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# Impacts of hunting on tropical forests in Southeast Asia

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**Abstract:** *Although deforestation and forest degradation have long been considered the most significant threats to tropical biodiversity, across Southeast Asia (Northeast India, Indochina, Sundaland, Philippines) substantial areas of natural habitat have few wild animals (>1 kg), bar a few hunting-tolerant species. To document hunting impacts on vertebrate populations regionally, we conducted an extensive literature review, including papers in local journals and reports of governmental and nongovernmental agencies. Evidence from multiple sites indicated animal populations declined precipitously across the region since approximately 1980, and many species are now extirpated from substantial portions of their former ranges. Hunting is by far the greatest immediate threat to the survival of most of the region's endangered vertebrates. Causes of recent overhunting include improved access to forests and markets, improved hunting technology, and escalating demand for wild meat, wildlife-derived medicinal products, and wild animals as pets. Although hunters often take common species, such as pigs or rats, for their own consumption, they take rarer species opportunistically and sell surplus meat and commercially valuable products. There is also widespread targeted hunting of high-value species. Consequently, as currently practiced, hunting cannot be considered sustainable anywhere in the region, and in most places enforcement of protected-area and protected-species legislation is weak. The international community's focus on cross-border trade fails to address overexploitation of wildlife because hunting and the sale of wild meat is largely a local issue and most of the harvest is consumed in villages, rural towns, and nearby cities. In addition to improved enforcement, efforts to engage hunters and manage wildlife populations through sustainable hunting practices are urgently needed. Unless there is a step change in efforts to reduce wildlife exploitation to sustainable levels, the region will likely lose most of its iconic species, and many others besides, within the next few years.*

**Keywords:** bushmeat, defaunation, enforcement, extinction, extirpation, overexploitation, tropical forest, wild meat, wildlife trade

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Impactos de la Caza sobre los Bosques del Sureste Asiático

**Resumen:** *Aunque la deforestación y la degradación de los bosques han sido consideradas durante largo tiempo como las amenazas más significativas para la biodiversidad tropical, a lo largo del sureste asiático (noreste de India, Indochina, Sondalandia, Filipinas) hay áreas sustanciales de hábitat natural que tienen algunos animales silvestres (>1 kg), excluyendo a algunas especies tolerantes a la caza. Para documentar los impactos regionales de la caza sobre las poblaciones de vertebrados realizamos una revisión extensiva de la literatura, incluyendo artículos de revistas locales y reportes de agencias gubernamentales y no gubernamentales. La evidencia de los múltiples sitios indicó que las poblaciones animales declinaron precipitosamente en la región desde aproximadamente 1980 y que muchas especies ahora están extirpadas de porciones sustanciales de sus extensiones previas. La caza es por mucho la mayor amenaza inmediata para la supervivencia de la mayoría de los vertebrados en peligro de la región. Las causas del exceso reciente de caza incluyen el acceso mejorado a los bosques y a los mercados, tecnología mejorada de caza, productos medicinales derivados de la vida silvestre y los animales silvestres como mascotas. Aunque los cazadores generalmente toman a especies comunes, como los cerdos y las ratas, para su propio consumo, también toman especies raras de manera oportuna y venden la carne excedente y los productos de valor comercial. También existe una extensa caza enfocada en especies de alto valor. En consecuencia, como es practicada actualmente, la caza no puede considerarse sustentable en ningún lugar de la región y en la mayoría de las localidades la aplicación de la legislación de áreas y especies protegidas es débil. El enfoque de la comunidad internacional sobre el mercado transfronterizo falla en abordar la sobreexplotación de la vida silvestre porque la caza y la venta de la carne salvaje son en general un asunto local y la mayoría es consumida en las aldeas, pueblos rurales y ciudades cercanas. Además de una aplicación mejorada, los esfuerzos por involucrar a los cazadores y por manejar las poblaciones de vida silvestre por medio de prácticas de caza sustentable son una necesidad urgente. A menos que haya un cambio de paso en los esfuerzos por reducir la explotación de la vida silvestre a niveles sustentables, la región probablemente pierda la mayoría de sus especies icónicas, además de muchas otras, en el transcurso de los próximos años.*

**Palabras Clave:** aplicación, bosque tropical, carne de animales silvestres, carne silvestre, defaunación, extinción, extirpación, mercado de vida silvestre, sobreexplotación

## Introduction

Tropical Southeast Asia (Northeast India, Indochina, Sundaland, Philippines) is experiencing a wildlife crisis (Wilcove et al. 2013). Across the region, extensive areas of natural forest are near devoid of large animals (here defined as >1 kg), except for perhaps a few hunting-tolerant species. Based on current and historical range maps, Morrison et al. (2007) estimated that only 1% of the land area in tropical Asia supports an intact fauna of mammals >20 kg. In reality the situation is far worse. Throughout Southeast Asia, most large animals have experienced substantial population declines over much of their remaining ranges (Supporting Information). Forests that supported an intact fauna up to about 1990 have lost 20–40% of their bird species (Harrison 2011; Sreekar et al. 2015*a*). In many areas, hunters have been forced to target progressively smaller species and now regularly take small birds (<25 g) and squirrels (Liang et al. 2013; Brodie et al. 2014; Sreekar et al. 2015*a*).

These declines have been driven by a wave of unsustainable hunting that has spread across South East Asia over the past 20–30 years (Supporting Information). Cheaper outboard motors and motorbikes have afforded hunters increased access to forests (Robinson & Bennett 2000). The widespread availability of improved hunting technology, such as modern guns, wire snares, mist nets, and torches, has reduced the skill required to hunt (Robinson & Bennett 2000). Improved transport infrastructure and increased affluence in urban areas has spurred an expansion of markets for wild meat, wildlife-derived medicinal products, and wild animals as pets (Robinson & Bennett 2000; Milner-Gulland et al. 2003). In many places, consumption of wild meat increased dramatically and wildlife stocks were quickly exhausted (e.g., Rao et al. 2010).

The failure of government agencies and the international conservation community to appreciate the scale and extent of overhunting, much less respond appropriately, continues to be a major impediment to addressing the wildlife crisis in Southeast Asia. For example, at the First Asia Parks Congress in 2013 in Japan there was no explicit consideration of hunting as a key threat to wildlife in Southeast Asia's protected areas (IUCN 2014). The Convention on Biodiversity Aichi Target 11 (www.cbd.int/sp/targets) set the goal of expanding protected-area coverage of terrestrial ecosystems to 17%, and much of the subsequent discussion has focused on how this might be achieved and what its impact would be in terms of conservation gains (e.g., Pouzols et al. 2014). However, given such a large proportion of the region's natural forests have been defaunated, such analyses

provide a highly inflated picture of the conservation gains likely to be achieved by increasing protected-area coverage. Other factors must be considered, including quality of habitat, especially faunal intactness, the likelihood that areas designated will be effectively managed, and the added value for conservation of protecting these areas. Without such considerations, these initiatives are largely meaningless. Expanding reserve networks through the addition of land that has already lost a large proportion of its vertebrate fauna is a minimal gain to conservation (Sreekar et al. 2015*a*) unless areas are explicitly considered within a broader restoration and rewilding agenda.

Aichi Target 11 also states that protected areas should be " . . . effectively and equitably managed . . . ." In Southeast Asia, this is a much more critical element of the target. A step change in the effort dedicated to enhancing the effectiveness of protected areas across the region is required (Watson et al. 2014). There is also a need for greater recognition of the important role of areas outside protected-area networks, including secondary forests and multiuse landscapes, in contributing toward conservation goals (Edwards et al. 2014; Naniwadekar et al. 2015) and therefore a greater need for enhanced wildlife protection and management across the broader landscape. Aichi Target 12 calls for preventing species extinctions. With respect to large vertebrates, this can be achieved only by addressing the principle driver of population declines, namely overhunting.

The purpose of our review was first to document the scale and extent of hunting as a threat to wildlife in Southeast Asia. We discuss why people hunt, how they hunt, the determinants of geographical variation in hunting pressure, and the consequences of hunting for the ecology of forests. We also briefly reviewed commercial wildlife farming as an emerging threat to wildlife. In Supporting Information, we provide a comprehensive review of the impacts hunting has had in different countries or subregions. We finish by considering whether it is possible to have sustainable hunting in the region and what needs to be done to address the ballooning wildlife crisis in Southeast Asia.

## Hunting in Southeast Asia

Of the principle tropical forest regions, tropical Asia has the lowest proportion of natural forest cover remaining (Sodhi et al. 2004) and the highest rates of contemporary deforestation, driven largely by expanding oil-palm, rubber, and *Acacia* plantations (Hansen et al. 2013).

Nonetheless, national governments often working in collaboration with international conservation nongovernmental organizations (NGOs) have established an extensive network of protected areas, including national parks and wildlife reserves. This reserve system covers about 20 million ha across the region (Juffe-Bignoli et al. 2014). A large amount of the remaining natural forest outside these conservation zones is protected to some degree, either as forest reserved for watershed protection or for timber production. In 2010, there were an estimated 199 million ha of natural forest (pristine, degraded, and secondary regrowth) across the region (Wilcove et al. 2013). If these forests supported intact or near intact faunas, prospects for the survival of the region's wildlife would be reasonably good. However, a large proportion of remaining natural areas supports few large animals (Supporting Information). Forests with near intact faunas at near natural abundances probably no longer exist in Southeast Asia, and many protected areas are empty forests (Harrison 2011; IUCN 2014). Whereas in other regions, multiuse agricultural landscapes continue to support a wide diversity of wildlife and many species of conservation concern (Ranganathan et al. 2008; Chapron et al. 2014), in Southeast Asia this is rarely, if ever, the case.

Nevertheless, within Southeast Asia there are pronounced regional differences in hunting practices, firearm legislation, the degree to which hunting and firearm laws are enforced, local demand for wild meat, and access to (usually illegal) domestic and international markets for wild meat, wildlife products, and wild animals as pets (Supporting Information). Consequently, hunting intensity varies markedly across the region and sometimes even over distances of just a few tens of kilometers. Such marked geographical differences make it difficult to evaluate hunting at a regional scale and to date have limited syntheses, examination of its severity, and the design of effective conservation interventions.

## Why People Hunt

People hunt for three basic, interrelated reasons: culture, food, and money. However, the importance of these drivers varies from place to place, and this variation affects the species hunters target and the methods they employ, which in turn affects the impacts of hunting on wildlife and the likely effectiveness of different conservation interventions.

There is increasing evidence that the arrival of modern humans in the region 45,000–60,000 years ago coincided with the extinction of megafauna, which can probably be attributed due to human hunting (Sandom et al. 2014). Archaeological information also indicates that several species with highly restricted distributions today, such as orangutan (*Pongo pygmaeus*) and Asian elephant (*Elephas maximus*), were once widespread (e.g., Elvin 2008). Notwithstanding the initial megafaunal extinctions, this historical hunting led to a slow reduction in animal abundance with substantial populations persisting where human populations densities were low and there were large expanses of inaccessible forests. The

persistence of so many hunting-sensitive species into the modern era attests to this.

In the literature, a distinction between subsistence hunting and commercial hunting is often made. With respect to modern hunting, although differences in peoples' motivations to hunt certainly exist, such distinctions are not clear cut. Hunters often venture out without a specific quarry in mind or hunting may be incidental to other activities, such as collecting nontimber forest products or cutting firewood. Hunting is often opportunistic or indiscriminate (e.g., snares). (Given a field guide, 3 of us [R.D.H., R.S., and B.R.S.] have seen hunters in Southeast Asia flick haphazardly through it commenting on how appetizing this or that species is.) Upon returning from a successful hunt a hunter may decide to eat the carcass, share it among extended family and neighbors (in many communities a substantial part of the wild-meat harvest enters a customary system of exchange [Bennett et al. 2000; Aiyadurai et al. 2010]), or sell it, often illegally, to a market trader (Rao et al. 2010; Scheffers et al. 2012; Velho & Laurance 2013). Other products, such as antlers or skins, may likewise be consumed locally or traded. From the local market, wild meat may end up being eaten in a local restaurant or (again often illegally) sold to traders from a larger urban center or to international traders; the fate of the carcass being largely determined by its market value. Hunters closer to urban markets, who can therefore usually obtain a higher price, may be more likely to sell wild meat than hunters from remote villages (Brashares et al. 2011), and the highest value items, such as elephant ivory, rhinoceros horn, tiger bones, turtles, and pangolin, are inevitably traded illegally to Vietnam or China (Nijman 2010).

Few communities in Asia depend on wild meat for subsistence today, although it may be an important source of income for some rural families, albeit one that is usually illegal under national legislation and inevitably short-lived because animal populations quickly succumb to overhunting (Hilaluddin & Ghose 2005; Rao et al. 2010). Across most of the region there is not sufficient wild meat available, and even in remote areas domestic sources of protein are usually cheaper (Bennett 2002). This does not mean a large proportion of wild meat is not consumed by the hunter's family, neighbors, or friends. It is consumed mostly because it is preferred over domestic alternatives (Velho & Laurance 2013), because of cultural associations with hunting and eating wild animals, and because people enjoy hunting and view wild meat as a free source of protein (Bennett 2002).

For many hunters, the recreational value and the cultural values associated with hunting and eating wild meat are likely to be the principle motivations (Velho & Laurance 2013; Kai et al. 2014). This is confirmed by the fact that in many places people continue to hunt when the diversity and abundance of wildlife are drastically reduced (Brodie et al. 2014; Sreekar et al. 2015*a*, 2015*b*); thus, the likelihood of economic or nutritional gains is trivial. In addition to these intangible values, the motivation to hunt is determined by the expected return, in terms of quarry obtained and its value. The hunting methods employed, skill of the hunter, and abundance of different species determine the likelihood of obtaining particular quarry. However, opportunistic or indiscriminate hunting methods do not require much skill. Hence, it is the abundance of wildlife that principally determines what quarry and how many are likely to be killed, and the availability of markets for a wide range of species provides a financial incentive for hunting in most situations. Although the probability of obtaining rare high-value species may be low, such species are still killed when they are encountered. Meanwhile, the costs of hunting are very low. Guns, ammunition, and snares can be made easily at home or purchased cheaply, and opportunity costs are trivial because hunters tend to hunt at night or during periods of agricultural inactivity.

## What People Hunt

One of the most distinctive characteristics of hunting in tropical forests, including Southeast Asia, is the lack of selectivity. Indiscriminate methods, such as snares and gum traps (for birds), are commonplace, and even hunters with shotguns frequently shoot smaller quarry (Sreekar et al. 2015*a*). This has been attributed to the fact that, even at natural abundances, encounter rates with animals are low and hence the opportunity cost of selectivity is high (Robinson & Bennett 2004). Hence, the notion of game species is foreign to most hunters. A direct consequence of this is that threatened species continue to be hunted regardless of how rare they become (Branch et al. 2013). Indeed, the killing of a rare animal is sometimes celebrated because of its rarity (e.g., Drury 2011).

Some degree of quarry selectivity may be derived from a preference for larger species (Sreekar et al. 2015*a*, 2015*b*) but, as mentioned above, as larger species become rare hunters tend to take progressively smaller quarry. Some species may also be avoided, either because they do not taste good or because they are taboo. For example, Muslims do not eat wild pigs (*Sus* spp.), moon rats (*Echinosorex gymnura*) are avoided because of their bad smell, and at least in one area of Sarawak orangutan are protected by local taboos (Horowitz 1998). Some selectivity is determined by the hunting method. For example, hunters often wait under fruiting trees, especially figs (*Ficus* spp.); hence, frugivores are vulnerable even at relatively low hunting intensities (Harrison 2011; McConkey et al. 2011). Species that roost in aggregations, such as flying foxes (*Pteropus* spp.), are also particularly vulnerable (Struebig et al. 2007; Scheffers et al. 2012). Even common species may be harvested quickly by efficient hunting methods, such as drift fences, often

stretching several kilometers, that contain hundreds of snares (O'Kelly 2013).

Although there is a market for most things, targeted hunting of commercially valuable species by professional hunters is also evident (Nijman 2010). Tigers (*Panthera tigris*) and other large carnivores are killed for their skins, penises, and bones, rhinoceros (*Rhinoceros sondaicus* and *Dicerorhinus sumatrensis*) for their horn, elephants for their ivory, bears (*Helarctus malayanus* and *Ursus thibetanus*) and gaur (*Bos guarus*) for their gall bladders, langurs (*Presbytis* spp. and *Trachypithecus* spp.) for their Bezoar stones, and horned ungulates as trophies (Nijman 2010). These large mammals are usually hunted with large snares, guns (often high-powered rifles or automatic weapons), or other specialized techniques, including baited explosive traps for tigers. Professional hunters may spend several weeks in the forest tracking down their quarry. Pangolins (*Manis* spp.) are harvested in huge quantities across the region for their meat and scales for use in Chinese traditional medicine. Tortoises and turtles are highly prized for both food and medicinal uses, as well as for pets. Teams of hunters search for pangolin, tortoises, and turtles with dogs, and they are increasingly rare over much of the region (IUCN 2015). Song birds, especially those with attractive voices, are prized for the pet trade, especially in Indonesia (Jepson & Ladle 2005). Although some species are captive bred, wild-caught birds are often considered better ensuring the continued attrition of wild populations.

## Determinants of Geographical Variation in Hunting Pressure

Levels of defaunation and hunting pressures are not evenly distributed across the region (Supporting Information) and common hunting methods and quarry preferences differ. Moreover, amidst all the evidence of declining populations, there are a few places where hunting pressure is lower and wildlife still exists in reasonable abundance. Understanding these differences is important for the control of poaching and the management of wildlife populations.

The most obvious determinant of both past and current hunting pressure at both regional and local scales is rural population density. Areas that have high human populations, especially those whose populations were also high historically, have relatively little remaining natural forest cover and have experienced high hunting pressure in remaining fragments (e.g., Scheffers et al. 2012). Such areas include Singapore, much of Java, Philippines, Thailand, and most coastal areas across the region. The next most important determinant is proximity to major markets for wild meat and wildlife products. Thus, although southern China and Vietnam have a high proportion of forest cover, these forests contain few wild animals (Liang et al. 2013; Sreekar et al 2015*a*) and with the exhaustion of wildlife in these countries hunting has intensified in other parts of Indochina, especially Cambodia and Laos. Culture interacts with these other determinants of hunting pressure in a complex and sometimes synergistic manner, often making it difficult to identify the principle drivers. For example, in Laos it seems likely that various factors, including culture (strong hunting traditions among minority ethnic groups), history (the American war disrupting agricultural practices), and geography (proximity to Vietnamese wildlife markets), have all contributed to the extremely high levels of hunting despite very low human population densities.

In the humid tropical forests of Southeast Asia, pigs represent the only abundant large-bodied animal. Thus, the fact that Muslims do not eat pigs substantially reduces the motivation to hunt. Hence, overall hunting pressure and specifically hunting for wild meat tends to be much lower in Muslim areas. However, where there is hunting in Muslim areas, it tends to be targeted hunting of high-value species for trade (Jepson & Ladle 2005; Nijman et al. 2009). In contrast, people living on forest margins tend to hunt for meat and sell it to supplement their incomes (Hilaluddin & Ghose 2005; Rao et al. 2010). Sometimes areas with relatively low densities of humans have very few large animals, such as much of Borneo and Laos (Brodie et al. 2015). Often increased access through the construction of roads, including logging roads and roads servicing plantations, damns, or mines, stimulates commercial hunting in such areas (Bennett & Gumal 2001; Clements et al. 2014).

The availability of firearms, or conversely the level of antifirearm enforcement, is an important determinant of hunting methods. Where guns are widely owned, which is most places, this is the weapon of choice. Where gun-control legislation is more strictly enforced, such as in Indonesia or Vietnam, snares are used more widely.

Perhaps the biggest surprise is that occasionally there is abundant wildlife close to urban areas. For example, in parts of Peninsula Malaysia even hunting-intolerant species, such as gibbons and hornbills, may sometimes be seen in forests bordering suburban gardens (R.H., personal observations). This urban halo effect possibly reflects a loss of hunting culture among urbanites and recreational use of forest areas, which deters poaching. It suggests a transition in people's relationship with wildlife as societies become more affluent. However, elsewhere urban demand for wildlife products is depleting animal populations from increasingly large areas (Drury 2011).

## Consequences of Hunting for Tropical Forests

Vertebrates perform important functions in the ecology of tropical forests as herbivores, seed predators, seed dispersers, and carnivores. Hence, the extirpation of vertebrate species from forests has implications for the

conservation of biodiversity that go beyond a simple concern for the species themselves (Wright 2003). Two functional groups of vertebrates are especially sensitive to hunting and thus are usually the first to be extirpated from a forest: large herbivores and large seed dispersers.

In Southeast Asia, large herbivores, such as rhinoceros, elephants, wild cattle, and large deer, are now confined to small, scattered, isolated populations (IUCN 2015). Through their feeding activities these species cause selective mortality of tree seedlings and hence alter the community structure of forests (Young et al. 2013). Large herbivores are also important seed dispersers for certain tree species with very large seeds (McConkey et al. 2011), and through trampling may play an important role in opening salt licks that are critical to the survival of a large number of other animals (Ghanem & Voigt 2014). A healthy population of large herbivores is also essential for sustaining viable populations of large carnivores.

Because many large frugivorous birds and mammals habitually move long distances and because they congregate at fruiting trees, they are particularly vulnerable to hunting. Large frugivores, such as hornbills, fruit pigeons, and gibbons, swallow bigger seeds and move them greater distances. Moreover, tree species with large seeds tend to be late successional species. Dispersal failure is likely to lead to increased density-dependent mortality of seeds and seedlings; hence, the loss of large seed dispersers threatens to reduce recruitment success of a large proportion of tree species in tropical forests. In a severely defaunated forest in Borneo, tree species with large fruits became increasingly clustered over time and had lower recruitment success than species with abiotically dispersed seeds (Harrison et al. 2013). In an era of global climate change, large seed dispersers may prove critical in enabling tree species to migrate and hence track their bioclimatic envelopes (McConkey et al. 2011). In particular, large seed dispersers are able to move across large gaps and thus may facilitate the movement of plant species across agricultural landscapes. Finally, large seed dispersers may help restore forests (Lindsell et al. 2015). In their absence, seeds need to be collected, cultivated in nurseries, and then planted at the cost of several thousand dollars per hectare (R.H., personal observations). With over 1,340,000 $km^2$ of degraded forests across the region (Wilcove et al. 2013), intact seed-disperser communities could provide a valuable service. Unfortunately, this is unlikely to be realized unless strong measures are taken to restore frugivore populations.

## Emerging Threat of Commercial Wildlife Farming

Commercial captive breeding of wildlife, also known as wildlife farming, has been suggested as a potential instrument to address illegal hunting and wildlife trade through the provision of legal, cheap, and sustainable sources of wildlife for the trade in wild meat and medicines (Drury 2009). However, several studies show that wildlife farms and legalized trade have often exacerbated illegal hunting and trade (Kirkpatrick & Emerton 2010). On the one hand, farming animals often increases the aggregate demand for species, whereas on the other hand wild-sourced animals are often considered more desirable than their farmed alternatives (Drury 2009; Brooks et al. 2010; Kirkpatrick & Emerton 2010). Among urban consumers, wild meat and wildlife-derived medicinal products are often luxury goods and people are prepared to pay a premium for wild-sourced products to demonstrate wealth and status (Brooks et al. 2010; Kirkpatrick & Emerton 2010).

Captive-bred animals are also not always cheaper than wild-sourced stock as a result of the investment required to breed and raise animals (Drury 2009; Brooks et al. 2010; Kirkpatrick & Emerton 2010). Moreover, farms often engage in illegal activities, including sourcing animals from wild populations to supplement their captive stock and providing a front for laundering wild animals (Drury 2009; Brooks et al. 2010; Kirkpatrick & Emerton 2010). Several species have declined substantially throughout their ranges in Southeast Asia partly or largely as a result of wildlife farming (IUCN 2015), including Siamese crocodile (*Crocodylus siamensis*) and Asiatic black bear (*Ursus thibetanus*). Other species have declined locally, such as long-tailed macaque (*Macaca fascicularis*), sika deer (*Cervus nippon*), porcupines (*Hystrix* spp.; Brooks et al. 2010), and pythons (*Python* spp.; Stuart 2004).

The pros and cons of wildlife farming as a tool to reduce pressure on wild populations are still debated, and the outcome is likely to vary considerably among species. For example, faster-breeding species that are cheap and easy to feed are likely to be better subjects for farming. However, at the very least, improved monitoring and enforcement are needed to ensure that wild populations of threatened species are not negatively affected (Brooks et al. 2010; Natusch & Lyons 2014).

## Toward Sustainable Hunting in Southeast Asia

As currently practiced, nowhere within the region can hunting be considered sustainable. Nevertheless, it is probably true that in many places at least wild pigs and possibly other small ungulates could potentially be harvested sustainably (Robinson & Bennett 2004). It may also be possible to sustainably harvest some birds and certain small mammals, such as bamboo rats, squirrels (Dollo et al. 2010), and common civets. In addition, control of agricultural pests, such as wild pigs and macaques, is desirable (Luskin et al. 2013).

Permitting hunting of a limited set of hunting-tolerant species may be an option for traditional hunting to continue and provide protein and income for people

living on forest margins (Robinson & Bennett 2004; Dollo et al. 2010; Rao et al. 2010). The problems arise in governing the system. With the genuine support of local communities, it may be an equally beneficial situation, whereby legitimate hunters help police forests against poaching by commercial hunters and prevent the use of indiscriminate methods, such as snares. In developed countries, the hunting community is often an important ally of conservation because of their interest in maintaining natural habitat and wildlife populations (Harrison 2015). However, there is a risk that with weak enforcement, which is unfortunately the norm throughout much of South East Asia (Supporting Information), and poor cooperation legitimate hunting becomes a front for the continued persecution of threatened species. In Peninsula Malaysia, where there is a licensed hunting system, the regulations are routinely flaunted (Kawanishi et al. 2014). Nevertheless, a potential advantage of a licensed hunting system is that it could engage traditional community-level governance systems, which may be more respected by hunters and therefore more effective (Ostrom 2008; Dollo et al. 2010). Failure to recognize the rights of local communities through the imposition of national protected-species legislation has sometimes actually promoted unsustainable exploitation of species. For example, on the Philippines' Turtle Islands conservation of turtles through management of a sustainable turtle-egg harvest was quite successful when it was under community control, but collapsed when the state intervened with prohibitions (Lejano & Ingram 2007).

Local hunters often lament the decline of animal populations, so one might expect that they would be receptive to interventions aimed at restoring animal populations. However, rarely are local institutions in themselves sufficient to protect wildlife populations (Velho et al. 2016). In a review of management of common-pool resources, Ostrom (2008) identified 8 critical ingredients for success, including clearly defined boundaries to the resource and the rights to harvest resource units; proportion equivalence between the costs and benefits of accessing the resource; monitoring with monitors that are at least partially accountable to users; inclusiveness in decision making; graduated sanctions depending on seriousness of offense; conflict-resolution mechanisms; tenure security over the resource; recognition of rights of local organizations; and nested enterprises for resources that are part of a larger system (e.g., inshore fisheries across several villages within a district). There is every reason to suppose that application of these principles would be appropriate for managing hunting in South East Asia. Success in species recovery programs is also linked to obtaining strong stakeholder consensus (Crees et al. 2016). Unfortunately, across most countries in the region hunting (or gun ownership) is either illegal or governed by an impractical, centrally controlled permitting system (e.g., Kawanishi et al. 2014). This places most resource users outside the law and makes them essentially ungovernable. Legitimacy of wildlife laws is also often undermined by the fact that at least some species may be abundant. Complicating the picture still further, hunters are often from ethnic minorities or economically marginalized communities (e.g., Bennett et al. 2000; Hilaluddin & Ghose 2005; Rao et al. 2010); hence, authorities are understandably reluctant to use heavy-handed approaches. Well-designed, locally implemented permitting systems could potentially circumvent many of these difficulties. As well as regulations controlling the hunting itself, licenses could be linked to conservation activities, such as captive rearing, maintenance of specific habitat requirements (e.g., salt licks or nest boxes), and habitat restoration. It could also be used to support protected-area management by justifying hunting prohibitions in some places and integrating protected-area management with the management of wildlife in the broader landscape.

There does not appear to have been any research on the potential viability of different permitted hunting systems in Southeast Asia. However, given that prohibitions and protected species legislation have been largely ineffective, it is imperative that the conservation community explore an expanded toolkit for wildlife management.

## Addressing the Wildlife Crisis in Southeast Asia

The scale and extent of the wildlife crisis in Southeast Asia has not been properly appreciated by national governments and international bodies, such as the Conference of Parties to the Convention on Biodiversity (CBD). With this review and the associated online Supporting Information, we have assembled a substantial body of evidence demonstrating that poaching threatens a large number of vertebrate species across Southeast Asia. Unless there is a large effort to reduce wildlife exploitation to sustainable levels, multiple vertebrate species in Southeast Asia are likely to become extinct in the near future.

As a first, urgent step to addressing this issue, a more substantial dialogue on hunting needs to be established at national and regional levels, with donors and at the Conference of Parties to the CBD. Perhaps most fundamentally, there needs to be a shift in conservation strategy from an emphasis on increasing protected-area coverage to one focused on enhancing the effectiveness of protected-area management and the protection of threatened species in the broader landscape. Indicators, such as faunal intactness (or biodiversity intactness [Scholes & Biggs 2005]) and management effectiveness for protected areas (Hockings et al. 2006) should be made standard in reporting on progress in meeting conservation targets. It also needs to be understood by the international conservation community and especially the

donor community that the international trade in wildlife is just one of a suite of drivers behind the wildlife crisis in Southeast Asia. To be successful in curbing poaching of threatened species and ultimately restoring wildlife populations across Southeast Asia, interventions must also target local consumption of wild meat, wildlife products, and wild animals as pets (Milner-Gulland et al. 2003). A far greater number of animals are consumed close to source, in villages, rural towns, and nearby cities, than are traded internationally. It also needs to be appreciated that a large amount of hunting is essentially recreational. So, market interventions, such as prohibitions on the sale of wild meat, will not be sufficient to prevent overhunting. Interventions must also target hunters and their communities. Finally, greater efforts are needed to reduce the demand for wildlife through educational programs targeting both local consumer groups and large markets such as China and Vietnam.

Site-based enforcement is essential for effective conservation, and an increase in the resources dedicated to the basic management of protected areas and to patrolling and other enforcement efforts is critical. Poaching needs to be recognized as a serious crime, and meaningful sentences need to be imposed on hunters and traffickers. Gun-control legislation must be better implemented and laws introduced to regulate the use and ownership of mist nets, snares, and other tools of indiscriminate hunting. Also needed is a shift in philosophy from managing wildlife in isolated fenced-off reserves to one that considers the management of threatened-species populations in a broader landscape in which protected areas are just one element and wildlife is a component of a human socioecological system.

Authorities and conservation NGOs need to improve cooperation with local communities, both through education (Steinmetz et al. 2006) and development of opportunities for co-benefits from wildlife. Wherever possible, authorities and conservation NGOs need to engage hunters and develop agreed-upon regulations, with appropriate monitoring, accountability, and sanctions that protect threatened species but enable a sustainable offtake of hunting tolerant species. Ultimately, the cooperation of local hunters, who have the greatest interest in legitimizing their activity and reducing harvests to sustainable levels, will be critical to the long-term success of conservation efforts.

Historically, conservation in the tropics has focused on abating deforestation and on the protection of primary forests. Although habitat protection is still an important conservation goal, the fact that in Southeast Asia and elsewhere vast areas of natural habitat harbor very few large animals suggests that hunting is a serious and more immediate threat to many species. Moreover, secondary forests and even landscape matrices containing intensive agricultural areas, agroforests, and forest fragments sometimes support high levels of biodiversity, including many threatened species, in the absence of hunting. These facts suggest that a refocus of tropical conservation strategy is in order. Unless there is a substantial and urgent effort to reduce wildlife exploitation, a significant proportion of Southeast Asia's large (>1 kg) animals are likely to become extinct in the near future.

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## Supporting Information

A review of hunting threats to conservation by country and subregion′ (Appendix S1) is available online. 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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