Experimentally assessing the effect of search effort on snare detectability

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Experimentally assessing the effect of search effort on snare detectability

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ABSTRACT

Reducing threats to biodiversity is the key objective of ranger patrols in protected areas. However, efforts can be hampered by rangers' inability to detect threats, and poor understanding of threat abundance and distribution in a landscape. Snares are particularly problematic due to their cryptic nature and limited selectivity with respect to captured animals' species, sex, or age. Using an experimental approach, we investigated the effect of search effort, habitat, season, and team on rangers' detection of snares in a tropical forest landscape. We provide an effort-detection curve, and use our findings to make preliminary predictions about snare detection under different scenarios of patrol effort. Results suggest that the overall probability of a searcher detecting any given snare in a 0.25/km^2 area, assuming 60 min (or approximately 2 km) of search effort is 20% (95% CI ± 15–25%), with no significant effect of season, habitat or team. Our models suggested this would increase by approximately 10% with an additional 30mins/1 km of search effort. Our preliminary predictions of the effectiveness of different patrolling scenarios show that detection opportunities are maximised at low effort levels by deploying multiple teams to a single area, but at high effort levels deploying single teams becomes more efficient. Our results suggest that snare detectability in tropical forest landscapes is likely to be low, and may not improve dramatically with increased search effort. Given this, managers need to consider whether intensive snare-removal efforts are the best use of limited resources; the answer will depend on their underlying objectives.

1. Introduction

Protected area (PA) networks are a cornerstone of global efforts to conserve biodiversity (Bruner et al., 2001). Their success depends on effective management, including the reduction of threats to species and habitats (Watson et al., 2014). A primary tool available to PA managers to address threats is patrolling by ranger teams (Hilborn et al., 2006; Lynam et al., 2016). Through regular patrolling, rangers monitor adherence to conservation rules, deter potential perpetrators, and punish infractions when detected (Keane et al., 2008). To design optimal patrol strategies, PA managers require robust information about the distribution and abundance of threats in a landscape (Critchlow et al., 2017) alongside a means of assessing which approach is most likely to yield the greatest conservation benefit at the lowest possible cost (Plumptre et al., 2014).

Data collected by rangers are increasingly used to map spatio-temporal trends in threats and evaluate patrol performance. These are often collected by patrols for little additional cost (Brashares and Sam, 2005). Subsequently, the data can be used with open-access tools such as the Spatial Monitoring and Reporting Tool (SMART) to assess threats and prioritize patrol effort within conservation landscapes (Hötte et al., 2016; Stokes, 2010). However, gathering data is not the primary objective of patrols and ranger-collected data may be subject to considerable bias (Keane et al., 2011). Patrol data must therefore be handled with caution to avoid misleading conclusions and ineffective targeting of patrol effort (Critchlow et al., 2015; Keane et al., 2011). While a growing suite of statistical methods exists to account for these biases (see Critchlow et al., 2015; Marescot et al., 2019; J. F. Moore et al., 2017), there is also a broader need for independent tests of key aspects of patrol effectiveness, such as the amount of patrol effort required to successfully detect a certain proportion of threats present within expansive conservation landscapes (Dobson et al., 2018). Well-

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designed experiments can provide effective and affordable means to trial different approaches, and have been used to improve understanding of the effects of environmental covariates on the detectability of traps set by hunters in both tropical forest (O'Kelly et al., 2018a) and savannah (Rija, 2017) landscapes. However, no experimental study has yet explored the relationship between search effort and threat detection, knowledge of which would enable PA managers to distribute patrol effort more efficiently, and thereby improve PA effectiveness.

Hunting poses one of the greatest threats to wildlife in PAs globally (Ripple et al., 2016; Schulze et al., 2018) and snares are one of the most prevalent hunting technologies used worldwide (Gray et al., 2017a; Harrison et al., 2016). Usually made from wire, cable, or nylon, snares are affordable, accessible, and can trap a wide range of arboreal and terrestrial species, whether diurnal or nocturnal (Borgerson, 2015; Ingram et al., 2017). Due to their limited selectivity with respect to species, sex, or age of captured animals, snares are a potent threat to biodiversity (Noss, 1998). Although animals sometimes escape snares, subsequent non-fatal injuries often jeopardize their long-term survival (Gray et al., 2017b). For example, chimpanzees with snare injuries have been found to suffer significantly higher parasite loads than those without (Yersin et al., 2017). Unlike other forms of hunting, snares present a persistent threat to wildlife as they remain operational in the landscape after a hunter has departed, and are difficult for patrols to detect (Lindsey et al., 2011).

A key assumption is that the more patrol effort invested in searching, the more snares will be discovered. However, the improvement in detection with effort has not been quantified and is likely to be affected by factors such as habitat, season, atmospheric conditions (e.g. precipitation, temperature), terrain and topography and the type of snare set (Keane et al., 2011; Jachmann, 2008). For example, snares which are physically connected and set in lines that stretch many hundreds of metres may be more detectable than individual snares (O'Kelly et al., 2018b). In addition, snare detection is influenced by rangers themselves. Studies of wildlife observation and plant detection have recorded considerable variability between observers depending on their experience and expertise (Moore et al., 2011; Sunde and Jessen, 2013). And, even if rangers are capable of finding snares, they may not always be motivated to search (Jachmann, 2008). Conservation law enforcement operations are typically under-resourced, with rangers often inadequately trained, poorly remunerated, and insufficiently equipped to work in challenging conditions (Belecky et al., 2018; Long et al., 2016).

Here, we adopt an experimental approach to test how a vital element of patrol effectiveness – snare detection – is affected by the amount of patrol effort invested. Our study provides an effort-detection curve for snare detectability in a tropical forest context, investigates the effects of habitat and season on detection probability, and assesses the extent to which performance varies between search teams and individual searchers. We use our findings to predict the snare detection levels that could be achieved in a Cambodian PA under different patrolling scenarios.

2. Materials and methods

2.1. Study site

The study was conducted in Keo Seima Wildlife Sanctuary (formerly Seima Protection Forest), a 2927km^2 PA situated in Mondulkiri Province, eastern Cambodia (12°26′70″N, 106°E 94′90″). The PA is topographically diverse, ranging in altitude from 60 to 750 m (Evans et al., 2013). The habitat is heterogeneous, and consists of a complex forest mosaic that includes deciduous dipterocarp and fully evergreen forest (Walston et al., 2001). The PA supports populations of Asian elephant *(Elephas maximus*) and wild cattle (*Bos* spp.), alongside globally significant primate populations. In 2011, a systematic survey conducted over 2200 km, detected 1300 snares in 140 different locations in the PA, with an experimentally calculated detection rate of 28–36% (O'Kelly et al., 2018a).

2.2. Experimental design

Setting snares.

We adapted a methodology originally piloted by O'Kelly et al. (2018b), and established five 3.25 km transects around a patrol station (Fig. 1, Appendix S1). Habitat here is highly heterogenous; comprised of a mosaic that reflect vegetation types found across the wider landscape. The area also supports a full complement of species, which occur in relatively high densities. Either side of each transect, we delineated 6 × 0.25km^2 (500 m × 500 m) quadrats at 50 m intervals (Appendix S1). This quadrat size was chosen so teams could conduct intensive searches in realistic time-frames. Within each quadrat we set between zero and 15 snares (the number randomly drawn from a Poisson distribution with mean = 7.5), based on estimates of typical snare densities identified by other studies (Dobson et al., 2019). Single foot snares made from black nylon string (5 mm), an inexpensive material often used by hunters in this area, were set without a trigger mechanism to prevent harm to wildlife, and all snares were successfully removed at the end of each transect survey.

We recruited local guides from surrounding communities, who were instructed to set single snares as a local hunter might, in locations they deemed suitable to catch popular prey species such as wild pig (*Sus scrofa*), Northern red muntjac (*Muntiacus vaginalis*) and sambar (*Rusa unicolor*). Prior to setting snares, teams explored each quadrat for 30 min to identify suitable snare locations. Once set, teams recorded the GPS coordinates of each snare and the dominant habitat type of the quadrat. Teams were asked not to disclose the location or number of snares set in each quadrat to other teams or to leave obvious signs of their presence which future teams might use as cues.

2.3. Data collection

2.3.1. Searching for snares

The experiment required four separate teams, each led by a staff member from the Wildlife Monitoring Team of Wildlife Conservation Society (WCS) Cambodia. Team leaders had expertise in snare detection, and were accompanied by two other searchers – either a local guide or another WCS staff member. WCS staff remained the same in each team, but changes in availability meant that local guides varied between transects. All team members searched for snares, with team leaders also recording data, coordinating the search strategy and ensuring searchers stayed within quadrat boundaries. Each team was allocated quadrats to search for a designated time period. No quadrat was searched simultaneously by more than one team, and teams never searched quadrats in which they had set snares. To maximize statistical power and to account for the considerable challenge of implementing the survey at a larger scale, each quadrat was searched three times, for a fixed search duration varying between 15 and 90 min in 15-min intervals (Appendix S1). Every effort was made to minimize the effect of previous searches on the detectability of snares by subsequent teams.

Teams were encouraged to search purposefully by following cues in the landscape (e.g. human footprints, wildlife tracks, cut vegetation). The start and finish time, the vegetation type in the quadrat, the distance travelled, the GPS locations of the search routes and any artificial or real snares detected were recorded throughout. We also recorded search order, to account for the fact that the more a quadrat was searched, the more cues were left in the landscape. The later the search, the harder for searchers to differentiate between cues set by the snare setting team (clues) and those left by previous searchers (decoy cues). Teams were shadowed by first author HI to ensure that protocols were adhered to, and to observe and question teams on their choice of snare placement and search strategies. We included the presence of HI as a variable within our models, to assess whether her observation of the

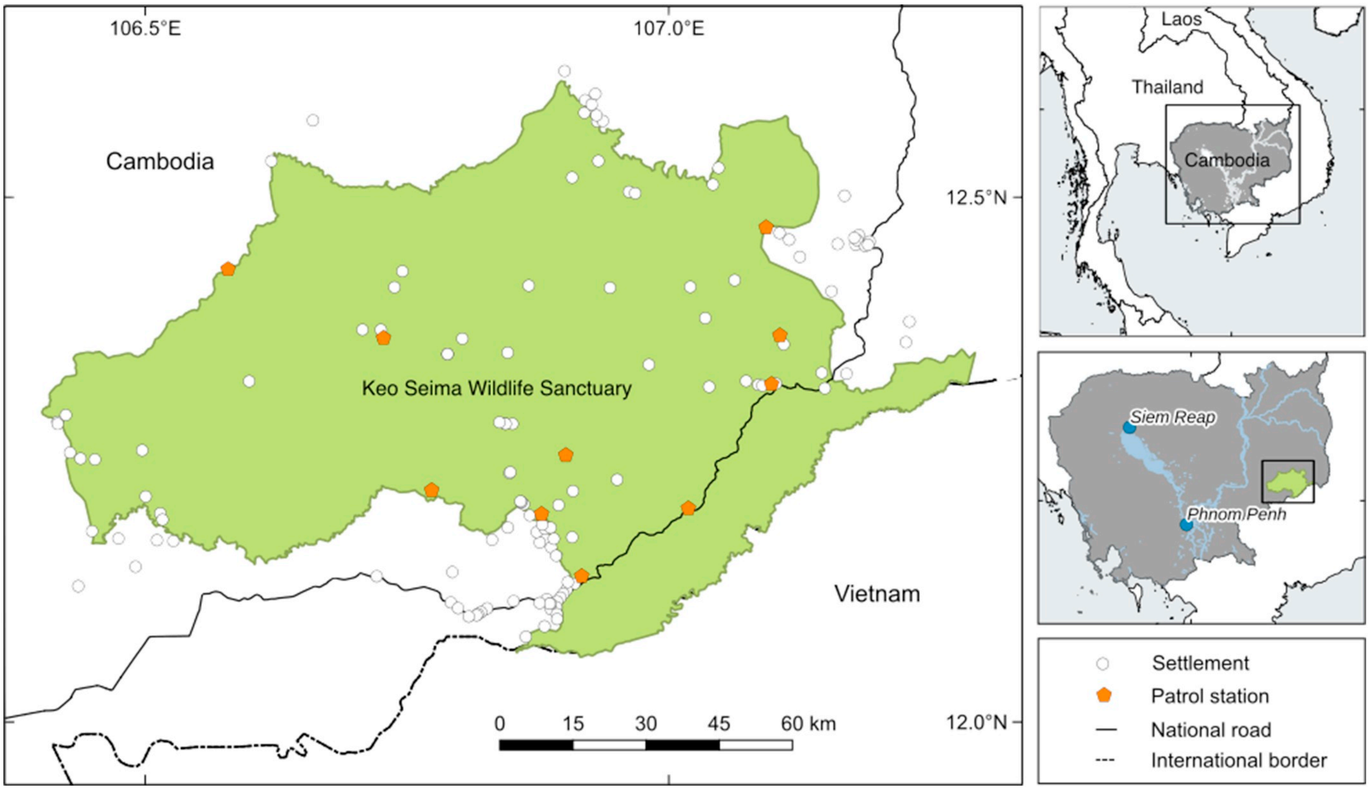

Fig. 1. Keo Seima Wildlife Sanctuary, Mondulkiri province, Cambodia. Study area highlighted in gray rectangle.

search team had any effect on detection performance. The methodology was piloted in December 2016, and conducted during dry season in January–February 2017 and wet season in October–November 2017.

2.4. Ethical considerations

Employing local community members with relevant hunting experience helped to ensure that artificial snares were realistic, but raised several ethical issues. Firstly, by participating, local guides risked implicating themselves in illegal activity (e.g. by affirming their hunting expertise or knowledge of suitable hunting grounds within the PA). To mitigate this risk, only former hunters recommended by WCS were recruited. Prior to participation, the experimental nature and purpose of the research was explained to local guides, and voluntary verbal consent to participate was sought. Individuals were assured that no information or inferences about their hunting knowledge would be passed onto authorities. An additional concern was that the experiments would introduce individuals to new hunting grounds. However, after consultation with WCS it was decided that the risk was negligible; most local guides were born in or around the PA, and were highly familiar with the study landscape. Protocols were reviewed and approved by the University of Oxford Central University Research Ethics Committee (Ref No. R43030/RE002), with permission to conduct research granted by the Royal Government of Cambodia.

2.5. Analysis

Analyses were performed in R version 3.5.1 (R Core Team, 2017) using the package rstanarm (Goodrich et al., 2018). We fitted a series of hierarchical generalised linear models to the data, expressing different hypotheses about the factors influencing snare detection. These were compared using WAIC, a Bayesian information criterion akin to AIC (Watanabe, 2010). The response variable in every model was a binary indicator of whether or not each snare was detected during a given search period. The full set of predictor variables used in one or more of these models is shown in Table 1. Effort was represented by either time or distance. Based on a comparison of WAIC between models 1 and 2 (intercept and grouping parameters only, no covariates), time was chosen as the better-fitting effort measure for model explorations which included covariates, although the two measures were highly correlated (Spearman's Rho = 0.79, 95% CI =77–81; Fig. S2a). Effort measured as time was experimentally manipulated rather than observed, so was centred around 45 min (50% of the maximum search time) and included in the model using hours as the unit of measurement. Effort measured as distance and distance to the nearest snare were observed quantities so were scaled by subtracting the mean and dividing by two standard deviations, either precisely (for effort) or using approximate values for the mean and standard deviation (for distance to the nearest snare) to improve the interpretability of the coefficients. All other models included variables for quadrat search order and previous snare detections. Two snare density-related variables were next added, and finally we explored three models which also included variables related to season, team, or placement within the environment.

Model parameters were given weakly informative Students-t priors with 7 degrees of freedom and scale 2.5, except for the intercept which was given a Normal prior with mean 0 and standard deviation 10. Weakly informative priors were chosen to stabilise computation and to express our weak prior beliefs that very large effects would be rare (Gelman et al., 2008). The coefficients for transect ID, quadrat ID, date, setting team ID and searching team ID were each given independent hierarchical LKJ priors with regularization parameter 1 (Lewandowski et al., 2009). For each model, 2000 Markov Chain Monte Carlo (MCMC) samples were drawn from four independent chains. Convergence of MCMC chains was evaluated using trace-plots and the Gelman-Rubin diagnostic, with values < 1.05 taken to indicate that convergence had been reached (Gelman et al., 2013). The fit of the model with the lowest WAIC value was examined using graphical posterior predictive checks.

Using the effort-detection relationship derived from our fitted model, and assuming replication of the search strategies employed during our experiment, we explored how dividing search effort within a

Table 1
Description of variables and interaction terms, and their inclusion in the candidate models fitted to the snare detection data. Grouping variables are shown below the dividing line.

Variable	Description	Type	Levels	Model										
				0	1	2	3	4	5	6	7	8	9	10
Effort (time)	Time (minutes) spent searching each quadrat for snares	Continuous	Centred on 45 min & scaled by dividing by 60		X		X	X	X	X	X	X	X	X
Effort (distance)	Total distanced travelled (km) during each search	Continuous	Centred on its mean value & scaled by two standard deviations			X								
Quadrat search order	Search order	Factor	1st, 2nd, 3rd				X	X	X	X	X	X	X	X
Previous snare detections	Number of times the snare was previously detected by other teams	Factor	0, 1, 2				X	X	X	X	X	X	X	X
Distance to nearest snare	Mean distance (m) of a snare to other snares within the same quadrat	Continuous	Centred on 150 m & scaled by dividing by 100					X	X	X	X	X	X	X
No. of snares set in quadrat	Total number of snares set in the quadrat	Continuous	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15					X	X	X	X	X	X	X
Season	Season in which quadrat was searched	Factor	Wet, Dry						X	X				X
Season: Effort	Interaction term									X				X
HI present during search	Whether HI accompanied the team during the quadrat search	Factor	Yes, No										X	X
Team leader	ID of the team leader	Factor	1, 2, 3, 4										X	X
Vegetation type	Dominant vegetation type within the quadrat	Factor	Bamboo, mixed-deciduous, semi-evergreen								X			X
Presence of animal trail	Whether the snare was set on an animal trail	Factor	Yes, No								X			X
Presence of animal sign	Whether the snare was set near wildlife signs (e.g. foot prints, dung)	Factor	Yes, No								X			X
Presence of water	Whether the snare was set near a stream, river, pond or salt lick	Factor	Yes, No								X			X
Transect	Transect ID	Factor	1, 2, 3, 4, 5	X	X	X	X	X	X	X	X	X	X	X
Quadrat within transect	Quadrat ID	Factor	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	X	X	X	X	X	X	X	X	X	X	X
Date	Date each search was conducted	Factor	DD-MM-YY	X	X	X	X	X	X	X	X	X	X	X
Team setting snares	ID of the team that set snares in the quadrat	Factor	W1, W2, W3, W4, D1, D2, D3, D4									X	X	X
Team searching for snares	ID of the team searching for snares in the quadrat	Factor	1, 2, 3, 4									X	X	X

quadrat across multiple teams might affect detection probability. We assumed that n teams searched the same quadrat independently and sequentially and that each team had the same constant probability, p, of detecting snares that were present. We therefore modelled the proportion of snares remaining after all searches were completed, r, as:

$$r = 1 - (1 - \mathrm{p})\,\mathrm{n}$$

Deploying more search teams is likely to incur transaction costs (e.g. more time is required to travel to sites, and additional salary is required to pay more team leaders). In the absence of empirical data, we incorporated these costs by expressing them in terms of effort lost from the total budget: 10 min of search effort was removed from the initial total for each extra team added, and the remaining effort was then split equally between all teams (i.e. at 90 min, four teams would search for 15 min each). To examine the sensitivity of our findings to the steepness of the effort-detection relationship we also explored the difference in results when the slope of the effort-detection curve was 50% higher or lower than the observed slope on the logit scale, in order to determine the sensitivity of our results to the specific shape of the effort-detection curve.

3. Results

3.1. Effect of search effort on detection probability

3.1.1. Snare locations

In total, 886 artificial snares were set, 442 in dry season and 444 in wet season. Local guides reported that they generally sought specific features when placing snares; for example, water sources (66% of snares set), animal trails (44%), animal signs (e.g. footprints or faeces; 44%), or fruiting trees (2%).

3.1.2. Detection probability

A total of 535 artificial snare detections was recorded out of a possible 2661 opportunities, with a detection rate of 0.20 averaged across the entire experiment, or 0.24 per hour of searching. In addition, 55 real snares were detected. These detections were not included in analyses, as once detected real snares were removed, meaning subsequent search teams had no opportunity to detect them. 42% of the total population of artificial snares were discovered; 26% were found by only a single team, 13% by two teams, and 3% by all three search teams (S2, Fig. 2).

3.1.3. Predictors of snare detectability

The magnitude and direction of the effect of all covariates were consistent across the set of candidate models considered (see Appendix S2). The best-fitting model (Model 8; Table 2) included time spent searching, quadrat search order, number of times a snare was previously detected, snare clustering and density (Fig. 3), and batches of variables describing the variability between transects, between quadrats within transects, over time and between the teams responsible for setting and searching for snares (Figs. S2d-f). The model did not include season, vegetation type within the quadrat, or the proximity of the snare to water, animal trails or animal signs. Model 9, which included variables relating to the team leader, and the presence of author HI as an observer of the search team, was only marginally less supported while other models were much less well supported (Table 2). However, the effects of team leader and HI's presence in model 9 were inconclusive (Fig. S2b).

The overall probability of searchers detecting any given snare on the first search of an area was 20% (95% CI ± 15–25%), assuming 60 min (or approximately 2 km) of search effort. Detection probability increased by approximately 10% for every additional 30mins/1 km of search effort from approximately 8% with 15 mins of search to approximately 30% with 90 mins (Fig. 4). Snares which were previously detected by a search team were more likely to be detected in subsequent searches (mean raw detection rates: Never previously detected = 0.17; Detected once previously = 0.33; Detected twice

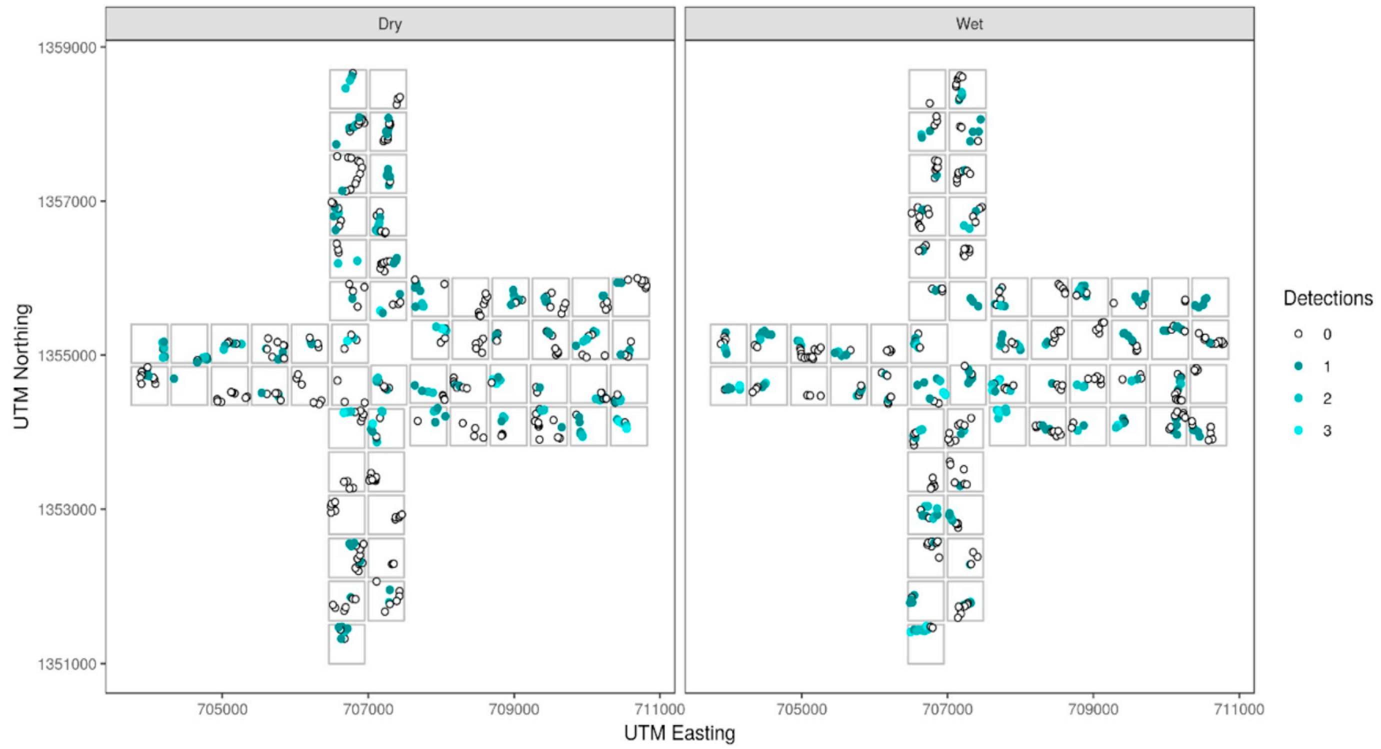

Fig. 2. Detections in situ; colour coding represents the number of teams which detected a given snare.

Table 2
WAIC values for the fitted models, the difference from the best-fitting model (δWAIC) and the standard error of that difference (SE(δWAIC)). See Table 1 for models.

Model	WAIC	δWAIC	SE(δWAIC)
8	2412.7	0.0	–
9	2414.1	1.5	1.8
10	2424.2	11.5	3.4
4	2461.4	48.7	14.4
5	2462.9	50.2	14.4
7	2465.3	52.6	14.2
6	2465.5	52.9	14.4
3	2471.8	59.1	16.0
1	2515.5	102.8	21.6
0	2527.6	114.9	23.0
2	2532.9	120.2	22.4

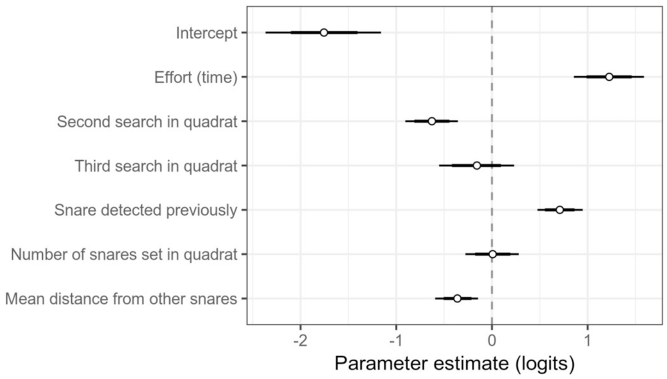

Fig. 3. Parameter estimates for the best-fitting model, Model 8. Points represent the mean estimate; thick lines represent 80% credible intervals and thinner lines represent 95% credible intervals.

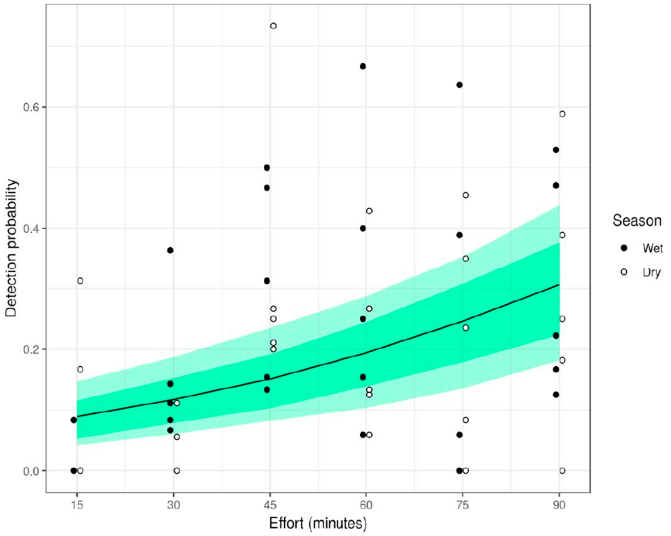

Fig. 4. Effort-detection curve. Black line indicates mean probability of snare detection at differing levels of effort, predicted from the best-fitting model (Model 8) under the assumption that the quadrat has not previously been searched. Light green shading indicates the 95% credible interval for detection probability, while the darker green shading indicates the 85% credible interval. Summaries of the proportion of snares detected in each transect in the raw data are plotted as filled circles for wet season and open circles for dry season. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

previously = 0.54; Fig. 3). Perhaps because previous searchers left cues, such as footprints or cut branches, which made it easier for subsequent searchers to follow their path. Accounting for this, there was an effect of whether the quadrat was being searched for the first, second or

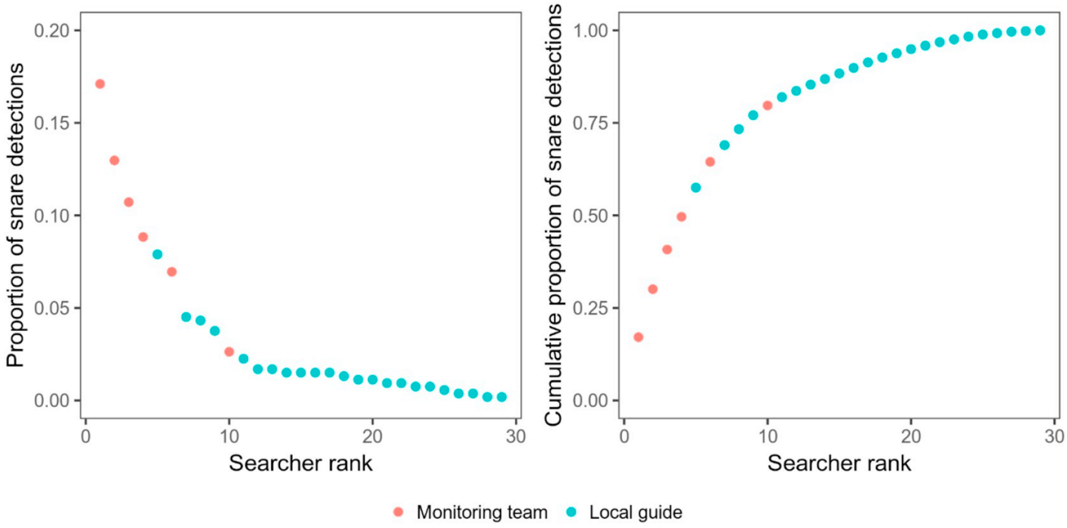

Fig. 5. Proportion of snares detected by individual searchers.

third time, with lower rates of detection in the second search than the first, but no clear difference between the first and third searches (mean raw detection rates: First search = 0.21; Second search = 0.16; Third search = 0.24). Snares were more easily detected when they were placed in closer proximity to other snares in a quadrat, but there was no effect of snare density on detection rates (Fig. 3).

3.1.4. *Team variability*

The identity of the setting and searching teams had little effect on the probability of detection (Fig. S2c). Differences in success were largely attributable to the performance of specific individuals; over 40% of all snare detections were achieved by three searchers, and the best searchers were disproportionately from the professional WCS wildlife monitoring team rather than local guides (Fig. 5). Although WCS staff were responsible for recording data, there was little opportunity for them to claim snares found by others for themselves, as each searcher's detections were verifiable via timestamped GPS tracks of each individuals' search route. We found no evidence that any false recording occurred. Field observations of searchers suggested that detection was mainly influenced by skill and experience. A peer- and self-evaluation exercise suggested that peers more accurately predicted others' detection abilities than individuals did themselves (Appendix S3). The best-performing individual was a WCS employee born in a local village who hunted in childhood.

3.2. *Effective allocation of search effort*

Our fitted models show that as the amount of total search effort increases from 15 to 90 min, the proportion of snares detected by a single team can be expected to increase by approximately 20%. Simulations of search effort allocation suggest that at low search efforts, a 10% increase in detection can be expected for each additional team searching (Fig. 6). For example, four teams searching the same quadrat at separate times for 5 min each (in total 20 min) may find up to 25% of snares. However, as search effort increases, it can become more efficient to deploy just one team, rather than multiple teams - particularly when the relationship between effort and snare detection is steeper.

4. Discussion

PA managers increasingly require information about the best allocation of patrol effort (Lynam et al., 2016). Our results suggest that overall, the ability of rangers to detect snares is low. Although detection increased with distance between snares and search effort, 60 min of

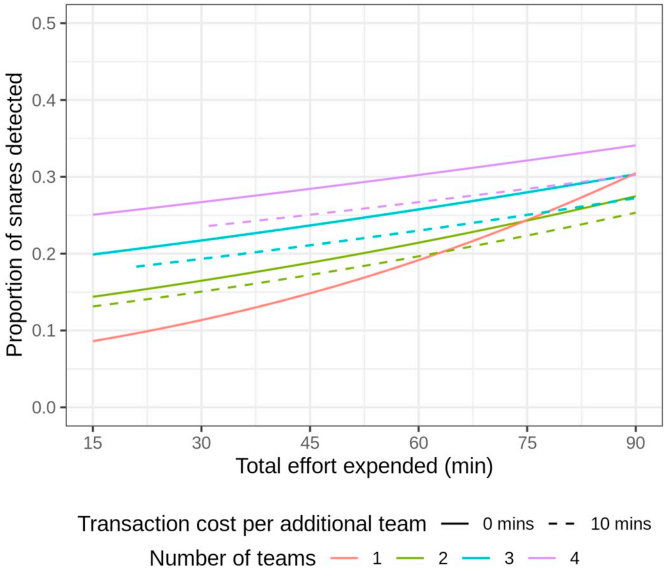

Fig. 6. Modelled effect of dividing total search effort across multiple search teams on detection probability, when effects of effort on detection and transaction costs vary.

searching (approximately 2 km) resulted in the detection of 20% (± 15–25%) of snares, comparable to the 15% detection reported by O'Kelly et al. (2018b) at similar levels of search effort. Higher detection rates might be achieved by deploying more teams to search within a specific area for shorter periods. However, this finding assumes teams independently search the same area, that they are not reliant on cues left by previous searchers, that detected snares are left in situ, and that each search team has equal detection probability. In reality, few of these assumptions are met. Regardless, given the large size of most PAs, the recommendation to deploy multiple teams within a specific area for shorter periods may be financially and logistically unviable unless there is a particular reason to concentrate on a specific “hotspot”. Ultimately, more effective and efficient use of resources will be achieved by deploying a single team to intensively search one area.

Surprisingly, we found no effect of snare density on detection probability. While setting more snares might result in more potential opportunities for snares to be found, searchers still need to target their efforts in the right places. The skill of individual searchers, along with search effort were stronger predictors of detection probability, highlighting the need for PA managers to carefully select personnel with demonstrated skill at detecting snares for patrols. Also unexpected, was that detection was higher during the first and third searches than the second. One reason may have been due to time of day. The second search was usually conducted in the afternoon, when temperatures often exceeded 33 °c. By this point individuals had already exerted substantial effort in searching and were physically and mentally fatigued. Our results along with observations during the study, highlight the need for PA managers to carefully consider environmental factors such as temperature when designing patrolling strategies. Managers must demonstrate an awareness of the physical and psychological demands patrolling places on individuals and adapt patrols accordingly (Belecky et al., 2018; Moreto, 2015).

Many PA management regimes prioritize and invest heavily in patrol-based snare removal efforts. However, the low detectability of snares, despite high levels of search effort, raises questions about the efficiency of this approach. If the primary aim of snare removal is to reduce animal mortality to sustainable levels, snare detection and removal rates must be high enough to alleviate pressure on remaining wildlife populations. Knowing what is “high enough” requires robust estimates of snare detection, as well as a good understanding of snare-related mortality rates and their impact on species population trends. Currently, however, there is virtually no empirical information on any of these parameters. If the aim is to deter snaring, then detectability must be high enough to raise costs sufficiently to make it unprofitable (Gray et al., 2017a). If the aim is to visibly advertise to potential offenders that snaring is an issue taken seriously by PA managers, then making snare removal efforts visible to communities could be beneficial, even if the actual percentage removed is low. PA managers must therefore consider their aims carefully. All these objectives may benefit from targeted snare removal in known hunting and/or wildlife hotspots, especially if accompanied by legislative reform, consistent enforcement that criminalises the possession of snares, and measures which ensure a high proportion of successful prosecutions occur (Gray et al., 2017a). Currently, however, little is known about whether snare removal actually deters hunters, and if so, what the spatial and temporal extents of a deterrent effect are. Better understanding of the relative deterrent effect of different law enforcement strategies on snare hunters' behaviour is urgently required. PA managers should also look beyond snare removal efforts, to other interventions, such as community outreach and alternative livelihoods, which could help to alleviate hunting pressure. However, better understanding of the effect such interventions may have on hunter behaviour is still needed. Any intervention adopted will require careful design, and must be underpinned by a rigorous monitoring and evaluation programme, so that the impact can be empirically assessed (Veríssimo and Wan, 2019).

The finding that WCS staff members were better at locating snares than local guides was contrary to our expectations, but it makes sense. WCS staff had more experience searching for other peoples' snares, and were also more motivated to do so. Local guides were paid on a daily basis, rather than per snare detection, and thus had no long-term incentive (nor contractual obligation) to perform well. The work was considered hard for little reward, and was potentially against their own interests. Often the exercise was received with bemusement by local guides, who in some cases viewed the setting of ineffective snares as wasted effort. By contrast, WCS staff employed on permanent contracts, with personal and professional interests in protecting wildlife, expressed the desire to improve their snare-detection abilities and had a greater appreciation of the value of experimental work. Investing effort in developing incentive schemes that reward individual performance may increase detections. However, these require careful consideration to ensure they are equitable, affordable and impermeable to ‘cheating’. Few studies have assessed the impact incentives schemes have on snare removal; further experimental research would help to clarify their potential for impacting snare abundance and the prevalence of snare hunting.

There is a debate about the costs and benefits associated with hiring rangers from local communities versus those from ‘outside’ (Paley, 2015). Whilst our study provides some evidence of the benefits of the former, realistically our sample size was too small to draw any credible conclusions. Additionally, we must consider that the artificial nature of our experiment meant that it was devoid of the usual conflicts of interest which can occur when employing local rangers to remove snares possibly set by relatives or neighbours (Paley, 2015). Within conservation, the social factors that affect the behaviour and performance of rangers is relatively under-researched (although see Moreto et al., 2015; Spira et al., 2019), and greater empirical understanding of the factors that incentivise and disincentivise rangers during different patrolling activities is needed.

Prior to the study we hypothesised that both habitat and season would affect snare detection, however we found no evidence for either effect in our experiment. In the case of habitat, this might be due to the relatively high within-quadrat habitat variability. Working in the same PA, (O'Kelly et al. (2018b) found a 9% difference in the detectability of single snares in mixed forest (14%) compared to evergreen forest (23%). However, O'Kelly et al.'s comparisons were made between two spatially distinct areas with very different habitats, while the habitat measurements within this study recorded small differences between vegetation within a single area. The lack of an effect of season is perhaps more surprising. In tropical forests, hunters are usually more active during wet season, when soil conditions are more amenable to snare placement (Ibbett et al., 2020; van Vliet and Nasi, 2008). We expected that the soft soil would also make the tracks of wildlife and snare setters more visible, providing searchers with clues to follow. The lack of seasonal difference in our study may be due to logistical constraints, which forced us to conduct surveys towards the end of the wet season (October–November). Unfortunately, a shorter wet season in 2017 meant that rains had effectively stopped by the time we surveyed the last two transects, resulting in less contrast in physical and meteorological conditions than expected.

Our study demonstrates the utility of a field experiment as an effective and affordable approach to hypothesis testing. Rarely used in conservation contexts, experiments have many advantages; they can be replicable, results can be independently verified, and importantly, they enable researchers to control for extraneous variables so conclusions about the effects of individual variables can more confidently be drawn (Karban et al., 2014). However, as with any scientific research, they require careful design and there are limits to their ability to accurately mimic reality. For example, in our experiments, searches were carried out over small areas (0.25km^2), and only teams of three were deployed. In reality, PA managers work at much larger spatial and temporal resolutions; patrols are planned over hundreds of km^2, effort is measured in days rather than minutes, and patrols are usually comprised of 4–7 rangers (Bowman, 2013). The maximum number of snares set per quadrat was limited to 15, yet local guides reported that in reality they saturate suitable areas (e.g. around salt licks, or fruiting trees) with snares to maximize capture opportunities. During the experiment they felt unable to do so due to the limited number of snares, and because they didn't want to increase snare detectability for other teams. Indeed, our results confirm that snares set in closer proximity to each other were more likely to be found than those set-in isolation. Guides sometimes felt required to set snares even in the absence of suitable habitat or wildlife signs, potentially resulting in unrealistic snare placement and/or densities too high for the habitat type. While we acknowledge this bias may have affected snare detectability, we mitigated its impact on our estimates by explicitly modelling the effect of the setting team on detection probability. This variation may also be reflective of reality. Hunters naturally vary in their hunting skill and experience, meaning some snares will always be set in suboptimal locations, and some will be harder to detect than others.

This study provides an effort-detection curve for snare removal for a tropical forest context, and highlights how a quantitative understanding of snare detectability can benefit PA managers. In addition, our parameter estimates can be incorporated into statistical analyses of ranger-collected data to draw more robust conclusions about snare abundance and distribution within this conservation landscape. Although the applicability of our findings is limited to sites characterised by similar habitat types and hunting behaviours, our experimental protocol provides a framework adaptable to different contexts, which can be used to explore efficient allocation of resources for other conservation threats.

CRediT authorship contribution statement

Harriet Ibbett:Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing - original draft.**E.J. Milner-Gulland**:Conceptualization, Methodology, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Colin Beale**:Conceptualization, Methodology, Writing - review & editing.**Andy Dobson**:Conceptualization, Methodology, Writing - review & editing.**Oliver Griffin**:Methodology, Investigation, Resources, Writing - review & editing.**Hannah O'Kelly**: Methodology, Writing - review & editing.**Aidan Keane**: Conceptualization, Methodology, Formal analysis, Data curation, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data accessibility

Data available from http://reshare.ukdataservice.ac.uk/854333/

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2020.108581.

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