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Contributed Paper

Effects of law enforcement and community outreach on mammal diversity in a biodiversity hotspot

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Abstract: *Management activities such as law enforcement and community outreach are thought to affect conservation outcomes in protected areas, but their importance relative to intrinsic environmental characteristics of the parks and extrinsic human pressures surrounding the parks have not been explored. Furthermore, it is not clear which is more related to conservation outcomes—the management itself or local people's perceptions of the management. We measured objective (reports by park staff) and subjective (reports by local people) levels of community outreach and law enforcement based on responses to 374 questionnaires. We estimated mammal abundance and diversity of 6 protected areas based on data from 115 camera traps in Xishuangbanna, southwest China, a biodiversity hotspot with high hunting and land-conversion pressures. We then examined correlations among them and found that local people's perception of law enforcement was positively related to the local abundance of 2 large, hunted species, wild boar (*Sus scrofa*) (β = 15.22) and muntjac (*Muntiacus vaginalis*) (β = 14.82), but not related to the abundance of smaller mammals or to objective levels of enforcement. The subjective frequency of outreach by park staff to local communities (β = 3.42) and park size (β = 3.28) were significantly and positively related to mammal species richness, whereas elevation, human population density, and subjective frequency of law enforcement were not. We could not conclude that community outreach and law enforcement were directly causing increased mammal abundance and diversity. Nevertheless, the patterns we detected are some of the first empirical evidence consistent with the idea that biodiversity in protected areas may be more positively and strongly related to local perceptions of the intensity of park management than to either intrinsic (e.g., elevation, park size) or extrinsic (e.g., human population density) environmental factors.*

Keywords: camera trap, conservation effectiveness, protected area, species richness, Xishuangbanna

Efectos de la Aplicación de la Ley y la Participación de la Comunidad sobre la Diversidad de Mamíferos en un Punto Caliente de Biodiversidad

Resumen: *Las actividades de manejo como la aplicación de la ley y la participación de la comunidad afectan los resultados de conservación dentro de las áreas protegidas, pero su importancia en relación con las características ambientales intrínsecas de los parques y las presiones humanas extrínsecas que rodean a los parques no han sido exploradas. Además, no está claro cuál está más relacionado con los resultados de*

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*conservación – el manejo en sí o las percepciones que las personas locales tienen sobre el manejo. Medimos los niveles objetivos (reportes dados por el personal del parque) y subjetivos (reportes dados por los locales) de la participación de la comunidad y la aplicación de la ley con base en las respuestas a 347 cuestionarios. Estimamos la abundancia y diversidad de mamíferos de seis áreas protegidas con base en datos de 115 cámaras trampa en Xishuangbann, al suroeste de China, un punto caliente de biodiversidad con altas presiones causadas por la caza y la conversión del uso de suelo. Después examinamos la correlación entre ellos y encontramos que la percepción que los locales tienen sobre la aplicación de la ley estuvo relacionada positivamente con la abundancia local de dos grandes especies que son cazadas, el jabalí (*Sus scrofa*) (β = 15.22) y el muntíaco (*Muntiacus vaginalis*) (β = 14.82), pero no estuvo relacionada con la abundancia de mamíferos más pequeños o con los niveles objetivos de la aplicación de la ley. La frecuencia subjetiva del alcance del personal del parque hacia las comunidades locales (β = 3.42) y el tamaño del parque and (β = 3.28) estuvieron relacionadas significativa y positivamente con la riqueza de las especies de mamíferos, mientras que la elevación, la densidad de la población humana, y la frecuencia subjetiva de la aplicación de la ley no lo estuvieron. No pudimos concluir que la participación de la comunidad y la aplicación de la ley estuvieran causando directamente una abundancia y diversidad aumentada de mamíferos. Sin embargo, los patrones que detectamos son de las primeras evidencias empíricas consistentes con la idea de que la biodiversidad en las áreas protegidas podría estar relacionada positiva y fuertemente con la percepción que tienen los locales de la intensidad del manejo del parque y no con los factores ambientales intrínsecos (p. ej.: elevación, tamaño del parque) o extrínsecos (p.ej.: densidad de la población humana).*

Palabras Clave: área protegida, cámaras trampa, eficacia de la conservación, riqueza de especies, Xishuangbanna

摘要: *保护区执法 和社区宣传 等管理活动被认为会影响保护区的保护成果, 但其相对于保护区内在环境特征因素以及保护区周边的外在人类活动因素的重要性尚未得到探索。此外, 尚不清楚哪个与保护结果更相关 - 管理本身或当地人对管理行为的感知。我们通过 374 份问卷测量了客观 (由保护区工作人员报告的) 和主观 (由当地人报告的) 执法和社区宣传水平。我们通过 115 个相机陷阱估算了西双版纳的 6 个保护区的哺乳动物丰度和多样性, 西双版纳是一个具有高狩猎压力和土地流转压力的生物多样性热点地区。我们接下来验证了管理活动和生物多样性指标的相关性, 发现当地居民对执法行为的感知与 2 种大型猎物, 野猪 (*Sus scrofa*) (β = 15.22) 和赤麂 (*Muntiacus vaginalis*) (β = 14.82) 的相对多度呈正相关, 但与较小的哺乳动物的相对多度无相关性关, 且客观的执法水平猎物丰富度也无相关性。当地居民感知的保护区宣传频率 (β = 3.42) 和保护区面积 (β = 3.28) 与哺乳动物物种丰富度显著正相关, 而与海拔, 保护区周边人口密度和保护区汇报的宣传频率无相关性。虽然, 相关性不等于因果关系, 我们无法得出是保护区执法和社区宣传直接导致了保护区哺乳动物多度和多样性地增加。不过, 我们发现的结果可能是第一个与平时推测相一致的实验性证据:保护区周边居民对保护区管理的感知与保护区内的生物多样性的相关性高于保护区内在环境特征 (例如保护区海拔和面积) 以及保护区周边的外在人类活动因素 (例如保护区周边的人口密度) 与保护区内的生物多样性的相关性。*

Introduction

Protected areas are at the forefront of global efforts to protect biodiversity and are the most important units for in situ conservation (Chape et al. 2005). However, the success of protected areas at conserving biodiversity is often questioned (Rodrigues et al. 2004; Chape et al. 2005; Laurance et al. 2012). Retrospective assessments of protected-area efficacy highlight that many parks, particularly in tropical countries, fail to halt illegal exploitation and declines in wildlife populations (Gaston et al. 2008; Laurance et al. 2012; Geldmann et al. 2013).

Proper law enforcement in protected areas has long been thought to be essential for effective protected-area management (Rowcliffe et al. 2004; Gibson et al. 2005). But this has seldom been examined quantitatively, so a general understanding of how law enforcement is related to biodiversity outcomes within protected areas is lacking (Geldmann et al. 2013). In addition to law enforcement, managers also try to engage local communities via outreach (Wells et al. 1992). Although outreach can lead to significant changes in attitude toward conservation and reduce illegal encroachment into protected areas (Holmes 2003; Kideghesho et al. 2007; Steinmetz et al. 2014), little quantitative evidence exists as to how outreach ultimately relates to biodiversity conservation on the ground (Mascia et al. 2003; Williams & Gordon 2015).

Moreover, information on the role of management itself and local peoples' perceptions about the management in achieving conservation outcomes is lacking. The ways individuals observe, understand, interpret, and evaluate a referent action, experience, policy, or outcome can be extremely important in determining human impacts on biodiversity (Bennett 2016). For example, subjective perceptions of management can affect peoples' conservation decisions (Xu et al. 2006; Allendorf et al. 2012) and attitudes toward protected areas (Liu et al. 2010). But whether subjective perceptions are related to ultimate conservation outcomes, such as metrics of biodiversity, remains unclear (Webb et al. 2004; Bennett 2016).

We assessed how objective (reported by protected area staff) and subjective (reported by local villagers) frequencies of community outreach and law enforcement relate to mammal diversity and abundance in a suite of protected areas in the Xishuangbanna Region of southwestern China. This region is a global biodiversity hotspot (Myers et al. 2000) and holds most of the remaining habitat for several endangered or critically endangered megafauna in China such as the Asian elephant (*Elephas maximus*) and gaur (*Bos gaurus*). We measured mammal diversity and local abundance in 6 nature reserves that have similar environmental conditions but vary in their management to determine how multiple factors, independently and interactively, relate to the conservation effectiveness of each park. We hypothesized that mammal diversity is positively related to both the intensity of law enforcement within parks and the frequency of community outreach activities conducted by park authorities. Our goal was to determine the conditions under which parks succeed at supporting populations of large animals so as to help direct future conservation efforts. Without counterfactual or experimental approaches one cannot rigorously assess causality in any management–conservation relationships. Nevertheless, determining whether such relationships even exist is a necessary first step in assessing the potential influence of management activities on biodiversity conservation outcomes.

Methods

Study Sites

Xishuangbanna is in the Yunnan Province of southwestern China (Fig. 1) in the upper Mekong River basin and is a part of the Indo-Burma biodiversity hotspot (Myers et al. 2000). The total area of Xishuangbanna is 19,200 km^2 (0.5% of China's landmass) and it holds over 16% (about 5,000 species) of the country's vascular plant species and 22% (102 species) of its mammal species (Zhang & Cao 1995). The landscape of Xishuangbanna was relatively intact until the dramatic expansion of rubber plantations, particularly since the 1990s (Li et al. 2007; Ziegler et al. 2009; Xu et al. 2014). Xishuangbanna was established as a set of nature reserves in 1958 (Xu et al. 2014). Forest cover within reserves in Xishuangbanna is much higher and less fragmented than outside reserves (Li et al. 2009). Overall, the environmental conditions of the nature reserves in Xishuangbanna are similar but their management differs.

We conducted research at 6 sites in 3 nature reserves: Xishuangbanna National Nature reserve (XNR), Nabanhe National Nature Reserve (NNR), and Bulong County Natural Reserve (BNR) (Fig. 1). The Chinese Forestry Department established XNR in 1958. It is composed of 5 independently managed subreserves (Mengla, Mangao, Menglun [Fig. 1], Mengyang, and Shangyong) and has a cumulative area of 2,417 km^2. We conducted camera trap and administered questionnaire surveys in the former 3 subreserves. All people and villages were relocated from the core zone of the reserves. Human activities other than scientific research are forbidden in the core zones of the reserves but allowed in surrounding buffer areas (but people cannot live in buffer zones). Nabanhe National Nature Reserve (NNR) (266 km^2), in the same region, was established in 1991 to protect a small watershed and is managed by the Environment Department. This reserve has villages in the buffer zone and villagers are allowed to collect forest products and to plant crops in the buffer zone. Bulong County Natural Reserve (BNR) (353 km^2) was established in 2009 and has 2 major sections, Bulangshan and Mengsong, that are in 2 different counties and have different management histories and village composition. Residents of Bulangshan and Mengsong were mostly Bulang and Hani people, respectively (Supporting Information). Among the 3 subreserves in XNR, Mangao and Mengla have moderate law enforcement (Sreekar et al. 2015), whereas Menglun (112 km^2), the smallest forest patch among the reserves, has weak enforcement (Sreekar et al. 2015). The NNR has a reputation for cooperating with local communities and having strict enforcement of regulations (C.C. & R.Q., personal communication). Both sections of BNR have relatively weak enforcement (Sreekar et al. 2015).

Mammal Sampling

We deployed camera traps (Ltl Acorn, Shenzhen Ltl Acorn Electronics Co. Ltd., Shenzhen, China) in 6 reserves: Mengla, Menglun, Mangao subreserve of XNR, NNR, Mengsong, and Bulangshan from May to October in 2014 and 2015 (Fig. 1). The climate of Xishuangbanna at this time of year is dominated by a southwestern monsoon that brings high levels of rainfall (Zhang & Cao 1995). Camera traps had infrared motion triggers and were set to medium sensitivity to reduce misfiring. The time interval between 2 trigger events was set to 1 minute, and 3 photos were taken with each trigger. Camera traps were installed along 5- to 10-km transects spaced 300–800 m apart and were active 24 hours/day. Cameras were attached to the base of trees about 70–100 cm above the ground. We selected trees that were 10–20 m away from trails to reduce potential sabotage from local residents and selected areas where light and slope conditions conferred high visibility for the cameras. Cameras did not face the trails. The transects covered the core zones of each nature reserve and spanned gradients in forest type. Each transect had at least 8 camera traps. The sampling effort for each camera was determined as the deployment to retrieval time if the camera functioned properly throughout or deployment to time of last photograph if a camera was not functioning at retrieval. Consecutive

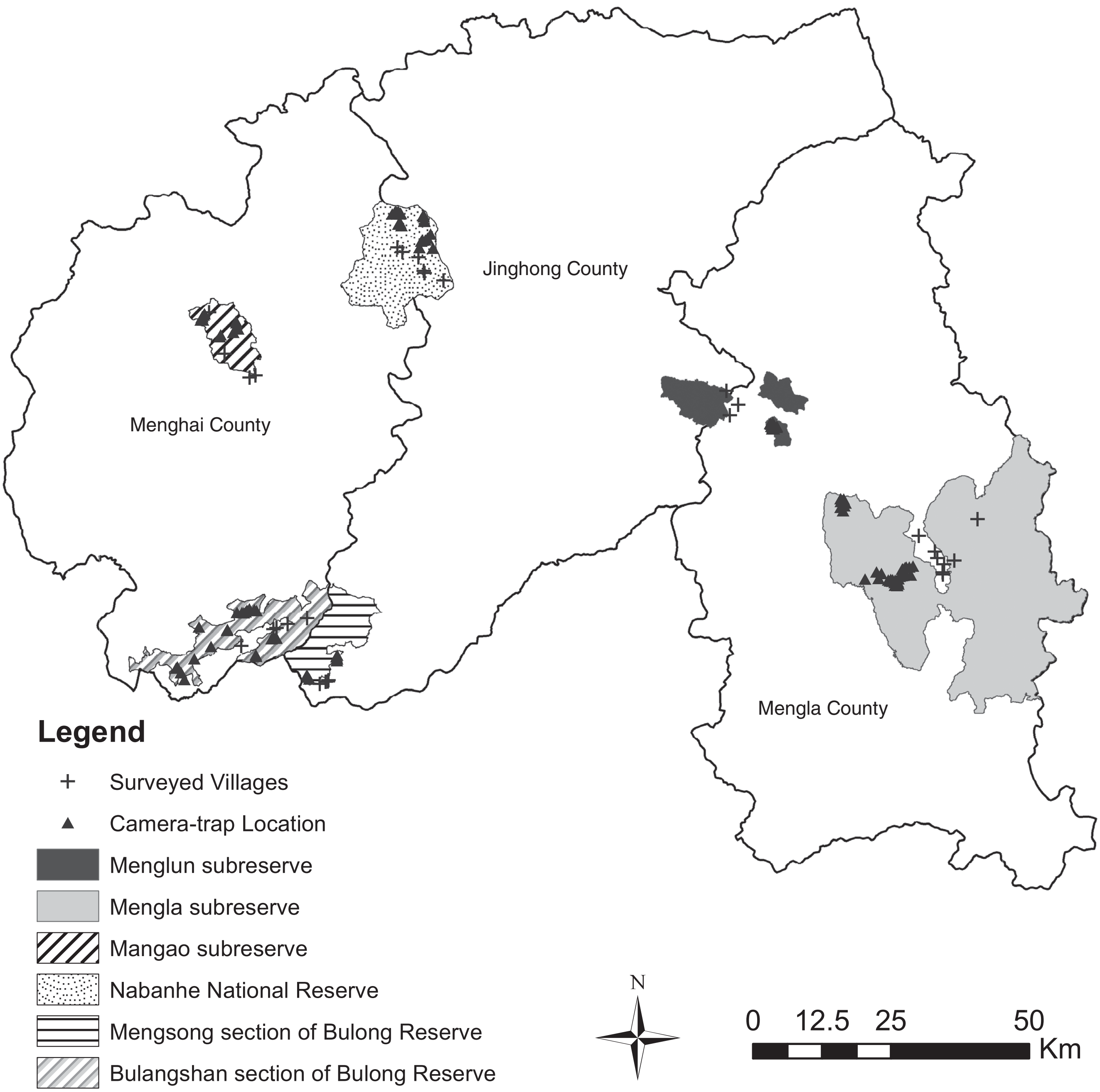

Figure 1. Camera locations and surveyed villages in 6 nature reserves in Xishuangbanna, China.

photographs were considered independent detections if they contained different species or clearly different individuals; were of the same species but separated by more than 1 h; or were of the same species but with other species photographed in between (O'Brien et al. 2003; Yue et al. 2015). We calculated a simple relative abundance index (RAI) as the number of independent detections of each species per 100 camera-trap days and used the photographic captures in hierarchical models that accounted for imperfect detectability of each species (see "Factors Related to Mammal Local Abundance").

Management-Level Surveys

We conducted questionnaire surveys to assess local peoples' self-reported perceptions of law enforcement level and the frequency of outreach conducted by staff of the nearby protected area (Supporting Information). Surveys took place from 0800 to 1800 from May to October 2015. To gauge the level of government-sponsored law enforcement and outreach, the surveys contained quantitative questions about the number of punishments the park meted out for law violations and qualitative questions about the relationship between park staff and villagers and knowledge about the rules of the protected area regarding hunting and the collection of nontimber forest products. We used data from the questionnaires about the number of punishments meted out for law infractions as a metric of people's perception of law enforcement activity for each area (Gavin et al. 2009).

Our metric of outreach frequency was calculated as the average reported number of times park staff conducted outreach (Supporting Information). Answers reporting 0, 1-2, 3-5, 5-10, 10-15, or >15 outreach events per year were coded as 0, 1.5, 4, 7.5, 12.5, and 15, respectively (Hazzah et al. 2009). Similarly, our metric of level of law enforcement was calculated from the average reported number of punishments park staff meted out to law violators (Supporting Information). Answers reporting 0, 1-5, 5-10, 10-15, 15-20, or >20 punishments per year were coded as 0, 2.5, 7.5, 12.5, 17.5, and 20, respectively. Questionnaire surveys were approved by the Human Subject Ethics committee of the University of British Columbia (UBC BREB number: H15-01106).

We also collected outreach and punishment frequency information directly from staff of the parks. Staff were asked to report the total number of outreach activities and the number of punishments meted out from 2014 to 2015. We calculated the total number of park-staff-reported outreach activities and punishments, weighted by the number of villages, within the administration of each park and then correlated these objective management metrics with the subjective (villager-reported) metrics. The park staff of Bulong reserve were not able to separate management frequency information for Mengsong and Bulangshan, so the mean values of villager-reported outreach and punishment of these 2 sections were used in the correlation test.

Factors Related to Mammal Local Abundance

Hunting in Southeast Asia affects numerous species, although some may be targeted more heavily than others (Harrison et al. 2016). We used Royle–Nichols (RN) latent abundance *N*-mixture models (Royle & Nichols 2003) to estimate how the local abundance (sensu Brodie et al. 2018) of 4 common and commonly hunted species varied across the parks: wild boar (*Sus scrofa*), northern red muntjac (*Muntiacus vaginalis*), common palm civet (*Paradoxurus hermaphroditus*), and masked palm civet (*Paguma larvata*) (Supporting Information). These were the species for which sufficient detections were obtained for the RN models to run and converge. Wild boar and muntjac are large, terrestrial, and the most commonly hunted species, whereas the civets are medium sized, mostly arboreal species that are less frequently hunted (Corlett 2007). The abundance of common species is a driver of ecosystem-service delivery and contributes more to ecosystem function than the abundance of rare species (Winfree et al. 2015).

We modeled the latent local abundance of a species at site j with a Poisson distribution of parameter λ: $N_j \sim \text{Poisson}(\lambda_j)$. The detection of a single individual at site j during sample period $k(\omega_{jk})$ was considered a Bernoulli process of the detection probability of individual r_j: $\omega_{jk} \sim \text{Bernoulli}(r_{jk})$. We stated the relationship between detection probability of one site (p_{jk}) and detection probability of an individual (r_{jk}) as $p_{jk} = 1 - (1 - r_{jk})^{N_j}$.

Site covariates thought to potentially relate to local abundance were modeled as

$$\log(\lambda_j) = \varepsilon\text{park}_i + a1 * \text{elevation}_j + a2 * \text{population}_j + a3 * \text{distance}_j . \quad (1)$$

At park i, the covariates thought to potentially relate to local abundance were modeled as

$$f(\varepsilon\text{park}_i) = a0 + a4 * \text{park size}_i + a5 * \text{outreach}_i + a6 * \text{punishment}_i . \quad (2)$$

Factors potentially related to detection probability were modeled as

$$\text{logit}(r_j) = \beta 0 + \beta 1 * \text{cam\_angle}_j . \quad (3)$$

To select factors that potentially relate to mammal abundance, we considered elevation (a proxy for forest type in this region) as a fundamental factor potentially affecting species occurrence. We hypothesized that human disturbance influences animal distributions. We used human population density and the distance from each camera to the border of the protected area (a metric of site accessibility) as indices of potential human disturbance. Human density within 3 km of each camera was calculated based on the Chinese population map of 2010 (Gaughan et al. 2016). We included a random intercept $\varepsilon_{\text{park}}$ to account for spatial autocorrelation within parks not driven by the environmental factors in our models. This intercept was a function of the size of the park, park outreach frequency, and park punishment frequency. For outreach and punishment, we ran the model with villager-reported and park-reported data separately. All continuous covariates were standardized to have a mean of 0 and variance of 1. For detection covariates, we used a binary determination of whether cameras were installed at angles that conferred low visibility (cam_angle). Deploying cameras at angles was necessary in some instances to account for reduced visibility at a particular site due to, (for example, microtopography or downed trees).

We ran the models with a Gibbs sampler with diffuse priors and random initial values in the package jagsUI (Kellner 2015) in R version 3.4.3 (R Core Development Team 2017). We ran 1,500,000 iterations after an adaptation of 10,000 and had a burn-in of 50,000 and 100 iteration thinnings. Model convergence was checked by using Gelman–Rubin diagnostics, for which values <1.1 indicated convergence (Gelman et al. 2013), as well as through visual inspection of the trace, density, and autocorrelation plots.

Factors Related to Mammal Species Richness

We used community-level Bayesian hierarchical models to determine how villager-reported law enforcement and outreach related to overall mammal species richness. The multispecies occupancy model assumes occurrences (Z) of observed species is represented by a Bernoulli process of the probability (Ψ) that species i occurs at site j, where $Z = 1$ when the species is present and 0 when absent (Brodie et al. 2015). Detection ($Y_{i,j,k}$) is also a Bernoulli process of both occurrence ($Z_{i,j}$) and the probability of detection ($P_{i,j}$). In addition to those 2 levels, we used hierarchical estimation and data augmentation to estimate the number of species present in the community but not detected at any site (Royle & Dorazio 2008; Iknayan et al. 2014). These models assume the occurrence state (W) of all partially observed and unobserved species is a Bernoulli-distributed random variable indexed by the parameter Ω. The detection of n species is augmented by m unobserved pseudospecies, or species that may be present in the system but not detected by sampling (Royle & Dorazio 2008; Iknayan et al. 2014). The number of species should be larger than the observed number (Royle & Dorazio 2008). We augmented the 22 observed species with 25 unobserved: $Z_{i,j} \sim \text{Bernoulli}(W_i * \Psi_{i,j})$, $Y_{i,j,k} \sim \text{Bernoulli}(Z_{i,j} * \text{P}_{i,j})$, and $W_i \sim \text{Bernoulli}(\Omega)$. Occupancy ($\Psi_{i,j}$) is governed by species-specific factors ($\alpha 0_i$) and relevant site covariates (αj_j) in the logit link functions:

$$logit(\Psi_{i,j}) = \varepsilon_{\text{park}} + \alpha 1_i * \text{elevation}_j + \alpha 2_i * \text{population}_j + \alpha 4_i * \text{distance}_j \quad (4)$$

Similar to the single-species models described above, we included factors potentially related to mammal richness, including a random intercept for each park, elevation, human population density, and distance to the park border (a proxy for site accessibility):

$$f(\varepsilon_{\text{park}}) = \alpha 0_f + \alpha 4_f * \text{park size}_f + \alpha 5_f * \text{outreach}_f + \alpha 6_f * \text{punishment}_f \quad (5)$$

As with the RN models, the park effect ($\varepsilon_{\text{park}}$) was a function of park size, outreach frequency, and enforcement frequency. Again, both villager-reported and park-reported data were modeled.

Detection probabilities were governed by species-specific covariates ($\beta 0_j$) and relevant site covariates (the number of hours that each trap was active and cam_angle).

$$\text{logit}(\text{P}_{i,j}) = \beta 0_i + \beta 1_j * \text{camhour}_j + \beta 2_i * \text{cam\_angle}_j \quad (6)$$

The models used diffuse priors and random initial values and were run with 500,000 iterations after a burn-in of 250,000 and 100 iteration thinnings with jagsUI. Model convergence was checked by using Gelman–Rubin diagnostics and through visual inspection of the trace, density, and autocorrelation plots. To estimate species richness at each site, we generated probability distributions of species richness for each camera location by summing the number of estimated species (which $Z_i = 1$ at site j) in the occupancy matrix ($\mathbf{Z}_{\mathbf{i,j}}$) during each of the 500,000 iterations (Zipkin et al. 2010).

Results

The 115 camera stations, cumulatively active for 12,148 camera-trap days during the sampling period, yielded 1,213 independent detections of 22 medium- to large-sized mammal species. Two of these species were listed as critically endangered on the latest China Biodiversity Red List (Jiang et al. 2016), gaur (RAI = 0.187) and pig-tailed macaque (*Macaca nemestrina*) (RAI = 0.203), and

Table 1. Mean frequency of outreach events per village conducted by park personnel and annual number of punishments per village for law violations as perceived by local people and park personnel in 6 protected areas in Xishuangbanna, China.

Group and protected area	*Reported outreach/year*[a] *(SD)*	*VillagerReported Punishments/year*[b] *(SD)*
Villagers[a]		
Bulangshan	3.00 (3.03)	1.00 (1.89)
Mangao	2.94 (2.67)	0.54 (1.16)
Mengla	2.64 (2.79)	0.85 (2.53)
Menglun	2.23 (1.20)	0.47 (1.10)
Mengsong	3.14 (3.01)	1.25 (1.71)
Nabanhe	5.67 (5.23)	1.10 (2.63)
Park staff[b]		
Bulangshan & Mengsong	3.37	0.91
Mangao	2.00	0.26
Mengla	2.74	0.30
Menglun	1.96	0.61
Nabanhe	6.86	7.71

[a] *Calculations of outreach frequency are in Supporting Information and pertain to survey question 1 and calculations of punishments are in supporting Information and pertain to question 2.*
[b] *Outreach frequency was the total number of events reported by staff in 2014 plus 2015 for each park divided by number of villages subject to park administration. The Bulangshan and Mengson sections of Bulong reserve were combined. The frequency of punishments was calculated as the total number of events reported by staff in 2014 plus 2015 for each park divided by number of villages subject to park administration. Bulangshan and Mengson sections of Bulong reserve were combined.*

1 was listed as endangered, dhole (*Cuon alpinus*) (RAI = 0.008) (Supporting Information). Differences in the number of species detected and the relative abundance of 4 common species in each reserve are in the Supporting Information.

Law Enforcement and Outreach Levels Across Parks

Subjective outreach frequency was significantly different among protected areas (Kruskal–Wallis H test: $\chi^2 = 15.89$, df = 5, $p = 0.007$). Nabanhe had the highest outreach frequency (mean [SD] = 5.67 events/year [4.39]) and Menglun the lowest (mean = 2.23/year [1.20]) (Table 1). The subjective outreach frequency was significantly correlated with objective (park-staff reported) outreach frequency ($p = 0.0067$, Pearson's $r = 0.97$) (Supporting Information).

The total number of punishments reported by villagers across the 6 parks was low but there were significant differences among the parks (Kruskal–Wallis χ^2 test = 11.16, df = 5, $p = 0.048$). Mengsong had the highest number of punishments (mean [SD] = 1.25/year [1.71]) and Mangao the lowest (mean = 0.54/year [1.16]) (Table 1). However, the subjective (villager-reported) punishment frequency was not correlated with objective (park-staff-reported) frequency ($p = 0.52$, Pearson's $r = -0.40$) (Supporting Information). Nabanhe reserve had a significantly higher objective punishment frequency than the other reserves (Table 1).

Factors Related to Mammal Local Abundance

Estimated average abundance was 2.27 (SD 2.36) for wild boar, 1.90 (2.27) for muntjac, 1.46 (1.60) for masked palm civets, and 0.38 (0.63) for common palm civets per camera station.

The frequency of villager-reported punishments was marginally positively related (i.e., 95% CI included 0, whereas the 90% CI did not) to the local abundance of wild boar ($\beta = 15.22$; 90% CI = 0.98:39.70) and muntjac ($\beta = 14.82$; 90% CI, 1.07:39.60) (Fig. 2). The local abundance of wild boar and common palm civet was

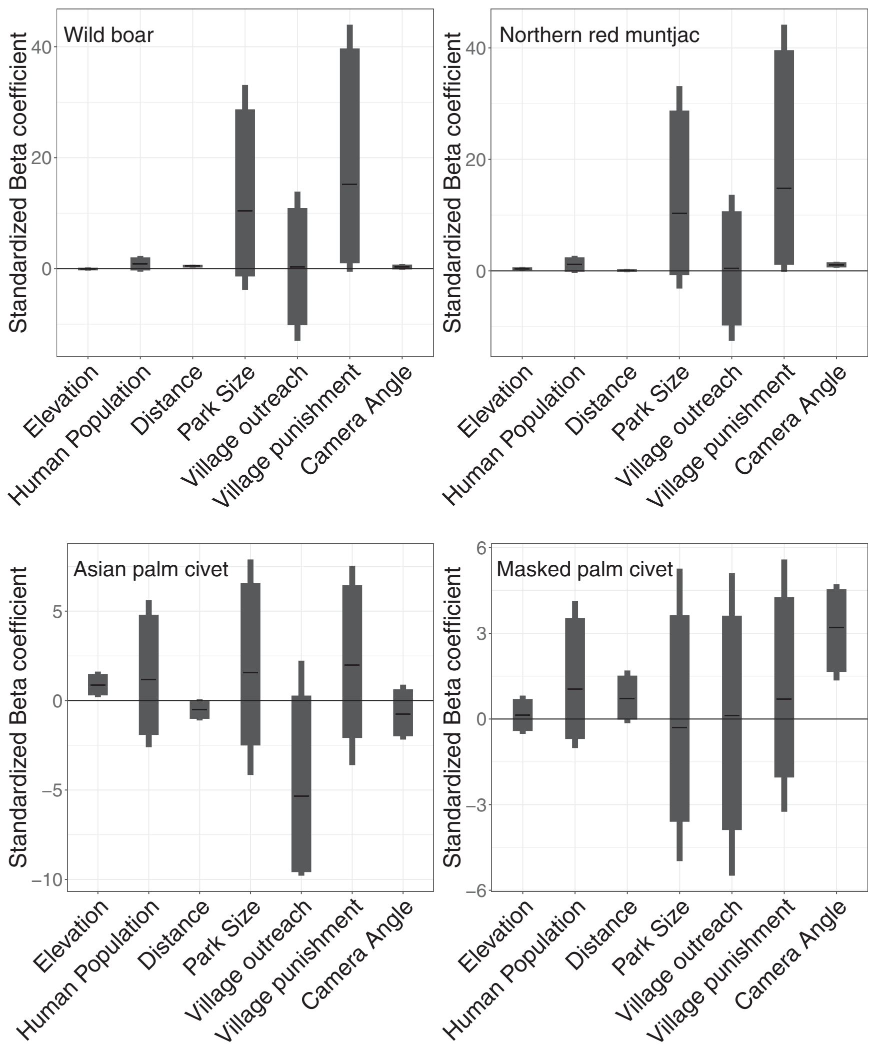

Figure 2. Regression (β) coefficients for factors (x-axis) potentially related to the local abundance of 4 mammals (horizontal line within bars, mean; narrow bars, 95% CI; wide bars, 90% CI).

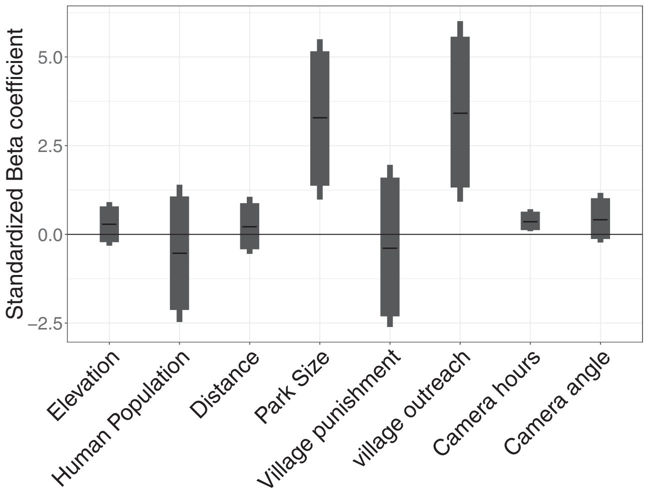

Figure 3. Regression (β) coefficients for factors potentially related to mammal species richness in protected areas in Xishuangbanna, China (horizontal line within bars, mean; narrow bar 95% CI; wide bars, 90% CI). Villager-reported punishment and outreach data were used for punishment and outreach factors.

significantly related to the distance from each camera trap to the protected-area border (wild boar: $\beta = 0.46$; 95% CI, 0.17:0.74; common palm civet: $\beta = -0.52$; 90% CI, -1.02: -0.03) (Fig. 2). Muntjac and common palm civet local abundance increased as elevation increased (muntjac: $\beta = 0.36$; 95% CI, 0.08:0.64; common palm civet: $\beta = 0.87$; 95% CI, 0.19:1.62) (Fig. 2). Detectability was affected by camera angle for muntjac ($\beta = 1.08$; 95% CI, 0.53:1.63) and masked palm civet ($\beta = 3.21$; 95% CI, 1.35:4.72) (Fig. 2). No significant relationships were found between objective outreach and punishment frequency and mammal local abundance (Supporting Information).

Factors Related to Mammal Species Richness

The Bayesian posterior predictive check of the multi-species occupancy model was 0.52, indicating the model fit the data well (Gelman et al. 2013). The total estimated species richness across the 6 reserves was 28 species (95% CI, 22:38); 22 species were actually detected on the camera traps. Average species richness at each camera site was 9.67 (SE 4.99). Mammal richness was significantly related to villager-reported outreach frequency ($\beta = 3.42$; 95% CI, 0.92:6.01) and park size ($\beta = 3.42$; 95% CI, 0.92:5.50) (Fig. 3). Estimated mammal richness in 250-km^2 parks, for example, was less than half that in 1000-km^2 parks (Fig. 4a). Estimated richness was 2-fold higher in reserves where there were 5 outreach activities per year, for example, than in reserves where there were 2 (Fig. 4b).

Overall mammal species richness was not significantly related to elevation, human density, distance to the park border, the subjective frequency of punishments, or the objective frequency of either outreach or punishment (Fig. 3 & Supporting Information). For individual species, the mean predicted effects of elevation, human density, distance to the park border, park size, subjective punishment frequency, and subjective outreach frequency were positive for 4.55%, 13.6%, 68.28%, 4.55%, 4.55%, and 100% of species, respectively (Supporting Information).

Discussion

Understanding how different management strategies affect biodiversity in protected areas is critical for tropical

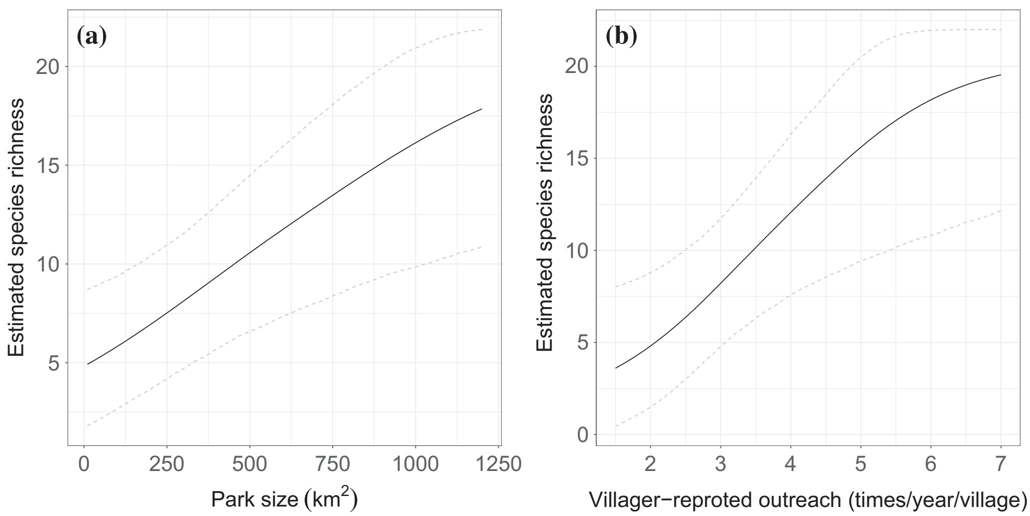

Figure 4. Relationships between estimated mammal species richness and (a) size of protected area and (b) villager-reported frequency of community outreach by park staff (dotted lines, 95% CI).

conservation. To our knowledge this is the first study to measure the associations between community outreach, law enforcement, animal abundance, and protected-area biodiversity with multispecies hierarchical models that account for imperfect detection of all species. The size of protected areas was significantly and positively related to the diversity of the fauna therein, a finding corroborated by other studies (Struhsaker et al. 2005) and ecological theory (Wilson & MacArthur 1967). Mammal diversity in protected areas was significantly related to the frequency of community outreach by protected area staff. Both the local abundance of 2 large species and overall mammal diversity was more strongly correlated with villagers' perceptions about law enforcement than with the levels of enforcement reported by park staff. This provides, to our knowledge, the first quantitative evidence consistent with the hypothesis that local peoples' perceptions of management may influence biodiversity conservation in protected areas. Based on our study design, we could not conclusively say park management and biodiversity were causally linked. It is possible that management was more intensive in parks with relatively higher species diversity and abundance because managers want to protect the more abundant wildlife there. Nevertheless, demonstrating significant statistical associations is a necessary step in eventually determining whether and how different types of management affect conservation outcomes.

Local abundance of the large hunted mammals was positively related to the local perception of law enforcement activity in each park. Much of the current hunting in Xishuangbanna is recreational rather than for subsistence, and hunters typically prefer large-bodied species (Chang et al. 2017). But this form of hunting is a crime in China, subject to up to 10 years imprisonment, fines, and confiscation of property. Recreational hunters tend to be aware of the laws governing hunting (Chang et al. 2017). So in this case, it may be that community outreach and education about resource regulations does not help curtail hunting, and only the prospect of punishment could limit the activity.

The waysin which outreach is conducted can strongly influence its effectiveness (Jacobson et al. 2006). In this region, the most commonly reported outreach technique was delivery of leaflets and posting of informational banners, followed by occasionally hosting outdoor educational movies. Park staff and rangers generally have limited training in outreach. It may be that enhanced skills in negotiation, consensus building, and public communication could pay conservation dividends and increase the abundance of hunted species. Research in other fields also suggests that outreach programs should be designed based on psychological theory and the social conditions of the target villages in order to induce the most behavioral changes (Steinmetz et al. 2014).

Local peoples' perceptions of outreach activities were consistent with objective measures of outreach, whereas perceptions about law enforcement did not match with objective measures. One explanation for this could be that activities are more often perceived the same by most people in the village. In contrast, information about law infractions by particular people may not be disseminated widely. In conservation science generally, data on noncompliance are difficult to gather and are often of low quality (Keane et al. 2008). We recommend that further studies on conservation effectiveness use robust metrics of enforcement such as patrol-based monitoring (Stokes 2010).

It is possible that park staff strengthen enforcement when there are more animal species to protect or that increased animal diversity and abundance leads to higher hunting pressure, resulting in more punishments. For example, Nabanhe protected area contains a threatened flagship species, the gaur (*Bos gaurus*), which has led to strict enforcement of hunting restrictions. However, most of protected areas where we worked lacked robust data on animal populations and distributions (Silveira et al. 2003). Therefore, it is unlikely that the protected areas in our study allocated management resources based on precise knowledge of their local wildlife. Moreover, our study provided evidence that community outreach and law enforcement may link to local peoples' attitudes toward conservation and thus provide a mechanism by which these management activities might influence biodiversity. Our data could also serve as a baseline against which to monitor trends in mammal populations and diversity.

Although the need for long-term biodiversity monitoring in protected areas has often been discussed, we propose that it would also be extremely useful to monitor peoples' attitudes over time. It would be illustrative, for example, to determine how management actions affected peoples' views of conservation, which could in turn directly relate to their levels of compliance with resource strategies and regulations. Studies that assess hunting pressure (Benítez-López et al. 2017) through a combination of interview surveys (Coad et al. 2013) and spatial analysis of wildlife distribution and abundance are strongly recommended. As our results suggest, research that can link conservation-attitude assessments, animal-population estimation, and hunting-pressure assessments can reveal clearer patterns of conservation efficacy than studies on any one of those facets alone.

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Supporting Information

Information on the questionnaire surveys (Appendix S1), details of the study sites (Appendix S2), a list of mammal species detected (Appendix S3), species photographs (Appendix S4), correlations between subjective and objective management frequencies (Appendix S5), model results for objective management data (Appendix S6), and species-specific model coefficients for all parameters (Appendix S7) are available online. All our data and R scripts are available on Github (https://github.com/ccheng91/Chen_etal_2018). The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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