Quantifying rates of horn regrowth of Southern white (*Ceratotherium simum simum*) and South-eastern black (*Diceros bicornis minor*) rhinoceros in Selati Game Reserve

By Isabella Cutts – 30059065

Supervised by Dr Anthony Caravaggi and Dr Emma Higgins

A Dissertation

Submitted to Faculty of Computing, Engineering and Science

University of South Wales

In Fulfilment of the Requirements

For BSc (Hons) International Wildlife Biology

Word Count; 9,738

Acknowledgements

This dissertation is dedicated to all the rhinos fighting against the odds for survival.

I want to express my deepest gratitude to my incredible supervisors, Anthony Caravaggi and Emma Higgins. Your unwavering support throughout this journey has been instrumental, and you have been the pillars of my university experience. Over these past three years, I have grown so much, and I can hardly convey how thankful I am to you both, as well as to all the other lecturers who have guided me along the way.

To the remarkable team at Selati Game Reserve (Madeline Siegel, Steven Seager, Matthias Niederer, Santenay Ayers), it has been a true honour to collaborate with you and gain your trust while working with your beautiful rhinos. My first visit to Selati was a transformative moment, revealing my passion for what I want to pursue for the rest of my life.

Mum and Dad, I strive to make you proud, and I love you both very much. Granny and Pompa, your presence in my life means so much to me, I don't know what I'd do without you both. Josh, you have been my best friend my whole life, and I can't envision any journey without. Ellie, travelling to Africa with you twice was an unforgettable experience, and despite the smell, I wouldn't trade those memories for anything. To my North Walians, I love you all. I'm forever grateful for this dissertation in multiple ways, one of which was meeting Sante. Though we've known each other for only a few of months, you have made this year immeasurably better with our walks, pub outings, and shared moments over wine and takeout, I honestly don't believe I would have completed this dissertation without you.

Lastly, thank you to 22. The moment I saw you, my life was transformed. I have faced doubts about my abilities as a conservationist—both mentally and physically—over the years, but your presence ignited a fire within me. I realised then that nothing would deter me, as anyone who knows me can attest to my stubbornness, from doing everything in my power to ensure that you and all other rhinos have a future for many generations to come.

"*No body knows nothing about anything - but we try*" - Emma Higgins

Contents

Figure Content Page

Table Content Page

Abstract

This study investigates the factors influencing the regrowth rates of rhinoceros horns in the Southern white rhinoceros (*Ceratotherium simum simum*) and the South-eastern black rhinoceros (*Diceros bicornis minor*) within the Selati Game Reserve, South Africa. Horn regrowth is vital for the success of dehorning as a conservation strategy aimed at deterring poaching. The research analysed horn growth in relation to various factors, including sex, age, number of dehorning procedures, days between dehorning events, and reproductive status. The key findings indicate that horn regrowth rates are affected by a combination of these factors. Both species of rhinoceros exhibited a consistent baseline horn regrowth rate of 0.02 cm per day. Males had larger horns, measuring 24.12 cm ± 11.28 for white rhinos and 20.81 cm ± 10.72 for black rhinos. They also had a slightly higher dehorning frequency compared to females, with white rhinos averaging 2 ± 1.01 procedures and black rhinos 2.06 ± 1.06, while females had horn lengths of 20.80 cm ± 10.06 for white rhinos and 16.74 cm ± 8.38 for black rhinos, along with dehorning frequencies of 1.83 ± 0.91 and 1.82 ± 0.95, respectively. Age was a significant factor influencing regrowth, as younger rhinos demonstrated faster regrowth rates. For both species, those in age class C had a regrowth rate of 0.03 ± 0.01, while older rhinos (in age class F) showed significantly slower rates at 0.02 ± 0.01. Repeated dehorning events also impacted regrowth; white rhinos exhibited a decrease in regrowth rates, dropping from 0.03 cm/day after one or three dehornings to 0.02 cm/day across all procedures. In contrast, black rhinos showed a potential compensatory mechanism after multiple dehornings, with their regrowth rate increasing to 0.04 cm/day following the fourth dehorning. Reproductive status influenced horn regrowth as well, with lactating and pregnant white rhinos displaying reduced regrowth rates compared to non-pregnant rhinos. For example, rhinos with a calf at foot exhibited significantly lower equivalent daily horn growth (EDHG) than non-pregnant rhinos.

This research offers crucial insights that can significantly enhance management practices at Selati Game Reserve. By providing a deeper understanding of rhinoceros behaviours, it paves the way for the formulation of targeted and effective conservation strategies to safeguard these important species for future generations.

Introduction

1. 1 *Ceratotherium simum ssp. simum* and *Diceros bicornis ssp. minor*

White rhinoceros, *Ceratotherium simum* (*C. simum*) are the biggest and most numerous of all five extant rhino species. They have an estimated population of approximately 17,019 individuals, inhabiting 11 African countries (IUCN Species Survival Commission., 2022). The total annual number of *C. simum* deaths has been declining since it peaked in 2015, but the rhino horn trade remains the biggest threat to the *C. simum* species (Ferreira *et al*., 2015) (see Figure 1). Although this is still the case, the International Union for the Conservation of Nature (IUCN) Species Survival Commission's African Rhino Specialist Group (AfRSG) whose mission is to "promote the development and long-term maintenance of viable populations of the various sub-species of African rhinos in the wild" (IUCN., 2024) announced *C. simum* has seen a 3.4% population increase for the first time in over a decade resulting in an estimated population of 17.464 as of 2023 (CITES CoP19., 2022). *C. simum* has two recognised subspecies of white rhinos: the northern white rhino (*C. s. cottoni*) and the southern white rhino (*C. s. simum*) (Ryder *et al*, 2020). *C. s. cottoni* is now functionally extinct as the population consists of two females (mother and daughter) (Videmšek and Videmšek., 2023). Meanwhile, *C. s. simum* has undergone a resurgence, climbing from a low population of 2,100 in the early 1970s ('t Sas-Rolfes *et al*., 2022) to over 21,320 by the end of 2012 (Emslie., 2020a). Their growing numbers from 2012 made them a prime target for poachers, individuals who partake in the illegal trade of rhino horn (Figure 1). This led to a decline in their population, with *C. s. simum* experiencing a 24% decrease, resulting in an estimated count of 15,942 by the end of 2021. (CITES CoP19., 2022)

The black rhino, *Diceros bicornis* (*D. bicornis*), has an estimated population of 6,421 individuals distributed across 12 different African countries (Balfour *et al*., 2024). *D. bicornis* is currently the second most numerous rhino species; it was once the most prevalent rhino species worldwide. In 1960, its population in Africa was estimated to be as high as 100,000 but by 1970, widespread poaching had reduced their numbers to approximately 37,000 (Harper *et al*., 2018). This continued decline led to a low number of around 2,100 individuals in the mid-1990s (Harper *et al*., 2018). As a result, in 1996, the IUCN reclassified *D. bicornis* from endangered to critically endangered (Emslie and

Brooks., 1999). Due to intensive management and conservation initiatives, the population of *D. bicornis* has experienced an increase of 28% over the past decade (Emslie., 2020b). The population consists of three subspecies: approximately 2,583 southwestern black rhinos (*D. b. bicornis*), 2,450 southeastern black rhinos (*D.b. minor*), and 1,388 eastern black rhinos (*D. b. michaeli*) (Figure 1) (Emslie., 2020b).

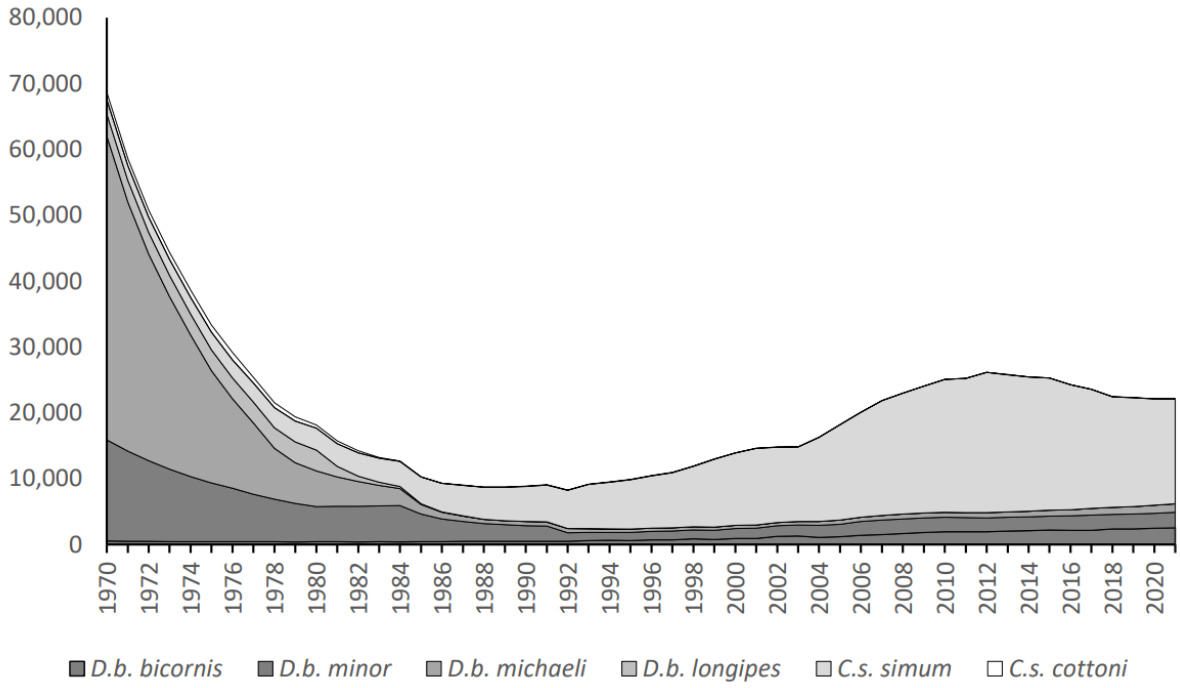

Figure 1. Estimated populations of the African rhino subspecies from 1970 to 2020. (CITES CoP19., 2022)

1. 2 Poaching

The illegal poaching of rhinos for their horns has resulted in a decline in rhino populations across both Africa and Asia (Amin *et al*., 2006). In Africa, this decline was initially precipitated by legalising automatic firearms in several African states in the early 70s (Douglas-Hamilton., 1983). Coupled with the high demand for rhino horn, this led to a surge in the hunting and killing of rhinos. Between 1960 and 1995, the black rhino population plummeted by 98% (Moodley *et al*, 2017). In response to this decline, legislation was enacted to make automatic firearms illegal once again, unless

individuals could demonstrate competency and obtain specific licenses (Carnelley., 2018). Although this has aided in restricting gun control, the surge in available rhino horn made the demand for rhino horn increase, as it was now considered a 'premium product' that only a few people could get their hands on (Jagwanth and Thipanyane, 1993; Ruggiero., 1990).

Rhino horn can be transported/ used in multiple ways. One way is known as "raw" rhino horn, this is when the horn is transported or displayed (i.e. trophy hunting) exactly how it comes off the rhino (Chaudhry., 2020). The other is in the form of a powder, this will be where the horn is ground up into a powder (Singer., 1991). This will then be used either in traditional Chinese medicine (TCM) (Gao *et al*, 2016; Zhang *et al*., 2024) or in places like the USA or Vietnam, it will be used as a party drug (Rademeyer, 2012; Ladendorf and Ladendorf., 2023). TCM believes that rhino horn possesses specific advantageous medicinal qualities (Cheung *et al*, 2021). Rhino horn is thought to confer medicinal benefits (e.g., dispelling of heat, detoxifying and cooling the blood) (Ellis 2013; But *et al*., 1991; Cheung *et al*, 2018) (Figure 2). The evidence for this is scarce however (But *et al*., 1990; Cheung *et al*, 2021). Rhino horn has been recorded to be listed as a drug of the medium category among other drugs in the Divine Farmer's Classic of Materia Medica/ The Shen Nong Ben Cao Jing – Chinese's oldest surviving Materia Medica which categorised plants into vegetables, grains, medicines and poisons for the benefit of the people (Nugent-Head., 2014) - which can be dated from roughly 200 B.C. to 200 A.D (But, *et a*l,1990; Liu, *et al*, 2010). The assertion that rhino horn is composed of keratin, analogous to human hair and fingernails (Roth *et al*, 2024), prompts a critical examination of its unique significance in various practices.

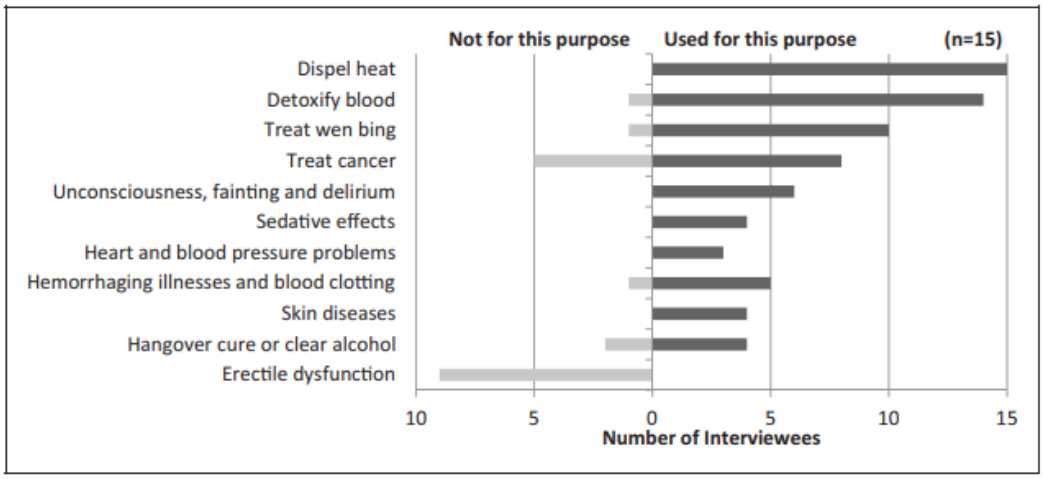

Figure 2. In their 2018 study, Cheung et al. conducted interviews with TCM practitioners regarding their use of rhino horn in treatment. The black bars represent the number of practitioners who affirmed the use of rhino horn for specific purposes, while the grey bars indicate the number of practitioners who denied its use for those same purposes.

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) addressed the demand for rhino horn by making its trade illegal in 1977 (AWF, 2017). However, some countries, such as South Africa, did not agree with the illegalisation of the rhino horn trade. The South African Constitutional Court on the 5th of April 2017, ruled to make the domestic trade of rhino horn legal (Chapman and White., 2020). This has caused a divide among people's opinions, as some see the catastrophic consequences of having this domestic trade legal, but others see how making the trade illegal could also cause negative impacts (Eikelboom *et al.*, 2020). This subject has been addressed in various CITES meetings, resulting in votes in 2016 and 2019 that both declined proposals to remove the ban (CITES CoP18., 2019).

The rationale for advocating the legalisation of rhinoceros horn centres on the potential to diminish both demand and market prices, consequently leading to a reduction in poaching activities (Di Minin *et al*, 2015; Jakins., 2018). Arguments against the legalisation of the trade are that using stockpiles of rhino horn won't be able to keep up with the demand (Biggs *et al*., 2013; Fischer, C., 2004). This theory was also used for

the stockpiles of ivory obtained in lots of African countries, the fates of these stockpiles were debated for years with countries like Kenya burning majority of their stockpile due to expenses of protecting the ivory and continued pushback of selling the ivory (Nadal and Aguayo., 2016; t'Sas-Rolfes et al., 2014; Braczkowski *et al.*, 2018). The street value of the rhinoceros' horn is estimated to exceed that of precious metals and substances, including gold, diamonds, and cocaine (Biggs *et al*. 2013; Rademeyer., 2016). Rhinoceros poaching is predominantly motivated by the high market value of their horns, which can command prices ranging from USD $30,000 to $60,000 per kilogram in the illegal trade (Haas and Ferreira., 2016). This substantial financial incentive underscores the urgent need for conservation efforts aimed at mitigating the impact of poaching on rhinoceroses' populations.

1. 3 Biology of Horn Growth

Currently, the primary method to prevent rhinos from being poached for their horns is through a process known as dehorning, which ethically removes the horn roughly every 18 months. To combat poaching, conservationists have adopted dehorning as a preventative measure and conservation tool. This practice initially began in Zimbabwe, Namibia, and Swaziland and has now been implemented in most African countries that are home to rhinos (Rachlow and Berger, 1997). During the dehorning process, a veterinary team removes a significant portion of the visible horn (Du Toit and Anderson, 2013; Chimes *et al.*, 2022). The initial idea behind dehorning was not only to protect rhinos from poachers but also to aid financially strained developing nations in their efforts for rhino conservation, as these nations could sell the horns obtained from ethical dehorning (Crookes and Blignaut., 2015). However, this latter aspect of the process has become less common. Both public and private game reserves routinely dehorn their rhinos, with Kruger National Park aiming to have all its rhinos dehorned by the end of 2021 – this target was not completed but 805 rhinos were dehorned between 2021 and 2022 (Africa Geographic., 2022)

Rhinos primarily use their horns for various social interactions, including mating, marking territory, and occasionally for seeking food and self-defence against predators

or other rhinos (Duthé *et al*., 2023; Penny *et al*., 2022). A study examined the potential impact of dehorning on behaviours such as resource access, wallowing, and rubbing, all of which are considered social behaviours among rhinos. The results of the study indicated that there was no evidence to suggest that the dehorning process disrupts the social behaviours of rhinos (Penny *et al*., 2021). Pfannerstill *et al* (2023), also studied the social behaviours of rhinos in Botswana, specifically looking to see if the chasing involved in the dehorning process influences the social behaviours post-dehorning but found that there were no major effects on the rhinos' behaviours. But Pfannerstill *et al* (2023) did highlight the importance of knowing if dehorning does reduce the rhinos' chances of being poach, as although it is believed to affect their behaviours it is still an invasive procedure.

1. 4 Survival Rates

Researchers investigated four populations of *D. bicornis*, classifying population A as being outside a protected area and populations B, C, and D as participants in the Black Rhino Custodianship Programme. Population B, which had never been subjected to dehorning, showed the shortest lifespan and the highest poaching mortality rate at 65%, as well as the lowest female fecundity, with an average lifespan of 7.111 years (± 0.308 SE, n=14) (Chimes *et al*., 2022). Moreover, population B faced the highest calf mortality rate, with 30% of calves lost to predation and 70% categorised as having unknown causes which was similarly found in other studies (Penny *et al*., 2020).

Dehorning may well protect rhinos from being poached by humans, but it potentially has a negative correlation with calf mortality due to losing their defence mechanisms. Berger and Cunningham (1997) studied the survival rates of calves from horned and dehorned female black rhinos in the Namib Desert. Research findings showed that calf mortality was higher in a dehorned population that coexists with spotted hyenas (*Crocuta crocuta*) compared to areas without hyenas, or where mothers were horned.

A model was created to determine how frequently an African rhino needs to be dehorned for the process to be sustainable and to evaluate whether dehorning is a viable practice for rhino survival (Milner-Gulland *et al*., 1992). Milner-Gulland *et al*

(1993), used this model and found that a rhino must be dehorned every 1.3 years to effectively deter poachers; rhinos that went longer without dehorning were at greater risk of being killed. It is important to note, however, that Milner-Gulland *et al* (1992), acknowledged a limitation in their study: they had to estimate horn growth rates due to the lack of available data at the time. While some research has been conducted on the sustainability of rhino horn production using known growth rates (Taylor et al., 2017), this study primarily focused on the hypothetical legal trade of rhino horn and did not address conservation perspectives.

1. 5 Horn growth

Giving rhinos the best chance of survival, it is crucial to take into account the varying growth rates of rhino horns, which can significantly impact the effectiveness of dehorning as a conservation strategy. Studying horn growth is important because the growth of rhino horn is unique; although rhino horn is mainly made of keratin it also has components of calcium and melanin which can strongly influence the horn growth behaviour (Yang., 2011; Hieronymus *et al*., 2006). Rhino horn is again unique as it isn't attached to the rhino's skull, making them different to other species, e.g. saiga, goats, sheep that also possess keratin horns (Hieronymus *et al*., 2006) (Figure 3).

Despite the advantages of dehorning, a significant challenge therefore persists regarding the management of this practice due to a notable absence of precise and consistent data on rhino horn regrowth rates. This research gap presents difficulties in establishing the most effective intervals for dehorning. In the absence of reliable information, there is a risk of implementing suboptimal dehorning schedules, which could potentially lead to either inadequate protection for rhinos or unnecessary interventions that may stress the animals (Milner-Gulland *et al*., 1992). As such, addressing this knowledge deficiency is crucial for developing evidence-based management strategies that can better safeguard rhino populations from the threat of poaching.

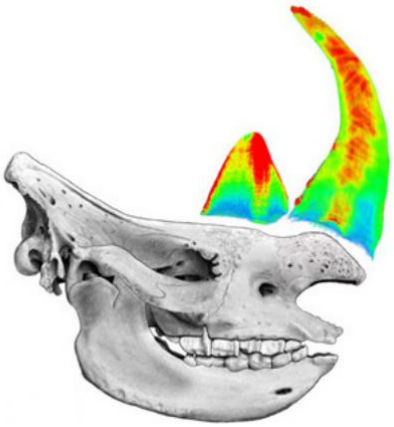

Figure 3. CT scan showing the components of a rhino horn. Denser areas of calcium and melanin are demonstrated using red, and blue for the least dense areas. (Yang., 2011)

1. 6 Aims and Hypothesis

The fundamental aim of this project is to explore variations in rhinoceros' horn (re)growth and provide important, population-specific data for the management team at Selati Game Reserve.

The primary hypothesis is that male rhinos will exhibit a faster rate of horn growth compared to their female counterparts (Whyte and Hall-Martin., 2018; Corlatti *et al*., 2015). Additionally, it is hypothesised that juvenile rhinos will have a swifter horn growth rate, whereas the growth rate of old adult rhinos is relatively slower (Bonenfant *et al*., 2009). Furthermore, *C. s. simum* front horn will grow at a faster pace than *D.b. minor,* as on average they have a larger front horn (Pienaar., 1991).

Methods

2. 1 Ethics

The dehorning procedure is carried out in accordance with stringent licensing regulations and is closely supervised by a qualified wildlife veterinarian and a designated government official. Although there may be temporary increases in stress and behavioural changes as suggested by studies such as Badenhorst *et al* (2016), and Penny *et al* (2020), and subsequent behavioural changes noted in studies by Penny *et al* (2021), and Duthe *et al* (2023), it is important to note that the decision to employ this invasive procedure is grounded in its vital role in deterring poaching, thereby preventing rhino mortality. For this study specifically, an ethics declaration and risk assessment were carried out (see Appendix A).

2. 2 Study site

Situated in the Limpopo Province, between the towns of Gravelotte and Phalaborwa, Selati Game Reserve (hereby referred to as Selati) is a private, non-commercial conservancy spanning nearly 28,000 hectares. Its coordinates are between 23^0 54' S and 24^0 06' S, and 30^0 36' E and 30^0 55' E (Comley *et al*, 2020), and the average temperatures range from 7°C to 36°C (Kettles and Slowtow, 2009) (Figure 4). With a rich ecosystem, it is home to 50 different mammal species, including leopards (*Panthera pardus pardus*), cheetahs (*Acinonyx jubatus jubatus*), elephants (*Loxodonta africana*), klipspringers (*Oreotragus oreotragus*), and Sharpe's grysboks (*Raphicerus sharpei*). Selati is home to two rhino species: the *C. s. simum* and the *D. b. minor*. Notably, Selati received a black rhino in 2010 as part of the BRREP (Black Rhino Range Expansion Project) initiated by the WWF (World Wildlife Foundation) (Madeline Siegel, *Pers.Comm*). Since 2014, Selati has been utilising dehorning as a conservation tool for its rhino population. (Steven Seager, *Pers.Comm*; Selati Game Reserve., n.d.)

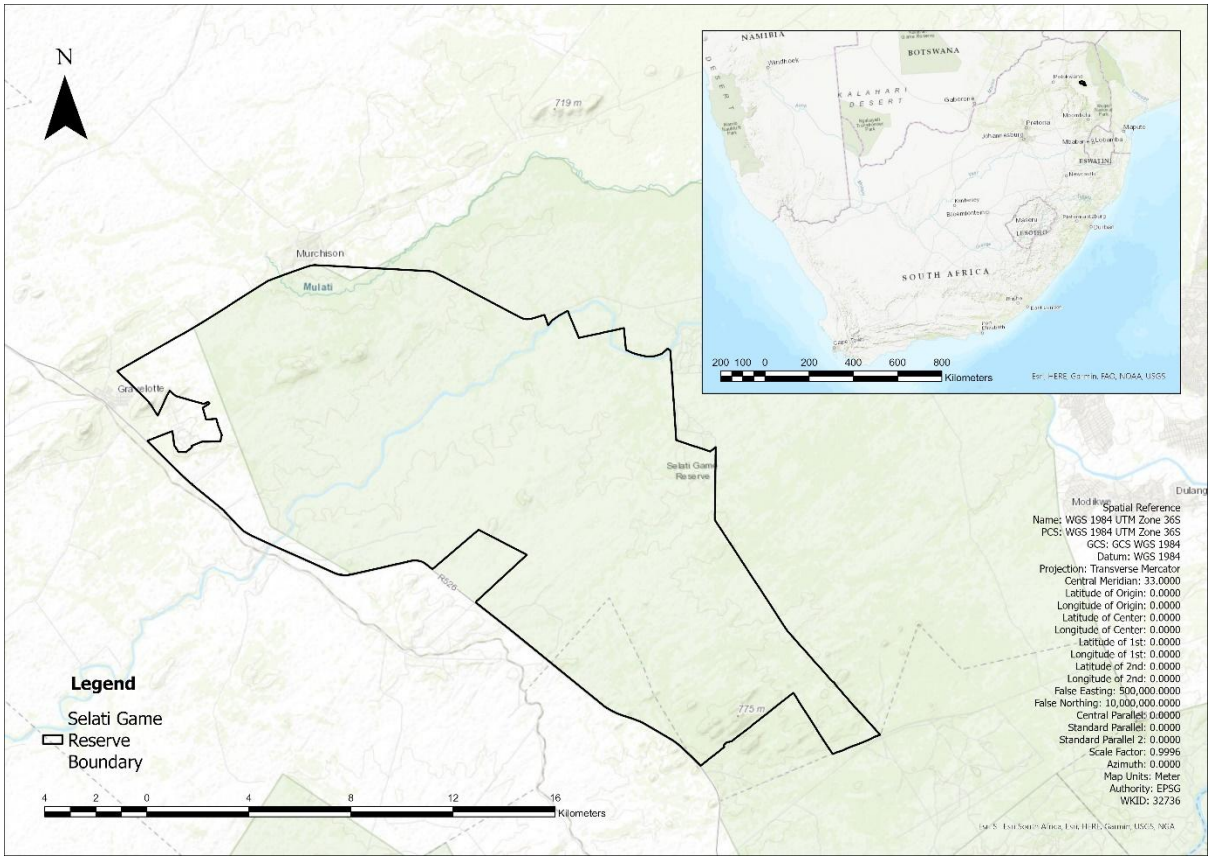

Figure 4. Location and site map of the study site, Selati Game Reserve

2. 3 Influencing variables

To calculate estimated daily horn growth (EDHG) measurements that were taken before and after dehorning were utilised (See Appendix B for a Comprehensive Overview of the dehorning process). Before dehorning, measurements were taken of the height and circumference of both the anterior and posterior horn. Once these measurements are taken, vets will use a chainsaw to remove a large portion of the rhino's horn, the remaining horn will be left with either a square cut or a rounded cut. Subsequently, post-dehorning measurements were taken of the height of the anterior horn only, as generally only about an inch of the posterior horn is left (Figure 5). Once the horn is removed, additional measurements are taken for the outer and inner heights of both the removed horns in centimetres, as well as the weight of the horn. This data is primarily collected for governmental purposes.

The pre- and post-dehorning heights of the anterior horn were solely used to calculate the EDHG in this study. In instances where the pre- and post-dehorning heights were not feasible to obtain during the dehorning process, post- and pre-dehorning photos (either from the dehorning procedure and/or camera traps, along with the outer horn lengths) will be utilised to estimate the missing measurements. At Selati, rhinos have been dehorned since 2012; however, the data analysed in this study will begin from 2014. The measurements recorded in 2012 were found to be inaccurate, as the post-dehorning lengths suggested that the rhinos had either no horn left or negative measurements, failing to accurately reflect the true post-dehorning status.

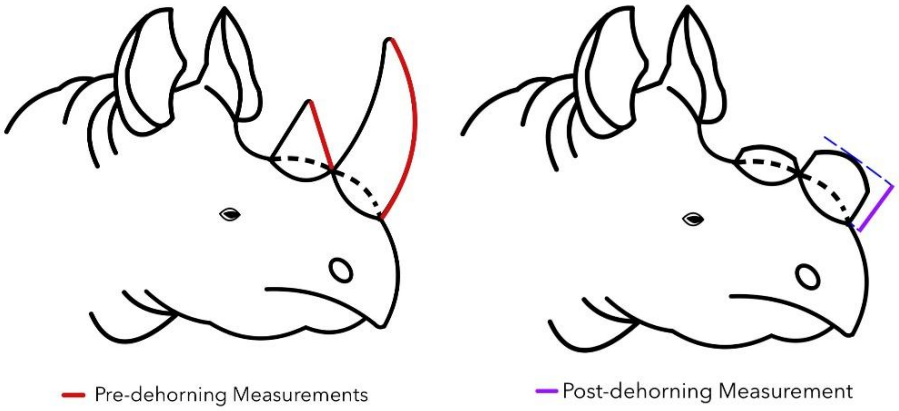

Figure 5. Illustration of how rhino horn measurements are taken.

At Selati, rhinos are categorised by age. For this study, we will utilise the old subcategories (as shown in Table 1), since the current age categories at Selati result in only three unevenly distributed groups. The ages of the rhinos will be approximated, as their exact birth dates are rarely known. This estimation will be based on the first sighting recorded via camera traps or personal observation, coupled with the size of the individual to refine the estimation of their birth dates. For the rhinos still in Selati's population as of January 1, 2024.

Table 1. Age categories used at Selati

Current Age Categories used by Selati	**Old Age Categories used by Selati (Subcategories)**	**Age**
Calf	A	0-3 months
Calf	B	3 months – 1 year
Calf	C	1 – 2 years
Calf	D	2 – 3.5 years
Sub-Adult	E1	3.5 – 6 years
Sub-Adult	E2	6 – 7 years
Adult	F	7 + years

2. 4 Statistical analysis

To analyse the data, R (version 4.4.2) and RStudio (version 2024.12.1+563) were utilised. Descriptive analyses were performed for the different influences; age, sex, number of dehorning procedures, average age at time of dehorning, days between dehorning procedures and pre-dehorning measurements using the *describe* and *summary* functions from the '*psych*' package (Revelle., 2024).

Preliminary investigations into the dataset revealed a statistical outlier concerning the *C. s. simum* population. This outlier was identified through both Cook's Distance and Cleaver SD methods, prompting the decision to exclude this particular data row from subsequent analyses. The evaluation of the *D. b. minor* population with the application of Cook's Distance did not reveal any statistical outliers within the dataset. However, the Cleaver SD method indicated the presence of a potential outlier. Given the limited sample size of the study population and the absence of any statistical outliers identified by Cook's Distance, the decision was made to retain all data rows in the analysis.

The first model, a generalised linear model was fitted with EDHG as the response variable, and the interaction between the number of dehornings and age at the time of dehorning as explanatory variables. A Gaussian distribution with a log link function was specified. To evaluate the improvement in model fit by including the interaction term, an analysis of deviance, *anova()* was performed comparing the fitted model with a baseline model. A Chi-square test was used to determine the statistical significance of the difference in deviance between the two models.

A second model, a linear regression model, was fitted with EDHG as the response variable and age at the time of dehorning and days between dehornings as predictor variables, including their interaction term (age at the time of dehorning * days between dehornings). Prior to analysis, the variables age at the time of dehorning and days between dehornings were transformed using the *scale* function to standardise their ranges. Variance inflation factors (VIFs) were calculated using the *car::vif()* function from the package car (Fox and Weisberg., 2019) to assess multicollinearity among the predictors (VIF < 2). The scaled variables were then back-transformed to their original units using the saved mean and standard deviation values from the scaling process.

The third model, A linear regression model, was fitted with EDHG as the response variable and reproductive status (P.or.CF.or.N) as the predictor variable. Reproductive status was treated as a categorical factor with three levels: Pregnancy (P), Calf at Foot (CF), and None (N) – a fourth category was present for the *C. s. simum*, Pregnant + Calf at foot (P + CF). To determine which specific reproductive status categories differed significantly in terms of EDHG, a post-hoc Tukey's Honestly Significant Difference (TukeyHSD) test was conducted. First, an analysis of variance (ANOVA) was performed using the *aov()* function to partition the variance in EDHG attributable to reproductive status. Then, the *TukeyHSD()* function was applied to the ANOVA object to calculate pairwise comparisons between reproductive statuses, and controlling for multiple comparisons.

Results

3. 1 *C. s. simum*

3. 1. 1 *C. s. simum* Sex

The population of *C. s. simum* exhibits a slight sex disparity, with females constituting 54.20% and males 45.80% of individuals who have undergone dehorning events. EDHG rates for both sexes are relatively consistent, recorded at 0.02 cm (± 0.01) per day. Additionally, males exhibit a higher average frequency of dehorning, with lifetime occurrences averaging 2 (±1.01), compared to females who average 1.83 (±0.91). Pre-dehorning metrics (Figure 5) indicate that males demonstrate an average horn size of 28.61 cm (± 11.64), while females average slightly smaller at 25.67 cm (± 9.40). Post-dehorning metrics indicate that males average a post-dehorning horn size of 7.84 cm (± 2.57), while females on average are left with slightly larger horns at 7.98 cm (± 4.77). Both sexes fall into the F category (Table 2) in terms of age at the time of dehorning.

Table 2. Overall descriptive statistics (mean and stand deviation) for males and females of the *C. s. simum* population.

	MEAN (sd)	
SEX	Males	Females
Number of Dehorning Procedures	2 (± 1.01)	1.83 (± 0.91)
Age at the time of Dehorning (days)	2699.22 (± 1704.04)	2928.90 (± 2311.84)
Days between Dehorning Procedures	1184.20 (± 841.04)	1236.45 (± 902.07)
Overall Growth (cm)	24.12 (± 11.28)	20.80 (± 10.06)
Estimated Daily Horn Growth (cm/ day)	0.02 (± 0.01)	0.02 (± 0.01)

3. 1. 2 *C. s. simum* Age

The population age ratios of *C. s. simum* exhibit a male bias, with the exception of age class B, which shows a preference for females, and age class E2, which demonstrates no significant bias (Table 3). Analysis of EDHG measurements reveals a consistent downward trend in growth rates correlating with advancing age for both sexes. Notably, there is a decline in EDHG rates from age classes B to D and from C to E1, with females exhibiting a more pronounced reduction, demonstrating a decrease of 0.03 cm/day between age classes B and F (Table 4). In terms of overall growth, there is a positive relationship with increasing age until a peak is reached at age class E1, after which a decline in overall growth is observed for both sexes (Table 5). However, males reach their peak at age class E2, averaging 31.50 cm (±13.98), before undergoing a subsequent decline in growth. Furthermore, trends in pre-dehorning growth closely align with overall growth patterns, indicating a peak in pre-dehorning growth at age class E2 for all observed individuals (Table 6).

Table 3. Overall descriptive statistics (mean and standard deviation) for the age classes of the *C. s. simum* population.

	MEAN (SD)					
Age Class (sex ratio F:M)	B (1:3)	C (5:3)	D (7:5)	E1 (15:11)	E2 (1:1)	F (34:31)
Number of Dehorning Procedures	1.00 (± 0.00)	1.00 (± 0.00)	1.42 (± 0.51)	1.5 (± 0.65)	1.75 (± 0.71)	2.46 (± 0.95)
Age at the time of Dehorning (days)	279.00 (± 45.54)	599.12 (±118.31)	1046.25 (± 140.12)	1693.81 (± 281.16)	2374.5 (± 181.3)	4930.32 (± 4918.83)
Days between Dehorning Procedures	279.00 (± 45.54)	599.12 (±118.31)	821.67 (± 275.12)	1313.65 (± 464.82)	1472.25 (± 723.62)	1688.58 (± 1515.03)

Table 4. The mean daily horn growth of the *C. s. simum* in cm for all six different age categories, further split into male, female and both (female + male)

	Daily Horn Growth (cm) (SD)		
Age Class	Female	Male	Both
B	0.04 (± 0.00)	0.04 (± 0.00)	0.04 (± 0.00)
C	0.03 (± 0.01)	0.03 (± 0.00)	0.03 (± 0.01)
D	0.03 (± 0.00)	0.03 (± 0.01)	0.03 (± 0.00)
E1	0.02 (± 0.00)	0.02 (± 0.01)	0.02 (± 0.01)
E2	0.02 (± 0.01)	0.02 (± 0.00)	0.02 (± 0.00)
F	0.01 (± 0.01)	0.02 (± 0.00)	0.02 (± 0.01)

Table 5. Mean overall horn growth between dehorning procedures in female, male, and both (combined) *C. s. simum* groups, across varying age classes.

	Overall Horn Growth (cm) (SD)		
Age Class	Female	Male	Both
B	5.00 (± 0.00)	11.67 (± 3.55)	10.00 (± 4.42)
C	20.15 (± 2.85)	19.42 (± 4.19)	19.88 (± 3.29)
D	19.71 (± 0.00)	24.60 (± 9.45)	21.75 (± 8.04)
E1	25.60 (± 8.30)	27.41 (± 7.98)	26.37 (± 8.06)
E2	20.13 (± 6.61)	31.50 (± 13.98)	25.81 (± 11.77)
F	19.63 (± 12.28)	24.05 (± 12.76)	21.74 (± 12.61)

Table 6. Mean front horn pre-dehorning length in female, male, and both (combined) *C. s. simum* groups, across varying age classes.

	Front Horn Length – Pre-Dehorning (cm) (SD)		
Age Class	Female	Male	Both
B	10.50 (± 0.00)	11.67 (± 3.55)	11.38 (± 2.95)
C	20.15 (± 2.48)	19.42 (± 4.19)	19.88 (± 3.29)
D	21.86 (± 4.83)	27.60 (± 5.46)	24.25 (± 5.69)
E1	29.00 (± 5.41)	30.14 (± 5.27)	29.48 (± 5.27)
E2	26.63 (± 3.71)	34.50 (± 10.91)	30.56 (± 8.64)
F	26.94 (± 11.89)	30.89 (± 13.45)	28.82 (± 12.71)

3. 1. 3 *C. s. simum* Number of Dehorning Procedures

In the Selati population, only one male *C. s. simum* underwent dehorning procedures five times, at the age of 3779 days. Prior to dehorning, the front horn length measured 22 cm, which was reduced to 6.5 cm post-procedure. The daily horn growth rate was recorded at 0.02 cm/ day.

The EDHG for the *C. s. simum* population in both sexes was recorded at 0.02 (± 0.01/± 0.02) across all dehorning procedures (see Table 8). Male *C. s. simum* demonstrated a higher EDHG rate of 0.03 (± 0.01) after undergoing one or three dehorning procedures. A general trend indicates a decline in overall horn growth with an increasing number of dehorning procedures (refer to Table 9). The age at which dehorning occurs shows a positive correlation with the number of procedures, as individuals being dehorned for

the first time typically fall within the E1 age class, while those undergoing multiple dehorning procedures in their lifetime are all classified in the F age class (Table 7). Conversely, the interval between dehorning procedures exhibits a negative relationship.

The interaction between the number of dehornings and the age at the time of dehorning significantly influenced the EDHG (cm/day). Across all dehorning frequencies, a consistent negative relationship was observed between the age at dehorning and the EDHG (Figure 6). Specifically, as the age at dehorning increased, the EDHG decreased. This pattern was most pronounced in animals dehorned only once, where the EDHG decreased from approximately 0.04 cm/day at younger ages to below 0.01 cm/day at older ages. While the negative trend was consistent across all dehorning frequencies, the effect appeared to decline with increasing numbers of dehornings. For instance, in animals dehorned four or five times, the EDHG showed a less dramatic decrease with increasing age at dehorning compared to those dehorned fewer times. For *C. s. simum* that underwent 1 to 4 dehornings, there is a statistically significant relationship between age at dehorning and the response variable, as indicated by the extremely low p-values (ranging from 1.78e-11 to 7.55e-07). However, for *C. s. simum* experiencing 5 dehorning procedures, the relationship is not statistically significant (p = 0.0815).

Table 7. Overall descriptive statistics (mean and standard deviation) for the number of dehorning procedures of the *C. s. simum* population.

	MEAN (SD)			
Number of Dehorning Procedures (sex ratio F:M)	1 (32:23)	2 (23:20)	3 (1:1)	4 (1:1)
Age at the time of Dehorning (days)	1671.15 (± 1563.62)	3250.51 (± 2084.77)	4070.79 (± 1852.24)	4592.75 (± 1165.81)
Days between Dehorning Procedures	1671.15 (± 1563.62)	1311.35 (± 760.25)	742.42 (± 288.89)	794.38 (± 237.65)
EDHG (cm/ day)	0.02 (± 0.01)	0.02 (± 0.01)	0.02 (± 0.01)	0.02 (± 0.01)

Table 8. EDHG (cm/day) in female, male, and both (combined) *C. s. simum* groups, across varying numbers of dehorning procedures

	Daily Horn Growth (cm) (SD)		
Number of Dehorning Procedures	Female	Male	Both
1	0.02 (± 0.01)	0.03 (± 0.01)	0.02 (± 0.01)
2	0.02 (± 0.00)	0.02 (± 0.01)	0.02 (± 0.01)
3	0.02 (± 0.01)	0.03 (± 0.01)	0.02 (± 0.01)
4	0.02 (± 0.01)	0.02 (± 0.01)	0.02 (± 0.01)

Table 9. Mean overall horn growth between dehorning procedures in female, male, and both (combined) *C. s. simum* groups, across varying numbers of dehorning procedures.

	Overall Horn Growth (cm) (SD)		
Number of Dehorning Procedures	Female	Male	Both
1	26.38 (± 10.47)	27.78 (± 10.76)	27.06 (± 10.33)
2	18.52 (± 7.53)	27.03 (± 12.79)	31.23 (± 12.25)
3	13.67 (± 5.06)	16.00 (± 3.92)	21.88 (± 4.16)
4	10.63 (± 2.50)	15.50 (± 2.48)	20.06 (± 3.80)

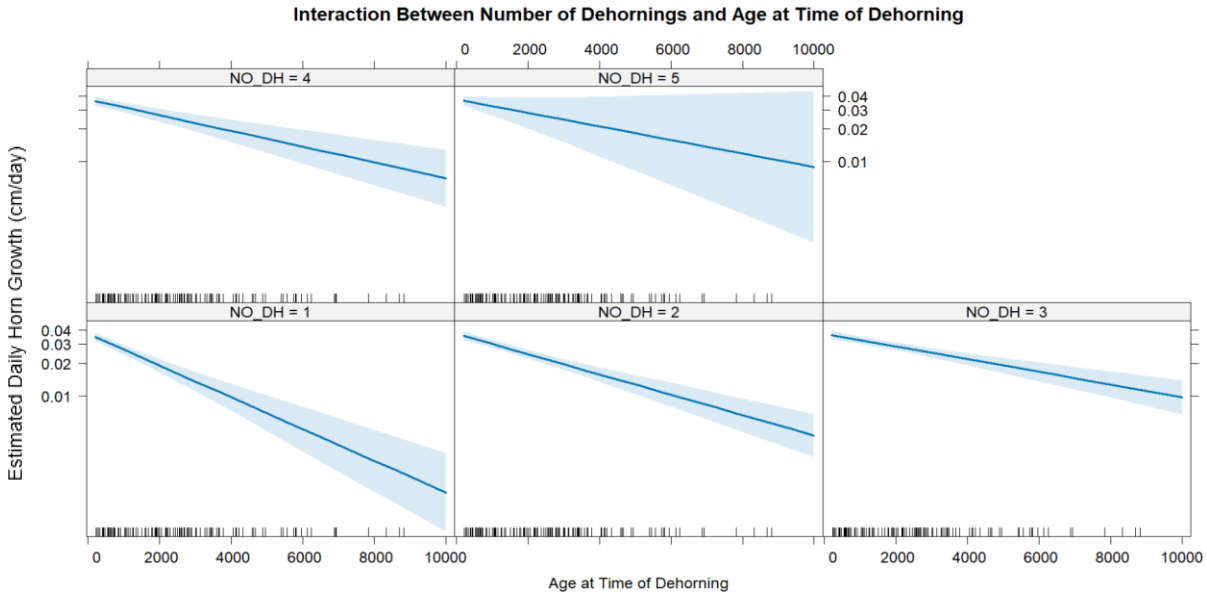

Figure 6. The interaction between the number of dehornings (NO_DH) and the age at the time of dehorning on the EDHG rate (cm/day) in *C. s. simum*. Each panel represents a different number of dehornings (NO_DH = 1, 2, 3, 4 and 5), showing the relationship between age at dehorning and EDHG within that specific dehorning frequency.

3. 1. 4 *C. s. simum* Days Between Dehorning

Within the initial 302 days following dehorning, there is a marked decrease in EDHG with increasing age at dehorning. This trend is less pronounced in the subsequent time interval (302-1684 days), where a slightly negative relationship is still observed. However, in the later time intervals (1584-3259, 3259-4244, and 4244-6215 days), the relationship between age at dehorning and EDHG shifts, exhibiting a positive trend, particularly pronounced in the final two intervals. The interaction between age at dehorning and days since dehorning significantly influences EDHG ($p = 0.000135$). (Figure 7)

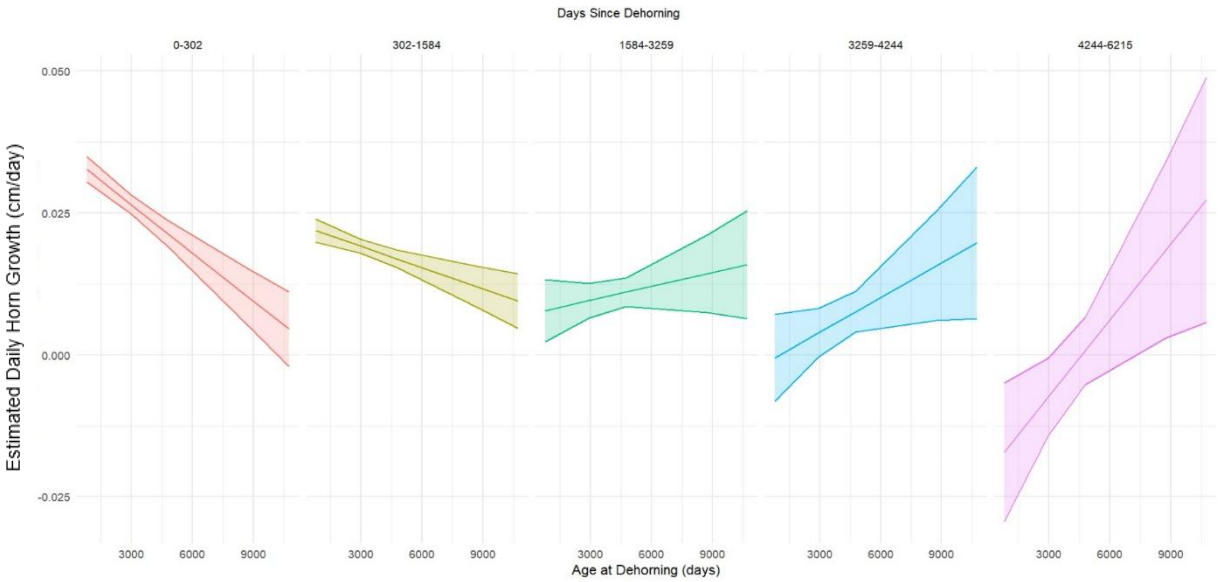

Figure 7. EDHG growth (cm/day) in relation to age at dehorning (days), stratified by days since dehorning. The plot displays the EDHG across a range of ages at which dehorning occurred, separated into five categories based on the time elapsed since the dehorning procedure (0-302 days, 302-1584 days, 1584-3259 days, 3259-4244 days, and 4244-6215 days). Shaded areas represent confidence intervals for the predicted values.

3. 1. 5 *C. s. simum* Reproductive Status

The data reveals a significant difference in EDHG rates between reproductive categories. Specifically, rhinos with a calf at foot (CF) exhibited a significantly lower EDHG compared to non-pregnant rhinos (N) (EDHG = 0.013 cm, P = 0.001). Conversely, pregnant rhinos (P) showed a significantly lower EDHG rate compared to non-pregnant rhinos (N), with a difference of -0.009 cm and a statistically significant p-value of 0.003. (Figure 8)

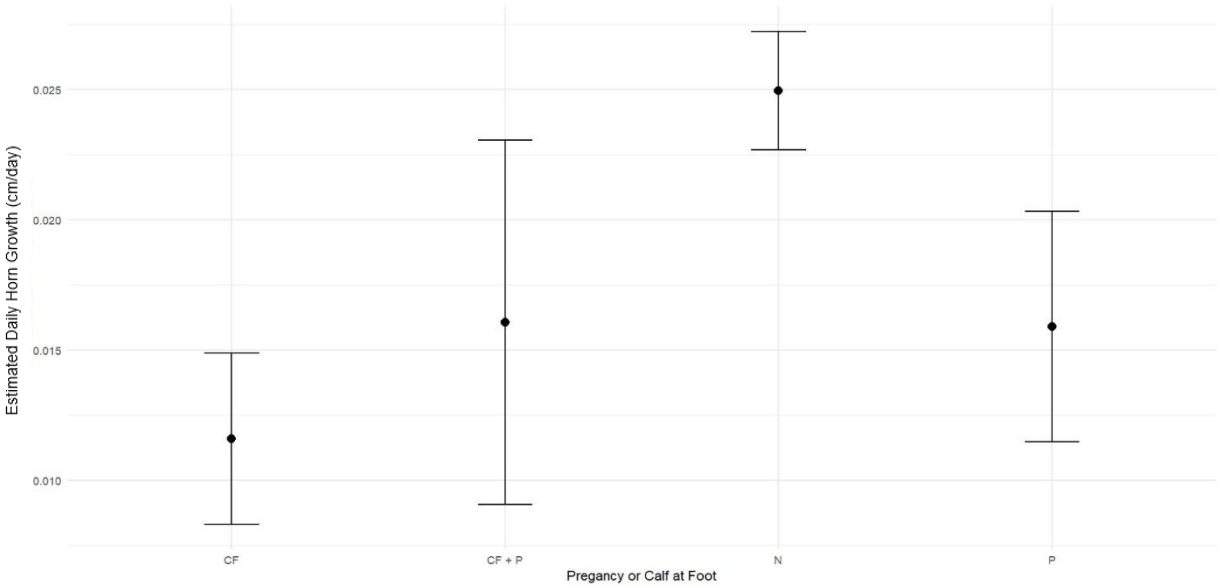

Figure 8. The plot illustrates the EDHG rate (cm) in rhinos across four reproductive categories: rhinos with a calf at foot (CF), rhinos with both a calf at foot and pregnancy (CF + P), non-pregnant rhinos (N), and pregnant rhinos (P). The error bars representing the confidence intervals around the predicted mean horn growth for each category.

3. 2 *D. b. minor*

3. 2. 1 *D. b. minor* Sex

The sex distribution within the *D. b. minor* population reveals that females account for 48.57% while males constitute 51.43% of individuals who have experienced dehorning events. Both sexes exhibit an EDHG rate of 0.02 cm (± 0.01) (Table 10), mirrors the growth rates observed in *C. s. simum*. Analysis of dehorning frequency shows that males undergo an average of 2.06 (± 1.06) procedures, whereas females experience an average of 1.82 (± 0.95). Prior to dehorning, males exhibited an average horn size of 28.86 cm (± 11.20), in contrast to the smaller average size of 25.67 cm (± 9.40) observed in females. Following dehorning, males' average horn size is 8.06 cm (± 2.36), while females average 8.68 cm (± 1.41) in horn size. Both sexes fall into the F category regarding age at dehorning, but males average nearly double the age of females.

Table 10. Overall descriptive statistics (mean and standard deviation) for males and females of the *D. b. minor* population.

	MEAN (sd)	
Sex	MALE	FEMALE
Number of Dehorning Procedures	2.06 (± 1.06)	1.82 (± 0.95)
Age at the time of Dehorning (days)	4370.33 (± 2451.54)	2871.53 (± 1953.45)
Days between Dehorning Procedures	1623.33 (± 1384.95)	1558.00 (± 1283.30)
Overall Horn Growth (cm)	20.81 (± 10.72)	16.74 (± 8.38)
EDHG (cm)	0.02 (± 0.01)	0.02 (± 0.01)

3. 2. 2 *D. b. minor* Age

The demographic analysis of the *D. b. minor* population reveals age ratios that are generally balanced, with a female bias in group E2 and a male bias in group F, as illustrated in Table 11. EDHG measurements indicate a consistent downward trend in growth rates with increasing age, specifically recording averages of 0.03 (± 0.00) for groups C and D, and 0.02 (± 0.01) for groups E1, E2, and F (Table 12). Overall growth exhibits a significant increase when comparing groups C and D, with growth metrics rising from 17.50 (± 1.06) to 28.75 (± 3.18) for both sexes, followed by a general levelling off after group D, though a decline is noted post-E2 (Table 13). Group C exhibits the smallest overall growth, which correlates with the earliest age at dehorning and the shortest intervals between dehorning procedures (Table 11). Pre-dehorning growth trends align closely with overall growth patterns, reflecting the largest increase from group C to D and subsequent stabilisation after group D (Table 14).

Table 11. Overall descriptive statistics (mean and standard deviation) for the age classes of the *D. b. minor* population.

	MEAN (sd) (cm)				
Age Class (sex ratio F:M)	C (1:1)	D (1:1)	E1 (1:1)	E2 (2:1)	F (5:6)
Number of Dehorning Procedures	1.00 (± 0.00)	1.00 (± 0.00)	1.33 (± 0.52)	1.00 (± 0.00)	2.41 (± 0.96)
Age at the time of Dehorning (days)	579.50 (± 91.22)	1142.00 (± 173.95)	1726.00 (± 399.07)	1776.00 (± 1007.15)	4925.23 (± 1952.36)
Days between Dehorning Procedures	579.50 (± 91.22)	1142.00 (± 173.95)	1315.50 (± 629.15)	2462.67 (± 1842.00)	1681.00 (± 1461.05)
Daily Horn Growth (cm)	0.03 (± 0.00)	0.03 (± 0.00)	0.02 (± 0.01)	0.02 (± 0.01)	0.02 (± 0.01)

Table 12. EDHG (cm/day) in female, male, and both (combined) *D. b. minor* groups, across varying age classes

	Daily Horn Growth (cm) (SD)		
Age Class	Female	Male	Both
C	0.03 (± 0.00)	0.03 (± 0.00)	0.03 (± 0.00)
D	0.03 (± 0.00)	0.02 (± 0.00)	0.03 (± 0.00)
E1	0.02 (± 0.00)	0.02 (± 0.00)	0.02 (± 0.01)
E2	0.02 (± 0.01)	0.01 (± 0.00)	0.02 (± 0.01)
F	0.01 (± 0.00)	0.02 (± 0.00)	0.02 (± 0.01)

Table 13. Mean overall horn growth between dehorning procedures in female, male, and both (combined) *D. b. minor* groups, across varying age classes.

	Overall Horn Growth (cm) (SD)		
Age Class	Female	Male	Both
C	16.00 (± 0.00)	19.00 (± 0.00)	17.50 (± 1.06)
D	26.50 (± 0.00)	31.00 (± 0.00)	28.75 (± 3.18)
E1	25.33 (± 10.49)	24.83 (± 14.18)	25.08 (± 11.16)
E2	28.00 (± 14.14)	26.00 (± 0.00)	27.33 (± 10.07)
F	17.65(± 9.63)	23.21 (± 13.22)	20.68 (± 11.80)

Table 14. Mean front horn pre-dehorning length in female, male, and both (combined) *D. b. minor* groups, across varying age classes.

	Front Horn Length – Pre-Dehorning (cm) (SD)		
Age Class	Female	Male	Both
C	16.00 (± 0.00)	19.00 (± 0.00)	17.50 (± 2.12)
D	26.50 (± 0.00)	31.00 (± 0.00)	28.75 (± 3.18)
E1	27.67 (± 6.60)	26.33 (± 12.7)	27.00 (± 9.08)
E2	28.00 (± 14.14)	26.00 (± 0.00)	37.33 (± 10.07)
F	25.05 (± 9.21)	30.38 (± 2.26)	27.95 (± 11.06)

3. 2. 3 *D. b. minor* Number of Dehorning Procedures

The EDHG recorded for the *D. b. minor* population in both males and females remained at 0.02 (± 0.00/ ± 0.02) until the fourth dehorning, where it increased to 0.04 (± 0.03) (see Table 15). Male *D. b. minor* displayed similar EDHG values, starting at 0.02 (± 0.01) and then rising to 0.05 (± 0.02) following the third dehorning (Table 16). In contrast, female *D. b. minor* maintained a consistent EDHG of 0.02 (± 0.01) across all dehorning sessions but showed a unique decline at the second dehorning. Overall, there appears to be a trend of decreasing horn growth with each successive dehorning until the third procedure, after which horn growth increases again (refer to Table 17 and Figure 9). The timing of dehorning is positively correlated with the number of procedures, as first-time dehorning usually occurs in the E1 age class, while individuals subjected to multiple dehorning procedures are classified in the F age class. On the other hand, the interval

between dehorning procedures shows a negative correlation (Table 15). For *D. b. minor* dehorned once, there was a statistically significant negative relationship between age at dehorning and EDHG rate (p = 3.79e-06), this is also found in *D. b. minor* dehorned four times, (p = 7.75e-14). For *D. b. minor* dehorned two and three, the relationship between age at dehorning and EDHG rate was not statistically significant (p = 0.294 and p = 0.300).

Table 15. Overall descriptive statistics for the number of dehorning procedures of the *D. b. minor* population.

	MEAN (sd)			
Number of Dehorning Procedures (sex ratio F:M)	1 (8:7)	2 (1:1)	3 (3:4)	4 (1:2)
Age at the time of Dehorning (days)	2180.60 (± 1544.93)	4066.70 (± 2185.19)	5286.29 (± 2211.9)	5700.67 (± 2412.66)
Days between Dehorning Procedures	2317.93 (± 1639.62)	1362.70 (± 770.50)	775.29 (± 129.35)	627.67 (± 110.26)
Front Horn Length – Pre-Dehorning (cm)	27.80 (± 8.63)	28.65 (± 11.51)	21.79 (± 3.4)	31.83 (± 20.06)
Front Horn Length – Post Dehorning (cm)	8.37 (± 2.09)	8.70 (± 2.37)	7.93 (± 1.57)	8.17 (± 0.58)
Overall Horn Growth (cm)	19.43 (± 8.87)	19.95 (± 10.33)	13.86 (± 4.42)	23.67 (± 19.78)
EDHG (cm)	0.02 (± 0.01)	0.02 (± 0.00)	0.02 (± 0.01)	0.04 (± 0.03)

Table 16. EDHG (cm/day) in female, male, and both (combined) *D. b. minor* groups, across varying numbers of dehorning procedures.

	Daily Horn Growth (cm) (SD)		
Number of Dehorning Procedures	Female	Male	Both
1	0.02 (± 0.01)	0.02 (± 0.01)	0.02 (± 0.01)
2	0.01 (± 0.00)	0.02 (± 0.01)	0.02 (± 0.00)
3	0.02 (± 0.01)	0.02 (± 0.01)	0.02 (± 0.01)
4	0.02 (± 0.00)	0.05 (± 0.02)	0.04 (± 0.03)

Table 17. Mean overall horn growth between dehorning procedures in female, male, and both (combined) *D. b. minor* groups, across varying number of dehornings.

	Overall Horn Growth (cm) (SD)		
Number of Dehorning Procedures	Female	Male	Both
1	26.13 (± 7.38)	29.71 (± 10.11)	27.80 (± 8.63)
2	19.10 (± 12.44)	20.90 (± 10.61)	20.00 (± 10.84)
3	12.17 (± 2.47)	13.63 (± 4.43)	13.00 (± 3.39)
4	10.00 (± 0.00)	31.00 (± 21.92)	24.00 (± 19.68)

Table 18. Mean pre-dehorning lengths in female, male, and both (combined) *D. b. minor* groups, across varying number of dehornings.

	Front Horn Length – Pre-Dehorning (cm) (SD)		
Number of Dehorning Procedures	Female	Male	Both
1	26.13 (± 7.38)	29.71 (± 10.11)	27.80 (± 8.63)
2	27.80 (± 12.94)	29.05 (± 11.36)	28.65 (± 11.51)
3	21.33 (± 2.08)	22.13 (± 4.46)	21.79 (± 3.40)
4	20.00 (± 0.00)	37.75 (± 24.40)	31.83 (± 20.06)

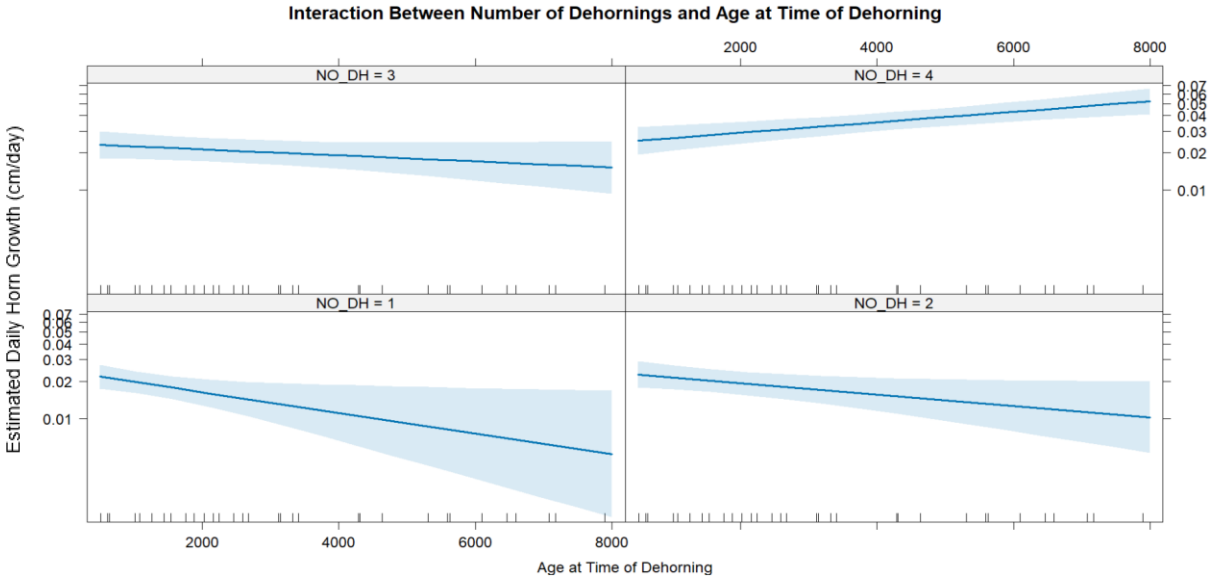

Figure 9. The plot depicts the interaction between the number of dehornings (NO_DH) and the age at the time of dehorning on the expected daily horn growth rate (cm/day) in *D. b. minor*. Each panel represents a different number of dehornings (NO_DH = 1, 2, 3, and 4), showing the relationship between age at dehorning and horn growth within that specific dehorning frequency.

3. 2. 4 *D. b. minor* Days Since Dehorning

In the shortest time frame post-dehorning (0-296 days), EDHG exhibited a slight positive trend with increasing age at dehorning. At intermediate time intervals (296-1656 and 1656-2768 days), EDHG displayed a relatively stable pattern across the range of ages at dehorning, with a slight decrease observed at the higher end of the age range in the 1656-2768 day category. Similarly, for 2768-4004 days, a U-shaped pattern was observed, but with a higher EDHG at both younger and older ages. The 4004-5240 day category showed a more complex pattern, with a sharp decline at the highest age range. However, no statistically significant effect of age at dehorning on EDHG rate was found ($p = 0.8482$). (Figure 10)

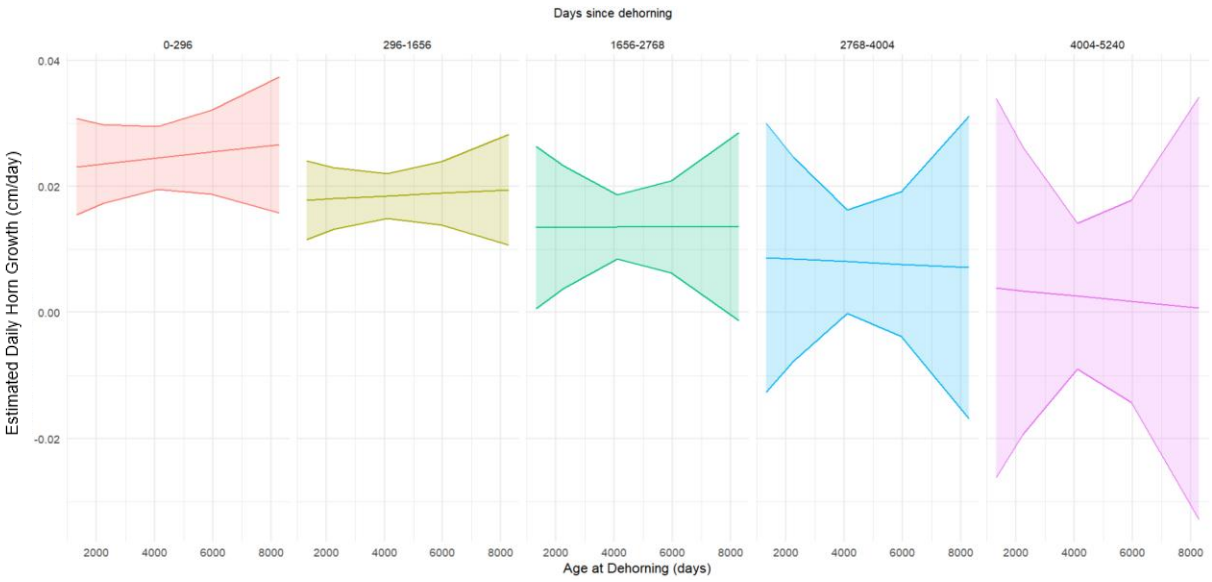

Figure 10. EDHG (cm/day) in relation to age at dehorning (days), stratified by days since dehorning. The plot displays the predicted horn growth across a range of ages at which dehorning occurred, separated into five categories based on the time elapsed since the dehorning procedure (0-296 days, 296-1656 days, 1656-2768 days, 2768-4004 days, and 4004-5240 days). Shaded areas represent confidence intervals for the predicted values.

3. 2. 5 *D. b. minor* Reproductive Status

The data suggests a trend where rhinos with a calf at foot (CF) have a lower EDHG rate compared to non-pregnant rhinos (N), with a difference of 0.008 cm. However, this difference is not statistically significant ($p = 0.071$). Pregnant rhinos (P) exhibit a lower EDHG rate compared to non-pregnant rhinos (N), with a difference of -0.009 cm. This difference is also not statistically significant ($p = 0.174$). (Figure 11)

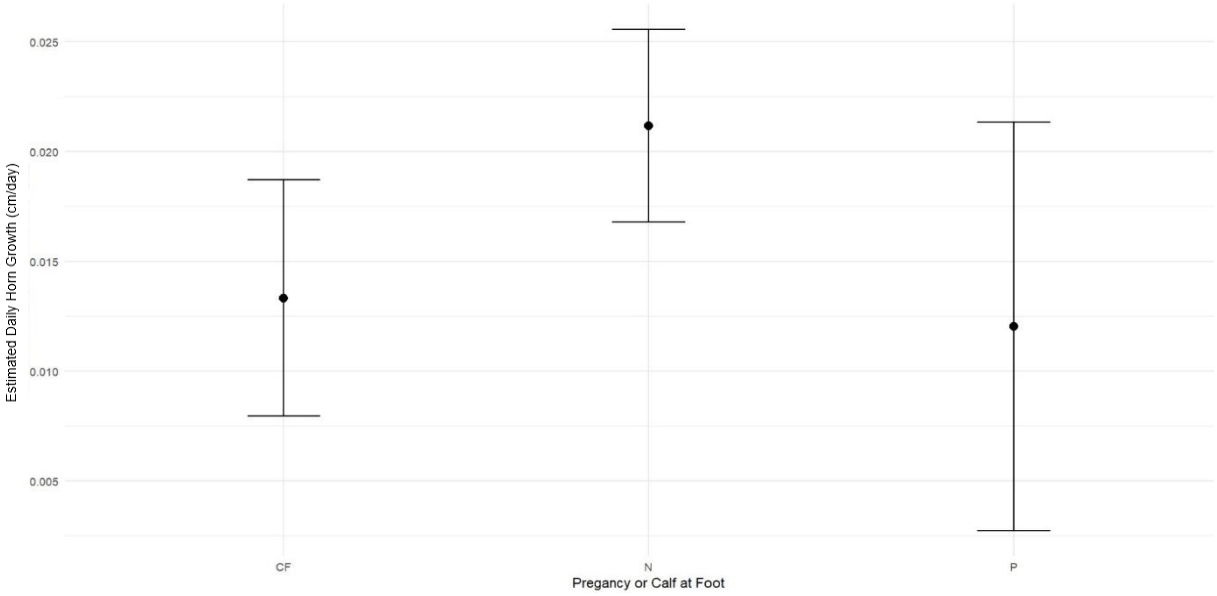

Figure 11. The plot illustrates the EDHG rate (cm) in rhinos across four reproductive categories: rhinos with a calf at foot (CF), rhinos with both a calf at foot and pregnancy (CF + P), non-pregnant rhinos (N), and pregnant rhinos (P). The error bars representing the confidence intervals around the predicted mean horn growth for each category.

4. 1 Discussion

Key findings highlight a consistent baseline regrowth rate across species and sexes, yet demonstrate nuanced variations based on age, dehorning frequency, time since dehorning, and reproductive status. Specifically, *C. s. simum* exhibited a clear trade-off between reproduction and horn growth, with lactating and pregnant individuals showing significantly reduced regrowth, likely due to resource allocation constraints (Rogowitz., 1996; Hamel and Côté., 2008). Conversely, *D. b. minor* showed a similar trend, albeit non-significant, suggesting species-specific physiological responses. Age significantly impacted horn regrowth in both species, with younger individuals displaying higher regrowth rates, and older males of *D. b. minor* showing significantly older age at dehorning, possibly due to poaching targeting larger horns or differing maturation rates (Bronikowski *et al.*, 2022). Furthermore, repeated dehorning progressively impaired regrowth in *C. s. simum*, while *D. b. minor* showed a potential compensatory mechanism after multiple dehornings.

4. 2 Sex

The observed near-equal sex distribution within dehorned populations of both *C. s. simum* and *D. b. minor* underscores the vulnerability of both sexes to poaching and subsequent dehorning interventions. This highlights the necessity for conservation strategies that adopt a holistic approach (Hausdorf., 2021), encompassing the entire rhino population rather than focusing on a single sex. The consistent EDHG rate of 0.02 cm (± 0.01) across both species and sexes suggests a similar physiological capacity for horn regeneration (KILTIE., 1985). This baseline regrowth rate is likely influenced by inherent physiological constraints related to keratin production and horn matrix activity (Tombolato., 2010). Such consistency is valuable for developing standardised dehorning protocols and predicting horn regrowth timelines, which are crucial for effective conservation management (Derkley *et al*., 2019).

The slightly higher dehorning frequency in males of both species, despite relatively small differences, warrants consideration. This trend aligns with the established sexual dimorphism in rhinos, wherein males exhibit larger average horn sizes (Berkeley., 2011). This increased horn size may render males more attractive targets for poachers, who seek larger horn volumes (Allendorf and Hard., 2009). Additionally, behavioural differences, such as increased territoriality and aggression in males, could lead to higher encounters with humans or other rhinos, potentially resulting in more frequent dehorning interventions (Rachlow., 1997; Haidt *et al*., 2018). The larger pre-dehorning horn sizes observed in males across both species further support this notion. However, the slightly larger post-dehorning horn size in female *D. b. minor*, despite smaller pre-dehorning horns, necessitates further investigation. This discrepancy could be attributed to variations in dehorning techniques, such as differences in the amount of horn removed, or inherent differences in horn morphology between males and females of ungulate species (Caro *et al*., 2003).

The finding that both sexes in both species, on average, fall within the same age category (F) at the time of dehorning suggests a consistent management approach or similar variability across age groups. However, a significantly older average age of male *D. b. minor* at dehorning compared to females was observed. This age discrepancy could reflect differences in maturation rates, with males reaching a target horn size or

age later than females (Traill *et al*., 2014). Social dynamics, such as male territoriality and competition (Cinková and Shrader., 2020), might also influence the timing of dehorning interventions. Specifically, increased male territoriality and competition could lead to more frequent encounters with management personnel or other rhinos, resulting in earlier identification and subsequent dehorning (Rachlow., 1997; Haidt *et al*., 2018). Furthermore, the increased visibility or detectability of males due to their behaviour could influence monitoring strategies and dehorning schedules. It's also possible that targeted poaching pressure on older males, potentially due to their larger horn size, cannot be ruled out (Ferreira *et al*., 2024). While the Selati data does not explicitly isolate poaching events, the significantly older age of dehorned males suggests a potential bias in interventions, which could indirectly reflect targeted poaching or pre-emptive dehorning of individuals deemed at higher risk.

4. 3 Age

The demographic analyses of *D. b. minor* and *C. s. simum* reveal distinct patterns in age structure and horn growth dynamics. In *D. b. minor*, while age ratios are generally balanced, the observed female bias in group E2 and male bias in group F suggest potential variations in survival or recruitment rates across age classes. These variations could be influenced by factors such as sex-specific mortality, dispersal patterns, or differences in resource allocation during different life stages (Ndlovu, L., 2023; Rachlow, *et al*., 1999). The consistent downward trend in EDHG with increasing age in *D. b. minor* aligns with the expected decline in physiological resources allocated to growth in older individuals (Huber., 2018). This trend is consistent with general life history theory, which posits that resource allocation shifts from growth to reproduction and maintenance as organisms age (Boggs., 2009).

The significant increase in overall horn growth from age groups C to D, followed by a levelling off and subsequent decline after group E2, suggests a 'window' of optimal horn growth during mid-age ranges. This pattern may reflect age-related shifts in hormonal regulation, nutrient availability, or cellular mechanisms that influence horn regeneration (Owen-Smith., 1988; Santiago-Moreno *et al*., 2005; Jones *et al*., 2018). Notably, the youngest age group (C), exhibiting the smallest overall growth, also experienced the

shortest intervals between dehorning procedures. This observation suggests that frequent dehorning may disproportionately impact horn regeneration capacity in younger individuals. Specifically, younger individuals, still undergoing substantial skeletal and tissue development, may prioritise resource allocation towards these essential growth processes rather than horn regrowth (Hieronymus *et al*., 2006; Robbins., 2012). This resource prioritisation could result in a reduced capacity for horn regeneration following repeated dehorning interventions, as the metabolic demands of overall growth compete with the demands of horn tissue production (Penny *et al*., 2020). Consequently, the observed lower horn growth in younger individuals subjected to frequent dehorning could be a direct result of this developmental resource allocation trade-off (Pfannerstill *et al*., 2023).

In *C. s. simum*, the observed male bias in population age ratios, with exceptions in age classes B and E2, could be attributed to a variety of factors, including sex-specific mortality, dispersal patterns, or sampling biases (Lemaître *et al*., 2020). Similar to *D. b. minor*, *C. s. simum* also exhibited a downward trend in EDHG with increasing age, with females demonstrating a more pronounced decline. This suggests potential sex-specific differences in resource allocation and horn regeneration capacity (Penny., 2019). The peak in overall growth at age class E1 for both sexes, with males peaking slightly later at E2, suggests a potential age-related shift in resource allocation towards horn growth (Austad., 1997). This shift could be influenced by hormonal changes, such as increased testosterone levels in males, or changes in metabolic processes (Low., 2013). The alignment of pre-dehorning growth trends with overall growth patterns in both species indicates that pre-existing growth trajectories are likely influential in post-dehorning horn regeneration.

The differences in peak growth ages between the two species may reflect variations in their life history strategies, growth rates, or responses to dehorning. *C. s. simum*, being a grazer (Waldram *et al*., 2008), may exhibit different growth patterns compared to *D. b. minor*, a browser (Borges *et al*., 2024), due to differences in dietary intake and nutrient availability. The observation that younger *D. b. minor* individuals, experiencing more frequent dehorning, exhibit lower overall growth compared to older individuals, suggests that dehorning frequency may have a more significant impact on horn

regeneration in younger age classes. This is likely because, like *C. s. simum*, younger individuals are still undergoing significant skeletal and tissue development, diverting resources towards these essential growth processes rather than horn regrowth (Hieronymus *et al.*, 2006; Robbins., 2012). Consequently, the physiological capacity for horn regeneration in these younger rhinos may be more susceptible to the stress induced by repeated dehorning procedures (Ricklefs and Wikelski., 2002; Patton., 2021). This highlights the importance of considering age-specific responses to dehorning when developing conservation management strategies.

4. 4 Number of Dehorning Procedures

The consistent average EDHG of 0.02 cm/day observed across both species and sexes suggests a baseline regrowth rate, however, significant variations emerge when considering dehorning frequency, age at dehorning, and inter-dehorning intervals.

In *C. s. simum*, a clear trend of decreasing EDHG with increasing dehorning frequency was observed. Older individuals, typically falling within the F age class, were more likely to have undergone multiple dehornings. This suggests that repeated horn removal may progressively impair the rhino's ability to regenerate horn tissue. Potential mechanisms include resource depletion, cumulative tissue damage, or alterations in horn matrix activity due to repeated 'trauma' (Eming *et al.*, 2014). The significant negative relationship between age at dehorning and EDHG across most dehorning frequencies, particularly pronounced in first-time dehornings, indicates that younger *C. s. simum* exhibit a higher capacity for horn regrowth. This aligns with the general observation that younger individuals have higher metabolic rates and growth potential (Hillman-Smith *et al.*, 1986). The single *C. s. simum* male dehorned five times, despite showing a non-significant relationship between age and EDHG, potentially represents an outlier or highlights the limitations of extrapolating from a single individual.

Conversely, *D. b. minor* displayed a more nuanced response to repeated dehorning. While a similar trend of decreasing EDHG was seen until the third dehorning, a subsequent increase was observed after the fourth. This suggests a potential compensatory mechanism or physiological adaptation in *D. b. minor* that allows for enhanced regrowth following multiple dehornings (Yang *et al.*, 2017). This could involve

upregulation of genes involved in keratin production or increased blood flow to the horn matrix (Kalabusheva *et al.*, 2023). The statistically significant negative relationship between age at dehorning and EDHG in first-time and fourth-time dehorned *D. b. minor* mirrors the pattern observed in *C. s. simum*, indicating a general age-related decline in regrowth capacity. However, the lack of significance at two and three dehornings suggests a more complex interaction of factors in this species. The observed sex-specific variations in *D. b. minor*, with males showing higher EDHG after multiple dehornings and females maintaining a consistent rate, further underscores the importance of considering individual and sex-specific responses.

The negative correlation between inter-dehorning intervals and dehorning frequency observed in both species implies that rhinos dehorned more frequently tend to have shorter intervals between procedures. This could be due to increased monitoring, targeted interventions, more frequent detections, or higher perceived risk of poaching in these individuals.

4. 5 Days Between Dehorning

The analysis of EDHG in *C. s. simum* revealed a complex and time-dependent relationship with age at dehorning. While the initial analysis, examining broad time intervals post-dehorning, suggested a lack of statistically significant effect of age on EDHG ($p = 0.8482$), a more refined analysis, considering specific time windows, revealed a significant interaction between age at dehorning and days since dehorning ($p = 0.000135$).

The initial observation of a slight positive trend in EDHG with increasing age in the immediate post-dehorning period (0-296 days) might reflect an initial compensatory growth spurt, potentially more pronounced in older individuals (Werner and Grose., 2003). This could be due to the release of growth factors or increased blood flow to the horn matrix following dehorning (Tonnesen *et al.*, 2000). However, the subsequent stability and slight decline in EDHG at intermediate time intervals suggest a shift in growth dynamics. The U-shaped pattern observed at 2768-4004 days, with higher EDHG at both younger and older ages, could indicate a complex interplay of age-related

physiological factors influencing horn regeneration (Grunschloss., 2016). The sharp decline in EDHG at the highest age range in the 4004-5240 day category might indicate a decline in horn regeneration capacity in very old individuals, possibly due to senescence or age-related physiological changes (Kirkwood., 2005).

The significant interaction between age and days since dehorning highlights the dynamic nature of horn regrowth post-dehorning. The shift from a negative relationship between age and EDHG in the early post-dehorning phase to a positive relationship in later phases suggests that the influence of age on horn growth is not static.

The discrepancy between the initial non-significant result and the later significant interaction underscores the importance of considering temporal dynamics in ecological studies. Analysing data across broad time frames can obscure subtle but significant patterns that emerge when data are examined at finer temporal resolutions.

4. 6 Reproductive Status

The results highlight a contrasting pattern in EDHG rates between *C. s. simum* and *D. b. minor*, particularly in relation to reproductive status. In *C. s. simum*, a clear and statistically significant influence of reproductive state on EDHG was observed. Rhinos with a calf at foot exhibited a substantial decrease in horn growth compared to non-pregnant individuals, while pregnant rhinos also showed a significant reduction (Rughetti and Festa-Bianchet., 2011). These findings suggest a strong physiological trade-off in *C. s. simum*, where resources are potentially diverted away from horn growth towards the demands of lactation and pregnancy (Steams., 1989; Bronson., 1989). This observation aligns with the established understanding of resource allocation in large mammals, where reproductive investment often comes at the expense of other physiological processes (Gittleman and Thompson., 1988). Lactation and pregnancy impose significant energetic demands on female rhinos, requiring resources for milk production and fetal development (Osthoff *et al*., 2021). This resource allocation trade-off is likely mediated by hormonal changes, such as increased progesterone and prolactin levels, which can suppress keratin production and horn matrix activity (Moyes *et al*., 2011; Grymowicz *et al*., 2020). To further anchor

this concept, it can be contextualised within the broader framework of life history theory, where the optimisation of resource allocation for survival and reproduction is a central tenet (Wootton., 1993).

Conversely, the analysis of *D. b. minor* data revealed a trend in the same direction—lower EDHG in both lactating and pregnant rhinos—but these differences did not achieve statistical significance. This suggests that while reproductive status may influence horn growth in *D. b. minor*, the effect is either weaker or more variable compared to *C. s. simum*, requiring a larger sample size to detect a statistically significant difference. The lack of significance could also indicate that other factors, not accounted for in this study, play a more dominant role in determining horn growth rates in *D. b. minor*, such as environmental influences.

The observed differences between the two species may be attributed to variations in their life history strategies, physiological adaptations, or ecological niches (Mamba., 2018). *C. s. simum*, being grazers with a more specialised diet (Shrader *et* al., 2006; Milne., 1991), might experience more pronounced resource constraints during lactation and pregnancy, leading to a greater impact on horn growth (Oftedal., 2018). *D. b. minor*, as browsers with a more diverse diet, might be less susceptible to these constraints (Okita-Ouma *et al*., 2021). Furthermore, potential differences in hormonal regulation or metabolic processes between the two species could also contribute to the observed disparities (Penny *et al*., 2020).

5. 1 Conclusion

This study revealed complex interactions between rhino horn growth and factors like sex, age, dehorning frequency, and reproductive status across *C. s. simum* and *D. b. minor*. While both species showed similar baseline regrowth rates and age-related declines, species-specific differences, particularly in response to repeated dehorning and reproductive state, highlight diverse physiological adaptations.

Sexual dimorphism in horn size and dehorning frequency indicates that targeted conservation strategies are needed. Age-specific regrowth patterns, especially in young rhinos, demand tailored dehorning protocols. The dynamic relationship between

dehorning intervals and horn growth underscores the need for longitudinal studies. (Ververs *et al*., 2018)

Future studies should explore the underlying mechanisms driving observed patterns, focusing on hormonal profiles, genetic analyses, and cellular processes (Tubbs *et al*., 2014; Ruggeri *et al*., 2023; Ruggeri *et al*., 2024). Longitudinal tracking of individual rhinos across dehorning events and reproductive cycles is crucial (Chimes *et* al., 2022; Garnier *et al*., 2002). Investigating ecological and behavioural consequences of dehorning, including social dynamics and reproductive success, is essential for evidence-based conservation. Comparative studies across populations and habitats will refine our understanding of horn growth dynamics and optimise conservation management.

References

't Sas-Rolfes, M., Emslie, R., Adcock, K. and Knight, M., 2022. Legal hunting for conservation of highly threatened species: The case of African rhinos. *Conservation Letters*, *15*(3), p.e12877. https://conbio.onlinelibrary.wiley.com/doi/pdf/10.1111/conl.12877

Africa Geographic., 2022. *Another year of loss – an update on Kruger's rhino populations*. [Website] https://africageographic.com/stories/another-year-of-loss-an-update-on-krugers-rhino-populations/ Last Accessed 11/01/2025

Allendorf, F.W. and Hard, J.J., 2009. Human-induced evolution caused by unnatural selection through harvest of wild animals. *Proceedings of the National Academy of Sciences*, *106*(supplement_1), pp.9987-9994. https://www.pnas.org/doi/pdf/10.1073/pnas.0901069106

Amin, R., Thomas, K., Emslie, R.H., Foose, T.J. and Strien, N.V., 2006. An overview of the conservation status of and threats to rhinoceros species in the wild. *International Zoo Yearbook*, *40*(1), pp.96-117. https://zslpublications.onlinelibrary.wiley.com/doi/pdfdirect/10.1111/j.1748-1090.2006.00096.x

Austad, S.N., 1997. Comparative aging and life histories in mammals. *Experimental gerontology*, *32*(1-2), pp.23-38. https://www.sciencedirect.com/science/article/pii/S0531556596000599

Badenhorst, M., Ganswindt, A., Otto, M. and Van der Goot, A.C., 2016. Stress steroid levels and the short-term impact of routine dehorning in female southern white rhinoceroses (Ceratotherium simum simum). *African Zoology*, *51*(4), pp.211-215. https://journals.co.za/doi/abs/10.1080/15627020.2016.1261002

Balfour, D., Makoma, K. and Ferreira, S.M., 2024. African Rhino Specialist Group Chair report/Rapport du Groupe de Spécialistes du Rhinocéros d'Afrique. *Pachyderm*, *65*, pp.20-34. https://pachydermjournal.org/index.php/pachyderm/article/download/1311/1296

Berger, J. and Cunningham, C., 1996. Is rhino dehorning scientifically prudent. *Pachyderm*, *21*, pp.60-68. [PDF] https://pachydermjournal.org/index.php/pachyderm/article/download/844/823

Berkeley, E.V., 2011. *Sex allocation, diet, and small population management of African rhinoceros* (Doctoral dissertation, Open Access Te Herenga Waka-Victoria University of Wellington). https://openaccess.wgtn.ac.nz/articles/thesis/Sex_Allocation_Diet_and_Small_Population_Management_of_African_Rhinoceros/16985548/1/files/31412893.pdf

Biggs, D., Courchamp, F., Martin, R. and Possingham, H.P., 2013. Legal trade of Africa's rhino horns. *Science*, *339*(6123), pp.1038-1039. https://www.academia.edu/download/42124386/Rhino_poaching_supply_and_demand_uncerta20160205-26865-14mzdkl.pdf

Boggs, C.L., 2009. Understanding insect life histories and senescence through a resource allocation lens. *Functional Ecology*, *23*(1), pp.27-37. https://besjournals.onlinelibrary.wiley.com/doi/pdfdirect/10.1111/j.1365-2435.2009.01527.x

Bonenfant, C., Pelletier, F., Garel, M. and Bergeron, P., 2009. Age-dependent relationship between horn growth and survival in wild sheep. *Journal of Animal Ecology*, *78*(1), pp.161-171. https://besjournals.onlinelibrary.wiley.com/doi/pdfdirect/10.1111/j.1365-2656.2008.01477.x

Borges, J., Symeonakis, E., Higginbottom, T.P., Jones, M., Cain, B., Kisingo, A., Maige, D., Oliver, O. and Lobora, A.L., 2024. Assessing habitat suitability: the case of black rhino in the Ngorongoro Conservation Area. *Remote Sensing*, *16*(15), p.2855. https://www.mdpi.com/2072-4292/16/15/2855

Braczkowski, A., Holden, M.H., O'Bryan, C., Choi, C.Y., Gan, X., Beesley, N., Gao, Y., Allan, J., Tyrrell, P., Stiles, D. and Brehony, P., 2018. Reach and messages of the world's largest ivory burn. Conservation Biology, 32(4), pp.765-773. https://conbio.onlinelibrary.wiley.com/doi/pdfdirect/10.1111/cobi.13097

Bronikowski, A.M., Meisel, R.P., Biga, P.R., Walters, J.R., Mank, J.E., Larschan, E., Wilkinson, G.S., Valenzuela, N., Conard, A.M., de Magalhães, J.P. and Duan, J., 2022. Sex-specific aging in animals: perspective and future directions. *Aging Cell*, *21*(2), p.e13542. https://onlinelibrary.wiley.com/doi/pdfdirect/10.1111/acel.13542

Bronson, F.H., 1989. *Mammalian reproductive biology*. University of Chicago Press. https://books.google.com/books?hl=en&lr=&id=UmZmmW7DghMC&oi=fnd&pg=PP11&dq=Mammalian+reproductive+biology&ots=Ub2SFS4jsx&sig=VD8wrnKutwwtwJekgdBqYV4h1Zk

But, P.P.H., Lai-Ching, L. and Yan-Kit, T., 1990. Ethnopharmacology of rhinoceros horn. I: Antipyretic effects of rhinoceros horn and other animal horns. *Journal of Ethnopharmacology*, *30*(2), pp.157-168. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=33dc27bbc517ed8b60cc596419867cd54fc93117

But, P.P.H., Yan-Kit, T. and Lai-Ching, L., 1991. Ethnopharmacology of rhinoceros horn. II: Antipyretic effects of prescriptions containing rhinoceros horn or water buffalo horn. *Journal of Ethnopharmacology*, *33*(1-2), pp.45-50. http://www.rhinoresourcecenter.com/pdf_files/117/1178937442.pdf

Carnelley, M., 2018. Firearms. *South African journal of criminal justice*, *31*(3), pp.483-492. https://journals.co.za/doi/epdf/10.10520/EJC-1471ec432d

Caro, T.M., Graham, C.M., Stoner, C.J. and Flores, M.M., 2003. Correlates of horn and antler shape in bovids and cervids. *Behavioral Ecology and Sociobiology*, *55*, pp.32-41. https://link.springer.com/article/10.1007/s00265-003-0672-6

Chapman, L.A. and White, P.C., 2020. The future of private rhino ownership in South Africa. *Wildlife Research*, *47*(6), pp.441-447. http://www.rhinoresourcecenter.com/pdf_files/160/1602527838.pdf

Chaudhry, P.E., 2020. Assessing demand reduction measures for rhino horn consumption. *Psychology & Marketing*, *37*(12), pp.1664-1676. https://onlinelibrary.wiley.com/doi/pdf/10.1002/mar.21416

Cheung, H., Mazerolle, L., Possingham, H.P. and Biggs, D., 2018. Medicinal use and legalized trade of rhinoceros horn from the perspective of traditional Chinese medicine practitioners in Hong Kong. *Tropical Conservation Science*, *11*, p.1940082918787428. https://journals.sagepub.com/doi/pdf/10.1177/1940082918787428

Cheung, H., Mazerolle, L., Possingham, H.P. and Biggs, D., 2021. Rhino horn use by consumers of traditional Chinese medicine in China. *Conservation Science and Practice*, *3*(5), p.e365. https://conbio.onlinelibrary.wiley.com/doi/pdf/10.1111/csp2.365

Chimes, L.C., Beytell, P., Muntifering, J.R., Kötting, B. and Neville, V., 2022. Effects of dehorning on population productivity in four Namibia sub-populations of black rhinoceros (Diceros bicornis bicornis). *European Journal of Wildlife Research*, *68*(5), p.58. [PDF] Effects of dehorning on population productivity in four Namibia sub-populations of black rhinoceros (

Cinková, I. and Shrader, A.M., 2020. Rival assessment by territorial southern white rhinoceros males via eavesdropping on the contact and courtship calls. *Animal Behaviour*, *166*, pp.19-31. https://www.sciencedirect.com/science/article/pii/S0003347220301494?casa_token=4C2_EjFs6icAAAAA:ukpOh_m22v4MiNHqrWCjrf8QBrgQl5tqSti-cMoW6QyRxAA_zx6buhtbseVSSpPK2YWU4RqDZtI

CITES CoP18 Prop. 9., 2018. *CONVENTION ON INTERNATIONAL TRADE IN ENDANGERED SPECIES OF WILD FAUMA AND FLORA*. Consideration of Proposals for Amendment of Appendices I and II. https://cites.org/sites/default/files/eng/cop/18/prop/010319/E-CoP18-Prop-09.pdf

CITES CoP19. Doc. 75, 2022. *CONVENTION ON INTERNATIONAL TRADE IN ENDANGERED SPECIES OF WILD FAUMA AND FLORA*. African and Asian Rhinoceros – Status, Conservation and Trade https://cites.org/sites/default/files/documents/E-CoP19-75.pdf

Comley, J., Joubert, C.J., Mgqatsa, N. and Parker, D.M., 2020. Do spotted hyaenas outcompete the big cats in a small, enclosed system in South Africa?. *Journal of Zoology*, *311*(2), pp.145-153. https://zslpublications.onlinelibrary.wiley.com/doi/full/10.1111/jzo.12772?casa_token=VsMIgZZ5noIAAAAA%3AA1vc1ijzUXHRSjox_Gd9xuISTTVz3OBC4TtJJ0fZ2aD8kHsQ1qCrGdan95eN5Rq3EOBPkivyEjZdJ2zm

Corlatti, L., Gugiatti, A. and Imperio, S., 2015. Horn growth patterns in Alpine chamois. *Zoology*, *118*(3), pp.213-219. https://doi.org/10.1016/j.zool.2015.01.003

Crookes, D.J. and Blignaut, J.N., 2015. Debunking the myth that a legal trade will solve the rhino horn crisis: A system dynamics model for market demand. *Journal for Nature Conservation*, *28*, pp.11-18. [PDF] Debunking the myth that a legal trade will solve the rhino horn crisis: A system dynamics model for market demand

Derkley, T., Biggs, D., Holden, M. and Phillips, C., 2019. A framework to evaluate animal welfare implications of policies on rhino horn trade. *Biological Conservation*, *235*, pp.236-249. https://www.sciencedirect.com/science/article/pii/S0006320718311947?casa_token=IIuTnh6e_PMAAAAA:Utjf4-mmqoRnyEALhbQD-AkUPElgAGmriyGxzqUusqlxSOzzQcAL213Plkn4fky89Hc1tMT5vsI

Di Minin, E., Laitila, J., Montesino-Pouzols, F., Leader-Williams, N., Slotow, R., Goodman, P.S., Conway, A.J. and Moilanen, A., 2015. Identification of policies for a sustainable legal trade in rhinoceros horn based on population projection and socioeconomic models. *Conservation Biology*, *29*(2), pp.545-555. https://conbio.onlinelibrary.wiley.com/doi/pdfdirect/10.1111/cobi.12412

Douglas-Hamilton, I., 1983. Elephants hit by African arms race: recent factors affecting elephant populations. *Pachyderm*, *2*, pp.11-13. https://pachydermjournal.org/index.php/pachyderm/article/download/559/538

Duthé, V., Odendaal, K., Van der Westhuizen, R., Church, B., Naylor, S., Boshoff, S., Venter, M., Prinsloo, M., Ngwenya, P., Hanekom, C. and Kelly, C.P., 2023. Reductions in home-range size and social interactions among dehorned black rhinoceroses

(Diceros bicornis). *Proceedings of the National Academy of Sciences*, *120*(25), p.e2301727120. https://www.pnas.org/doi/abs/10.1073/pnas.2301727120

Eikelboom, J.A., Nuijten, R.J., Wang, Y.X., Schroder, B., Heitkönig, I.M., Mooij, W.M., van Langevelde, F. and Prins, H.H., 2020. Will legal international rhino horn trade save wild rhino populations?. *Global Ecology and Conservation*, *23*, p.e01145. https://doi.org/10.1016/j.gecco.2020.e01145

Ellis, R., 2013. *Tiger bone & rhino horn: the destruction of wildlife for traditional Chinese medicine*. Island Press. http://www.rhinoresourcecenter.com/pdf_files/117/1175858271.pdf

Eming, S.A., Martin, P. and Tomic-Canic, M., 2014. Wound repair and regeneration: mechanisms, signaling, and translation. *Science translational medicine*, *6*(265), pp.265sr6-265sr6. https://www.science.org/doi/pdf/10.1126/scitranslmed.3009337

Emslie, R. and Brooks, M., 1999. Status survey and conservation action plan: African rhino. IUCN/SSC African Rhino Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. http://www.rhinoresourcecenter.com/pdf_files/117/1175863242.pdf

Emslie, R., 2020a. *Ceratotherium simum. The IUCN Red List of Threatened Species 2020: e. T4185A45813880* http://www.rhinoresourcecenter.com/pdf_files/158/1589193466.pdf

Emslie, R., 2020b. *Diceros bicornis. The IUCN red list of threatened species 2020: E. T6557A152728945* http://www.rhinoresourcecenter.com/pdf_files/158/1589193546.pdf

Ferreira, S.M., Balfour, D., Barichievy, C., Chege, G., Dean, C., Doak, N., Dublin, H.T., du Toit, R., Ellis, S., Emslie, R.H. and Flamand, J., 2024. Risky conclusions regarding shrinking rhino horns. *People and Nature*, *6*(3), pp.1015-1018. https://search.proquest.com/openview/ad1219addf667f12ef1f614a08da4d6c/1?pq-origsite=gscholar&cbl=4570187&casa_token=KTYOo5kCMc0AAAAA:wFLh3mqDEcC2BlLqfZul2HwW_3NTSse4j0yJuJPAi5H2tIhbf1SfHxHyjNb_6Mk20nypsMoGwg

Ferreira, S.M., Greaver, C., Knight, G.A., Knight, M.H., Smit, I.P. and Pienaar, D., 2015. Disruption of rhino demography by poachers may lead to population declines in Kruger National Park, South Africa. *PloS one*, *10*(6), p.e0127783. https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0127783&type=printable

Fischer, C., 2004. The complex interactions of markets for endangered species products. *Journal of Environmental Economics and Management*, *48*(2), pp.926-953. https://www.sciencedirect.com/science/article/pii/S0095069603001426

Fox, J and Weisberg, S., 2019. An R Companion to Applied Regression, 3rd Edition. Thousand Oaks, CA https://socialsciences.mcmaster.ca/jfox/Books/Companion/index.html

Garnier, J.N., Holt, W.V. and Watson, P.F., 2002. Non-invasive assessment of oestrous cycles and evaluation of reproductive seasonality in the female wild black rhinoceros (Diceros bicornis minor). *Reproduction*, *123*(6), pp.877-889. https://rep.bioscientifica.com/downloadpdf/view/journals/rep/123/6/877.pdf

Gao, Y., Stoner, K.J., Lee, A.T. and Clark, S.G., 2016. Rhino horn trade in China: An analysis of the art and antiques market. *Biological Conservation*, *201*, pp.343-347. https://doi.org/10.1016/j.biocon.2016.08.001

Gittleman, J.L. and Thompson, S.D., 1988. Energy allocation in mammalian reproduction. *American zoologist*, pp.863-875. https://repository.si.edu/bitstream/handle/10088/4360/Gittleman1988a.pdf?sequence=1&isAllowed=y

Grunschloss, S., 2016. *Association Between Horn Size Anthropometrical Parameters and Scrotal Circumference of Gemsbok Bulls (Oryx Gazella)* (Master's thesis, University of Pretoria (South Africa)). https://repository.up.ac.za/bitstream/handle/2263/63217/Grunschloss_Association_2017.pdf?sequence=1

Grymowicz, M., Rudnicka, E., Podfigurna, A., Napierala, P., Smolarczyk, R., Smolarczyk, K. and Meczekalski, B., 2020. Hormonal effects on hair follicles. *International journal*

of molecular sciences, *21*(15), p.5342. https://www.mdpi.com/1422-0067/21/15/5342?utm_campaign=DSL_resenas-de-champu-briogeo

Haas, T.C. and Ferreira, S.M., 2016. Combating rhino horn trafficking: The need to disrupt criminal networks. *PLoS One*, *11*(11), p.e0167040. https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0167040&type=printable

Haidt, A., Kamiński, T., Borowik, T. and Kowalczyk, R., 2018. Human and the beast—Flight and aggressive responses of European bison to human disturbance. *PLoS One*, *13*(8), p.e0200635. https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0200635&type=printable

Hamel, S. and Côté, S.D., 2008. Trade-offs in activity budget in an alpine ungulate: contrasting lactating and nonlactating females. *Animal Behaviour*, *75*(1), pp.217-227. https://www.sciencedirect.com/science/article/pii/S0003347207003867?casa_token=H-3XvuUQWU0AAAAA:eaHaUW0bB3h5_AOKl0sRy8Mf1nsoUXVUpDK1We1YYWUlCxXpUfuaViUPMrUo5KO65nDspt6Ku-c

Harper, C., Ludwig, A., Clarke, A., Makgopela, K., Yurchenko, A., Guthrie, A., Dobrynin, P., Tamazian, G., Emslie, R., Van Heerden, M. and Hofmeyr, M., 2018. Robust forensic matching of confiscated horns to individual poached African rhinoceros. *Current Biology*, *28*(1), pp.R13-R14. https://www.cell.com/current-biology/pdf/S0960-9822%2817%2931450-1.pdf

Hausdorf, B., 2021. A holistic perspective on species conservation. *Biological Conservation*, *264*, p.109375. https://www.sciencedirect.com/science/article/pii/S0006320721004274

Hieronymus, T.L., Witmer, L.M. and Ridgely, R.C., 2006. Structure of white rhinoceros (Ceratotherium simum) horn investigated by X-ray computed tomography and histology with implications for growth and external form. Journal of

Morphology, 267(10), pp.1172-1176. https://onlinelibrary.wiley.com/doi/pdf/10.1002/jmor.10465

Hillman-Smith, A.K.K., Owen-Smith, N., Anderson, J.L., Hall-Martin, A.J. and Selaladi, J.P., 1986. Age estimation of the white rhinoceros (Ceratotherium simum). *Journal of Zoology*, *210*(3), pp.355-377. http://www.rhinoresourcecenter.com/pdf_files/151/1519405897.pdf

Huber, K., 2018. Invited review: resource allocation mismatch as pathway to disproportionate growth in farm animals–prerequisite for a disturbed health. *Animal*, *12*(3), pp.528-536. https://www.sciencedirect.com/science/article/pii/S1751731117002051

International Union for Conservation of Nature (IUCN)., 2024. IUCN SSC African Rhino Specialist Group. Accessed on 23 January 2025. https://iucn.org/our-union/commissions/group/iucn-ssc-african-rhino-specialist-group

IUCN Species Survival Commission 2022. African and Asian Rhinoceroses – Status, Conservation and Trade. Report from the IUCN Species Survival Commission (IUCN SSC) African and Asian Rhino Specialist Groups and TRAFFIC. CoP19 Doc. 75: Annex 4. Working document for CITES CoP19

Jagwanth, S. and Thipanyane, T.S., 1993. Gun control in South Africa: A critical review. *S. Afr. J. Crim. Just.*, *6*, p.21. https://heinonline.org/hol-cgi-bin/get_pdf.cgi?handle=hein.journals/soafcrimj6&section=9&casa_token=MNPSnd4c1QUAAAAA:QQfHwNW70TKMfcNuB7vcUnTltd8pV0ZRa4lUaDwZjshntix8EFB2EIMUUzBnoDvF4fYjyRn3xw

Jakins, C., 2018. A discussion of rhino horn domestic trade legalisation in South Africa. *Acta Criminologica: African Journal of Criminology & Victimology*, *31*(4), pp.169-185. https://www.researchgate.net/profile/Catherine-Jakins/publication/330909899_A_discussion_of_rhino_horn_domestic_trade_legalisation_in_South_Africa/links/5d3818b4299bf1995b457064/A-discussion-of-rhino-horn-domestic-trade-legalisation-in-South-Africa.pdf

Jones, P.D., Strickland, B.K., Demarais, S., Wang, G. and Dacus, C.M., 2018. Nutrition and ontogeny influence weapon development in a long-lived mammal. *Canadian Journal of Zoology*, *96*(9), pp.955-962. https://utoronto.scholaris.ca/bitstreams/1455e4bc-1000-4989-887a-3fa07592f23a/download

Kalabusheva, E.P., Shtompel, A.S., Rippa, A.L., Ulianov, S.V., Razin, S.V. and Vorotelyak, E.A., 2023. A kaleidoscope of keratin gene expression and the mosaic of its regulatory mechanisms. *International Journal of Molecular Sciences*, *24*(6), p.5603. https://www.mdpi.com/1422-0067/24/6/5603/pdf

Kettles, R. and Slotow, R., 2009. Management of free-ranging lions on an enclosed game reserve. *South African Journal of Wildlife Research-24-month delayed open access*, *39*(1), pp.23-33. https://journals.co.za/doi/pdf/10.10520/EJC117310

KILTIE, R.A., 1985. Evolution and function of horns and hornlike organs in female ungulates. *Biological Journal of the Linnean Society*, *24*(4), pp.299-320. https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1095-8312.1985.tb00377.x?casa_token=KrlaIMu3gjYAAAAA:UR1EvKicHstLpGqAj0S3sF5oUe27vg2mO6wkA6FpPg9cxzGVnY7gchTA_9H4_VnhCjapB4QKUdAwMg

Kirkwood, T.B., 2005. Understanding the odd science of aging. *Cell*, *120*(4), pp.437-447. https://www.cell.com/fulltext/S0092-8674(05)00101-7

Ladendorf, B. and Ladendorf, B., 2023. HOW MYTHS AND SUPERSTITIONS ARE DRIVING ANIMAL EXTINCTIONS. *Unreason: Best of Skeptical Inquirer*, p.136. https://books.google.com/books?hl=en&lr=&id=XIjVEAAAQBAJ&oi=fnd&pg=PA136&dq=party+drug+rhino+horn+&ots=o8KHL2JbJK&sig=efN5PTYvTFA5w5fzXgvY3koeMX8

Lemaître, J.F., Ronget, V., Tidière, M., Allainé, D., Berger, V., Cohas, A., Colchero, F., Conde, D.A., Garratt, M., Liker, A. and Marais, G.A., 2020. Sex differences in adult lifespan and aging rates of mortality across wild mammals. *Proceedings of the National Academy of Sciences*, *117*(15), pp.8546-8553. https://www.pnas.org/doi/pdf/10.1073/pnas.1911999117

Liu, R., Wang, M., Duan, J.A., Guo, J.M. and Tang, Y.P., 2010. Purification and identification of three novel antioxidant peptides from Cornu Bubali (water buffalo horn). *Peptides*, *31*(5), pp.786-793. https://doi.org/10.1016/j.peptides.2010.02.016

Low, B.S., 2013. Life History and Ecological Aspects. *Evolution's Empress: Darwinian Perspectives on the Nature of Women*, p.222. https://books.google.com/books?hl=en&lr=&id=7lC4-Db2S2kC&oi=fnd&pg=PA222&dq=Mammalian+reproductive+strategies:+an+evolutionary-ecological+perspective&ots=wqDDgsIvH8&sig=4bBNv_cP9OtSqXVbVbWpB8Q209M

Mamba, H.S., 2018. Human and Climate Change Influences on Black (Diceros bicornis) and White (Ceratotherium simum) Rhinos in Southern Africa. https://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1674&context=masters_theses_2

Milne, J.A., 1991. Diet selection by grazing animals. *Proceedings of the Nutrition Society*, *50*(1), pp.77-85. https://www.cambridge.org/core/services/aop-cambridge-core/content/view/49DFC992092860B74D0B3DCD751DAD61/S0029665191000162a.pdf/diet-selection-by-grazing-animals.pdf

Milner-Gulland, E.J., Beddington, J.R. and Leader-Williams, N., 1992. Dehorning African rhinos: a model of optimal frequency and profitability. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *249*(1324), pp.83-87. https://royalsocietypublishing.org/doi/abs/10.1098/rspb.1992.0087

Milner-Gulland, E.J., Williams, L. and Beddington, J.R., 1993. Is dehorning African rhinos worthwhile?. *Pachyderm*, *17*, pp.52-58. https://pachydermjournal.org/index.php/pachyderm/article/download/783/762

Moodley, Y., Russo, I.R.M., Dalton, D.L., Kotzé, A., Muya, S., Haubensak, P., Bálint, B., Munimanda, G.K., Deimel, C., Setzer, A. and Dicks, K., 2017. Extinctions, genetic erosion and conservation options for the black rhinoceros (Diceros bicornis). *Scientific reports*, *7*(1), p.41417. file:///C:/Users/Student/Downloads/srep41417.pdf

Moyes, K., Nussey, D.H., Clements, M.N., Guinness, F.E., Morris, A., Morris, S., Pemberton, J.M., Kruuk, L.E. and CLUTTON-BROCK, T.H., 2011. Advancing breeding phenology in response to environmental change in a wild red deer population. *Global change biology*, *17*(7), pp.2455-2469. https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2486.2010.02382.x?casa_token=6tqEE7QqBvYAAAAA:FQucIYXkGHUaEsw_kJKCwDLxhrhqNLw5VqDQdtisH8a-eABtegEjtliXBGgk2NfXrZuOUYQRtnPs2Q

Nadal, A. and Aguayo, F., 2016. Use or destruction: on the economics of ivory stockpiles. *Pachyderm*, *57*, pp.57-67. https://pachydermjournal.org/index.php/pachyderm/article/download/391/394

Ndlovu, L., 2023. The effects of resource variability on the demographic rates of black and white rhinoceroses. https://wiredspace.wits.ac.za/bitstreams/abccef78-a380-4d3a-8c57-807b47a0009c/download

Nugent-Head, J., 2014. The First Materia Medica: The Shen Nong Ben Cao Jing. *Journal of Chinese Medicine (JCM)*, (104). https://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=01438042&AN=94786476&h=sqH6pVYlQxb%2F5lQh1vrE5ixxm6SkGuWpGH8cCJ0eGTA77c98TUJNPaDA8Hjdvulp%2Fv7FRZybyXoI0C7l2Ep7OQ%3D%3D&crl=c

Oftedal, O.T., 2018. Pregnancy and lactation. In *Bioenergetics of wild herbivores* (pp. 215-238). CRC Press. https://www.taylorfrancis.com/chapters/edit/10.1201/9781351070218-10/pregnancy-lactation-oftedal

Okita-Ouma, B., Pettifor, R., Clauss, M. and Prins, H.H., 2021. Effect of high population density of eastern black rhinoceros, a mega-browser, on the quality of its diet. *African Journal of Ecology*, *59*(4), pp.826 841. https://onlinelibrary.wiley.com/doi/pdf/10.1111/aje.12893

Osthoff, G., Beukes, B., Steyn, A.C., Hugo, A., Deacon, F., Butler, H.J., O'Neill, F.H. and Grobler, J.P., 2021. Milk composition of white rhinoceros over lactation and comparison with other Perissodactyla. *Zoo Biology*, *40*(5), pp.417-428. https://onlinelibrary.wiley.com/doi/pdf/10.1002/zoo.21618?casa_token=M42ukVQUTysAAAAA:EQ-c1fBb6B1byHrrjj-oFhsOpv76LDLzxIOnvoKwnzUxv-sewkxzt_rwq4A-Gx_XXodVxzeoc-X9TA

Owen-Smith, R.N., 1988. *Megaherbivores: the influence of very large body size on ecology*. Cambridge university press. https://books.google.com/books?hl=en&lr=&id=1jT72JdLVIcC&oi=fnd&pg=PR13&dq=Megaherbivores:+The+influence+of+very+large+body+size+on+ecology.&ots=VRrzGgNd60&sig=8zRhFESa77gesAR6aGyjZ-9qss8

Patton, F.J., 2021. A rudimentary assessment of rhinoceros horn regrowth in Africa based on photographs. *Pachyderm*, *62*, pp.135-142. https://pachydermjournal.org/index.php/pachyderm/article/download/285/465

Penny, S.G., 2019. *The impact of dehorning on the white rhinoceros (Ceratotherium simum) and the evaluation of novel anti-poaching tactics* (Doctoral dissertation, University of Brighton). https://research.brighton.ac.uk/files/21323059/Penny_2019_doctoral_thesis.pdf

Penny, S.G., White, R.L., MacTavish, L., Scott, D.M. and Pernetta, A.P., 2020. Negligible hormonal response following dehorning in free-ranging white rhinoceros (Ceratotherium simum). *Conservation Physiology*, *8*(1), p.coaa117. https://academic.oup.com/conphys/article/8/1/coaa117/6054544

Penny, S.G., White, R.L., Scott, D.M., MacTavish, L. and Pernetta, A.P., 2021. No evidence that horn trimming affects white rhinoceros horn use during comfort behaviour and resource access. *Animal Biology*, *71*(3), pp.243-259. https://research.brighton.ac.uk/files/23195223/Penny_et_al_Animal_Biology_accepted_author_manuscript.pdf

Penny, S.G., Withey, M., White, R.L., Scott, D.M., MacTavish, L. and Pernetta, A.P., 2022. Changes in social dominance in a group of subadult white rhinoceroses

(Ceratotherium simum) after dehorning. *African Zoology*, *57*(1), pp.32-42. https://zslpublications.onlinelibrary.wiley.com/doi/pdfdirect/10.1111/jzo.13115

Pfannerstill, V., Härdtner, R., Maboga, O.S., Balkenhol, N., Bennitt, E. and Scheumann, M., 2023. Dehorning impacts white rhinoceros behaviour less than social events: evidence from Botswana. *Journal of Zoology*, *321*(4), pp.249-259. [PDF] https://zslpublications.onlinelibrary.wiley.com/doi/pdfdirect/10.1111/jzo.13115

Pienaar, D.J., Hall-Martin, A.J. and Hitchins, P.M., 1991. Horn growth rates of free-ranging white and black rhinoceros. *Koedoe*, *34*(2), pp.97-105. https://koedoe.co.za/index.php/koedoe/article/view/426/421

Rachlow, J.L. and Berger, J., 1997. Conservation implications of patterns of horn regeneration in dehorned White Rhinos: implicaciones conservacionsitas de los Patrones de Regeneración de Cuernos en Rinocerontes Descornados. *Conservation Biology*, *11*(1), pp.84-91. https://conbio.onlinelibrary.wiley.com/doi/pdf/10.1046/j.1523-1739.1997.95523.x

Rachlow, J.L., 1997. *Demography, behavior, and conservation of white rhinos*. University of Nevada, Reno. https://www.researchgate.net/profile/Janet-Rachlow/publication/35277867_Demography_behavior_and_conservation_of_white_rhinos/links/0deec52f5239a43869000000/Demography-behavior-and-conservation-of-white-rhinos.pdf

Rachlow, J.L., Kie, J.G. and Berger, J., 1999. Territoriality and spatial patterns of white rhinoceros in Matobo National Park, Zimbabwe. *African Journal of Ecology*, *37*(3), pp.295-304. https://onlinelibrary.wiley.com/doi/pdf/10.1046/j.1365-2028.1999.00175.x?casa_token=6nWk8KbGCr4AAAAA:Qb_fmO9Lhq73IiQ9pNiOSDF68itiIwSuFIl55Leg5go4IM-39eNxrMT4eAdd9xlRuob9ck0rMlIojw

Rademeyer, J., 2012. *Killing for profit: Exposing the illegal rhino horn trade*. Penguin Random House South Africa. https://books.google.co.uk/books?hl=en&lr=&id=GQxbDwAAQBAJ&oi=fnd&pg=PT7&dq=rhino+horn+party+drug+use&ots=d0qy7SvEpF&sig=guGBp-

220L9EpPjhihBd_1uZqYA&redir_esc=y#v=onepage&q=rhino%20horn%20party%20drug%20use&f=false

Rademeyer, J., 2016. Tipping point: transnational organised crime and the 'war'on poaching. *Global Initiative against Transnational Organized Crime, Geneva*. https://globalinitiative.net/wp-content/uploads/2016/07/TGIATOC-Tipping-Point_-Transnational-organised-crime-and-the-%E2%80%98war%E2%80%99-on-poaching-web.pdf

Revelle, W., 2024. _psych: Procedures for Psychological, Psychometric, and Personality Research_. Northwestern University, Evanston, Illinois. R package version 2.4.12, https://CRAN.R-project.org/package=psych

Ricklefs, R.E. and Wikelski, M., 2002. The physiology/life-history nexus. *Trends in ecology & evolution*, *17*(10), pp.462-468. https://www.sciencedirect.com/science/article/pii/S0169534702025788?casa_token=8m0GOOb9MxEAAAAA:DRKATjPPTb_oCzaKcoTzN7RN2OTBlSfC5jJpyFXM9EefsqQTuFvWxXq8K64VsuoW85l0EK7C_tM

Robbins, C., 2012. *Wildlife feeding and nutrition*. Elsevier. https://books.google.com/books?hl=en&lr=&id=rkc-S6Lwe7wC&oi=fnd&pg=PP1&dq=Wildlife+feeding+and+nutrition.&ots=6WDJhTDt86&sig=t1qAWw6pwNBP24xdmy97ECaqg9o

Rogowitz, G.L., 1996. Trade-offs in energy allocation during lactation. *American Zoologist*, *36*(2), pp.197-204. https://academic.oup.com/icb/article-pdf/36/2/197/343635/36-2-197.pdf

Roth, T.L., Rebolloso, S.L., Donelan, E.M., Rispoli, L.A. and Buchweitz, J.P., 2024. Rhinoceros horn mineral and metal concentrations vary by sample location, depth, and color. *Scientific Reports*, *14*(1), p.13808. https://www.nature.com/articles/s41598-024-64472-z.pdf

Ruggeri, E., Klohonatz, K., Sirard, M.A., Durrant, B. and Coleman, S., 2023. Genomic insights into southern white rhinoceros (Ceratotherium simum simum) reproduction:

Revealing granulosa cell gene expression. *Theriogenology Wild*, *3*, p.100055. https://www.sciencedirect.com/science/article/pii/S2773093X23000399

Ruggeri, E., Klohonatz, K., Durrant, B. and Sirard, M.A., 2024. Identification and Preliminary Analysis of Granulosa Cell Biomarkers to Predict Oocyte In Vitro Maturation Outcome in the Southern White Rhinoceros (Ceratotherium simum simum). *Animals*, *14*(23), p.3538. https://www.mdpi.com/2076-2615/14/23/3538

Ruggiero, R., 1990. The effects of poaching disturbance on elephant behaviour. *Pachyderm*, *13*, pp.42-44. 1628258421.pdf

Rughetti, M. and Festa-Bianchet, M., 2011. Effects of early horn growth on reproduction and hunting mortality in female chamois. *Journal of Animal Ecology*, *80*(2), pp.438-447. https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2656.2010.01773.x

Ryder, O.A., Friese, C., Greely, H.T., Sandler, R., Saragusty, J., Durrant, B.S. and Redford, K.H., 2020. Exploring the limits of saving a subspecies: The ethics and social dynamics of restoring northern white rhinos (Ceratotherium simum cottoni). *Conservation Science and Practice*, *2*(8), p.e241. https://conbio.onlinelibrary.wiley.com/doi/pdf/10.1111/csp2.241

Santiago-Moreno, J., Gómez-Brunet, A., Toledano-Díaz, A., González-Bulnes, A., Picazo, R.A. and López-Sebastián, A., 2005. Influence of age on the relationship between annual changes in horn growth rate and prolactin secretion in the European mouflon (Ovis gmelini musimon). *Animal reproduction science*, *85*(3-4), pp.251-261. https://www.sciencedirect.com/science/article/pii/S0378432004001186?casa_token=1o2vwU0NOXAAAAAA:re2YHNj3HvJwWUecBEf6ANrPXgeyvJawDS0PPNtqlwX8tr-wBsmTSglqfxB7Sy5I0a0QpDGYovo

Selati Game Reserve. n.d. *Biodiversity - Selati Game Reserve*. https://www.selatigamereserve.co.za/biodiversity/ Last Accessed: 22/03/2025

Shrader, A.M., Owen-Smith, N. and Ogutu, J.O., 2006. How a mega-grazer copes with the dry season: food and nutrient intake rates by white rhinoceros in the

wild. *Functional ecology*, pp.376-384. http://www.rhinoresourcecenter.com/pdf_files/117/1177316075.pdf

Singer, N.F., 1991. Rhino Horn and Elephant Ivory. *Arts of Asia*, *21*(5), pp.98-105. http://www.rhinoresourcecenter.com/pdf_files/128/1284804851.pdf

Stearns, S.C., 1989. Trade-offs in life-history evolution. *Functional ecology*, *3*(3), pp.259-268. https://stearnslab.yale.edu/sites/default/files/21.stearnsfunctecol1989.pdf

Taylor, A., Balfour, D., Brebner, D.K., Coetzee, R., Davies-Mostert, H., Lindsey, P.A. and Shaw, J., 2017. Sustainable rhino horn production at the pointy end of the rhino horn trade debate. *Biological Conservation*, *216*, pp.60-68. https://doi.org/10.1016/j.biocon.2017.10.004

Tombolato, L., Novitskaya, E.E., Chen, P.Y., Sheppard, F.A. and McKittrick, J., 2010. Microstructure, elastic properties and deformation mechanisms of horn keratin. *Acta biomaterialia*, *6*(2), pp.319-330. https://www.sciencedirect.com/science/article/pii/S1742706109002852?casa_token=6FwbcHBS9bUAAAAA:EDQTKRp9n-Kwf7rgDjXSvbCDRMWglcaOnDywZlw4Mo4IhNMs51ea8p3XdK3p8rrlgCtCh4jXsnU

Tonnesen, M.G., Feng, X. and Clark, R.A., 2000, December. Angiogenesis in wound healing. In *Journal of investigative dermatology symposium proceedings* (Vol. 5, No. 1, pp. 40-46). Elsevier. https://www.sciencedirect.com/science/article/pii/S0022202X15528571

Traill, L.W., Schindler, S. and Coulson, T., 2014. Demography, not inheritance, drives phenotypic change in hunted bighorn sheep. *Proceedings of the National Academy of Sciences*, *111*(36), pp.13223-13228. https://www.pnas.org/doi/pdf/10.1073/pnas.1407508111

Tubbs, C., McDonough, C.E., Felton, R. and Milnes, M.R., 2014. Advances in conservation endocrinology: the application of molecular approaches to the conservation of endangered species. *General and Comparative Endocrinology*, *203*, pp.29-34.

https://www.sciencedirect.com/science/article/pii/S0016648014000562?casa_token=OCXu7WkYpLoAAAAA:jnuf8h3hjAPLm-Uv9iek7xBxtb8a6EU_pGUX9YJNbkf3RX58m08E0A8bFJdxTS88XNi12QT5kuw

t'Sas-Rolfes, M., Moyle, B. and Stiles, D., 2014. The complex policy issue of elephant ivory stockpile management. *Pachyderm*, *55*, pp.62-77. https://pachydermjournal.org/index.php/pachyderm/article/download/355/313

Ververs, C., Hostens, M., Otto, M., Govaere, J., Van Soom, A. and van Zijll Langhout, M., 2018. The effect of dehorning and other potential factors influencing horn growth in game-ranched white rhinoceroses (Ceratotherium simum simum). *BREEDING ON THE BRINK OF EXTINCTION*, p.71. http://www.rhinoresourcecenter.com/pdf_files/153/1531917954.pdf#page=79

Videmšek, B. and Videmšek, M.P., 2023. *The Last Two: The Battle to Save the Northern White Rhinos*. Rowman & Littlefield. https://books.google.co.uk/books?hl=en&lr=&id=ibO7EAAAQBAJ&oi=fnd&pg=PR9&dq=white+rhino+fatu+najin&ots=PSI0LFd60f&sig=CkIP0fyYYCOzfAyH72itm5vg71c&redir_esc=y#v=onepage&q=white%20rhino%20fatu%20najin&f=false

Waldram, M.S., Bond, W.J. and Stock, W.D., 2008. Ecological engineering by a mega-grazer: white rhino impacts on a South African savanna. *Ecosystems*, *11*, pp.101-112. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=367806b4b29eafbcfd264f1542a8cad9f058ecba

Werner, S. and Grose, R., 2003. Regulation of wound healing by growth factors and cytokines. *Physiological reviews*, *83*(3), pp.835-870. https://journals.physiology.org/doi/pdf/10.1152/physrev.2003.83.3.835

Whyte, I. and Hall-Martin, A., 2018. Growth characteristics of tusks of elephants in Kruger National Park. *Pachyderm*, *59*, pp.31-40. https://pachydermjournal.org/index.php/pachyderm/article/download/78/39

Wootton, R.J., 1993. The evolution of life histories: theory and analysis. *Reviews in Fish Biology and Fisheries*, *3*(4), pp.384-385.

https://www.academia.edu/download/67537490/bf0004339420210606-19302-8m7rzp.pdf

Yang, S., 2011. A review of rhinoceros horn. *ENGR3810 Structural Biomaterials*, pp.1-10. http://www.rhinoresourcecenter.com/pdf_files/133/1331459082.pdf

Yang, X., Cui, Y., Yue, J., He, H., Yu, C., Liu, P., Liu, J., Ren, X. and Meng, Y., 2017. The histological characteristics, age-related thickness change of skin, and expression of the HSPs in the skin during hair cycle in yak (Bos grunniens). PLoS One, 12(5), p.e0176451. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0176451

Zhang, M., Zhang, Z., Chen, J., Cirella, G.T. and Xie, Y., 2024. Understanding and Mitigating the Purchase Intention of Medicines Containing Saiga Antelope Horn among Chinese Residents: An Analysis of Influencing Factors. *Diversity*, *16*(1), p.49. https://www.mdpi.com/1424-2818/16/1/49/pdf

Appendix B - The Dehorning Process: A Comprehensive Overview

Written based on the observations of wildlife veterinarians Dr. Joel Alves and Dr. Ben Muller, along with Madeline Siegel and Steven Seager (personal communication).

Prior to commencing the dehorning process, it is essential to acquire all necessary permits in advance and to ensure the presence of representatives from relevant government agencies at each dehorning session to oversee the procedure and verify the licenses.

The dehorning process is initiated by using a plane to locate the rhinoceros, which is subsequently tranquillised and guided to a suitable open area devoid of vegetation, if feasible, with the aid of a helicopter. When dealing with *C. s. simum*, tranquilisation is administered in the neck, shoulder, or thigh muscles using 4 mg of Etorphine and 40 mg of Azaperone. Subadults are tranquilised with 1.5–3 mg of Etorphine and 10–20 mg of Azaperone, while calves, typically over 1 year old, are tranquilised with 0.5–2 mg of Etorphine and 5–20 mg of Azaperone. For *D. b. minor*, tranquilisation is similar, with the addition of 2–0.5 mg of Thiafentanil. Both rhinoceroses receive 5000IU of Hyaluronidase (which is used to reduce stress to the animal and increase absorption rates, as well as any necessary treatments or supplements. *C. s. simum* additionally get given a partial reversal of Butorphanol before the dehorning commences. The tranquilisation cocktail is tailored based on the rhino's body size, age, and overall condition. The tranquilisation phase typically lasts 2-5 minutes for *C. s. simum* and approximately 5-7 minutes for *D. b. minor*.

Following immobilisation, the ground team steps in. Veterinarians play a crucial role in stabilising the rhino by monitoring its heart rate, providing oxygen, covering its eyes, and inserting earplugs into the rhinoceros's ears to reduce external stimuli. If the rhino is over 5 years old, an AI monitoring collar is attached to its ankle, which is used to monitor the rhino expected daily for the next 2 years. During a rhino's initial dehorning, an ear notch is made, a microchip is implanted, and a DNA sample is collected from the rhino's right ear. These measures are key for identifying the rhinos.

Before dehorning, measurements of the posterior and anterior horns are taken, including height and circumference. These measurements are also taken after the horn

is removed for record-keeping purposes. Once the measurements are completed, the veterinarian marks four fingers around the anterior horn and approximately an inch on the posterior horn with chalk. An electric chainsaw is then used to remove the horns. Depending on the veterinarian, the horn will either be left with a square cut or the edges will be rounded off to prevent any damage or irregular growth. Afterward, a hoof solution, typically used on horses, is applied over the top of the cut horns to fill in any cracks and assist in regrowth.

Following the procedure, veterinarians will administer Naltrexone for a full reversal of the initial drugs to gently awaken the rhinoceros. The entire dehorning process should only take between 20 to 40 minutes to minimise stress on the rhinoceros. The rhinos will be monitored through game drives and, if equipped, their collars for the next couple of days.