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Abstract

Local and regional extirpations of individual species, typically high profile cases, are now well documented, leading to calls for urgent action for particular species in specific locations. There is a need to broaden our assessments of extinction to identify landscapes that contain high proportions of threatened species and therefore, how more holistic species conservation responses might be developed. The conservation status of species is especially concerning in Southeast Asia and within the region, the avian family Phasianidae affords the opportunity to develop an approach for examining species richness and extinction probability for an entire family at landscape scale. There are 42 pheasant, partridge and quail species in the region and 77 % of Southeast Asia encompasses the geographic range of at least five species. Due to high levels of uncertainty about how species respond to anthropogenic threats, we created an expert elicited Bayesian Belief Network to explore survival prospects using publically available data on IUCN extinction probability categories, proxies of threat (effects of hunting, forest loss and protected area effectiveness) and species geographic ranges to assess where the overall risk to survival was highest.

Western Myanmar, Central Indoburma (Thailand/Myanmar), the Annamite mountains and Central Vietnam lowlands, Peninsular Malaysia, Sumatra and Borneo are priorities for avoiding large numbers of extinctions of phasianids. This assessment will be strengthened by more detailed data on intensity of hunting pressure across the region, and variation in species' tolerance to human disturbance. Strategically, therefore, conservation and research should be targeted towards these landscapes.

Keywords: Aichi Target 12, extinction probability, Galliformes, protected area effectiveness, forest loss

Introduction

The loss of biodiversity in Southeast Asia (Sodhi et al. 2010, Hoffmann et al. 2010) has reached the point where urgent action is needed if a substantial and imminent increase in species extinctions is to be avoided (Duckworth et al. 2012). At present, 92 out of 3807 birds and mammals are listed as Critically Endangered in the region (IUCN 2016) representing a clear challenge to meeting the Convention on Biological Diversity's Aichi Target 12 of avoiding species extinctions and reversing the decline of those species that are most threatened (https://www.cbd.int/sp/targets/default.shtml). There are now many examples of local and regional extirpations and probable or functional extinctions amongst individual vertebrate species across Southeast Asia (e.g. Javan rhinoceros *Rhinoceros sondaicus annamiticus* in Vietnam: Brook et al. 2012; Tiger *Panthera tigris* in Cambodia: Goodrich et al 2015, Green Peafowl *Pavo muticus* in Peninsular Malaysia: McGowan et al. 1999, Gurney's Pitta *Pitta gurneyi* in Thailand: Round 2014), and the demise of such iconic species inevitably draws attention.

In order to make meaningful progress towards Aichi Target 12 (and whatever species target replaces it in 2020), there is a need to take a more strategic approach to determining where action to avoid widespread species extinctions is most needed. Understanding where such 'hotspots' of extinction are likely to be is important in order to provide an objective analysis of the impact of anthropogenic pressures arising in diverse contexts across the whole region, countering the attention given to a few high profile species in particular countries. A broader assessment may indicate where deeper problems lie for a wide range of species. Such an assessment should consider species richness, the extinction probability of each species and additional factors that will influence their survival prospects (such as the effectiveness of protected areas that they occur in and habitat change) and would identify landscapes where particularly high numbers of species face extinction. Here, we start that process in Southeast Asia by identifying landscapes where the survival prospects of an ecologically diverse, highly threatened taxonomic group are of especial concern.

One group that has a relatively large proportion of species with high extinction probability is the avian Order Galliformes (e.g. pheasants, partridges and quails). Whilst 13.2% of the 10,424 bird species are listed as threatened with extinction on the IUCN Red List, 25% of the 308 Galliformes species in the world are so listed (IUCN 2016). For Southeast Asia the situation is similar with 10% (of 2696) of all bird species and 27% of the (76) Galliformes species listed as threatened with extinction. Although the status of individual species has been assessed against the IUCN Red List Criteria (IUCN 2016), there is no overall analysis of the conservation challenges facing the family. This hampers the broader scale understanding of how best to take immediate steps that would have the widest benefit. Species in the Galliformes family

Phasianidae are subject to a range of human pressures, both direct and indirect. The proportionally high degree of threat facing this group is largely a consequence of the extent to which direct exploitation adds to the pressures from habitat change. The Phasianidae does, therefore, offer insights into the survival prospects of species facing a range of human pressures, across all major habitats throughout Southeast Asia.

Data on species responses to pressures are very limited, so we are reliant on inference from what little data we do have. Using a Bayesian Belief Network (BBN) allows us to make logical, adaptable, repeatable and transparent decisions on where best to focus our resources in the region (Marcot et al. 2001) and it enables us to propose a framework of how pressures on species interact to affect their survival prospects. We use that approach here in order to assess where pressures on the avian family Phasianidae are resulting in the highest level of threat across the region. Specifically, we: 1) define areas in the region where family species richness and its extinction probability levels, based on IUCN categorisation, are highest; 2) combine information on hunting, forest loss and protected area effectiveness to assess the potential risk factors that species in the family face and that is not reflected in current Red List assessments; and 3) incorporate information from objectives 1 and 2 to identify priority areas where to focus conservation action.

Methods

Southeast Asia has been variously defined, but herein we include all tropical land masses between the Myanmar-Bangladesh border to the west and the Wallace Line to the east (excluding the tip of Kachin State in northern Myanmar). Thus, the countries of Brunei Darussalam, Cambodia, the western part of Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam were included under our definition.

The Phasianidae species and their threats

The majority of Phasianidae in the region are associated with forest habitat (Table S1). There has been a great deal of land transformation within the region (Koh et al. 2013), with ongoing massive deforestation highlighted as a major cause of local extinctions (Sodhi et al. 2010). Despite this, forest still dominates regional land cover, with 40.6% of the total area under forest cover (FAO 2010), although pristine forest makes up only 1.85% of this total and the integrity of the forest in these areas is highly variable.

Hunting, impacting almost all remaining forest in Southeast Asia, has led to declines in vertebrate populations with some local and global extinctions (Corlett 2007). Phasiandae may be targeted as a source of protein, for their eggs and feathers, or may be by-catch in snares targeting other species, such as mammals. We have very little evidence of species' responses to hunting in the region, but at least some are thought to be quite resilient to hunting pressure where their reproductive rate is relatively high (e.g. Brickle et al. 2008). A number of proxies for hunting pressure specific to Galliformes have been suggested previously (Keane et al. 2005), both for specific areas as well as country-level socio-economic factors shown to relate to wildlife exploitation (McDonald & Boucher 2011; Bradshaw et al. 2015).

Phasianidae richness

We focused on the 42 Phasianidae species found in the region (Table S1) for which there are global distribution data. All of these species make some use of forest habitat. Data on the global distribution of Phasianidae were derived from BirdLife International and NatureServe (2012). These digitised distributions were summed in the raster package (Hijmans 2015) of the R programme (R Core Team 2016). We weighted each species by its use of forest habitat and its IUCN status: habitat data and threat status for each species was downloaded from the IUCN Red List using the letsR package (Vilela and Villalobos 2015) again in the R programme. Forest affinity was calculated as the proportion that forest habitat comprised of the total number of habitats recorded (so if a habitat for species. A is listed as being forest, scrub and woodland then the forest affinity score was 0.33). For the threat status we used the "Evolutionarily Distinct and Globally Endangered" (EDGE) classification of Issac et al. (2007) where least concern = 0, near threatened = 1, Vulnerable = 2, Endangered = 3, Critically Endangered = 4.

Creation of Bayesian Network

We used a Bayesian Belief Network (BBN) approach to model areas of greatest extinction probability for Phasianidae in Southeast Asia. This approach is being increasingly used in decision-making processes that need to be rapid and where empirical data are unavailable (Marcot et al. 2001, Tantipisanuh et al. 2014). It is used here to propose a conceptual framework for how pressures interact to affect species conservation status. It will help guide the collection of new data that can then improve identification of important issues and areas.

BBNs are graphical models that can take the form of an influence diagram in which variables of interest are represented as nodes and dependencies between nodes are indicated by directed arrows (known as arcs). Conditional dependences underlie the relationship between "parent" and "child" nodes (the state of child nodes are dependent on the state of parent nodes). The model is parameterised by estimation of the probabilities for each node state (conditional for child nodes and unconditional for parent nodes). Here we used expert opinion to determine model structure and to parameterise the model.

The structure of the model was determined through a structured discussion between MG, PM and TS and with reference to the literature on threats to vertebrates. The model was developed from the terminal node ("priority areas") with conditional relationships discussed and mapped (Figure 1). Potential datasets were identified for each node (see below).

Priority areas were conditional on the level of threat, the presence and effectiveness of protected areas and species richness (un-weighted and weighted by both forest affinity and IUCN Red List). Protected area effectiveness was defined as the proportion of forest lost between 2000 and 2013 in protected areas in each country (Figure S1A & S1B). The level of threat combined both the forest loss and hunting threat nodes. Forest loss was determined from the Global Forest Change dataset (see Hansen et al. 2013). Protected area shapefiles were downloaded from www.protectedplanet.net (IUCN and UNEP-WCMC 2015).

The probability of hunting was conditional (i.e. dependent) on both local and country-scale proxies of hunting pressure, as well as on protected area effectiveness (at the country-scale). For the local scale (within 20 km of forest habitat), data on human population density and the location of roads within the region were used as proxies. Human population density data and road data was downloaded from the NASA Socioeconomic Data and Applications Center: CIESIN and CIAT (2005) and CIESIN and ITOS (2013). Both of these spatial datasets were clipped to the study region in ERSI ArcGIS 10.1.2. We then calculated the distance to roads using the Spatial Analyst Tool in ArcGIS. At country-level, the WWF Wildlife Crime Score (Nowell 2012), Corruption Index (http://www.transparency.org/), percentage of primary education and gross national income (http://data.worldbank.org/) were used as proxies to indicate probability of hunting.

Model structure was assessed and validated by SB and PJG following the recommendations of Pitchforth & Mengerson (2013).

Conditional probabilities

Conditional probability tables (see Tables S2, S3, S4, S5 and S6) were parameterised by two of the authors who have relevant experience (PM, TS) and then moderated by SB, PJG. Categories (High, Medium or Low) were elicited from authors through structured questions for each node state (Kuhnert et al. 2010). For example, authors were asked, when considering hunting risk, if the distance to a road is less than 5 km and the population density is less than 5 people per hectare, what level of hunting threat they would expect (High, Medium or Low).

Data analysis

All datasets were converted to raster format. We then determined the raster value for each of the spatial data layers across the whole study region with a 1 km^2 raster cell resolution using the following packages in R (rgdal: Bivand et al. 2016; maps: Minka & Deckmyn 2016; maptools: Bivand & Lewin-Koh 2016; rgeos: Bivand & Rundel 2016). Data for each cell (i.e. raster values associated with each parent node) was processed through the Bayesian Belief Network in Netica (Norsys Software 1995-2015). Netica uses data for each $1km^2$ raster cell as findings or evidence from which to propagate belief through the network. The probability of each state of each child node was written to an output file that was then used to develop probabilistic maps of risk factors in R.

Results

Species richness and extinction probability for Phasianidae in Southeast Asia

Southeast Asia contains 42 Phasianidae species, of which 28 are endemic to the region. It includes the entire geographic range of most of the species in three polytypic Phasianidae genera: *Lophura*, *Arborophila* (but see Chen et al. 2015, who resurrect the genus *Tropicoperdix*) and *Polyplectron*. One species is listed as Critically Endangered (*Lophura edwardsi*), two as Endangered (*Pavo muticus, Polyplectron schleiermacheri*), eight as Vulnerable and thirteen as Near-threatened (Table S1). Considering species richness (Figure 2A), most of the region appears to be important: 99.2 % of the land area encompasses the geographic range of at least one species and 77 % covers the range of at least five species. When considering family-level extinction probability (Figure 2B) the Sundaic region and the Annamite Mountain range and associated coastal lowlands in Central Vietnam (18.6 %) stand out.

Overall risk to survival

The IUCN Red List has adopted a classification of threats and this has been applied to the 24 species that are threatened with extinction (Table S1), but not those that are considered to be Least Concern (IUCN 2016). Most of the threatened species ranges are subject to habitat loss (fragmentation and conversion) and the species themselves to biological resource use (hunting and logging) (IUCN 2016).

The majority of Phasianidae in the region are associated with forest habitat, with 32 of the 42 having their known range consisting of at least 40% forest (Table S1). Combining rates of habitat loss, extent of hunting and the effectiveness of protected areas, to go beyond the Red List categorisation, indicates that the overall highest risk facing the Phasianidae occurs on mainland Southeast Asia, particularly coinciding with areas of greatest species range overlap in Myanmar and the Annamite Mountains in central Vietnam. There are also high levels of risk coinciding with extensive range overlap between species in western Java (Figure 3).

Priority areas

Parts of Peninsular Malaysia, northern Sumatra and central Borneo have both the highest risk and extinction probability, with much of the rest of Sundaland, parts of central Vietnam and smaller areas of Myanmar also standing out (Figure 4).

After highlighting the areas denoting a high risk of reduced species richness (Figure 4A) and increased overall extinction probability (Figure 4B) a total of six strongholds have been defined (Figure 5) with strongholds 1 to 3 referring uniquely to the overall extinction probability while the other three refer to both criteria (albeit with lesser importance for overall extinction probability). The current level of protection across all strongholds for reduced species richness is 8.81 % and for global extinction is 29.1 %. Stronghold 1 (Western Myanmar) currently has no protection. Protection for Stronghold 2 (Central Indoburma hotspot) is of 8.25%, Stronghold 3 (Anamite mountain and Central Vietnam lowland) is of 8.34%, Stronghold 4 (Peninsular Malaysia) is 20.40%, Stronghold 5 (Sumatra) is of 31.7% and Stronghold 6 (Borneo) is of 42.52%.

Discussion

Projections of extinction probability (i.e. IUCN Red List assessments) of Galliformes in the region are rarely based upon very recent field data, and information on occurrence and abundance probably lags behind the species' responses to the dynamic nature of contemporary human pressures. As it is not easy to predict the impact of anthropogenic change on individual species, it is consequently challenging to assess where and how to act in a way that will have the most significant long-term conservation benefit. Our model is based upon expert-opinion, rather than empirical data, which are not available for Galliformes species in the region, and, as noted above, it is not possible to test the predictive accuracy of the model at this time (Pitchforth and Mengerson 2013). However, it offers a conceptual model that may prove critical in identifying priorities for immediate action. Furthermore, BBNs can be updated easily and rapidly, so that as empirical data are collected they can be used to update the model and its predictions. Currently the model is based upon threats (hunting and habitat loss) and will be improved significantly as our understanding of the mechanisms and magnitude of these threats on Galliformes populations increases. Climate change and other threats may also become increasingly measurable in the region and may therefore be included in future iterations of the model.

Our analysis of region-wide risk factors (habitat change, hunting and protected area effectiveness) indicates that there is additional information that could be incorporated into IUCN threat assessments. This may result in revision of the IUCN threat status for individual species, which may also result from the collection of more adequate field data in at least parts of the region, particularly in Myanmar. However, by immediately going beyond the Red List categorisation through the use of expert opinion on the potential threats to species in a single family we can identify areas of priority for research and/or action that are possibly highly important to reduce the probability of local (population level) extinctions.

The traditional approach to conserving areas that are seen as important for biodiversity is the creation, expansion and management of protected areas (e.g. proposed Lenya National Park [Donald et al. 2015]): at present 24% of Southeast Asia's forest is thus protected. Although forest degradation continues (Figure S1B), this protection does slow the rate of forest decline, with the majority of protected areas exhibiting less than 20% loss in forest cover between 2000 and 2010 (Figure S1A & S1B). Looking ahead, the value of protected areas is likely to be context-dependent. For example, where hunting has been controlled effectively, population recovery has been quite rapid (e.g. mammals, Steinmetz et al. 2010). Unfortunately, such information is missing for Galliformes with the exception of the green peafowl population of south-central Vietnam (Sukumal et al. 2015).

Increasing economic development will lead to greater investment in infrastructure, (e.g. Laurance et al. 2014), increased human population density and increased pressure on natural resources. These changes, in combination with other emerging threats such as climate change, may lead to increased negative impacts on habitat structure (e.g. Struebig et al. 2015). Our assessment of the risk to Phasianidae, encompassing both threats and the efficacy of protected areas, suggests that there is a need to revise assessments as to where action is both needed and what form it should take. Although Phasianidae are often considered to be tolerant to human disturbance (e.g. agriculture), at least in the north of the region, current patterns of habitat change are such that this must be tested against observed and predicted rates of change. Predictive models of range change in the face of direct threats (e.g. habitat degradation and loss and hunting) and climate change are badly needed (see Sukumal et al. 2010 for *Lophura diardi*).

Aichi Target 12 is concerned with both avoiding extinctions and with reversing the declines of the most threatened species. Reacting to high profile cases of probable imminent national, regional or global extinction is likely to result in targeted action in a small part of the region. This may lead to widespread local extinctions of other species given the current pattern of threats and protected area effectiveness. A broader perspective, incorporating species richness, extinction probability (i.e. IUCN threat status) and risk factors, is more likely to identify landscapes that should be the focus of action to reverse declines of threatened species.

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Figures

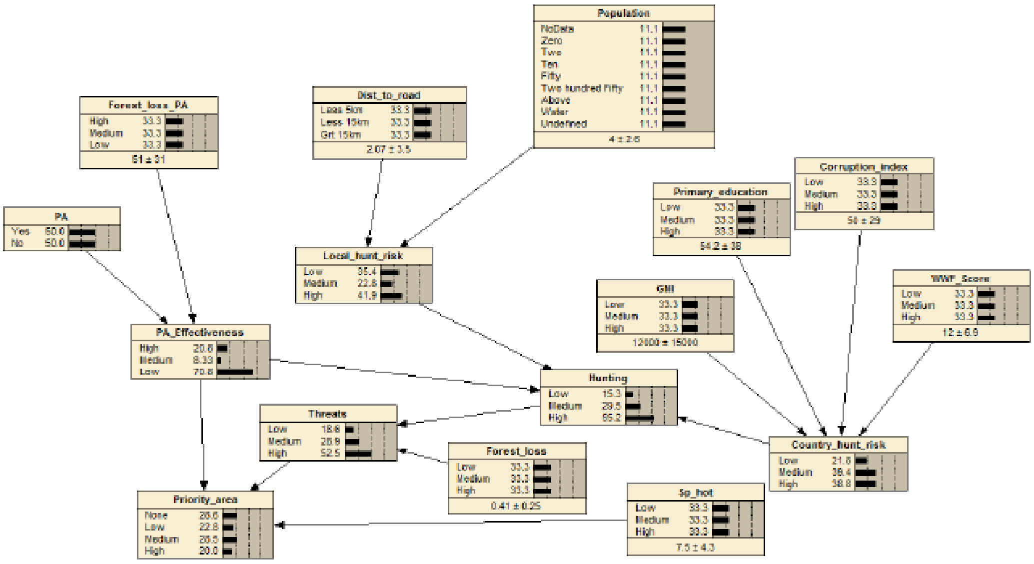

Figure 1: Bayesian belief network. Here we assume the threatening processes (hunting, logging and land use change) have an increasing negative effect on populations and that protected areas that are effectively managed provide mitigation for these threats.

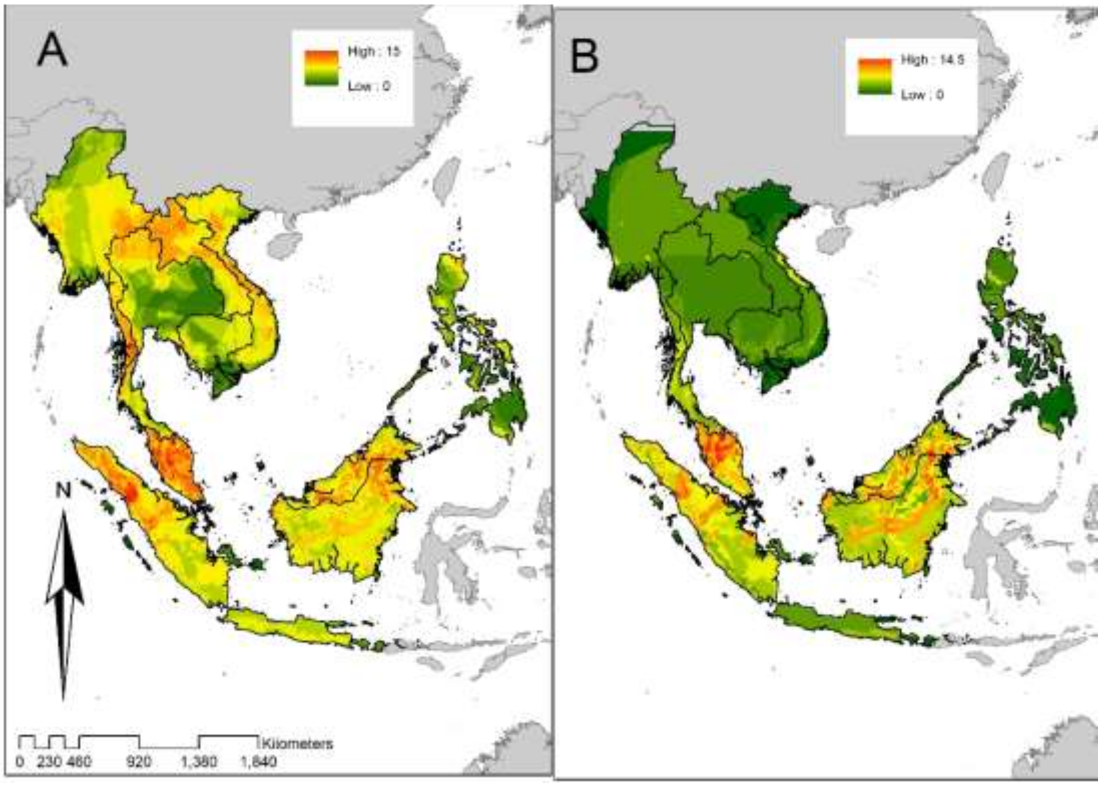

Figure 2: (A) Species richness for Phasianidae in Southeast Asia, which is defined as the area of greatest overlap of the range of each species. Data on the global distribution of Phasianidae were derived from BirdLife International and NatureServe (2012). (B) Extinction probability is calculated by adding the relative IUCN Red List threat category (IUCN 2013). Areas of high species richness and of high family-level extinction probability are shown in red.

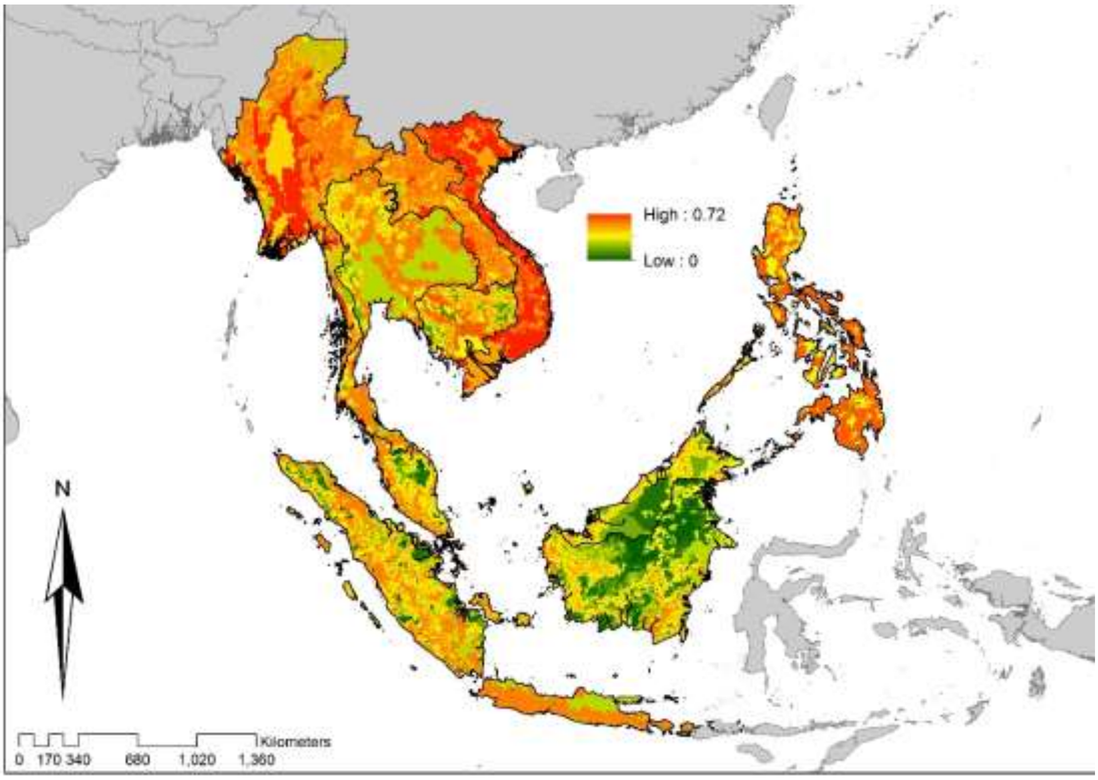

Figure 3: Risk across Southeast Asia, defined by combining habitat loss, protected area effectiveness and hunting. Red areas indicate a higher combined risk for Phasianidae species.

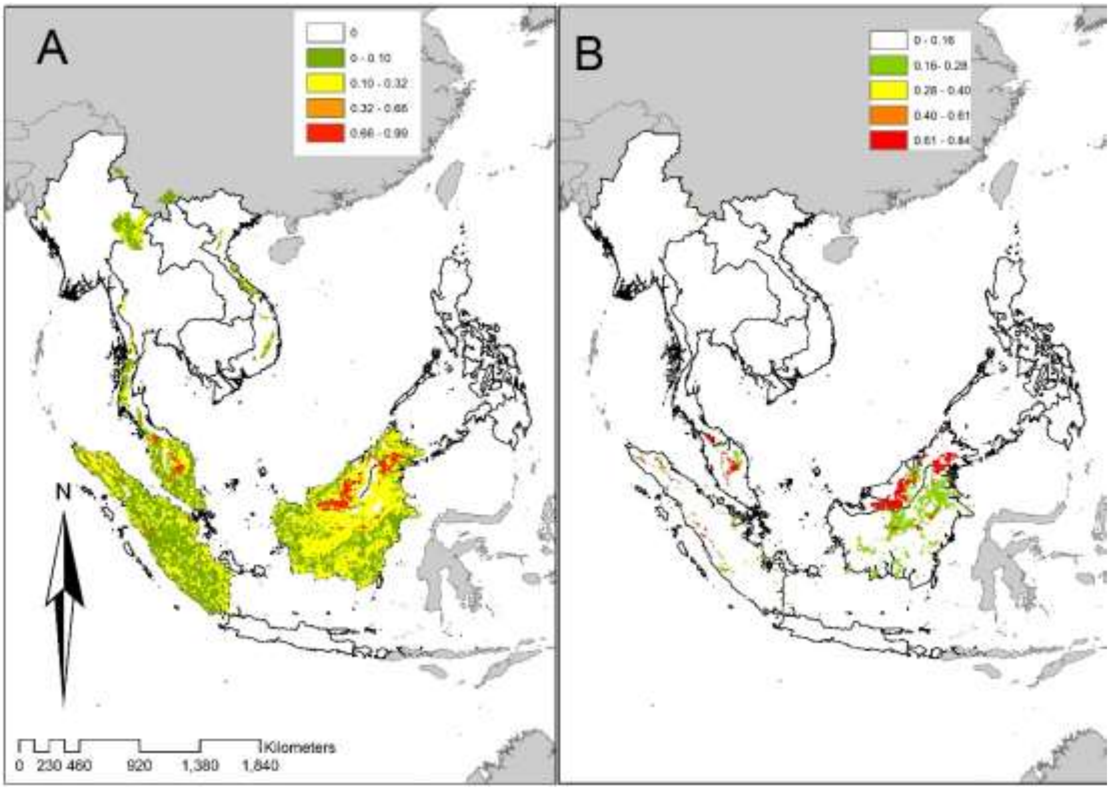

Figure 4: Areas where forest associated Phasianidae in Southeast Asia are most likely to suffer from: (A) reduced species richness; and (B) global species extinction. A) Red denotes areas where risk and species richness are both high and green denotes areas where they are both low; B) red denotes areas where risk, and overall extinction probability, is highest and green denotes areas where they are lower. White patches in both figures indicate areas where the number of threatened Galliformes species is low (Figure S1).

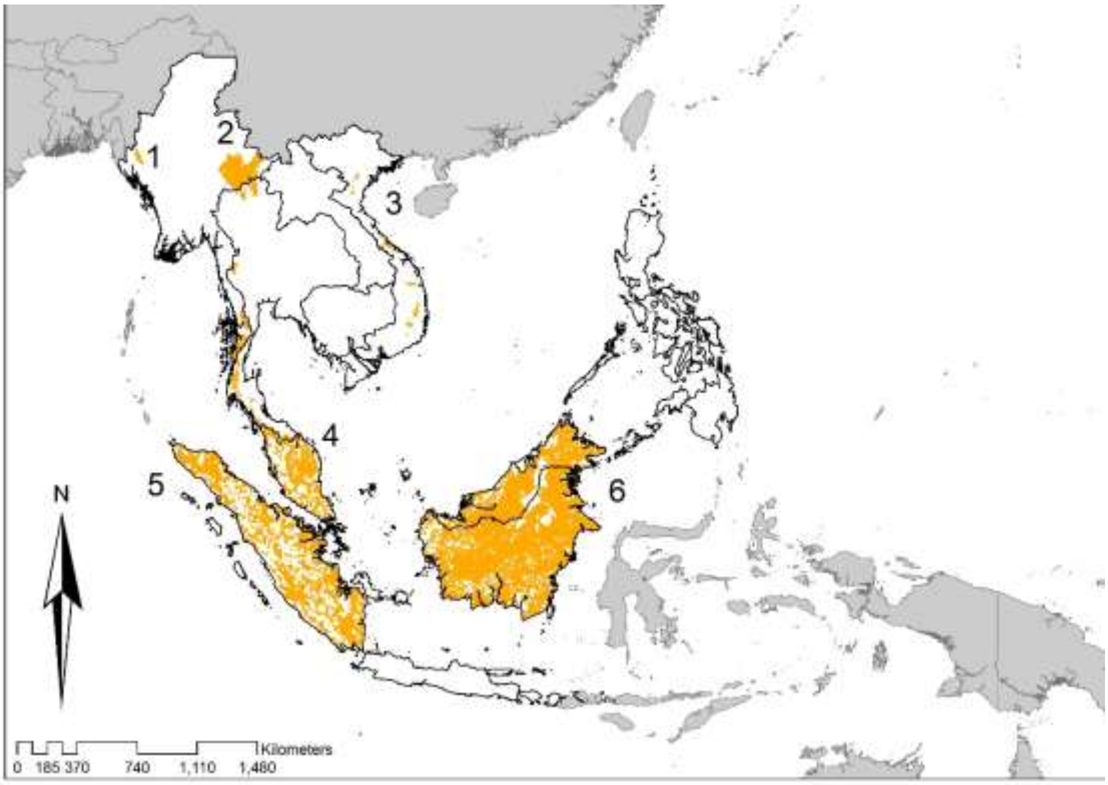

Figure 5: The six strongholds for the avoidance of Phasianidae species richness loss and global extinctions combined. The numbers refer to the text above.

Supplementary Material

Table S1: The 42 Phasianidae species found in the region, their IUCN Red List threat status (* indicates threats have been assessed against IUCN Red List criteria) and the percentage of the range encompassing forest cover

English name	Scientific name	Forest - with agricultural activities	Forest - with moderate or higher livestock density	Forest - protected	Forest - virgin	Percentage of forest in the range
White-cheeked Partridge	Arborophila atrogularis*	10.41	39.05	5.50	1.78	56.74
Bar-backed Partridge	Arborophila brunneopectus	15.23	10.41	9.48	0.13	35.25
Chestnut-headed Partridge	Arborophila cambodiana	5.09	13.43	32.87	0.00	51.39
Malaysian Partridge	Arborophila campbelli	70.94	5.42	15.76	2.96	95.07
Chestnut-breasted Tree-partridge	Arborophila charltonii*	30.91	6.21	15.10	0.14	52.36
Green-legged Partridge	Arborophila chloropus	13.18	12.60	12.82	0.35	38.95
Orange-necked Partridge	Arborophila davidi*	11.76	35.29	27.45	0.00	74.51
Red-breasted Partridge	Arborophila hyperythra	47.75	0.00	25.00	23.93	96.67
Chestnut-bellied Partridge	Arborophila javanica	5.80	16.71	2.32	0.00	24.83
Grey-breasted Partridge, White-faced partridge	Arborophila orientalis*	6.35	17.46	7.14	0.00	30.95
Roll's Partridge	Arborophila rolli	16.45	26.75	38.60	0.00	81.80
Red-billed Partridge	Arborophila rubrirostris	17.65	19.24	33.46	0.00	70.34
Rufous-throated Partridge	Arborophila rufogularis	13.97	19.84	7.24	0.36	41.42

Sumatran Partridge	Arborophila sumatrana	27.61	15.43	35.87	0.00	78.91
Great Argus	Argusianus argus*	30.91	3.32	7.90	2.85	44.98
Mountain Bamboo-partridge	Bambusicola fytchii	10.88	28.19	3.42	1.02	43.51
Ferruginous Partridge	Caloperdix oculeus	28.67	9.20	15.49	0.57	53.92
Japanese Quail	Coturnix japonica*	9.44	19.54	4.09	0.53	33.60
Chinese Francolin	Francolinus pintadeanus	10.40	13.75	6.62	0.23	31.01
Red Junglefowl	Gallus gallus	12.28	11.74	6.83	0.30	31.15
Green Junglefowl	Gallus varius	2.88	5.48	1.57	0.00	9.93
Crimson-headed Partridge	Haematortyx sanguiniceps	48.97	0.00	35.27	7.36	91.61
Bulwer's Pheasant	Lophura bulweri*	58.88	0.31	14.03	14.03	87.25
Diard's Fireback, Siamese Fireback	Lophura diardi	16.36	12.04	13.31	0.10	41.80
Edwards's Pheasant	Lophura edwardsi*	29.87	5.19	0.00	0.00	35.06
Crestless Fireback	Lophura erythrophthalma*	32.73	2.10	4.47	2.32	41.63
Crested Fireback	Lophura ignita*	39.97	4.10	8.37	3.20	55.65
Salvadori's Pheasant	Lophura inornata*	25.64	14.10	36.67	0.00	76.41
Kalij Pheasant	Lophura leucomelanos	7.84	28.80	2.33	0.89	39.86
Silver Pheasant	Lophura nycthemera	12.42	10.75	7.35	0.30	30.82
Black Partridge	Melanoperdix niger*	32.39	2.15	4.44	2.30	41.27
Green-necked Peafowl, Green Peafowl	Pavo muticus*	15.06	20.51	10.36	0.44	46.37
Grey Peacock-pheasant	Polyplectron bicalcaratum	12.36	21.12	6.77	0.63	40.88
Bronze-tailed Peacock-pheasant	Polyplectron chalcurum	18.03	20.59	30.84	0.00	69.47
Germain's Peacock-pheasant	Polyplectron germaini	11.71	24.95	7.38	0.00	44.03
Mountain Peacock-pheasant	Polyplectron inopinatum*	72.11	5.44	14.29	0.68	92.52

Crested Peacock-pheasant	Polyplectron malacense*	32.46	2.84	5.39	1.09	41.78
Napoleon's Peacock-pheasant, Palawan Peacock-pheasant	Polyplectron napoleonis*	1.46	0.00	40.15	0.00	41.61
Bornean Peacock-pheasant	Polyplectron schleiermacheri*	0.45	65.75	10.85	5.92	82.96
Crested Argus	Rheinardia ocellata	16.30	11.28	5.27	0.00	32.84
Long-billed Partridge	Rhizothera longirostris*	28.72	4.47	8.88	0.38	42.45
Crested Partridge	Rollulus rouloul*	32.64	3.25	8.55	2.98	47.42

Table S2: Condition Probability Table 1 – Protected area (PA) effectiveness is conditional on protected areas and forest loss in protected areas.

		PA effectiveness		
Protected areas	Forest loss in protected areas	High	Medium	Low
Yes	High	0	0	1
Yes	Medium	0.25	0.5	0.25
Yes	Low	1	0	0
No	High	0	0	1
No	Medium	0	0	1
No	Low	0	0	1

Table S3: Condition Probability Table 2 – Local hunting risk is conditional on distance to the road and population density.

		Local hunting risk		
Distance to the road	Population	Low	Medium	High
Less 5km	NoData	0.33	0.33	0.33
Less 5km	Zero	0.3	0.3	0.4
Less 5km	Two	0.2	0.3	0.5
Less 5km	Ten	0	0.4	0.6
Less 5km	Fifty	0	0.3	0.7
Less 5km	Two hundred	0	0	1
Less 5km	Above	0	0	1
Less 5km	Water	1	0	0
Less 5km	Undefined	0.33	0.33	0.33
Less 15km	NoData	0.33	0.33	0.33
Less 15km	Zero	0.8	0.2	0
Less 15km	Two	0.7	0.3	0
Less 15km	Ten	0.2	0.4	0.4
Less 15km	Fifty	0.1	0.5	0.4
Less 15km	Two hundred	0	0	1
Less 15km	Above	0	0	1
Less 15km	Water	1	0	0
Less 15km	Undefined	0.33	0.33	0.33
Grt 15km	NoData	0.33	0.33	0.33
Grt 15km	Zero	0.95	0.05	0
Grt 15km	Two	0.8	0.2	0
Grt 15km	Ten	0.4	0.5	0.1
Grt 15km	Fifty	0.1	0.7	0.2
Grt 15km	Two hundred	0	0	1
Grt 15km	Above	0	0	1
Grt 15km	Water	1	0	0
Grt 15km	Undefined	0.33	0.33	0.33

Table S4: Condition Probability Table 3 – Country hunting risk is conditional on WWF crime score, corruption index, per capita primary education and gross national income.

WWF crime score	Corruption index	Primary education	Gross national income	Country hunting risk: Low	Medium	High
Low	Low	Low	Low	0.25	0.5	0.25
Low	Low	Low	Medium	0.35	0.4	0.25
Low	Low	Low	High	0.4	0.4	0.2
Low	Low	Medium	Low	0.35	0.4	0.25
Low	Low	Medium	Medium	0.4	0.4	0.2
Low	Low	Medium	High	0.6	0.4	0
Low	Low	High	Low	0.4	0.4	0.2
Low	Low	High	Medium	0.6	0.4	0
Low	Low	High	High	0.9	0.1	0
Low	Medium	Low	Low	0	0.4	0.6
Low	Medium	Low	Medium	0.25	0.5	0.25
Low	Medium	Low	High	0.35	0.4	0.25
Low	Medium	Medium	Low	0.25	0.5	0.25
Low	Medium	Medium	Medium	0.35	0.4	0.25
Low	Medium	Medium	High	0.4	0.4	0.2
Low	Medium	High	Low	0.35	0.4	0.25
Low	Medium	High	Medium	0.4	0.4	0.2
Low	Medium	High	High	0.6	0.4	0
Low	High	Low	Low	0	0.3	0.7
Low	High	Low	Medium	0	0.4	0.6
Low	High	Low	High	0.25	0.5	0.25
Low	High	Medium	Low	0	0.4	0.6
Low	High	Medium	Medium	0.25	0.5	0.25
Low	High	Medium	High	0.35	0.4	0.25
Low	High	High	Low	0.25	0.5	0.25
Low	High	High	Medium	0.35	0.4	0.25
Low	High	High	High	0.4	0.4	0.2
Medium	Low	Low	Low	0	0.4	0.6
Medium	Low	Low	Medium	0.25	0.5	0.25
Medium	Low	Low	High	0.35	0.4	0.25
Medium	Low	Medium	Low	0.25	0.5	0.25
Medium	Low	Medium	Medium	0.35	0.4	0.25
Medium	Low	Medium	High	0.4	0.4	0.2
Medium	Low	High	Low	0.35	0.4	0.25
Medium	Low	High	Medium	0.4	0.4	0.2
Medium	Low	High	High	0.6	0.4	0
Medium	Medium	Low	Low	0	0.3	0.7
Medium	Medium	Low	Medium	0	0.4	0.6
Medium	Medium	Low	High	0.25	0.5	0.25
Medium	Medium	Medium	Low	0	0.4	0.6
Medium	Medium	Medium	Medium	0.25	0.5	0.25
Medium	Medium	Medium	High	0.35	0.4	0.25
Medium	Medium	High	Low	0.25	0.5	0.25
Medium	Medium	High	Medium	0.35	0.4	0.25
Medium	Medium	High	High	0.4	0.4	0.2
Medium	High	Low	Low	0	0.2	0.8
Medium	High	Low	Medium	0	0.3	0.7
Medium	High	Low	High	0	0.4	0.6
Medium	High	Medium	Low	0	0.3	0.7
Medium	High	Medium	Medium	0	0.4	0.6
Medium	High	Medium	High	0.25	0.5	0.25
Medium	High	High	Low	0	0.4	0.6
Medium	High	High	Medium	0.25	0.5	0.25
Medium	High	High	High	0.35	0.4	0.25
High	Low	Low	Low	0	0.3	0.7
High	Low	Low	Medium	0	0.4	0.6
High	Low	Low	High	0.25	0.5	0.25
High	Low	Medium	Low	0	0.4	0.6
High	Low	Medium	Medium	0.25	0.5	0.25
High	Low	Medium	High	0.35	0.4	0.25
High	Low	High	Low	0.25	0.5	0.25
High	Low	High	Medium	0.35	0.4	0.25

Protected area effectiveness	Country hunting risk	Local hunting risk	Hunting		
			Low	Medium	High
High	Low	Low	1	0	0
High	Low	Medium	0.32	0.45	0.23
High	Low	High	0.27	0.32	0.41
High	Medium	Low	0.32	0.45	0.23
High	Medium	Medium	0.32	0.45	0.23
High	Medium	High	0.18	0.32	0.5
High	High	Low	0.27	0.32	0.41
High	High	Medium	0.18	0.32	0.5
High	High	High	0	0.1	0.9
Medium	Low	Low	1	0	0
Medium	Low	Medium	0.17	0.56	0.28
Medium	Low	High	0.11	0.39	0.5
Medium	Medium	Low	0.17	0.56	0.28
Medium	Medium	Medium	0.25	0.5	0.25
Medium	Medium	High	0	0.39	0.61
Medium	High	Low	0.11	0.39	0.5
Medium	High	Medium	0	0.39	0.61
Medium	High	High	0	0.1	0.9
Low	Low	Low	0.7	0.3	0
Low	Low	Medium	0.15	0.55	0.3
Low	Low	High	0.2	0.25	0.55
Low	Medium	Low	0.06	0.56	0.38
Low	Medium	Medium	0.06	0.56	0.38
Low	Medium	High	0	0.25	0.75
Low	High	Low	0.1	0.2	0.7
Low	High	Medium	0.1	0.2	0.7
Low	High	High	0	0	1

Table S5: Condition Probability Table 4 – Threat is conditional on hunting (local and country level combined) and forest loss (at the local scale)

		Threat		
Hunting	Forest loss	Low	Medium	High
Low	Low	1	0	0
Low	Medium	0.8	0.2	0
Low	High	0.4	0.6	0
Medium	Low	0.5	0.5	0
Medium	Medium	0.25	0.5	0.25
Medium	High	0	0.4	0.6
High	Low	0	0.2	0.8
High	Medium	0	0.2	0.8
High	High	0	0.2	0.8

Table S6: Condition Probability Table 5 – Priority area is conditional on protected area effectiveness, threats and species richness (weighed or unweighted by IUCN Red List Category).

			Priority area			
Species richness	Threats	Protected area effectiveness	None	Low	Medium	High
Low	Low	High	0	0.7	0.3	0
Low	Low	Medium	0	0.6	0.4	0
Low	Low	Low	0.9	0.1	0	0
Low	Medium	High	0	0.6	0.4	0
Low	Medium	Medium	0.9	0.1	0	0
Low	Medium	Low	0.9	0.1	0	0
Low	High	High	0.9	0.1	0	0
Low	High	Medium	0.9	0.1	0	0
Low	High	Low	1	0	0	0
Medium	Low	High	0	0	0.2	0.8
Medium	Low	Medium	0	0	0.6	0.4
Medium	Low	Low	0	0.3	0.6	0.2
Medium	Medium	High	0	0	0.7	0.3
Medium	Medium	Medium	0	0.3	0.3	0.3
Medium	Medium	Low	0.2	0.3	0.4	0
Medium	High	High	0	0.3	0.6	0.1
Medium	High	Medium	0	0.2	0.6	0.2
Medium	High	Low	0	0.9	0.1	0
High	Low	High	0	0	0	1
High	Low	Medium	0	0	0.2	0.8
High	Low	Low	0	0	0.3	0.7
High	Medium	High	0	0	0.2	0.8
High	Medium	Medium	0	0	0.4	0.6
High	Medium	Low	0	0.1	0.6	0.3
High	High	High	0	0	0.3	0.7
High	High	Medium	0	0.1	0.6	0.3
High	High	Low	0	0.1	0.6	0.3

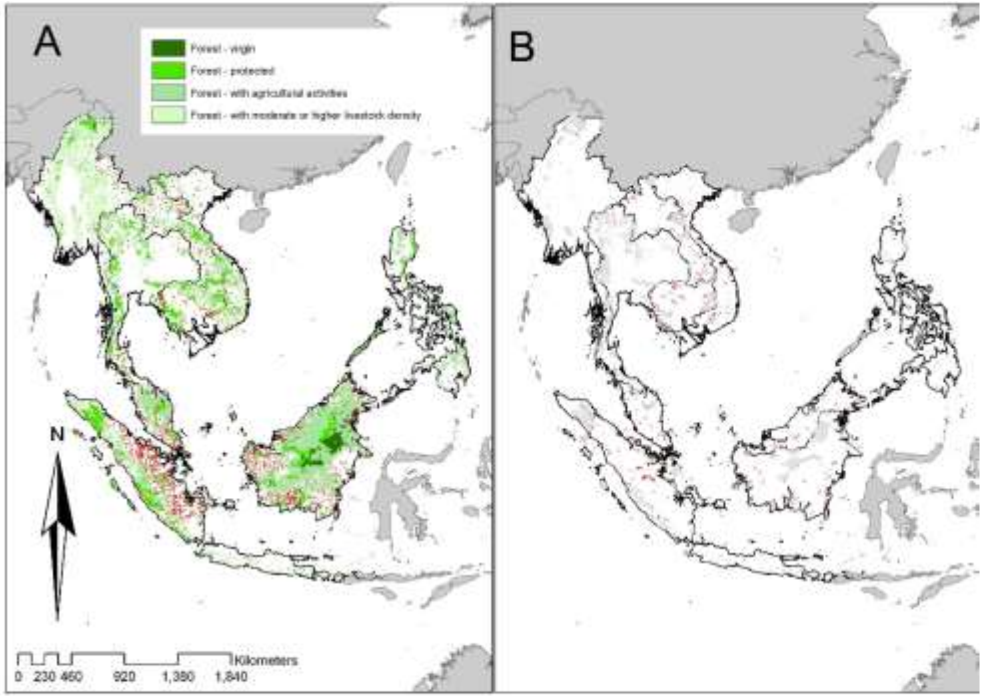

Figure S1: (A) Forest cover (green) and forest loss (marked in red points) between 2000 and 2013 over the study region and (B) protected areas network (light grey shading) and efficiency (red points indicate forest loss in Protected Areas between 2000 and 2013).

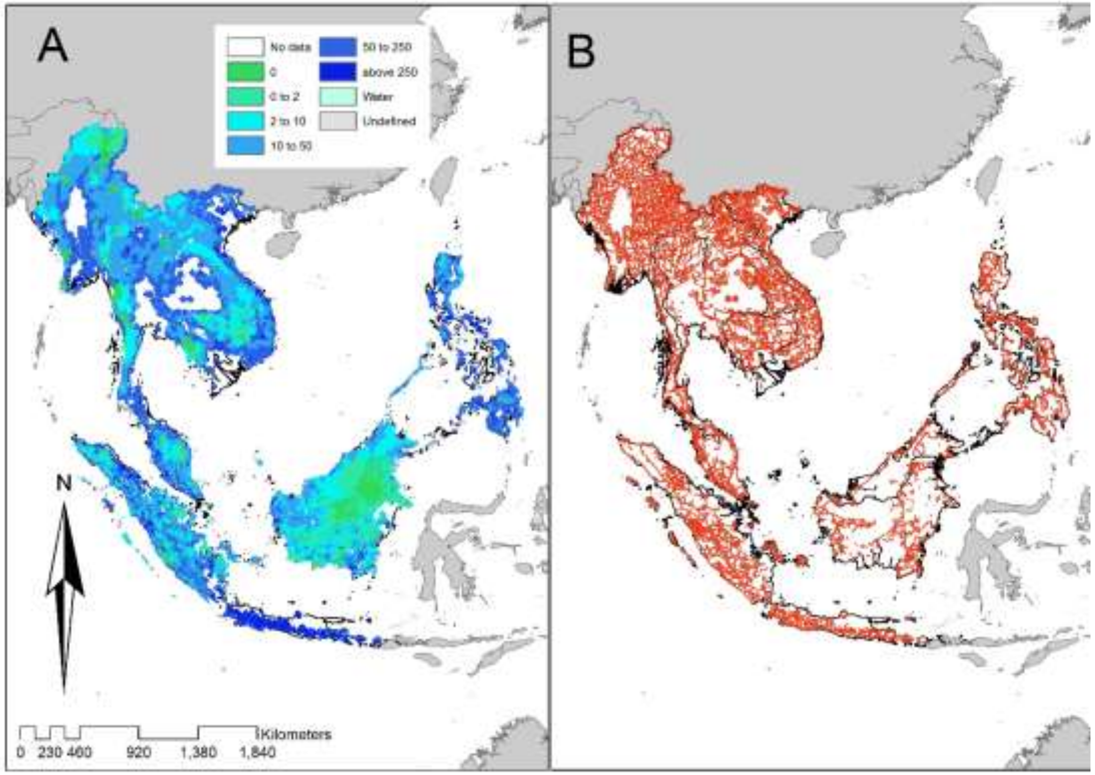

Figure S2: Local (raster scale) hunting pressure was defined using data on (A) human population density and (B) the location of roads within the region as proxies for the potential for hunting.