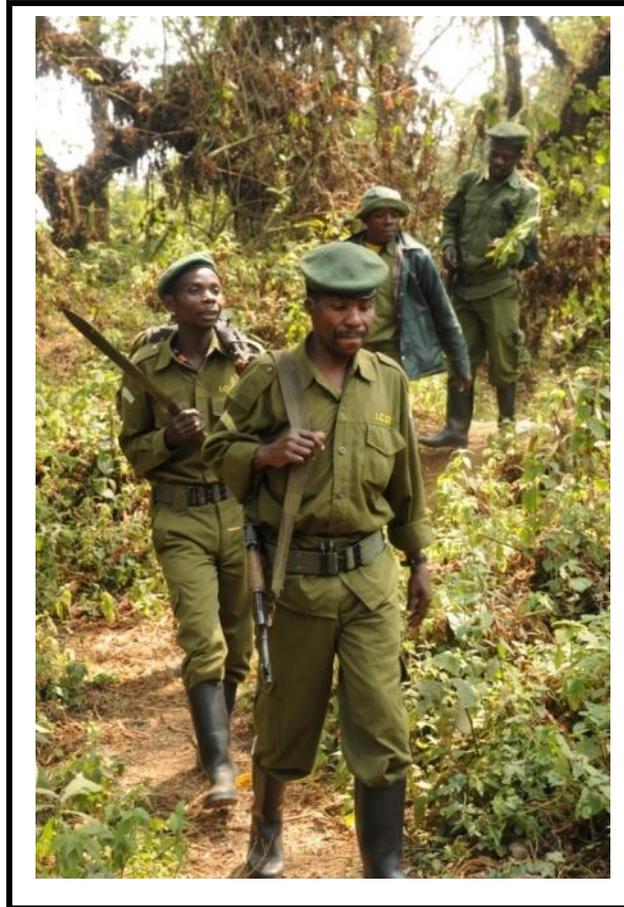


Improving ranger patrol effectiveness and efficiency using law enforcement monitoring data



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Introduction

Illegal activities such as poaching and harvesting of natural products are increasing and a major threat to biodiversity throughout many protected areas (Hilborn *et al.* 2006; Keane *et al.* 2008; Underwood, Burn & Milliken 2013; Biggs *et al.* 2013). Conservation of protected areas, especially in regions with high biodiversity, requires effective law enforcement policies at all levels, from efficient ranger patrols on the ground, through uncorrupted criminal justice systems, to trade restrictions (Keane *et al.* 2008). Ranger patrols are particularly important for successful law enforcement because the rangers in the field represent the primary deterrent that render higher-level policies such as financial deterrents and imprisonment effective (Milner-Gulland & Leader-Williams 1992; Leader-Williams & Milner-Gulland 1993; Rowcliffe, de Merode & Cowlishaw 2004).

While policies such as trade restrictions and education can be effective management tools to reduce illegal activities (Rosen & Smith 2010; Laurance 2013; Gandiwa *et al.* 2013), the effectiveness of law enforcement in the field is regularly identified as the key to successful law enforcement (Leader-Williams & Milner-Gulland 1993; Hilborn *et al.* 2006). In criminology, it is now common for police forces to spatially map illegal activities to inform and improve the efficiency of police resources (Andresen 2005; Chainey, Tompson & Uhlig 2008). Surprisingly, therefore, there have been few studies assessing the spatial distribution of illegal activities in protected areas in relation to the distribution of ranger patrols, and even fewer attempts to identify how to improve the ranger patrol strategies to focus on areas where illegal activities are most likely to occur. In phase one of our work (Critchlow, *et al.* 2014) we developed methods to use ranger-derived monitoring data to create spatio-temporal maps of different classes of illegal activity across Queen Elizabeth National Park. We found that different types of illegal activities (e.g. poaching for high-value commercial animal products versus encroachment by cattle) occur in different geographic regions of a protected area, meaning that the optimal ranger patrol strategies to target different types of activity should be in different areas. The second stage of this project is to use the spatial crime maps generated during the first phase to identify the efficiency of the current patrol strategy in relation to patterns of illegal activity, and ultimately to develop methods allowing the identification of the optimal patrol strategy for any given set of conservation priorities to be identified using the existing patrol resource.

Methods

In previous analyses fully described elsewhere (Critchlow *et al.* in prep) we identified the spatial and temporal patterns of illegal activities (Table 1) within the Queen Elizabeth National Park (QENP), Uganda by fitting a series of Bayesian, spatially explicit occupancy models (Figure 1a). We fitted separate models to each class of activity across the entire time period (1999-2012). These models required information on the spatial patterns of observer effort and the covariates likely to influence levels of illegal activity, and allow estimation of the underlying patterns of illegal activities independently of the probability of detecting

such activity. Within the covariates we included a number of variables that are likely to influence the distribution of illegal activities such as animal densities, habitat type and primary productivity. All covariates, evidence of illegal activities and ranger patrols were extracted to a 500m resolution grid. Using the outputs of these models, we can now analyse the behaviour of ranger patrols in order to increase patrol efficiency.

Table 1. Classification of illegal activities within the Queen Elizabeth National Park

Illegal activities	Example of values in MIST database ¹	Number of records
Encroachment	Livestock grazing, mining, trespassing	1570
Fishing	Fishing	443
Plant Commercial	Pitsawing, cultivation	260
Plant Non Commercial	Medicinal Plants, grass harvesting	605
Animal Commercial	Hippo, Elephant, Buffalo	241
Animal Non Commercial	Snares, other animal hunting, honey harvesting	1589

Calculating expected number of detections:

The process we used to estimate the expected number of cells with detections of each class of illegal activity is relatively straightforward. Every 500 m cell has both an estimate of the probability of illegal activity occurring (Figure 1a) and a known amount of ranger effort (Figure 1b). Ranger effort was measured as a utilisation distribution (UD), which is an estimate of probable routes and time spent between known locations, and has arbitrary units. From the initial modelling stage, we know the relationship between ranger effort and the probability of detecting each illegal activity (D_i) given that it has occurred in the focal cell (equation 1; Figure 1c).

$$D_i = 1 - \exp(-1 \times Eff_i \times \beta) \quad (\text{equation 1})$$

Where Eff is observer effort and β is a parameter estimating observer efficiency from phase one of the study (in practice we use all 1000 parameter estimates from 1000 samples of 10000 Markov Chain Monte Carlo (MCMC) iterations after a burn-in of 1000 iterations from a Bayesian occupancy model estimating the probability of occurrence of illegal activities). To calculate the expected number of detections (N) we then simply need to multiply the detection probability given that the activity has occurred (Figure 1d) by the probability of occurrence in each cell, and sum for all cells (equation 2):

$$N = \sum D_i \times P_i \quad (\text{equation 2})$$

¹ From Observation or Observation_Code columns within ranger patrol (MIST) database

Where P_i the occurrence probability in cell i (again in practice we use the 1000 estimates of the MCMC output to fully incorporate uncertainty).

Calculating optimal strategies:

The optimal patrol strategy for maximizing the detection of any given class of illegal activity is simply the strategy that places maximum patrol effort in areas with maximum probabilities of occurrence of that class of activity. In practice, we implemented this by ordering the existing ranger patrol effort in each cell according to the ranked probabilities of each activity occurring per cell, so that the highest probability cells received the greatest amount of effort (Figure 1e).

By substituting the optimal patrol strategy in place of the spatial pattern of existing ranger effort (Eff) in equation 2, we can then estimate the number of detections (and associated uncertainty) for any given strategy (Figure 1f).

To identify the patrol strategy that simultaneously optimises multiple conservation priorities (e.g. maximise efficiency of detecting all six illegal activities simultaneously, or instead focus mainly on commercial animal poaching, but also include encroachment and other illegal activities at lower priorities) is more complex. As an illustration of the potential for using our models to inform such strategies we decided to illustrate four different strategies: one representing the optimal mix of all six, a second focussing evenly on both classes of animal poaching but with no consideration of other activities, and two representing different proportional weightings to the two animal poaching categories and encroachment (40 % commercial animal, 40 % non-commercial animal and 20 % encroachment, or 60 %, 30 %, 10 % respectively). To optimize ranger effort to target all illegal activities simultaneously ('Optimal mixed strategy') we selected the maximum normalized probability values for each cell from across the six illegal activities and used the rank of these probabilities to order existing ranger effort as before. To create blends we first weighted the normalised probability values for each illegal activity according to the required conservation priorities assigned to them.

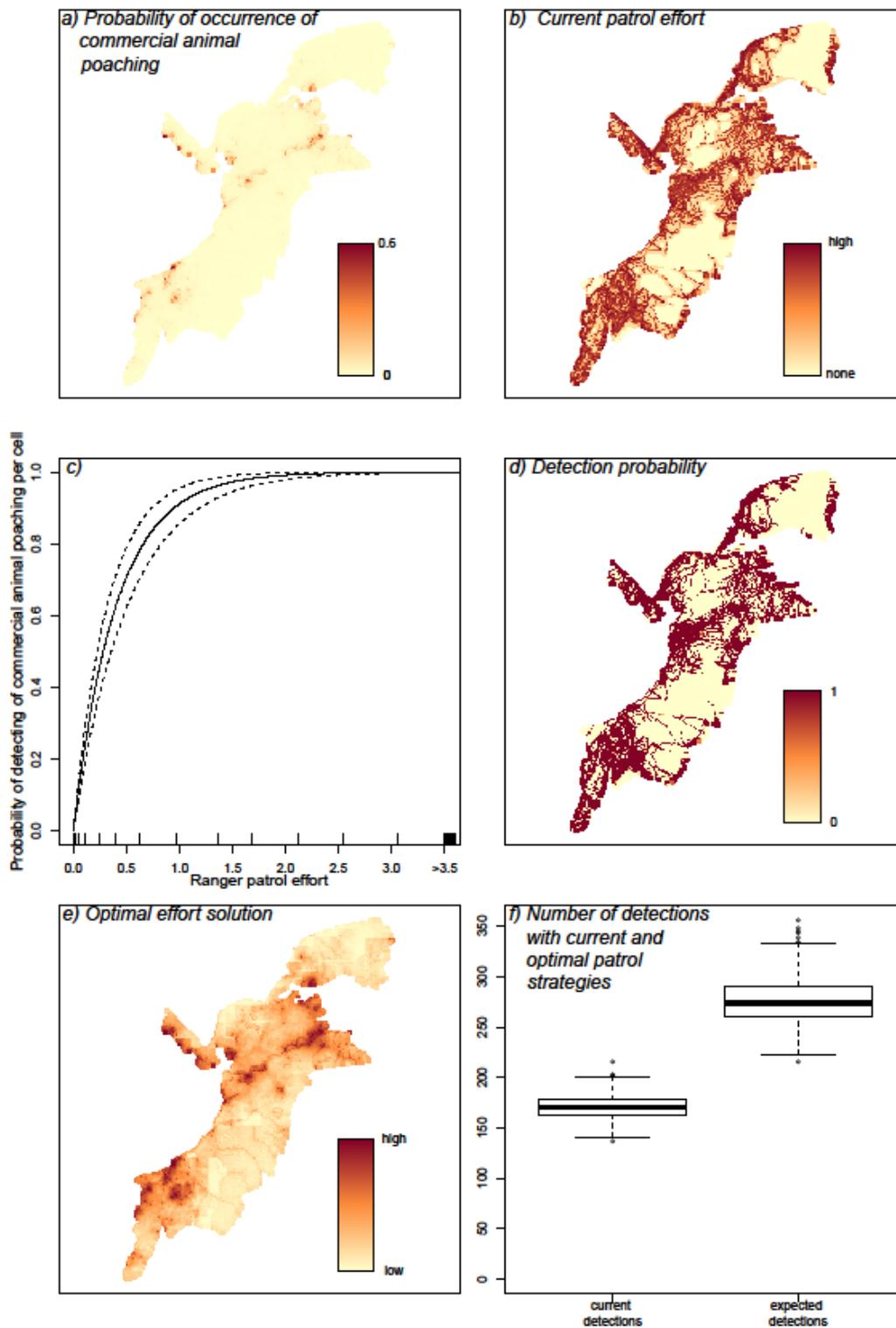


Figure 1. Commercial animal poaching in the Queen Elizabeth National Park, Uganda. (a) Current estimated probability of occurrence. (b) Current ranger patrol effort. (c) Modelled relationship between probability of detection and patrol effort (including 95% confidence intervals). Rug plot indicates the percentile distribution of patrol effort (UD). (d) Current effective detection probability given (b) and (c). (e) Optimal ranger patrol strategy. (f) Expected detections of animal poaching using current effort and using optimal strategy

Differences between current and optimal strategies:

To identify areas where current patrol effort is either too high or too low relative to optimal strategies we simply subtracted the two values. As a further complication we recognised that there may be cells for which irrespective of what optimisation strategy is chosen, recommended patrol effort should always increase, or should always decrease. Cells where increased effort is always recommended were identified as the difference between current patrol strategy and the minimum recommended effort from optimisation for any of the five terrestrial classes of illegal activity (i.e. excluding fishing), cells where decreased effort is always recommended were identified using the difference from the maximum recommended effort for all five activities.

Results

Optimising for each activity will increase the number of cells reported with illegal activities for each group (Table 2). The current patrol strategies are detecting between 28.9% and 62.4% of the cells with illegal activities that would be identified using strategies optimised for each activity in turn. Optimizing ranger effort for any activity always results in an increase in detections of most other categories of activity with respect to current patrol strategy.

The optimal mixed strategy suggests patrol effort should be directed to the periphery of the QENP and along the Kazinga Channel, with the greatest amount of effort would be focussed on eastern parts of the Maramagambo (Figure 2a). It would result in around a 50 % increase in detections in most classes of activity with respect to current, and should detect a minimum of 80 % of the optimal strategy for each class in turn (Table 2). Arranging patrols to focus different proportions of effort on encroachment, commercial animal poaching and non-commercial animal poaching (Figure 2b-d) indicates that a greater number of cells in the south of the QENP would receive high amount of effort than the optimal mix. All four strategies would improve detection of all illegal activities with respect to current ranger effort, with the differences between these and current patrol strategies shown in Figure 3 and Table 2.

Irrespective of chosen patrol strategy, we identified areas within the QENP that require increases or decreases relative to the current patrol effort (Figure 4). Areas where current patrol effort is too high are mostly in the south and central regions of the QENP, whilst areas where current effort is too low are dominated by large areas in the north and south-east of the QENP.

Table 2. Expected mean number of cells reporting illegal activities within the Queen Elizabeth National Park, Uganda, assuming the optimum patrol strategies for each class of illegal activity. Optimal patrol strategies are defined by matching patrol effort according to cells with high probability of illegal activity. Values in bold represent the number of expected cells recorded with each illegal activity for the optimum strategy would report, Values in brackets represent the percent of the optimum achieved for each given alternative strategy.

		Expected number of cells with detections of:					Plant Non-commercial
		Animal Non-commercial	Animal Commercial	Encroachment	Fishing	Plant Commercial	
Effort optimised for:	Animal Non-commercial	1511 (100%)	130 (47.4%)	696 (62.1%)	302 (57.6%)	150 (55.6%)	358 (64.4%)
	Animal Commercial	733 (48.5%)	274 (100%)	396 (35.3%)	238 (45.4%)	70 (25.9%)	202 (36.3%)
	Encroachment	965 (63.7%)	109 (39.7%)	1121 (100%)	304 (58.0%)	175 (64.8%)	376 (67.6%)
	Fishing	881 (58.3%)	146 (53.3%)	629 (56.1%)	524 (100%)	110 (40.75)	286 (51.45)
	Plant Commercial	827 (54.7%)	98 (35.8%)	623 (55.6%)	261 (49.8%)	270 (100%)	362 (65.1%)
	Plant Non-commercial	966 (63.9%)	111 (40.5%)	729 (65.0%)	300 (57.3%)	207 (76.7%)	556 (100%)
Alternative patrol strategies. Expected number of cells with detections of:	Current	763 (50.5%)	171 (62.4%)	583 (52.0%)	205 (39.1%)	78 (28.9%)	257 (46.2%)
	optimal mix	1209 (80.0%)	219 (79.9%)	958 (85.5%)	449 (85.7%)	240 (88.9%)	484 (87.1%)
	50% each animal poaching	1398 (92.5%)	250 (91.2%)	615 (54.9%)	296 (56.5%)	121 (44.8%)	317 (57.0%)
	40% non-commercial animal, 40% commercial animal, 10% encroachment	1357 (89.8%)	243 (88.7%)	932 (83.1%)	308 (58.8%)	130 (48.1%)	343 (61.7%)
	30% non-commercial animal, 60% commercial animal, 10% encroachment	1304 (86.3%)	256 (93.4%)	810 (72.3%)	294 (56.1%)	112 (41.5%)	316 (56.8%)

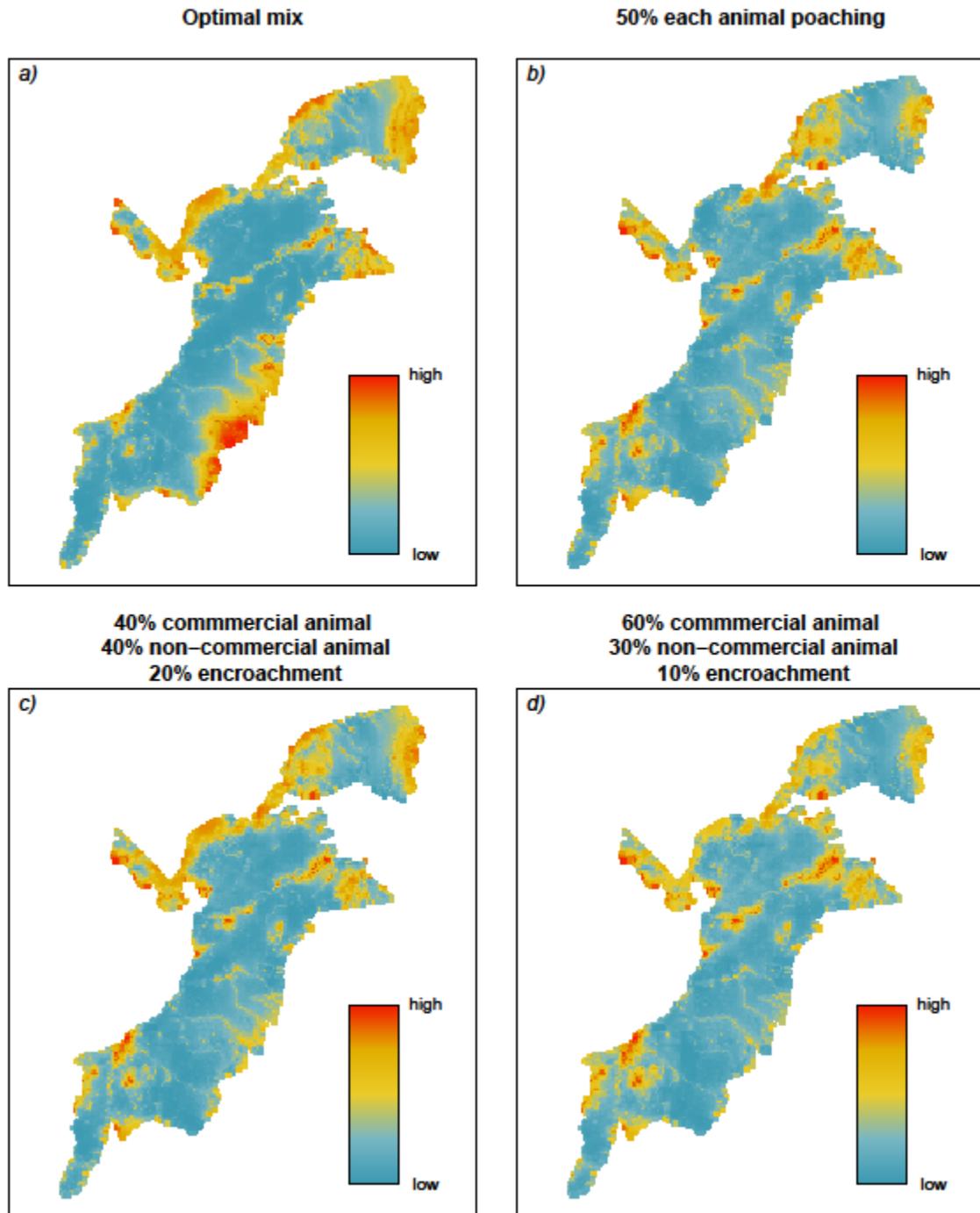


Figure 2. Scenarios of how to arrange existing patrol strategies to increase efficiency of detecting illegal activities in the Queen Elizabeth National Park, Uganda.

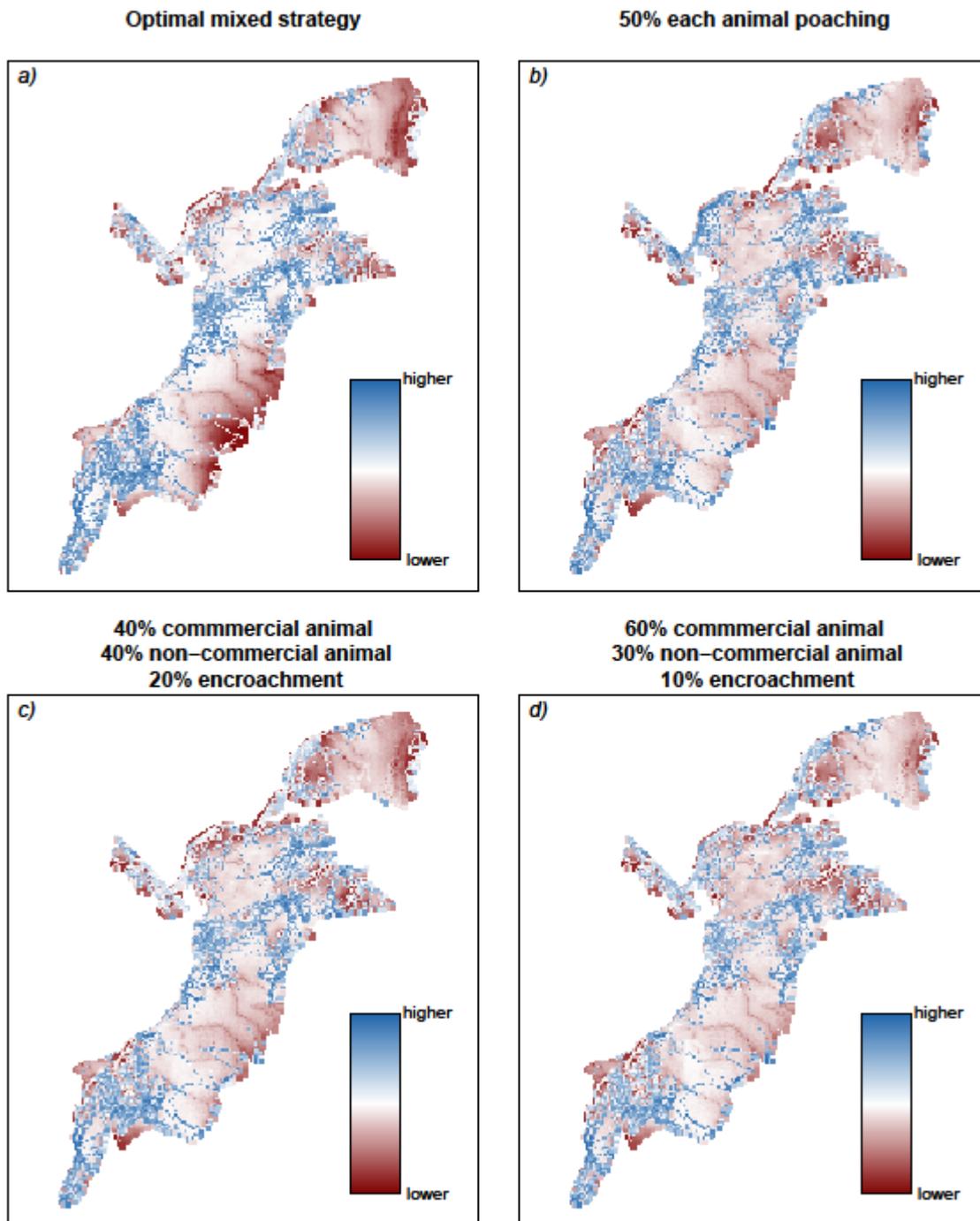


Figure 3. Differences between optimal patrol scenarios (Figure 3) and existing ranger patrols within the Queen Elizabeth National Park, Uganda.

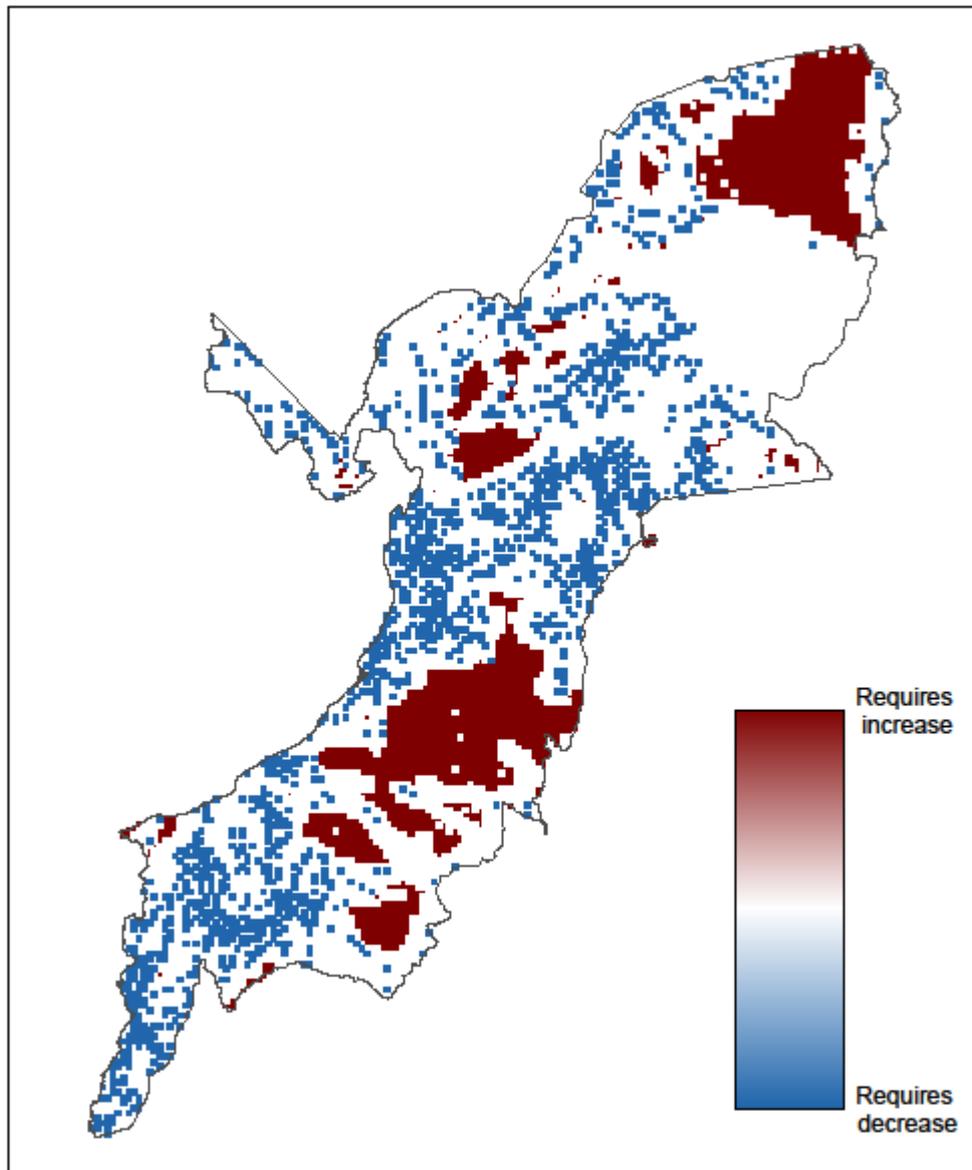


Figure 4. Changes in patrol effort with respect to current patrol strategy that are recommended irrespective of conservation priorities within the Queen Elizabeth National Park, Uganda.

Discussion

Substantial increases in detections of illegal activity are possible by optimising the existing ranger patrol behaviour in the QENP; detections of all illegal activities can be increased by altering the distribution of ranger patrols. Exactly what strategy for altering existing patrol effort should ultimately be determined by conservation policy decisions explicitly weighing up the importance of different classes of activities, but our methods will be able to help direct ranger patrols once policies are formulated.

Although our models suggest that using spatial crime mapping to inform ranger patrol planning could result in considerable benefits it is important to test these predictions using explicit manipulation of patrol behaviour before encouraging widespread adoption. Testing how the changes of patrols impact on illegal activities will also allow us to determine to what degree ranger patrols act as a deterrent to illegal activities, as these deterrent effects of patrols are currently unknown yet may influence how ranger patrols should be distributed. For example, there may be a threshold of ranger patrol effort that reduces illegal activities even if they are not detected by patrols – thus some areas with currently low probabilities of occurrence may reflect the deterrent effect of relatively high patrol coverage. There is consequently a potential conflict that requires further study: should ranger effort be directed primarily towards the areas where illegal activities currently occur, or should the effort be spent primarily on preventing activities from occurring in the core, or most important zones? The answer to this question can only be determined experimentally, and requires estimating the number of illegal activities that do not happen in each area as a consequence of ranger patrols, a considerable challenge. This analysis also makes the assumption that poacher behaviour is stable across the park. Analysis of the past 12 years does indicate this is generally the case and that one of the best predictors of illegal activity is patterns in previous years (Critchlow *et al.* 2014). However if patrolling were to be changed greatly, it is probable that poacher behaviour would also change and there is a need to maintain the deterrence effect where it currently exists.

Additional factors that still need incorporating within an optimal ranger patrol planning system would be the importance of including some ranger patrols in areas where detections are currently expected to be low. Our earlier work discovered that although the key priority areas for each class of illegal activity are relatively static over time, temporal changes in illegal activity do occur, reflecting changes in poacher behaviour, perhaps in response to changed demand but maybe also as a consequence of changed patrol effort. Consequently, some monitoring of currently low probability areas must be built into patrol responsibilities to provide early detection of spatio-temporal changes. Equally, although we have identified areas to which ranger patrols can be directed, the routes that patrols should take to meet these overall objectives still needs to be identified.

Overall, we conclude that evidence-based planning of ranger patrols using spatial crime mapping techniques offers considerable potential for improving law within protected areas

without altering the existing resources required for patrols. To fully realise these benefits will require field testing of the recommendations and further investigation of the role deterrence has on poacher behaviour.

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