Integrative Zoology 2016; 11:2–15 doi: 10.1111/1749-4877.12168

ORIGINAL ARTICLE

Indicators of success for smart law enforcement in protected areas: A case study for Russian Amur tiger (*Panthera tigris altaica*) reserves

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Abstract

Although considerable conservation resources have been committed to develop and use law enforcement monitoring and management tools such as SMART, measures of success are ill-defined and, to date, few reports detail results post-implementation. Here, we present 4 case studies from protected areas with Amur tigers (*Panthera tigris altaica*) in Russia, in which indicators of success were defined and evaluated at each. The ultimate goal was an increase in tiger numbers to 1 individual/100 km^2 at each site. We predicted that improvements in law enforcement effectiveness would be followed by increases in prey numbers and, subsequently, tiger numbers. We used short-term and long-term indicators of success, including: (i) patrol team effort and effectiveness; (ii) catch per unit effort indicators (to measure reductions in threats); and (iii) changes in target species numbers. In addition to implementing a monitoring system, we focused on improving law enforcement management using an adaptive management process. Over 4 years, we noted clear increases in patrol effort and a partial reduction in threats. Although we did not detect clear trends in ungulate numbers, tiger populations remained stable or increased, suggesting that poaching of tigers may be more limiting than prey depletion. Increased effectiveness is needed before a clear reduction in threats can be noted, and more time is needed before detecting responses in target populations. Nonetheless, delineation of concrete goals and indicators of success provide a means of evaluating progress and weaknesses. Such monitoring should be a central component of law enforcement strategies for protected areas.

Key words: adaptive patrol management, Amur tiger, anti-poaching, law enforcement monitoring, SMART

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INTRODUCTION

Over the past decade much attention has been paid to law enforcement monitoring (LEM) tools such as

MIST (Management Information SysTem) and the more recently developed SMART (Spatial Monitoring and Reporting Tool) as a means to improve anti-poaching patrol performance and results (Schmitt & Sallee 2002; Stokes 2010; Saunders 2011; Moreto *et al.* 2014; no author 2015). These tools, which focus on measuring law enforcement efforts and threats in a particular landscape, have been applied across a large number of conservation sites throughout Asia, Africa and South America, with the aim of improving the protection of conservation target species that are especially vulnerable to poaching (such as rhinoceros, elephants and tigers). If used in an adaptive management framework (Stokes 2010) and combined with monitoring of target species, LEM could provide strong correlative evidence of the relationship between law enforcement efforts and trends in target species numbers.

However, with so much energy, funding and staffing committed to the development and application of these tools, there is surprisingly very little known about whether they are actually helping to meet the stated goals of: (i) improving anti-poaching effort; (ii) reducing threats (e.g. poaching levels), and, most importantly; (iii) increasing target species numbers. In most cases, clear indicators of success have yet to be delineated to demonstrate improvements in anti-poaching efforts or reductions in threats, although well-defined biological monitoring systems have been developed (e.g. Karanth *et al.* 1995; Gopalaswamy *et al.* 2012).

In many localities throughout Asia, the most immediate threat to tigers (*Panthera tigris* Linnaeus, 1758) is direct poaching, prey depletion (another form of poaching) or a combination of the two (Karanth & Stith 1999; Chapron *et al.* 2008; Robinson *et al.* 2015). Therefore, eliminating or reducing poaching pressure has become a top priority for securing a future for tigers in the wild. We began implementation of LEM and an adaptive management system in protected areas of the Russian Far East where tiger numbers generally appeared to be in decline (Miquelle *et al.* 2010), and wanted clear indicators of both short-term and long-term progress. We developed a hypothetical framework for how improved law enforcement should influence key parameters and target species, and then developed indicators that could document progress (or the lack thereof). In this paper we propose a framework for evaluating the success of law enforcement efforts in protected areas and demonstrate how we evaluated progress at four model sites in the Russian Far East. Our goal is not to proclaim success at all model areas, but to use these relatively short-term examples as a means of deriving appropriate indicators of success and to encourage others to adopt similar means of evaluation.

MATERIALS AND METHODS

Study area

We implemented patrol monitoring and management at four protected areas in Primorskii Krai, a province in the Russian Far East: Land of the Leopard National Park (LLNP), Lazovskii State Zapovednik (LAZO), Sikhote-Alin Biosphere Zapovednik (SABZ) and Zov Tigra National Park (ZOTI; see online Suppl. Fig. S1). Descriptions of the study sites can be found in Kerley *et al.* (2015). All sites are federally protected under the jurisdiction of the Ministry of Natural Resources of the Russian Federation. Two of the study sites (LAZO and SABZ) are designated as “zapovedniks,” which are IUCN category Ia strictly-protected nature reserves with minimal access by the public, where hunting, logging and all other forms of resource use are categorically banned. The other two sites (LLNP and ZOTI) are national parks where tourism is encouraged, but where hunting and logging are both prohibited. The landscape surrounding the four protected areas is mostly federal forest land, where timber resources are exploited and game species (including tiger prey species) are hunted and trapped.

All sites employ their own law enforcement staff members, who have the legal authority to apprehend violators, but only within their given protected area and its buffer zones. At all sites, protection is enforced by 2–5 “mobile” teams consisting of 2–6 individuals who conduct motorized and foot patrols. Roads are generally absent within these protected areas (except for former logging roads or forest roads maintained for access by reserve staff), but a network of foot trails linking patrol/research cabins are common, especially in the zapovedniks. Protected areas range in size from approximately 800 to 4000 km^2 (Table 1).

A suite of ungulates including key tiger prey species such as sika deer (*Cervus nippon* Temminck, 1838), wild boar (*Sus scrofa* Linnaeus, 1758) and Siberian roe deer (*Capreolus pygargus* Pallas, 1771) were present in varying densities at all four sites. Red deer (*Cervus elaphus* Linnaeus, 1758) occurred at all sites but LLNP.

Table 1 Four protected areas where SMART law enforcement monitoring was implemented (2011–2014), including start date, status, size, and initial, final and target numbers of tigers at each area in the Russian Far East

Site	LEM start date	Protected area status	Size (km^2)	Minimum numbers of Amur tigers		
				2011	2014	Goal†
Land of the Leopard (LLNP)‡	1 January 2011	National Park	2719	7	8	27
Lazovskii (LAZO)	1 January 2011	Reserve	1192	11	10	12
Zov Tigra (ZOTI)	1 January 2012	National Park	821	1	8	8
Sikhote-Alin (SABZ)	1 August 2011	Reserve	4016	9	19	40

†Potential numbers assuming densities of 1 tiger/100 km^2. ‡Results for 2011–2014 for only a portion of the entire park.

Law enforcement monitoring and management tools

The SMART and MIST computer software programs, which are based on geographic information system (GIS) technology, facilitate storage and analysis of spatial patrol monitoring data (www.ecostats.com, http://smartconservationtools.org). We initially used MIST in Russia at the four protected areas but have transitioned to SMART given its greater flexibility (e.g. Russian-language interface).

Law enforcement patrol teams use a global positioning system (GPS) to record their movements and on paper forms record violations, threats, wildlife sightings and other data considered useful for management. This information is subsequently entered into the software program by a protected area staff member, and then analyzed to assess activities and performance. The software can be programmed to provide data on patrol effort (e.g. distance covered, time spent on patrols and areas visited) and patrol results (e.g. the number of confiscated guns and issued citations) to patrol managers in a standardized, accurate and timely fashion.

Framework for using law enforcement monitoring and adaptive patrol management

Stokes (2010) proposed a framework for successful implementation of law enforcement monitoring based on prior experience at conservation sites in eight tiger range countries; including: (i) institutional support; (ii) availability of appropriate equipment and staff; (iii) standardized data collection; (iv) mechanisms for feedback of LEM results; (v) institutional stability; and (vi) protocols for access to and evaluation of LEM data at the provincial, national and international levels. We assessed capacity at each site to fulfill each of these components, and, as necessary, provided the necessary support to ensure progress could be made. At the same time, we attempted to increase capacity for protected area staff to absorb more management responsibilities.

We designed a straightforward and robust law enforcement monitoring and adaptive management system (subsequently, we use LEM to refer to the combination of these two components) with the following characteristics: the data model (that, in turn, defined field data collection requirements) was simple with only minor differences between sites and with a strong focus on documenting effort and violations. Violations were documented when a suspect was apprehended, when wildlife remains were discovered, or other extractive paraphernalia (e.g. baskets with pine nuts, snares and fishing nets) were confiscated or removed. Threats in the absence of a citable offense (e.g. when tracks of a trespasser or remains of a campfire were found, but the intruders themselves were not) were initially not recorded to minimize demands on patrol staff (these have been added later as inspectors became comfortable with the system, but are not reported here). In addition, tiger observations (e.g. tracks, excrement and visual encounters) were documented. Inspectors were responsible for filling out three data sheets while on patrol: (i) patrol information (date, individuals participating and mode of transport); (ii) violations (trespassing, poaching, logging, fishing and non-timber forest product collection); and (iii) observations or sign of tigers.

To ensure that teams were not prohibited from active patrolling due to lack of operational resources, financial support was provided to each protected area for fuel and maintenance of patrol vehicles. Because salaries of law enforcement staff at the four sites were low (approximately US$330/month when we began; this is half what a low-ranking police officer earned), we provided financial bonuses as a stimulus to patrol teams that performed well based on the efforts and results documented with LEM data. All reported patrol observations were rewarded in the bonus system, but had to be documented and verified (e.g. with photographs, videos and/or citation paperwork).

We established an adaptive patrol management cycle (i.e. review periods) on a quarterly basis in which the following activities occurred: (i) all data entry for the previous quarter was completed and quality checked; and (ii) data were analyzed and patrol performance reports were developed. During meetings in which all inspectors and their managers were present, (iii) patrol performance of the previous quarter was evaluated; (iv) bonuses were allocated appropriately; (v) patrol targets for the next period were defined; and (vi) information exchange and feedback between inspectors and management occurred.

A predictive model of successful law enforcement

To derive appropriate indicators of success (both short term and long term), we developed a simple predictive model that relates actions and responses to improved law enforcement (Fig. 1). We predicted that if patrol quality improved (which we defined as increased effort and greater temporal and spatial unpredictability; see below), there should be a decline in threats (our primary focus was on poaching rates). Because poaching in the Russian Far East is commonly focused on ungulates, we predicted that with a decline in poaching rates ungulate numbers should increase (with some lag time after a reduction in poaching). Consequently, if tiger numbers are depressed due to low prey densities, tiger numbers should increase some time after ungulate numbers have rebounded. Alternatively (not shown in Fig. 1), if tiger numbers are depressed due to direct persecution, tiger numbers may increase independently of ungulate numbers.

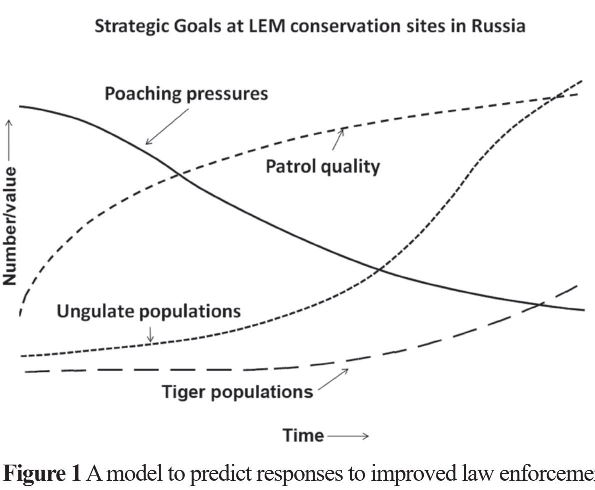

Figure 1 A model to predict responses to improved law enforcement and employment of the LEM system. Improved patrol quality leads to a reduction in threats which in turn results in a numerical response of ungulate populations, which in turn stimulates a numerical response in tiger numbers (assuming tiger numbers were depressed by inadequate prey numbers).

Indicators of success

Stokes (2010) provides a framework for achieving success with LEM, but does not define what constitutes success. Given the above model (Fig. 1), we sought to derive indicators of success for each of four processes (changes in: patrol quality, threats, prey numbers and tiger numbers; Table 2). These indicators were derived independently from protected area staff management; many (but not all) were incorporated into the protected area patrol strategy (see below).

Improved patrol quality

We sought to improve patrol quality by increasing effort and effectiveness. Instead of defining a specific target level of patrol effort, we focused on encouraging continuous improvements using three parameters: (i) kilometers covered on foot/month/patrol team; (ii) kilometers covered by motorized patrols/month/patrol team; and (iii) number of hours patrolled/month/patrol team.

We suspected that timing and locations of patrols were highly predictable both spatially and temporally prior to implementation of LEM, and that large sections of protected areas were not patrolled at all, a situation which would embolden poachers who recognized these spatial–temporal patterns. Therefore, we attempted to increase patrol effectiveness by encouraging increased spatial coverage as well as increased spatial and temporal unpredictability. We encouraged patrol teams to visit more and different parts of a protected area at varying times of day and night. We created a 1-km^2 grid network for each protected area and measured the number of times each grid cell was visited by patrol teams over the course of a year. We also recorded the time of day when patrols began and ended, and encouraged more nighttime (continuing after 2300

Table 2 Indicators of success for implementation of a law enforcement monitoring and adaptive management system for protected areas in the Russian Far East

Target		Parameter	Indication of success
Patrol quality			
	Patrol effort		
	i	km covered on foot/patrol team/month	Increased patrol km
	ii	km covered by motorized vehicles/patrol team/month	Increased patrol km
	iii	Time (h) on patrol/patrol team/month	Increased time on patrol
	Patrol effectiveness		
	i	% of 1-km^2 cells visited/year	Increase in percentage cells visited
	ii	% of 1-km^2 cells visited >10 times/year	Reduction in % visited >10 times/year
	iii	% of patrols conducted at night	Increase in number of night patrols
Threats			
	i	Number of firearms confiscated/1000 h on patrol	Reduction over years
	ii	Number of poaching violations/1000 h on patrol	Reduction over years
	iii	Number of citations for all other types of violations/1000 h on patrol	Reduction over years
	iv	Total amount of fines/year	Reduction over years
Target species			
	i	Sika deer tracks/10 km on defined survey routes	Increase in track abundance
	ii	Minimum number of tigers photographed/survey period	Increase in minimum number of tigers
	iii	Mark–recapture estimate of tiger abundance	Increased density to 1/100 km^2

hours) and early morning (beginning between 0000 and 0800 hours) patrols, which were initially rare (and when poachers are likely to be active). Following on from the three parameters outlined above, we defined indicators of success in increasing patrol effectiveness as: (iv) a decrease in the percentage of 1-km^2 cells not visited over the course of a year (indicating increased coverage); (v) a reduction in the number of cells visited more than 10 times in the course of a year (indicating reduced spatial predictability); and (vi) an increase in the number of night and early morning patrols. With these last three indicators, we were not seeking continuous increases (in contrast to patrol effort), but rather some proportional change from initial measurements to reduce the temporal and spatial predictability of patrols.

Reducing conservation threats

We predicted that improved patrol quality, as defined above by six indicators, should result in a reduction in threats (Fig. 1). We used catch per unit effort (CPUE; Walston *et al.* 2010) measurements as the number of violations/1000 h of patrol time on a yearly basis for 4 threat indicators: (i) number of firearms confiscated; (ii) number of poaching citations issued; (iii) number of citations for all other types of violations; and (iv) total amount of fines/year. If poaching rates declined, we predicted there should be a decline in the rate at which firearms are confiscated and poaching citations issued.

We averaged measurements of patrol effort (indicators i–iii) by month and then by year beginning with the LEM implementation date at each site in 2011 through 2014. SABZ and ZOTI began late in 2011; therefore, with small sample sizes, we do not present results for 2011 for these two sites. Coverage of each protected area by patrol teams (indicators iv–v) was averaged across years while the percentage of all patrols conducted early morning and night (indicator vi) was summarized by review period (generally three months, but ranging from two to five months). Measurements of conservation threats were summarized by year from 2011 to 2014, except for ZOTI and SABZ, which began collecting useful threat data in 2012.

Conservation target species: Ungulates

Assuming that poaching was depressing ungulate populations, we expected that improved patrol performance would result in increases in ungulate numbers, and expected that numerical responses should, in many cases, be more rapid than that of tigers. Monitoring of ungulates in some of the protected areas has been conducted for over 40 years (Stephens *et al.* 2006), but was improved and standardized during development of an Amur Tiger Monitoring Program (Miquelle *et al.* 2010). Non-random but fixed routes were traveled 1–3 times/winter, usually on foot or skis after a recent snowfall. All "fresh" (<24 h) tracks were recorded and species were differentiated by size and distinctive hoof patterns (Pikunov *et al.* 2004). Actual animal density can be derived from track density if daily travel distances are known (Stephens *et al.* 2006), but we used average track densities/10 km of transect as a simpler standard measurement because daily travel distance was, in most sites, not well defined. As examples, we provide results of yearly monitoring of sika deer, an important tiger prey species, at the three reserves with long-term ungulate monitoring programs (1997–2014). Because an absence of snow (an extremely rare event) prevented surveys in SABZ in 2014, we present information from 2015. Ungulate monitoring at ZOTI is still developing and results are not presented here.

Conservation target species: Tigers

We set an initial goal of recovering tiger numbers at all sites to 1 individual/100 km^2 (Table 1). This target is simplistic because: (i) habitat quality for tigers varies among sites; and (ii) it is a basic estimate of density (numbers/reserve area does not account for movements of individuals outside the reserves). Nonetheless, this goal provides a comprehensible target for managers and is a reasonable target for all sites.

To monitor tigers, we followed standardized protocols for establishing camera trap surveys of tigers (Karanth 1995) adapted for low density populations (Soutyrina *et al.* 2013). Briefly, pairs of camera traps (to photograph both sides of an animal) were set at locations where tigers are likely to travel and at a sufficient density to ensure some probability of capturing all tigers in the study area (usually approximately four pairs of camera traps per estimated female home range size). Individual tigers were identified by their unique stripe patterns. Camera trap studies began at different times and with different capacities at each of the protected areas. In 2 of the 4 protected areas (SABZ and LLNP) longer-term surveying has been conducted within a subset of the protected area, and in all sites sample sizes (numbers of tigers) have at least occasionally been too small to allow for robust mark–recapture analyses (study area size for camera trap surveys ranged in size from 309 to 1000 km^2). As human capacity and camera technology has improved (initially film cameras and weak batteries necessitated constant servicing of camera traps), survey areas have expanded so that currently all protected areas are fully surveyed each year with spatially-explicit mark–recapture analyses (Gopalaswamy 2013) conducted (e.g. Hernandez-Blanco *et al.* 2013). However, to provide a longer-term perspective on tiger numbers, here we provide a simple estimate of the minimum numbers of tigers captured by camera traps during a survey period on a yearly basis at each site.

RESULTS

Patrol quality

The number of kilometers patrolled per month on foot showed consistent yearly increases in 3 of the 4 protected areas, with only a slight decline in LLNP in 2014 (Fig. 2). Across all sites the number of kilometers covered on foot patrols in the 4th year was on average 1.9 times greater than in the first year.

The number of kilometers covered by motorized patrols per month also generally increased over the study period (Fig. 2). Kilometers by vehicle/month/team increased on average 3.5 times over all 4 sites from 2011 to 2014, but improvements in motorized patrols were variable across sites, with SABZ showing dramatic increases from 2011 to 2014, and LAZO showing no increase (Fig. 2). Analyses after two years at LAZO and LLNP revealed that the vast majority of poachers were captured during foot patrols (Hötte *et al*., unpublished data), and we consequently encouraged greater numbers of foot patrols at all sites by emphasizing this component in the bonus system. Motorized patrols were more effective in detecting other types of illegal activity in the protected areas (e.g. illegal intrusions), but the emphasis on foot patrols may have resulted in less consistent results for motorized patrols.

Total time per month spent on patrols increased consistently at all sites across the 4 years (Fig. 2).

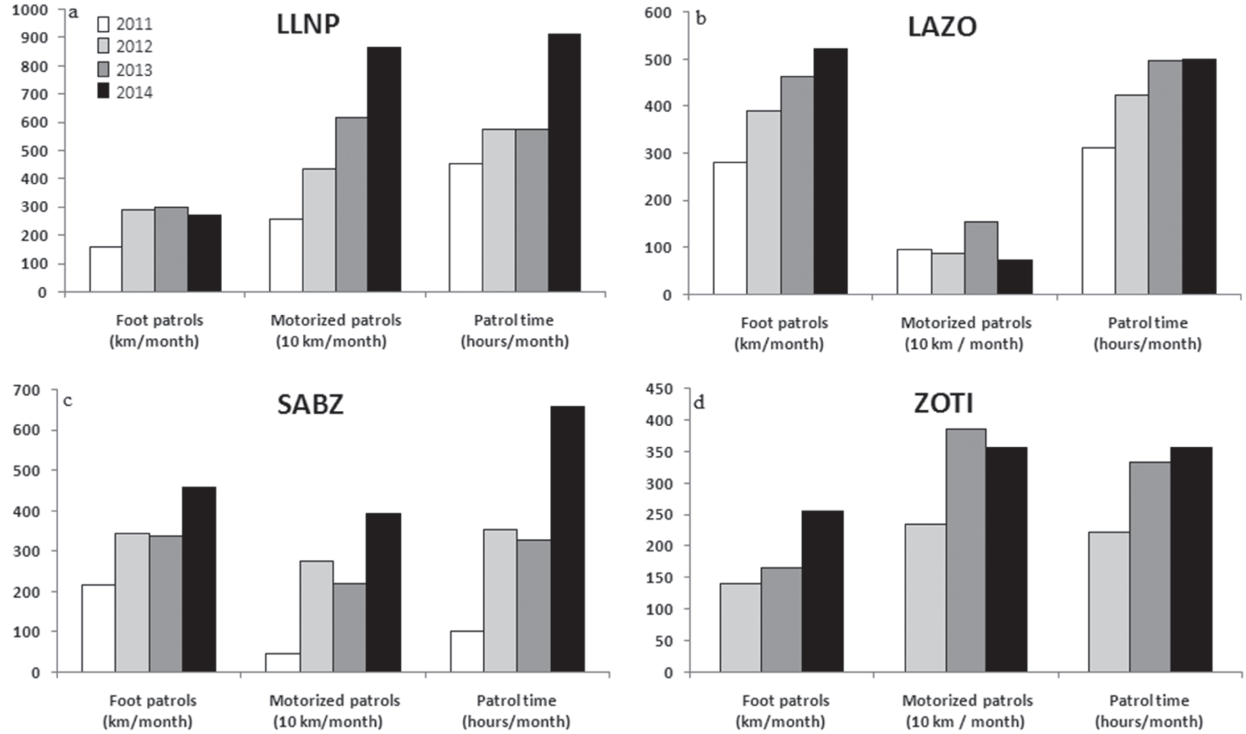

Figure 2 Three indicators of law enforcement effort in 4 protected areas [a] Land of the Leopard National Park, [b] Lazovskii State Zapovednik, [c] Sikhote-Alin Biosphere Zapovednik and [d] Zov Tigra National Park) of the Russian Far East, 2011–2014: (i) number of kilometers travelled on foot per month by teams of inspectors; (ii) number of kilometers travelled by vehicle, motor bike, snowmobile, or all-terrain vehicle per month by teams of inspectors; and (iii) total time spent on patrol per month (in hours) for teams of inspectors. Data for 2011 for Sikhote-Alin Biosphere Zapovednik are based on the period 1 August–31 December, and no suitable data was collected in 2011 in ZOTI. All other data are based on full calendar years.

Overall, time spent on patrols in 2014 was 2.9 times greater than when the program began in 2011.

Overall, quarterly reviews of all three patrol effort indicators demonstrated increases from the previous quarter a total of 24 times, and decreases only 8 times, with the relative increase on average much greater than the decreases.

Patrol effectiveness indicators were not as consistent. LAZO and LLNP showed small declines (7–11%) in the number of cells not patrolled over the 4 years, suggesting better and expanded coverage of the protected area (Fig. S2). SABZ and ZOTI showed no clear trends. SABZ consistently had the largest percentage of 1-km^2 cells not visited (73–82%) partly due to the fact that this is the largest and most remote of the 4 protected areas. There was no consistent decrease in the number of cells visited greater than 10 times at any of the sites (Fig. S2), suggesting that spatial predictability remained close to initial levels.

After initially documenting few or no nighttime/early morning patrols over the first several review periods, increases in such patrols occurred at all four sites when they were identified as a priority (Fig. 3). However, response levels varied greatly among protected areas, and at nearly all sites, after initial positive responses “fatigue” set in and the percentage of nighttime patrols declined (Fig. 3). Nonetheless, for all sites combined the average percentage of nighttime/early morning patrols during the last three review periods was 16% higher than the initial 3, indicating that some progress had been made in decreasing the temporal predictability of patrols.

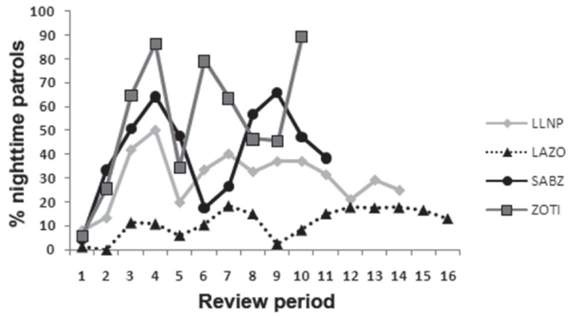

Figure 3 Percentage of all patrols begun at night or early-morning for sequential reporting periods (usually 3 months) at 4 protected areas using law enforcement monitoring (LLNP, Land of the Leopard National Park; LAZO, Lazovskii State Zapovednik; ZOTI, Zov Tigra National Park; and SABZ, Sikhote-Alin Biosphere Zapovednik), 2011–2014. Data collection began at different times and reporting periods varied in length, so number of periods varied among protected areas.

Reducing conservation threats

Poaching rates (poaching citations/1000 h patrol time) were highest in the first year at LLNP and LAZO, and while there has been a consistent decline in LLNP, the rate of poaching citations increased in 2013 at LAZO (although not to 2011 levels) before dropping again in 2014 (Fig. 4). The rate at which firearms were confiscated in LLNP and LAZO dropped across the 4 years, but, again, not consistently (Fig. 4). Confiscation of firearms and poaching citations were either completely or practically absent at the other two sites. The citation rate for other violations varied among sites, showing no clear trends (LLNP and LAZO), increasing (SABZ) and decreasing (ZOTI). Total fines/1000 patrol hours was the most variable threat indicator, reaching a high in 2013 at LLNP, showing an increasing trend in LAZO and SABZ, and decreasing over 2 years after an initial high rate in ZOTI (Fig. 4).

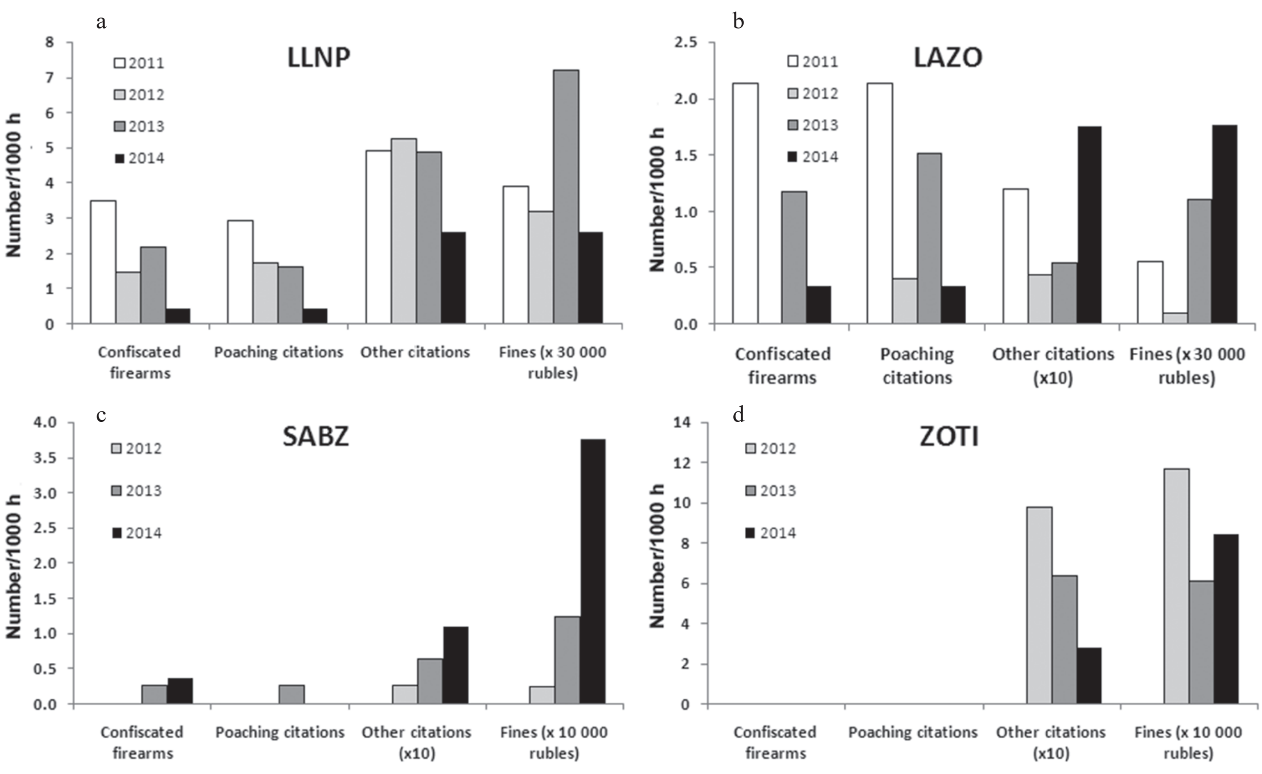

Figure 4 Four "catch per unit effort" indicators of success in reducing conservation threats in 4 protected areas of the Russian Far East: (a) Land of the Leopard National Park; (b) Lazovskii State Zapovednik; (c) Zov Tigra National Park; and (d) SABZ, Sikhote-Alin Biosphere Zapovednik), 2011–2014. (1) Number of confiscated firearms/1000 h patrol time; (2) number of poachers cited per 1000 h patrol time; (3) number of other citations (in addition to the first 2) per 1000 h of patrol time; and (4) amount of fines (in rubles) per 1000 h of patrol time.

Ungulate densities

Data on sika deer track densities showed varying trends at the 3 protected areas where long-term monitoring has been conducted (Fig. S3). Sika deer numbers in LLNP seemed to be in a long-term decline, while numbers were increasing at SABZ. Implementation of LEM has not resulted in any noticeable trends at either LAZO or LLNP, but an increase in sika deer numbers at SABZ does appear to have occurred after LEM began (Fig. S3).

Tiger numbers

Tiger surveys began at varying times, starting earliest in LLNP (2005), while beginning in ZOTI only in 2011.

The minimum number of tigers photographed/year has remained stable or increased since the implementation of LEM at all 4 sites (Table 1, Fig. S4). Tiger numbers in LAZO increased prior to the introduction of LEM and after the apprehension of a poacher with skins identified (from camera trap photos) to be from LAZO (Kerley *et al.*, unpubli. data), with a spatially-explicit mark-recapture estimate of 12 ± 3 in 2014. In SABZ the tiger population collapsed around 2010 due to multiple factors (Miquelle *et al.* 2015), but appears to be rebounding: the 2014 survey of the entire reserve estimated 20 ± 12.3 tigers (Soutyrina *et al.*, unpubl. data). Numbers of tigers in LLNP appear to have increased within the study area since surveys were initiated (2005), with the most recent survey of the entire park resulting in an estimate of 22 ± 3.5 (Rybin *et al.*, unpublished data). ZOTI initially had few tigers, but numbers there appear to have increased dramatically during the relatively short survey period (Table 1, Fig. S4). Only ZOTI has achieved the goal of recovering tiger numbers to 1/100 km^2 (Table 1).

DISCUSSION

Law enforcement monitoring was successfully implemented, and after four years is still functional at all four protected areas (to date, two more protected areas with tigers have implemented the use of SMART LEM in the Russian Far East). Implementation of LEM at each of the study sites largely conformed to the 6-component framework proposed by Stokes (2010). We received support for implementing LEM from site management (Component 1); we were able to develop appropriate levels of standards for training, and there already existed adequate staffing and equipment (Component 2). The amount of time needed to institutionalize standardized data collection protocols (Component 3) varied among sites, from just a few months to almost a year. Due to staffing limitations, feedback meetings (i.e. review periods; Component 4) were held only quarterly at all sites, and were totally dependent on non-protected area staff for the first 2 years. In general, there was adequate institutional stability for LEM implementation (Component 5) but it quickly became apparent that strong support from directors was critical for successful implementation. At one site implementation was not successful until the directorship changed hands. Although support from directors has greatly increased over time, there is so far scant institutional support from provincial or federal conservation agencies, and, therefore, as yet there is no dissemination, access to or evaluation of law enforcement monitoring data at the provincial, national and international levels (Component 6). However, some directors of sites with SMART are suggesting dissemination across the protected areas system within the Russian Federation.

The bonus system employed in the Russian Far East is somewhat controversial in the implementation of LEM systems. Globally, they are used at some sites and strongly opposed at others. The decision to include a bonus system is very much site-specific and is dependent on culture, traditions, staff morale, available budgets and other factors. We designed a system in which inspectors collected only data that can be independently verified, and we built a bonus system to reward all patrol efforts, results and observations. In more favorable circumstances (e.g. with higher staff morale), a bonus system is probably not needed and could even have negative effects. We found that the bonus system stimulated friendly competition between patrol teams and was at least partially responsible for the observed increases in patrol effort. For this type of stimulation to be effective, teams must operate with some degree of independence in deciding where and when to patrol, but with close oversight by reserve management. We recommend introducing bonuses only if it is possible to provide financing long term, because discontinuation is likely to have a very negative impact on inspector morale and patrol efforts. However, bonus systems dependent on obtaining a fixed target (e.g. x km, x h) are least desirable, because once targets are met, there is no motivation to continue to improve and it is difficult to subsequently change targets without discontent from inspectors.

Patrol quality indicators

Introduction of LEM in 4 federally-protected areas in Amur tiger habitat overall produced a substantial increase in patrol effort based on the parameters we used (Table 2). All three indicators of patrol effort showed consistent increases over the four years LEM was used. While we recognize that such consistent improvement will not continue indefinitely, the adaptive management process of monitoring and setting targets for patrol teams (with regular meetings to assess and review) appears to have been at least partially responsible for increasing effort. Attempts to reduce spatial and temporal predictability of patrols were partially successful. The proportion of nighttime/early morning patrols initially increased when patrol teams were asked to conduct more of such patrols, but has declined in all places, although not to original low levels.

Whereas patrol coverage improved somewhat at two sites, the other two sites showed no change, and repeated visits to some areas (high predictability) persisted despite our efforts to reduce this tendency. Goals delineated within the context of the LEM program were not always fully endorsed by the management team at a protected area, sometimes with good reason. For instance, simply increasing coverage (increasing the number of cells visited) may not always be an effective strategy. In winter, it is possible to monitor entry to most of the protected areas by patrolling the border and searching for tracks in the snow. In such a situation, the percentage of cells visited is probably not a good indicator of patrol effectiveness. In other situations, repeated visits to particular cells makes strategic sense: for example, during salmon runs patrol teams constantly monitor rivers to capture poachers. Therefore, such indicators should probably be revised in view of these lessons learned.

Patrol intensity in the Russian Far East might be considered low compared to other tiger conservation sites in Asia, especially in tropical areas. However, at least for 3–5 months per year snow cover makes it nearly impossible for a poacher to enter a protected area without leaving an obvious trail, making detection and apprehension of poachers easier. In contrast to much of Asia, there are also hunting/poaching opportunities outside protected areas, where punishments are lower. Nonetheless, as already demonstrated, increasing patrol intensity has been a priority within the context of this LEM program, and will likely be a key factor in decreasing threats.

Conservation threat indicators

Estimates of CPUEs showed much more fluctuation than indicators of patrol effort. While poaching rates clearly declined in two of the four sites over four years, the changes were not as consistent in comparison to patrol effort. Patrol data can be heavily biased (Keane *et al.* 2011), and, subsequently, CPUEs have their pitfalls. CPUEs can be a reliable index of poaching rates, assuming: (i) patrol records are reliable; (ii) the relationship between law enforcement effort and catch is constant; and (iii) CPUE is proportional to the true abundance of the threat (Walston *et al.* 2010). While we worked hard with patrol staff to ensure patrol records were reliable, it is unlikely that the relationship between law enforcement effort and catch rates is constant across all seasons. We have no way to assess whether the CPUEs we used were proportional to the true abundance of threat. Clearly, CPUEs must be interpreted with caution, but they still represent a relatively simple and repeatable index of poaching pressure that may provide useful indicators within any given reserve (Moreto *et al.* 2014). Additional years of data collection may provide clearer evidence of the trends and usefulness of CPUE estimates. At the same time, it would be useful to examine what factors influence CPUE estimates of poaching rates and how we may better estimate poaching pressures within protected areas (Moreto *et al.* 2014).

While in many sites where LEM is implemented inspectors collect more data on conservation threats (e.g. human footprints, fire scars and encroachment; Plumptre *et al.* 2014), we initially decided not to collect this type of data so as not to overwhelm inspectors with too many responsibilities. We have since included this category of data, but believe our indicators of firearms confiscation and poaching violation rates provide sufficient information to track trends of the major threats to tigers.

While it is impossible to directly compare patrol effort and poaching rates to the period previous to LEM implementation (as no data exist), based on discussions with inspectors it appeared that effort was lower and poaching rates were higher. While LEM is not the only reason for these changes, it has, at the very least, provided a means for measuring changes in patrol effort and effectiveness, as well as the level of threats.

The absence (or near absence) of confiscated firearms and poaching citations at SABZ and ZOTI are not necessarily indicative of low poaching rates. Morale of inspector staff at SABZ was extremely low through most of the period in question, and incentives to take any risks to capture poachers were small. ZOTI is a high-elevation protected area, and deep snows in winter reduce human access, so poaching rates may, indeed, be lower there than in other protected areas. Nonetheless, the absence of poaching citations also suggests that problems still exist within inspector ranks there.

Hence, while it is clear that LEM by itself will not guarantee improvements in law enforcement at protected areas, it provides a lens through which it is possible to identify potential problems and rectify them. For instance, morale (and effort to capture poachers) at SABZ has increased noticeably with the arrival of a new director, and effort and numbers of citations have recently increased (Figs 2,4), a reflection of this change.

Conservation target indicators

Ungulate monitoring programs were in place at three of the four protected areas before implementation of LEM. However, variance associated with these surveys is large, and we recognize the need to expand survey effort to reduce variance and, thereby, better detect trends. However, even with increased sampling, we expect fairly high variation in counts, requiring multiple years of data to detect clear trends.

We did not expect to detect noticeable trends in ungulate numbers after a 3–4 year period of LEM implementation, and, therefore, the absence of such trends is not of particular concern. Nonetheless, the increase in sika deer numbers in SABZ in 2015 (Fig. S3) is intriguing. Poaching of sika deer along a road that passes through the reserve was common in the past, and the increase in 2015 coincides with indicators of increased patrol effort and the capture of some poachers working this area through 2014 (Fig. 2). However, sika deer numbers appear to be increasing in SABZ (while declining in LLNP) since 1997, independent of law enforcement efforts. Therefore, any short-term changes must also be interpreted in the context of these longer-term trends (Fig. S3).

Minimum number of tigers derived from camera traps is not an ideal indicator (there is no estimate of detectability or error associated with the value) but given similar effort (duration of survey, locations of camera traps and numbers of camera traps being consistent) it can provide a crude indicator of trends in tiger numbers. At all sites this indicator suggests tiger numbers were increasing or at least stable after implementation of LEM. While the timeline is short, these results provide some indication that law enforcement efforts may be assisting in the recovery of tigers, independent of any change in ungulate numbers. This numerical response in tiger numbers independent of a response by prey species is consistent with studies that indicate that direct poaching of tigers is by far the most common source of mortality (Goodrich *et al.* 2008; Robinson *et al.* 2015) and is likely limiting population growth (Chapron *et al.* 2008). The process of improving and expanding camera trap survey effort in all protected areas has taken time and was partially dependent on camera trap technology. We have finally achieved a level of survey intensity and consistency to provide more rigorous estimates of tiger numbers that will allow more accurate monitoring in the future.

Management implications

We observed that the introduction of LEM usually led to an immediate improvement in patrol effort and quality, but proportional increases decline over time as effort reaches a plateau limited by number of workdays and other responsibilities of staff. Nevertheless, monitoring was extremely useful in quickly identifying negative trends in patrol effort that could then be addressed and corrected in a timely fashion.

We are still refining components of this monitoring system. Improvements in monitoring target species are ongoing, with regular review and assessment of methods and results allowing us to improve over time. Similarly, there is a need to review and assess the indicators of patrol quality and threats to ensure they are appropriate. Our intent here is not to demonstrate that dramatic improvements have occurred at any one site, or to suggest that these indicators are appropriate elsewhere, but to demonstrate that such a system provides a powerful lens through which it is possible to assess and improve law enforcement efforts. This fairly complex set of monitoring tools takes time to develop and needs to be regularly re-assessed, but provides a tool which can impartially assess how changes in management lead (or fail to lead) to improved law enforcement. Other indicators may be more appropriate at other sites, but in all situations monitoring progress with a suite of short-term and long-term indicators of the multiple components of the system (patrol effort and effectiveness, threats, indications of poaching levels and biological monitoring) will ultimately allow assessments of law enforcement quality, and whether increased patrol quality is correlative with changes in target species abundance. This level of accountability is essential if we are to openly assess the successes and failures of our conservation interventions, and adjust our interventions in continuous management cycles of improvement. We hope that similar monitoring systems will be applied in other sites where LEM is being deployed so that collectively we can define determinants of success.

ACKNOWLEDGMENTS

We thank the Liz Claiborne and Art Ortenberg Foundation, the North American Association of Zoos and Aquariums, the Disney Conservation Fund, Feld Entertainment, the Gordon and Betty Moore Foundation, the Phoenix Fund, the Tigris Foundation, the United States Agency for International Development (USAID; Associate Award #118-A-00-11-00007-00), the United States Fish and Wildlife Service's Rhinoceros and Tiger Fund (grant numbers F10AP00399 and F14AP00659), the Columbus Zoo and the Zoological Society of London for their financial support of the SMART program in Russia. We are grateful to Yevgeny Stoma for trial testing the collection of data for the LEM program, and we thank the staff and directors of Lazovsky State Zapovednik, Land of the Leopard National Park, Zov Tigra National Park and Sikhote-Alin Biosphere Zapovednik for agreeing to participate in this program and for their efforts to make SMART a success.

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SUPPORTING INFORMATION

Figure S1 Four federal-level protected areas in Primorskii Krai, Russia, where SMART law enforcement monitoring and adaptive management were implemented in 2011, numbered here based on the order in which LEM was implemented (1= Land of the Leopard National Park, 2 = Lazovskii State Zapovednik, 3 = Sikhote-Alin Biosphere Zapovednik, 4 = Zov Tigra National Park).

Figure S2 Patrol frequency at four protected areas in the southern Russian Far East: Land of the Leopard National Park (LLNP), Lazovskii State Zapovednik (LAZO), Zov Tigra National Park (ZOTI), and Sikhote-Alin Biosphere Zapovednik (SABZ). Values show the proportion of 1-km^2 grid cells that were patrolled 0, 1, 2, 3-4, 5-10, or >10 times in a given year. A reduction in the proportion of "0" cells visited over time would indicate more complete coverage of the protected area, and a reduction in the proportion of cells visited >10 times would indicate less predictable patrolling.

Figure S3 Mean number of sika deer tracks/10 km (+/- standard error) along long term (since 1997) fixed survey routes in 3 protected areas where LEM was implemented in 2011: a) Lazovskii State Zapovednik; b) Land of the Leopard National Park; and c) Sikhote-Alin Biosphere Zapovednik (data for 2014 in SABZ was not collected due to absence of snow: data for 2015 is presented).

Figure S4 Camera trap estimates of tigers in 3 protected areas of the Russian Far East: Lazovskii State Zapovednik (LAZO) results using mark-recapture M_h model, while results for other protected areas (LLNP= Land of the Leopard National Park, ZOTI = Zov Tigra National Park, and SABZ = Sikhote-Alin Biosphere Zapovednik) reflect only minimum number of tigers photographed at each protected area per year.

Cite this article as:

Hötte M, Kolodin I, Bereznuk S *et al*. (2016). Indicators of success for smart law enforcement in protected areas: A case study for Russian Amur tiger (*Panthera tigris altaica*) reserves. *Integrative Zoology* **11**, 2–15.