. Such a system could be linked to CITES in such a way to ensure that only sealed batches of approved horns are shipped from range states to consumer countries at specified intervals (e.g., quarterly). The system could also be designed to restrict the quantity of legal horn exported to ensure that supply levels are sustainable. However, in line with the concerns raised by Damania and Bulte (2007), we would advise against price manipulation: prices should preferably be determined in a competitive setting within consumer countries (batch auctions of commodities such as tobacco may provide an instructive model to follow).

This proposed system differs in some important respects from the system established under CITES for the 2008 one-off sale of elephant ivory. Critics

22

of the ivory sale argue that it stimulated further demand, confused the market and provided a cover for illegal sourced ivory (Rice, 2012), although this view is not universally shared by relevant experts. For example, Stiles (2013) argues that East Asian ivory demand is driven by other factors and that poaching pressure is exacerbated by the uncertainty of supply related to the one-off nature of the sale. Nonetheless, in describing the mechanics of the 2008 sale, Christy (2012) identifies an important flaw: the CITES mechanism allowed buyers to exert monopsony power. The Chinese buying agency enjoyed low purchase prices and then restricted the flow of ivory to Chinese wholesale buyers, reselling it at highly inflated prices (an alleged mark-up of 650%).

Such a result is inimical to elephant conservation: it is the opposite of the goal of receiving the highest possible selling prices for elephant custodians but lowest possible end user prices (so as not to stimulate illegal competition). We submit that the objective of a legal sale system should be to reduce the transactions costs of legal transfer from producer to end user while maintaining the highest possible transactions costs for illegal suppliers. In other words, the system should strive to confer a significant cost advantage upon the legal source suppliers.

A regular and direct international legal rhino horn supply conduit, accompanied by a certification system, would support this objective. To overcome the current risks of purchasing fake horns in consumer countries, illegal wholesale buyers are likely to seek out whole horns (which are more securely identifiable). Whole horns are typically costly to conceal and smuggle to consumer countries. Legal and certified horns would offer a superior low-risk alternative and would almost certainly be preferred by most discerning buyers. Providing ongoing and regular batches of supply (in contrast with one-off sales), such a system would also create the desired element of supply certainty in the market to reduce potentially threatening levels of speculation. To provide support for the legal system, existing deterrents for all forms of illegal activity should be maintained and all market participants should be positively encouraged to shun illegal sources.

Our simulations suggest that such a system would yield the most posi-

tive direct results for intensively managed white rhino populations in South Africa. Extensively managed populations of white rhinos would benefit to the extent that horn stockpiles from natural mortalities are sold, sale prices of live animals increase and incentives for poaching are reduced. Black rhino populations would also benefit to the extent that they share habitat with white rhinos as well as indirectly if illegal horn prices decline. Rhino populations in other African countries would also benefit somewhat less and indirectly and perhaps the least benefit would be to populations of the Asian rhino species. The only benefit to the latter would be by way of reduced horn prices.

What if horn prices increase under a legal trading regime? With a greatly increased and regular certified supply source our simulations suggest that prices will most likely decline over time, but we cannot exclude the possibility of income-driven demand shifts that result in price increases. Price increases would favor a shift to intensive management and may pose a threat to the other rhino species. To mitigate this potential problem, a contingent system of side payments linked to the price of rhino horn could be implemented to cross-subsidize protection of extensive rhinos. Such a system would amount to a tax on profits of intensive managers, and would be particularly important in the event of price increases. These amounts could then be reallocated to supplement protection expenditures for the most vulnerable rhino populations.

6 Conclusion

Poaching of rhinos in South Africa has expanded dramatically in the past several years. As various pathways for rhino horn to enter the lucrative Asian markets have been shut off, both prices and poaching have soared. Without effective policy intervention, white rhinos may once again face extinction in South Africa. This paper suggests a radical policy shift. This would entail the legalization of trade in verified rhino horn, which would require amendment to the current ban established by CITES. We simultaneously propose allowing rhino owners who regularly dehorn their animals to sell

the harvested horns in the verified horn market. This creates the incentive for such intensive managers to protect their lucrative rhino stock. Poachers harvest one horn from an animal, but an intensively-managed rhino can produce as much as eight times the volume of horn over a lifetime.

Our simulation study suggests that a legal rhino horn trading regime would increase both horn and rhino stocks while lowering horn prices. The creation of such a regime would likely require large immediate investments in rhino protection. However, we expect such expenditures to decline over time. The rents from a legal horn trade could provide funding for these needed protections. Our calibration indicates that rhinos would not become extinct without this policy, but the reduced population requires substantial protective expenditures that have no apparent source, and leaves the remaining rhino stocks susceptible to possible environmental or market shocks.

A number of possible extensions to this work deserve additional study. First, sellers in the new verified rhino horn market may attempt to act as a cartel. The goal of higher revenues may have an unintended consequence of increasing poaching pressure, especially on rhino populations outside the cartel. Second, the animal science of the intensive rhino farming sector is still developing and may offer considerable room for improvement. Third, because the only current outlets for horn are illegal, transition to a verified market is uncertain. Es-tablishing the optimal timing of legal sales deserves further consideration, especially given the large protective expenditures that we anticipate will be necessary while the market develops. A legal market would provide valuable information about underlying fundamentals. Finally, because rhino horn can be stored, strategic release of existing stockpiles creates the possibility of price effects that we do not explore here. Experience in other commodity markets suggests that a full array of future and option contracts will smooth the price path; existing stockpiles can augment the flow of legal horn from intensively-managed rhinos. These topics are important to current policy debates over the poaching epidemic.

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7 Figures and Tables

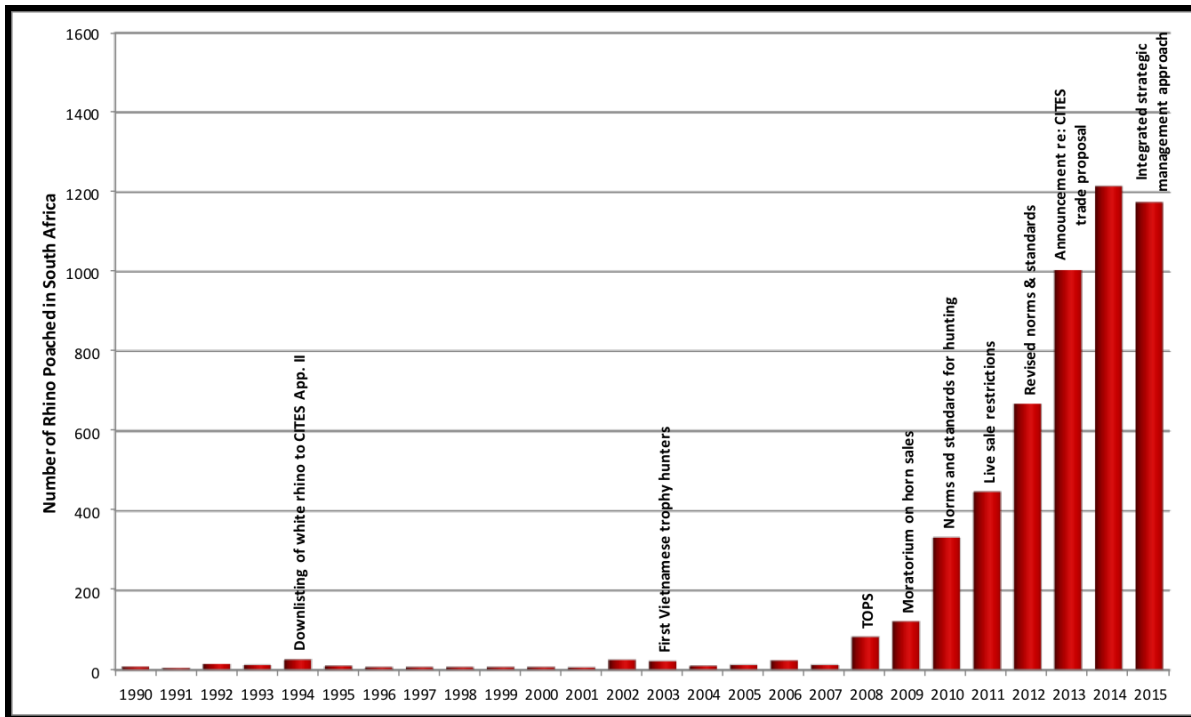Figure 1: Historical poaching levels in South Africa and related significant events

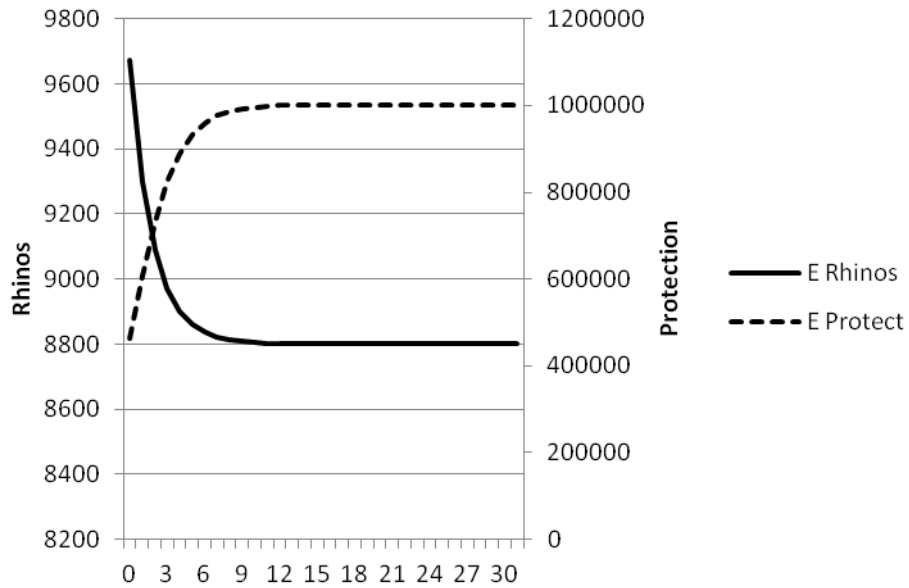Figure 2: Simulation Results: No Intensive Management or Legal Horn Trade

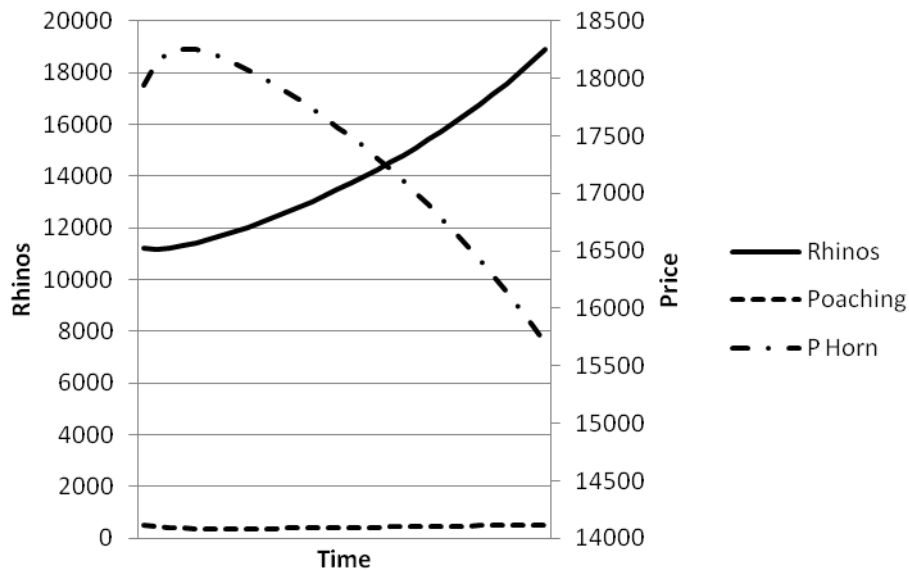Figure 3: Simulation Results: Total Rhinos and Poaching

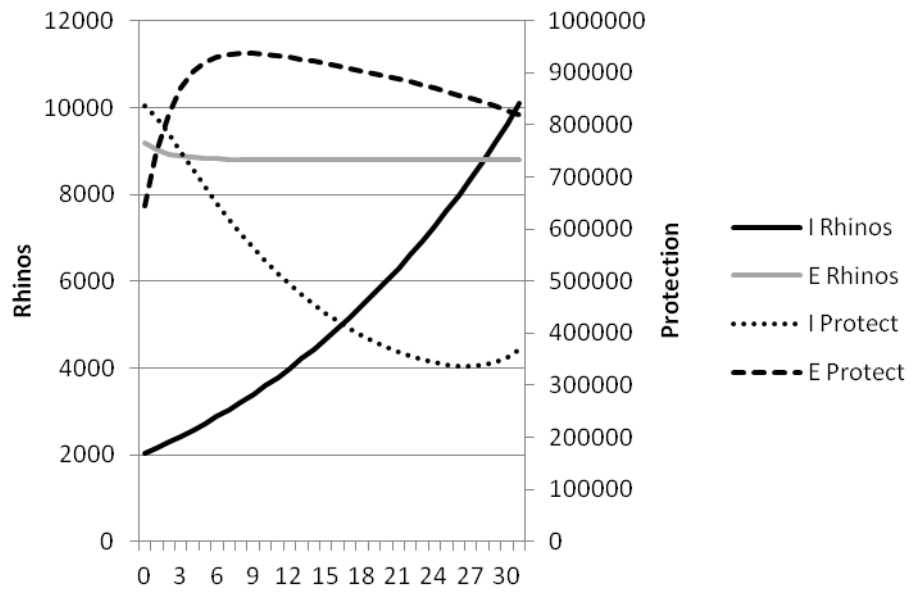Figure 4: Simulation Results: Intensive Management and Protection

Table 1: Selected past population estimates and current status of rhino species

Species	Scientific Name	Population Estimate					Current IUCN Status
		1900	1970	1981	1993	2013	
Sumatran	Dicerorhinus sumatrensi			<600	<540	<100	critically endangered, decreasing
Javan	Rhinoceros sondaicus			50	<100	50	critically endangered, unknown
Indian	Rhinoceros unicornus	<100	700	1,500	<2,025	2,600	vulnerable, increasing
Black	Diceros bicornis	<1,000,000	65,000	12,753	2,550	5,055	critically endangered, increasing
White	Ceratotherium simum cottoni		2,000	<20	<30	0	effectively extinct
	Ceratotherium simum simum	<50	1,552	<3,561	6,784	20,405	near threatened, increasing

Source: IUCN

Table 2: Past and present distribution of all rhino subspecies

Species	Scientific Name	Historic Distribution	Current Distribution
Sumatran	Dicerorhinus sumatrensis sumatrensis	Thailand, Malaysia, Indonesia	Indonesia, Malaysia?
	Dicerorhinus sumatrensis harrissoni	Indonesia, Malaysia	Malaysia, Indonesia?
	Dicerorhinus sumatrensis lasiotis	India, Bhutan, Bangladesh, Myanmar	Myanmar?
Javan	Rhinoceros sondaicus sondaicus	Indonesia	Indonesia
	Rhinoceros sondaicus annamiticus	Vietnam, Cambodia, Laos, Thailand, Malaysia	EXTINCT
	Rhinoceros sondaicus inermis	India, Bangladesh, Myanmar	EXTINCT
Indian	Rhinoceros unicornus	India, Nepal, Pakistan, Bangladesh, Bhutan, Myanmar, China	India, Nepal
Black	Diceros bicornis michaeli	Sudan, Ethiopia, Somalia, Kenya, Tanzania, Rwanda	Kenya, Tanzania
	Diceros bicornis longipes	Cameroon, Chad	EXTINCT
	Diceros bicornis minor	Tanzania, Zambia, Zimbabwe, Mozambique, South Africa, Dem. Rep. Congo, Angola, Botswana, Malawi, Swaziland	South Africa, Zimbabwe, Tanzania, Botswana, Malawi, Swaziland, Zambia, Mozambique
	Diceros bicornis bicornis	Namibia, Angola, Botswana, South Africa	Namibia, South Africa
White	Ceratotherium simum cottoni	Uganda, Chad, Sudan, Cent. Afr. Rep., Dem. Rep. Congo	EXTINCT
	Ceratotherium simum simum	Botswana, Namibia, South Africa, Swaziland, Mozambique, Zimbabwe	South Africa, Namibia, Botswana, Zimbabwe, Swaziland, Zambia*, Kenya*, Uganda*

Note: * indicates non-native (introduced) population.