RESEARCH ARTICLE

The impact of COVID-19 government responses on rhinoceroses in Kruger National Park

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Received 23 April 2021. To authors for revision 14 June 2021. Accepted 24 August 2021

Global COVID-19 responses by governments restricted international travel, imposed national lockdowns, reduced economies, and influenced people's livelihoods. Travel restrictions and national lockdowns may constrain international illegal supply chains of high value wildlife products such as rhinoceros (rhino) horn. We evaluated whether the COVID-19 lockdown responses by South Africa induced a poaching pause on rhinos in Kruger National Park. We collated information on poaching incidences from 2017 and made predictions for expected incidences during 2020 using trends noted between 2017 and 2019. Rangers observed substantially fewer incidences of poaching during South Africa's hard lockdown. As restrictions eased, poaching incidences increased. Despite the COVID-19 poaching pause, both black and white rhinos continued to decline in Kruger National Park as recruitment could not offset poaching and natural deaths.

Keywords: COVID-19 pandemic, poaching incidences, rhino surveys, rhino vital rates, rhino population estimates, rhino trends.

INTRODUCTION

Global responses to the COVID-19 pandemic focused on nationalist isolation and totalitarian surveillance (Harari, 2020). Many countries imposed drastic measures such as lockdowns that confined people to their homes and restricted their movements. In addition, governments instituted both local and international travel bans, and carried out militarized enforcement of these regulations. COVID-19-induced government responses shrank economies, degraded people's well-being and breached several rights of citizens (Nay, 2020; Nicola *et al.*, 2020). Historical rural– urban inequalities, often in developing countries, amplified impacts on poorer communities trying to survive in a job-market slump (Visagie & Turok, 2021). Loss of livelihoods, especially for low-income people, forced food insecurity upon thousands, often millions, of citizens (Laborde, Martin, Swinnen & Vos, 2020). Food insecurity in developing countries predicts an increased use of natural resources, both legally and illegally, despite government food support (Rondeau, Perry & Grimard, 2020).

The consequence of COVID-19 responses on the national and international movement of people, however, most likely imposed constraints on the poaching of high-value species (Nataraajan, 2020). Often, end-users of wildlife products are distant from producing countries resulting in complex national and international supply chains (Rosen & Smith, 2010). Trafficking of large numbers of species takes place at global scales, often across several international boundaries, and is driven by organized crime (Daszak *et al.*, 2020). Consequently, disruption of organized crime (Haas & Ferreira, 2016) is a key mechanism of any response aimed at mitigating illegal activities such as poaching (Conrad, 2012). Nationalist isolation and totalitarian surveillance (Harari, 2020) may effectively act as a massive global scale disruption of organized crime supply chains. This scenario therefore predicts substantial reduction in the poaching for high-value species that have international supply chains.

We use trends in poaching of rhinoceroses (rhinos) in Kruger National Park (Kruger), one of

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ISSN 2410-8200 [Online only] — DOI: https://doi.org/10.3957/056.051.0100

the world's rhino strongholds in South Africa (Emslie *et al*., 2019), as a case study to test for a COVID-19 poaching pause. Sadly, trends in rhino populations in Kruger provide an ideal case. Despite all-inclusive anti-poaching initiatives since 2013 (Rademeyer, 2018; Jooste & Ferreira, 2018), poaching for horn continues to pose a significant threat to the conservation status of rhinos in the park (Emslie *et al*., 2019).

The inadvertent COVID-19 disruption of organized crime supply networks (Nataraajan, 2020) potentially provided a respite from poaching pressure for the rhino populations of Kruger. During March 2020, South Africa introduced a graded lockdown response (Table 1, Department of Health, 2020) that resulted in many months of no international and substantially restricted local travel. This situation resulted in no visitors to Kruger; nearly all non-essential personnel working in Kruger being homebound, often outside Kruger; and a zero-tolerance attitude to the breaking of any rules. Opportunities to enter and kill rhinos in Kruger, at times assisted by complicit staff, virtually disappeared, and smuggling opportunities using international flights were extremely rare. We predicted an acute decline in the short-term in the incidences of poaching. As a result, annual poaching rates should be lower than recorded in recent years (Ferreira, le Roex & Greaver, 2019).

Factors such as droughts (Ferreira *et al*., 2019) and birth synchrony (le Roex & Ferreira, 2021), influence the vital rates of white rhinos (*Ceratotherium simum*). For black (*Diceros bicornis*) rhinos (le Roex & Ferreira, 2020), additional influences include higher predation of calves from increased predators (Ferreira & Funston, 2020), reduced probability of finding mates (*e.g.* Courchamp, Clutton-Brock & Grenfell 1999), and disruption of social structures (*e.g.* Tuyttens *et al*., 2000). Further influences on both species come from indirect effects of poaching such as additional deaths of calves depending on cows for nutrition and safety (Nhleko, Ahrens, Ferreira & McCleery, 2021).

The relatively long gestation periods, older ages of first reproduction, the birth of one calf at a time, and a weaning age of just over one year for both species (Skinner & Chimimba, 2005), predicts limited population responses in the short-term. Thus, we did not expect population level responses and predicted continued declines during 2020.

We use data from an aerial survey of rhino populations in Kruger during 2020, the year of variable responses by governments to the COVID-19 pandemic, to evaluate three predictions. First, we expected that COVID-19 regulations would result in a substantial reduction in poaching for a high-value commodities like rhino horn. Second, COVID-19 regulations were unlikely to influence the vital rates of rhinos given their life histories. Third, rhino numbers would continue to decline during 2020.

METHODS

Study area

During 2020, the rhino survey focused on southern Kruger (area south of the Olifants River), which covers 9138 km² of low-lying savanna in South Africa. Annual rainfall exceeds 450 mm (Gertenbach, 1980). Mixed *Combretum* and *Senegalia/Vachellia* (*Acacia*) spp. dominate on granite and gneiss deposits, separated by Karoo sediment. Wooded *Sclerocarya caffra* and *Senegalia nigrescens* savannas prevail on basalt soils (Gertenbach, 1983).

Although our formal aerial survey focused on southern Kruger, we also collated information from incidental observations of rhinos in northern Kruger. In northern Kruger, *Colophospermum mopane* dominates both the basalt and granite substrates. However, taller *C. mopane* as well as *Combretum* spp. and *Senegalia/Vachelia* (*Acacia*) spp. occur more often on the granites, whereas stunted or shrub-like *C. mopane* sparsely interspersed with *S. caffra* are found on the basalts.

Aerial survey

The rhino population aerial survey targeted 11 ranger sections using two helicopters to count black and white rhinos from 24 August to 29 September 2020 focusing on the historical 3 × 3 km blocks distributed randomly across southern Kruger (Ferreira *et al*., 2015) (Fig. 1). Observers systematically completed transects comprising a 200 m observation strip on each side of the helicopter within each block, with flights 45 m above ground at a speed of 65 knots. The survey team comprised a pilot, a data recorder and two observers. The survey team assigned ages and sexes to most individual rhinos encountered after recording the geographical position of the observation.

The rhino aerial survey overlapped with a simultaneous elephant (*Loxodonta africana*) population survey that focused on 20 areas of concern around

Table 1. A summary of the risk-adjusted strategy for economic activity that South Africa implemented under various levels of threat posed by the COVID-19 pandemic (Department of Health, 2020).

	Alert Level 5	Alert Level 4	Alert Level 3	Alert Level 2	Alert Level 1
Threat Level	High virus spread, and/or low health system readiness	Moderate to high virus spread, with moderate readiness	Moderate virus spread, with moderate readiness	Moderate virus spread, with high readiness	Low virus spread, high health system readiness
Objective	Drastic measures to contain the spread of the virus and save lives	Extreme precaution to limit community transmission and outbreaks, while allowing some activity to resume	Restrictions of many activities, including workplaces and socially, to address high risk of transmission.	Physical distancing and restrictions on leisure and social activities to prevent a resurgence of the virus	More normal activity can resume, with precautions and health guidelines followed at all times.
Sectors permitted	Only essential services	All essential services. Food retail stores already permitted to be open and may sell full line of products within existing stock. All agriculture (horticulture, export agriculture including wool and wine, floriculture and horticulture, and related processing). Forestry, pulp and pape. Mining (open cast mines at 100% capacity, all other mines at 50%). All financial and professional services. Global business services for export markets. Postal and telecommunications services. Fibre optic and IT services. Formal waste recycling (glass, plastic, paper and metal).	Licensing and permitting services, deeds offices and other government services designated by the Minister of Public Service and Administration. Take-away restaurants and online food delivery. Liquor retail within restricted hours. Clothing retail. Hardware stores. Stationery, personal electronics and office equipment production and retail. Books and educational products. E-commerce and delivery services. Clothing and textiles manufacturing (at 50% capacity). Automotive manufacturing. Chemicals. Bottling. Cement and steel. Machinery and equipment. Global business services. SANRAL construction and maintenance. Transnet at 100%	Construction. All other retail. All other manufacturing. Mining (all mines at 100% capacity). All government services. Installation, repairs and maintenance. Domestic work and cleaning services. Informal waste-pickers	All sectors

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Table 1 (continued)

	Alert Level 5	Alert Level 4	Alert Level 3	Alert Level 2	Alert Level 1
Transport restrictions	Bus services, taxi services, e-hailing and private motor vehicles may operate at restricted times, with limitations on vehicle capacity and stringent hygiene requirements	Bus services, taxi services, e-hailing and private motor vehicles may operate at all times of the day, with limitations on vehicle capacity and stringent hygiene requirements	Bus services, taxi services, e-hailing and private motor vehicles may operate at all times of the day, with limitations on vehicle capacity and stringent hygiene requirements. Limited passenger rail restored, with stringent hygiene conditions in place. Limited domestic air travel, with a restriction on the number of flights per day and authorization based on the reason for travel	Domestic air travel restored. Car rental services restored	All modes of transport, with stringent hygiene conditions in place
Movement restrictions	No inter-provincial movement of people, except for transportation of goods and exceptional circumstances (*e.g.* funerals)	No inter-provincial movement of people, except for transportation of goods and exceptional circumstances (*e.g.* funerals)	No inter-provincial movement of people, except for transportation of goods and exceptional circumstances (*e.g.* funerals)	Movement between provinces at Level 1 and 2 restrictions	Interprovincial movement allowed, with restrictions on international travel

elephant impacts identified by SANParks as part of the Kruger Management Plan (SANParks, 2002). Eleven of these areas of variable sizes are within southern Kruger (Fig. 1). Observers recorded rhino species on these Elephant Impact Assessment (EIA) areas. The blocks and areas sampled in this way during 2020 covered 41.1% of the Marula North Region and 53.4% of the Marula South Region.

Poaching pause

The South African government's graded response had several consequences that can influence various aspects of the drivers and facilitators of trafficking of rhino horn. During early 2020, there were no responses, but on 15 February 2020, the South African Government imposed international travel restrictions (Department of Health, 2020). Such a response would provide some disruption on trafficking supply chains that distribute illicit products through smuggling using commercial international flights (Nataraajan, 2020).

The various levels of responses by the South African Government (Table 1) inadvertently may have had effects across five areas that can disrupt illegal supply chains (Table 2). The first is reduced international travel (*I*). Some levels will also reduce local inter-provincial travel, restricting the movement of illicit products from the supplier to local distributors or facilitators into the international link (*L*). At times, restrictions imposed complete access control into protected areas, limiting entrance and/or exit of poachers (*A*). High levels of restrictions had the effect of implementation of zero-tolerance for breaking rules (*Z*). Finally, high levels of restrictions also resulted in a substantial reduction of personnel to largely essential and resident staff that inadvertently reduced the pool of potentially compromised staff that criminal syndicates recruited and depended on within protected areas (*S*) (Table 2). The various response levels, and implications for the effects on an illegal supply chain, allowed us to categorize periods in progressive control categories (None→*I*→*IL*→*ILAZ*→*ILAZS*, Table 2).

To define a COVID-related pause in poaching, we compared year-on-year weekly incidences of poaching (expressed as carcasses per day) from January 2017. The number of carcasses attributed to poaching decreased in recent years (DFFE, 2020). We are also aware of seasonal patterns in poaching. To accommodate both of these factors, we calculated the weekly change from one year to

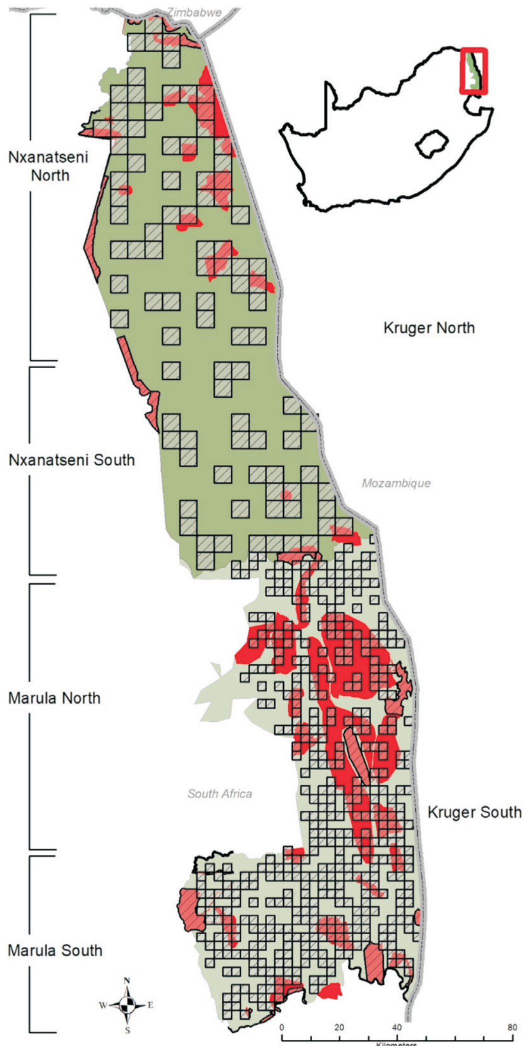

Fig. 1. Map of Kruger National Park illustrating the placement of aerial survey blocks (3 km × 3 km in southern Kruger) during the 2020 aerial survey focussing on rhino populations. We also illustrate blocks surveyed as part of a simultaneous elephant population survey (6 km × 6 km in northern Kruger) that included surveys of Elephant Impact Areas (red areas). Our analysis made use of rhinos encountered on the Elephant Impact Areas surveyed in southern Kruger.

the next as an instantaneous exponential rate of change. We used the exponential rate of change from 2017 to 2019 for each week to predict what the expected number of rhino carcasses per day would be for that corresponding week in 2020. Because we could categorize each week-period within the identified categories (see Table 2), we

Table 2. Graded responses implemented by the South African Government during 2020 in response to the health risks that the COVID-19 pandemic posed to citizens and the inadvertent effect on elements of an illegal supply chain of rhino horn: (None, no restrictions; I, international travel restrictions; L, provincial travel restrictions; A, protected area access restrictions; Z, zero tolerance to breaking rules; S, essential and residential personnel only).

COVID-19 lockdown level	Park open	Dates	International travel restrictions	Provincial travel restrictions	Protected area access restrictions	Zero tolerance to breaking rules	Essential and resident personnel only	Categories for effects on supply chain
No restrictions		1 Jan – 14 Feb	No	No	No	No	No	None
Informal Level 1	Yes	15 Feb – 25 Mar	Yes	No	No	No	No	I
Level 5	No	26 Mar – 30 Apr	Yes	Yes	Yes	Yes	Yes	ILAZS
Level 4	No	1 May – 31 May	Yes	Yes	Yes	Yes	No	ILAZ
Level 3*	No	1 Jun – 8 Jun	Yes	Yes	Yes	Yes	No	ILAZ
Level 3	Yes	9 Jun – 17 Aug	Yes	Yes	No	No	No	IL
Level 2	Yes	18 Aug – 20 Sep	Yes	No	No	No	No	I
Level 1	Yes	21 Sep – 30 Sep	Yes	No	No	No	No	I
Level 1 revised	Yes	1 Oct – 28 Dec	No	No	No	No	No	None
Level 3	Yes	29 Dec – 31 Dec	Yes	No	No	No	No	I

could estimate the mean number of carcasses per day with 95% confidence intervals for each of these categories. We concluded that observed carcasses per day differed from predicted carcasses per day within a sequential category period if the 95% confidence intervals did not overlap.

Evaluating the cumulative effect of lockdown regulations, we calculated the residual of observed *versus* expected carcasses per day for each week. We calculated the average residual and its 95% confidence interval for each of the five categories irrespective of whether they were sequential or not. We concluded a significant reduction in poaching incidences associated with specific restriction categories if the mean residual value was below zero and the confidence intervals excluded zero.

Population size

A revised Jolly's estimator (Seber, 2002) allowed landscape estimates and overall estimates after analysts accounted for bias. We used the 2013 availability bias assessments derived from relationships between vegetation cover (Bucini *et al.*, 2011) and rhino visibility (Ferreira *et al.*, 2015) and the relationship between vegetation cover and the average Normalized Difference Vegetation Index (NDVI) on a block at the time (Ferreira, Greaver, Nhleko & Simms, 2018) for each block. Observer bias came from estimates made during a previous black rhino survey (Ferreira, Greaver & Knight, 2011). Detectability bias was minimal given the size of observation strips being narrower than noted by previous studies (Kruger, Reilly & Whyte, 2008) when detectability was negligible.

We calculated age- and sex-specific frequencies for both black and white rhinos using the same age assignment criteria as Goddard (1970). From these data, we could estimate the recruitment between two surveys (*i.e.* the number of rhinos born, and which survived the year between two surveys). We calculated recruitment rate as the number of rhinos born that survived the year between surveys (September 2019 to September 2020) expressed as a fraction of the number of rhinos estimated during September 2019 (Ferreira *et al.*, 2019).

We collated updated information on rhinos poached* which allowed us to estimate poaching and natural mortality as the number of rhinos that died between the 2019 and 2020 aerial surveys. We calculated poaching rates as the number of rhinos poached expressed as a fraction of the number of rhinos estimated during September 2019. To help with comparisons, we extracted previously published estimates of recruitment, natural death, and poaching rates.

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RESULTS

During 2020, observers encountered 1199 white rhinos on the 443 blocks of 3 × 3 km that were part of the sample-based aerial survey blocks since 2013 in southern Kruger. Observers also encountered a further 30 white rhinos on the 11 elephant sampling areas of varied sizes surveyed in southern Kruger. In total, 198 sample blocks and seven elephant sampling areas had white rhinos present. At the same time, observers encountered 90 black rhinos present on 47 of the sample survey blocks. There were no black rhinos noted on any of the elephant sampling blocks. Observers did not record any rhinos on the blocks surveyed north of the Olifants River as part of the elephant survey. Rangers, however, reported 11 white and no black rhinos from field records during the survey year north of the Olifants River.

Poaching pause

We noted a significant reduction in poaching incidences when restrictions imposed controls on all elements of the illegal supply chain (Fig. 2a). Stepwise analyses, however, highlighted the key role which implementing zero-tolerance to the rule breaking played in reducing poaching incidences (Fig. 2b). This situation created a COVID-19 poaching pause for rhinos in Kruger. The trends from 2017 to 2019 predicted 68 rhino carcasses for the periods when South Africa had lockdown Levels 4 and 5, yet rangers recorded only 14 carcasses during those periods in total – a 79.4% reduction in poaching pressure.

Sadly, the benefits of hard lockdown (Alert Levels 4 and 5, see Table 1) for reduced poaching were lost after the South African Government eased lockdown restrictions (Fig. 2a). This easing of restriction resulted in a significantly higher number of observed poaching incidences per day during 2020 compared to that predicted for the same period by trends from 2017 to 2019. The result indicates that year-to-year poaching rates during 2020 were not significantly lower than those in previous years for both white and black rhinos in Kruger (Table 3).

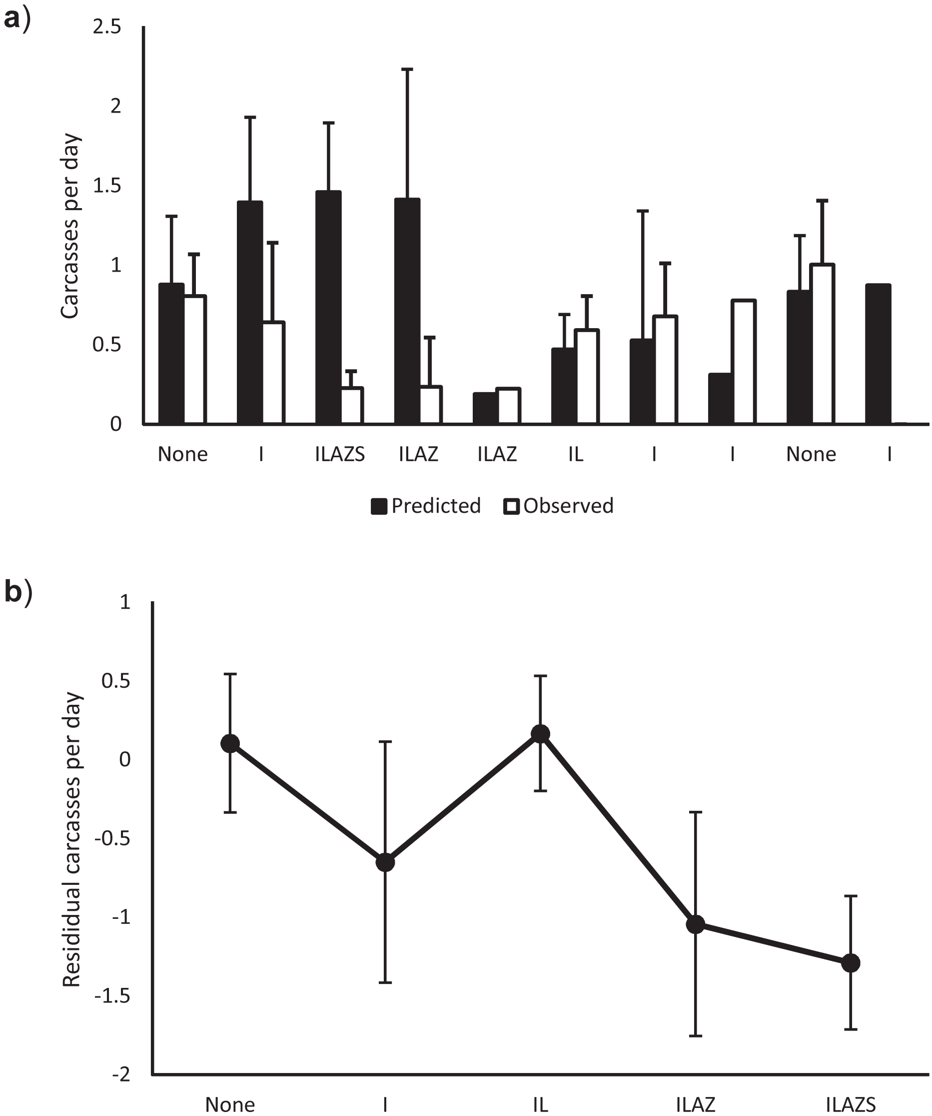


Fig. 2. Comparison of predicted rhino poaching rate (carcasses per day) with those observed during (**a**) sequential periods of different restrictions imposed by COVID-19 regulations during 2020 (see Table 2) (I, international travel restrictions; L, provincial travel restrictions; A, protected area access restrictions; Z, zero tolerance to breaking rules; S, essential and residential personnel only), as well as cumulative intensity of the combination of restrictions (**b**). The error bars represent 95% confidence intervals estimated from weekly calculations of daily poaching rates.

Rhino populations

An estimated 202 (95% CI: 172–237) black rhinos lived in Kruger during 2020. Surveyors noted 3.3% of individuals were less than one year old, translating to seven (95% CI: 6–8) calves born and surviving in the survey year. At the same time, an estimated 2607 (95% CI: 2475–2752) white rhinos lived in Kruger. In this case, surveyors noted that 8.7% of white rhino individuals were less than one year old, translating to 226 (95% CI: 215–239) calves born and surviving during the survey year from mid-September 2019 and mid-September 2020.

Both black and white rhinos had the lowest recorded annual recruitment rates since 2013 (number of calves born and surviving in a survey year expressed as a fraction of the number of rhinos estimated at the start of that survey year, Ferreira *et al.*, 2019) and were lower than the combined natural death and poaching rates (Table 3).

Table 3. Vital rates of rhinos (values from 2014 to 2019 extracted from previous publications). The values in brackets reflect 95% confidence intervals.

	Recruitment rate (%)	Natural death rate (%)	Poaching rate (%)
White rhino			
2014–2015	9.0 (7.8–10.1)	1.1 (1.1–1.3)	9.9 (9.7–11.8)
2015–2016	7.8 (6.8–9.0)	1.5 (1.4–1.6)	7.5 (7.1–8.0)
2016–2017	4.7 (2.9–7.0)	1.7 (1.6–1.8)	7.3 (6.6–8.0)
2017–2018	8.7 (5.9–13.1)	0.6 (0.5–0.7)	7.5 (7.0–8.1)
2018–2019	10.2 (6.5–11.3)	0.9 (0.6–1.2)	8.1 (5.9–11.2)
2019–2020	6.4 (5.4–7.6)	0.9 (0.8–1.0)	6.2 (5.6–7.0)
Black rhino			
2014–2015	11.6 (7.8–16.9)	4.8 (4.0–6.0)	12.6 (10.5–15.7)
2015–2016	7.3 (5.3–10.2)	3.0 (2.6–3.7)	11.3 (9.6–13.9)
2016–2017	8.1 (6.0–10.9)	1.2 (1.1–1.4)	4.2 (3.7–4.9)
2017–2018	4.7 (2.0–8.7)	1.8 (1.6–2.2)	8.4 (7.3–10.0)
2018–2019	12.2 (5.8–15.7)	1.7 (1.1–3.3)	5.8 (3.9–11.3)
2019–2020	2.5 (1.7–4.1)	1.5 (1.2–2.1)	3.0 (2.3–4.2)

The variable recruitment rates noted for both black and white rhinos since 2013 could not offset the declining poaching rates. As a result, the populations of both species continued to decline during 2020 (Fig. 3).

DISCUSSION

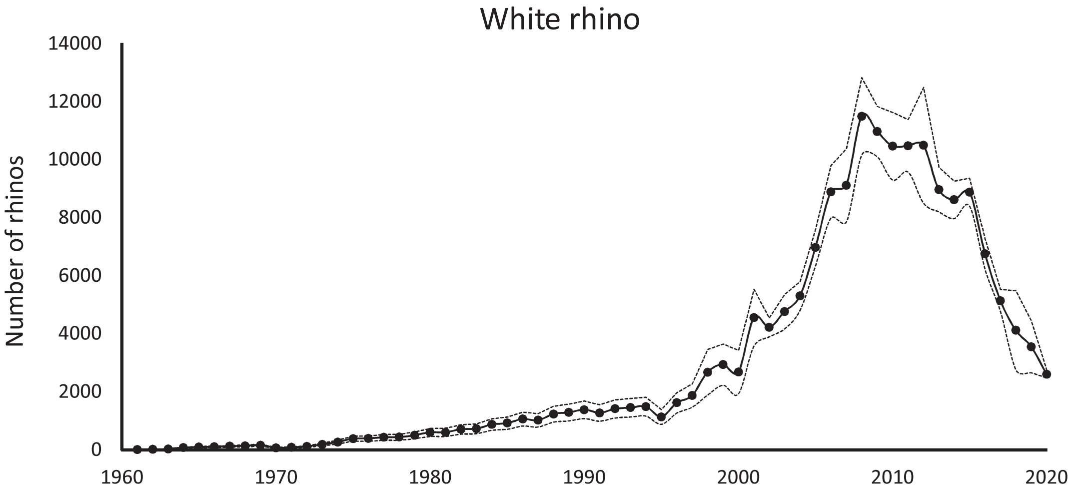
Despite expectations that a COVID-19 pause in wildlife trafficking may benefit wildlife species (Rondeau *et al.*, 2020), during 2020, both rhino species continued the decline noted previously in Kruger (Ferreira *et al.*, 2018). The black rhino population estimates fluctuated considerably over time and actual population sizes may be higher because sample surveys underestimate abundance (Ferreira, le Roex, Greaver & Dreyer 2020). Despite the higher imprecision of estimates over time, the declining trends mirror that of the white rhino population.

Since 2013, both black and white rhino populations had the lowest recruitment rates during the 2019–2020 survey year and this is of significant concern. White rhino recruitment showed resilience following a drought and may even have had synchronized births as indicated by the relatively high birth rates the second and third year after the drought of 2015/2016 (Le Roex & Ferreira, 2021). This recruitment followed the drought impact on white rhino conceptions that resulted in substantially reduced recruitment rates a year after the drought (Ferreira *et al.*, 2019). Incidences of synchronized resilience should result in fewer cows conceiving after synchronization, until such time as the synchronized effect dissolves as has been noted for elephants elsewhere (Moss, 1988).

Poaching also had indirect disruptive effects on black rhinos (Le Roex & Ferreira, 2020). The long lags associated with the environmental consequences of drought and disruptive poaching resulted in the low recruitment rates observed for black rhinos. For both rhino species, however, the low recruitment rates did not offset the combined direct poaching effects and natural mortality during 2020.

We noted a short pause of poaching incidences during the most intensive months of South Africa's lockdown when Government imposed a hard lockdown (Department of Health, 2020). The hard lockdown response induced a COVID-19 pause on poaching with nearly 80% reduction in poaching incidences. The benefits of the COVID-poaching pause, however, could not overcome the increased poaching incidences after the easing of hard lockdown restrictions together with the indirect poaching lag effects. Lag effects include the loss of calves dependent on cows as well as the loss of future calves when poachers kill an adult cow (Nhleko *et al.*, 2021), disruptive effects on black rhinos (Le Roex & Ferreira, 2020) and drought lag effects (Ferreira *et al.*, 2019).

Although the absolute number of rhino carcasses declined from 2017 to 2020 (DFFE, 2020), the poaching rates in recent years have not declined in a similar way. During the 2019–2020 survey year, authorities recorded the first indication of decline in poaching rates since the 2015–2016 survey year. Even so, we provide a note of caution because the detection of carcasses is typically imperfect (Huso, 2011).



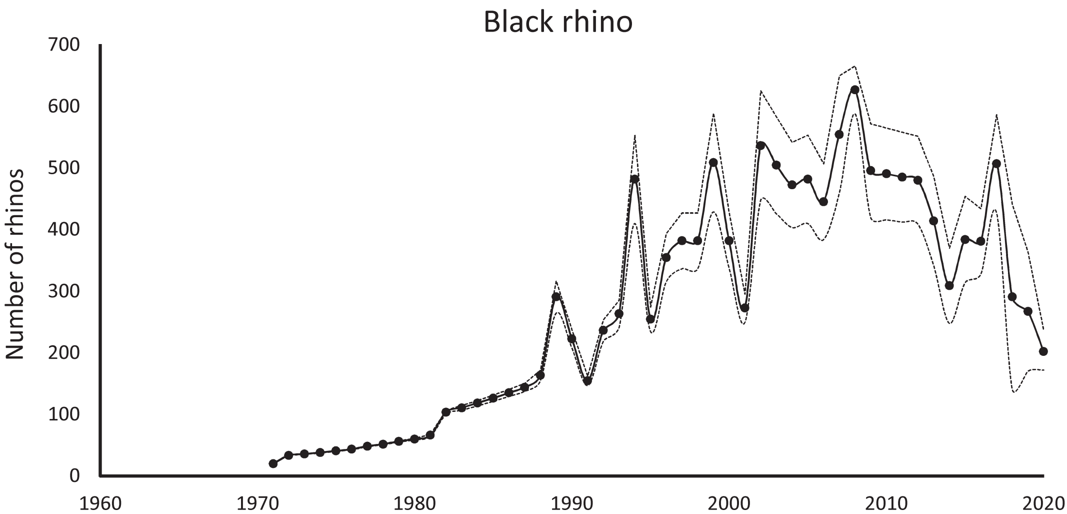


Fig. 3. Population trends of white and black rhinos in Kruger since introductions (white rhino: 1961 first introduction; black rhino: 1971 first introduction). The broken lines reflect 95% confidence intervals of estimates. Trends extracted from previous publications.

The trends in rhino populations, and the limited benefit derived from the COVID-19 poaching pause in Kruger, necessitate a reflection using new insights and perhaps new opportunities to rethink current rhino protection approaches. What is particularly concerning is that the predictions made by the trends noted in 2010 (Ferreira, Botha & Emmett, 2012), were realized in 2016 (Ferreira *et al.*, 2018) and continue to be realized in 2020, despite impressive anti-poaching initiatives (Rademeyer, 2018).

Our results demostrate a disruption of illegal supply chains. Surprisingly, though, incidences of poaching did not decline substantially with international travel restrictions, a major mechanism of transporting contraband (Nataraajan, 2020). The largest reduction took place when South Africa had a hard lockdown (Department of Health, 2020) that imposed the full suite of disruptive effects on illegal supply chains (Rosen & Smith, 2010; Nataraajan, 2020). This disruption included no international or inter-provincial travel, limited access to the Park, complete enforcement of rules, and reduced risk of potentially compromised personnel.

Our analyses of progressive impacts of harder and harder restrictions on poaching incidences confirmed that a key aspect was complete enforcement of rules that had a cascade effect on other aspects such as zero access to Kruger and reduced opportunities for compromised staff to collude with poachers. Sadly, when South Africa relaxed lockdown regulations, poaching soared and rangers detected more rhinos that had been killed by poachers during the relaxed lockdown period from June 2020 to December 2020 (165 poached rhinos; 27 rhinos that died through natural causes) compared to the same period during 2019 (144 poached carcasses; 29 rhinos that died through natural causes).

Clearly, lockdowns are not a permanent intervention. As movement of people resumes and interactions among compromised staff and poachers increase, management authorities must look for alternatives that can mimic the benefits that the COVID-19 pause in poaching illustrated. These alternatives should focus on effective security interventions that reduce rhino deaths through limiting poaching, targeting the supply chain elements, and biological management which aims to increase rhino births.

CONCLUSIONS

A combination of various mechanisms and factors have led to the observed trends in the white and black rhino population numbers in Kruger, despite the COVID-19 poaching pause. Our results highlight the need for new, innovative and complimentary tactics. A key outcome of the COVID-19 poaching pause was the provision of strong guidance by authorities – creating conditions that resulted in adequate enforcement of rules, equal to that imposed by South Africa's hard lockdown, will result in substantive reduction of poaching risks. Such conditions would ensure recovery of rhinos in Kruger, and generate the various opportunities and benefits that people can gain when rhino populations have low risks of local extinction (Haas & Ferreira, 2016).

ACKNOWLEDGEMENTS

We are grateful for the financial support provided by the World Wildlife Fund – South Africa, supported by USAID through the Khetha Initiative. The response to COVID-19 resulted in significant constraints on financing rhino management and protection initiatives. WWF-SA provided outstanding support at short notice. We also appreciate the continued support for the Rhino Logistics Coordinator, a key member of the SANParks Aerial Survey Team, provided by the Peace Parks Foundation.

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Responsible Editor: A.M. Shräder