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A Theory of Change to grow numbers of African rhino at a conservation site

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Abstract

Rhino horn is highly valued and this drives the illegal hunting of rhino. As a strategy to counter rhino losses incurred through poaching, managers of African protected areas face pressure to increase the number of rhino in their populations by promoting their growth. These efforts are commonly constrained by being balanced against other protected area objectives which seek to manage toward a “natural ecological state”. This is reflected in the draft continental rhino conservation plan as well as many national-level rhino plans in Africa, but details on how this can be achieved at a site level are limited; indeed a framework for thinking about the problem is lacking. Here we develop a Theory of Change (ToC) which guides management interventions when seeking to grow rhino numbers at a conservation site. We identify four thematic areas for intervention namely; habitat management; range availability; containment and natural attrition; and rhino population management. As many protected areas are underfunded they seek to attract funding, but many donors are uncertain as to best practice and/or are hesitant to dictate how funds should be spent. This ToC can serve as a framework to guide funding. It can also guide policy in this regard.

KEYWORDS

African rhinoceros, endangered species, population growth, protected area management, Theory of Change

1 | INTRODUCTION

Rhino horn is thought to be one of the most highly valued commodities on the planet (Hübschle, 2016a). About 85% of the global rhino population of ~29,000 is found in protected areas in Africa; ~20,000 are white rhino *Certotherium simum* and ~5,000 are black rhino *Diceros bicornis* (Emslie et al., 2016). Illegal hunting (poaching) of African rhino for their horn, forms a significant part of the illegal wildlife trade (Milliken, 2014) despite a ban placed on international trade in rhino horn in 1977 (UNEP-WCMC (2019)). It is widely understood that poaching of African rhino is undertaken because of the extremely high prices that can be obtained for the horn (Hübschle, 2016a; Milliken, 2014). The value of the illegal trade in rhino horn has been estimated to be between USD 64 and USD 190 million (Nellemann, Henriksen, Raxter, Ash, & Mrema, 2014), and the horn itself has been valued, anecdotally, in the region of USD 36,000 per kg or more when sold to the end user (Gwin, 2012) and between USD 35,000 per kg and USD 65,000 per kg in 2013/2014 (Hübschle, 2016a). The potential supply of horn into these markets through annual rhino horn production in South Africa is estimated to range between 5,300 and 13,000 kg (Taylor et al., 2017). In contrast, a living rhino is auctioned for between USD 10,000 and USD 30,000 (M. Knight (Personal communication, May 2016)), and this has implications for the management of the two species.

Since 2008, a substantial increase in rhino poaching pressure in African protected areas has resulted in many protected area managers having to increase their counter poaching measures significantly (M. Knight (Personal communication, May 2016)). In selected protected areas the protection of rhinos has received significant resourcing (e.g., Howard Buffet contributed USD 24 million to combat rhino poaching in the Kruger National Park; The Guardian, 2014) which has enabled the deployment of advanced technologies (Nguyen et al. 2016; CSIR (2019); Peace Parks Foundation (2019)) aimed at reducing what is effectively commercial rhino poaching orchestrated by criminal syndicates (Lunstrum, 2014). Various counter insurgency strategies, some derived in the military, have also been adopted by law enforcement units (Duffy, 2014). The consequences of this type of intervention for neighboring communities, and their relationships to protected areas (Cooney et al., 2016), have raised concerns (Buscher & Ramutsindela, 2015; Duffy, 2014; Lunstrum, 2014), and led to further interventions aimed at improving relationships between protected areas and neighboring communities (see GKEPF) as well as to contributing to a reduction in poaching.

Range state rhino poaching rates in Africa varied between 0 and 12% in 2017 (Emslie et al., 2018). Rhino poaching rates also vary between sites and at sites rhino poaching rates vary over time. In South Africa, the annual number of rhino poached nationally increased from 200 in 2009 to a peak of 1,300 in 2015 and more recently has declined to an estimated 900 or less in 2018 (Emslie et al., 2018). In this period, some sites have had the entire rhino population exterminated, others have lost very few. Kruger National Park with the world's largest population of rhino has been losing rhino to poaching at approximately 8% per annum for the past 5 years (Emslie et al., 2018). All else being equal, sites which are better protected are likely to lose a lower percentage of the rhino population to poaching than those with less effective security measures. Securing sites against poaching is thus a key element of rhino management.

The converse of losing rhinos to poaching is growing their numbers. From a national or global meta-population perspective, every rhino born serves as a buffer to a poaching loss, and thus decreases the risk of species extinction. Thus a site at which a rhino population zero has population zero growth, represents an opportunity cost in the fight against poaching. On the other hand, a site at which the rhino population is growing at a high rate is able to buffer losses to the meta-population. Importantly, considered over time and across populations, increased growth in rhino populations is compounded further reducing the extinction risk. Individual sites may still be exposed to local extermination, but by growing rhino numbers, the global population is more secure. Managing rhino populations for growth is thus also a key element of rhino management.

The maximum growth rate of a normally structured rhino population ($r_{\max}$) can be derived from basic demographic parameters in an ideal environment, for example, if half the population is female and half of the females are immature, and if the mean inter-calving interval of white rhino is 2.4 years (Owen-Smith, 1981), 40% of females (or 10% of the population) will give birth each year; that is, the potential birth rate is 10% per year. Subtracting mortalities (2–3% annually) results in a net annual population growth rate of 7–8%. Stated theoretically as $r_{\max}$ is inversely related to body weight in kg (W); or $r_{max} = 1.5\ W^{-0.36}$ (Caughley & Krebs, 1983). For white rhino this is approximately 8% per annum.

Our understanding of the biology and applied management of rhino populations in protected areas has improved rapidly recently (e.g., Ferreira & Okita-Ouma, 2012; Linklater & Shrader, 2017). Central to this has been managing individual rhino populations in bounded protected areas in a manner that stimulates them to grow at, or close to, their maximum rate of increase sensu (Caughley and Krebs (1983); see also Emslie (2001)). A rhino conservation site has a density at which the population reaches its maximum size (K), also called the ecological carrying capacity (ECC), at which it has a zero-growth rate (Caughley, 1977). At a population size lower than K, all else being equal, the population will grow according to some species specific function (Fowler, 1981; Jones & Sandland, 1974). If the density of a rhino population is kept appropriately below a zero growth density, by translocating a number of rhino to new range for example, growth rates in the range predicted by Caughley and Krebs (1983) can be achieved.

This approach, of actively managing rhino populations at a site, where the overall management objectives relate to broad biodiversity conservation, and specific rhino management interventions seek to maintain largely natural populations while stimulating high growth in rhino populations has been implemented over the past two decades in South Africa with positive outcomes (Emslie et al., 2016). There remains, however, no overarching framework to guide the conservation management of rhino, at the level of a protected area, and thus how to better allocate resources. To understand and guide interventions aimed at reducing rhino losses to poaching and stimulating the underlying growth of individual rhino populations, we developed a Theory of

Change (ToC) aimed at providing a site level framework for achieving the goal of *"growing rhino populations close to their maximum potential while at the same time minimizing negative impacts on the general biodiversity conservation objectives of the protected area"*. We abbreviated this goal to "*grow more rhino as quickly as possible*".

Importantly, the ToC does not work in a more intensive or semi intensive agricultural model for rhino production, for example, "rhino farming as conducted on Buffalo Dream Ranch which relies heavily on sex ratio manipulations and supplemental feeding of the rhino (News Desk, 2018)". Rather it seeks to make more effective use of existing protected areas, which are already significantly funded either privately or by the state, and which have a number of other conservation related objectives. It aims to achieve this by managing the rhino populations in a manner that will promote their growth, while at the same time managing for a natural ecosystem. This logic is underpinned by the uncertainty that exists around the financial viability of intensive rhino farming when there are no established and legal market mechanisms for selling the horn to cover operating costs.

1.1 | Developing a ToC for site based rhino conservation

A ToC is a structured approach to planning including the process of defining desired outcomes, setting goals, and being responsive to the need for flexibility in a complex environment. It entails describing a causal framework linking the present state to an agreed set of interventions selected for their ability to lead to the desired outcome or impact (see www.theoryofchange.org). This is enhanced by a clear articulation of the logic linking interventions and outcomes, including contextual assumptions that are being made. By adopting a ToC approach it is possible to keep the processes of implementation and evaluation transparent (Margoluis et al., 2013) as used in the Conservation Measures Partnership and the Open Standards for the Practice of Conservation. The ToC approach has been used in the context of natural resource management, illicit wildlife trade, and community engagement (Biggs et al., 2017). As with adaptive management (Stankey, Clark, & Bormann, 2005), a ToC ideally views each intervention as a hypothesis that requires testing in relation to its contribution toward achieving a predefined outcome, and the review of inappropriate interventions.

1.2 | Thematic elements of the rhino growth ToC

The authors have collectively been working in rhino site management in Africa for over 65 years. This has involved numerous workshops and management meetings, interactions with rhino conservation managers, veterinarians, members of the IUCN/SSC African Rhino Specialist Group, NGOs, and government officials and includes monitoring and security experience. The elements of this site-level African rhino conservation management ToC draw heavily on and distil that experience. In addition, the draft African Rhino Range States African Rhino Conservation Plan (ANON, 2016) as well as available national and site-specific management plans and strategies have been interpreted. Informal review was sought by presenting the ToC to a meeting of 49 African rhino conservation managers and scientists in March 2018. There was no resulting criticism of the ToC, and this was interpreted as clear support.

To establish a focus on countering losses that rhino populations are experiencing at a site level due to poaching, and at the same time to set an aspirational goal, the desired outcome (impact) has been set as to "*grow more rhino as quickly as possible*". This is a SMART (i.e., specific, achievable, results focused, and time-bound) goal and thus avoids a weakness of the Biggs et al. (2017) ToC for community based responses to illegal wildlife crime which does not define a desired outcome or impact. Because the current reality is that the vast majority of African rhino are in protected areas, which mostly have multiple objectives, one of which is variously phrased as "to maintain a natural state" or "to conserve biodiversity in all its fluxes", the ToC is aimed at *relatively* un-manipulated wild populations of rhino sensu Leader-Williams et al. (1997) and excludes intensive or semi-intensive breeding facilities where management will have access to different opportunities to intervene.

The ToC describes four thematic intervention streams ("pathways to impact" in the language of Biggs et al. (2017)). They are (a) habitat management, (b) range availability, (c) containment and attrition, and (d) rhino population management (Figure 1). Although presented as a series of parallel processes, in reality the intervention streams are networked and developments in one stream can have an influence on others. Successful rhino conservation requires engagements, expertise, and resources at a number of levels and a site with good enabling conditions (e.g., see Worboys, Lockwood, Kothari, Feary, & Pulsford, 2015) is more likely to succeed than one where the enabling conditions are weak.

1.3 | Thematic intervention 1: Habitat management

Contemporary conservation practice has a focus on biodiversity (sensu Noss, 1990). Underlying this approach is the understanding that biodiversity objectives are best served if the ecological context (pattern) under which species evolved is kept largely intact together with the ecological processes

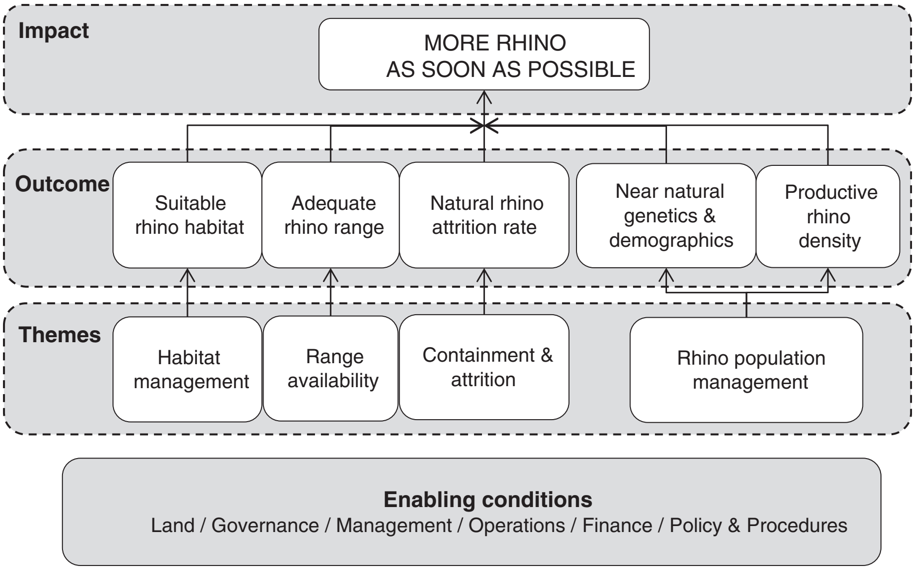

FIGURE 1 High level theory of change to achieve "more rhino as quickly as possible" under conditions of conservation management. The four intervention streams which feed into the supporting outcomes are illustrated. The streams have some interdependency. See text for details

that sustain the patterns (Balmford, Mace, & Ginsberg, 1998; Cowling, Pressey, Lombard, Desmet, & Ellis, 1999; Walker & Goodman, 1983). This approach has entered into the practice of both conservation management (Moritz, 2002) and conservation planning (Possingham, Franklin, Wilson, & Regan, 2005).

For this reason, there is a Habitat Management intervention stream in this ToC. The intervention stream effectively acknowledges that conservation managers will make decisions that are designed to benefit biodiversity conservation as a whole but may not be ideal or optimal for rhino growth for example, the restoration of an apex predator such as lion *Panthera leo* to a rhino conservation site, at an appropriate density, may increase the risk of predation of young rhino calves but would be considered appropriate under this ToC as it would promote natural ecological functioning with a net biodiversity benefit. Equally, the removal of an alien plant species which may be palatable to rhino would be supported.

The Habitat Management theme is underpinned by the logic for why the habitat in which rhino are being conserved should not be managed in a manner that will specifically favor rhino (i.e., in a single-species agricultural approach). Rather, that management should seek to intervene as little as possible and then only to minimize the impacts of an anthropogenic nature on the functioning of local ecological processes. Thus for example management will intervene if there is an altered ecology due to an invasion by an alien plant (e.g., Rozen-Rechels et al., 2017; Spear & Chown, 2009) or an anthropogenically altered fire regime (Archibald, Stava, & Levin, 2012; Bond, Smythe, & Balfour, 2001) or dispersal and population regulation dynamics are affected by the presence of a fence around the protected area which limits dispersal opportunities for larger mammals (Elmhagen & Angerbjörn, 2001; Pulliam, 1988). It is not possible to prevent occasional rhino deaths caused by disease but under the Habitat Management theme it may become necessary to remove animals to prevent large losses due to an infectious disease outbreak (Hess, 1996).

Thus five sub-themes are identified (water, fire, disease, alien species, and other large mammals). They may not be exhaustive.

1.4 | Thematic intervention 2: Range availability

The Range Availability intervention stream has two elements. The first is the need for rhino range to be legally secure and to be committed to rhino conservation. In the case of a state protected area, this usually means that the necessary legislation is in place as well as the appropriate management plans. For privately owned protected areas, this usually means that appropriate agreements are in place as well as an appropriate management plan.

Second, for a rhino population to grow, it needs space to grow into. Once a population has reached its maximum size, some rhino will need to be relocated to "new range" if further growth is to be achieved (see Emslie, Amin, & Kock, 2009). Availability of new or additional range is thus important for the success of any rhino conservation project. New range needs to meet certain criteria (Emslie et al., 2009; Linklater et al., 2011; IUCN, 2013). Preparation of new range requires adequate resources and can take years to complete. The process will be influenced by non-site specific dynamics such as the recent move of private properties in South Africa toward disinvesting in rhino due to the increased risks and costs associated with countering the recent surge in poaching (DEA, 2016).

1.5 | Thematic intervention 3a: Containment

Attrition or loss of rhino from a population can take place by emigration or death. Emigration can take place if a rhino walks out of an uncontained site or through theft; which is a seldom reported event. Apart from a few populations in the Cunene region of Namibia and Tsavo West National Park in Kenya and in northern Botswana there are few free ranging rhino remaining in Africa. In most instances there are fences and human settlements or agricultural activities within meters of the boundary of rhino conservation sites and rhino are functionally restricted in their movement. Where there are free ranging rhino they generally do not cross significant landscape barriers such as steep slopes or perennial rivers which can be seen as effective barriers to movement. Distance can substitute for containment where rhino occur in large and open landscapes and are able to move considerable distances yet still be considered part of the same population. Increasingly there is an expectation of a rhino site manager to ensure that the rhino population is adequately contained within a site and this is achieved through adequately specified and maintained fencing (Grant, Bengis, Balfour, & Peel, 2008) and containment has the effect of preventing population attrition through emigration or dispersal of rhino.

1.6 | Thematic intervention 3b: Reduced losses to poaching

With the desired state being "*more rhino as quickly as possible*", the focus of this theme is to minimize the loss of rhino over and above natural attrition rates due to poaching. Poaching of rhino is undertaken by groups ranging from opportunistic small-scale poachers (individuals or small groups) through to syndicated networks of individuals who control the functioning of teams of people using modern communication technologies. The increase in poaching over the past decade represents an increase in the number of poachers as well as an increase in levels of sophistication behind poaching attempts (Hübschle, 2016b). While increasing effort is being channeled into collapsing international syndicates (Haas & Ferreira, 2016) and reducing demand for rhino horn (Ayling, 2012), they lie outside the control of a rhino conservation site manager and are thus not considered here.

In recognition that poaching is more than simply an enforcement problem (Challender & MacMillan, 2014) efforts to reduce the loss of rhino to poaching are considered in four sub-themes; (a) namely preemptive intelligence, (b) patrol and response, (c) neighbor engagement, and (d) prosecutorial and judicial engagement. The logic of the sub-themes is based on a conceptual flow of events (Figure 2) aimed at understanding individual poaching events and where interventions may best take place to reduce losses due to poaching. Before a poacher enters a rhino conservation site (first panel) intelligence is a key tool available to site managers and law enforcement officials and can assist them in taking pre-emptive action to prevent a poaching event.

At a strategic level, conservation law enforcement generally aims to deter criminals through the threat of sanction (Durlaf & Nagin, 2011; Nagin, 2013), and this is operationalized by creating an environment where it is difficult for a poacher to operate freely. Once a rhino site has been entered by a person intending to poach it is important to detect and prevent them from firing a shot (or setting a snare) (Critchlow et al., 2016). This requires the capacity to detect and to respond to poachers (Figure 2, second panel).

There are many reasons why a rhino conservation site should work to establish a good relationship with neighboring communities (Biggs et al., 2017; Brockington, 2004; Child, 2004; Milupi, Somers, & Ferguson, 2017), and there are many risks to not doing so, but they are not the focus here. This ToC recognizes that where neighbors of a rhino conservation site perceive the site positively its members are

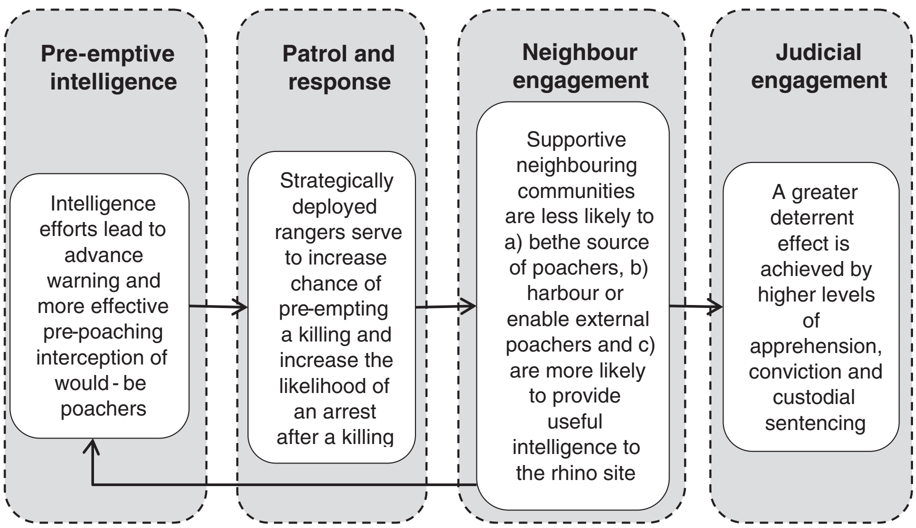

FIGURE 2 The flow of logic which on which the Theory of Change is based. Each shaded block represents a set of interventions and the arrows highlight some of the flows and feedback between these sets of interventions

more likely to act in a manner which is favorable to the site and wildlife conservation in general (Cooney et al., 2016; Ihwagi et al., 2015). With the value of rhino horn as high as it currently is, it is unrealistic to argue that good neighbor relations can replace strong law enforcement efforts, but care also needs to be taken to ensure that strong law enforcement does not result in negative community experiences which then sour relationships between the rhino conservation site and neighboring communities (Figure 2; third panel).

Poachers always have the element of surprise in relation to when and how they enter a site. There is thus always a chance that they will be successful in shooting a rhino and removing the horn. The final opportunity to act is through effective investigative policing and efficient administration of prosecutorial and judicial processes. For this reason effective relationships between the conservation staff and the policing, prosecutorial and judicial services can contribute in a meaningful manner to deterring further would-be poachers.

1.7 | Thematic intervention 4: Biological management

Three features of a rhino population can reasonably be managed, that is, the density, the age and sex ratios, and aspects of the gene pool. A rhino conservation site has a density at which the population reaches it maximum size (K), also called the ECC, and thus a zero-growth rate (Caughley, 1977). This density may vary with time. The growth rate of both black and white rhinos slows as the density approaches the ECC (Greaver, Ferreira, & Slotow, 2013; Okita-Ouma, Amin, Van Langevelde, & Leader-Williams, 2010; Rachlow & Berger, 1998). If the density of a rhino population is kept appropriately below ECC, by translocating a number of rhino to new range, growth rates in the range predicted by Caughley and Krebs (1983), that is, white rhino in the region of 7 to 9% and black rhino at 8 to 9% per annum, can be achieved. Similar results can be achieved by removing rhino at a constant rate per annum as long as the removal rate is in the appropriate range (Goodman, 2001).

In the absence of evidence to the contrary it is reasonable to assume that the sex ratio of natural rhino populations fluctuate around 1:1 (Clutton-Brock & Iason, 1986). This is the ratio that rhino populations should be managed toward. The same approach is applicable to the age structure of the population where the closer it is to a natural rhino age structure (e.g., Conway & Goodman, 1989; Goddard, 1970), the more likely it is to meet conservation objectives. In a highly fragmented context with a substantially reduced gene pool and no natural gene flow, it is important to manage toward a genetically diverse population of rhino. New knowledge on the genetic structure and history of individual rhino populations (e.g., Moodley et al., 2017) should be incorporated into all population and meta-population management decisions (Braude & Templeton, 2009; Frankham, Bradshaw, & Brook, 2014). We recognize that any management intervention (veterinary or otherwise) carries risk for the life of the animal and simply argue that at all times actions should be taken to keep loss of life to a minimum.

1.8 | Management, policy, and funding implications

The draft African Rhino Range States' African Rhino Conservation Plan (ARRSARCP, 2016) specifically targets sustained growth of African rhino populations to counter the impact of loss due to poaching. The national Biodiversity Management Plans for black and white rhino in South Africa, which is custodian to over 80% of the continental rhino population, does likewise (Knight, Balfour, & Emslie, 2013; Knight, Emslie, Smart, & Balfour, 2015). Yet there is no framework as to how this should be achieved, specifically in a protected area which has multiple objectives which may limit specific interventions which are taken to achieve rhino conservation goals. The ToC detailed here provides a framework for achieving the objective of growing rhino populations at the level of a site and will serve to guide any protected area manager wishing to counter rhino poaching losses. A clear consequence of adopting this approach to rhino population management is the need for a monitoring program which enables a manager to track progress and to make appropriate decisions relating to the management of their area and the rhino populations.

It is possible, in an environment of effective counter-poaching interventions at a site, that there will be a need to remove rhino and place them as part of a founder population in new sites. This raises the need for effective meta-population management of rhino populations. Meta-population management of rhino will require coordination and movement of animals, both nationally and internationally, and this will be best conducted in a policy environment which articulates a clear governance structure for decision making and which guides and regulates management interventions. The adoption of this ToC within a country would contribute a framework for guiding policy development, and common adoption among African rhino range states would extend that to international governance and coordination of rhino meta-population management and would provide a mechanism for implementing the draft ARRSARCP (2016).

Although most protected areas in Africa receive some funding they remain underfunded relative to their objectives (Brunner, Gullison, & Balmford, 2004). This has led to a situation where many protected area managers approach donors in their efforts to boost their financial resources.

Although donors have historically supported protected areas by contributing funds to buy equipment, vehicles and uniforms, increasingly they are looking to defining desired outcomes for a protected area, rather than simply funding inputs. This has led to the development of tools for certification or measures of management effectiveness (IUCN & WCPA, 2016). These tools still do not inform potential donors of the value or appropriateness of specific interventions which they may be approached to fund. This ToC, however, provides a clear logic stream between the status quo and a future desired state. This logic stream can then be used to develop a specific set of appropriate interventions and from this a work plan and a costing schedule. By using this approach, it is clear what is funded through core funding and what is unfunded. The ToC process thus contributes to identifying the "funding gap" and provides a significant opportunity to improve outcomes achieved through the expenditure made by donors and opens the door to impact investing which is gaining momentum globally (GIIN (2019); ZSL (2019)).

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

A structure for the Theory of Change was developed by D.B. and C.B. who also drafted the manuscript. The draft ToC was workshopped by all four authors to test it for completeness and consistency. C.G. and R.B. contributed to the detail and logic flow of the manuscript.

DATA ACCESSIBILITY STATEMENT

There are no data for this article.

ETHICS STATEMENT

This is a conceptual framework. No ethical issues have been identified by the authors.

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REFERENCES

ANON. (2016). Draft of the African Rhino Range States' African Rhino Conservation Plan. Retrieved from http://www.flauna.co.za/

Archibald, S., Stava, A. C., & Levin, S. A. (2012). The evolution of human-driven fire regimes. *PNAS*, *109*, 847–852.

ARRSARCP. (2016). Retrieved from https://www.environment.gov.za/sites/default/files/docs/african_rhinoconservation_plan.pdf

Ayling, J. (2012). *What sustains wildlife crime? Rhino horn trading and the resilience of criminal networks. Transnational environmental crime project* (Working Paper No 2/2012).

Balmford, A., Mace, G. M., & Ginsberg, J. R. (1998). The challenges to conservation in a changing world: Putting processes on the map. In G. M. Mace, A. Balmford, & J. R. Ginsberg (Eds.), *Conservation in a changing world*. Cambridge, England: Cambridge University Press.

Biggs, D., Cooney, R., Roe, D., Dublin, H. T., Allan, J. R., Challender, D. W. S., & Skinner, D. (2017). Developing a theory of change for a community-based response to illegal wildlife trade. *Conservation Biology*, *31*, 5–12.

Bond, W. J., Smythe, K.-A., & Balfour, D. A. (2001). Acacia species turnover in space and time in an African savanna. *Journal of Biogeography*, *28*, 117–128.

Braude, S., & Templeton, A. R. (2009). Understanding the multiple meanings of 'inbreeding' and 'effective size' for genetic management of African rhinoceros populations. *African Journal of Ecology*, *47*, 546–555. https://doi.org/10.1111/j.1365-2028.2008.00981.x

Brockington, D. (2004). Community conservation, inequality and injustice: Myths of power in protected area management. *Conservation and Society*, *2*, 411–432.

Brunner, A., Gullison, R., & Balmford, A. (2004). Financial costs and shortfalls of managing and expanding protected-area systems in developing countries. *Bioscience*, *54*, 1119–1126.

Buscher, B., & Ramutsindela, M. (2015). Green violence: Rhino poaching and the war to save southern Africa's peace parks. *African Affairs*, *115/458*, 1–22.

Caughley, G. (1977). *Analysis of vertebrate populations*. New York, NY: John Wiley.

Caughley, G., & Krebs, C. J. (1983). Are big mammals simply little mammals writ large. *Oecologia*, *59*, 7–17.

Challender, D. W. S., & MacMillan, D. C. (2014). Poaching is more than an enforcement problem. *Conservation Letters*, *7*, 484–494.

Child, B. (2004). *Parks in transition: Biodiversity, rural development and the bottom line*. London, England: Earthscan.

Clutton-Brock, T. H., & Iason, G. R. (1986). Sex ration variation in mammals. *The Quarterly Review of Biology*, *61*, 339–374.

Conway, A. J., & Goodman, P. S. (1989). Population characteristics and management of black and white rhino in Ndumu Game Reserve. *Biological Conservation*, *47*, 109–122.

Cooney, R., Roe, D., Dublin, H. T., Phelps, J., Wilkie, D., Keane, A., … Biggs, D. (2016). From poachers to protectors: Engaging local communities in solutions to illegal wildlife trade. *Conservation Letters*, *10*, 367–374.

Cowling, R. M., Pressey, R. L., Lombard, A. T., Desmet, P. G., & Ellis, A. G. (1999). From representation to persistence: Requirements for a sustainable system of conservation areas in the species-rich Mediterranean-climate desert of southern Africa. *Diversity and Distributions*, *5*, 51–71.

Critchlow, R., Plumptre, A. J., Alidria, B., Nsubuga, M., Driciru, M., Rwetsiba, A., … Beale, C. M. (2016). Improving law-enforcement effectiveness and efficiency in protected areas using ranger-collected monitoring data. *Conservation Letters*, *10*, 572–580.

CSIR. (2019). Retrieved from https://www.csir.co.za/csir-cmore-team-recognised-rhino-conservation-awards

DEA. (2016). Retrieved from https://www.environment.gov.za/mediarelease/molewa_rhinoowners_association_wildliferanching_southafrica

Duffy, R. (2014). Waging a war to save biodiversity: The rise of militarized conservation. *International Affairs*, *90*, 819–834.

Durlaf, S., & Nagin, D. (2011). Imprisonment and crime – can both be reduced? *Criminology & Public Policy*, *10*, 13–54. https://doi.org/10.1111/j.1745-9133.2010.00680.x

Elmhagen, B., & Angerbjörn, A. (2001). The applicability of metapopulation theory to large mammals. *Oikos*, *94*, 89–100.

Emslie, R. (2001). In *Proceedings of the SADC Rhino Management Group (RMG) Workshop on Biological Management to meet Continental and National Black Rhino Conservation Goals*, p. 127.

Emslie, R., Amin, R., & Kock, R. (2009). *Guidelines for the in situ re-introduction and translocation of African and Asian rhinoceros*. Gland, Switzerland: IUCN. vi+115p.

Emslie, R., Milliken, T., Talukdar, B., Ellis, S., Adcock, K., & Knight, M. (2016). African and Asian rhinoceroses – Status, conservation and trade: A report from the IUCN Species Survival Commission (IUCN SSC) African and Asian rhino specialist groups and TRAFFIC to the CITES secretariat pursuant to resolution Conf. 9.14 (Rev. CoP15).

Emslie, R. E., Milliken, T., Talukdar, B., Burgess, G., Adcock, K., Balfour, D., & Knight M.H. (2018). CoP18 Doc. 83.1, Annex 2. African and Asian Rhinoceroses – Status, Conservation and Trade: A report from the IUCN Species Survival Commission (IUCN SSC) African and Asian Rhino Specialist Groups and TRAFFIC to the CITES Secretariat pursuant to Resolution Conf. 9.14 (Rev. CoP17). Retrieved from https://cites.org/sites/default/files/eng/cop/18/doc/E-CoP18-083-02.pdf

Ferreira, S. M., & Okita-Ouma, B. (2012). A proposed framework for short-, medium- and long-term responses by range and consumer States to curb poaching for African rhino horn. Pachyderm 51: January–June.

Fowler, C. W. (1981). Density dependence as related to life history strategy. *Ecology*, *62*, 602–610.

Frankham, R., Bradshaw, C. J. A., & Brook, B. W. (2014). Genetics in conservation management: Revised recommendations for the 50/500 rules, red list criteria and population viability analyses. *Biological Conservation*, *170*, 56–63.

GIIN. (2019). Retrieved from https://thegiin.org/

Goddard, J. (1970). Age structure and vital statistics of a black rhinoceros population. *African Journal of Ecology*, *8*, 105–121.

Goodman P. S. (2001). Paper 10: Black rhino harvesting strategies to improve and maintain productivity and minimize risk. In R. H. Emslie (Ed.), *Proceedings of A SADC Rhino Management Group (RMG) Workshop on Biological Management to Meet Continental and National Black Rhino Conservation Goals.* KwaZulu-Natal: Giants Castle Game Reserve.

Grant, C. C., Bengis, R., Balfour, D., & Peel, M. (2008). Controlling the distribution of elephants. In R. J. Scholes & K. Mennell (Eds.), *Elephant management: A scientific assessment*. Johannesburg, South Africa: Wits University Press.

Greaver, C., Ferreira, S., & Slotow, R. (2013). Density-dependent regulation of the critically endangered black rhinoceros population in Ithala Game Reserve, South Africa. *Austral Ecology*, *39*, 437–447. https://doi.org/10.1111/aec.12101

Gwin, P. (2012). Rhino Wars. Retrieved from https://www.nationalgeographic.com/magazine/2012/03/rhino-wars/

Haas, T., & Ferreira, S. M. (2016). Combating rhino horn trafficking: The need to disrupt criminal networks. *PLoS One*, *11*(11), e0167040. https://doi.org/10.1371/journal.pone.0167040

Hess, G. (1996). Disease in metapopulation models: Implications for conservation. *Ecology*, *77*, 1617–1632.

Hübschle, A. (2016a). The social economy of rhino poaching: Of economic freedom fighters, professional hunters and marginalized local people. *Current Sociology*, *63*, 1–21.

Hübschle, A. (2016b). *A game of horns – transnational flows of rhino horn*. Köln, Germany: International Max Planck School on the Social and Political Constitution of the Economy Retrieved from http://kups.ub.uni-koeln.de/6685/

Ihwagi, F. W., Wang, T., Wittemyer, G., Skidmore, A. K., Toxopeus, A. G., Ngene, S., … Douglas-Hamilton, I. (2015). Using poaching levels and elephant distribution to assess the conservation efficacy of private, communal and government land in northern Kenya. *PLoS One*, *10*(9), e0139079. https://doi.org/10.1371/journal.pone.0139079

IUCN/SSC. (2013). *Guidelines for reintroductions and other conservation translocations, version 1.0*. Gland, Switzerland: IUCN Species Survival Commission, viiii + 57 pp.

IUCN & WCPA. (2016). *IUCN green list of protected and conserved areas: Standard, version 1.1*. Gland, Switzerland: IUCN.

Jones, R. J., & Sandland, R. L. (1974). The relation between animal gain and stocking rate: Derivation of the relation from the results of grazing trials. *Journal of Agriculture Science (Cambridge)*, *83*, 335–351.

Knight, M., Balfour, D., & Emslie, R. (2013). *Biodiversity management plan for the black rhinoceros (Diceros bicornis) in South Africa – 2011 to 2020*. South Africa: Department of Environmental Affairs.

Knight, M., Emslie, R., Smart, R., & Balfour, D. (2015). *Biodiversity management plan for the white rhinoceros (Ceratotherium simum) in South Africa*. South Africa: Department of Environmental Affairs.

Leader-Williams, N., Brett, R. A., Brooks, M., Craig, I., du Toit, R. F., Emslie, R. H., … Stockil, O. (1997). A scheme for differentiating and defining the different situations under which live rhino are conserved. *Pachyderm*, *23*, 24–28.

Linklater, W. L., Adcock, A., du Preez, P., Swaisgood, R. R., Law, P. R., Knight, M. H., … Kerley, G. I. H. (2011). Guidelines for large herbivore translocation simplified: black rhinoceros case study. *Journal of Applied Ecology*. *48*(2), 493–502. https://doi.org/10.1111/j.1365-2664.2011.01960.x.

Linklater, W. L., & Shrader, A. M. (2017). Rhino management challenges: Spatial and social ecology for habitat and population management. In J. P. G. M. Cromsight, S. Archibald, & N. Owen-Smith (Eds.), *Conserving Africa's mega-diversity in the Anthropocene*. Cambridge, England: Cambridge University Press.

Lunstrum, E. (2014). Green militarization: Anti-poaching efforts and the spatial contours of Kruger National Park. *Annals of the Association of American Geographers*, *104*, 816–832. https://doi.org/10.1080/00045608.2014.912545

Margoluis, R., Stem, C., Swaminathan, V., Brown, M., Johnson, A., Placci, G., … Tilders, I. (2013). Results chains: A tool for conservation action design, management, and evaluation. *Ecology and Society*, *18*, 22.

Milliken, T. (2014). *Illegal trade in ivory and rhino horn: An assessment report to improve law enforcement under the Wildlife TRAPS Project*. Johannesburg, South Africa: USAID and TRAFFIC.

Milupi, I. D., Somers, M. J., & Ferguson, W. (2017). A review of community-based natural resource management. *Applied Ecology and Environmental Research*, *15*, 1121–1143.

Moodley, Y., Russo, I. M., Dalton, D. L., Kotzé, A., Muya, S., Haubensak, P., … Bruford, M. W. (2017). Extinctions, genetic erosion and conservation options for the black rhinoceros (*Diceros bicornis*). *Nature Scientific Reports*, *7*, 41417. https://doi.org/10.1038/srep41417

Moritz, C. (2002). Strategies to protect biological diversity and the evolutionary processes that sustain it. *Systematic Biology*, *51*, 238–254.

Nagin, D. (2013). Deterrence: A review of the evidence by a criminologist for economists. *Annual Review of Economics*, *5*, 83–105.

Nellemann, C., Henriksen, R., Raxter, P., Ash, N., & Mrema, E. (Eds.). (2014). *The environmental crime crisis – threats to sustainable development from illegal exploitation and trade in wildlife and forest resources. A UNEP rapid response assessment*. Nairobi and Arendal: United Nations Environment Programme and GRID-Arendal.

News Desk. (2018). Rhino breeder John Hume says he is on verge of bankruptcy, appeals for cash. *Africa Geographic* Retrieved from https://africageographic.com/blog/rhino-breeder-john-hume-bankruptcy-appeals-cash/

Nguyen, T. H., Sinha, A., Gholami, S., Plumptre, A., Joppa, L., Tambe, M., … Beale, C. (2016). CAPTURE: A new predictive anti-poaching tool for wildlife protection. In J. Thangarajah, K. Tuyls, S. Marsella, & C. Jonker (Eds.), *Proceedings of the 15th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2016), Singapore*. International Foundation for Autonomous Agents and Multi-agent Systems. Retrieved from http://www.ifaamas.org

Noss, R. (1990). Indicators for monitoring biodiversity: A hierarchical approach. *Conservation Biology*, *4*, 355–364.

Okita-Ouma, B., Amin, R., Van Langevelde, F., & Leader-Williams, N. (2010). Density dependence and population dynamics of black rhinos (*Diceros bicornis michaeli*) in Kenya's rhino sanctuaries. *African Journal of Ecology*, *48*(3), 791–799.

Owen-Smith, N. (1981). The white rhino overpopulation problem and a proposed solution. In P. A. Jewel, S. Holt, & D. Hart (Eds.), *Problems in management of locally abundant wild mammals*. New York, NY: Academic Press.

Peace Parks Foundation. (2019). Retrieved from https://www.peaceparks.org/a-safe-space-for-rhinos/

Possingham, H. P., Franklin, J., Wilson, K., & Regan, T. J. (2005). The roles of heterogeneity and ecological processes in conservation planning. In G. M. Lovett, M. G. Turner, S. G. Jones, & K. C. Weathers (Eds.), *Ecosystem function in heterogeneous landscapes*. Berlin, New York, Tokyo: Springer Verlag.

Pulliam, R. H. (1988). Sources, sinks and population regulation. *American Naturalist*, *132*, 652–661.

Rachlow, J., & Berger, J. (1998). Reproduction and population density: Trade-offs for the conservation of rhinos in situ. *Animal Conservation*, *1*(2), 101–106. https://doi.org/10.1111/j.1469-1795.1998.tb00017.x

Rozen-Rechels, D., te Beest, M., Dew, A., le Roux, E., Druce, D. J., & Cromsigt, J. P. G. M. (2017). Contrasting impacts of an alien shrub on mammalian savanna herbivores revealed on a landscape scale. *Diversity and Distributions*, *23*, 656–666.

Spear, D., & Chown, S. L. (2009). Non-indigenous ungulates as a threat to biodiversity. *Journal of Zoology*, *279*, 1–17.

Stankey, G. H., Clark, R. N., & Bormann, B. (2005). Adaptive management of natural resources: Theory, concepts, and management institutions. United States Department of Agriculture; Forest Service; Pacific Northwest Research Station; General Technical Report PNW-GTR-654.

Taylor, A., Balfour, D., Brebner, D.K., Coetzee, R., Davies-Mostert, H., Lindsey, P.A., Shaw, J., 't Sas-Rolfes, M. 2017. Sustainable rhino horn production at the pointy end of the rhino horn trade debate. *Biological Conservation 216*: 60–68.

UNEP-WCMC. (2019). Checklist of CITES species. Retrieved from https://www.unep-wcmc.org/resources-and-data/checklist-of-cites-species

Walker, B. H., & Goodman, P. S. (1983). Some implications of ecosystem properties for wildlife management. In R. N. Owen-Smith (Ed.), *Management of large mammals in African conservation areas*. Pretoria, South Africa: Haum.

Worboys, G. L., Lockwood, M., Kothari, A., Feary, S., & Pulsford, I. (Eds.). (2015). *Protected area governance and management*. Canberra, Australia: ANU Press.

ZSL. (2019). Retrieved from https://www.zsl.org/conservation-initiatives/animals-on-the-edge/rhino-impact-investment-project

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