Biological Conservation 202 (2016) 99–109

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/bioc

To protect or neglect? Design, monitoring, and evaluation of a law enforcement strategy to recover small populations of wild tigers and their prey

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ARTICLE INFO

Article history:
Received 7 November 2015
Received in revised form 6 June 2016
Accepted 17 August 2016
Available online xxxx

Keywords:
Tiger
Anti-poaching
Law enforcement monitoring and evaluation
Adaptive management
Laos
MIST

ABSTRACT

Many remaining wild tiger populations persist in small numbers at sites where densities are less than half of their estimated carrying capacity and will continue to decline if not protected from poaching. Although law enforcement is frequently used to protect tigers and their prey, the conditions under which enforcement is likely to be effective in recovering small populations of wild tigers are not well understood. We evaluated the effectiveness of a law enforcement strategy to recover tigers and their prey in Lao PDR where extensive habitat provided favorable conditions for large increases in tiger numbers if protected from poaching. Over a seven-year period, we monitored along a theory of change to evaluate assumptions about the causal linkages between intermediate results and biological outcomes. Although we found a strong positive correlation between funding for enforcement and days patrolled (rs $= 0.786$, $n = 7$, $p = 0.05$) and a significant negative correlation between days patrolled and overall hunting catch per unit effort (rs $= -0.893$,$n = 7$, $p < 0.05$), ultimately a proliferation in snaring was associated with decline in several indices of tiger abundance. We conclude that actions were sufficient to reduce poaching and increase prey populations, but insufficient to curtail extirpation of tigers. Recovering small populations of high-value wildlife such as tigers in promising source sites is dependent on establishing a complete enforcement regime, complimentary strategies that build support for the enforcement regime, and a nimble monitoring and evaluation system for agile adaptive management.

1. Introduction

Many remaining wild tiger populations persist in small numbers at sites where densities are less than half of their estimated carrying capacity (Walston et al., 2010b). These populations are threatened by poaching for illegal trade in tiger parts or as the result of human-tiger conflict (Karanth et al., 2011). In most cases, tiger prey populations at these sites are also declining due to over-hunting (O'Kelly et al., 2012, Vongkhamheng et al., 2013). To reverse tiger decline, conservationists are urged to vigorously protect remaining "source sites", defined as areas with the potential to maintain at least 25 breeding females that can in time repopulate the larger landscapes in which they are embedded (Walston et al., 2010b, Karanth et al., 2011). Studies of tiger population dynamics indicate that high recruitment rates are possible with adequate prey and protection (Karanth et al., 2006). To better protect tigers and prey, wildlife law enforcement is a commonly applied conservation strategy (Lynam, 2010, Stokes, 2010, O'Kelly et al., 2012, Goodrich et al., 2013, Hötte et al., 2015). In contrast to larger tiger populations that may be able to withstand up to 20% annual losses (Karanth et al., 2006), recovery of small tiger populations requires conservation strategies that are initially able to nearly eliminate poaching.

The 5950 km^2 Nam Et-Phou Louey (NEPL) National Protected Area (NPA) in northern Lao PDR (People's Democratic Republic; hereafter Laos) provides an illustrative example of the opportunities and challenges of achieving the necessary conditions to protect and recover small but promising tiger source sites. Among the six remaining tiger

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http://dx.doi.org/10.1016/j.biocon.2016.08.018

subspecies, the Indochinese tiger (*Panthera tigris corbetti*) is considered one of the most vulnerable to extinction due to increasing threats of poaching, prey depletion and habitat loss (Lynam, 2010, Goodrich et al., 2015). NEPL was identified as the only potential tiger source site remaining in Indochina (Laos, Vietnam, Cambodia, Walston et al., 2010a, O'Kelly et al., 2012), and was considered an “irreplaceable site” for maintaining tigers in Indochina (Lynam, 2010) and a Class 1 Tiger Conservation Landscape with sufficient habitat for a small tiger population to expand if successfully protected (Wikramanayake et al., 2010). A 2004 baseline survey confirmed that tigers persisted at low density (<-1 individual/100 km^2) in NEPL, but were suppressed by commercial poaching and overhunting of prey (Johnson et al., 2006). If these threats could be reduced, several features of the landscape provided optimism for rebuilding tiger and prey populations. These included: 1) the lowest human population density in Southeast Asia (Sodhi et al., 2010), with space for tigers and people to coexist; 2) an estimated ungulate density of 5.29 (SE 0.30) individuals/km^2, sufficient to support an estimated 25–30 tigers (Karanth et al., 2010, Vongkhamheng et al., 2013); and 3) evidence of tiger reproduction confirmed through DNA analysis of tiger scat (Vongkhamheng, 2011). Given these features, it was assumed that with adequate resources to effectively protect tigers and prey, tiger numbers could increase by 50% by 2015, with an ultimate goal to establish 25 breeding females that could expand to potentially 150 individuals in the very long term (Walston et al., 2010a).

To achieve these goals, two conservation strategies – law enforcement and conservation outreach – were initiated in NEPL in 2005 (Johnson, 2012). The law enforcement strategy included working with local government, communities and the military to establish and enforce sizable inviolate core zones where tiger and prey would not be hunted (Johnson et al., 2006). The outreach strategy involved changing the attitudes and ultimately behavior of villagers, local hunters, and government officials to support and comply with law enforcement to reduce tiger poaching and illegal hunting of their prey (Johnson et al., 2012, Saypanya et al., 2013). Contrary to many conservation projects where monitoring to evaluate strategy outcomes is lacking (Pullin et al., 2004, Sutherland et al., 2004, Brooks et al., 2006), the NEPL site was relatively unique in that as a *Tigers Forever* site (Stokes, 2010; Walston et al., 2010a), monitoring the status of tigers and prey as well as the effectiveness of strategies to achieve anticipated results had been ongoing since conservation activities were initiated in 2005 (Johnson et al., 2012, Goodrich et al., 2013).

In this paper, we present the initial assumptions of how a law enforcement strategy was expected to reduce poaching and ultimately increase tigers and prey over time. We report the results of law enforcement and biological monitoring over a seven-year period and evaluate the linkages between law enforcement funding, effort and action, shifts in hunting and the status of tigers and prey over time. We use the evidence generated to define recommendations for improving effectiveness of conservation strategies to recover wild tigers and ungulates in sites such as northern Laos, where success is dependent on vigorously protecting and rebuilding initially small, but promising populations of high-value wildlife.

2. Methods

2.1. Study area

Established in 1993, the NEPL NPA is an IUCN Category VI protected area where a proportion of the area is open to sustainable use of natural resources (Berkmuller et al., 1995, Johnson, 2012). Altitudes range from 400 to 2257 m with over 60% of the NPA above 1000 m and 91% along slopes > 12%. The habitat includes montane grasslands, mixed deciduous forests and an extensive river network. There is a long history of human settlement with most villages engaged in subsistence activities and limited integration into the market economy. Livestock, a principle source of cash income, graze freely in forested areas and grasslands. Wild foods make up > 50% of household food consumption.

NEPL has been under active management with ongoing international technical and financial support from the Wildlife Conservation Society (WCS) since 2003 through the *Tiger Conservation Project* (hereafter called the project, Johnson, 2012). The geographic focus of the project is the NPA and three adjacent provinces (Fig. 1). WCS's *Landscape Species Approach* (Didier et al., 2009) and the *Open Standards for the Practice of Conservation* (CMP, 2013) were used to design the project and a monitoring framework to assess effectiveness of strategies to reduce threats and achieve the goal of increasing tigers and prey. Following this approach, results from the 2004 baseline survey on human-carnivore conflict were used to develop a conceptual model (Margoluis et al., 2009) illustrating the project's assumptions of the major factors that were understood to be driving poaching of tigers and prey in the NPA (see Johnson et al., 2012). Based on this situation analysis, a law enforcement strategy to protect tigers and prey was designed and initiated in 2005.

2.2. Implementing and monitoring the effectiveness of law enforcement

2.2.1. Law enforcement implementation

The expected outcomes of the law enforcement strategy were that increased technical and financial support to the NPA would result in demarcation of a Totally Protected Zone (TPZ) and lead to increased patrol effort that would improve detection and apprehension of poaching and trade, reduce hunting in the TPZ, and increase the abundance and distribution of ungulate prey and ultimately tigers. In conservation planning and evaluation, this string of expected outcomes that result from implementing a conservation strategy is defined as a “theory of change” (Margoluis et al., 2013). To evaluate the accuracy of these assumptions, we monitored along the theory of change to assess linkages between key intermediate results and biological outcomes (Fig. 2). Law enforcement and biological monitoring results were reviewed regularly at three different venues, i) monthly meetings of the NEPL Management Unit, ii) annual NEPL meetings that included government agencies, partner organizations, and donors, and iii) annual meetings of *Tigers Forever* projects from across Asia. Operational and financial data were analyzed annually to assess the relative cost of implementing the strategies and monitoring plan. Internal and peer review of monitoring results were used to revise assumptions, and with analysis of operational and financial data, to adapt strategies accordingly (Johnson et al., 2012).

The law enforcement strategy included three major activities. The first was working with district governments to delineate a 3000 km^2 NPA TPZ with sufficient habitat to sustain viable populations of tigers and their prey and where access and hunting was prohibited in accordance with national Forestry and Wildlife Laws (GoL, 2007a, 2007c). This activity also included developing regulations to specify what and how wildlife could be hunted outside the TPZ. The national laws prohibited all wildlife trade as well as any hunting of tiger and large ungulates (Gaur *Bos gaurus*, Southwest China serow *Capricornis milneedwardsii*, Sambar deer *Cervus unicolor*). These laws permitted hunting of other ungulates, including wild pigs (*Sus spp.*), and muntjacs (*Muntiacus spp.*) outside the TPZ by adjacent villages for subsistence, following NPA regulations on gear and harvest seasons. The NEPL regulations that resulted from this process (GoL, 2007b) included a map of TPZ boundaries (Fig. 1) and procedures for issuing warnings, collecting and distributing fines, and for rewarding the public and government enforcement officers with some part of the fine, which was intended to incentivize wildlife crime reporting and response. Fines were set at twice the market value of the traded animal to reduce the incentive for trade.

The second activity was training and deployment of foot patrol teams to detect and apprehend wildlife crime in the TPZ. Each team was made up of 4–7 village, forestry and military officers that patrolled on foot through designated TPZ enforcement sectors (Fig. 1). From 2005 to 2007, part-time teams were intermittently deployed from NPA

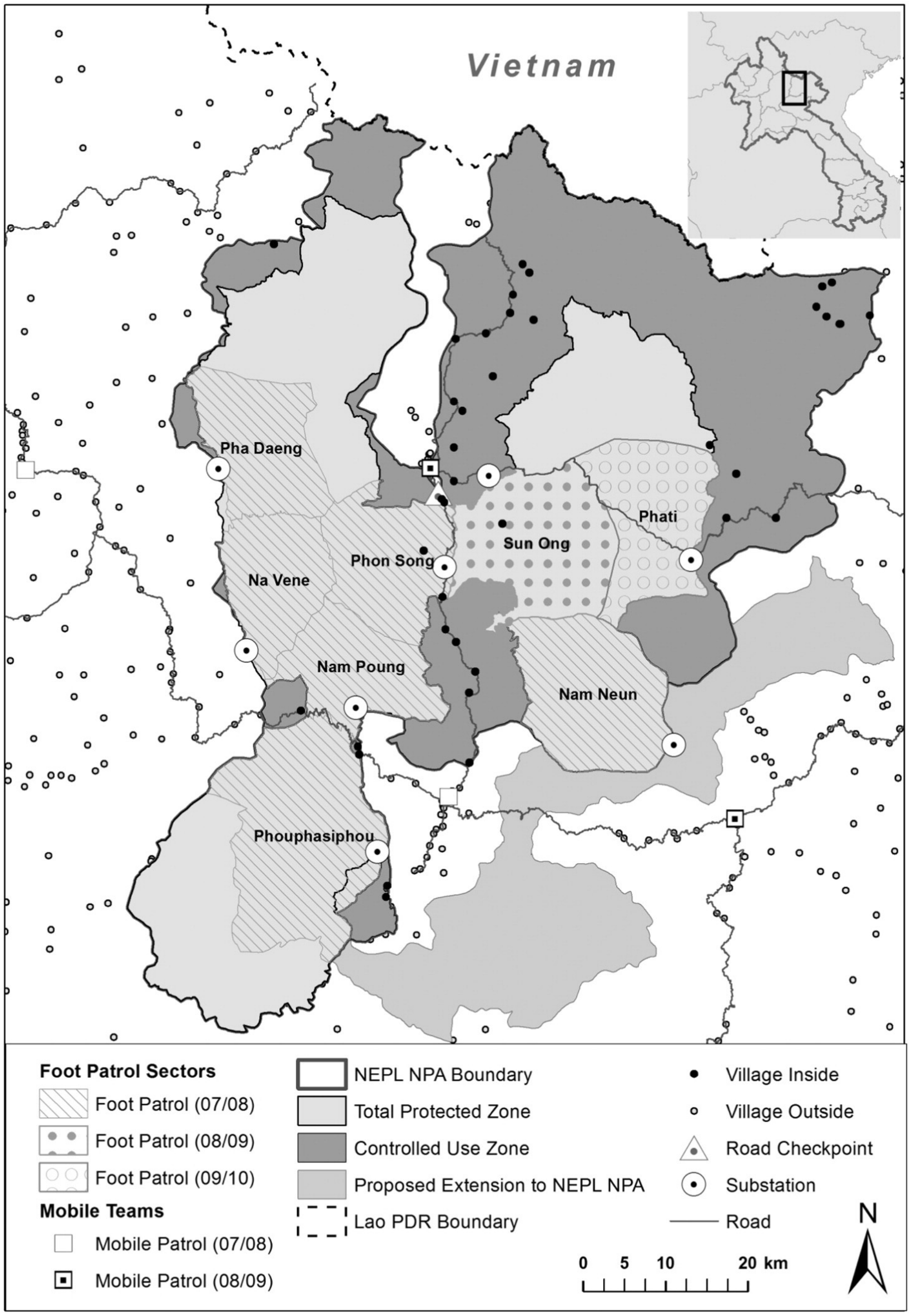

Fig. 1. Nam Et-Phou Louey National Protected Area management zones and enforcement strategy activities.

headquarters. From 2008 to 2012, substations to house full-time patrol teams were constructed at strategic trailheads leading into the eight TPZ enforcement sectors. In each sector, a subset of each team patrolled, while others manned the substation to prevent vandalism and illegal entry into the TPZ. The location of sectors and timeline for establishing substations was prioritized according to known locations of tigers and large ungulates, which was informed by biological monitoring in the TPZ (Johnson et al., 2012).

The third activity was training and deployment of mobile patrol teams outside the TPZ to conduct surveillance and respond to public reports of wildlife crime. These teams ranged from 2 to 5 enforcement officers based in district towns or at a checkpoint along the main wildlife trade route from the NPA to Vietnam (Fig. 1). Mobile teams patrolled for wildlife trade in markets and restaurants, and set up temporary roadblocks at strategic locations to search vehicles for illegal wildlife and weapons.

The law enforcement strategy was supported by a conservation outreach strategy (Fig. 2). NPA outreach teams worked in conjunction with law enforcement to engage villages and government authorities in the design and implementation of NPA zoning and regulations to control wildlife hunting and use (see Saypanya et al., 2013). This joint effort led to establishing a Wildlife Crime Unit and hotline to facilitate public reporting and apprehension of wildlife crime in one district. The objectives of the outreach strategy were to increase public understanding and

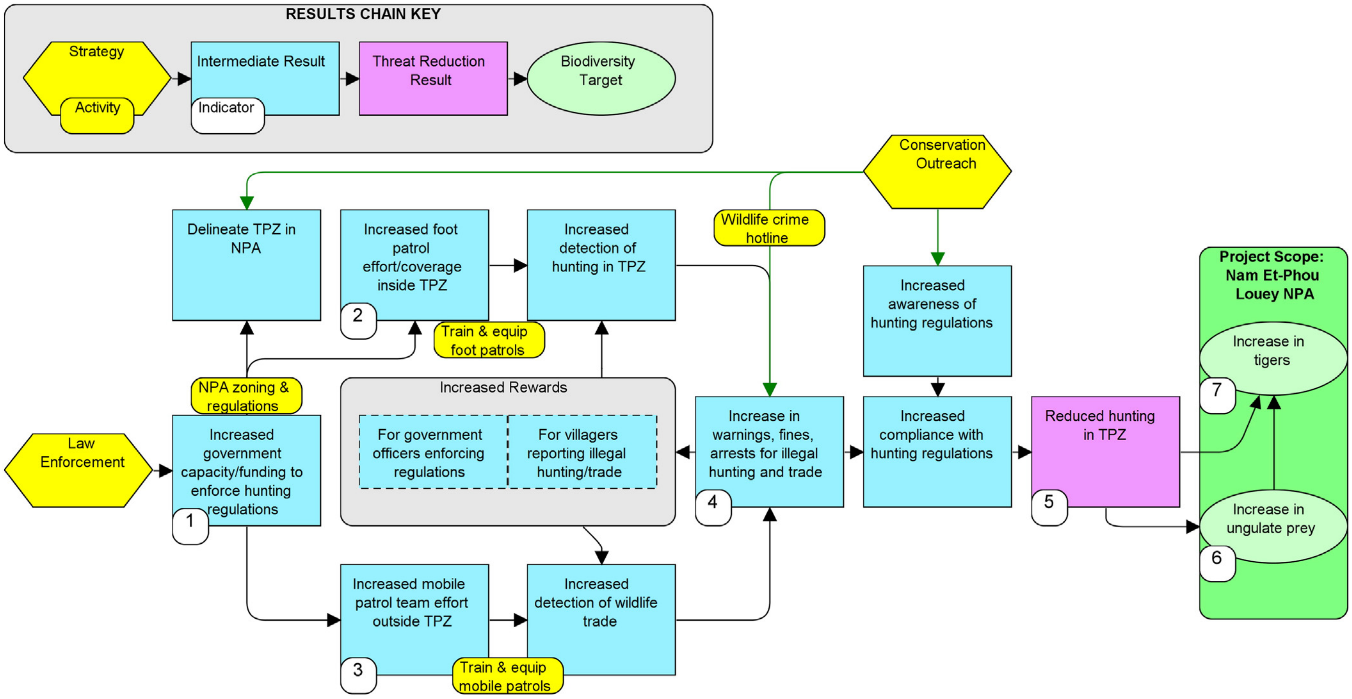

Fig. 2. Results chain illustrating assumptions of how implementation of the law enforcement strategy, supported by a conservation outreach strategy, would lead to intermediate results, a reduction in hunting, and an increase in tigers and prey. Variables monitored over time to evaluate expected outcomes included, 1) law enforcement funding, 2) foot patrol effort/coverage, 3) mobile patrol effort, 4) warnings, fines and arrests, 5) catch per unit effort, and relative abundance of 6) ungulate prey and 7) tigers.

support for sustainable use of NPA resources, change behavior of local community members to report illegal activities, and of law enforcement agencies to process wildlife crime cases.

2.2.2. Law enforcement monitoring

Law enforcement monitoring (LEM) was initiated in 2005 to measure the effectiveness of the law enforcement strategy. A computerized Management Information System (MIST) was used for ranger-based data collection, and to store and analyze data on illegal activities and patrol team performance (Schmitt and Sallee, 2002, MIST™, 2006, Stokes, 2010). Foot and mobile patrol teams were trained to use standardized forms to collect data on several indicators of hunting and trade, including poachers and traders confronted, hunting weapons and wildlife confiscated, gun shots heard, hunting camps destroyed, and enforcement action taken (warnings, fines, or arrests). Each month, teams submitted data forms and GPS spatial data to NPA headquarters, which were verified and entered into the MIST database. Teams used MIST automated mapping queries to present patrol coverage and detections of wildlife crime, tiger and large ungulate sign to enforcement, outreach and biological monitoring team leaders at monthly NPA Management Unit meetings (Johnson et al., 2012). Following an adaptive management process for LEM assessments (Jachmann, 2008), results were used to determine spatial deployment of enforcement and outreach effort and actions for the following month.

The LEM activities and data were summarized annually (July–June) to evaluate trends in (1) funding for law enforcement, (2) spatial, and (3) temporal coverage of patrols, (4) poacher catch ratio (proportion of sightings of poachers in the TPZ by foot patrol teams that resulted in confrontation), and enforcement response ratio (proportion of foot patrol confrontations in the TPZ that resulted in enforcement action, including warnings, fines, and arrests) and (5) hunting catch per unit effort (CPUE; number of signs of hunting detected per kilometer patrolled) (Fig. 2). For hunting CPUE, the monthly aggregate number of signs of hunting per aggregate distance (in km) patrolled was calculated for each patrol sector and the annual mean of those values for each sector.

2.3. Monitoring tigers and prey

2.3.1. Camera trapping

Camera trapping was used to collect baseline data on tigers and ungulates prior to implementation of the law enforcement strategy in 2005, and again in 2012, after seven years of strategy implementation. For the baseline (2003/04), 50 CamTrakker passive infrared film camera traps were set in pairs in five 100 km^2 sampling blocks in the TPZ, each divided into 25 four-km^2 subunits, as far from villages as possible (for details see Johnson et al., 2006). From January – July 2012, camera trapping was conducted over three 396-km^2 blocks positioned to roughly cover all foot patrol sectors (Fig. 1 and Supplementary Fig. A.1), which overlapped completely with three of the sampling blocks from the baseline survey. Each block was divided into 9-km^2 grid cells and we attempted to place a pair of digital cameras (PantheraCam V3, Panthera, New York, NY, USA) at a single station in each grid cell, but ultimately 120 of 132 subunits received cameras. Camera stations were placed in areas deemed most likely to be used by tigers and chosen by searching each grid cell for evidence of tigers during a 2011 reconnaissance survey. Cameras were operational 24 h/day and set to take 3 consecutive photos 1 s apart with each trigger during the day, with no delay between triggers, and 1 photo approximately every 8 s (the time taken for the flash capacitor to recharge) in low-light conditions when the flash was activated. Cameras were left in the forest for ≥45 days and checked to download data and change batteries 3–4 weeks after being set.

Trap-days per camera (CTD) were calculated from the time the camera was mounted until the date of the final photo or retrieval of the camera. CTD per trap site was calculated from only one camera of each camera pair; if CTD varied within the pair, the larger number was used. Photo results from 2003/04 were entered into an Access database, recording frame number, date, time, and object/s for each film. Photo results from 2012 were catalogued by adding location and species to metadata embedded in each photo. For all years, each photo was identified to species and rated as a dependent or independent event with an "independent capture event" defined as 1) consecutive photographs of different individuals of the same or different species, 2) consecutive photographs of individuals of the same species taken >0.5 h apart, 3) nonconsecutive photos of individuals of the same species (O'Brien et al., 2003). For each species, we calculated the number of independent photographs (IP) per 100 CTD as an index of relative abundance (RAI), using CTD from only one camera of each camera pair. Separate one-sided randomization tests (Manly, 2007) with 999 randomizations were used to test the null hypothesis of no difference in average RAI for tiger and four prey species (Sambar deer, pig, serow and muntjac) between the 2003/04 and 2012 surveys at a significance level of 5%. During each randomization the RAI count values were randomly allocated to the 2003/04 or 2012 survey and the test statistic (difference between the mean RAI for each survey) was calculated. The 1000 test statistics (999 randomization results and the actual difference in mean RAI between surveys) were then sorted in ascending order. If the actual difference in mean RAI was larger than the 95th quantile of the ordered values for the prey species and smaller than the 5th quantile for tiger, then the test results were statistically significant at the 5% level.

2.3.2. Large carnivore sign

2.3.2.1. Track measurements. From January 2008 to July 2012, law enforcement foot patrol teams in the TPZ recorded all observations of tiger tracks. Measurements of total pad width at the widest point between the two outermost toes were recorded and locations determined using GPS coordinates. Tracks with pads >7.0 cm wide were identified as tiger (Khao Nang Rum Wildlife Research Station Department of National Park, Wildlife and Plant Conservation, Thailand, unpublished data).

2.3.2.2. Scat collection. From 2007 to 2011, large carnivore scat samples were collected opportunistically to obtain an estimate of minimum tiger numbers in the TPZ. Scats were collected by biological monitoring teams during an occupancy survey for ungulates covering 2600 km^2 of the TPZ from January to June 2008 (Vongkhamheng et al., 2013), during camera trap surveys, and by law enforcement foot patrol teams across 2066 km^2 of the TPZ from July 2007 to June 2011. From November 2009 to May 2010, two biological monitoring teams were also deployed in the TPZ to specifically walk and search for large carnivore scats, and from November 2010–May 2011 a biological monitoring team collected scats while conducting a reconnaissance survey for the 2012 camera trapping effort. Carnivore scats >2.0 cm diameter were collected and GPS coordinates recorded. Each fecal sample was measured, air dried and stored with silica gel. DNA extraction and species identification was done by the Center for Conservation Genetics and Global Felid Genetic Program of American Museum of Natural History (AMNH), New York (Vongkhamheng, 2011).

3. Results

3.1. Law enforcement effectiveness

3.1.1. Law enforcement funding

Annual in-country expenditures on the law enforcement strategy ranged from \$14,470 to \$203,266 (mean \$134,678; 2005–2012) (Fig. 3). Annual expenditures were greatest during initial construction of permanent substations and placement and training of full-time foot patrol teams in the TPZ (2007–2009). Relative to in-country expenditures on conservation outreach and the biological monitoring of tigers and prey, the majority of annual project expenditures over the seven-year period were on law enforcement (mean 59.1%; range 52.5–70.1%).

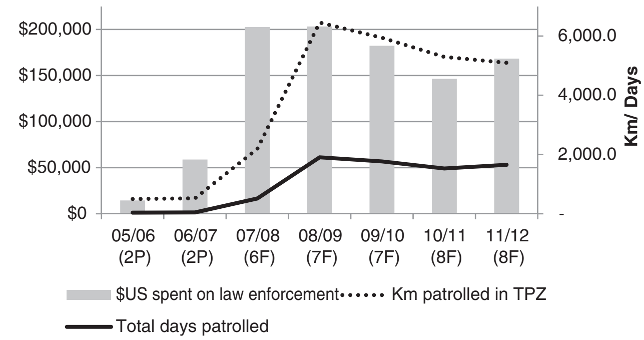

Fig. 3. Annual in-country expenditures on law enforcement relative to foot patrol effort inside the TPZ, given the number of part-time (P) and full-time (F) foot patrol teams.

3.1.2. Patrol effort

Over the seven-year period, there was a strong positive correlation between financial investment in the law enforcement strategy and annual foot patrol effort (total days patrolled; $r_s = 0.786$, $n = 7$, $p = 0.05$ and kilometers patrolled; $r_s = 0.750$, $n = 7$, $p > 0.05$) (Fig. 3). In the first four years, mean monthly foot patrol effort in the TPZ increased from 1.7 days per part-time team (2005–2007) to a high of 22.7 days per full-time team in 2008/09, while kilometers patrolled increased over three-fold from 21.2 km per part-time team to 76.9 km per full-time team during the same time periods. Annual spatial coverage of the TPZ increased five-fold from a mean 372.6 km^2 by part-time teams in the first two years to 1931.0 km^2 by full-time teams in 2009/10 (Fig. 4). A relative decline in donor funding (2009–2012) was associated with a mean drop in days and kilometers patrolled (4.2% and 7.5%, respectively) and patrol coverage (3.7%; 2010–2012).

Patrol effort was adapted to maximize detection of wildlife crime relative to available funding and effectiveness of patrol techniques. From 2007 to 2011, most mobile patrol effort focused on temporary roadblocks to search vehicles (79.3%, $n = 743$ days) (Fig. 5). In 2008/09, the number of mobile teams was doubled and roadblocks set up regularly, but frequently did not detect wildlife or weapons. Thus, after July 2009, relatively more effort focused on intelligence gathering while roadblocks were reserved to respond to crime hotline reports (Saypanya et al., 2013). Foot patrols and mobile team response to intelligence led to the majority of encounters with poachers or traders (48.9% and 26.4% respectively; $n = 231$) and seizures of illegally traded ungulate parts (42.1% and 38.2% respectively; $n = 76$; Fig. 6). Whereas, foot patrols in the TPZ resulted in most of the encounters leading to confiscation of guns (90.9%; $n = 132$) and all detections of wire snares (100%; $n = 81$). Given these results, funding was increasingly prioritized to support foot, versus mobile, patrols.

3.1.3. Law enforcement action

The poacher catch ratio (proportion of times that hunters sighted were successfully confronted and enforcement action taken) dropped from a high of 100% of reported encounters ($n = 9$; 2008/09) to only 31% of reported encounters ($n = 32$; 2011/12) (Fig. 7), which was associated with relatively less enforcement funding and reduced patrol effort during this same period. In all cases, when poachers were confronted by foot patrol teams ($n = 54$, range 9–14 per year) some type of enforcement action resulted. In most cases, violators were fined (63.0%, $n = 54$). Others were warned and informed of hunting regulations (24.1%) and some arrested (3.7%). For the remainder of cases, type of action was not recorded. When violators were fined, a subset of cases ($n = 40$, July 2007–February 2010) 47.5% resulted in the successful collection of the entire fine amount, while only a part or none of the fine amount was collected in the remainder of cases (42.5% and 10.0%, respectively).

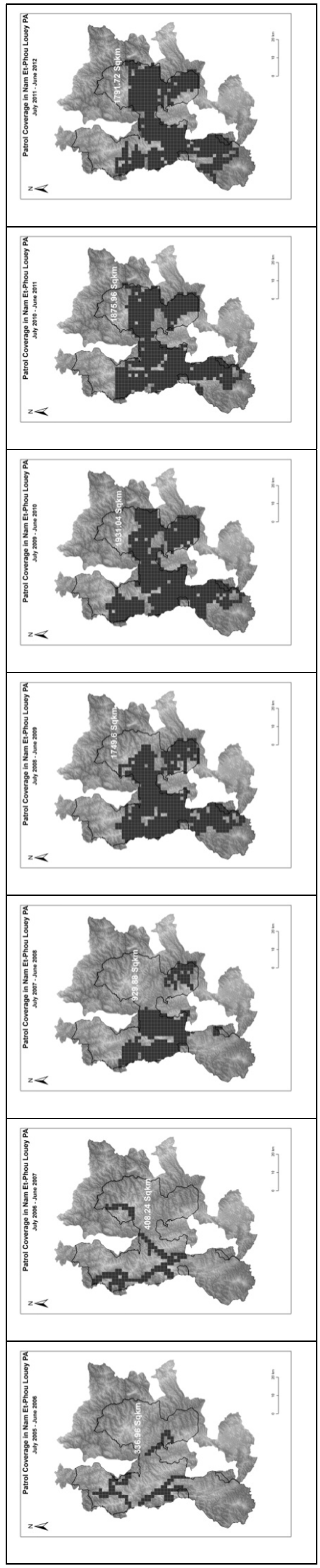

Fig. 4. Annual foot patrol coverage (km^2) in the TPZ.

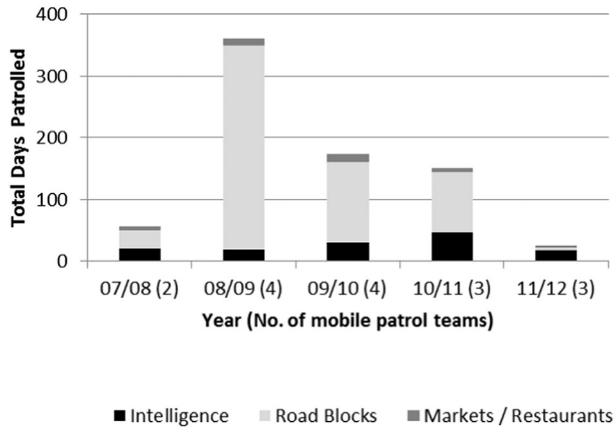

Fig. 5. Annual effort (days) by mobile patrol teams on intelligence gathering, road blocks and market/restaurant surveillance.

3.1.4. Hunting in the TPZ

From July 2005–June 2009, mean CPUE dropped from 7.2 signs of hunting per 100 km patrolled (SD = 2.846, $n = 2$ teams) in 2005/06 to 1.6 signs (SD = 1.143, $n = 7$ teams) in 2008/09 (Fig. 8). Over the seven-year period, there was a significant negative correlation between total days patrolled and mean CPUE in the TPZ ($r_s = -0.893, n = 7$, $p < 0.05$). From July 2009–June 2012, CPUE increased along with an exponential proliferation in confiscation of wire snares (mean 0.52 snares per 100 km patrolled in 2009/10 to over 5.04 snares per 100 km patrolled in 2011/12; Fig. 9). The rate of guns encountered in the TPZ over this same period remained at or below a mean of 0.25 snares per 100 km patrolled.

3.2. Status of tigers and ungulates

3.2.1. Camera trapping

Baseline camera trap surveys (2003/04) were conducted over a 14-month period for a total of 3588 CTD, with a mean trapping effort of 718 CTD per 100 km^2 (Johnson et al., 2006). In 2012, camera trap surveys were completed in a five-month period for a total of 6100 CTD, with a mean effort of 513 CTD per 100 km^2. Relative to the baseline, in 2012 there was an increase in mean RAI for all ungulate species across sampled areas (Table 1), ranging from over a two-fold increase (2.52) for muntjac to over a four-fold increase (4.80) for Sambar deer. In contrast, there was a seven-fold decline in mean RAI for tigers over the seven-year period (0.24, 2003/04; 0.03, 2012). Tiger abundance was estimated at 0.2–0.7 per 100 km^2 in 2004 (Johnson et al., 2006), but tiger photographs were too few ($n = 2$ tigers and 2 photos) to estimate

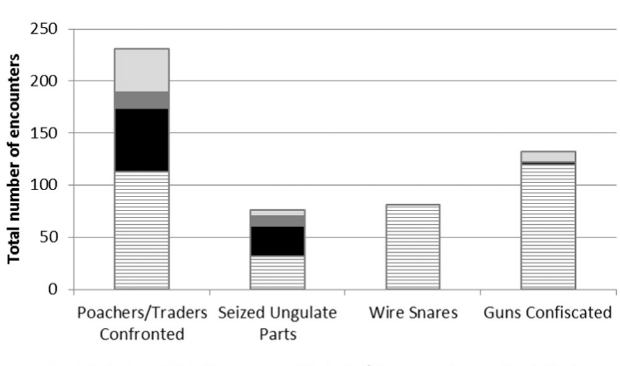

Fig. 6. Effectiveness of various foot and mobile patrol enforcement techniques to detect wildlife hunting and trade.

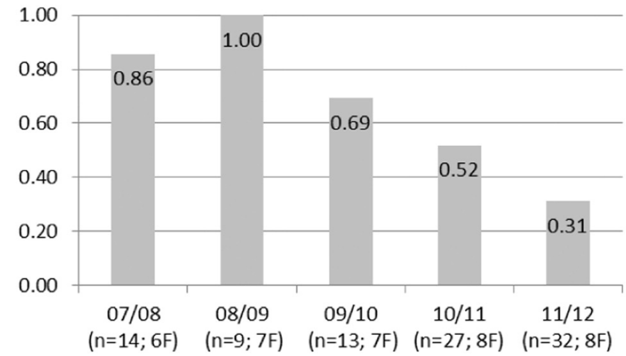

Fig. 7. Annual poacher catch ratio (proportion of times that people seen hunting in the TPZ where confronted by foot patrol teams and enforcement action taken), where n is the total times that teams sighted people hunting and F is the number of full-time foot patrol teams.

abundance in 2012, despite a two-fold increase in area covered in 2012 (1188 km^2) compared to 2003/04 (500 km^2).

For tiger and all four ungulate species the hypothesis of no difference in average RAI between the surveys was rejected at the 5% level (see Supplementary Fig. A.2). For Sambar deer, pig, serow and muntjac there was a statistically significant increase in the mean RAI between surveys of 1.10, 0.68, 0.79 and 4.09, respectively. For tiger there was a statistically significant decrease of −0.20 in the mean RAI between the surveys.

3.2.2. Large carnivore sign

3.2.2.1. Track measurements. From 2007 to 2012, tiger tracks with pads >7.0 cm wide were recorded on 109 independent foot patrols in the TPZ. The mean number of tiger tracks found per 1000 km patrolled from 2007 to 2010 was 8.1 (range 7.0–8.2), declining to 3.0 tracks per 1000 km patrolled in 2011/12 (Fig. 10). There was a strong negative correlation between snares encountered per 100 km patrolled and tiger tracks per 1000 km patrolled in the TPZ ($n = 5$, $r_s = -0.90$, $p = 0.10$).

3.2.2.2. Scat collection. From July 2007–June 2011, field teams collected 249 carnivore scats. Despite annual increases in the area of the TPZ surveyed, the number and percentage of scats collected each year that were identified as tiger declined from 15.6% ($n = 45$) in 2008/09 and 15.4% ($n = 39$) in 2009/10 to 3.6% ($n = 111$) in 2010/11.

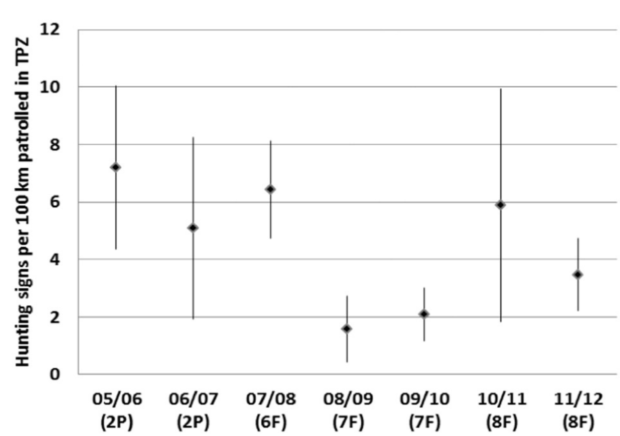

Fig. 8. Annual mean catch per unit effort (number of hunting signs detected per 100 km patrolled) and 95% confidence limits across patrol sectors, given the number of part-time foot (P) and full-time (F) foot patrol teams.

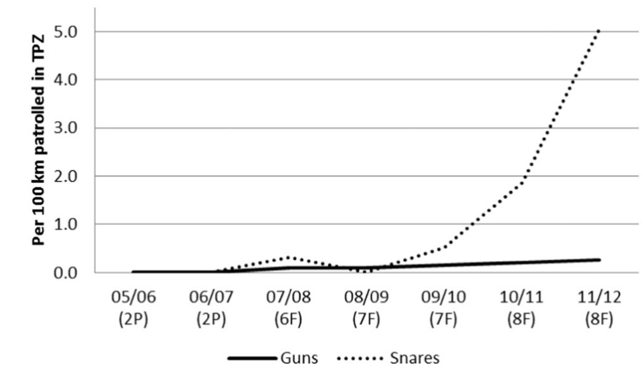

Fig. 9. Number of guns and large wire snares detected per 100 km patrolled in the TPZ, given the number of part-time foot (P) and full-time (F) foot patrol teams.

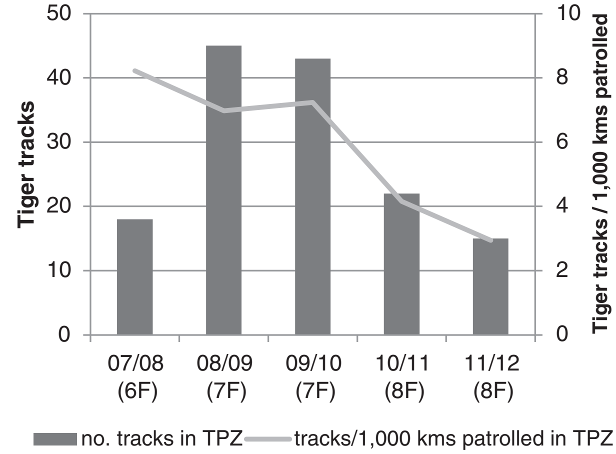

Fig. 10. Number of tiger tracks (pads > 7.0 cm wide) recorded per 1000 km patrolled, given the number of full-time (F) foot patrol teams.

4. Discussion

Our evaluation of the effectiveness of a law enforcement strategy to protect tigers and ungulate prey from poaching in the NEPL NPA indicates that actions were sufficient to reduce poaching and increase prey populations, but were insufficient to curtail the extirpation of tigers. Although most assumptions of the strategy proved to be valid and effectiveness of law enforcement did increase dramatically relative to the baseline, actions to protect tigers were ultimately limited by several conditions including, 1) insufficient funding, 2) staff capacity and turnover, 3) an exponential proliferation in snaring, and 4) an inadequate enforcement regime.

4.1. Status of tigers and prey

We monitored two different indices of tiger abundance and one direct measure of abundance, including tiger tracks and scats, and independent photographs of tigers to assess change in tiger status over a seven-year period. All three sources of evidence indicate that tiger abundance in the TPZ significantly declined during this time. In 2012, sample sizes were too small to calculate abundance using capture-recapture techniques, so a statistical comparison was not possible. However, that only two tigers were photographed despite substantially greater effort strongly suggests decline as indicated by the randomization results. In contrast, independent photographs from surveys prior to the implementation of the law enforcement strategy in 2005 and again in 2012 show an increase in relative abundance of the four ungulate species. Although indices of animal abundance are widely used to infer actual change in animal abundance, they do not include detection probability and hence are sensitive to changes therein (Keane et al., 2011, Sollmann et al., 2013). Detection probability could have been influenced by a number of factors that may have differed between camera trapping periods, including changes in the effectiveness of camera placement between the two periods, differences in effectiveness of the cameras themselves, or changes in prey distribution due to changes in human, tiger, and other predator abundance and distribution. Nonetheless, because there was a significant two- to four-fold increase in the average RAI for all prey species, we believe this reflects an actual increase in abundance, but of unknown magnitude.

4.2. Law enforcement effectiveness

4.2.1. Law enforcement funding

Enforcement costs in developing countries are naturally high because landscapes patrolled are generally extensive with permeable borders and high threat levels to resources (Robinson et al., 2010). In these areas, like in NEPL, it is not uncommon for law enforcement to make up the bulk of the annual operating budget (Robinson et al., 2010, Plumptre et al., 2014). In 2010, Lao government support for NEPL was approximately \$11/km^2, which was <5% of the estimated \$205/km^2 needed for law enforcement to adequately protect tigers in the NPA (Walston et al., 2010a). These estimated costs for law enforcement are consistent with those from other similar-sized areas in developing countries (Jachmann, 2008, Plumptre et al., 2014). With project support, average annual expenditures on NEPL law enforcement increased to \$95.7/km^2 patrolled (range \$78–116; July 2008–June 2012), which positively correlated with foot patrol effort. Yet, this was still less than half of what we estimated was needed to adequately reduce tiger poaching. Levels of funding for anti-poaching have been shown to affect trends in abundance of high-value wildlife and that the amount of illegal activity depends on the resources allocated for law enforcement

Table 1
Number of independent photos per 100 CTD (RAI) and mean and range of relative abundance index values for tiger and prey in the NEPL NPA from five sampling blocks (500 km^2) in 2003–2004 (Johnson et al., 2006) and from three sampling blocks (1188 km^2) in 2012.

Common name	2003/2004			2012		
	# ind. photos	Mean (RAI)	Range (RAI)	# ind. photos	Mean (RAI)	Range (RAI)
Tiger *Panthera tigris corbetti*	9	0.24	0–0.48	2	0.03	0–0.05
Muntjacs *Muntiacus* spp.	99	2.77	1.85–3.95	429	6.97	5.03–9.78
Wild pigs *Sus* spp.	14	0.40	0.14–1.06	71	1.16	0.43–1.84
Southwest China serow *Capricornis milneedwardsii*	11	0.29	0–0.69	65	1.05	0.43–2.24
Sambar deer *Cervus univcolor*	9	0.25	0–0.55	73	1.20	0.61–1.62

(Leader-Williams and Albon, 1988, Hilborn et al., 2006). The effectiveness of various patrol techniques in NEPL (Fig. 6) illustrates the strategic importance of foot patrols for detecting poachers and snares. As funding for law enforcement, and subsequently patrol effort, declined in NEPL, the occurrence of snaring increased and was negatively correlated with tiger sign. Others indicate that deterrence of illegal hunting may decay over time if effort is not maintained (Milner-Gulland and Clayton, 2002).

Given the level of funding for NEPL, the ratio of area patrolled annually per foot patrol officer was 33.7km^2 (2010 − 2012), which was half again as much as the patrol staffing ratio allocated for protecting similar size areas in central Africa (Plumptre et al., 2014). The staffing ratio for all protected area management activities in NEPL (~17 per 1000 km^2, Walston et al., 2010a) was approximately 40% less than the average global protected area ratio of 27.6 per 1000 km^2 for developing countries (James et al., 1999). With the apparent lack of resources to adequately protect high-value tigers in NEPL, it may have been advisable to initially intensify protection to a smaller area of the TPZ (see Leader-Williams and Albon, 1988). While this would not have provided sufficient area for large-ranging tigers dependent on a low density of large ungulate prey over the long term, it may have helped to build a model for successful protection that could have been disseminated to a larger area (Goodrich et al., 2013). To achieve the ultimate goal of establishing 25 breeding females, NEPL ultimately needed to protect up to 2500 km^2 with a density of 3 tigers/100 km^2 (Walston et al., 2010a).

4.2.2. Staff capacity and turnover

The project in NEPL started only ten years after the NPA system had been declared and no formal training program for protected area management existed in the country (Rao et al., 2014). This meant that most staff had never worked in an NPA or had formal training in the tasks to which they were assigned. Instead, law enforcement skills were taught on the job through training workshops as staff were hired. Staff turnover was relatively frequent resulting from low pay and fatigue due to assignment to remote locations, and physically difficult and dangerous working conditions. Even the NPA directorship changed four times during the seven-year period. Given these conditions, law enforcement supervision was insufficient to deliver the necessary trainings for new recruits while also maintaining rigorous enforcement practices across an expanding number of patrol sectors and staff. These conditions are not atypical of developing countries and especially acute in areas where intensive protection of high-value wildlife is required (Lynam, 2010, Robinson et al., 2010). In India, lack of leadership and training for enforcement contributed to the extirpation of small populations of tigers from the Panna and Sariska Tiger Reserves (Rastogi et al., 2012).

4.2.3. Snaring

A decline in hunting catch per effort from 2005 to 2010 suggests that hunting in the TPZ was successfully reduced but never eliminated. Observations and law enforcement reports confirmed that at least eight tigers were poached in the TPZ from 2005 to 2012. Most of these were caught with wire snares, which are known to have a deadly impact on felid populations (Becker et al., 2013). Although tiger scat analysis indicated that reproduction was occurring (Vongkhamheng, 2011), given a baseline estimate of only 7–23 tigers it was likely that the population was unable to sustain this degree of snaring without some decline. In practice, "perfect enforcement" where hunting of a high-value wildlife animal is completely eliminated is rare and extremely costly (Robinson et al., 2010).

Although CPUE is a common index used for monitoring the impact of law enforcement patrols on hunting (Jachmann, 2008), we considered several aspects of patrol and hunter behavior over time that may have biased CPUE data (Hilborn et al., 2006, Keane et al., 2011). First, patrol sectors were established in areas where hunting had been occurring and initially patrols encountered considerable hunting sign. But with repeated patrolling in these same sectors, only new hunting signs were encountered and in most cases CPUE leveled off (Fig. 8; e.g., 2006/07, 2008/09, and 2011/12). Secondly, increased detection of snares and other hunting sign in later years was likely not the result of patrols being better trained or incentivized, given frequent staff turnover and the difficulty of collecting fines. There may have been disincentives to detect hunting if poachers were rewarding teams to look the other way (Hilborn et al., 2006), although we had little direct evidence of this. Third, although foot patrols were concentrated in areas where tiger and large prey were known to occur and where poachers were more active, this patrol behavior was consistent across the seven-year period and likely not responsible for the observed increase in encounter rates of snaring in later years (see Keane et al., 2011). Thus, we believe the increased encounter rate is indicative of a real and dramatic increase in the number of snares in the TPZ.

The increased snaring likely resulted from local hunters changing techniques to more effectively target tigers. Snares were not common until Vietnamese and Chinese traders from outside the area began providing local hunters with this gear. When hunting regulations were formalized in 2007, hunters caught in the TPZ were allowed two warnings before serious action was taken. With sustained enforcement, hunters targeting tigers likely adapted their behavior to avoid or run from patrol teams, which may explain why patrols were less successful in confronting poachers in later years. In contrast, evidence suggests that subsistence hunters targeting ungulates stopped entering the TPZ as enforcement expanded. What were once well-established foot trails in the TPZ became overgrown and most signs of hunting declined. Independent studies indicate that forest cover in the TPZ has increased and human use decreased (Castella et al., 2013). For subsistence hunters, the 2007 NPA regulations clarified that hunting of less-threatened ungulates was permitted outside of the TPZ (Saypanya et al., 2013), which may bolster public support for the protection of source populations (see Robinson et al., 2010).

4.2.4. Enforcement regime

Although changes in patrol effort and poacher behavior likely contributed to the observed decline in poacher catch ratio, there were also systemic deficiencies in the enforcement regime driving this trend. An enforcement regime consists of the probability of a poacher being detected and fined, as well as the successive probability of arrest, prosecution, and conviction, with enforcement success limited by the least effective of these steps (Robinson et al., 2010). In NEPL, a number of conditions inherent to the legal system limited the success of the enforcement regime, especially as it related to tiger poaching.

First, when violators were confronted and fined by patrol teams, the full fine was collected in less than half of the recorded cases and the consequences for violators were limited if they did not comply. In many developing countries, regulations governing wildlife management are relatively new and initially difficult to enforce (Hershfield et al., 2014). In NEPL, district and provincial government officials, prosecutors, and judges had no previous experience with wildlife law enforcement and were reluctant to prosecute and convict violators of the relatively new NPA regulations, which was exacerbated by documented linkages between corruption and wildlife trafficking (Nooren and Claridge, 2001, Stuart-Fox, 2006, Sodhi et al., 2010). Secondly, the regulations were designed such that rewards were paid from the fines collected (GoL, 2007b). If fines were not collected because violators could not be prosecuted and convicted, rewards could not be paid to enforcement officers or the public for responding to illegal activity. These barriers served as a disincentive to enforcement and an incentive for crime (Saypanya et al., 2013). Third, none of the known cases of tiger poaching in NEPL resulted in an arrest, prosecution or conviction. In most cases, evidence was deemed insufficient to support prosecution. In other cases, witnesses were unwilling to provide evidence without assured reward. While the outreach strategy successfully built a constituency for wildlife law enforcement in one district (Saypanya et al., 2013), funding was insufficient to scale up activities to achieve similar results across all seven districts encompassing the NPA.

4.3. Recommendations for improving law enforcement effectiveness

Evidence from this case provides several lessons on actions needed to recover small but promising populations of high-value wildlife. First, our results indicate that not only the level, but also the timing and scale of investment in law enforcement is critical. It may be advisable to initially target resources at establishing a small but solid model of an effective enforcement regime that extends from detection to conviction, which is then scaled up across the larger landscape. Even at a small scale, this will entail intensive and sustained capacity building and support along the enforcement chain. This is a very different approach than the support for ongoing deployment of law enforcement at source sites where there are better-developed enforcement regimes and larger tiger populations (Karanth et al., 2010, Miquelle et al., 2010), which can withstand higher annual mortality. In less established source sites, the cost of establishing an enforcement regime to turn fragile source sites into more robust populations will likely be very high for several years relative to the immediate return on tiger recovery.

Secondly, while improving law enforcement is clearly critical, in most cases this strategy alone will not be sufficient to build government and community support for an enforcement regime to reduce poaching (Challender and MacMillan, 2014). Where conservation outreach is implemented alongside law enforcement, there is evidence of increased community and government support for wildlife protection (Saypanya et al., 2013, Steinmetz et al., 2014). In NEPL, intelligence from an informant network developed by and dependent on the outreach strategy led to apprehension of a significant number of wildlife crimes (Fig. 6). Likewise, law enforcement coupled with comprehensive actions to reduce tiger attacks on livestock has been essential for mitigating negative attitudes towards tigers (Goodrich, 2010). Although these additional strategies were identified and implemented in NEPL (Johnson et al., 2012), funding was insufficient to effectively deploy activities at scale in tandem with law enforcement.

Finally, because small populations of tigers are especially susceptible to decline (Kenney et al., 1995, Chapron et al., 2008, O'Kelly et al., 2012), it is essential to have robust and agile monitoring and adaptive management systems in place to systematically assess the effectiveness of conservation actions, as well as the status of the species (Salzer and Salafsky, 2006). Scientific consensus recommends that tiger populations in these vulnerable source sites should be monitored every 1–2 years at intensities of >500 trap-nights per 100 km^2 (Karanth et al., 2011a, Goodrich et al., 2013). Our results demonstrate how there is no adequate proxy to good data on tiger numbers. Although law enforcement and prey monitoring suggested effective enforcement at least until 2010, the number of tigers continued to decline despite increases in prey. In less-established tiger source sites, this will require not only having resources to collect and quickly analyze critical indicators of both status and effectiveness along a clear theory of change, but also the support to build and maintain the capacity to undertake the necessary monitoring and evaluation (Johnson et al., 2012).

5. Conclusions

Dissemination of results from systematic monitoring and evaluation of conservation actions is critical for improving the practice of conservation and the recovery of endangered species (Brooks et al., 2006, Sodhi et al., 2010, Sodhi et al., 2011). From this study, we conclude that capitalizing on the opportunities for recovering small populations of tigers in promising source sites is dependent on significant and sustained financial and technical support for establishing a functional law enforcement regime, complimentary strategies to build government and public support for law enforcement, and a robust monitoring and evaluation system to support agile adaptive management. In most cases, much of the initial cost must be borne by the global community (Balmford and Whitten, 2003, Walston et al., 2010b, Sodhi et al., 2011) and it will be the actions of this community, as much as of those in the countries that harbor these potentially important tiger populations, that determine if the necessary conditions to support tiger recovery can be met.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.biocon.2016.08.018.

Acknowledgements

This study was conducted under a MoU between the Wildlife Conservation Society and the Department of Forestry with funding from Panthera, the United States Fish and Wildlife Service Rhinoceros and Tiger Conservation Fund 98210-3-G546 (2003); 98210-5-G086 (2005); 98210-6-G199 (2006); 98210-7-G275 (2007); 96200-9-G033 (2009); 96200-0-G008 (2010); 96200-0-G171 (2010); 96200-1-G037 (2011), and the Save the Tiger Fund No. 2002-0301-007; No. 2003-0087-025; No. 2005-0013-016. This work benefitted from the commitment of numerous NEPL enforcement, outreach, monitoring and management staff; we thank each one of them for their inputs. We also thank Mahendra Shrestha and an anonymous reviewer for helpful comments on the manuscript.

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