
Conservation Implications of Patterns of Horn Regeneration in Dehorned White Rhinos

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Abstract: *The demand for rhino horn has led to drastic declines in numbers of rhinos in Asia and Africa. Although all trade in rhino products has been illegal since the mid-1970s, a lucrative illegal market flourishes and poaching continues. Horn removal from African rhinos has been conducted in Zimbabwe, Namibia, and Swaziland to deter poaching. Regeneration of horns following dehorning has created the potential for a sustainable harvest of rhino horn through dehorning programs. Establishment of a regulated legal market for rhino horn has been suggested to help fund rhino conservation programs in African countries. However, evaluation of an economic harvest of rhino horn from dehorning programs has been limited because few data on rates and form of horn regeneration exist. Because rate of horn regeneration will determine the interval at which rhino horns could be harvested profitably, we measured horn regrowth for two white rhino (*Ceratotherium simum*) populations studied in Zimbabwe between 1991–1995. Measurements of horn sizes were collected before and after dehorning, and mass to volume relationships were calculated. Von Bertalanffy growth curves were used to model horn size and rates of horn regrowth relative to age. Adult males had larger horn bases ($p < 0.001$) and faster rates of horn regrowth than adult females. Regenerated horn mass for adult males (>1.3 kg/yr) was almost twice the mass of adult females. Based on an economic model for profit maximization, intervals for dehorning range from 1.16 to 1.51 years and vary with both sex and age. We suggest managers use these values as minimum dehorning intervals to balance profits with longer-term management goals. Rates of horn regeneration are likely to be less important than law enforcement in determining the efficacy of dehorning as a deterrent to rhino poaching.*

Implicaciones Conservacionistas de los Patrones de Regeneración de Cuernos en Rinocerontes Descornados

Resumen: *La demanda de cuernos de rinoceronte ha llevado a declinaciones drásticas en el número de rinocerontes en Asia y África. A pesar de que el comercio con productos de rinoceronte es ilegal desde mediados de los 70 un lucrativo mercado florece y la caza furtiva continua. La remoción de cuernos de rinocerontes africanos se ha llevado a cabo en Zimbabwe, Namibia y Swazilandia para detener la cacería furtiva. La regeneración de cuernos ha creado el potencial para la utilización sustentable de cuernos de rinoceronte a través de programas de descornamiento. Se ha propuesto el establecimiento de un mercado regulado legal de cuernos de rinoceronte para ayudar al financiamiento de programas de conservación de rinoceronte en varios países africanos. Sin embargo, la evaluación económica de la cosecha de cuernos de rinoceronte en programas de descornamiento es limitada porque existen pocos datos sobre la tasa y forma de la regeneración de cuernos. Debido a que la regeneración de cuernos determina el intervalo en el que se pueden cosechar cuernos rinoceronte rentablemente, medimos la regeneración de cuernos en dos poblaciones de rinoceronte blanco (*Ceratotherium simum*) en Zimbabwe estudiadas entre 1991 y 1995. Se realizaron mediciones del tamaño de cuernos antes y después de descornamiento y se calculó la relación masa a volumen. Se emplearon curvas de crecimiento de Von Bertalanffy para modelar el tamaño del cuerno y las tasas de crecimiento en relación con la edad. Los machos adultos tuvieron bases de cuerno mayores ($p < 0.001$) y tasas de crecimiento más altas que las de hembras adultas. La masa de cuernos regenerados en machos adultos (>1.3 kg/año) fue*

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casi el doble que la de hembras adultas. Con base en un modelo económico para maximización de ganancias, los intervalos para descornar varían entre 1.16 y 1.51 años y varían tanto con el sexo y la edad. Proponemos que se empleen estos valores como intervalos mínimos de descornamiento para equilibrar ganancias con metas de manejo a largo plazo. Para determinar la eficacia del descornamiento sobre la caza furtiva del rinoceronte, las tasas de regeneración de cuernos probablemente tienen menor importancia que la aplicación de leyes.

Introduction

The demand for rhino horn has pushed rhino populations in Asia and now in Africa into precipitous declines (Cumming et al. 1990; Leader-Williams 1992; Western & Vigne 1985). Although all trade in rhino products is banned under CITES, illegal trade in rhino horn continues today supporting aggressive poaching syndicates and a lucrative black market (Nowell et al. 1992).

Traditional conservation efforts for African rhinos have focused on military-style anti-poaching protection (Cumming et al. 1990). Such programs are costly, especially in areas with low densities of rhinos (Leader-Williams & Albon 1988; Martin 1993). Rarely have sufficient funds been available to support anti-poaching work in African nations; in the absence of adequate resources and field staff, poachers have rapidly decimated rhino populations (Borner 1981; Hillman-Smith 1990; Leader-Williams & Albon 1988; Milliken et al. 1993).

Since the ban on international sale of rhino products was mandated nearly 20 years ago, over 95% of Africa's black rhinos (*Diceros bicornis*) have been killed (Milliken et al. 1993; Western & Vigne 1985). Critics of the trade ban have argued for regulated, legal sale of rhino horns. Horn removal from live rhinos has recently added to the stockpiles of horn held by African governments. Further, the potential for a sustainable harvest of rhino horn has been proposed to help support under-funded rhino conservation in developing nations (Kock & Atkinson 1993; Milliken et al. 1993; Sas-Rolfes 1990).

Empirical data about rates and form of horn regrowth following dehorning are needed to evaluate the efficacy of this strategy. Growth rates for intact anterior horns of black and white rhinos (*Ceratotherium simum*) were documented when transmitters were imbedded into the horns (Pienaar et al. 1991). Regrowth for dehorned black rhinos has been measured at 6.0 cm/year and 2.7 cm/year for the anterior and posterior horns, respectively (Berger et al. 1993). Comparable data for white rhinos are lacking. Although Berger et al. (1993) observed that the horns of juvenile black rhinos regrew more rapidly, the relationships between horn growth, regrowth, sex, and age are not well understood for either of the African species.

Data about horn regrowth are relevant to rhino conservation for two principal reasons. First, the efficacy of

horn removal as a deterrent to poaching has been questioned, largely because horns regrow and thus, rhinos regain their value to poachers (Berger 1993; Milner-Gulland et al. 1993). Secondly, establishment of a legal market for rhino horn continues to be debated (Leader-Williams 1992; Nowell et al. 1992; Milliken et al. 1993). Dehorning of managed populations could provide a renewable supply of horn if the ban is lifted. However, data regarding horn regeneration must first be available and then evaluated to assess the feasibility of maintaining a sustainable yield through dehorning programs. Our goal here is to present information regarding horn regeneration following dehorning of white rhinos as it relates to the latter of these conservation issues.

Background, Study Areas, and Methods

Two dehorned populations of white rhinos were studied in Zimbabwe during July 1991-January 1995. Field work was conducted in Hwange National Park (HNP) from July 1991 to September 1993. The HNP is a 14,600 km² area in northwestern Zimbabwe on the eastern edge of the Kalahari sands (Jones 1989). Over 90 individuals were identified in HNP during this study. Matobo National Park (MNP) is located in southwestern Zimbabwe and encompasses over 425 km² of the Matobo Hills, characterized by rugged, granitic domes and kopjes (Wilson 1969). A total of 55 individual white rhinos was identified in MNP during 1994 (Rachlow & Gumede 1994).

Dehorning

Rhino horns appear solid and consist of densely-packed microscopic protein fibers (Ryder 1962). Growth occurs from a layer of vascular germinal tissue covering the nasal bones at the base of the horns (Bigalke 1945; Kock 1991). Seventy-one white rhinos were immobilized in HNP during May-November 1991, of which 59 were dehorned. Twelve calves were immobilized and ear-notched, but not dehorned. An additional 18 rhinos were immobilized in HNP in July-August 1992, of which 13 were dehorned. Thirty white rhinos were dehorned in MNP during October 1992, and an additional six sub-adults were dehorned during 1994. A chainsaw was used to cut off both horns just above the vascular tissue

and to trim the remaining horn stubs as closely as possible. All rhinos in both parks were ear-notched during the first immobilization for individual identification.

We used several methods to age rhinos. Ages were known or estimated: (1) from previous monitoring work at MNP (Rachlow & Gumede 1994); (2) for calves in HNP based on body size in relation to adult females (Owen-Smith 1973); and (3) from tooth wear patterns following death and collection of skulls (Hillman-Smith et al. 1986). All other rhinos ($n = 64$) were placed into two broad age categories: subadults (2.5–4.5 years) and adults (>4.5 years): based on body and horn sizes.

Horn Measurements

Horns were measured on immobilized rhinos prior to dehorning. Basal circumference was measured for each horn along the horn-skin interface. Measurements were recorded to the nearest 0.5 cm.

Rates of horn regrowth were calculated by comparing linear horn lengths (recorded from the mid-point of a lateral surface of the horn at the horn-skin interface to the tip of the horn) on the date of dehorning with actual measurements 0.8–2.2 years later. Linear lengths of regrown horn stubs were measured on 21 adults immobilized in HNP in July–August 1992 and on 14 adults immobilized for radio-collaring in MNP during 1994. Regrowth was estimated on an additional 18 rhinos in

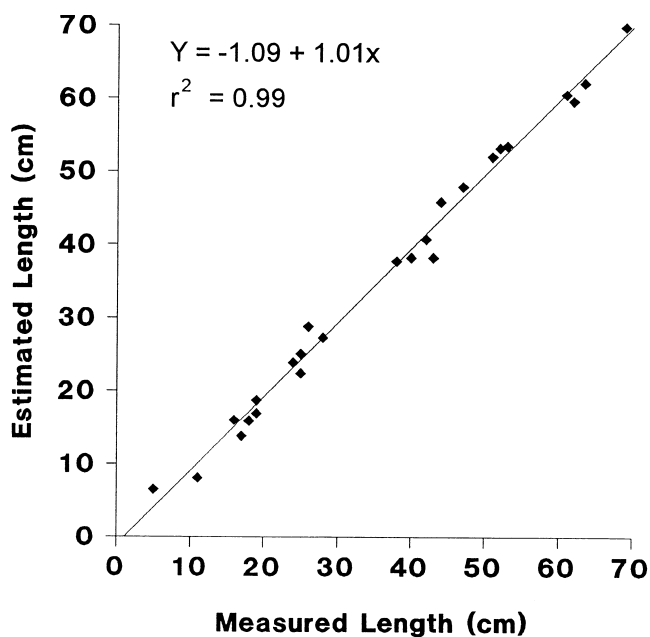


Figure 1. Regression of estimated horn lengths obtained using the photocalibration method on measured horn size. Estimates of horn lengths were corrected based on this regression (actual size = $-1.09 + 1.01 \times$ estimated size; $r^2 = 0.99$).

MNP using a photogrammetric device mounted on a 300 mm telephoto camera lens (Berger & Cunningham 1994). This device measures the distance between the camera and the animal accurately, resulting in a reliable method for scaling an object's size from photographs. Figure 1 shows the estimates of horn length from photographs of 25 horns compared with actual sizes determined using a tape measure ($y = -1.09 + 1.01x$; $r^2 = .99$). A correction factor was developed to refine the estimates of horn size (estimated size = $1.08 \text{ cm} + 0.99 \times$ photo-estimated size). The corrected horn length estimates were used to calculate linear rates of horn regrowth for rhinos that we did not immobilize again after dehorning.

Density of horns was determined from 49 white rhino horns by water displacement and calculation of mass/volume per horn. Horn density was used subsequently to calculate mass of horn regenerated following dehorning.

Data Analyses

Basal circumferences of all adult males and females were compared using two-tailed, two-sample *t*-tests (Zar 1984). Mean values are reported ± 1 SE. Because growth of mammals tends to be asymptotic, a sigmoid growth function, the von Bertalanffy growth curve, was used to model basal circumference as a function of age for each sex (Kaufmann 1981; Leberg et al. 1989). We modified an equation for exponential decay in an analogous fashion to the von Bertalanffy growth equation to fit the relationship between rate of horn regrowth and age. Nonlinear least squares estimation was used to fit the von Bertalanffy curves (Wilkinson 1990). The function for age-specific rate of horn regrowth was combined with that for age-specific basal circumference to estimate the volume of horn regenerated annually for each sex. The mean density of horn was incorporated into this equation to determine age-specific mass of horn regenerated annually.

Results

Horn Sizes and Density

Horn basal circumferences of adult males were significantly larger than those of adult females for anterior horns ($\bar{x} = 70.2 \pm 1.58$ cm for males; $\bar{x} = 60.9 \pm 0.90$ cm for females; $t = -5.365$; $df = 86$; $p < 0.001$) and posterior horns ($\bar{x} = 58.2 \pm 1.87$ cm for males; $\bar{x} = 49.3 \pm 0.95$ cm for females; $t = -4.452$; $df = 82$; $p < 0.001$). As with horn length, basal circumference increased rapidly with age for both sexes approaching an asymptote around 20+ and 15+ years for the anterior and posterior horns, respectively (Fig. 2; Appendix 1).

Mean density for all horns measured ($n = 49$) was 1.30 g/cm^2 (± 0.026). No significant difference was de-

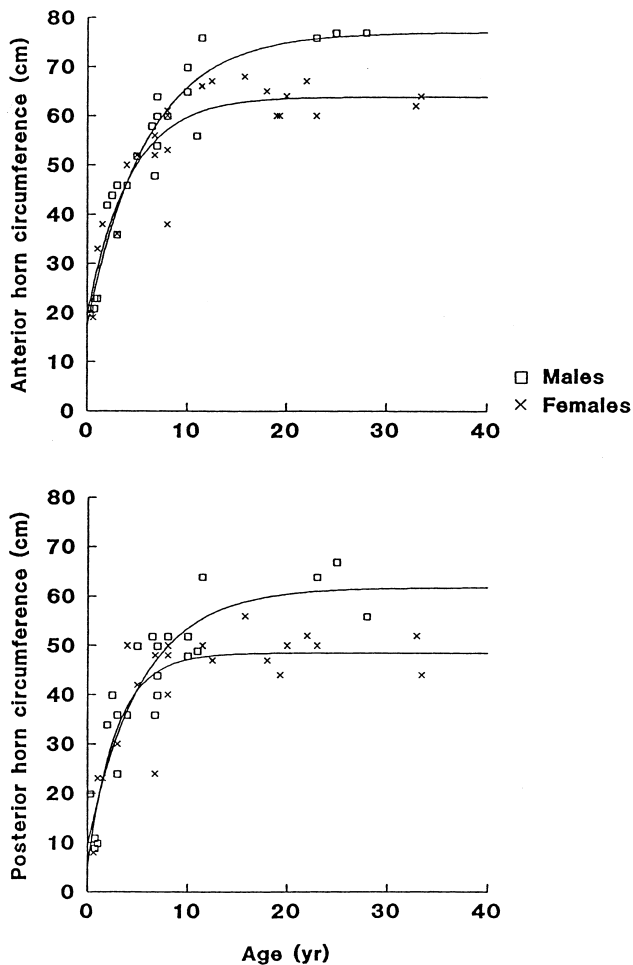


Figure 2. Measurements of the basal circumferences of horns of white rhinos fitted with the von Bertalanffy growth curves $Y = a-b \cdot \exp(-c \cdot \text{age})$ for the anterior horns and the posterior horns of males and females. Fitted values are given in Appendix 1.

tected between the horns of males ($n = 20$) and females ($n = 29$) ($\bar{x} = 1.32 \pm 0.03 \text{ g/cm}^2$ for males; $\bar{x} = 1.29 \pm 0.04 \text{ g/cm}^2$ for females; $t = -0.571$; $df = 47$; $p = 0.571$). However, density of anterior horns ($\bar{x} = 1.36 \pm 0.12 \text{ g/cm}^2$) was significantly greater than the density of posterior horns ($\bar{x} = 1.20 \pm 0.22 \text{ g/cm}^2$) ($t = 3.392$; $df = 47$; $p < 0.001$).

Horn Regrowth

Linear rates of horn regrowth after dehorning decreased with age in both sexes for the first 10 years, after which rate of regrowth appears to approach an asymptote (Fig. 3). Males had faster rates of regrowth than females for the anterior horns, and slightly faster regrowth for the posterior horns, but only two older males were sampled.

Because rhino horns are roughly conical in form (Fig.

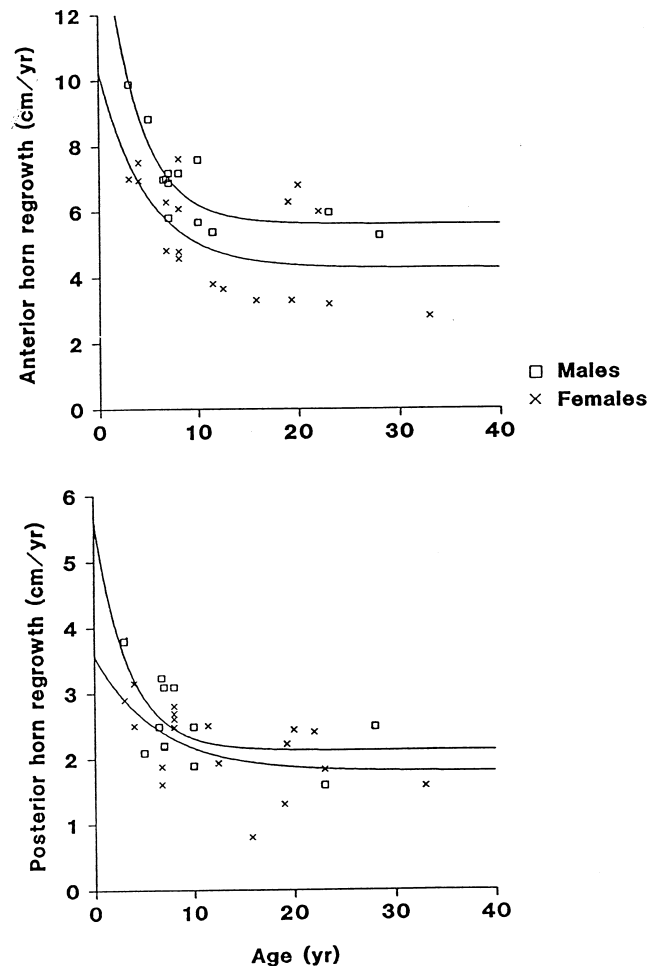


Figure 3. Rates of horn regrowth after dehorning for white rhinos fitted with von Bertalanffy-like modified equations for exponential decay $Y = a + b \cdot \exp(-c \cdot \text{age})$ for the anterior horns and the posterior horns of males and females. Fitted values are given in Appendix 1.

4), we calculated mass of horn regenerated annually after dehorning using the equation for the volume of a cone (Pienaar & Hall-Martin 1993) (Appendix 1). We combined the von Bertalanffy growth curves for basal circumferences (Fig. 2) and the age-specific regrowth rates (Fig. 3) with mean horn density (anterior or posterior) for each sex independently. Females reach a peak in horn regeneration at 8 years of age, whereas mass of horn regenerated by males approaches an asymptote slowly at over 30 years of age (Fig. 5). The shapes of the functions of horn regeneration differ between the sexes because basal circumference approaches an asymptote at a later age for males than for females (Fig. 2). For much of their adult life span, males regenerate horn material at almost twice the rate of females (Fig. 5). This method for estimation of regenerated horn mass appears accurate because estimated horn mass was highly correlated with

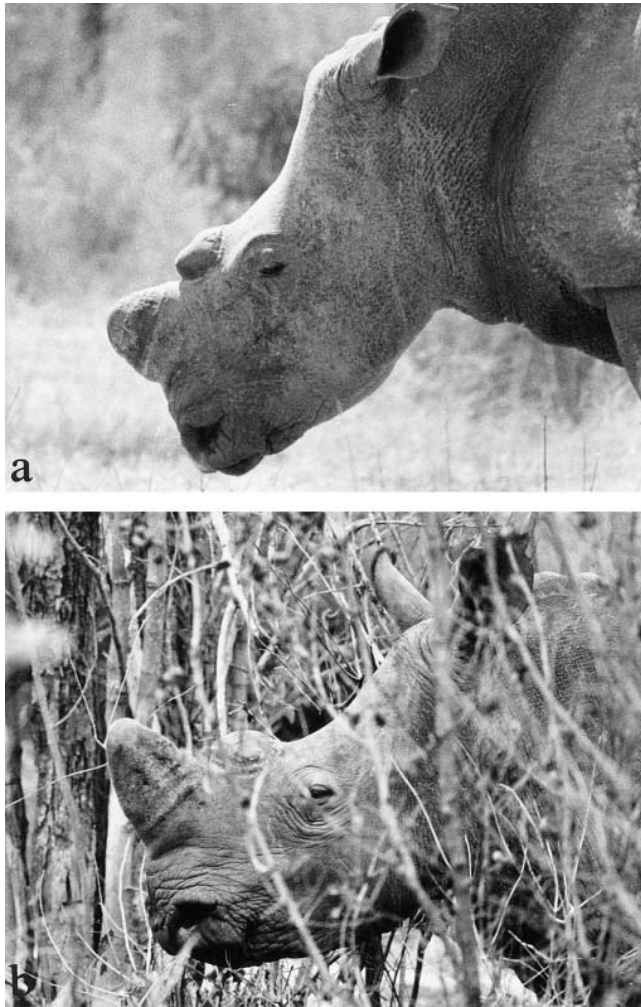


Figure 4. Horn regrowth in white rhinos two years after dehorning: 35-year-old female (a) and 7-year-old male (b).

actual measures of horn mass from 11 regrown horns collected from rhinos that died 0.8 - 2.0 years after dehorning (pairwise Pearson correlation coefficient $r = 0.976$; $p < 0.001$).

Discussion

Although data exist on horn size and regrowth after dehorning for black rhinos (Berger et al. 1993), for white rhinos there are none. Understanding patterns of horn growth and regrowth can be important in three principal ways. First, because legalization of the horn trade has been suggested as a possible way to generate revenue for conservation programs in southern Africa (Kock & Atkinson 1993; Milliken et al. 1993), it is necessary to predict how much horn might be harvestable. Second, because both sex and age affect horn size and mass, it is essential to know something about inherent variation

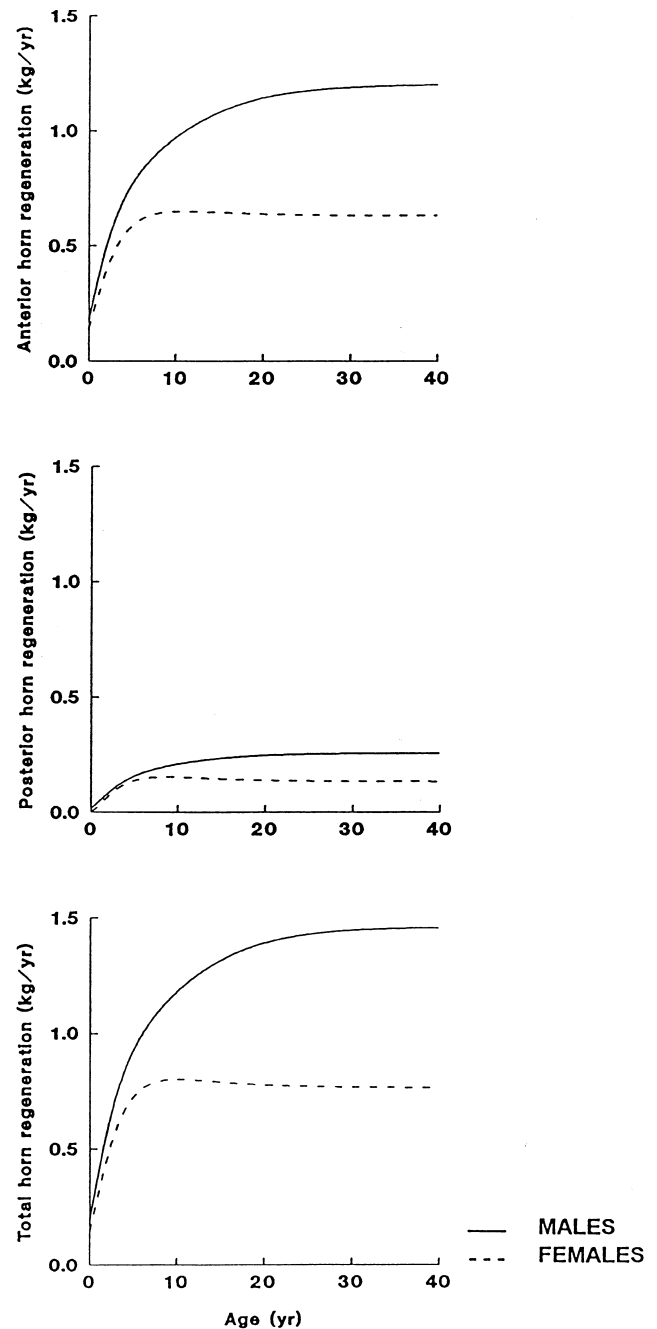


Figure 5. Annual rate of horn regeneration relative to sex and age of white rhinos for anterior horns, posterior horns, and total of both horns.

and distribution of horn sizes within a population. Third, models that have examined the economics of dehorning and rhino protection have been forced to rely on assumptions about the constancy of growth patterns that we are now able to refine.

With respect to growth, horns proliferate throughout an individual's lifespan. However, wear at the tips of the horns may result in static or even decreasing horn lengths in older animals (Pienaar et al. 1991), although

we observed little wear on the dorsal or lateral surfaces of regrown horn stubs, even two years after dehorning. Indeed, rates of regrowth after horn removal are similar to intrinsic rates of horn growth (the actual rate at which horns are produced) reported for white rhinos in South Africa (Pienaar et al. 1991). Regrowth rates for dehorned black rhinos also approximate those reported for intact horns in that species (Berger et al. 1993; Pienaar et al. 1991).

Both age and sex influenced horn regrowth in dehorned white rhinos. Linear rates of regrowth decreased with age in both sexes, but the horns of males regrew more rapidly (Fig. 3). Mean rates of horn regrowth for adult black rhinos in Namibia were 6.0 cm/year and 2.7 cm/year for the anterior and posterior horns, and regrowth was more rapid for the horns of juveniles (8.9 and 4.4 cm/year) (Berger et al. 1993). Thus, in both species of African rhinos, rates of horn regrowth appear to decrease with age, but the effect of sex has not been examined in black rhinos.

Mass of horn regenerated annually depends on the basal circumference and linear rate of horn regrowth. Because both of these attributes are strongly influenced by age in white rhinos, it is not surprising that marked differences occur in mass of horn regenerated relative to age. Likewise, white rhinos exhibit sexual dimorphism in horn size and regrowth, and consequently large sexual differences exist in the rate of horn regeneration (Fig. 4). Adult males produce almost twice the mass of horn annually as adult females of similar ages (Fig. 5c).

Mass of rhino horns is the key factor in determining their value because sale for medicinal consumption ultimately is priced per unit mass (Nowell et al. 1992). Rate of horn regeneration following dehorning is central to the issue of whether a sustainable harvest would be feasible if a legal market for rhino horn were established. Prices reported for retail sale of African rhino horns have ranged from \$3250/kg to over \$10,000/kg (Miliken et al. 1993). However, a price of \$2000/kg has been noted for wholesale of horns by African governments if trade were legalized (Milner-Gulland et al. 1993). At this price, male white rhinos over 20 years old will regenerate, on average, over \$2600 of horn annually.

Regeneration rates will influence the frequency of horn trimming necessary for a profitable yield. Milner-Gulland et al. (1992, 1993) adapted a forestry model for optimal harvest to suggest dehorning intervals for rhinos. This model considers two variables that influence the rotation time for harvest: (1) the cost-price ratio, which is the ratio between the cost of dehorning a rhino and the profit received from sale of the horns; and (2) the discount rate, which is the rate at which the potential for future profits decrease. Milner-Gulland et al. (1992) suggest that their model is insensitive to variation in the discount rate, and that a conservation agency with a strong interest in future yields may experience a very

low discount rate. Thus, setting the discount rate equal to zero, the model can be simplified to

$$V'(T)/(V(T) - c), \quad (1)$$

where T is the optimal rotation time with respect to profit maximization, $V(T)$ is the value of the horn at time t , and c is the cost of dehorning (Milner-Gulland et al. 1992).

The costs of dehorning rhinos varies with population density and methods used to locate individuals. In Zimbabwe the costs have ranged from \$350–\$1800 per rhino (Kock & Atkinson 1993). The higher values occurred in low-density populations that had experienced severe levels of poaching. Most rhinos surviving in Zimbabwe currently are managed within rhino sanctuaries or reserves. If horn harvesting in managed populations were to occur, values at the lower end of this cost spectrum would be more realistic assuming that encounter rates do not change when individuals are dehorned at different intervals. Thus, using an average cost of \$400 per rhino and the suggested wholesale price of \$2000/kg for legal sale of rhino horn, a realistic cost-price ratio would be 0.2.

What predictions about horn harvesting follow from the economic model given our data on horn regeneration? Because rates of horn regeneration vary with sex and age, optimal frequency of dehorning for profit maximization also will vary among individuals according to these parameters. Optimal dehorning intervals for both sexes decrease throughout their lives, however, the change is very slow, especially for older individuals. For example, optimal intervals for males are 1.38 years at 3 years of age and 1.16 years at 30 years of age. Because females regenerate less horn mass annually than males, optimal intervals for dehorning females always will be slightly longer than for males. Calculated optima are 1.51 years and 1.40 years for 3- and 30-year-old females, respectively. In reality this level of precision in predicting optima is largely academic because other factors such as availability of funding, equipment, personnel, and seasonal rainfall patterns are likely to influence the exact intervals at which dehorning could be accomplished.

Dehorning intervals calculated using this model are optimal only with respect to profit maximization. However, managers may consider other "costs" of dehorning, of which there may be many. Although mortality rates associated with dehorning both black and white rhinos in Zimbabwe have been very low (0% to 3%) (Kock & Atkinson 1993), the risk of mortality exists each time an animal is immobilized. Additionally, it is unclear whether frequent immobilization of animals with narcotic drugs might have long term effects. Finally, managers may wish to avoid disturbance of females with young calves and to adjust dehorning schedules for females accordingly. Thus, we suggest that dehorning intervals that maximize profits should be considered

minimum intervals with respect to other population management objectives.

A second application of the economic model for horn harvesting has been to examine the effectiveness of dehorning in deterring rhino poachers (Milner-Gulland et al. 1992, 1993). Theoretically, rhino poaching should cease when the costs relative to the rewards become too great to provide incentives for poachers. However, this economic equation may not apply precisely to rhino poaching in Africa. Monetary rewards received by most poachers are an insignificant proportion of the potential value of the horns they have collected and are only loosely related to horn size or mass (Milliken et al. 1993). A second challenge in applying a strict cost-price model to a poacher's decision to kill dehorned rhinos is that the cost of poaching is difficult to define in monetary terms. The Zimbabwean authorities maintain a shoot-to-kill policy for armed poachers in national parks (Martin 1993), and the real cost of poaching to the hunters is the risk of death or imprisonment (Milner-Gulland & Leader-Williams 1992). It is only at the level of African-based middlemen that the cost-price ratios become important (Milliken et al. 1993). Thus, there may be only an indirect relationship between the cost of poaching and the size or mass of horns obtained.

The cost or risk of being caught poaching is likely related to amount of monies allocated for anti-poaching activities. Where funds for law enforcement have been low, rhino populations have declined (Hillman-Smith 1990; Leader-Williams & Albon 1988). A dehorned population of white rhinos in Hwange National Park, Zimbabwe, experienced high levels of poaching after law enforcement in the national parks was sharply curtailed due to a lack of funding for anti-poaching work. Such factors as this funding crisis are likely to have an overriding impact on the success or failure of dehorning programs in deterring poaching. In reality, data on horn regeneration after dehorning are likely to be more useful in decision making about dehorning intervals for horn harvest rather than for predicting poacher behavior.

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Appendix 1

Equations and fitted values for horn circumferences and rates of regrowth as a function of age for males and females.

Formula for the von Bertalanffy growth curves used to model basal circumference with age: $Y = a - b \cdot \exp(-c \cdot \text{age})$.

Fitted values:

Horn Circumferences

Males:	anterior:	a = 77.009;	b = 59.356;	c = 0.166
	posterior:	a = 61.749;	b = 52.120;	c = 0.184
Females:	anterior:	a = 63.844;	b = 44.222;	c = 0.238
	posterior:	a = 48.502;	b = 43.172;	c = 0.345

Formula for the von Bertalanffy-like modification of exponential decay used to model decreasing rate of horn regrowth with age: $Y = a + b \cdot \exp(-c \cdot \text{age})$.

Fitted values:

Rates of Regrowth

Males:	anterior:	a = 5.616;	b = 10.418;	c = 0.286
	posterior:	a = 2.123;	b = 3.489;	c = 0.294
Females:	anterior:	a = 4.281;	b = 5.979;	c = 0.206
	posterior:	a = 1.792;	b = 1.767;	c = 0.156

Equation for mass of regrown horns using the equation for volume of a cone:

$\text{mass} = \text{volume} \times \text{density}$ where volume = $1/3$ (basal area \times height); basal area = $\pi \times r^2$, r = horn basal circumference (cm)/2 $\times \pi$; and height = linear horn length (cm).

