TYPE Original Research
PUBLISHED 23 August 2023
DOI 10.3389/fcosc.2023.1213552

OPEN ACCESS

EDITED BY
Carlos R. Ruiz-Miranda,
State University of Northern Rio de Janeiro, Brazil

REVIEWED BY
Matthew Grainger,
Norwegian Institute for Nature Research (NINA), Norway
Timothy C. Haas,
University of Wisconsin–Milwaukee, United States

*CORRESPONDENCE
Rob Stuart Alexander Pickles
rpickles@panthera.org

RECEIVED 28 April 2023
ACCEPTED 31 July 2023
PUBLISHED 23 August 2023

CITATION
Lam WY, Phung CC, Mat ZA, Jamaluddin H, Sivayogam CP, Zainal Abidin FA, Sulaiman A, Cheok MKY, Osama NAW, Sabaan S, Abu Hashim AK, Booton MD, Harihar A, Clements GR and Pickles RSA (2023) Using a crime prevention framework to evaluate tiger counter-poaching in a Southeast Asian rainforest.
Front. Conserv. Sci. 4:1213552.
doi: 10.3389/fcosc.2023.1213552

Using a crime prevention framework to evaluate tiger counter-poaching in a Southeast Asian rainforest

Wai Yee Lam[1,2], Chee-Chean Phung[1], Zainal Abidin Mat[3], Hamidi Jamaluddin[3], Charina Pria Sivayogam[2,4], Fauzul Azim Zainal Abidin[3], Azlan Sulaiman[1], Melynda Ka Yi Cheok[1], Noor Alif Wira Osama[3], Salman Sabaan[3], Abdul Kadir Abu Hashim[3], Mark Daniel Booton[5], Abishek Harihar[5], Gopalasamy Reuben Clements[2,6] and Rob Stuart Alexander Pickles[1]*

[1]Panthera Malaysia, Kuala Lumpur, Malaysia, [2]Rimba, Kuala Lumpur, Malaysia, [3]Department of Wildlife and National Parks of Peninsular Malaysia (PERHILITAN), Kuala Lumpur, Malaysia, [4]Durrell Institute of Conservation and Ecology, School of Anthropology and Conservation, Faculty of Social Sciences, University of Kent, Canterbury, United Kingdom, [5]Panthera Corporation, New York, United States, [6]Zoological Society of London, London, United Kingdom

Tigers are a conservation-reliant species, as multiple populations face the risk of local extinction due to poaching arising from the continued demand for their body parts. Preventing tiger poaching poses a challenge for the rangers responsible for their protection, particularly in Southeast Asia, where the protected areas are typically large, mountainous tropical forests guarded by small teams of rangers. Improving counter-wildlife crime tactics is hindered without robust evaluations, and inefficient approaches are perpetuated. We evaluate an eight-year project aiming to recover a tiger population in Peninsular Malaysia. Three distinct poaching problems by Vietnamese, Thai and Cambodian groups, differing by organisation, target species and tactics, were prioritised, and ranger counter-poaching tactics were tailored to reduce these. Applying a framework developed to evaluate crime prevention known by the acronym EMMIE, here we: (1) examine evidence our intervention was *Effective* in reducing the poaching threat; (2) resolve the *Mechanisms* by which our intervention caused a reduction in harm from poaching and how intervention effectiveness is *Moderated* by the three poaching types; (3) define the elements necessary for *Implementation* and the *Economic* costs involved. We found poaching incursion frequency fell 40% from baseline years to treatment years across all poaching types while poaching incursion depth declined, with disrupted incursions on average, 2.6 km (Thai) and 9.1 km (Cambodian) closer to the forest edge. However, wire snares increased from baseline to treatment years as Vietnamese poachers increased the number of snares per incursion eightfold. No poaching incursions were observed during the Covid-19 pandemic. Tiger density remained below recovery potential (0.48/100km^2 in 2014 to 0.53/

100 km^2 in 2021) but stabilised as key females survived and were detected breeding. Leopard, sun bear, muntjac and wild boar densities remained stable. Disarming active snares and seizing an increased proportion of snares before being deployed directly reduced the potential risk of mortality to medium-large mammals once a poaching incursion began. Attributing the decline in poaching attempts to our intervention is supported for Cambodian poachers via three plausible mechanisms: increased cost of reoffending by repatriated poaching team leaders; reduction of detailed knowledge sharing and imitation by peers; general deterrence at community level from increased awareness of the elevated risk of arrest and low likelihood of enjoying rewards. We found ranger performance enhancements at three critical stages of counter-poaching were instrumental in increasing arrest certainty, this was made possible by institutionalising a learn-and-adapt cycle underpinned by a dedicated site analyst. This study highlights how investing in problem analysis and going beyond simple assumptions of deterrence can greatly enhance the effectiveness and efficiency of small wildlife protection teams.

KEYWORDS

tiger poaching, adaptive management, EMMIE, crime prevention, rangers, evaluation

1 Introduction

Tigers (*Panthera tigris*) are among the world's most iconic animals and umbrella species in their habitats. However, wild tiger populations occupy a mere 7% of their historical range due to centuries of persecution. Recent estimates highlight that there are approximately one million km^2 of tiger habitat devoid of tigers - a testament to the continued poaching problem in Asia, driven by the illegal trade in tigers and prey animals (Goodrich et al., 2022). This threat is acutely realised in Southeast Asia, where vast swaths of seemingly intact forests experience hunting-induced defaunation. As a significant cause of this defaunation, indiscriminate snaring driven by the demand for bushmeat locally and in urban centres, as well as wire snares being an inexpensive and highly effective method of capturing several species of commercial importance (Gray et al., 2017), has dramatically altered mammalian assemblages, even leading to the extinction of certain tiger sub-populations (O'Kelly et al., 2012; Johnson et al., 2016; Gray et al., 2017) and range declines of other endangered carnivores such as leopards *Panthera pardus* (Rostro-García et al., 2016) and clouded leopards *Neofelis nebulosa* (Macdonald et al., 2019; Macdonald et al., 2020). In response to the crisis, range country governments and NGOs have improved law enforcement efforts; however, on-the-ground interventions that prevent poaching must be conducted and evaluated (eg. Linkie et al., 2015).

Protecting tigers in rugged landscapes can be costly and logistically challenging, and arrests of poachers are rare. Rangers tasked with protecting tigers need to be better equipped and more motivated to perform a dangerous and highly technical role (Belecky et al., 2021). Furthermore, solutions proposed to address these challenges are often simplistic and based on perceived best practices, such as increasing the number of "boots on the ground" or implementing harsher penalties with the flawed assumption that general deterrence will cause the poaching problem to decline (Moreto and Charlton, 2019; Wilson and Boratto, 2020). General deterrence theory suggests that the effectiveness of punishment depends on the certainty, speed, and severity of punishment (Beccaria, 1986), with certainty recognised as the most important (Nagin, 2013). Across conservation, impact evaluation is extremely rare. Whether in projects using behavioural change campaigns or with law enforcement interventions, systematic reviews have found that extremely few published studies either describe the impact or attempt to critically examine the causal relationship between the intervention and any decline in the threat (Delpech et al., 2021; Thomas-Walters et al., 2022). This absence of a robust evidence base prevents critical lessons about what works from being learned and shared, leading to the repetition of perceived yet ineffective approaches.

To evaluate the project's impact on reducing tiger mortality, one could use a crime prevention framework that has become the gold standard in evaluating police interventions (Johnson et al., 2015) – EMMIE. This framework stipulates that an evaluation should describe the *Effect* of the intervention (how much it caused the problem to decline by), the *Mechanism* of the intervention (how exactly did the intervention work), what factors *Moderate* the effectiveness of the intervention, how was it *Implemented* and what were sources of success or failure, and finally what were the *Economics* of the project (how much did it cost and was there evidence of cost-savings). Beyond confirming a causal relationship between the intervention and a decline in the problem, the utility of evaluations to other practitioners is boosted by identifying how and why the intervention worked and in what context.

The full impact of an intervention can only be assessed when incorporating an understanding of any crime displacement that occurred, as well as any diffusion of benefits to non-focal groups or outside the focal area. Crime displacement occurs when offenders react to an intervention by switching target, changing tactics, moving to a new location, switching to a different type of crime altogether, or by one offender group replacing another (Eck, 1993). Crime displacement in conservation is rarely considered or applied to describe unusual trends without closely examining underlying assumptions (Kurland et al., 2017). This may derive from confusion over whether a phenomenon is intentional or an artefact of sampling, and whether it is a reaction to an intervention, or an independent innovation. Criminals innovate new techniques, exploit new places and markets independently of any interventions. However, interventions may accelerate and direct the nature of these innovations, and crime displacement was found to occur in 25% of studies examined, the same rate as studies reporting diffusion of benefits from an intervention (Guerette and Bowers, 2009).

Here, we used EMMIE to evaluate the effectiveness of protection efforts to conserve wild tigers, focusing on the impact of key structures and processes developed to control tiger poaching in a mountainous protected area in northeast Peninsular Malaysia. We also examine the challenges and limitations of our approaches and suggest ways to improve or strengthen them. Overall, our findings can contribute to developing more effective conservation strategies for wild tigers and help ensure the long-term survival of this iconic species in the region.

2 Materials and methods

2.1 Background

In Peninsular Malaysia, poaching for the illegal wildlife trade has been identified as the most critical threat to the Malayan tiger subspecies (*P. t. jacksoni*) (Clements et al., 2010), with the population plummeting from an estimated 3,000 in 1954, to 200 by 2020 (Ten et al., 2021). The Kenyir Core Area (hereafter known as Kenyir), comprises 1,200km^2 of mountainous tropical forest in Taman Negara, a globally recognized source site embedded in a priority tiger landscape (Sanderson et al., 2006; Walston et al., 2010), Kenyir State Park (gazetted 2018) and permanent forest reserves in Terengganu state (Figure 1). In 2014, in line with Malaysia's National Tiger Action Plan (Department of Wildlife and National Parks Peninsular Malaysia, 2008) and Panthera's Tigers Forever Protocol (Goodrich et al., 2013), Malaysian NGO Rimba, in partnership with Panthera and Woodlands Park Zoo, initiated a project with the Department of Wildlife and National Parks (DWNP) to recover Kenyir's tiger population by 50% by 2024.

2.2 Problem analysis and poaching type moderators

Between 2015-2023 poaching sign observations detected by patrols were categorised by poaching type and stored and managed in Spatial Monitoring And Reporting Tool (SMART; www.smartconservationtools.org). A poaching incursion was defined by nine key activities including entry of the poaching team to the site, camping, harvesting wildlife and departing (Figure 2). During an incursion, poaching teams leave sign with distinct characteristics. Poaching sign was aggregated to a specific incursion through the age of the sign, geographical proximity, and unique identifiers such as litter, tree markings, camp and snare signatures.

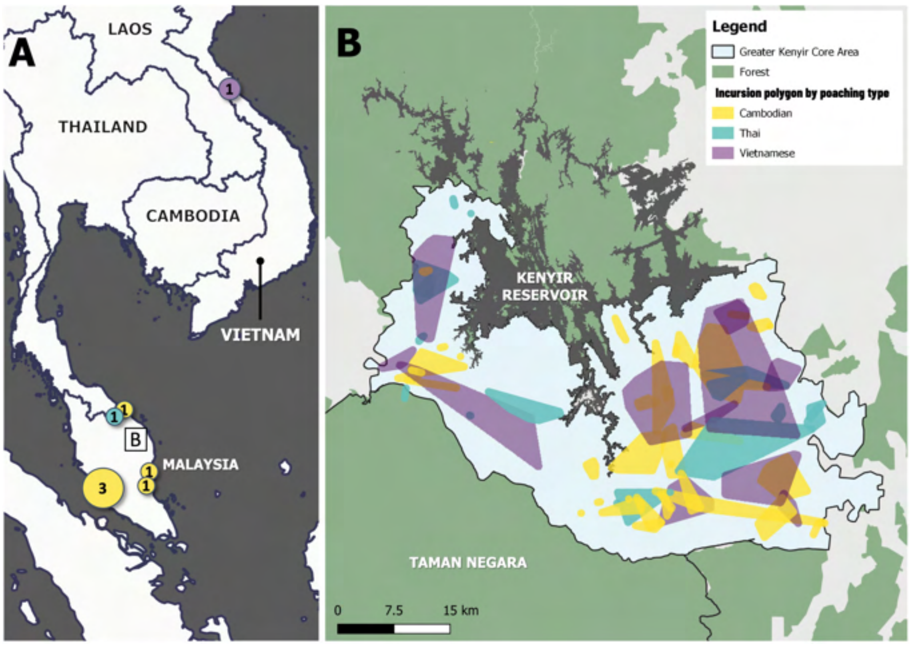

FIGURE 1
(A) Location of the Kenyir Core Area within Peninsular Malaysia. Bubbles indicate district of origin of Thai, Cambodian and Vietnamese poaching teams where known. Bubble size indicates the number of known poaching incursion attempts made from each district; **(B)** The Kenyir Core Area in detail indicating the extent of poaching incursions detected.

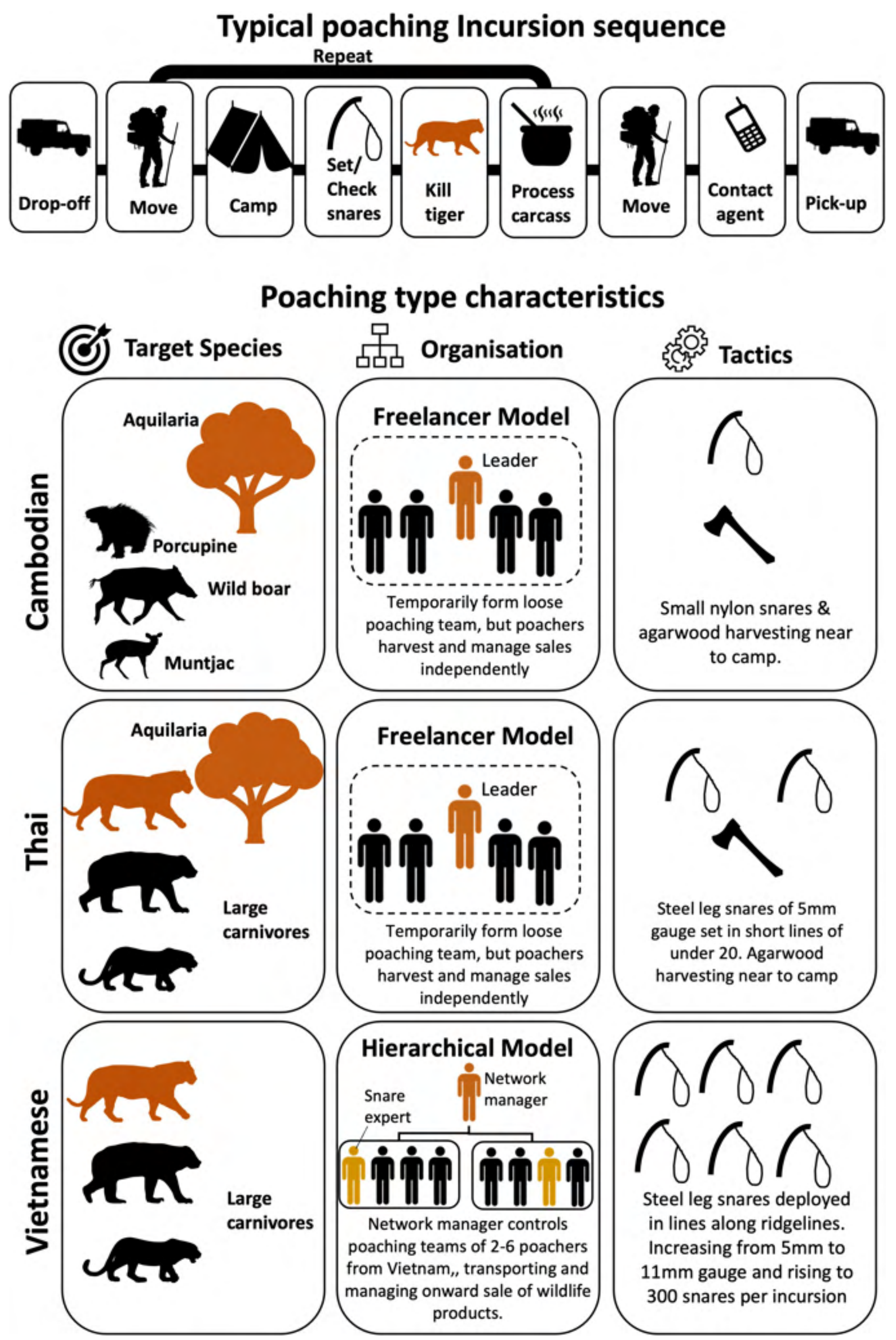

FIGURE 2
A typical poaching incursion sequence and characteristics distinguishing the three poaching types in the Kenyir Core Area.

Following the patrol debrief, all observations attributed to an incursion were tagged with an incursion-unique reference number to enable spatial querying. From 2016 onwards, DWNP Investigating Officers began asking questions in post-arrest interviews regarding poaching team organisation and decision-making within the landscape. From 2016-2019, seven interviews took place. This was complemented with by-catch data from tiger survey cameras, and poacher cameras deployed at the forest edge.

Investments in problem analysis and institutional learning were instrumental in developing this intervention. The team adopted a problem-oriented wildlife protection approach (Lemieux and Pickles, 2020). Increasing the granularity of threat from 'tiger poaching' or 'sharing' to resolve specific poaching problems provided sharper focus and mission objectives. Analysis of snare volume by poaching type conducted in 2016 identified non-Malaysian poachers as a priority threat to address, sharing similarities including living far from the site, operating for multiple months deep inside the forest, and being supported by vehicle transportation by a third party (Lam, 2018). Disaggregating this poaching threat revealed three distinct nationalities: Vietnamese, Thai and Cambodians, differing in target species, organisation and methods (Figure 2). Vietnamese and Thai poaching incursions involved wire leg-snares set for large carnivores (tiger, leopard and sun bear), to sell body parts to traditional Chinese medicine markets. Tiger carcasses were flensed and skeletons boiled in large pots over several days to create bone glue, while sun bear gall bladders, claws and canines, and leopard claws and canines were removed and dried (Lam and Mat, 2020). Cambodian poaching teams were recorded using rope or nylon snares for argus pheasant, mouse deer, porcupine, muntjac and boar for consumption inside the forest. Cambodian teams almost primarily harvested valuable agarwood from Aquilaria trees, for perfume markets in the Middle East.

Analysis of non-Malaysian poaching types informed a revised protection strategy in 2018. Our strategy assumed three mechanisms to reduce poaching and recover the tiger population. First, counter-poaching performance improvements would lead to earlier detection and arrest of Vietnamese, Thai and Cambodian poaching teams, resulting in fewer snares deployed and less immediate harm to tigers. Second, awareness of the increased risk to poachers would spread within poaching communities and dissuade other poaching teams from targeting Kenyir, resulting in a decline in poaching incursion attempts. Third, understanding that there are different roles within a poaching team, the impact of any arrest on subsequent poaching attempts would depend on the role and experience played by a poaching team member arrested (Duijn et al., 2014). Apprehending a poaching team leader or experienced snare setter was judged to have a greater disruption impact on subsequent poaching attempts than a porter, cook, or junior member. Maximising arrests within a poaching team was therefore prioritised before conducting a snare sweep. DWNP and NGO partners Rimba and Panthera developed a specialisation in deep-forest counter-poaching operations (DFCPO), synthesising tracking and search and rescue theory. The NGO partners maintained civilian scout teams, detecting active incursions and guiding arrest teams. DWNP ranger teams could detect incursion alerts but were also instrumental in conducting arrests. In 2017, DWNP formed the Special Protected Areas Response Team (SPARTA) unit as a deep-forest specialist counter-poaching unit.

2.3 Evaluation approach

This evaluation covers eight years from January 2015-January 2023, in which we compare Baseline years (2015-2016) with Treatment years (2018-2019) following the implementation of the revised strategy. We examine the COVID-19 pandemic years (2020-2021) and post-COVID years (2022) separately. We use EMMIE (Johnson et al., 2015) as our overarching framework and have structured the methods and results accordingly (Figure 3). First, we establish the impact (Effect) of the intervention on the poaching problems and tiger recovery, using Eck's (Eck, 2017) Four Point Test to examine the evidence for causation. We then examine how the intervention may have worked (Mechanism) by testing a theory of change using a logical framework (Stewart et al., 2020) and assessing 15 indicators (Table 1). We contrast the three poaching types to identify where the intervention appears to have worked best (Moderators). Finally, we examine how the intervention was conducted, the main challenges overcome (Implementation), and the costs (Economics).

2.3.1 Effect of the intervention

2.3.1.1 Did the poaching problems decline?

The size of each poaching problem was assessed using four dimensions. Starting at the community level, we used post-arrest information to identify the number of different communities poaching teams were coming from, and to examine the cessation of poaching activity by specific communities (Indicator 7). We measured the success of poaching incursion attempts in Kenyir each year (Indicator 8) by classifying incursions as 'successful' if the ranger team did not intercept. Poaching incursions were classified as 'failed' if there was an apprehension, or a ranger team seized or destroyed essential equipment and rations, forcing the poaching team to abort. We assessed the change in maximum penetration depth of incursions (Indicator 9) by first estimating the likely drop-off point direction from the overall distribution of sign. Potential access routes including recent logging roads, plantations and minor roads were digitised from satellite image data by students from the University of Montana's Geography Department, and the symmetrical difference operation was performed using QGIS 3.16.9 to exclude road segments within Kenyir. Closest potential vehicle drop-off point to the deepest point for each incursion was determined using the 'st_nearest_feature' from the 'sf' package (Pebesma, 2018) in the R Statistical Software v4.2.1 (R Core Team, 2021) and Euclidean distance between the deepest point of each incursion and potential drop-off point was calculated using the "st_distance' function from the 'sf' package (Pebesma, 2018). Boxplots were generated using the 'ggplot2' package (Wickham, 2016) for each poaching type for baseline and treatment years to assess change in incursion depths. We quantified the extent to which the project mitigated harm to tigers from snares by classifying snares based on status when found and scoring them based on their kill potential (Indicator 10). All snares used in Kenyir involved the same basic construction involving a wire noose was attached to a sapling spring pole and held under tension, lying on a small platform above a pit approximately 30cm deep. The snare was activated by an animal placing its foot on the platform, pushing it into the pit, and releasing the spring pole, which drew the noose tight. These construction elements allowed snare placements to be detected over a year later. For all snares and poaching signs detected, the 'date of last use' was estimated by experienced trackers based on weathering characteristics. Ageing stands of discards and sign commonly found in a poaching incursion were maintained at the field station for comparison, and refresher training was regularly conducted. This technique allowed us to avoid snare counts being highly sensitive to current patrol efforts, as snares could be detected by a patrol in 2020 but backdated to an incursion in 2019, for example.

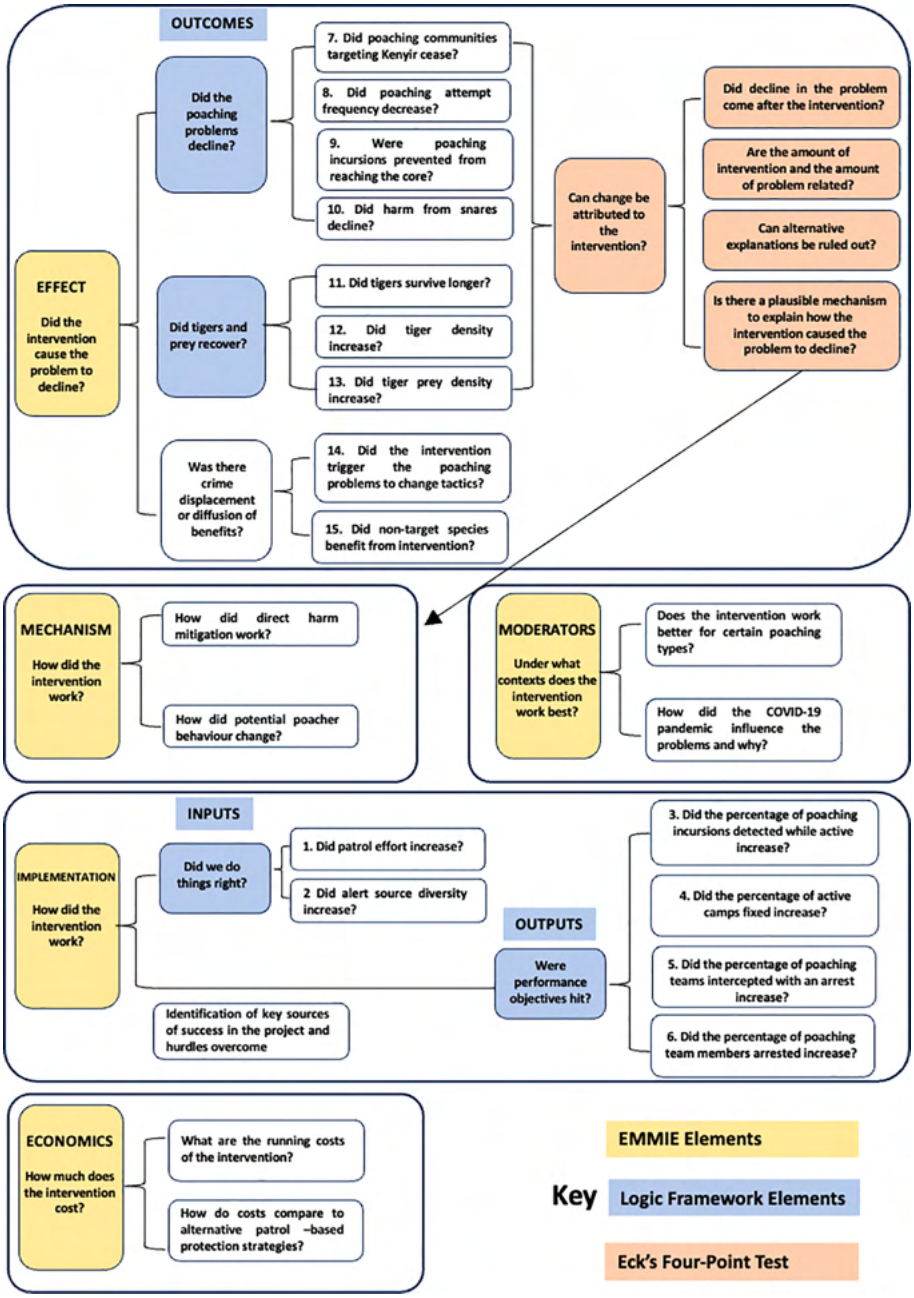

FIGURE 3
Assessment methods used in the evaluation of the counter-poaching intervention in Kenyir and specific indicators used. The arrangement of questions corresponds to the flow of this publication.

2.3.1.2 Did tigers and prey recover?

Large-scale camera trap surveys were conducted in 2014, 2017 and 2021 with camera traps deployed in a 2.5 x 2.5km array covering a monitoring area of 600 km^2 in the centre of Kenyir. Surveys were conducted from May to November when conditions were dry. PantheraCam V4, V5 and V7 units (Oliff et al., 2014) were placed on ridgelines and places with tiger signs to maximise detection. For the years not covered by systematic surveys, *ad hoc* cameras were placed in high detection stations to maintain awareness of focal individual tigers. Individual tigers were manually identified by their stripe pattern and tracked across survey years to estimate persistence (Indicator 11). Next, we used spatially explicit capture-recapture (SECR) to estimate tiger density using the maximum likelihood approach (Indicator 12). All analyses were done with packages "secr" (Efford, 2018), "rgdal" (Bivand et al., 2015), "wiqid" (Meredith, 2020), and "nimble" (Ghoting et al., 2011) in Rstudio (RStudio Team, 2020). We calculated an index of tiger prey density using the space-to-event (STE) method (Moeller et al., 2018), which uses the spatial distribution of animal detection events. STE is a method for estimating population density; however, since we employed cameras that targeted tigers, we interpreted the

TABLE 1 Indicators used to evaluate success of counter-poaching operations.

Indicator	How measured
1. Protection Effort	Foot patrol hours inside the Kenyir Core site.
2. Alert Source Diversity	Ratio of alerts of poaching incursions from patrols, cameras and community contacts
3. Poaching incursions detected while active: Missed incursions ratio	An 'active' incursion was defined by the evidence for the alert estimated at under three weeks old (including ground signs, a report from the community, or camera trap image). Incursions for which the evidence was older than three weeks were classed as 'missed'.
4. Active poaching camp fixed: Camp missed ratio	A 'fixed active camp' was defined by a ranger team having direct sight of the poaching camp following a search operation and confirming that it was still in use. Search operations that failed to locate the active poaching camp were classed as 'missed'.
5. Interdiction successful: Interdiction failed ratio	An interdiction was classed as a success if at least one member of a poaching team was arrested.
6. Poachers arrested: Poachers escaped ratio	The total number of poachers in a team was estimated by a mix of evidence after an interdiction attempt including counting hammocks, identifying personal effects and through post-arrest interviews.
7. Cessation of activity of poaching communities	Communities of origin of poaching teams were assessed during post-arrest interviews.
8. Poaching incursions attempts and success	A poaching incursion was considered to have 'failed' if the patrol team had made an interdiction attempt and either the poacher was apprehended and/or the ranger and critical equipment were seized, forcing the team to abort. All other poaching incursions which were not disrupted were classed as 'successes'.
9. Maximum poaching incursion penetration depth	Euclidean distance between most central observation of an incursion and nearest potential vehicle access point on edge of Kenyir.
10. Snare Harm Mitigation	Snares were classified as prevented, disarmed or missed. A 'prevented' snare was removed by a ranger team before it could be deployed, either taken from a poacher's camp, or an uncut reel of steel wire in which potential snares were calculated based on a rule of 3m per snare. A 'disarmed' snare was removed by a patrol while still capable of trapping an animal. 'Missed' snares were no longer capable of trapping an animal due to age and weathering. Removal of missed snares had no harm mitigation effect.
11. Individual tiger persistence	The percentage of each cohort of tigers detected in a survey that had been redetected since the previous survey.
12. Tiger density	Densities of tigers were estimated using spatially explicit capture-recapture from camera trap images in a 600km^2 central monitoring zone.
13. Prey density	Density indices of wild boar and muntjac. were estimated using the space-to-event method from camera trap images in a 600km^2 central monitoring zone.
14. Crime displacement	Evidence appraised that two observed phenomena were (a) intentional, (b) a reaction to the intervention and (c) weakened the effect of the intervention.
15. Diffusion of benefits to non-focal species	Densities of leopard and clouded leopard were estimated using spatially explicit capture-recapture. Density indices of Malayan tapir, sun bear were estimated using the space-to-event method from camera trap images in a 600km^2 central monitoring zone.

density estimate as an index of density since the model relies on a random camera placement design. For the analyses, we applied an occasion definition of 5 seconds every 30 minutes, where simultaneous species detection across all camera trap stations was tabulated. The viewshed was kept constant throughout the years and stations, and the analyses were conducted with the package "spaceNtime" (Moeller and Lukacs, 2021) in Rstudio (RStudio Team, 2020). Using this index, we assessed the trends of tiger prey with sufficient detections: the southern red muntjac (*Muntiacus muntjac*) and wild boar (*Sus scrofa*) (Indicator 13).

2.3.1.3 Did our intervention cause the problems to decline?

To examine whether any decline in the poaching problems could be attributed to our intervention, we applied Eck's (Eck, 2017) four-point test. This asks: 1) the decline in the problem occurs after the intervention; 2) the amount of intervention and the amount of problem are related; 3) alternative explanations are rejected; and 4) there is a plausible mechanism to explain how the intervention caused the problem to decline. We assessed the evidence for points 1 and 2 by comparing annual incursion frequency estimates

(Indicator 8) against patrol hours inside Kenyir as a proxy measure for the combined intervention. We tested possible alternative explanations by developing predictions if they were true, and testing these using information from patrol observations, post-arrest interviews, online searches and interviews with subject matter experts. The evidence for plausible mechanisms by which the intervention caused the problems to decline is described below.

2.3.1.4 Was there crime displacement or diffusion of benefits?

We examined the evidence for crime displacement caused by the intervention using available patrol data, debriefings, and post-arrest interviews. It was not possible to test for geographical displacement due to changes in detection efforts outside Kenyir between baseline and treatment years. Trends detected in shifts in tactics or offenders were examined, and the evidence appraised that these were: a) caused by the intervention; and b) intentional decision-making by the potential poachers. Two possible crime displacement phenomena were detected: (1) an increase in the number of snares per Vietnamese incursion; (2) a decrease in the number of poachers per Cambodian poaching team. As snaring indiscriminately affected multiple medium to large ground-dwelling mammal species at our study site, we wanted to determine if our tiger-specific intervention conveyed benefits to non-target species. We estimated clouded leopard density (*Neofelis nebulosa*) using the maximum likelihood approach for SECR and tracked individual persistence across survey years. Melanistic leopard (*Panthera pardus*), detections did not allow individual identification with our Xenon flash camera traps. Hence, we implemented the Spatial Count (SC) (Chandler and Andrew Royle, 2013) model with priors from Hedges et al. (Hedges et al., 2015) to estimate leopard density. For two other species of high conservation value, Malayan tapirs (*Tapirus indicus*) and sun bears (*Helarctos malayanus*), we followed the same protocol as for tiger prey to develop a density index (Indicator 15).

2.3.2 Mechanism & moderators of the intervention

We investigated the mechanism by which the intervention may have caused the poaching problems to decline in two ways. First, we used a logical framework to map a theory of change by which our inputs would deliver intermediate results (outputs) and ultimately desired problem decline and population-level outcomes (Figure 4). We then measured indicators 7-10 to test this theory of change, conducting separate analysis for Vietnamese, Thai and Cambodian poaching types.

Second, we conducted a post-hoc interrogation of the mechanism by which elevated risk of arrest may have led to a reduction in incursion attempts to Kenyir. This combined opportunistic details of poacher decision-making from interviews with poachers, community members and subject matter experts in enforcement agencies, contextualised with wider open-source reporting. This was conducted separately for each poaching type and the reasons for differences examined.

2.3.3 Implementation & economics of the intervention

We use the logical framework (Figure 4) to detail how the intervention was implemented, including measuring input changes in personnel, patrol effort (Indicator 1) and poaching alert source diversity (Indicator 2). We then conduct a process evaluation using indicators 3-6 to examine improvements in counter-poaching operation performance at critical steps. We place this in a narrative identifying key sources of success and failure points overcome, to facilitate replication by other teams. We calculate annual operating costs for the team where costs were available. We then compare unit protection costs of our intervention against alternative ranger-based protection models recommended.

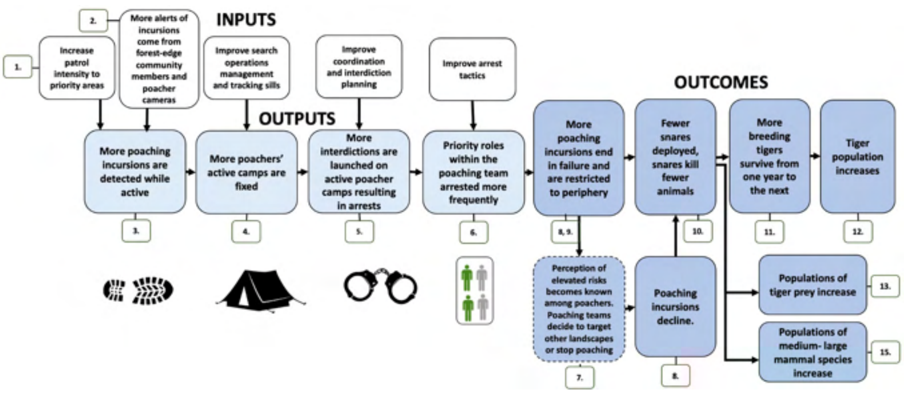

FIGURE 4
Theory of change for how the intervention was considered to lead to a tiger population increase. Numbers refer to the indicators used to measure progress and evaluate the mechanism (Table 1).

3 Results

3.1 Effect of the intervention

3.1.1 Did the problem decline?

Ninety-six poaching incursions of all nationalities were detected between 2015 and Feb 2023 inside Kenyir. Location data on the origins of poaching teams was only available for eight incursions (Figure 1; Supplementary Material). Thai (n=1) and Vietnamese (n=1) poaching teams initiated from their home countries and travelled overland to Malaysia before entering Kenyir. All Cambodian poaching teams intercepted (n=6) were residing in Malaysia and initiated the incursion from their home community. In each case, all poaching team members were from the same community. The first three Cambodian poaching teams apprehended in 2017-2018 were from Petaling District, Selangor, totalling 23 individuals. Subsequent Cambodian incursions in 2019-2023 were exclusively from east coast districts. It is possible that incursions from Petaling District were missed; however it also indicates potential cessation of poaching activity by Petaling District Cambodians.

Poaching incursion frequency declined by 40% from baseline years (n=34) to treatment years (n=20) across poaching types. Poaching incursions were absent during COVID-19 and low during post-COVID years (n=3) (Figure 5). Among the poaching types, Thai and Vietnamese incursions each recorded a decline of 34% and 13% in successful incursions. Success rates for Cambodian poaching incursions fell by 40% from baseline to

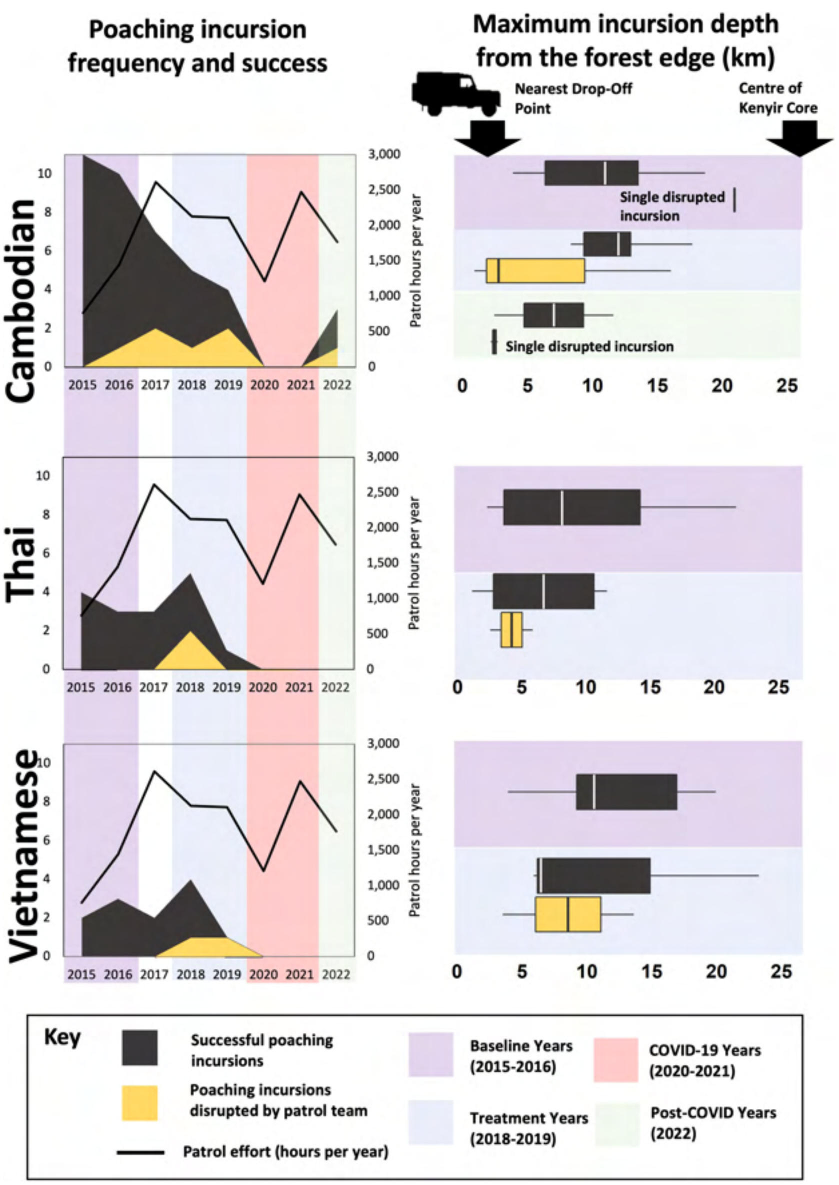

FIGURE 5
Declines in poaching incursion attempt frequency, and poaching success (left) and declines in penetration depth of poaching incursions (right) in the Kenyir Core Area for each poaching type.

treatment years. Vietnamese and Thai poaching incursions remained constant until 2018, then declined in 2019. From 2020-2023 no Thai or Vietnamese incursions were detected inside Kenyir, though incursions were detected on the surrounding landscape.

The depth of poaching incursion penetration into Kenyir decreased for all poaching types from baseline to treatment years (Figure 5). However, this was more marked when comparing successful and disrupted incursions during treatment years. Disrupted incursions were on average, 2.6 km (Thai) and 9.1 km (Cambodian) closer to the forest edge, respectively. No difference was detected for Vietnamese incursions. Maximum depth continued to decrease for successful and disrupted Cambodian incursions during the Post-COVID period. In each case, the effect was found to not be statistically significant due to low sample sizes. The overall effect of this spatial shift was a reduction in the proximity of poaching incursions from some of the most high-quality tiger habitat in Kenyir, whose central lowlands included higher prey densities, and two breeding females were detected here.

The number of wire snares detected inside Kenyir during treatment years was over four times higher than in the baseline years (Figure 6). Despite this, harm mitigation efforts improved. The proportion of wire snares disarmed before reaching full kill potential increased fourfold, with 10% of all snares entering Kenyir in treatment years seized before deployment. Between 2015 and 2019, patrols identified 44 animals trapped by snares, over half of which occurred during the 2019 mass snaring event. One Indochinese leopard and five sun bears were detected as target species, while bycatch of Asian tapirs and wild boar accounted for 18% and 38% of known catch mortality, respectively. Harm mitigation from snaring improved notably

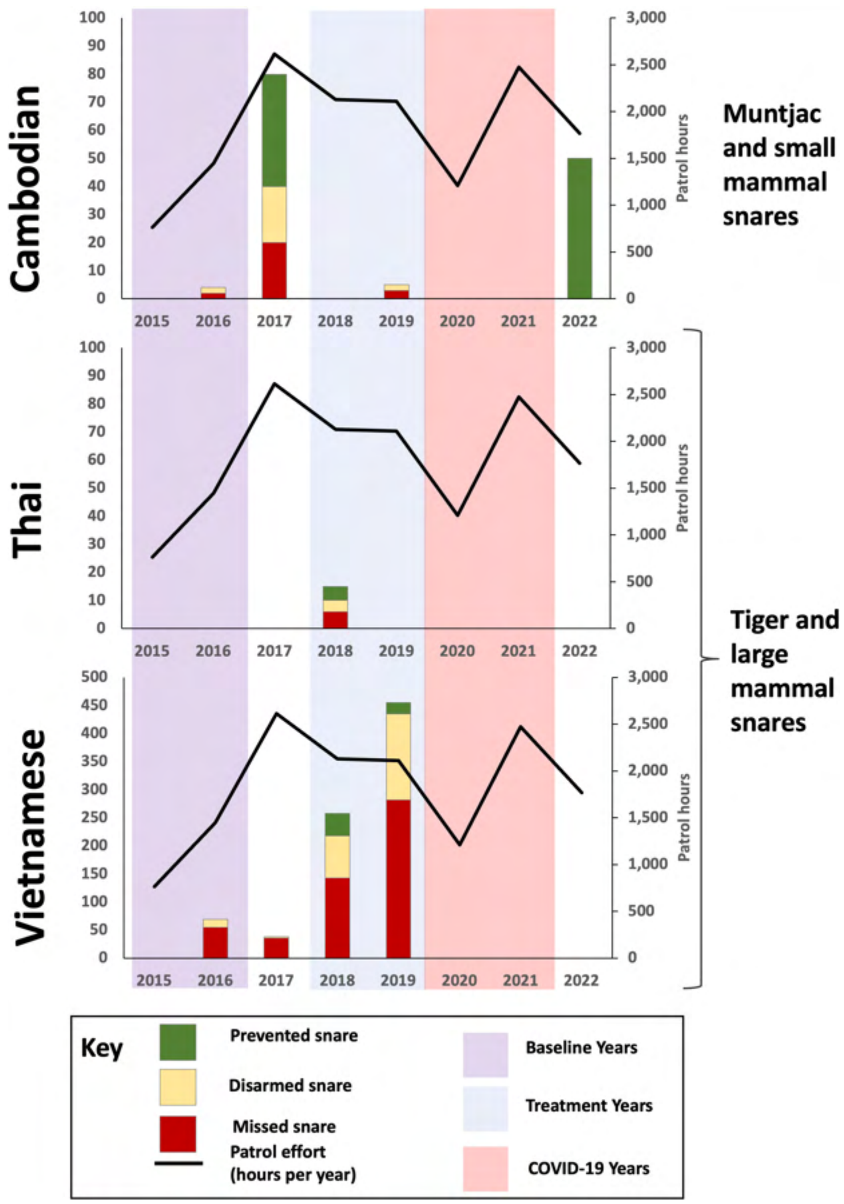

FIGURE 6
Mitigation of harm to wildlife from snares removed in the Kenyir Core Area for each poaching type.

 10.3389/fcosc.2023.1213552

against Cambodian poachers using rope and nylon snares for small and medium mammals.

3.1.2 Did tigers and prey recover?

Persistence of individual tigers was low throughout the study period. In the 2017 sampled population, 50% of the tigers detected were first-year detections, while first-years comprised 60% in 2021. A small core of three resident female tigers survived mass snaring events and were detected for seven years in Kenyir. Four breeding events were detected from these females during the study period. Eleven offspring were observed, with 10 classified as subadults, surviving the initial high mortality cub stage. Two offspring were redetected as adults; the female was detected breeding in one case. Mean tiger density fluctuated from 0.48/100 km2 (CI 0.22-1.04) in 2014 to 0.15/100 km2 (CI 0.04-0.52) in 2017 before stabilising to 0.53/100 km2 (CI 0.24-1.19) in 2021, well below the possible recovery range (Figure 7). Of the prey species in Kenyir, the Sumatran serow and sambar deer were detected at extremely low frequencies, and we could not compute density indices. Density indices for wild boar and southern red muntjac indicated steep

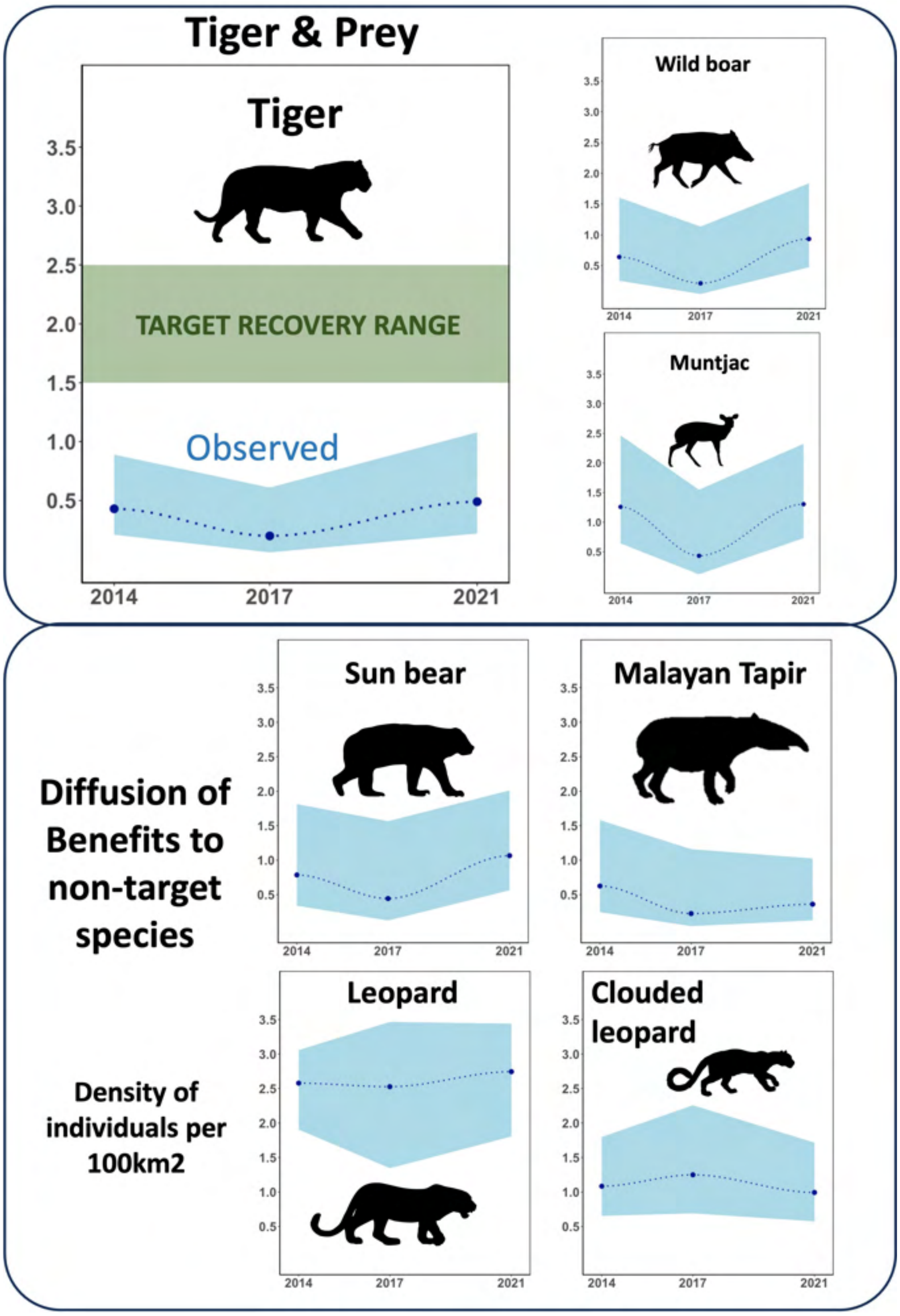

FIGURE 7
Density changes of tigers and prey and diffusion of benefits to non-target species in the Kenyir Core Area.

declines from 2014 to 2017 before stabilising around 2014 levels in 2021 (Figure 7).

3.1.3 Did our intervention cause the problems to decline?

There is reasonable support that the intervention was responsible for the decline in Cambodian poaching incursion attempts, passing all four of Eck's criteria (Table 2). The infrequent incursions and comparatively lower risks experienced by Vietnamese and Thai poaching teams mean there is insufficient support for the intervention causing the drop in these poaching types.

3.1.4 Was there crime displacement or diffusion of benefits?

While the frequency of Vietnamese poaching incursions was the same in baseline and treatment years, the number of snares deployed per incursion rose by more than eight times. This trend was associated with an observed switch in the snare wire gauge from 4-6 mm during baseline to 11mm during treatment years. A single catastrophic Vietnamese incursion was responsible for all 330 snares deployed in 2019. From 2019 until Feb 2023, at the time of writing, no wire snares were detected inside Kenyir. The trend in intensive snaring corresponded with a decline in agarwood harvesting by Vietnamese poaching teams. This was evidenced by reduced tree felling, sign of wood processing at camps, and the absence of agarwood chisels in arrests. While this trend correlates with the increased success of the ranger teams, the hypothesis that this was a response by poachers to the increased risk of arrest has insufficient support (Table 3) and more likely represents independent innovation to increase capture success innovation to increase capture success in a depressed carnivore population. Counts of sleeping spaces in nine Cambodian camps revealed a steadily declining trend in team size that began before the pandemic. No teams larger than ten were detected from 2018 onwards. Evidence is weak to support the hypothesis that Cambodians were adaptively switching to smaller team formations to avoid patrol detection (Table 3). The decline in poaching team size corresponds with the wider decline in Cambodia incursion frequency and supports the hypothesis for decreased recruitment at community level. Of the four non-target, high-conservation value mammal species, leopard density was stable from 2.58/100 km^2 (CI 1.90-3.06) in 2014 to 2.53/100 km^2 (Cl 1.34-3.46) in 2017 and 2.74/100 km^2 (Cl 1.81-3.44) in 2021 (Figure 7). Clouded leopard density remained broadly stable, from 1.08/100 km^2 (CI 0.66-1.80) in 2014 to 1.25 (CI 0.69-2.26) in 2017 and 0.99/100 km2 (CI 0.58-1.72) in 2021. The Malayan tapir and sun bear displayed the same declining trend in 2017 as tigers, with tapirs showing only marginal recovery by 2021. Sun bears, by contrast, stabilised to above 2014 levels.

3.2 Mechanism & moderators of the intervention

The mechanism of direct harm mitigation from snare removal, and preventing poaching teams from reaching priority areas of the site is described in 3.1.1. and is well supported by the available data. The reduction of Cambodian incursions can be explained by three possible mechanisms that complement and reinforce one another—triangulating from the limited data available. The pattern of change in the community of origin of poachers, reduction in poaching team size, and post-arrest testimony, offer partial support for all three of these.

TABLE 2 Appraisal of evidence in attributing decline of Cambodian poaching incursions in the Kenyir Core Area.

Test	Evidence & Conclusion
1. Decline in the problem comes after intervention	Pass. The year-on-year decline in Cambodian incursions followed a trebling of patrol effort and increase in arrests in 2017.
2. The amount of intervention and amount of problem's decline are related	Pass. Following the initial drop, sustained counter-poaching performance increased the risk of a poaching incursion failing to 1 in 2, this was associated with sustained decline in incursion attempts.
3. A clear mechanism by which the intervention caused the decline	Pass. The intervention may have caused the decline via three plausible mechanisms. There is circumstantial evidence to support all three. 1. Increased effort and costs of re-offending after arrest. 2. General Deterrence within small communities. 3. Reduced imitation by peers.
4. Alternative explanations are rejected	Pass. Four alternative explanations were examined and are unlikely to have caused the decline in Cambodian incursions in Kenyir. 1. Decline in international agarwood value 2. Deterrence or incapacitation of poachers by immigration sweeps 3. Voluntary repatriation of Cambodian agarwood harvesters 4. Agarwood stocks in Kenyir became depleted From 2016-2019 agarwood's value remained high; there were no actions, policies or initiatives which would have curtailed agarwood traders' ability to launder illegally harvested wild agarwood through licit channels; there were no notable immigration sweeps until 2020 or voluntary returning home of Cambodian nationals. Interviews with Cambodian poachers in 2023 indicated there were still perceptions of high agarwood stocks in Kenyir.

TABLE 3 Assessing the evidence for two hypotheses of crime displacement in Kenyir.

Displacement Hypothesis	Expected	Evidence	Conclusion
Tactical Displacement. Cambodians adaptively shrank team size to reduce likelihood of detection and arrest.	Cambodian poacher behaviour becomes increasingly covert.	Rejected. No other covert behaviour or countermeasures to detection observed by patrols.	Crime displacement unlikely. More plausible that the change reflects reduced recruitment to poaching.
	Smaller poaching teams carry lower risk of being detected. Individual poachers have lower risk of arrest.	Rejected. Small poaching teams were detected and camps fixed by patrol teams at the same frequency as large teams. Arrest rates were actually higher within smaller teams.	
	If solely a tactic to reduce risk, the frequency of incursions by poaching teams would not change.	Rejected. Number of poaching teams launching incursions declined at a similar rate to the number of individuals per poaching team	
Tactical Displacement. Vietnamese increased the number of snares per incursion to reduce the time needed to obtain carnivore body parts and reduce risk of detection and arrest.	Vietnamese poaching incursion duration shrinks.	Rejected. Poaching teams deploying larger snare arrays spent up to 5 months inside Kenyir.	Crime displacement unlikely. More plausible that the change was intended to increase likelihood of capture of remaining individual carnivores in a heavily depressed population
	Risk of detection and arrest for Vietnamese poachers reduced over time.	Rejected. The larger 2019 snare line enabled the patrol team to locate the camp faster and make arrests.	

3.2.1 Poacher repatriation increased the effort and costs of re-offending after arrest

Repetition of signature tree carvings across different incursions, and details shared in interviews with offenders indicate that the same poachers returned to Kenyir to conduct subsequent incursions, guiding teams with new members. Repeat victimisation occurs because a target is particularly attractive or vulnerable to offenders (the "flag" explanation), or specific offenders gain knowledge about the target from experience and use this to re-offend ("Boost" explanation) (Weisel, 2005). Offenders learn how to navigate the area, where and when security is and is not present, and what targets to return for. Interviews with burglars found that up to 75% of offenders had robbed a property twice or more (Ashton et al., 1998). Arrested Cambodian poachers received sentences ranging from 3 months to 1 year for illegal agarwood harvesting on failure to pay a fine. Most of the poachers were undocumented migrants whose work visas had expired, and they were routinely repatriated to Cambodia. Repatriation increased the costs and effort of an individual poacher attempting a subsequent incursion. Cambodian poaching teams did not have a strong hierarchy, and the incursion was instigated by one person in the team who would fill the team leader role, engage co-poachers and contract a transporter. While it was challenging to identify who the leader was in a poaching team, the increased percentage of team members arrested during the treatment years increased the likelihood that the leader was arrested. This mechanism is suspected of being weaker for Vietnamese and Thai poachers due to the low number of individuals arrested.

3.2.2 Repatriation reduced knowledge sharing and imitation by peers

In interviews with Cambodian poachers, interviewees described selecting the target location following advice and detailed descriptions from another team. For instance, "*I knew it was against the law to take things out of the forest, but I was willing to take the risk as I'd heard about success stories from other people who'd been to Area X*" (Interviewee 5). This suggests arresting and repatriating Cambodian poachers prevented them tempting peers to imitate their success. Second, it reduced the transmission of detailed information about Kenyir's terrain and security with peers in their community or to guide in new poachers. Reduced temptation and landscape awareness would have reduced the likelihood of another poaching team targeting Kenyir. But, again, this mechanism is suspected of being weaker for Vietnamese and Thai poachers due to the much lower number of individuals arrested.

3.2.3 General deterrence from increased awareness of the elevated risk of arrest and low likelihood of enjoying rewards

Certainty of arrest for a poacher rose significantly in Kenyir during the study period. Poachers escaping made heavy financial losses as they were forced to leave behind equipment and harvested wildlife products. From post-arrest interviews, Cambodian poachers invested approximately $170 each in rations and travel costs to embark on a poaching incursion and saved up in the months before. Post-arrest interviews with Cambodian poachers (n=9) revealed that many worked part-time, low-paid jobs. Awareness of the risk of arrest and potential financial losses could have been shared with potential Cambodian poachers within their community, from escaped poachers or from arrested poachers' families.

The Cambodian and Vietnamese poaching types offer contrasting examples of how effectiveness of a deterrence mechanism is moderated by risk awareness and rational choice (Figure 8). Interviews suggest Cambodian poachers operated a freelancing model with flexible group membership, conducting agarwood poaching as an income side-line. Nothing indicates coercion or impaired judgement, and individual poachers were responsible for the up-front costs of rations and travel

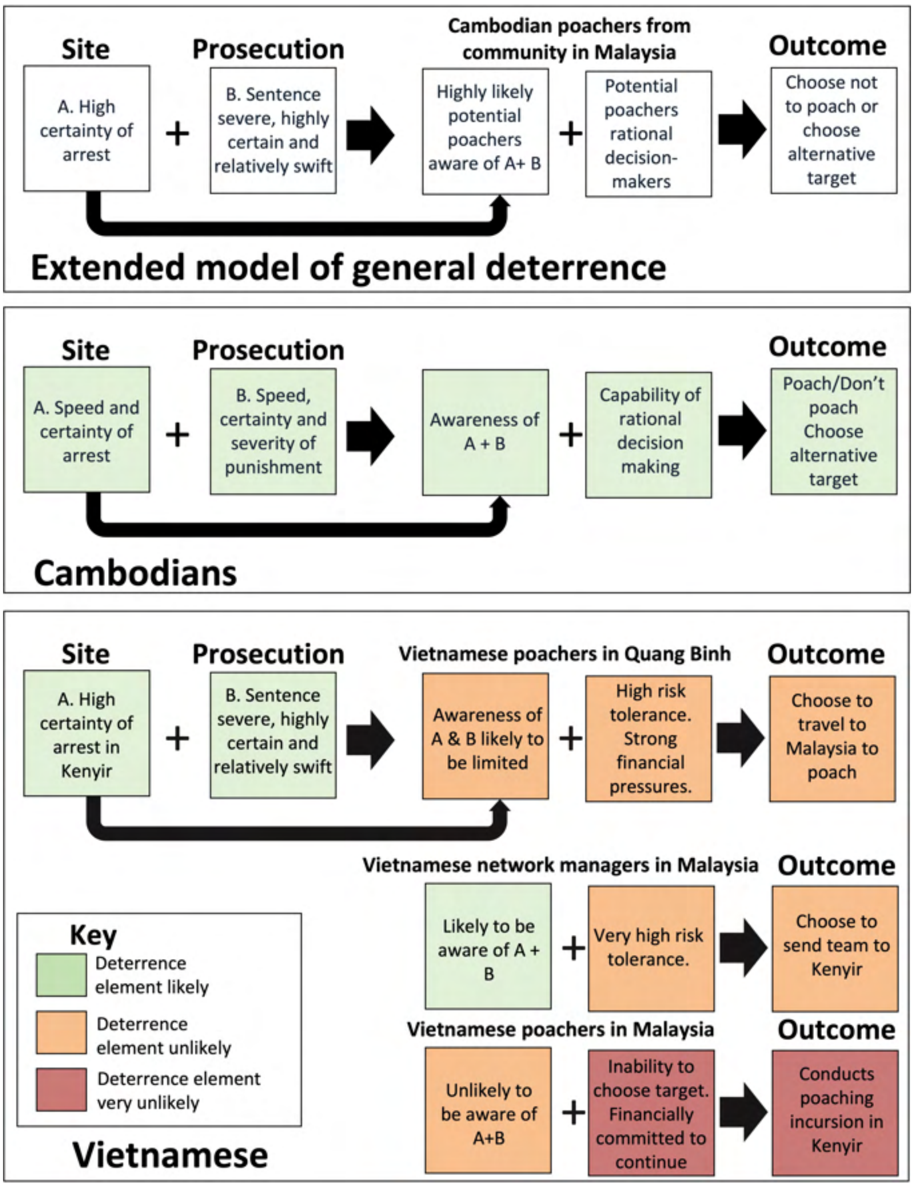

FIGURE 8
Contrasting perspectives for how the increased certainty of arrest in the Kenyir Core Area would influence Cambodian and Vietnamese poacher decision-making.

arrangements. Interviews suggest they could weigh costs and rewards to make an economically rational decision. As Cambodians were long-term residents of Malaysia, they were more likely to have a broad awareness of forest landscapes within Peninsular Malaysia. They could also choose an alternative target landscape or elect not to poach in response to locally elevated certainty of arrest. During interviews with Cambodian poachers from Pekan District arrested in 2023 without the usual small nylon snares used for trapping small animals, interviewees (n=2) indicated awareness of sanction severity "*Other people told me not to take wildlife because the penalty is very heavy*" (Interviewee 5). Still, they did not know anyone arrested for poaching or had any awareness of the elevated risk of arrest in Kenyir. After speaking to others from their community who had returned with a good agarwood harvest, the poachers were incited to attempt the incursion. In each of the six cases for which we have data, all poaching team members were from the same community in Malaysia. Given the large distance between Cambodian communities, knowledge about targets and risks may be relatively low, which could localise deterrence to a specific community.

Interviews with the two Vietnamese poachers arrested in 2019 provided a different insight into the limitations of deterrence. Both poachers had travelled to Malaysia specifically for a poaching expedition after being recruited by an agent in Vietnam supporting a Vietnamese network manager in Malaysia. Both poachers described raising personal and family debts to fund the $500 travel expenses. Two days after arriving in the country, they were taken to the forest edge with rations to begin a five-month incursion. This style was identified as a hall-mark of Vietnamese specialist poachers from community interviews, other prosecution cases and subject matter experts from the Wildlife Department (Lam and Mat, 2020). The Vietnamese hierarchical model involved tight control of multiple groups of Vietnamese poachers by a Vietnamese network manager living in Malaysia. In multiple cases, the poachers were contained inside safe houses until deployment and, in some instances, had their passports withheld by the network manager (Wildlife Justice Commission, 2021). Once inside Malaysia, Vietnamese poachers had limited ability to learn about relative risks across the peninsula or select a target. After committing expenses to arrive, there would be immediate pressure to generate income, increasing risk tolerance. The network manager living in Malaysia would be more likely to be aware of relative risks, but this person's risk tolerance would differ from that of poachers. While a network manager may lose potential earnings from the arrest of a poaching team, interviews suggested the poachers purchased their rations and equipment themselves, meaning very little actual financial loss fell on the network manager. As there was no immediate risk of arrest for the network manager, they may tolerate the poaching team being subject to even higher risks than the team itself would tolerate. Interview work conducted in Quang Binh suggests some awareness of general risks in poaching operations in Malaysia but also considerations that those caught were unlucky (Dan Tri Online, 2021). Therefore, reducing Vietnamese incursion attempts through general deterrence was found to be complex and unlikely.

3.2.4 COVID-19 effect

The abrupt absence of poaching incursions coinciding with the onset of the COVID-19 pandemic suggests national travel restrictions were the most significant moderator of the intervention across all three poaching types. All non-Malaysian poachers apprehended in Kenyir had entered the country legally. Malaysia closed its national borders to foreign tourists and workers for two years, from March 2020 until April 2022. Vietnam, Thailand and Laos also enacted similar border closures, severely limiting international travel options. Peninsular Malaysia enforced interstate travel restrictions by police roadblocks for three months in 2020 and one month in 2021. Non-Malaysian poachers found it challenging to enter the country and move to Kenyir. Concurrently, undocumented migrant workers were targeted by Malaysian Immigration during the pandemic (David, 2020). This may have reduced motivation for embarking on risky poaching incursions. The ability to move wildlife products out of Malaysia and into Vietnam appears to have been disrupted by reduced transport options and enhanced border screening (VOA News, 2020; Wildlife Justice Commission, 2020). Supply bottlenecks may have led to reduced orders and poacher recruitment. Interviews with members of the Vietnamese expatriate community in Malaysia during this time indicated that poaching network managers returned to Vietnam, removing the nucleus controlling Vietnamese poaching operations.

3.3 Implementation & economics of the intervention

Conducting arrests in the deep forest is exceptionally challenging. Three main failure stages were identified during the arrest process following failed arrest attempts in initial years. First, incursions had to be detected while there was still a window of time to conduct an arrest; we used three weeks as a cut-off for 'active incursions'. Second, the poachers' active camp had to be 'fixed' requiring a visual confirmation of the camp location and a DWNP enforcement team had to be guided to the location. Third, an ambush had to occur at the camp. To succeed, this required coordination, planning and clarity on the number of poachers and the camp's layout. Earlier attempts to snatch-arrest poachers moving in the forest had very low success rates due to the ease of escape, while rangers were also at risk from active poachers as each person carried a *parang, or machete*. Counter-poaching operations improved substantially during the study.

Improvements in operations were introduced in 2017. First, a risk map specific to the poaching types was used for tasking patrols (Lam, 2018), improving patrol scheduling to priority areas (Lam et al. In Prep). Incursion alerts doubled and diversified from scout team detections in baseline years, with nearly half of all alerts coming arising community members and camera traps in treatment years (Figure 9). Combined patrol effort of NGO scouts and DWNP rangers measured in active hours inside the forest doubled from baseline to treatment years to over 40,000 hours. This led to the detection of active poaching incursions improving by a factor of three from baseline to treatment years.

Enhanced search operation management and tracking were adopted, drawing from Search and Rescue (SAR) principles and providing guidelines for ranger teams coordinating with base support. Post-arrest interview questions intended to understand poacher decision-making and modus operandi were introduced and used to build search profiles for the three poaching types, improving ranger teams' ability to interpret signs and predict poacher behaviour. The patrol captain's influence was instrumental in maintaining team morale and leading ranger teams during extended and gruelling search operations. These enhancements led to doubling the proportion of active camps 'fixed' from baseline to treatment years.

Due to the risks in conducting arrests, a minimum ranger-to-poacher ratio of 2:1 was considered essential, with 3:1 preferred. Specific improvements included modifying the time of interception, enhanced reconnaissance by the ranger team, and improving raid planning. Once the camp was fixed, successful apprehensions resulted in all cases in treatment years. The odds of a poaching team member being detained shortened from 1 in 32 in baseline years to 3 in 7 during treatment years. The increase in risk was pronounced at an individual level within a poaching team (Figure 9). Once a ranger team fixed the active camp and initiated the apprehension, odds of escape shortened from over 5 to 1 to under 2 to 1.

10.3389/fcosc.2023.1213552

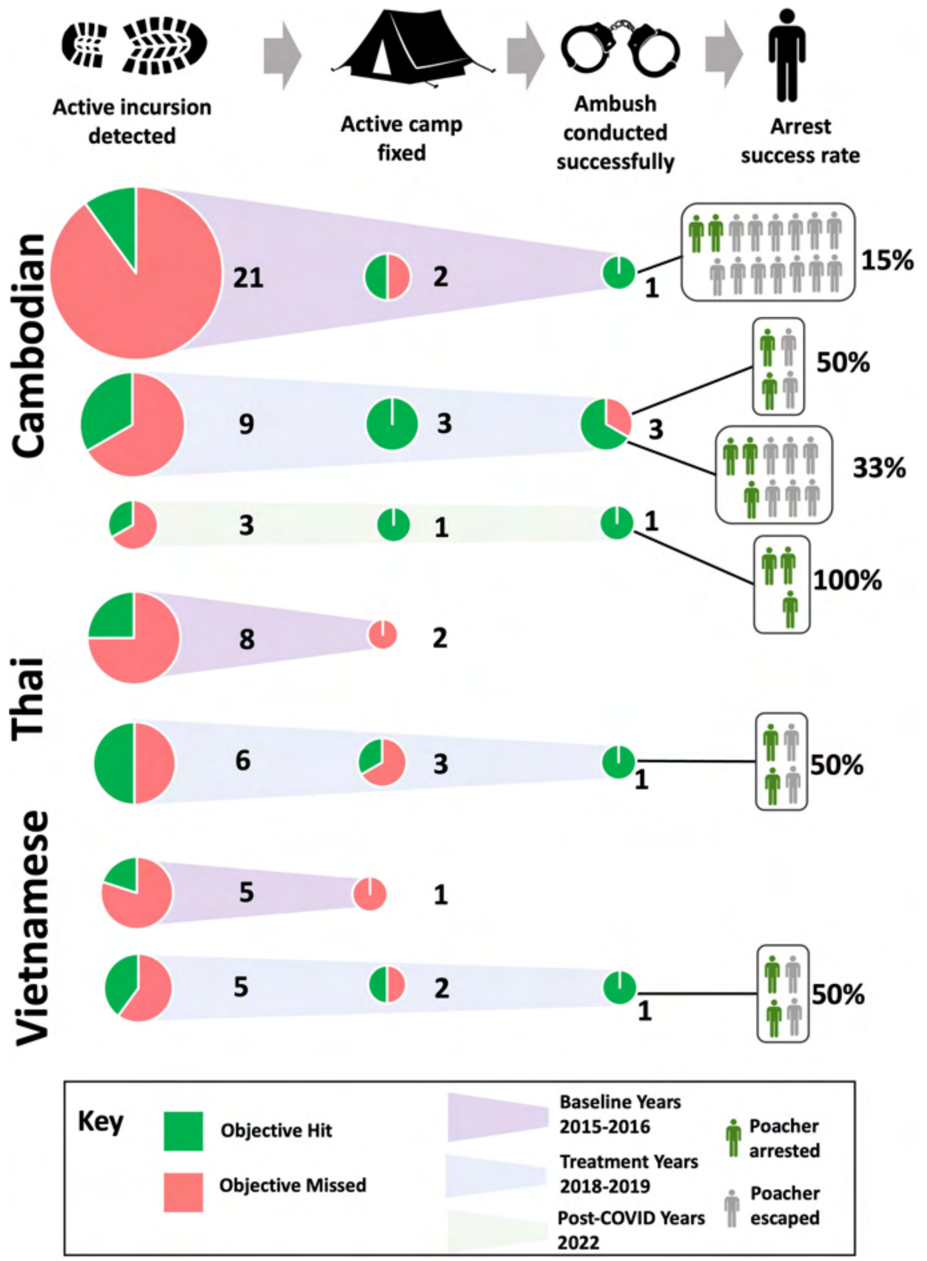

FIGURE 9
Attrition of success, and performance improvements at key stages of deep-forest counter-poaching operations in Kenyir, for each poaching type.

A key source of success was the institutionalisation of an adaptive management cycle designed to learn from failures and adapt tactics and was a key source of success. Each counter-poaching operation was followed by rigorous examination of patrol data, group debriefs and focal interviews with key staff. This process enabled the analyst and patrol captain to pinpoint specific failure points during the operation and identify improvements. Due to hesitance within the ranger team to change habits, a stage of consensus on tactical revisions involved trialling new approaches which were either sustained or rejected. Once there was agreement, updated standard operating procedures would be formalised, and training needs clarified to ensure staff were competent in the revised way of working.

While this intervention shows promise for certain poaching types, it may not be as successful if replicated elsewhere. This was developed to counter poachers spending extended months operating inside a forested landscape and would need modifying for other poaching types. Kenyir has very low footfall from other forest users, making detecting poaching incursion easier. In high-footfall landscapes, incursion analysis and search operations may be more complicated. Due to the hardship in traversing Kenyir carrying heavy packs, poachers follow predictable least-cost paths- ridgelines or riverbanks, which increased the likelihood of an incursion being detected. Detection of incursions is likely to be harder on flat homogenous terrain. Last, Thai, Cambodian and Vietnamese nationals are recognisable as outsiders, attracting interest and may be more likely to be reported on by rural Malaysian community members than local poachers.

Accurate costs were only available for the NGO scout team for the study years and staff salary costs. Scout team size increased from 20 to 21, and annual operating costs rose 2.5% from \$175,000 in baseline to \$180,000 in treatment years. This price rise was due to the changes in team composition with the recruitment of analysts, community engagement staff and a patrol captain, and comprehensive medical insurance for the scout team. Staff regularly patrolling decreased from 20 to 17. Routine patrols were conducted by all-NGO scout teams initially, although 2018-2019, joint NGO/DWNP regular patrols became more common. Logistics and consumables for a typical four-man, five-day patrol cost \$108 for a vehicle deployment or \$453 for a deployment by boat across the lake. At one ranger per 75 km^2, Kenyir falls far short of recommended ranger densities by the IUCN (one ranger per 5 km^2) or Appleton et al. (one ranger per 26 km^2; Appleton et al., 2022). If we followed IUCN recommendations, Kenyir would require 240 patrollers, with an associated annual staff budget of between \$200,000 and \$250,000 compared to the current \$180,000 total annual operating budget.

4 Discussion

This is the first study to use a crime prevention framework to assess the effectiveness of counter-poaching operations on a large mammal in Southeast Asia. Our evaluation indicates the intervention did not succeed in recovering Kenyir's tiger population, but it did enable key individuals to survive and reproduce until COVID-19 travel restrictions made poaching by non-Malaysians extremely difficult. Breaking down the threat of tiger poaching into specific problems allowed us to apply specific tactics tailored to the problems. We were then able to measure incremental performance improvements and track outputs to have confidence in the impact of the intervention. Challenging the assumption of causality gave us a clearer understanding of the processes by which the intervention worked, or not, attribute causality with higher confidence, and know in what contexts it would be likely to produce similar results. Lastly, testing hypotheses of poacher adaptation to our intervention, while examining cascading benefits to non-target species falling under the umbrella of tiger protection provided a more complete understanding of the impact of the intervention. This study offers protected area managers working with challenging poaching problems a template for evaluating patrol-based interventions (Table 4). Despite the data limitations of this study, it illustrates how to

TABLE 4 Summary of EMMIE elements from the intervention in the Kenyir Core Area.

EMMIE element	Details
Effect: Impact on the problem	1. Reduction in potential harm to tigers caused from snares 2. Reduction in incursion attempts by Cambodian agarwood poachers 3. Persistence of key individual tigers and reproduction 4. Stabilisation of non-target carnivores and tapir populations
Mechanism: How it works	1. Harm control by snare removal, and interception before poaching teams could reach sensitive areas. 2. Increased effort and costs of re-offending after arrest. 3. General Deterrence within small communities. 4. Certainty of reduced rewards of offending. 5. Reduced imitation by peers.
Moderators: Where it works	1. Poachers conducting extended incursions. 2. Low footfall landscapes where poachers leave sign. 3. Landscapes with well-defined topographical features and limited access points. 4. Poachers are outsiders, with most forest-edge locals not benefiting from the poaching activity and are easily identified. 5. Poachers come from limited number of small stable communities with knowledge of the wider landscape. 6. Poachers are prevented from returning to the same community after arrest.
Implementation: How to do it	1. Analyst embedded within the ranger team. 2. Strong manager on site 3. Post-operation dissections and rigorous tactical reviews and revisions. 4. Strong coordination among ranger teams. 5. Scenario development and tactical experimentation and refinement. 6. Training, retraining, 7. Good wage and health insurance. 8. Performance incentives 9. Centralised barracks and operations room 10. Strong and experienced patrol team leaders
Economics: How much it costs	\$180,000 annually to maintain a 21 person team including scouts, analysts, community liaison staff, patrol captain and project coordinator and all operational expenses. \$108 for a typical five day/four man patrol by vehicle deployment \$453 for a typical five day/four man patrol by boat deployment

triangulate from different source types to infer indications of how behavioural change mechanisms may work.

4.1 The limits of deterrence

Deterrence is either an explicit or implied intended mechanism for reducing wildlife crime using enforcement. However, vague use of the term weakens protection teams' ability to develop, and adequately evaluate this mechanism. Deterrence theory, as it was initially conceived, involves three elements to work: Punishment is swift, certain and severe (Beccaria, 1986). From the perspective of site protection, deterrence through the criminal justice system requires both speed and certainty of arrest combined with speed, certainty and severity of the sentence. Research indicates that the most important of these three factors in deterring crime is the certainty of arrest and punishment (Wilson and Boratto, 2020), which is most often chronically lacking in protected areas. However, if the certainty of being arrested is high, but the population of potential poachers is unaware, they cannot be deterred (Paudel et al., 2018). Even when there is broad awareness of true risk, potential poachers must be capable of rational decision-making and weigh the relative likelihood of risks and rewards to make an informed judgment (Clarke and Felson, 1993). Where potential rewards are extremely high, offenders may tolerate a high level of risk (Epper et al., 2022), judgement is impaired by alcohol, learning disabilities or acute need (Walters, 2015). The perception of those that were caught as being the ones who 'just got unlucky' or 'didn't know what they were doing' can be an essential factor in inhibiting offender decision-making away from continuing with the activity, particularly when contrasted with the highly visible success stories of the lucky few who made it. The support for deterrence of Cambodian poachers found here is caveated by the fact that this appears highly localised to specific communities, but also that non-deterrent mechanisms reducing poaching opportunity structures may have been involved in the decline.

4.2 Patroller quality over quantity

The causal relationship between enforcement officer numbers and decline of crime incidents is context specific and nuanced. In Nepal, Chitwan's success in recovering its rhino population following intensive counter-poaching work and heavy sentencing for wildlife crime is often used as a model for others to follow (Mahatara et al., 2018), leading to calls from NGOs to increase 'boots on the ground'. However, interviews with poachers in Chitwan suggested the general deterrence effect is overestimated (Paudel et al., 2018). Evidence is mixed that increasing police officer numbers cause crime to decline (Bradford, 2011), while increased officer numbers do not always increase perceptions of risk of arrest among offenders (Kleck and Barnes, 2014), or presence of armed guards deter rhino poachers in South Africa (Barichievy et al., 2017).

In other landscapes, large ranger teams formed from indigenous and local community members can provide an essential source of local employment. In such instances, general deterrence may be a less important mechanism of poaching reduction than occupying potential poachers' time with patrol work or providing an alternative income source to poaching. Understanding this is important for tailoring interventions to be more effective. Yet, the mechanism by which an intervention achieved a decline in the problem is rarely critically examined in publications (Delpech et al., 2021).

Rangers perform various essential roles preventing wildlife crime, aside from counter-poaching operations (Stolton et al., 2023). Simple and attractive policy goals such as an optimum patroller density can become counterproductive when the supporting infrastructure of management, analysis, training and equipment are secondarily and insufficiently factored into budget planning. Larger protection teams bring added complexity in management and resourcing. The hardship and risks associated with patrolling necessitate a high degree of training and support from strong management and incentives, which is often lacking (Belecky et al., 2021). Failure to provide sufficient wages, a strong professional approach and tight management oversight risks ranger effectiveness declining and rangers becoming vulnerable to corruption solicitations, a problem many protected areas face (Felbab-Brown, 2017). Elevated ranger numbers in guard posts can create blind spots of assumed deterrence while facilitating localised poaching (Jenks et al., 2012). For example, between 2009 and 2021, 42 staff from Kruger National Park in South Africa were dismissed for alleged involvement in rhino poaching (Keir, 2021), with up to 40% of staff estimated to be involved in corruption (Rademeyer, 2023). With limited budgets, heavy focus on enforcement-based interventions can draw resources away from community-based crime prevention measures (Cooney et al., 2017; Duffy et al., 2019).

Investment in limited resources was prioritised here over employing larger numbers. In Kenyir, scout numbers decreased slightly from the baseline to treatment years, but an increase in analysts compensated for this. The strong problem focus taken by the team, backed up by stronger analysis guiding patrols, led to a clearer mission and better scout team deployment, which increased the frequency of incursion alerts from patrol teams. The innovation of the federally deployable SPARTA unit proved highly effective. Based in Kuala Lumpur, with members in different states, the team could deploy to any forest patch in 24 hours to support a counter-poaching operation. This made maximal use of limited workforce. The close working relationship between experienced SPARTA officers and Panthera staff led to the formalisation of deep-forest counter poaching operations doctrine in a training guide and structured scenario-based course. A further key development was the tracking skills of teams.

In four key tiger landscapes in the Peninsular, NGOs provide civilian scout teams. These employ a large number of staff to augment government rangers, mostly from indigenous Orang Asli ethnic groups. The traditional field skills of veteran Orang Asli were recognised in 2019 when DWNP created the "VetOA" regiment. Orang Asli are a marginalised people within Malaysia and have suffered extensive land dispossession, including from Kenyir when the hydroelectric lake was created in 1985. In Kenyir, over half of the scout team comprised Orang Asli patrollers. Traditional skills were developed and enhanced with modern search and rescue techniques and combat tracking techniques. Under this process, senior patrollers were provided additional training and mentoring in instruction techniques to lead internal refresher trainings and run trainings for other teams. Early recognition of the value and adoption of traditional indigenous skills was instrumental in developing the team.

While more eyes and ears increase the likelihood of detecting a poaching incursion, these do not need to be salaried rangers. Indigenous people and local communities have a substantial role to play as front-line protectors of forests and wildlife (Roe et al., 2017), ranging from sharing alerts of a poaching incursion (Risdianto et al., 2016), to collaborating on joint community initiatives to reduce incentives for poaching (Jones et al., 2020), to forming organised community teams to patrol and protect the natural resource (Kragt et al., 2020). A major aspect of the Chitwan model was also the increased informal guardianship among the bordering communities, with a willingness to provide alerts due to benefits accruing in the communities from the rise in tourism (Mahatara et al., 2018). In Kenyir, the poaching problem conducted by non-locals operating far from their community of origin constrained our ability to directly engage with those poaching communities. However, relationships with forest-edge locals through recent cattle-predation reduction has led to increased poaching incursion alerts being shared. Engaging communities as partners to prevent poaching can offer a more cost-effective way of dealing with the problem than expanding an enforcement team. However, this requires analysis of the conditions for informal guardianship in the communities to find approaches that work alongside traditional practices and cultural beliefs (Viollaz et al., 2022).

4.3 Analysts and decentralised learning

The early investment in analysts based at sites trained in skills in wildlife crime problem analysis was a second crucial factor. Analysts have become more common in policing yet remain rare in wildlife protection. As the analysts in the Kenyir team consolidated a deeper understanding of decision-making and the modus operandi of the focal poaching types, this drove substantial improvements in the deployment of routine patrols to detect incursions, the speed of a search operation to locate the camp, and the tactics used to improve arrest effectiveness. However, not all teams have succeeded with analysts in policing or wildlife protection. Cultural constraints and budget cuts were identified as reasons for preventing analysts from being incorporated into the heart of policing, exacerbated by managers inadequately tasking analysts or being perceived as academic outsiders (Belur and Johnson, 2018). Key ingredients of success in Kenyir involved the analysts being well embedded in the protection team, able to go on patrols, engage in debriefs and encourage patrol members to challenge their interpretations. This helped legitimise their presence in the group and increased the likelihood that their recommendations would be adopted. This was driven and facilitated by a project manager with prior experience working as an analyst and a deep understanding of what was needed from the analyst to inform decision-making. Adopting a productive and self-critical culture within the team was significant, with failures being interrogated in an environment that encouraged participation and the identification of solutions. The post-operation dissection reports became a vital reference library on which to base tactical and procedural changes, with testing and consensus gained from the team before formalisation, training and implementation. This was essential for engaging the team in identifying and backing solutions to failures in operations. Rather than passively accepting orders, rangers were encouraged to voice opinions and be part of a refinement process. Despite their deep understanding of threats, the terrain, and their capabilities, rangers rarely engage in this way (Moreto and Charlton, 2019).

Within conservation, adaptive management has been promoted by which managers adaptively make and implement resource and tactical decisions based on an updated understanding of the state of the environment to achieve conservation goals. However, within the conservation literature, this more commonly focuses on regional or national policy settings, with relatively few examples of how the process should work at the level of a protected area (Lee, 1999). Furthermore, tight centralisation of performance and threat metrics and implementation of national-level tactics can impede the ability to solve complex problems at the local scale (Game et al., 2014). By contrast, empowering local teams and leaders to be creative in how they innovate ways to reduce priority problems within a knowledge-producing environment can be more productive (Moffat, 2002; Uhl-Bien et al., 2007).

4.4 Conclusion

This project aimed to increase the tiger population by 50% in ten years. By 2024, ten years after beginning the project, with a near-stable density and improved persistence of tigers, we are not yet on track to achieve this. The tiger population of Kenyir, as in other landscapes in Malaysia, has suffered an onslaught of poaching, leading to tigers falling below a national estimate of 200. Recovery becomes significantly more complicated once a species is extirpated from a landscape (Harihar et al., 2018; Miquelle et al., 2018), so a focus on counter-poaching operations was driven by the urgency of preventing extirpation of Kenyir's remaining tigers. The COVID pandemic gave us breathing room and the ability to review tiger protection investments, including this evaluation. This study illustrates the benefits and limitations of site protection in reducing a wildlife crime problem and a template for a more rigorous evaluation of counter-poaching investments. While we have compelling evidence that the investment reduced threats to tigers, and delivered diffusion of benefits to other felids and non-target species, we assess the intervention is unlikely to have been responsible for declines in incursion attempts by Thai or Vietnamese poachers. The increased understanding of offender decision-making from post-arrest interviews has highlighted options to prevent poachers from beginning the process of preparing to embark on an incursion at the level of their community of origin. These need to be explored further, particularly where wildlife trafficking overlaps with worker exploitation and human trafficking.

Data availability statement

The datasets presented in this article are not readily available because: data sharing will take place selectively on a case by case basis following agreement with partner data owners from PERHILITAN involved in this study and following careful review of the request. Requests to access the datasets should be directed to RPICKLES@PANTHERA.ORG.

Ethics statement

Ethical review and approval was not required for the animal study in accordance with the local legislation and institutional requirements because this study did not involve any invasive approaches. Data collection involved passive camera trap surveys. The research was conducted under permit by the Government of Malaysia.

Author contributions

LWY was responsible for leading the strategy, developing and institutionalising the problem analysis and evaluation presented. CCP and CPS played key roles both in analysing and interpreting the poaching and enforcement data presented. ZAM, HJ and AS were instrumental in developing the tactics, all three provided expert opinion and context to the findings to interpret poacher decision making. FAZA was responsible for analysing PERHILITAN's data. MKYC led the analysis and interpretation of the wildlife data. NAWO, SS and AKAH were responsible for overseeing PERHILITAN's tiger protection operations in Kenyir. They reviewed and provided expert opinion to the study. MDB led tactical trainings and was integral to the tactical refinement and Kenyir strategy formation. He provided expert opinion in the study. AH provided technical support to the project, shaping the strategy, and was integral to the development and refinement of the evaluation approach and writing up of the study. GRC initiated the Kenyir project and was integral to the development and refinement of the strategy, ideas discussed in the manuscript, reviewing and refining the study. RSAP provided technical and analytic support to the project, providing support in the writing and application of crime prevention frameworks in this study. All authors contributed to the article and approved the submitted version.

Acknowledgments

We are grateful to Dr. Andrew Lemieux for advice during the evaluation and to Dr. Sheema Abdul Aziz for providing useful comments to improve the manuscript. Thanks to Guido Giordano for assistance with the evaluation. Thanks to the cartographical support of Kevin McManigal, Nathaniel Robinson, Martin Viereckl, Craig Threlkeld, and Wayne Bazo. We wish to thank the Terengganu State Government for the trust and collaboration in this project. This work was funded by generous grants from Woodland Park Zoo, The Robertson Foundation, US Fish and Wildlife Service (F18AP00858), Rainforest Trust, United States Department of State Bureau of International Narcotics and Law Enforcement Affairs (SINLEC22GR0449) and the Government of Malaysia. The opinions, findings and conclusions stated herein are those of the authors and do not necessarily reflect those of the United States Department of State. We dedicate this to the rangers who tirelessly protect Kenyir's forests and wildlife and in particular, to Ahmad "Tulang" bin Amok, who tragically fell victim to a venomous pit viper bite while on duty.

Conflict of interest

Authors MB and AH were employed by the company Panthera Corporation. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2023.1213552/full#supplementary-material

References

Appleton, M. R., Courtiol, A., Emerton, L., Slade, J. L., Tilker, A., Warr, L. C., et al. (2022). Protected area personnel and ranger numbers are insufficient to deliver global expectations. *Nat. Sustain.* 5 (12), 1100–1110 doi: 10.1038/s41893-022-00970-0

Ashton, J., Brown, I., Senior, B., and Pease, K. (1998). Repeat victimisation: Offenders accounts. *Int. J. Risk Secur. Crime Prev.* 3, 269–279. Available at: https://repository.lboro.ac.uk/articles/journal_contribution/Repeat_victimisation_offenders_accounts/9580550.

Barichievy, C., Masterson, G., Munro, L., and Whittington-jones, B. (2017). Do armed field-rangers deter rhino poachers? An empirical analysis. *Biol. Conserv.* 209, 554–560. doi: 10.1016/j.biocon.2017.03.017

Beccaria, C. (1986). *On Crimes and Punishment* (Indianapolis, IN: Hackett Publishing Co). (Original work published 1764).

Belecky, M., Wide, W., Wwf, N., and Belecky, M. (2021). Employment conditions of public sector rangers : A major under-addressed problem. *Park Stewardship Forum* 37, 185–196. doi: 10.5070/P537151749

Belur, J., and Johnson, S. (2018). Is crime analysis at the heart of policing practice? A case study. *Policing Soc.* 28, 768–786. doi: 10.1080/10439463.2016.1262364

Bivand, R., Keitt, T., Rowlingson, B., Pebesma, E., Sumner, M., Hijmans, R., et al. (2015) *Package 'rgdal.' Bindings for the Geospatial Data Abstraction Library.* Available at: https://cran.r-project.org/web/packages/rgdal/index.html (Accessed 15 October 2017).

Bradford, B. (2011). Police numbers and crime rates – a rapid evidence review. *Her Majesty's Inspectorate Constabulary* 1–10. Available at: https://www.justiceinspectorates.gov.uk/hmicfrs/media/police-numbers-and-crime-rates-rapid-evidence-review-20110721.pdf.

Chandler, R. B., and Andrew Royle, J. (2013). Spatially explicit models for inference about density in unmarked or partially marked populations. *Ann. Appl. Stat* 7, 936–954. doi: 10.1214/12-AOAS610

Clarke, R. V., and Felson, M. (1993). *Routine Activity and Rational Choice.* (London and New York: Routledge).

Clements, R., Rayan, D. M., Zafir, A. W. A., Venkataraman, A., Alfred, R., Payne, J., et al. (2010). Trio under threat: Can we secure the future of rhinos, elephants and tigers in Malaysia? *Biodivers Conserv.* 19, 1115–1136. doi: 10.1007/s10531-009-9775-3

Cooney, R., Roe, D., Dublin, H., Phelps, J., Wilkie, D., Keane, A., et al. (2017). From poachers to protectors: engaging local communities in solutions to illegal wildlife trade. *Conserv. Lett.* 10, 367–374. doi: 10.1111/conl.12294

Dan Tri Online (2021) *The old farmers bet their lives, sucking on the bass: The rice bowl is near the blood bowl !.* Available at: https://dantri.com.vn/lao-dong-viec-lam/nhung-lao-nong-cuoc-mang-ngam-ngai-tim-tram-bat-com-o-gan-bat-mau-20211222082926200.htm.

David, A. (2020). Over 2,000 Vietnamese stranded in Malaysia set to return home. *New Straits Times*, 3–4. Available at: https://www.nst.com.my/news/nation/2020/07/605580/over-2000-vietnamese-stranded-malaysia-set-return-home#:~:text=KUALA%20LUMPUR%3A%20Over%202%2C000%20Vietnamese,work%20permits%20and%20their%20families.

Delpech, D., Borrion, H., and Johnson, S. (2021). Systematic review of situational prevention methods for crime against species. *Crime Sci.* 10, 1–21. doi: 10.1186/s40163-020-00138-1

Department of Wildlife and National Parks Peninsular Malaysia (2008). *National Tiger Conservation Acton Plan 2008-2020.* (Kuala Lumpur, Malaysia: Government of Malaysia).

Duffy, R., Massé, F., Smidt, E., Marijnen, E., Büscher, B., Verweijen, J., et al. (2019). Why we must question the militarisation of conservation. *Biol. Conserv.* 232, 66–73. doi: 10.1016/j.biocon.2019.01.013

Duijn, P. A. C., Kashirin, V., and Sloot, P. M. A. (2014). The relative ineffectiveness of criminal network disruption. *Sci. Rep.* 4 (1), 4238. doi: 10.1038/srep04238

Eck, J. E. (1993). The threat of crime displacement. *Criminal Justice Abstracts* 25, 527–546. Available at: https://pdfs.semanticscholar.org/e8a8/e0c789356f1c4b1665149e0676e060e07484.pdf.

Eck, J. E. (2017). Assessing responses to problems: did it work? An introduction for police problem-solvers. *Center Problem-Oriented Policing.* Available at: https://popcenter.asu.edu/sites/default/files/assessing_responses_to_problems_final.pdf.

Efford, M. G. (2018). secr: Spatially explicit capture-recapture models. Available at: https://cran.r-project.org/package=secr.

Epper, T., Fehr, E., Hvidberg, K. B., Kreiner, C. T., Leth-Petersen, S., and Rasmussen, G. N. (2022). Preferences predict who commits crime among young men. *Proc. Natl. Acad. Sci. U.S.A.* 119, 1–7. doi: 10.1073/pnas.2112645119

Felbab-Brown, V. (2017). *The Extinction Market* (London: C. Hurst & Co).

Game, E. T., Meijaard, E., Sheil, D., and Mcdonald-Madden, E. (2014). Conservation in a wicked complex world; challenges and solutions. *Conserv. Lett.* 7, 271–277. doi: 10.1111/conl.12050

Ghoting, A., Kambadur, P., Pednault, E., and Kannan, R. (2011). "NIMBLE: a toolkit for the implementation of parallel data mining and machine learning algorithms on mapreduce," in *Proceedings of the 17th ACM SIGKDD international conference on Knowledge discovery and data mining.* (San Diego, CA), 334–342.

Goodrich, J., Smith, J., and Rabinowitz, A. (2013). The tigers forever protocol: A roadmap for tiger conservation success. (New York: Panthera). doi: 10.13140/RG.2.2.19408.30722

Goodrich, J., Wibisono, H. T., Miquelle, D., Society, W. C., Lynam, A. J.Society, W. C (2022). Panthera tigris. *The IUCN red list of threatened species 2022: E.* T15955A214862019. doi: 10.2305/IUCN.UK.2022-1.RLTS.T15955A214862019.en

Gray, T. N. E., Lynam, A. J., Seng, T., Laurance, W. F., Long, B., Scotson, L., et al. (2017). Wildlife-snaring crisis in Asian forests. *Sci. (1979)* 355, 255–256. doi: 10.1126/science.aal4463

Guerette, R. T., and Bowers, K. J. (2009). Assessing the extent of crime displacement and diffusion of benefits: A review of situational crime prevention evaluations. *Criminology* 47, 1331–1368. doi: 10.1111/j.1745-9125.2009.00177.x

Harihar, A., Ghosh-Harihar, M., and Macmillan, D. C. (2018). Losing time for the tiger Panthera tigris: Delayed action puts a globally threatened species at risk of local extinction. *Oryx* 52, 78–88. doi: 10.1017/S0030605317001156

Hedges, L., Lam, W. Y., Campos-Arceiz, A., Rayan, D. M., Laurance, W. F., Latham, C. J., et al. (2015). Melanistic leopards reveal their spots: Infrared camera traps provide a population density estimate of leopards in Malaysia. *J. Wildlife Manage.* 79, 846–853. doi: 10.1002/jwmg.901

Jenks, K. E., Howard, J., and Leimgruber, P. (2012). Do ranger stations deter poaching activity in national parks in Thailand? *Biotropica* 44, 826–833. doi: 10.1111/j.1744-7429.2012.00869.x

Johnson, A., Goodrich, J., Hansel, T., Rasphone, A., Saypanya, S., Vongkhamheng, C., et al. (2016). To protect or neglect? Design, monitoring, and evaluation of a law enforcement strategy to recover small populations of wild tigers and their prey. *Biol. Conserv.* 202, 99–109. doi: 10.1016/j.biocon.2016.08.018

Johnson, S. D., Tilley, N., and Bowers, K. J. (2015). Introducing EMMIE: an evidence rating scale to encourage mixed-method crime prevention synthesis reviews. *J. Exp. Criminol* 11, 459–473. doi: 10.1007/s11292-015-9238-7

Jones, I. J., Macdonald, A. J., Hopkins, S. R., Lund, A. J., and Liu, Z. Y. (2020). Improving rural health care reduces illegal logging and conserves carbon in a tropical forest. *Proc. Natl. Acad. Sci. U.S.A.* 117 (45), 28515–28524 doi: 10.1073/pnas.2009240117

Keir, T. (2021). "How rhino protectors in South Africa have become a major threat to the species," in *Natl Geogr Mag.* (Washington D.C.). Available at: https://www.nationalgeographic.com/animals/article/how-rhino-protectors-in-south-africa-became-threat-to-species.

Kleck, G., and Barnes, J. C. C. (2014). Do more police lead to more crime deterrence? *Crime Delinq* 60, 716–738. doi: 10.1177/0011128710382263

Kragt, M. E., Hay, E., Scheufele, G., Bennett, J., and Renton, M. (2020). Predicting the effectiveness of community anti-poaching patrols for conserving threatened wildlife in the Lao PDR. *J. Appl. Ecol.* 57, 320–330. doi: 10.1111/1365-2664.13527

Kurland, J., Pires, S. F., McFann, S. C., and Moreto, W. D. (2017). Wildlife crime: A conceptual integration, literature review, and methodological critique. *Crime Sci.* 6 (1), 1–15. doi: 10.1186/s40163-017-0066-0

Lam, W. Y. (2018). Where and when are poachers most active in Kenyir's forests? Using crime science and wildlife research techniques to detect spatiotemporal patterns of activities associated with poaching.

Lam, W. Y., and Mat, Z. A. (2020). "Large carnivore poaching using steel wire snares by Vietnamese poaching groups in tropical forests of Peninsular Malaysia," in *The Poaching Diaries (vol. 1): Crime Scripting for Wilderness Problems* (Phoenix, AZ: Center for Problem-Oriented Policing).

Lee, K. (1999). Appraising adaptive management- ecology and society. *Ecol. Soc.* 3, 1–16. Available at: https://www.ecologyandsociety.org/vol3/iss2/art3/inline.html. Meredith, M. (2020). wiqid: Quick and Dirty Estimates for Wildlife Populations. Available at: https://cran.r-project.org/web/packages/wiqid/index.html.

Lemieux, A. M., and Pickles, R. S. A. (2020). *Problem-Oriented Wildlife Protection.* (Phoenix, AZ: Center for Problem Oriented Policing, Arizona State University).

Linkie, M., Martyr, D. J., Harihar, A., Risdianto, D., Nugraha, R. T., Maryati, M., et al. (2015). Safeguarding Sumatran tigers: Evaluating effectiveness of law enforcement patrols and local informant networks. *J. Appl. Ecol.* 52 (4), 851–860 doi: 10.1111/1365-2664.12461

Macdonald, D. W., Bothwell, H. M., Kaszta, Ż., Ash, E., Bolongon, G., Burnham, D., et al. (2019). Multi-scale habitat modelling identifies spatial conservation priorities for mainland clouded leopards (Neofelis nebulosa). *Divers. Distrib* 25, 1639–1654. doi: 10.1111/ddi.12967

Macdonald, D. W., Chiaverini, L., Bothwell, H. M., Kaszta, Ż., Ash, E., Bolongon, G., et al. (2020). Predicting biodiversity richness in rapidly changing landscapes: climate, low human pressure or protection as salvation? *Biodivers Conserv.* 29, 4035–4057. doi: 10.1007/s10531-020-02062-x

Mahatara, D., Rayamajhi, S., and Khanal, G. (2018). Impact of anti-poaching approaches for the success of Rhino conservation in Chitwan National Park, Nepal. *Banko Janakari* 28, 23–31. doi: 10.3126/banko.v28i2.24185

Meredith, M. (2020). wiqid: quick and dirty estimates for wildlife populations. *R Package version* 0.3, 0.

Miquelle, D. G., Poole, C. M., Mahood, S. P., Travers, H., Linkie, M., Goodrich, J., et al. (2018). Comments on "a framework for assessing readiness for tiger reintroductions". *Biodivers Conserv.* 27, 3287–3293. doi: 10.1007/s10531-018-1591-1

Moeller, A. K., and Lukacs, P. M. (2021). spaceNtime: an R package for estimating abundance of unmarked animals using camera-trap photographs. *Mamm. Biol.* 102, 581–590. doi: 10.1007/s42991-021-00181-8

Moeller, A. K., Lukacs, P. M., and Horne, J. S. (2018). Three novel methods to estimate abundance of unmarked animals using remote cameras. *Ecosphere* 9 (8), e02331. doi: 10.1002/ecs2.2331

Moffat, J. (2002). *Command and control in the information age: representing its impact* (New York: RenoufPublishingCompany Limited).

Moreto, W. D., and Charlton, R. (2019). Rangers can't be with every elephant: Assessing rangers' perceptions of a community, problem-solving policing model for protected areas. *Oryx* 55 (1), 89–98. doi: 10.1017/S0030605318001461

Nagin, D. S. (2013). Deterrence in the twenty-first century. *Crime Justice* 42, 199–263. doi: 10.1086/670398

O'Kelly, H. J., Evans, T. D., Stokes, E. J., Clements, T. J., Dara, A., Gately, M., et al. (2012). Identifying conservation successes, failures and future opportunities; assessing recovery potential of wild ungulates and tigers in eastern Cambodia. *PloS One* 7, 1–10. doi: 10.1371/journal.pone.0040482

Oliff, E., CW, C., Bruen, D., Yarmchuk, E., Pickles, R., and Hunter, L. (2014). The Pantheracam- a camera-trap optimized for monitoring wild felids. *Wild Felid Monitor* 7, 21–23. Available at: https://www.researchgate.net/publication/280319491_The_Panthercam_-_a_camera-trap_optimized_for_monitoring_wild_felids.

Paudel, K., Potter, G. R., and Phelps, J. (2018). Conservation enforcement: Insights from people incarcerated for wildlife crimes in Nepal. *Conserv. Sci. Pract.* 53, 1689–1699. doi: 10.1017/CBO9781107415324.004

Pebesma, E. (2018). Simple features for R: standardized support for spatial vector data. *R J.* 10, 439–446. doi: 10.32614/RJ-2018-009

Rademeyer, J. (2023). Landscape of Fear. Crime, corruption and murder in greater Kruger. Available at: https://enactafrica.org/research/research-papers/landscape-of-fear-crime-corruption-and-murder-in-greater-kruger.

R Core Team (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. (Vienna).

Risdianto, D., Martyr, D. J., Nugraha, R. T., Harihar, A., and Wibisono, H. T. (2016). Examining the shifting patterns of poaching from a long-term law enforcement intervention in Sumatra. *Biol. Conserv.* 204, 306–312 doi: 10.1016/j.biocon.2016.10.029

Roe, D., Cooney, R., Dublin, H., Challender, D., Biggs, D., Skinner, D., et al. (2017). First line of defence: Engaging communities in tackling wildlife crime. *Unasylva* 68, 33–38. Available at: https://www.fao.org/3/i6855en/I6855EN.pdf.

Rostro-García, S., Kamler, J. F., Ash, E., Clements, G. R., Gibson, L., Lynam, A. J., et al. (2016). Endangered leopards: Range collapse of the Indochinese leopard (Panthera pardus delacouri) in Southeast Asia. *Biol. Conserv.* 201, 293–300. doi: 10.1016/j.biocon.2016.07.001

RStudio Team (2020). *RStudio: Integrated Development for R. RStudio*. PBC. (Boston, MA). Available at: http://www.rstudio.com/.

Sanderson, E., Forrest, J., Loucks, C., Ginsberg, J., Dinerstein, E., Seidensticker, J., et al. (2006). *Setting Priorities for the Conservation and Recovery of Wild Tigers: 2005-2015 - The Technical Assessment* (New York - Washington, DC: WCS, WWF, Smithsonian, and NFWF-STF).

Stewart, A., Cornman, A., Johnson, A., Baker, A., Northrup, B., Stem, C., et al. (2020). Open standards for the practice of conservation. *Conserv. Measures Partnership*. Version 4.0. Available at: https://conservationstandards.org/wp-content/uploads/sites/3/2020/12/CMP-Open-Standards-for-the-Practice-of-Conservation-v4.0-English.pdf.

Stolton, S., Galliers, C., Timmins, H. L., Jackson, W., Dudley, N., Kettunen, M., et al. (2023). Essential planetary health workers: Positioning rangers within global policy. *Conserv. Lett.* e12955. doi: 10.1111/conl.12955

Ten, D. C. Y., Jani, R., Hashim, N. H., Saaban, S., Hashim, A. K. A., and Abdullah, M. T. (2021). Panthera tigris jacksoni population crash and impending extinction due to environmental perturbation and human-wildlife conflict. *Animals* 11 (4), 1032. doi: 10.3390/ani11041032

Thomas-Walters, L., McCallum, J., Montgomery, R., Petros, C., Wan, A. K. Y., and Veríssimo, D. (2022). Systematic review of conservation interventions to promote voluntary behavior change. *Conserv. Biol.* 37 (1), e14000. doi: 10.1111/cobi.14000

Uhl-Bien, M., Marion, R., and McKelvey, B. (2007). Complexity Leadership Theory: Shifting leadership from the industrial age to the knowledge era. *Leadership Q.* 18, 298–318. doi: 10.1016/j.leaqua.2007.04.002

Viollaz, J., Rizzolo, J. B., Long, B., Trung, C. T., Kempinski, J., Rawson, B. M., et al. (2022). Potential for informal guardianship in community-based wildlife crime prevention: Insights from Vietnam. *Nat. Conserv.* 48, 123–147. doi: 10.3897/natureconservation.48.81635

VOA News (2020). *Vietnam Wildlife Trafficking Arrests Rise, After COVID-19 Link to Animals* (VOA News). (United States of America). Available at: https://sentientmedia.org/in-China-traditional-remedies-for-covid-19-are-fueling-the-wildlife-trade/.

Walston, J., Robinson, J. G., Bennett, E. L., Breitenmoser, U., da Fonseca, G. A. B., Goodrich, J., et al. (2010). Bringing the tiger back from the brink-the six percent solution. *PloS Biol.* 8, 6–9. doi: 10.1371/journal.pbio.1000485

Walters, G. D. (2015). The decision to commit crime: Rational or nonrational? *Criminol Criminal Justice Law Soc.* 16, 1–18. doi: 10.21202/1993-047x.10.2016.3.252-270

Weisel, D. L. (2005). *Analyzing repeat victimization*. Center for Problem Oriented Policing. Phoenix, AZ.

Wickham, H. (2016) *ggplot2: Elegant Graphics for Data Analysis*. Available at: https://ggplot2.tidyverse.org.

Wildlife Justice Commission (2020). *Rapid Assessment of the Illegal Ivory Trade in 2020.* (Wildlife Justice Commission).

Wildlife Justice Commission (2021). *Convergence of wildlife crime with other forms of organised crime*. (Wildlife Justice Commission).

Wilson, L., and Boratto, R. (2020). Conservation, wildlife crime, and tough-on-crime policies : Lessons from the criminological literature. *Biol. Conserv.* 251, 108810. doi: 10.1016/j.biocon.2020.108810