RESEARCH ARTICLE

Conservation impacts and the future of the black rhinoceros (*Diceros bicornis*)

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The African black rhinoceros (black rhino) as a species is critically endangered on the Red List of the International Union for the Conservation of Nature (IUCN). This list categorizes threatened species assessed for risks of extinction. The IUCN Green Status is a new global standard of measurement created by IUCN to help show how a species is functioning within the ecological system it inhabits, and how much it has recovered thanks to conservation action. For the new Green Status, we provide an assessment of four conservation impact measures for the black rhino – conservation legacy, conservation dependence, conservation gain and recovery potential. Time sequences of estimates for four subspecies of black rhinos, collated from data provided by range States and various sources in the literature, provide the basis of this evaluation. Our findings reveal that in the absence of conservation interventions, the year 2022 would only have seen 296 black rhinos compared to 6487 reported, a legacy of 6191 individuals. If conservation interventions had been stopped in 2022, there would be 3354 black rhinos in 2032, *i.e.* there is a conservation dependence of 3133 rhinos. If conservation interventions continue, there will be 8943 black rhinos in 2032, a conservation gain of 2456 individuals, compared to the number in 2022. Various global change drivers contribute to available habitat for 20 952 black rhinos in 2122. Our analysis illustrated that the rhino recovery potential by 2022 was 14 465. For this to continue and materialize fully, the authorities will need to consider introducing ecological equivalent subspecies into available habitat, within ranges of extinct subspecies.

Keywords: black rhino, Green Status, conservation legacy, recovery potential, Africa.

INTRODUCTION

The number of African black rhinoceros (rhino) (*Diceros bicornis*) declined precipitously from an estimated 100 000 around the 1900s to less than 2400 in the mid-1990s (Emslie & Brooks, 1999). Although impressive recovery through dedicated conservation efforts resulted in ~6500 black rhinos by 2022 (Knight, Mosweu & Ferreira, 2023), the species remains critically endangered (Emslie, 2020). One of the subspecies, the Western black rhino (*D. b. longipes*) became extinct earlier this century, while the three extant subspecies have low numbers: Eastern black rhino (*D. b. michaeli*) – 1319; South-central black rhino (*D. b. minor*) – 2532; and South-western black rhino (*D. b. bicornis*) – 2636 (updated from Knight *et al.*, 2023).

The primary reasons linked to the decline in numbers of black rhinos are poaching (Linklater, 2003) and habitat loss (Amin, Thomas, Emslie, Foose & Strien, 2006). Authorities responded, and range States implemented various plans, including innovative biological management (Balfour, Barichievy, Gordon & Brett, 2019), such as translocations that re-introduced rhinos into their previous ranges (Sheriffs, 2006), as well as managing populations to maintain annual growths exceeding 5% (Emslie & Brooks, 1999). In recent years, concepts of meta-population management of rhinos in a network of populations started emerging

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(Barichievy *et al.*, 2021). Creating safe habitats, however, is a key intervention made by providing rhino protection at the protected area level (Chanyandura, Muposhi, Gandiwa & Muboko, 2021), while addressing transnational organized crime (Ayling, 2013). At the end of 2021, 20 African range States had rhino conservation plans active, under review or in development. Range States reported 94.6% partial or full achievement of their assessed objectives (Ferreira *et al.*, 2022).

The International Union for the Conservation of Nature (IUCN) Red List of Threatened Species assesses the risk of extinction (IUCN, 2024). The IUCN Green Status, in contrast, assesses the recovery of species in their natural habitat and measures conservation success (Grace *et al.*, 2021; see also www.iucnredlist.org/about/green-status-species). The Green Status assesses a species based on whether it is present, viable and performing its ecological functions in all parts of its range (Akçakaya *et al.*, 2018), and a Green Score ranging from 0–100% is generated.

The goal of the Green Status is not to have all species fully recovered as this is unrealistic. But it can serve as a measure of progress in recovery through measuring the impact of conservation activities. To this end, four key metrics are of importance (Akçakaya *et al.* 2018; Fig. 1): (1) *Conservation Legacy* reflects the impact of past conservation interventions; (2) *Conservation Dependence* focuses on what is predicted to happen over the next ten years, should current conservation actions cease; (3) *Conservation Gain* measures the change expected to occur within the next ten years brought by conservation actions; and (4) *Recovery Potential* reflects what is potentially achievable given the state of the world today and trends in global environmental change drivers. It relies on what proportion of the historical range authorities could expect to restore functional populations. These Green Status measures provide key information that can help prioritize initiatives seeking to restore the status as well as socio-ecological function of the critically endangered African black rhino. We provide estimates of these key metrics that help assess the impact of conservation actions on the species' past recovery, as well as its potential recovery in the longer term.

METHODS

The African Rhino Specialist Group (AfRSG) of the IUCN Species Survival Commission (SSC) collated rhino estimates for four black rhino subspecies from various sources with results reflected in an extensive, but incomplete time sequence series (available on request from the Scientific Officer within compliance to the AfRSG Data

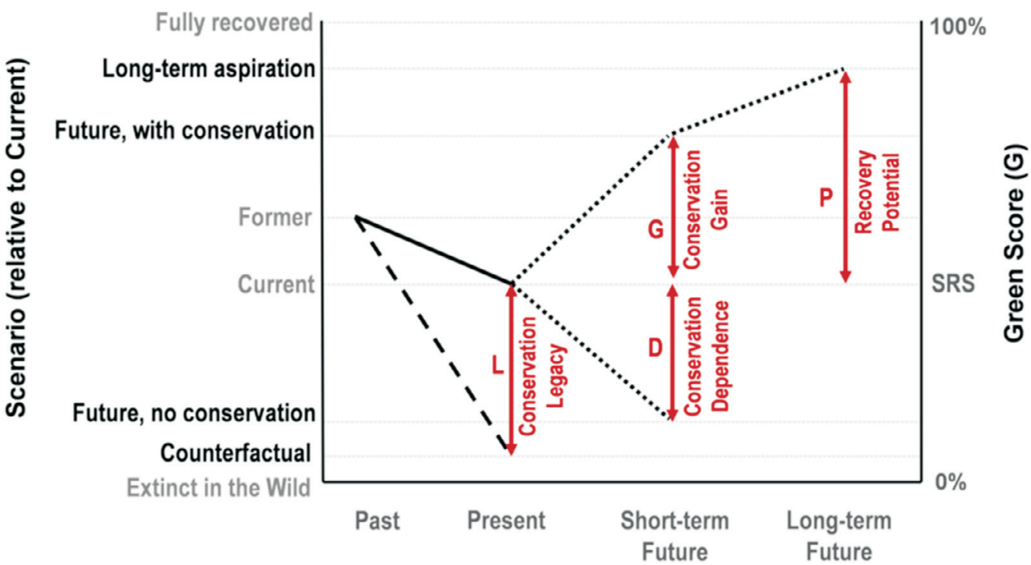

Fig. 1. The four metrics of conservation assessed for the Green Status of Species. The Green Score (G) (right *y*-axis) is estimated at each of the scenarios in bold on the left *y*-axis. Contextual reference points are also provided on the left *y*-axis. The differences between the Green Score generated under a scenario and the current Green Score (*i.e.* the Species Recovery Score, labelled SRS) produce the four Conservation Metrics (red arrows and text) (Adapted from Akçakaya *et al.*, 2018).

Access and Use Policy). We made use of Microsoft Excel to make calculations and estimate various parameters from the incomplete time series of estimates. The missing data in a time series (no years for *D. b. bicornis*, three years for *D. b. minor*, no years for *D. b. michaeli*, no years for *D. b. longipes*) were estimated through interpolation between time t and $t+x$, using the model $N_{t+x} = e^{rx}N_t$ assuming that an exponential model typically reflects year to year changes in rhino dynamics (*e.g.* Ferreira, Greaver & Knight, 2011) where N_t is the population estimate of a subspecies at time t and r is the exponential growth rate.

To obtain estimates back to 1970 (three missing years for *D. b. bicornis*, eight years for *D. b. minor*, ten years for *D. b. michaeli*, eight years for *D. b. longipes*), the analysis used the earliest eight available estimates in a time series based on the generation length (T) (see estimation below), to calculate exponential population change per annum (r). For this purpose, generation length used a definition of the time it takes for the population to grow by a factor of its net reproductive rate. $T = (\log R_0)/r$, where R_0 is the number of female calves a cow is expected to produce in a lifetime (Charlesworth, 1994). Age at first birth was 6.75 years old, age at last birth was 35 years old, translating to on average 28.25 reproductive years, while calving interval was every 2.5 years (Skinner & Chimimba, 2005). The population growth (r) is when there are no resource limitations and set at 8% based on the upper confidence intervals of performances in small areas, such as Marakele National Park (Ferreira & Greaver, 2016) and large areas, such as Kruger National Park (Ferreira, Greaver & Knight, 2011), both in South Africa. The analysis used the exponential model above assuming exponential population change to predict populations back to 1970.

The above procedure produced a time series of estimates for each subspecies. Point estimates for black rhinos irrespective of subspecies were derived from the sum of the estimates of the subspecies.

Past and current population status

Past status is the estimates for each of the subspecies of black rhino as extracted from the AfRSG database. Range States reported the number of rhinos within each country by the end of 2022. The totals of each black rhino subspecies, as well as all together disregarding subspecies, served as the current population status (updated from Knight *et al.*, 2023). Note that the taxonomy of black rhinos is under review and the attribution of a relevant subspecies to a specific population within a range State can carry uncertainty. For the Green Status Assessment, the analysis used the recent extant subspecies' distribution maps (Moodley *et al.*, 2017).

Conservation legacy

Conservation legacy reflects the outcome at present if there were no conservation actions taken. Overharvesting, and particularly illegal killing, reduced black rhino populations (Linklater, 2003) while land-use by increasing numbers of people reduced and fragmented habitats (Amin *et al.*, 2006). To predict what the outcome would have been for black rhinos without conservation interventions, we focused on the four subspecies extant in 1970. Reflecting on the estimates since 1970, South-western black rhinos declined from 1970 to 1984, South-central black rhinos from 1970 to 1994, Eastern black rhinos from 1970 to 1997, and the extinct Western black rhino from 1970 to 2003. We calculated the exponential rate of decline since 1970 by using the estimates in the years of decline and fitting the model $N_{t+1} = e^r N_t$, where N_t is the population estimate of a subspecies at time t and r is the exponential growth rate. To fit this model, we fitted $\ln(N_t)$ against t and used the linear regression function in Microsoft Excel for each subspecies. The slope and the estimated confidence interval of the slope of the regression line are estimates of r and its confidence interval, respectively.

We assumed that without conservation interventions the decline would have continued at the same rates as during the historical periods when rhinos were declining. We defined a 'base year' estimate for a subspecies as the year when the declining stopped and extracted the point estimate in 1984 for South-western black rhinos, 1994 for South-central black rhinos and 1997 for Eastern black rhinos. Western black rhinos are already extinct and thus the conservation legacy will be zero. We forecasted likely population sizes for each subspecies in 2022 using the model $N_t = e^{rt}N_0$, where N_0 is the population estimate in the base year for a specific subspecies and t the number of years from the base year to 2022. To accommodate variation in annual growth rates in our forecasts, we used functions in Microsoft Excel to randomly draw an exponential growth rate from the statistical distribution assumed to be normal, described by the estimated r and its confidence interval to estimate the likely 2022 population size for each subspecies 100 000 times. The median of this sample reflects the likely outcome with the 2.5% and 97.5% percentile representing the confidence intervals in the absence of conservation actions. The difference between the actual status in 2022 and the forecasted status reflects the conservation legacy.

Conservation dependence

Conservation dependence reflects the outcome in ten years in the absence of conservation, using the 2022 status of black rhinos. In this case, we assumed that without conservation, the decline would continue at similar rates as the historical periods when rhinos were declining. We used the estimated rates of decline to make predictions for 2032, a realistic timeframe for rhino conservation plans and initiatives (Ferreira *et al.*, 2022).

As before, we used the model $N_t = e^{rt}N_0$, where N_0 is the population estimate in 2022 for a specific subspecies and t has a value of 10 to predict the likely population size in 2032. We again randomly drew an exponential growth rate from the statistical distribution, this assumed to be normal, and described by the estimated r and its confidence interval, to estimate the likely 2032 population size for each subspecies 100 000 times. The median of this sample reflects the likely outcome with the 2.5% and 97.5% percentiles as confidence intervals in the absence of conservation actions. The difference between the actual status in 2022 and the forecasted status for 2032, should there be no conservation actions, reflects the conservation dependence.

Conservation gain

Conservation gain reflects the population size in 2032, a decade following the status in 2022. We assumed that the recent conservation interventions by range States (see Ferreira *et al.*, 2022) would most likely continue and thus reflect the impact of conservation actions in the ten-year forecasting framework. We fitted the estimates of the last eight years (2015 to 2022) to the model $N_{t+1} = e^{r}N_t$, where N_t is the population estimate of a subspecies at time t and r is the exponential growth rate. This reflects a period approximating a generation preceding 2022 (see above).

As before, we used the model $N_t = e^{rt}N_0$, where N_0 is the population estimate in 2022 for a specific subspecies and t has a value of 10 to predict the likely population size in 2032. We, however, randomly drew an exponential growth rate from the recent statistical distribution; this assumed to be normal, described by the estimated r and its confidence interval, to estimate the likely 2032 population size for each subspecies in the presence of conservation interventions 100 000 times. The median of this sample reflects the likely outcome with the 2.5% and 97.5% percentile as confidence intervals with effective conservation actions. The difference between the actual status in 2022 and the forecasted status for 2032 in the presence of conservation reflects the conservation gain.

Recovery potential

The long-term forecasting focused on 100 years into the future. A first step was to estimate the likely black rhino numbers in 1880, the year defined as when human activities still had negligible impact on the transformation of habitats (Steffen, 2003). An estimated ~65 000 black rhinos resided in Africa in 1970. Historical records suggest an estimated 100 000 black rhinos around the turn of the century in 1900 (Emslie & Brooks, 1999). We estimated the exponential decline from 1900 to 1970 using the model $N_{1970} = e^{70r}N_{1900}$, with r being the exponential annual growth rate. Using the estimated r, we could define the likely population size in 1880 as $N_{1880} = \frac{N_{1900}}{e^{20r}}$. We assumed that the r may have similar uncertainty as the declines observed after 1970. This provided an estimate of r with an assumed confidence interval. The drawing from this distribution allowed estimating population sizes 100 000 times. The median value and 2.5%, as well as the 97.5% percentiles were estimates of the likely population size and confidence interval of the black rhino numbers in 1880, occupying all available habitats with their original range at near optimum densities (K_{1880}). We reasoned that 'available habitat' is the proportion of a range that is suitable for black rhinos.

The next step was to partition the estimated optimal numbers (K_{1880}) into the four subspecies that were extant in 1880, as well as in 1970. The contemporary distribution of black rhino subspecies provided guidance (Moodley *et al.*, 2017). We defined the proportional contribution of each subspecies to the distribution of the black rhino as a species (p_s). Note that our approach uses distribution across a geographical area carrying an assumption that the density of black rhinos converges to an average across their range. The estimated optimal numbers for each subspecies came to $p_s K_{1880}$.

We then accounted for the influence of global environmental change drivers (MEA 2005) on rhino numbers. The primary driver has been overharvesting inclusive of legal (*e.g.* non-sustainable unregulated hunting) and illegal (*e.g.* poaching) killing of rhinos (Ferreira *et al.*, 2022). In the past decade, regulated hunting was sustainable ('t Sas-Rolfes, Emslie, Adcock & Knight, 2022), but poaching increased to 5.1% of the continental population of rhinos in 2015 inclusive of both black and white rhinos. This declined to 2.44% in 2021 (Ferreira *et al.*, 2022) and was 2.53% in 2022 (Knight *et al.*, 2023). We anticipated that the effect of poaching does fluctuate, but for this analysis we used an average poaching rate of 2.5% per annum.

A second key driver is habitat transformation (Watson *et al.*, 2016) that will likely result in further rhino habitat fragmentation, loss and degradation. We extracted human population trends (https://population.un.org/wpp/Download/Standard/MostUsed) and noted an annual exponential change in numbers of humans of 0.025 for the period 2020–2025, declining to 0.017 for 2045 to 2050 to be around 0.004 by 2095 to 2100. Using the estimated 1.3 billion people in Africa in 2020, we fitted the model $N_{t+1} = N_t e^{r\left(1-\frac{N_t}{K}\right)^{\theta}}$, where N_t is the human population at time t, r the exponential growth rate, K the likely size at which human growth may be zero and θ a variable that defines the shape of density-dependence in human population growth. We allowed procedures to vary model parameters so that the $\ln \frac{N_{t+1}}{N_t}$ is likely 0.025 (for the years 2020–2025), 0.017 (2045–2050) and 0.004 (2095–2100). Using the estimated values of r, K and θ enabled us to generate a smoothed human population curve and make forecasts of human population size in Africa until 2122, the 100 years horizon for forecasting since 2022.

The extracting of measures of habitat transformation in savanna ecosystems, *i.e.* 74.83% transformed in 1993 and 77.64% transformed in 2009 (Watson *et al.*, 2016) allowed estimated annual changes in habitat transformation from 1993 to 2009. Using the smoothed human population growth curve, we could also estimate the annual human population change from 1993 to 2009. This allowed us to estimate the percentage change in habitat transformed for each percentage change in human population size assuming that, at least recent past human population changes affect rhino habitat the same way in the future. We anticipate that a conservative 10% of existing and future transformed habitat within the range of a subspecies may be restored. Using this measure, we calculated the percentage change in the human population annually and converted this to additional habitat transformed, accounting for 10% restoration, to obtain a prediction of percentage habitat transformed by 2122 (T_{2122}).

A third and final driver we accounted for was the impact of climate change. Climate change influences species' range size (Beyer & Manica, 2020). The analyses for range size change in Africa allowed us to predict the likely range change for the black rhino within savanna systems by the year 2122. For this, we extracted the data of range restriction from (Beyer & Manica, 2020) over time and fitted the model $R_{t+1} = R_t e^{\alpha\left(1-\frac{R_t}{100}\right)}$, where R_t is the percentage range at time t and α the rate at which range due to climate is expected to change over time. Using this model, we predicted the percentage of range restricted by 2122 (R_{2122}).

To predict the likely population size for each subspecies in 2122, we made use of:

$$N_{t+1} = N_t e^{(0.025)\left(1-\frac{N_t}{p_s K_{1880}\left(1-\frac{R_{2122}}{100}\right)\left(1-\frac{T_{2122}}{100}\right)}\right)}.$$

Note that the model assumes that habitat transformation and climate change are additional, resulting in the estimate being at the higher end of possible habitat lost to these two drivers.

Through the approach, we accounted for three key global environmental change drivers: illegal overharvesting from trends in poaching, habitat transformation derived from human population trends, and climate change extracted from range constriction predictions, and estimated the likely population sizes of subspecies in 2032. We included the range of the extinct Western black rhino as authorities can consider other subspecies as ecological equivalents. The difference between the status in 2022 and the prediction for 100 years later serves as the recovery potential.

RESULTS

An estimated 65 384 black rhinos, composed of 565 South-western black rhinos, 15 311 South-central black rhinos, 46 137 Eastern black rhinos and 3371 Western black rhinos lived in Africa in

1970 based on back dating trends from rates of change. This used the earliest eight estimates as generation length was estimated at eight years. Nearly all subspecies declined (Fig. 2). Western black rhino was declared extinct by 2006 (Lagrot, Lagrot & Bour, 2007). The lowest numbers for South-western black rhinos were 418 by 1984 when they were declining at –1.7% per annum (95% CI: –1.2% to –2.3%) since 1970. The decline for the other two subspecies continued for longer: South-central black rhino numbers were lowest in 1994 (1202) declining at –9.9% per annum (–10.7% to –9.1%), while Eastern black rhino numbers were lowest in 1997 (483) declining at –19.0% per annum (–17.4% to –20.6%) per annum.

Conservation legacy

The above declining trends predicted substantially lower numbers of black rhinos for each subspecies in 2022 (Table 1) than the figures reported by the range States (Knight *et al.*, 2023). Without conservation actions, only 296 (281 to 312) black rhinos might have been alive in Africa. The conser-

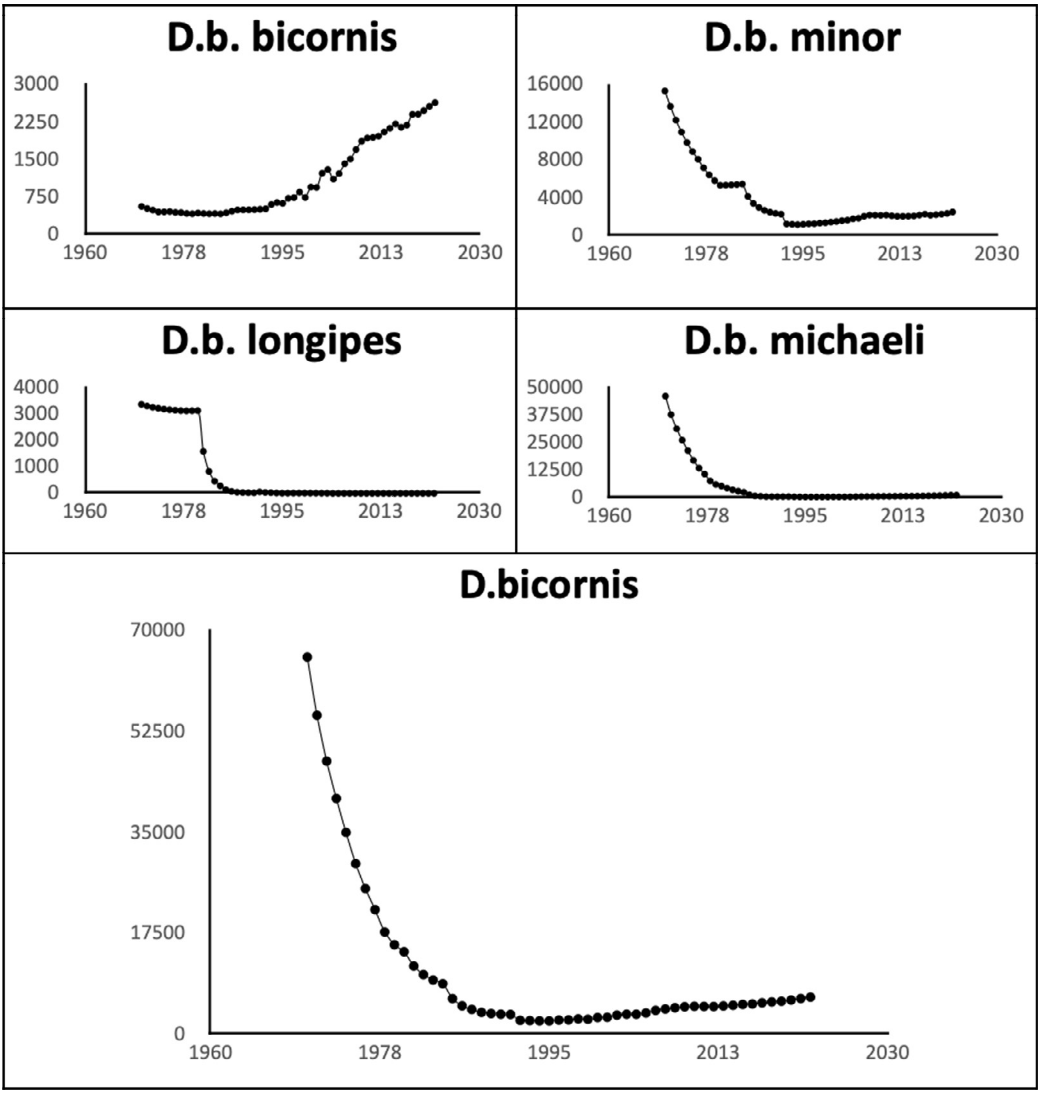

Fig. 2. Numbers estimated for the South-western black rhino (*Diceros bicornis bicornis*), South-central black rhino (*D. b. minor*), Eastern black rhino (*D. b. michaeli*) and Western black rhino (*D. b. longipes*). These subspecies contributed to the combined trend for the black rhino species (*D. bicornis*).

Table 1. A summary of Green Status metrics for the extant subspecies of black rhinos.

Year		*D. b. bicornis*	*D. b. minor*	*D. b. michaeli*	Black rhino
Conservation legacy					
	Status	2636	2532	1319	6487
2022	Without conservation	224 (210–238)	69 (63–75)	3 (3–4)	296 (281–312)
	Legacy	2412	2463	1316	6172
Conservation dependence					
2032	Without conservation	2217 (2146–2291)	942 (896–991)	195 (177–215)	3354 (3267–3444)
	Dependence	419	1590	1124	3133
Conservation gain					
2032	With conservation	3543 (3379–3717)	3079 (2918–3247)	2321 (2257–2388)	8943 (8702–9193)
	Gain	907	547	1002	2456
Recovery potential					
2122		3616 (3521–3709)	7228 (7039–7411)	7224 (7037–7401)	20952* (20620–21267)
	Potential	980	4696	5905	14465*

*Note that the range of the extinct *Diceros bicornis longipes* can have ecological equivalent subspecies totalling to 2884 (2702–3036) individuals.

vation legacy, for black rhinos as a species, results in 6191 black rhinos.

Conservation dependence

At the end of 2022, range States reported 2663 South-western black rhinos, 2532 South-central black rhinos and 1319 Eastern black rhinos, *i.e.* 6487 black rhinos in total. Note that a further 391 black (345 Eastern black rhinos, 32 South-central black rhinos and 14 black rhinos of unknown subspecies) were in *ex situ* collections, mostly outside Africa (Knight *et al.*, 2023). In the absence of conservation actions in the next ten years, the declines per subspecies as noted previously (1970 to 1984 for South-western black rhinos, 1970 to 1994 for South-central black rhinos and 1970 to 1997 for Eastern black rhinos) predicted that only 3354 (3267–3444) individuals will be living in Africa by 2032. This equates to a conservation dependence measure of 3133 black rhinos.

Conservation gain

The forecasts for 2032 in the presence of conservation actions predicted 8943 (8702–9193) black rhinos living in Africa then. Most gain will be through Eastern black rhinos estimated at 1002 additional individuals because of conservation actions (Table 1).

Recovery potential

Between 1900 and 1970, black rhino numbers declined from 100 000 at an estimated –0.6% per annum (–1.2% to 0.0%). At this rate, it is predicted that 112 950 (99 492 to 127 898) black rhinos lived in Africa around 1880.

Annual new habitat transformation from 1993 to 2009 was 0.23% per year. Human population change as predicted for the 1.3 billion people living in Africa over the next 100 years was best described by the model:

$$N_{t+1} = N_t e^{0.039\left(1-\frac{N_t}{5\,000\,000\,000}\right)^{1.31}}.$$

This gives an estimate of 570 813 801 and 956 890 237 people living in Africa in 1993 and 2009, respectively, reflecting an annual change of 3.1%. For every percentage change in the number of people, an estimated 0.07% of transformed habitat is to be added to the already existing transformed places. This predicts 77.65% habitat transformation by 2122. Range restrictions in Africa linked to climate change were best described by model $R_{t+1} = R_t e^{0.0083\left(1-\frac{R_t}{100}\right)}$, which predicted 36.0% (35.0% to 37.2%) of the range restricted due to climate change by 2122. Estimated habitat transformation, range restriction linked to climate change and habitat restoration suggest that suitable habitat (15.9% of that in 2022) for 20 952 (20 620 to 21 267) black rhinos would be available in 2122.

The contemporary distribution of black rhino subspecies using figures from Moodley *et al*. (2017) was broadly defined as 16.67% South-western black rhinos, 16.67% Western black rhinos, 33.33% Eastern black rhinos, and 33.33% South-central black rhinos. This brings us to a prediction that available habitat within ranges in the year 2122 would allow 3616 (3521 to 3709) South-western black rhinos, 7228 (7039 to 7411) South-central black rhinos and 7224 (7037 to 7401) Eastern black rhinos, based on the relative contribution of the range of each subspecies to the overall range of black rhinos. Note, however, that a further 2884 (2702 to 3036) black rhinos of appropriate subspecies (or blend of subspecies) would have to live in available suitable habitat within the range of the now extinct Western black rhino.

Although the overall recovery potential is 14 465 black rhinos, the recovery of the extinct Western black rhino will not be possible. The recovery potential for the subspecies varies (South-western black rhino – 980, South-central black rhino – 4496, and Eastern black rhino – 5905). Authorities may consider the use of ecological equivalents (Nogués-Bravo, Simberloff, Rahbek & Sanders, 2016) and introduce these subspecies into suitable places within the historical distribution of Western black rhinos, this to result in an additional 2884 recovery potential.

DISCUSSION

Estimating Green Status metrics can highlight important lessons. The recent conservation legacy generated through innovative biological management (Balfour *et al*., 2019) and strategy (*e.g.* du Toit, 2006) was considerable. Despite the Western black rhino having recently become extinct, there are 11.8, 36.7 and 439.3 times more South-western, South-central and Eastern black rhinos, respectively, because of conservation interventions. If such actions do not continue then there will likely be 1.2, 2.7 and 6.8 times fewer South-western, South-central and Eastern black rhinos, respectively, in 2032.

Habitat changes influenced by human activities impact available habitat: Africa held ~113 000 black rhinos in 1880, whereas humans had relatively low impact, but by 2122 Africa could only hold ~21 000, *i.e.* ~18.6% of the likely 1880 total of black rhinos. We accounted for influences on habitat by three key global change drivers – illegal harvesting, climate change and habitat transformation. Some surprises may also be realized in future. For instance, while concerns of worsening social problems overshadow that of biodiversity, a predicted continued urbanization of the continent brings opportunities to address ecological challenges elsewhere (Güneralp *et al*., 2017). In addition, large-bodied mammals experienced a substantial increase in the proportion of their current range within protected areas, while having lost substantial parts of their historical range – 50% of the current range of African rhinos are within government-protected areas as opposed to community or private lands, but rhinos have lost 55% of their range since the 1970s (Pacifici, Di Marco & Watson, 2020).

An additional consideration is that a government-protected area is not the only land-use mechanism that can contribute to rhino conservation aspirations. Incentivizing both private and communal landowners to participate in rhino conservation is playing a key role in adding safe areas where rhinos live in Namibia (Muntifering, *et al*., 2020), South Africa (Clements, Knight, Jones & Balfour, 2020), Zimbabwe (Chanyandura *et al*., 2021) and Kenya (Mulama *et al*., 2015). For instance, at the end of 2021, 53% of South Africa's Southern white rhinos (*Ceratotherium simum simum*) were on private land (Ferreira *et al*., 2022). This illustrates that the explicit consideration of other effective area-based conservation measures (OECMs) to contribute to the Global Biodiversity Framework (GBF) are increasingly being realized (Alves-Pinto *et al*., 2021). These approaches will be key for the wellbeing of people and nature alike.

In assessing the path of recovery towards ~21 000 black rhinos in Africa, we accounted for one key influence on rhino demographic processes: over-harvesting or poaching for rhino horn (Ferreira *et al*., 2022). These, however, have additional effects on rhino demography. For instance, social disruption related to the loss of individual rhinos to poaching was linked to reduced recruitment rates (birth and survival during the first year) of black rhinos in Kruger National Park, South Africa (le Roex & Ferreira, 2020), especially at a time when the poaching rate was high (Ferreira, Greaver, Simms & Dziba, 2021). In addition, for Southern white rhinos (*Ceratotherium simum simum*), the loss of cows irrespective of the cause of death resulted in 0.5 dependent calves dying, as well as the loss of 4.5 future calves (Nhleko, Ahrens, Ferreira & McCleery, 2022). These indirect compounding effects may result in reduced progress towards achieving the full recovery potential of 2122.

Climate change can have direct consequences on range restriction (Beyer & Manica, 2020) while varying environmental conditions have potential influence on birth and death rates. This century so far, for black rhinos (unlike white rhinos) acute droughts have not negatively influenced black rhino recruitment (le Roex & Ferreira, 2021), although extended droughts can influence the conception of cows, and in some instances, the survival of calves depends on annual rainfall and productivity (Ndlovu, 2023).

Even so, the recovery potential for rhinos in their natural habitat in 2122 is relatively high. The current population estimates reported by range States reflect 29.8% of the estimated total that available habitat in 2122 will allow. Rhino dynamics including density-dependent limitations (*e.g.* Okita-Ouma, Amin, van Langevelde & Leader-Williams, 2010) and underlying global influences such as poaching (Ferreira *et al.*, 2022) predict a 96.2% achievement by 2122. This will require continued biological management and innovative protection of rhinos. Black rhino existence depends on people's changing social needs and expectations which are increasingly linked to their importance for biological diversity. The need to conserve black rhinos is no longer just about recovering their numbers, but also about their key ecological role (*e.g.* Waldram, Bond & Stock, 2008) and contribution to the wellbeing of people in numerous ways (*e.g.* Morais, Bunn, Hoogendoorn & Birendra, 2018).

Evaluating the Green Status of species can prioritize investment into those with high conservation dependence and potential for gain (Akçakaya *et al.*, 2018). Our analyses evaluated black rhinos against a global standard for quantifying species recovery and assessing conservation impact (Grace *et al.*, 2021) which provided important insights and rationale for consideration of introductions of subspecies as ecological equivalents when the native subspecies are no longer extant (Nogués-Bravo *et al.*, 2016).

CONCLUSION

Although the potential area for black rhinos inhabiting large parts of Africa has been substantially reduced since the 1880s when people had relatively little impact on the habitat, the conservation legacy of various initiatives highlights opportunities for the future. Black rhinos remain critically endangered, but the species does carry positive recovery potential. Future conservation success requires biological management that is inclusive and innovative, emphasizing and involving international collaboration for the benefit of people and rhinos as umbrella species, helping to safeguard biodiversity for Africa and the world.

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DISCLAIMER

This preliminary Green Status assessment was conducted using some of the assessment materials made available by the IUCN SSC. The Green Status assessment of the species is not final, however, until it has been published on the Red List website.

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