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Do armed field-rangers deter rhino poachers? An empirical analysis

Chris Barichievy[a,b,1,*], Lawrence Munro[c,b,1], Geoffrey Clinning[b], Brendan Whittington-Jones, Gavin Masterson

[a] Zoological Society of London, Regent's Park, London, England NW1 4RY, United Kingdom
[b] Ezemvelo KZN Wildelife, Queen Elizabeth Park, 1 Peter Brown Drive, Pietermaritzburg, KZN, South Africa
[c] African Parks, Centurion Building, The Oval, Corner Meadowbrook Lane and Sloane Street, Johannesburg, South Africa

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ABSTRACT

The poaching of rhino for their horns has reached unprecedented levels, and the world can expect to witness their extinction in the wild by 2035 if a breakthrough is not made. The links between poaching, global instability and possibly terrorism have led to substantial investment from the developed world into conservation security development in Africa. Such an investment requires a quantitative monitoring approach that allows for the effectiveness of the expenditure to be determined. By combining criminological deterrence theory and spatially explicit field-ranger patrol monitoring, we develop a framework to measure the presence of field-rangers in the landscape. We test this framework empirically by comparing the presence of field-rangers in the landscape against the presence around 40 rhino poaching incidents. We empirically demonstrate that the analysed field ranger human resources and their deployment in a well-staffed protected area in Africa did not deter rhino poachers.

1. Introduction

Rhinoceros (rhinos) are a group of species synonymous with marked conservation successes and failures. Poaching of rhino for their horn is not a new phenomenon; rhino horn has been coveted and rhinos persecuted for their horns since the 1800s, particularly from the Far East and Yemen (Martin, 1985; Western and Vigne, 1985; Leader-Williams, 1988; Leader-Williams et al., 1990). In Africa, over the last 50–60 years alone, this is the second "catastrophic crisis" facing rhino. Conservation failures during this time are reflected in the functional extinction of the Northern White Rhino (*Ceratotherium simum cottoni*) (Emslie, 2011a, b) and the extinction of the western subspecies of Black Rhinoceros (*Diceros bicornis longipes*) in 2011 (Emslie, 2011a, b). However, major successes have been had as concerted global conservation efforts in the 1990s reversed the negative trends in certain rhino populations, and resulted in and expansion of Southern White Rhinoceros (*Ceratotherium simum simum*) and Southern Black Rhinoceros (*Diceros bicornis bicornis*). The recent upsurge in poaching pressure, attributed in part to the accelerated growth of the Vietnamese middle-class and acutely increased demand for rhino horn as a status symbol (Ayling, 2013; Milliken and Shaw, 2012), has eaten away at this success. Continued loss of rhino threatens these conservation achievements, and even the species themselves, with predictions of the species extinction in the wild by 2035 (Di Minin et al., 2014).

Protected areas (PAs) form the foundation of global efforts to protect biodiversity (Pfeifer et al., 2012). The majority of rhino are found within state-funded PAs that are patrolled by armed security personnel. The surge in rhino poaching has spawned a reactive increase in investment of substantial human and financial resources aimed at ensuring the safety of the rhino populations within PAs (Duffy, 2014). However, even a protected area with a sufficient contingent of trained and dedicated staff will not achieve its biodiversity conservation objectives if poachers are depleting its biodiversity (Hockings and Phillips, 1999). An inability to prevent poaching within a heavily-patrolled PA may have less to do with total resource allocation than with the strategy by which the resources are deployed. Given that conservation agencies are notoriously underfunded, how those resources are allocated is of utmost importance to ensure the maximum conservation impact.

International institutions have recognised the threat that poaching, along with its illicit revenue generation, has on global security and natural heritage; consequently, funding has been increased dramatically and is being invested into combating wildlife crime. For example, in July 2013 the United States Government committed a Presidential Task Force charged with developing a National Strategy for Combating Wildlife Trafficking. Furthermore, the US government pledged ten

* Corresponding author.
E-mail address: Chris.Barichievy@zsl.org (C. Barichievy).
[1] Previous affiliation during part of the study.

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million US Dollars to African Partners (Office of the Press Secretary, White House, 2013). In February 2014 the Dutch and Swedish postcode lotteries donated 15.4 million Euro to the Peace Parks Foundation (Peace Parks Foundation, 2014). In March 2014, 23.7 million US Dollars was given by the Howard G Buffet Foundation to South African National Parks (The Howard G. Buffet Foundation, 2014). In 2016, GEF released a report showing that over $1.3 billion was committed by 24 international donors between 2010 and late 2016, which approximated $190 million per year (The Global Environmental Facility, 2016). With international donations of this magnitude being made, it is imperative that the effectiveness of these expenditures be measured in a manner that allows for the direct cost-benefit analysis to be done.

It is a challenge to quantify the effect/efficacy of law enforcement actions because criminological studies are often too poorly conducted to draw precise or even realistic assessments as they are often retrospective in nature, inferred from interventions that are set up without rigorous experimental design (Paternoster, 2010). However, with the incorporation of increasingly sophisticated patrol monitoring systems such as SMART conservation software (www.smartconservation.org.) combined with a Cybertracker based patrol monitoring system (Hamilton, 2012), the quantity and quality of data available for patrol effectiveness analyses has improved. The volume and resolution of these patrol effort data, allow for patrol management to be viewed in a unique manner, linking fine scale spatiotemporal data to poaching activities. As the data volumes increase, new methods need to be developed to analyse the data and feed new information back into the security operations to allow for them to adapt at a rate fast enough to counter the poachers.

1.1. *Quantifying the effectiveness of law enforcement action: the Presence framework*

Presence is a well-utilized law enforcement concept, referring to whether a law enforcement officer is there at the time a crime is perpetrated. To maximise deterrence; it is important to maximise law enforcement officer presence or at least the perception thereof (Durlauf and Nagin, 2011). The presence of a law enforcement officer at a point in space and time should prevent a crime from happening at that point in space and time, as the threat of sanction is certain and swift. Unless a law enforcement officer is complicit in the act, it then follows that it is possible to measure the spatiotemporal law enforcement presence in an area. In this paper, we utilize the location of field-rangers in space and time to determine their presence. Poaching events are distributed in space and time, and an armed field-ranger team is either there when a poaching crime is committed, or they are not.

In wildlife crime, it is a sound axiom that deterring an activity is more beneficial to maintaining biodiversity objectives than apprehension after the fact. Deterrence refers to the omission of a criminal act because of the fear of sanctions or punishment (Paternoster, 2010). Deterrence theory is well established in criminology, and law enforcement agencies the world over manipulate the Certainty, Severity and Celerity (What is the certainty of a sanction actually being imposed on a perpetrator, how severe is the cost of the sanction if it is imposed and, how quickly the sanction is imposed if it occurs) aspects of sanctions to maximise the deterrence of criminals (Nagin, 2013). A general maxim is that certainty of punishment is more of a deterrent to crime than the severity of punishment (Doob and Webster, 2003; Mendes, 2004). This finding has profound implications for law enforcement strategies and is one of the drivers behind policies on visible policing, with the goal being to allocate police officers, and their criminal justice partners, in ways that heighten the perceived risk of apprehension (Durlauf and Nagin, 2011).

Numerous wildlife crime studies have investigated the effect of law enforcement effort in relation to the levels of illegal activities (Leader-Williams, 1988; Leader-Williams et al., 1990). Spatially explicit analyses are less common, but are recently being developed and demonstrated in conservation law enforcement (Critchlow et al., 2016, 2015; Hofer et al., 2000; Plumptre et al., 2014) and, there are few clear guidelines for effective field-ranger resource requirements. The International Union for the Conservation of Nature (IUCN) advises a human resource capacity of 1 field-ranger per 100 km^2 (Emslie and Brooks, 1999) in rhino reserves. However, despite many South African protected areas meeting this goal, rhino poaching has still increased. Although a valuable guideline, it was developed prior to the recent upsurge in poaching and incorporation of GPS based patrol monitoring, and therefore does not take into consideration the increased demand for rhino horn, the price paid to poachers and associated acceptance of risk, or the potential for more detailed investigations. Nor does the universal value take into account the temporal component of field-ranger deployment.

In many, if not the majority of PAs, foot-based patrols are still utilized as a significant deterrent and law enforcement force by PA management. There are financial, human resource and time constraints to managing the staff, equipment and infrastructure necessary to maintain regular foot patrols in a given area. By default, with a finite budget, the maintenance of foot-patrols is made at the expense of other possible interventions such as investing in intelligence operations or specialised anti-poaching units. Concurrently, well-intentioned donor funding is directed to expensive, media-friendly, yet ultimately untested technologies, such as drones and helicopters, sometimes at the expense of foundational security activities.

This paper has addressed a parochial aspect of law enforcement, the optimization of local law enforcement resource distribution. It is important to realize that this optimization process is nested within the larger socio-political landscape of protected area management. Many other factors need to be addressed to ensure a functional and resilient protected area, and these factors are distributed across multiple levels of organization (Cumming et al., 2015). For instance, optimized foot patrols are of no use if there is no ability to prosecute as the entire law enforcement chain is broken, or there is a large disjunct between socio-political values and conservation values (e.g., Barichievy et al. unpublished data). Corruption can undermine all aspects of the law enforcement chain and required good management practices and governance to address (Smith et al., 2015), and demand can change the nature of the threat. Therefore, reducing the demand and increasing governance, and research around mechanisms to achieve this (Biggs et al., 2013, 2016) is inextricable from a debate of environmental law enforcement.

1.2. *The presence framework*

We investigate Presence as follows: We assume that deterrence is directly proportional to a function of field-ranger presence ($DT \propto f(P)$; where DT = *Deterrence* and P = *Presence*). We divide field-ranger presence (P) into its two components that can be pragmatically managed; Frequency (F) and Duration (D). Frequency is a measure of how often a field-ranger is in a particular place over a specified time, while Duration is a measure of the length of time a field-ranger spends at a particular place. The distinction between the two has profound implications for how field-rangers are deployed when on patrol, and are already implicitly utilized by law enforcement management when directing observational patrols or general walking patrols.

A patrol group of field-rangers can only be at one place at any one time; it follows then that for any given point in space, the Frequency × Duration is equal to the presence of field-ranger in that particular place over a specified period ($DT \propto F\,x\,D$). Given that Duration and Frequency are quantifiable, we can plot them to generate what we term a presence framework, depicted in Fig. 1 generated from hypothetical data. The area covered by data points is indicative of the total presence available to law enforcement operations (Fig. 1). The utility of the framework for management is that the frequency and duration of the field-ranger movements can be manipulated in space

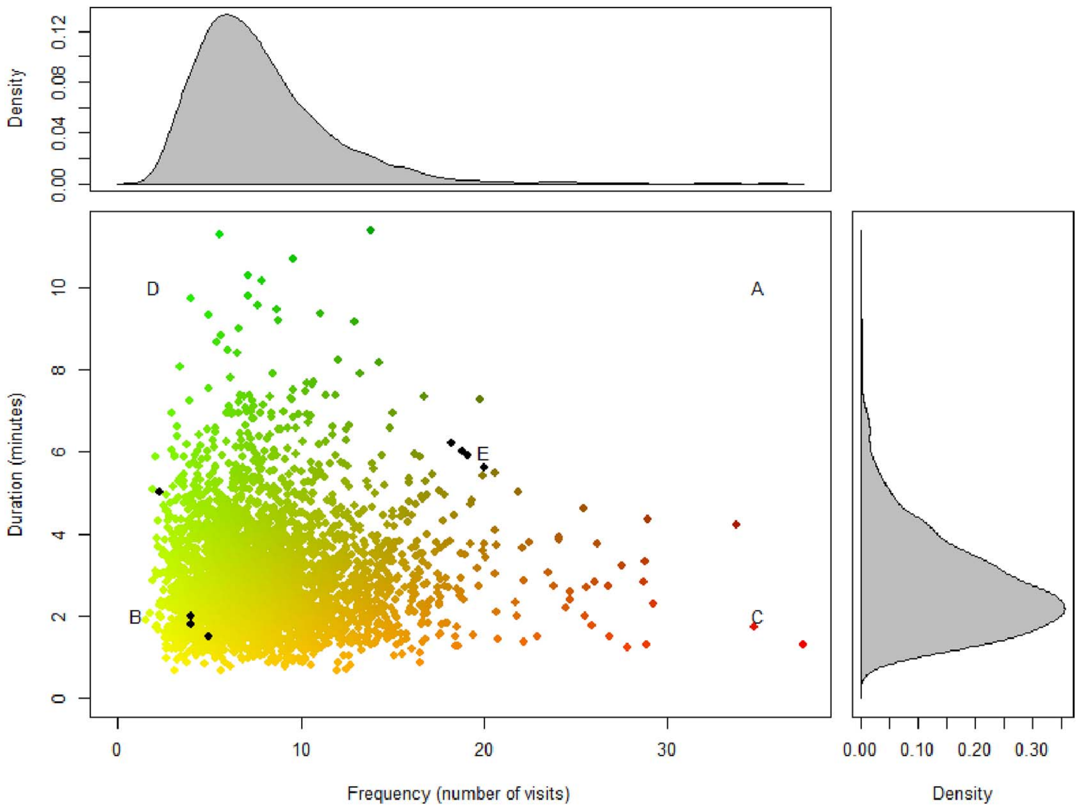

Fig. 1. The presence framework to measure field-ranger patrol presence as a function of frequency and duration. The graph shows a hypothetical presence of field-rangers, with frequency and duration of patrols within sample units sampled from a two-dimensional log-normal distribution. The density plots illustrate the distribution of Frequency, in an arbitrary units (Top) and distribution of Duration, in arbitrary units (Right). The colour value indexes the overall Presence value; High presence would be in the top right (A), yellow indicates a low overall presence (labelled B), with the amount of red and green indicating the combination of Duration and Frequency (C and D). Black circles represent hypothetical poaching events; it would be expected, that if field-ranger presence does deter rhinoceros poachers, the presence of field-rangers around Rhinoceros carcasses would be significantly different prom the ambient presence of field-rangers in the landscape. It would be expected that the poaching events would fall near E, as opposed to B, where there would be no difference in field-ranger presence between rhino poaching events and the landscape. The colours are used to project the presence back spatially onto a map of the PA, something not done is this paper at the request of the management agency. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and time (change the shape of the curve in the framework) but, the overall area under a fitted curve is dependent on what is available as dictated by budgets, trade union agreements and field-ranger capacity such as fitness levels, competence and initiative. Furthermore, because field-ranger presence is spatially explicit, utilizing presence allows for unique visualizations of conservation security resource allocation, when the frequency of patrols or duration of patrols or total field-ranger presence is projected back onto a patrol area map.

Presence is both intuitive and supported anecdotally. For instance, in protected areas with low rhino density, field-rangers walk with the rhino as their sole responsibility. Having a field-ranger with the rhino effectively puts them in an area of high field-ranger presence (in essence placing the rhinos into the area in the top right-hand corner of Fig. 1). For example; a known protected area that has lost 85% of its rhino to poaching between 2009 and 2012 has adopted this approach. The strategy ensured the protection of the remaining five rhinos for over two years during which period they bred successfully. A similar approach is used with the few remaining northern white rhino in Kenya. The success of walking with the rhino as an effective anti-poaching tool is qualitative evidence of the deterrent effect of increased presence. In areas of higher rhino density, the human resources become diluted as field-rangers no longer walk with individual animals but rather patrol areas. The question then becomes, at what level of field-ranger presence, does the deterrent effect fail to deter poachers.

Ultimately, this analysis must help management of rhino security: we acknowledge that there is more than one way to test such a deterrent relationship. For instance, it is possible to verify the proportion of time that field-rangers spend within an area over a given time, and compare areas where rhino have and have not been poached. However, although statistically simpler, it has less utility for management of human resources. Practically, the proportion of time in an area can only be affected by increasing frequency of visit, or duration of visit and the differentiation is critical in patrol resource deployment.

By using the field-ranger location data about poaching events, the deterrent effect of field-rangers on poaching should be measurable. If examined levels of field-ranger presence do in fact deter poachers; we hypothesise that there would be a significant difference between the field-ranger presence where the rhino are poached and the overall field-ranger presence in the landscape. We propose that the mechanism for such a difference is a selection by poachers for areas of lower field-ranger presence. It may be that poachers in many instances do know exactly where field rangers are, either by mounting their observations on Field Ranger camps or through information received from field rangers in the case of internal collusion. Alternatively, there is an increased number of unsuccessful poaching attempts in regions of higher field-ranger presence.

This investigation is aimed at the protected area level, designed to assist management with human resource allocation. We acknowledge that the presence framework derived for this study does not include the celerity and severity of sanctions in the analysis of deterrence. Here we only focus on the aspect of deterrence (certainty) that PA manager/management agency can control at the organisational level of the PA. The celerity and severity components of deterrence can be viewed as the context in which the PA management operates.

In this paper, we use the presence framework to test the effectiveness of foot patrol effort (defined as the amount of human resource, measured as time on patrol), and we use a case study of rhinos poached in a well-resourced protected area to demonstrate the effectiveness. We present the first known spatially explicit empirical analysis quantifying the effect of the efforts of armed field personnel on preventing the poaching of rhino.

2. Methods

Given the nature of rhino security information, following African rhino specialist group protocol throughout this paper, we do not present any information that identifies the protected area in question. We also utilize old data to demonstrate the analysis, while not publicising sensitive information.

We tested the deterrent effect of field-rangers in a leading rhino conservation area in South Africa run by Ezemvelo KwaZulu-Natal Wildlife. The PA has a large population of rhino within its boundaries and has experienced sustained poaching pressure. The law enforcement resources available for the protection of this particular protected area relative to its size are high relative to other state-funded protected areas and so represents a substantial resource investment to test for deterrence. However, the population of rhinos relative to law enforcement personal is still high and so individual monitoring or individual protection is not feasible. The PA management has taken steps to improve the protection of the rhino population, such as the inception of a Cybertracker patrol monitoring system in September 2011. As a result of this program, the PA is in a unique position of having high-resolution field-ranger data coupled with a significant number of rhino poaching events. The publishing of current patrol data is not recommended as it may compromise the current law enforcement effort in the PA. As a result, we make use of two years of patrol data for the period between 1 September 2011 and 30 September 2013.

2.1. Data analysis

Field-ranger locations were recorded at three-minute intervals during their foot based patrol actions. Distance and time of each interval varied dependent on the patrol objective such as sitting static observing an area from a vantage point (Observation Patrol) or moving through a landscape (Foot Patrol).

The PA was divided into 0.25 km^2 grid cells. Grid cell size was determined with a time-distance calculation using sample datasets from experienced PA managers in the specific PA. At the regular field-ranger walking pace of approximately 4 km/h–6 km/h, a grid cell of 0.25 km^2 ensures that a ranger cannot pass through each grid cell without their presence being recorded. Field-ranger presence was calculated as the number of unique days in which a field patrol has been registered within the grid cell (frequency) and the average amount of time spent within that grid cell (duration). Preliminary analyses indicated that the time to saturation (the length of time taken until all viable patrol areas have been covered at least once) averaged at about 4–6 months for a number of analysed reserve datasets. Therefore the presence was calculated for the six months before a carcass was found. Only grid cells where field-rangers have patrolled are used in the analyses, as the assumption of valid information in grid cells cannot be made if the field-rangers have never been in the grid cell. It may be that a field ranger moves through an edge of a polygon and is not recorded. However, this “presence” will then be minimal as it means that they have spent less than 3 min in the polygon in total.

We present the rhino carcasses within the deterrence framework, relative to the frequency and duration of patrols in the landscape. We calculated the frequency and duration of foot based patrols in the 0.25 km^2 grid cells that contained rhino poaching incidents found between January 2011 and September 2013. We used data from 40 rhino poaching incidents. Only carcasses for which there were six months of data of field-ranger presence before the date of the carcass being found were used to ensure equality between sample efforts. This ensures that the field rangers have likely patrolled in the area, giving the random sampling method a greater than zero chance of finding ranger presence and duration values for each cell.

The method assumes all rhino carcasses within the previous six months had been found. We are confident that the majority of rhino carcasses present in the PA were discovered as the PA has intense rhino monitoring and actively patrols on foot and by aircraft for carcasses. Data from aerial patrols is not used in this analysis, as it is foot patrol based, but carcasses found using aircraft was used an independent measure to detect carcasses. Our method assumes field-ranger patrolling was not manipulated by any means by external criminal agents. Age of carcasses was fresh (generally less than a week old). An incident refers to one “poaching event”, as multiple rhinos may be shot in one incident.

Spatial autocorrelation is of concern in field-ranger patrol data; this is because field-rangers do not move randomly in the landscape, but walk. Therefore, to remove any spatial bias in the data, the data for the entire period are randomly resampled 5000 times, with replacement, for each grid cell during the given sample period to generate a distribution of average frequencies, durations and presence within a grid cell.

Data were analysed for periods (binned), a period of 16:00–04:00 (Night) and 04:00–16:00 (Day), reflecting a chosen management unit for when patrols were primarily sent out. All analyses were performed on Night, Day and grouped data, the distinction of “Day and Night” is a management decision, linked to patrol deployment as opposed to a circadian measurement.

We used a bootstrapping test for differences to test for significant differences between the mean and medians of the frequency, duration and presence of field-rangers in the landscape compared to around carcasses. Cells were sampled with replacement 5000 times from the distributions generated from all cells within the 6 months previous to the date before the carcass was discovered. The difference between means and medians was bootstrapped for 10,000 iterations and 95% confidence interval evaluated as to whether or not it contains 0. Should the 95% CI for the difference in means and/or medians contain 0, there is no significant difference in the distributions. Should the values be negative, this indicates a higher value of carcass vs. landscape field-ranger presence.

3. Results

When represented graphically, rhino poaching events are seen to occur at a wide range of frequencies and durations of patrolling (Fig. 2). It was not possible to depict these data spatially for security reasons, but one must bear in mind each colour point represents a spatial polygon that can be mapped back onto the protected area, generating a spatial map of field ranger deterrence. Results of significance tests are inconsistent across the samples of the day, night and total presence of field rangers in the landscape when compared to the presence of field rangers around carcasses (Table 1); however significant differences (alpha = 0.05) were found.

3.1. Total sample (days and nights)

When the total 24-hour period was analysed; there was no significant difference between the average presence and the average duration of foot patrols around a poaching incident and in the landscape in general. There is a significant difference in the frequency of patrols, indicating that areas around poaching incidents had a significantly higher frequency of field-ranger patrol prior to the incident. There was a consistently higher median presence of patrols, the median frequency of patrol and median duration of patrol prior to the event, surrounding the poaching incidents when compared to the landscape.

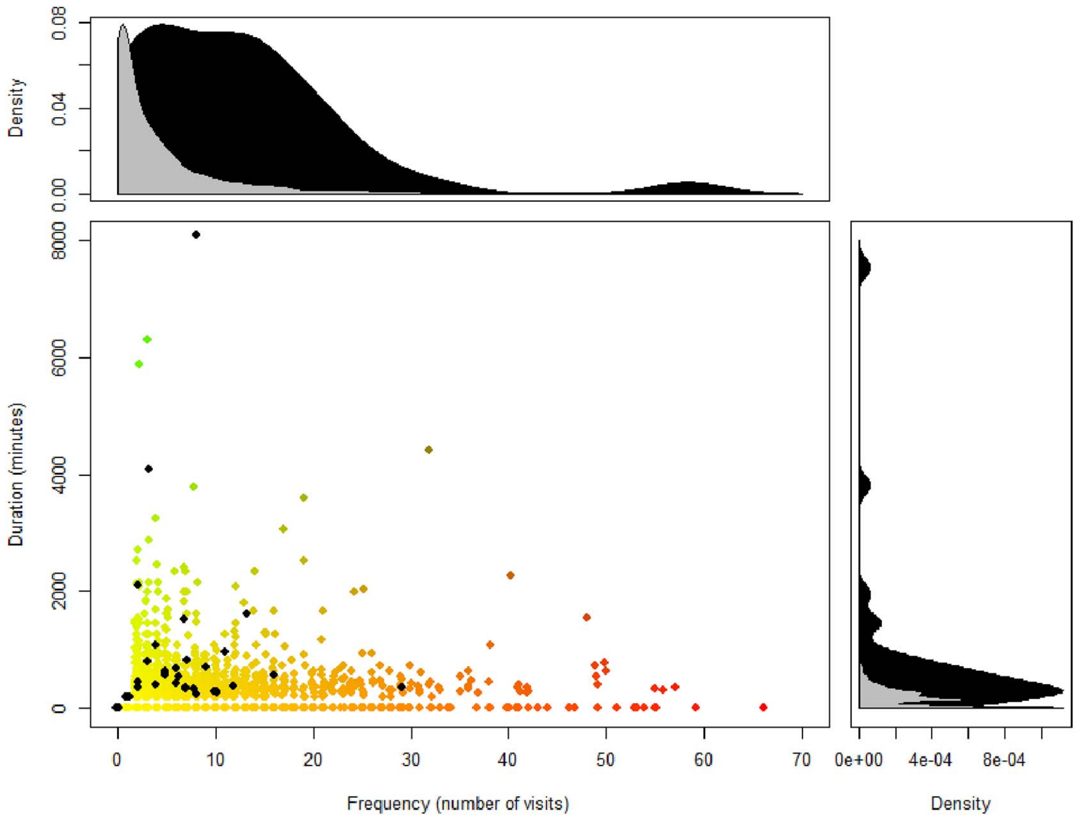

Fig. 2. The quantified presence of field-ranger patrols in the landscape and surrounding 40 poached rhinoceros in the selected PA between 2011 and 2013. The presence of field-rangers is a combination of the frequency (top plot) and duration (Right-hand plot) of field-rangers within 0.25 km^2 blocks in the protected area (grey) and around rhino carcasses (Black). The colour indexes the presence which is used to project the presence onto a map (not done here as publishing patrol effort is counterproductive for security efforts). The presence surrounding the rhino carcasses is indicated in black.

Table 1
The 95% Confidence intervals of the bootstrap comparisons of the mean and median of the patrol frequency, duration and patrol presence compared between areas around poaching events and in the landscape. Significant differences were calculated via bootstrapping differences of the landscape patrol values minus poaching event values. If 0 is found within the 95% confidence intervals, there is no significant difference (alpha = 0.05). If both CI are negative, it indicates a higher level of foot patrol presence around poaching event sites compared to the landscape (*), whereas both CI's being positive indicated a higher level of presence in the landscape (**).

	Total time	Days	Nights
Mean			
95%CI frequency	$(-0.17, -0.02)$*	$(-1.67\times10^{-1}, -2.15\times10^{-2})$*	$(-1.17\times10^{-4}, 1.75\times10^{-2})$
95%CI duration	$(-2.71\times10^{-4}, 2.09\times10^{-5})$	$(-2.61\times10^{-4}, -2.18\times10^{-6})$*	$(1.36\times10^{-5}, 4.15\times10^{-5})$**
95%CI presence	$(-2.38\times10^{-4}, 8.05\times10^{-5})$	$(-2.41\times10^{-4}, 3.63\times10^{-5})$	$(7.35\times10^{-6}, 1.84\times10^{-5})$
Median			
95%CI frequency	$(-0.06, -0.03)$*	$(-6.12\times10^{-2}, -2.26\times10^{-2})$*	$(-5.7\times10^{-3}, 1.3\times10^{-3})$
95%CI duration	$(-1.43\times10^{-4}, -2.35\times10^{-5})$*	$(-1.41\times10^{-4}, -1.71\times10^{-5})$*	$(-4.27\times10^{-6}, 3.26\times10^{-6})$
95%CI presence	$(-1.14\times10^{-5}, -2.12\times10^{-6})$*	$(-1.22\times10^{-5}, -1.36\times10^{-6})$*	$(-1.29\times10^{-7}, 1.83\times10^{-8})$

3.2. Day patrols

When only daytime patrols were analysed; there was no significant difference in the average presence of field-ranger patrols prior to the incident surrounding a rhino carcass, compared to the landscape. There was significantly higher mean frequency and mean duration of patrols prior to the incident, around poaching incident locations, compared to the landscape. There was a consistently significantly higher median presence, median frequency of patrol and median duration of patrol surrounding the poaching incidents when compared to the landscape.

3.3. Night patrols

There was no significant difference found comparing mean presence and frequency of patrols around carcasses and the landscape. There was significantly lower duration of patrols prior to the incident, around poaching incident locations, compared to the landscape. There was no significant difference in median frequency, duration or presence of patrols around poaching incidents, compared to the landscape.

4. Discussion

This paper presents a high-resolution, spatially-explicit investigation into the deterrent effect of field-rangers (Fig. 2). There is either no significant difference, or there is, in fact, higher mean patrol presence, duration or frequency around poaching event sites prior to the poaching incidents, than in the landscape. This is counter to what would be predicted by deterrence theory. However, there is a notable exception. There was a significant difference detected, showing a possible deterrent effect at night, as the poaching events have significantly less mean patrol duration, and therefore presence, at night around poaching event sites prior to the event, compared to the landscape. However, this result must be interpreted with caution as the absolute values are very close to 0 ($\times10^{-5}$, and $\times10^{-6}$). Given that the same is not the case for the comparisons of the median presence, duration and frequency, combined with the smaller night time sample size, we conclude that this difference is not meaningful. There is either no significant difference or higher patrol presence, duration and frequency around poaching event sites, compared to the landscape.

The higher field-ranger presence surrounding the rhino poaching events can be explained by two factors, either there is collusion between field rangers and poachers or, the rhino poaching events are not randomly distributed in the landscape; rather they are clustered. It is highly unlikely that any colluding field ranger would spend time in the region of where the poaching happened at the time of it happening, particularly carrying a GPS recording device to provide evidence of this. Moreover, despite thorough investigations around all poaching incidents, including internal investigations no evidence was found of collusion and so we reject that explanation. Rather we speculate that specific areas within a protected area can be targeted for numerous reasons including topography, rhino density due to habitat variations, proximity to access and egress points, drainage lines, collusion between security forces and poachers or in response to permanent security features. Rhino occurrence density and social biology can result in a number of opportunistic poaching events within a small area over a short space of time, termed “hotspots”. In response to these “poaching hotspots,” field-rangers were reactively deployed to the area, resulting in a relatively higher patrol density than in the rest of the protected area. However, despite the higher field-ranger presence, the rhino poaching in these hotspots continued. We propose that the proximate cause is that the field-rangers were in the right place at the wrong time, but the distal factor is that there are simply not the workforce resources necessary to generate a high enough field-ranger presence to deter poachers. This is not without precedent; Plumptre et al. (2014) succinctly demonstrated the effect of limited resources on patrol effectiveness in protected areas.

These results empirically show that the patrol efforts analysed in these data were seemingly ineffective at preventing poaching. The results indicate that a general presence approach does not deter rhino poaching in this particular PA. Patrol effort alone is not an efficient use of scant resources. Rather than querying the operational effectiveness of law enforcement staff, our results more crucially demonstrate that relatively simple analyses on datasets can provide profound insight into the effect of resource deployment. The presence framework presented is intuitively easy to understand and simple to analyse. The evidence suggests that despite the presence of field-rangers, poachers are in general successful at entering protected areas and killing rhino unchallenged. The poaching rate has only increased, indicating that efforts are not creating deterrence. Although we do not refute deterrence theory and that presence will create a specific deterrent effect as seen where field rangers walk with rhino, the deterrent effect of field-ranger patrols at the level undertaken in this study is insignificant and is seemingly ineffective at reducing poaching in general.

We acknowledge the parochial scope of the study. However, it must be highlighted that the law enforcement resources available for the protection of this particular protected area relative to its size are unsurpassed in state-funded protected areas, and arguably in Africa as a whole. If a deterrent effect of field-rangers on rhino poachers is to be measured anywhere, it is here. Unfortunately, rhino carcass records do not allow for possible displacement effects of forcing would be poachers to divert their efforts elsewhere to be measured. Similarly, we measure deterrence based on carcasses, which is unsuccessful deterrence in many regards. The ability to link presence to deterrence in short term time scales from carcass data is limited. Finer scale analysis of deterrence requires other data sources such as incursion records or indirect sign, which has recently being done in other studies, but not focused on rhino (Critchlow et al., 2015, 2016).

The lack of resources will be confounded by a spatiotemporal threshold necessary for deterrence to be expressed (Wyant et al., 2012), and the threshold regarding the certainty of sanctions (Loughran et al., 2012). Although our results show no evidence of field-ranger presence influencing deterrence of rhino poachers; we do not refute deterrence theory. we still assert that deterrence is proportional to a function of field-ranger presence. However, this function is not linear, varies with external factors such as collusion, and will only be felt within the constraints of a spatiotemporal threshold, and above a level of certainty in sanction.

Statistically, the effects of these constraints could be limited by increasing field-ranger presence through increased numbers of field-rangers or decreasing the area in which they patrol. Plumptre et al. (2014) suggest that in resource-limited systems, a plausible solution is to generate smaller areas of higher species concern that can be patrolled more effectively. This is paralleled for rhino IPZ (intensive protection zones) being developed around Africa in for rhino conservation. While this is a valid and worthwhile consideration, the net effect of such approaches is that the landscape level conservation effectiveness of the protected area is reduced.

We have not demonstrated that there is a threshold of presence. It must exist, but may not be logistically or financially feasible to implement. What is evident is that blanket recommendations such as the IUCN recommendation of 1 field ranger per 100 km^2 is arbitrary in today's conservation climate. We suggest that resources used for conservation need to be defended and that the technology to monitor and measure such effects of interventions exists. We propose that it is more effective to deploy resources strategically, in a true adaptive management framework where results of implementation are effectively recorded, which is to date not adequately formalized nor analysed. We suggest that an increase in intelligence networks, rapid data analysis by skilled practitioners, criminologists be implemented in addition to strategic militarization in a well documented adaptive management/evidence based approach. Ultimately we recommend that moving the focus of law enforcement operations towards the above-mentioned professionalisation of protected area networks would ultimately be more to conservation at large, and more efficient use of finite financial resources.

4.1. Developing the framework: the need for data collection and measurable effects

The presence framework and subsequent analysis presented here are not meant as a panacea for rhino poaching. It is an attempt to improve law enforcement effectiveness demonstrably. We acknowledge and must highlight that this study is focussed on optimizing operations at a protected area level. The war on poaching will unlikley be won solely by more guns and boots on the ground in the long term, but structural changes in the socio-ecological sysems surrounding wildife trade and protected area-community relations, that match societal values and conservation objectives (Biggs et al., 2016; Cumming et al., 2015). But these are longer term objectives, and maximising the effectiveness of local protection in the short tem is of paramount importance in ensuring survival of species such as rhino.

We believe that the spatially explicit analysis of field-ranger presence relative to poaching events can provide statistically rigorous information to advise resource deployment in conservation. The framework can easily be expanded to measure the effectiveness of expensive technologies such as drones and economic comparisons to intelligence-led policing. It is also possible, given the datasets, to begin to include covariates of detection probability into the analysis, such as vegetation cover, should it be available with high enough resolution. Moreover, there is potential for rigorous adaptive management trials in PA law enforcement. Criminal networks are evolving and the battle to counter them requires an adaptive but robustly targeted approach. Recent developments in GPS technology, software and data validation techniques results in the accumulation of vast quantities of useful data. Powerful and simple analysis tools now enable a quantitative approach understanding the effect of law enforcement presence for the deterrence of poachers.

Adaptive management is resource intensive (Rist et al., 2013). The analysis of these datasets and development of protocols to integrate the information into workable field operations solutions requires financial resources to support appropriate hardware and software, experienced analysts, and data management technicians. The distribution of resources in the field to implement rhino anti-poaching initiatives remains weighted towards field-ranger deployment despite complementary efforts to gather intelligence, provide aerial support and establish national investigative networks.

The simple analysis presented here indicates that there is a clear need to analyse consistently, data generated by such deployments, and the poaching activities they intend to deter. At the moment many conservation agencies globally simplistically focus on field-ranger ratios and coverage deployed per rhino reserve. Although the data are increasingly being collected, the crucial and rapidly evolving role of data management and analysis is still largely ignored. Field-ranger patrol monitoring systems have now evolved to a functionality which gives a new quantitative view of field-ranger presence which is being used at the level of PA management, yet few studies investigating field-ranger patrol effectiveness have been conducted. This clear omission within the operational sector highlights a significant opportunity for targeted resource deployment and up-skilling. The development of a collaborative, resilient, flexible analytical approach, inclusive of criminologists, spatial analysts and protected area law enforcement officials is crucial to guide field-rangers more effectively.

5. Conclusions

Law enforcement is a single component of the international fight against rhino poaching (Challender and MacMillan, 2014; Ferreira and Okita-Ouma, 2012). To complement sociological and economically driven measures being considered to reduce poaching demand and intensity, we urge an evidence-based approach that relies on rigorous analysis of well-designed and collected data protocols to empower field-based law enforcement as an increasingly effective, adaptive management tool. We recommend the deployment of appropriate technical specialists to use outcomes from structured experimental set-ups and current law enforcement data to augment fundamental adaptive PA law enforcement operations, to ensure the persistence of acutely threatened rhino populations.

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