Distribution and conservation of small carnivores focussing on the Bornean endemic Hose's civet

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CONTENT

ZUSAMMENFASSUNG

Borneo ist mit 25 verschiedenen Raubtierarten ein globaler Biodiversitäts-Hotspot. Auf keiner anderen Insel außer Madagaskar leben heute mehr endemische Raubtiere. Einige dieser Arten, wie der auf das Hochland spezialisierte Schlichtroller *Diplogale hosei*, unterscheiden sich ökologisch und genetisch stark von allen anderen Raubtieren und sind somit besonders schützenswert. Borneos diverse Raubtiergemeinschaft ist jedoch stark bedroht. Im Vergleich zu andern feuchttropischen Regenwäldern hat Borneo zurzeit eine doppelt so hohe Entwaldungsrate. Die verbleibenden Wälder sind häufig degradiert und fragmentiert. Neben diesem Verlust des Lebensraumes ist es sehr wahrscheinlich, dass viele Raubtiere auf Borneo durch den stetig steigenden Jagddruck bedroht werden. Die konkreten Auswirkungen der illegalen Jagd auf die Raubtiere sind jedoch noch unbekannt. Ineffiziente Strafverfolgung, ungeplante Infrastrukturprojekte, Waldbrände und der globale Klimawandel sind einige der weiteren Bedrohungen für Borneos Biodiversität. Somit ist es nicht verwunderlich, dass die Hälfte der Raubtiere Borneos auf der Roten Listen der Weltnaturschutzorganisation (IUCN) als global bedroht klassifiziert sind. Da bis heute sehr wenig über die Ökologie vieler Arten bekannt ist, ist es schwierig, effektive Schutzmaßnahmen gezielt für den Artenschutz zu entwickeln und einzusetzen.

Das Hauptziel dieser Doktorarbeit war es, das Verständnis der Ökologie und der Verbreitung von Raubtieren auf Borneo auf unterschiedlichen räumlichen Skalen (von kleinräumig innerhalb einer Forstkonzession bis zu großräumig über ganz Borneo) zu verbessern. Ein besonderer Schwerpunkt dieser Arbeit lag auf dem Schlichtroller. Kleinräumig zeigten unsere Ergebnisse die Notwendigkeit, auch Aspekte des Lebensraumes zu berücksichtigen, die häufig übersehen werden. So war zum Beispiel das Vorkommen des Schlichtrollers stark von der Moosbedeckung und tropischen Heidewäldern (Kerangas) abhängig. Somit ist der Schutz dieser Lebensräume für den Schutz dieser bedrohten Art von großer Bedeutung (Kapitel 4). Außerdem zeigten die feinräumigen Analysen, dass der Schlichtroller, der Bänderroller *Hemigalus derbyanus* und der Buntmarder *Martes flavigula* negativ auf Waldstörungen reagieren und im Fall des Schlichtrollers und des Larvenrollers *Paguma larvata* Straßen einen negativen Einfluss auf deren Vorkommen haben. Im Gegensatz dazu kamen andere nicht vom Aussterben bedrohte Raubtiere wie die Malaiische Zibetkatze *Viverra tangalunga*, die Kurzschwanzmanguste *Herpestes brachyurus* und die Bengalkatze *Prionailurus bengalensis* besser mit solchen Störungen zurecht – ihre Vorkommen nahm in diesen gestörten Gebieten zu. Diese Ergebnisse illustrierten, welch große Bedeutung den Zeigerarten zukommt, mit denen

die Nachhaltigkeit des Forstbetriebes bewertet werden. Wir haben einfach zu implementierende Strategien wie den Schutz von Fruchtbäumen, Bäumen mit Hohlräumen (inklusive Totholz) und von Gebieten mit weniger gestörten Hochlandwäldern vorgeschlagen. Außerdem zeigten unsere Arbeiten die Wichtigkeit der Einbeziehung der lokalen indigenen Bevölkerung, da nur mit ihrer Unterstützung die oft planlosen und kurzsichtigen Vorhaben lokaler Behörden gestoppt werden (Kapitel 6).

Die großräumigen Analysen für ganz Borneo zeigten, dass die Verbreitung des Schlichtrollers sich auf die zentrale Bergketten im inneren Borneos beschränkt. Diese Regionen liegen innerhalb der nördlichen Hälfte der grenzüberschreitenden "*Heart of Borneo"* Initiative (Kapitel 2 und 3). Obwohl diverse Schutzgebiete innerhalb dieses Gebietes liegen, sind diese zum Großteil nicht verbunden und oft sehr unzureichend von den Verantwortlichen betreut. Wir dokumentieren hier die Notwendigkeit für einen besseren Schutz und eine strengere Strafverfolgung in den Schlüsselgebieten, für eine nachhaltigere Forstwirtschaft und für Waldkorridore, um Raubtiere auch langfristig auf Borneo effektiv schützen zu können. Die Vorhersagen für die Verbreitung des Schlichtrollers unter verschiedenen Szenarien der Landnutzung und des Klimawandels bis 2080 zeigen, dass der Schlichtroller bis zu 86 % seines Lebensraumes verlieren könnte. Die letzten Lebensräume werden nicht nur sehr klein, sondern auch stark fragmentiert sein. Obwohl etwa 30 % der Gebiete unter Schutz stehen, sind die restlichen Gebiete als Forstwirtschaftsgebiete verzeichnet. Somit bekräftigten unsere Ergebnisse die Dringlichkeit der nachhaltigeren Forstwirtschaft und des Schutzes von Korridoren und Schlüsselgebieten (Kapitel 3).

Mithilef eines systematischen Ansatzes in der Naturschutzplanung haben wir Schlüsselgebiete für den Raubtierschutz für ganz Borneo identifiziert (Kapitel 5). Wir haben die Wichtigkeit der "*Heart of Borneo"* Initiative dargelegt. Es sind bereits mehrere Jahre nach der Drei-Länder-Vereinbarung vergangen, ohne dass bisher die geplanten Maßnahmen in den Waldgebieten implementiert wurden. Ohne solche Aktivitäten bleibt diese Initiative eine gut gemeinte Vision. Unsere Analyse zeigt, dass Gebiete außerhalb des "*Heart of Borneo"* im Flachland und in Feuchtgebieten nötig sind, um einige Arten, insbesondere die stark gefährdete Otterzivette *Cynogele bennettii* und Flachkopfkatze *Prionailurus planiceps,* zu schützen. Für einen gezielteren Raubtierschutz werden weitere wissenschaftliche Erkenntnisse über die Anpassungsfähigkeit vieler Raubtierarten an Störungen ihres Lebensraums benötigt. Außerdem müssen bisher wenig untersuchte Gebiete, besonders im indonesischen Teil von Borneo, untersucht werden und der Einfluss der Jagd auf Raubtierpopulationen besser verstanden werden.

Für viele untersuchte Arten gibt es immer noch große Wissenslücken. Die geringe Anzahl an Informationen und Daten schränkt die Verlässlichkeit der statistischen Modelle und somit auch die Robustheit der Vorhersagen in dieser Dissertation ein. Wir hoffen, dass die Ergebnisse dieser Dissertation einen Beitrag zum besseren Verständnis der Ökologie und der Verbreitung von Borneos Raubtieren leistet und die hier vorgestellte systematische Analyse für die relevanten Interessensgruppen (*Stakeholder*), Ministerien, Naturschutzorganisationen und Wissenschaftler in Borneo hilfreich sein werden, damit auch in Zukunft Borneos Raubtiere durch die Regenwälder streifen werden.

SUMMARY

Borneo has been identified as a global priority hotspot for carnivore conservation and is home to 25 species of carnivores, including more endemic carnivores than any other island except Madagascar. Some of these carnivores, such as the highland endemic Hose's civet *Diplogale hosei*, are remarkably distinct from all other carnivores worldwide. Borneo's highly diverse carnivore assemblage faces myriad challenges. Borneo currently suffers high levels of deforestation, losing its forest cover at nearly twice the rate of the rest of the world's humid tropical forests. In addition to habitat loss, degradation and fragmentation, hunting is a serious threat to many mammals on Borneo, probably including carnivores. The effects of hunting and wild meat consumption on Bornean carnivore populations are largely unknown, though illegal hunting and wildlife trade are increasing. Ineffective law enforcement, unplanned infrastructure development, forest fires and climate change are some of the other threats facing Borneo's carnivores. As a consequence, about half of Borneo's carnivores are classified by The IUCN Red List of Threatened Species as globally threatened, though there is little information on their basic biology and ecology available, including their tolerance to habitat disturbance. This complicates targeted conservation efforts.

The aim of this study was to improve our understanding of the ecology and distribution of Borneo's carnivores at different spatial scales, from the local scale to a coarse-scale Borneo-wide perspective. A particular emphasis was placed on the highland endemic Hose's civet. At the fine scale, we demonstrate the importance of recording overlooked habitat variables when conducting occupancy-based studies (Chapter 4). For example, the extent of moss cover and the presence of tropical heath forests ('kerangas') were the most important variables predicting the occurrence of Hose's civet. The preservation of such forest environments may therefore be crucial for the conservation of this species. Our fine scale results further showed that some small carnivores such as Hose's civet, banded civet *Hemigalus derbyanus* and yellow-throated marten *Martes flavigula* were sensitive to disturbance and, as in the case of Hose's civet and the masked palm civet *Paguma larvata*, were negatively affected by roads. In contrast, other small carnivores such as Malay civet *Viverra tangalunga*, short-tailed mongoose *Herpestes brachyurus* and leopard cat *Prionailurus bengalensis* were much more resilient to such disturbance and were more likely to be found in disturbed environments than elsewere (increased occupancy). Our results highlighted the importance of selecting the right indicator species for assessing the sustainability of forest management. We recommend easy-to-implement forest management strategies including preserving fruiting trees and trees with cavities, both standing and fallen, and preserving blocks of remote, less disturbed, mid-elevation to high-elevation forest. Our work on the ground highlighted the need to positively engage local communities, as their involvement and support are integral to the conservation of wildlife and the preservation of forests from the often haphazard and short-sighted intentions of local government (Chapter 6).

At the coarse scale, we predicted Hose's civet habitat to be largely restricted to the central spine of the mountainous interior of Borneo, covering much of the northern half of the transboundary 'Heart of Borneo' (HoB) complex (Chapters 2 and 3). Protected areas are scattered throughout this complex, though many are poorly managed. We recommended precautionary measures be taken such as increased law enforcement and patrolling in key protected areas within this complex, encouraging sustainable forestry in surrounding logging concessions, and maintaining forested corridors to support movement and gene flow between sub-populations (Chapter 2). The projection of habitat suitability for Hose's civet using land cover and climate change for the 21st century (Chapter 3) showed that changes in land cover have little impact on the predicted distribution and amount of suitable habitat for the species. However, habitat loss owing to climate change was approximately 86% by 2080 and suitable refuges predicted to remain for Hose's civet were worryingly small, consisting of a narrow strip of mainly highland forest in the central spine of Borneo. This likely refuge habitat is already fragmented, and although about a third of its area currently is protected, the rest is mainly earmarked for logging. Our results document the need for increased law enforcement and sustainable logging practices within these core areas. We also identified corridors to enhance connectivity between existing strongholds of species populations and the refuges identified (Chapter 3).

To identify key carnivore conservation landscapes across Borneo, we used a systematic framework for conservation planning, emphasizing large landscapes and connectivity between subunits (Chapter 5). We showed that the HoB complex is a critical landscape for most Bornean carnivores. This initiative therefore needs to be implemented in practice on the ground and not remain just a well-intentioned political vision. We also identified additional "carnivore" landscapes to cater for the full range of Bornean carnivores. Some of these additional areas extend the existing HoB complex whereas other priority carnivore landscapes comprised coastal wetlands and lowlands. Although many of these wetland and lowland areas are highly fragmented, preserving and restoring them is of utmost importance for wetland and lowland specialists such as the endangered flat-headed cat *Prionailurus planiceps* and the otter civet *Cynogale bennettii*. The most important research priorities for Bornean carnivores are to assess the resilience of each species to altered and fragmented landscapes, survey hitherto neglected regions and assess the effects and relative intensity of hunting across Borneo.

We acknowledge methodological constraints in our models and identified gaps in available information which could have strengthened and enhanced the utility of the models. We hope that the results of this dissertation increase the understanding of the ecology and distribution of Borneo's carnivores and provide valuable guidance for local stakeholders, ministries, conservation organisations and scientists in Borneo towards systematic carnivore conservation planning on Borneo.

CHAPTER 1

General Introduction

1. Southeast Asia and Borneo: a global biodiversity hotspot under crisis

Southeast Asia (Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Vietnam) is a global biodiversity hotspot (Myers et al., 2000) harbouring an extraordinary species richness (Myers et al., 2000; de Bruyn et al., 2014) and a high number of endemic plants and animals (Myers et al., 2000). Southeast Asia also contains the highest proportion of endangered taxa for vascular plants, birds and mammals in the world, making this biodiversity hotspot one of the top priority areas for conservation (Sodhi et al., 2010). The global review of threatened species of the Species Survival Commission (SSC) of the International Union for Conservation of Nature (IUCN) revealed that, compared to other geographic regions, Southeast Asian mammals face an accelerated extinction crisis (Schipper et al., 2008). Although complex in its details, this crisis is primarily the consequence of exponential human growth and subsequent exploitation of natural ecosystems to fulfil the growing demands of the human population (Myers et al., 2000). Moreover, Southeast Asia is characterised by the highest rate of deforestation worldwide (Wilcove et al., 2013) and increasingly, lowland forests are characterised by the so-called ‘empty forest syndrome’, with large mammals (mainly primates, carnivores and ungulates) locally extinct in vast areas of their former distribution range because of commercial hunting, even when suitable habitat is still present (Milner-Gulland & Bennett, 2003; Corlett 2007).

Within Southeast Asia, the Sundaic subregion or Sundaland, comprising the Thai-Malay peninsula and the islands of Borneo, Sumatra, Java and Bali, has very high mammal species richness and endemicity (Corbett & Hill, 1992). However, Sundaland features some of the most depleted habitats worldwide, with primary vegetation losses in recent decades amounting to more than 92% of its original extent (Myers et al., 2000). Sundaland has been identified as one of the world’s eight “hottest hotspots” when considering the numbers of endemics and endemic species/area ratios for both plants and vertebrates, and habitat loss (Myers et al., 2000).

Borneo, amongst the biologically richest units of Sundaland, is a major diversification hotspot through time and a key source for dispersal across the region (de Bruyn et al., 2014). Much of Borneo’s remarkable diversity is under extreme, sustained pressure from anthropogenic habitat conversion (Miettinen et al., 2011) and unsustainable use (Koh & Sodhi, 2010; Wilcove et al., 2013). Accelerated efforts to conserve Borneo's flora and fauna are essential (deBruyn et al., 2014). Of particular importance is the maintenance of extensive high priority conservation areas. An example of this is the much-publicised "Heart of Borneo" (HoB) initiative (Figure 1.1), an NGO-led and government supported agreement signed between Brunei, Indonesia and Malaysia, to sustainably manage the remaining relatively less-encroached band of forests in the centre of the island. The HoB initiative aims to create a mosaic of land uses that encourage sustainable development around core protected areas, as well as corridors between extant protected areas and the creation of new ones. Losing further large areas of forested land to development in these regions will result in the irreplaceable loss of the primary refuge area for the entire Sunda Shelf region (de Bruyn et al., 2014). Proposed extensions to the HoB, as outlined in Chapter 5 and other proposed priority conservation areas, are therefore likely to be vital for conservation efforts to succeed on Borneo.

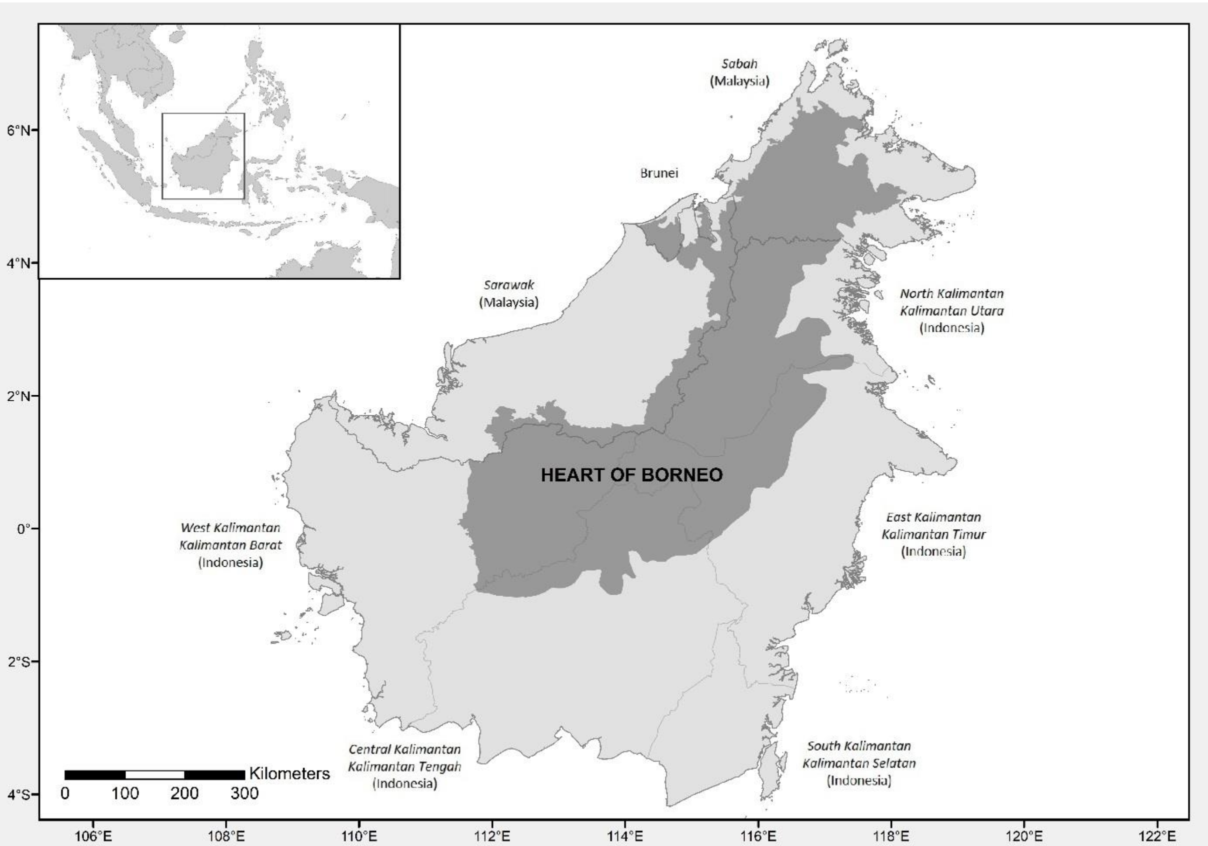

Figure 1.1: Location map of the Heart of Borneo (HoB) initative within Borneo.

1.1 Main threats to Borneo's wildlife

1.1.1 Forest degradation and logging

Logging is an important industry on Borneo, providing employment and contributing significantly to export revenues, particularly for Malaysia and Indonesia. Much of Borneo's forests have already been logged – between 1980 and 2000, timber exports from Borneo were more than all tropical Africa and the Amazon combined (Cleary et al., 2007). This high rate of harvest is not surprising because Bornean forests support a high density of commercially highly desirable dipterocarp trees (Bryan et al., 2013). Currently, the area of intact forest designated for logging on Borneo is greater than the area of intact forests located in protected areas (Gaveau et al., 2014). In parts of Borneo, illegal logging is rampant, both within and outside protected areas, including the logging concessions themselves (Smith et al., 2003; Gaveau et al., 2013). The density of logging roads on Borneo is also remarkably high compared to international standards. For example, the density of primary logging roads in Borneo between 1973 and 2003 was 16 times higher than that in Central Africa (Gaveau et al., 2014).

1.1.2 Forest loss and plantations and agriculture

In addition to forest degradation from logging, the rate of forest loss on Borneo is nearly twice that of the rest of the world's humid tropical forests. Within the last 40 years, over 30% of Borneo's forests were cleared, mainly to create and expand industrial plantations, particularly oil palm *Elaeis guineenis*, rubber *Hevea brasiliensis*, acacia (*Acacia* spp.) and eucalyptus (*Eucalyptus* spp.) (Gaveau et al., 2016). About 10% of Borneo is now covered in industrial scale monoculture plantations. At 56.9%, only Brunei has a high proportion of remaining intact forest compared to 32.6% in Kalimantan (Indonesian Borneo), 19.1% in Sabah (Malaysian Borneo) and 14.6% in Sarawak (Malaysian Borneo, Gaveau et al., 2014). Much of these remaining intact forests will be logged and converted to plantations under the current forest-use designations (Gaveau et al., 2014). Given the present distribution of intact forest across land use designations, the future extent of intact forest for all of Borneo may decline to less than 12% of Borneo's area; for lowland forest (< 500 m a.s.l.), the most threatened forest type, the corresponding figure is less than 6% of Borneo's lowlands.

Compared to intact forests, the structure and composition of (over-)exploited forests and agricultural landscapes are simplified. Tree density, tree diversity and tree canopy layers are reduced. Top soil is stripped by erosion or damaged by compaction, and the microclimate often becomes drier and hotter. Consequently, these new conditions bring changes in wildlife community structure and abundance, with endemic and specialised taxa most at risk of being replaced by invasive and generalist taxa (Meijaard et al., 2005).

1.1.3 Hunting

Hunting is an important threat to the survival of many of Southeast Asia's endangered vertebrates and, as currently practised, hunting cannot be considered sustainable anywhere in Southeast Asia (Corlett, 2007; Harrison et al., 2016; Gray et al., 2017). In Southeast Asia, although hunting and the sale of wild meat is often a local issue and much of the harvest is consumed in villages, rural towns and nearby cities (Harrison et al., 2016), there is also a large volume of wildlife that is traded internationally, which is widely believed to involve large syndicated networks operating in the region and beyond (Lin, 2005; Nijman, 2010).

A strong hunting culture is nearly ubiquitous across Borneo and, in combination with habitat loss, has resulted in the extirpation of many large animals (> 1kg), with populations of remaining wildlife severely depressed (Harrison et al., 2016). Current hunting on Borneo is mostly opportunistic, and most species are killed for consumption (Bennett et al., 2000), though hunting can also be a commercial endeavour, with substantial local demand (Brodie et al., 2015). Hunting appears to be a bigger problem in Sarawak and the Kalimantan provinces than in Brunei (where hunting might have been more common in the past) and Sabah, possibly because in the former two areas there are more (often non-Muslim) indigenous communities living in the forest who depend on wildlife for their protein and do not have, or have lost, religious or cultural hunting taboos (see also Bennett et al., 2000; Bennett & Gumal, 2001). Causes of overhunting include improved access to remote areas by logging and mining roads, motorised, affordable travel on rivers to remote upstream locations, improved hunting technology, escalating demand for wild meat and wildlife derivatives, particularly for the traditional medicine industry, commercial incentives to hunt for specific items/species, and the exotic pet trade (Chapter 5). Hunting intensity often remains high after wildlife abundance and diversity have been drastically reduced, probably for recreational or cultural reasons rather than food provisioning per se (Brodie et al., 2015). Across all the four political entities of Sarawak, Sabah, Brunei and Kalimantan, protected area and protected species legislation has been largely ineffective in preventing the harvest of threatened species and stemming declines in wildlife from protected areas. Therefore hunting has been identified as a leading factor threatening species survival on Borneo (Corlett, 2007).

1.1.4 Climate change

Climate change could be a serious threat particularly to tropical highland species, because the current altitudinal ranges of these species may not overlap with climatically suitable ranges of the future (so-called ‘range-shift gaps’). In addition, global warming may push climatically suitable conditions off mountain peaks leading to mountain-top extinction (Colwell et al., 2008), because potential upslope range shifts are impossible (Struebig et al., 2015a). On Borneo, although altitudes go up to 4,100 m above sea level, the land area above 1,500 m covers a mere 0.6 %, suggesting that the loss of suitable habitat below 1,500 m for such highland species would restrict their distributions to a tiny area, with substantial consequences for their viability. Both range-shift gaps and mountain-top extinctions are further exacerbated by the decline and fragmentation of available habitat for dispersal (Sheldon et al., 2011). Because Borneo has lost more than 30 % of its total forested area since the 1970s and almost half of the remaining forest is degraded through unsustainable logging practises (Gaveau et al., 2014), the ability of montane species to find and/or disperse to suitable habitat in the future is highly compromised. The importance of climate has also been emphasized in a recent study of the endangered Bornean orangutan *Pongo pygmaeus*, which, in contrast to the Bornean endemic Hose’s civet *Diplogale hosei*, is a predominantly lowland species. Here, rates of habitat loss under climate change projections were expected to exceed by a factor of three those under land cover change projections alone (Struebig et al., 2015b). Climate and land cover changes may most negatively affect species which are physiologically specialised to tolerate only a narrow band of environmental conditions (Colwell et al., 2008).

1.1.5 Other localised threats

1.1.5.1 Cronyism and haphazard land use planning

In Borneo and especially in Sarawak, ‘timber politics’ and ‘crony capitalism’ have led to the distribution of timber and mining concessions as political favours. This, in turn, has led to rapid and haphazard cut-and-run logging practices, since there is no incentive to invest in the sustainability of forest resources (Brosius, 2003; Cooke, 2006; Hitchner, 2010). With no long-term vision for sustainable forest stewardship, conservation planning is virtually non-existent, or at best, haphazard and ambiguous. For example, the HoB initiative itself has no fixed borders, its land and resource management strategies are not clearly defined, its projects do not follow a master plan, and its policies regarding who benefits from it are not obvious (Hitchner, 2010). This has led to a situation where successes cannot be measured because there are no clear, definable goals, and there are no consequences for entities that break their commitments and promises.

1.1.5.2 Ineffective law enforcement and apathy

Ineffective law enforcement is a common issue in studies of threatened species and protected areas and this is also very much the case in Borneo. Apart from hunting, encroachment into protected areas or other forests is common, by local communities for shifting agriculture and expansion of settlements, and by immigrants and plantation and mining companies (e.g. Santika et al., 2015). Little enforcement is carried out to curb this. For instance, between 1997 and 2002 nearly 79% of forest loss on Borneo took place within the boundaries of designated or proposed protected areas (Fullup et al., 2004). The existing legislation in Brunei, Malaysia and Indonesia is broadly sufficient to allow for effective law enforcement, provided it is properly implemented, yet implementation is highly patchy: rectifying this should be a law-related priority (see also Linkie et al., 2015; Crees et al., 2016).

There is also a lack of awareness and concern regarding conservation and legality issues amongst large sections of the general public. For example, there is little awareness amongst businesses such as restaurants and traditional medicine shops and urban consumers on the illegality of the trade in wildlife meat and parts, and the consumption of threatened wildlife (see The Star Online, 2015).

1.1.5.3 Poor and disenfranchised indigenous communities

There are no census data on the number of people who identify themselves as indigenous or who may be otherwise defined as such. Reports suggest that there are as many as 400 unique indigenous communities on Borneo (Lynch, 1992). Indigenous communities make up approximately 45% of Kalimantan’s population (Department of Home Affairs). In Sarawak, about 70% of the population are indigenous peoples (about 1.9 million people), in Sabah, they constitute approximately 60% (about 2.2 million people) of the total population (Jacquelin-Anderson, 2018). The HoB alone is home to around half a million people, many of them indigenous, from at least 50 culturally and linguistically distinct ethnic groups (WWF Malaysia & WWF Indonesia, 2007).

For these indigenous communities, the forest is their traditional home, where they have hunted, fished, gathered forest produce and practised shifting agriculture for generations. Over the last

40 years, their traditional lands have been taken from them and sold, often without their knowledge, to be logged or converted to plantations (Hitchner, 2010). Especially in Sarawak, tens of thousands of indigenous peoples have been displaced from their traditional lands because of the construction of large hydroelectric dams (Sovacool & Bulan, 2011). Indigenous peoples now suffer from a plethora of social problems such as poverty, malnutrition, overcrowding, poor sanitation and hygiene, polluted water supply and the consequences of other environmental contamination (How & Othman, 2017).

Many of these local communities are now displaced, live in poverty, have lost their traditional connection with the forests and wildlife and have pressing basic needs. They have little choice but to treat rainforests and wildlife simply as exploitable resources that supply food and short-term income. Even if their harvesting practices may often be illegal, and in the long run be unsustainable, they are less likely to cause substantive environmental damage than commercial interests (Martinez-Alier 2003).

1.1.5.4 Forest fires

A conservation concern more severe in the Kalimantan provinces than in other political units is forest fires, which result in degradation, alteration and/or loss of habitat for wildlife and contributes to climate change. Fires are usually started by small-scale farmers or large plantations to open up land for cultivation. The incidence of forest fires tends to increase near peat swamp forests which were drained by canals to facilitate the expansion of oil palm plantations. Impoverished local people also use fire for small-scale land clearance, hunting and in disputes over land ownership (Siegert et al., 2001). Intensified use of forests, e.g. through logging, also increases susceptibility to fires as a consequence of the hotter and drier conditions and drier microclimate and the possibility of air movements (wind) more likely to get through which fuels fire with additional oxygen. In 1997 – 1998 alone, 5.2 million hectares of land were affected by forest fires in East Kalimantan (Meijaard, 2015).

1.1.5.5 Contamination of wetlands and mangroves

Run-off from oil palm plantations, where fertilisers and pesticides are commonly used, and from mining, where chemicals, some toxic, are heavily used, results in the pollution of wetlands and mangroves (Castilhos et al., 2006; Dudley, 2009). How, and to what extent such pollution of wetlands and mangroves affects wildlife, particularly apex predators in such ecosystems on Borneo such as flat-headed cats and otter civets, is still unknown, though studies from other regions have shown how contamination of wetlands could potentially affect carnivorous mammals through bioaccumulation (e.g. Sanchez-Chardi et al., 2009).

1.1.5.6 Infrastructure development

The construction of roads (especially highways) and large hydro-electric dams fragment major forest complexes and act as catalysts for further development, thereby increasing fragmentation and degradation and consequently disrupting behavioural patterns, habitat use and movement patterns of most mammal species (Sodhi et al., 2010). Additionally, major roads increase the probability of direct mortality due to vehicular traffic and provide greater access to poachers targeting threatened mammals (Sodhi et al., 2010). For some carnivore species at least, occupancy was negatively correlated with distance to roads (Linkie et al., 2006; Chapter 4).

Especially in Sarawak, the construction of large hydroelectric dams, as envisaged under the SCORE (Sarawak Corridor of Renewable Energy) project, are planned within, or close to, the HoB. These dam projects will not only inundate large tracts of forest and wipe out entire populations of wildlife, but also displace many thousands of indigenous peoples. The mere process of construction, particularly of powerline routes, is likely to facilitate access to formerly remote areas, and the reservoirs improve boat access to large areas formerly accessible only on foot, thereby greatly increasing the range of forest products economically viable for commercial extraction (see also Shirley & Kammen, 2015).

The long-term impacts of all these changes discussed in the preceding sections on wildlife communities are not fully understood (Estes et al., 2011). What is known is that changes in the composition of wildlife communities affect the functionality of ecosystems and impoverish the value of the services they provide (Aerts & Honnay, 2011).

1.2 New models for conservation: maintaining enhanced biodiversity in disturbed landscapes

There is mounting empirical evidence that some biodiversity may be quite resilient to human disturbance. Although primary forests are irreplaceable for some species, disturbed forest such as selectively logged forests appear to contain relatively high levels of biodiversity (Gibson et al., 2011). Therefore, in the current era of large-scale modification and conversion of forested areas, conservation research needs to focus on non-protected areas that are exploited and transformed by various types of production such as forestry, agriculture or mining, and that are fragmented and further degraded by roads and human settlements (Meijaard et al., 2005; Streicher & Ulibarri, 2014). Some of these uses are considered to be "sustainable" practices, as verified by various certification schemes such as the Forest Stewardship Council (FSC) for timber exploitation or the Roundtable on Sustainable Palm Oil (RSPO) for palm oil production. In these non-protected areas, clarifying the impacts that these "sustainable" practices have on wildlife communities would enhance our understanding of how "sustainable" exploitation of non-protected areas and wildlife conservation could be combined. This might be relevant to land use policy as well as the development of integrated approaches to conservation-oriented landscape management and development planning.

2. Carnivores on Borneo – why are they important?

Borneo has been identified as a global priority hotspot for carnivore conservation (Schreiber et al., 1989; Di Marco et al., 2014) and is home to 25 species of carnivores, including more endemic carnivores than any other island except Madagascar (Shepherd et al., 2011). Some of these carnivores, such as the highland endemic Hose's civet, are remarkably distinct from all other species worldwide (Wilting & Fickel, 2012). About half of these carnivores are classified by The IUCN Red List of Threatened Species as globally threatened (IUCN, 2018), with little information available on their basic ecology and tolerance to habitat disturbance (resilience).

Many Bornean carnivores are sensitive to landscape change because of their low population density, low fecundity, limited dispersal ability across open or developed landscapes and other traits that reduce ecological resilience (Mathai et al., 2013). Bornean carnivores are also ecologically diverse, thereby potentially representing different forest types, trophic niches and responses to anthropogenic disturbances, and are functionally important because they serve, amongst other functions, as top predators and seed dispersers (Nakashima et al., 2010). This makes them potentially useful as indicator species in regional conservation planning, in which the conditions necessary for their long-term persistence could form one set of criteria by which to evaluate planning options (e.g. Carroll et al., 2001).

2.1 Challenges to study carnivores on Borneo

Although nearly half of Bornean carnivores are globally threatened, there is little information regarding their basic ecology and tolerance to habitat disturbance (Chapter 5). Furthermore, because the majority of studies conducted to date on Borneo have focussed on coastal areas and lowland forests, very little information is available on highland species such as Hose's civet and the Bornean ferret badger *Melogale everetti*.

Conducting field studies on tropical carnivores is challenging because of the large areas potentially traversed by the study animals, their occurrence at low densities, their elusive and secretive behaviour and their frequently nocturnal activity (Mathai et al., 2010). On Borneo, these challenges are compounded by a typically dense vegetation, a wet and humid climate and logistical challenges, including the remoteness of many areas in which these species occur. In mountainous terrain, physical and logistical challenges are even more demanding (Mathai et al., 2013). The appropriate selection and implementation of survey techniques to obtain sufficient data are therefore critical and must match the goals of a given study. Besides the technical, physical and logistical challenges of surveying Bornean carnivores, there also exists the very real problem of limited conservation funds. Many of Borneo's carnivores, with the exception of Sunda clouded leopard *Neofelis diardi* and Malayan sun bear *Helarctos malayanus*, are neither well known nor particularly charismatic. Hence, carnivores are often side-lined, and conservation attention and funds inevitably go towards Borneo's more charismatic icons such as Bornean orang utan, Asian elephant *Elephas maximus* and Sumatran rhino *Dicerorhinus sumatrensis*.

2.2 Hose's civet, a tropical highland Bornean endemic: what we know so far

Hose's civet (*Diplogale hosei*) is one of three carnivores endemic to Borneo. *Diplogale* is a monospecific genus and the species is remarkably distinct from all other carnivore species worldwide (Wilting & Fickel, 2012). Hose's civet is listed as Vulnerable by The IUCN Red List of Threatened Species (Mathai et al., 2015) and nothing is known about population densities, home-range size or dispersal patterns, making targeted conservation recommendations or interventions difficult.

Species distribution models predict as core habitat for Hose's civet areas of highland forest in the interior of north-eastern Borneo (Chapter 2). There are also a number of records from lowland forests (e.g. Samejima & Semiadi, 2012), which demonstrate habitat use at lower elevations, although it is currently unclear whether the species can subsist at these lower elevations, whether these areas contain spill-over populations originating from nearby source populations or whether these are dispersing individuals who cross these habitats rather than setting up permanent ranges. Despite the wide altitudinal spread of records, the low number of records currently available suggest strongly that there are ecological factors and life-history traits which render Hose's civet to be limited to a localised distribution, potentially at a low density (Mathai et al., 2015).

2.3 Lack of knowledge preventing targeted conservation actions

To derive sound management actions, design sustainable developmental practises and formulate targeted conservation initiatives, information on species distribution and ecology is critical (Elith & Leathwick, 2009). However, for many Bornean carnivores, this information is either limited or severely lacking, thereby hampering targeted conservation action. Information on species distributions can answer basic questions about potentially suitable areas for a species and the underlying environmental factors that influence species persistence (Elith & Leathwick, 2009). Such information could be useful in identifying the core areas for species conservation and could be the first step in management applications, such as site selection in reserve design (Zielinski et al., 2006).

Besides understanding coarse-scale distribution of carnivores, knowledge about fine-scale predictors of species occurrence is also necessary. Fine-scale ecological studies provide the context and basis to study the mechanisms and processes which underlie patterns of distribution, abundance, diversity and interactions of species (Landres et al., 1999; Underwood et al., 2000).

Other information that could be useful for informing carnivore conservation planning on Borneo include an understanding of how well species cope with anthropogenic habitat modification, such as different intensities of selective logging and fragmentation, and their use of monocultures, particularly oil palm plantations. Information on densities, movement patterns and dispersal abilities in different habitat types, including monocultures, would also be useful in improving conservation planning and management.

2.4 Species distribution models (SDMs): a method to obtain the required information necessary for conservation planning and management

Species distribution models (SDMs), which relate environmental variables to species occurrence records, are a commonly used tool to describe the geographic distribution of species by quantifying and extrapolating species-environment relationships (Guisan & Thuiller, 2005). The projection of the generated functions to areas where environmental factors are known, but species have not been sampled, allows a cost effective method to map species distributions in large regions and at low spatial resolutions (Guisan and Zimmerman 2000). Many modelling methods have been developed, their usefulness depending on several aspects, including their method of handling uncertainty in data, such as variable quality and quantity of input data (e.g. Graham et al., 2008), methodological choices (e.g. Buisson et al., 2010), species traits (e.g. Luoto et al., 2007) and the statistical method chosen (Thuiller, 2003, 2004). These choices therefore influence the outcome in terms of predictions and by implication, suitable conservation options, even when using the same data (Hernandez et al., 2006).

In general, two categories of SDMs can be distinguished: those that need presence-only data for model construction and those that use presence-absence data. Presence-only data differ from presence-absence data in that they indicate locations where the target species was observed to occur, but cannot be used to define locations where the species does not occur (Dettmers & Bart, 1999). Maximum entropy (Maxent) and generalised boosting models (GBM, commonly referred to as boosted regression trees) are examples of presence-only models. Recently, consensus methods (e.g. the package BIOMOD, Thuiller et al., 2009) have demonstrated their ability to cope with variability in species distribution predictions (Grenouillet et al., 2011) and are increasingly used for conservation purposes (Comte & Grenouillet., 2013). Consensus methods combine several SDM predictions from different modelling methods to yield a final predicted occurrence probability reflecting the majority trend, which tends to provide more accurate predictions (Marmion et al., 2009).

Despite the technical sophistication of presence-only methods, these models are not modelling the true distribution of a species but rather the apparent species distribution, i.e. the combination of the probability of occurrence of a species and the probability of detecting it. Any pattern in detection will be reflected in the species distribution model unless detectability is properly accounted for (MacKenzie et al., 2006). Thus, no matter how sophisticated the methods in conventional species distribution models, the resulting 'species distribution map' may at worst only depict the difficulty with which a species is found (its detectability), rather than its distribution.

Occupancy modelling approaches that account for imperfect detection have the potential to overcome this shortfall by simultaneously estimating the probability of occurrence and the probability of detection (MacKenzie et al., 2002, 2006). Such approaches rely on detection plus non-detection data and require multiple surveys at a site to estimate the probability of detection, assume a closed population and the absence of false positives (MacKenzie et al., 2002). Occupancy models can accommodate covariates associated with detection probability and the probability of occurrence. Hence, such occupancy modelling approaches obtain estimates of the true species distribution rather than the apparent species distribution, and provide unbiased estimates of the covariate effects on species distributions, thereby improving the predictive performance of SDMs. Their requirements assume a surveying effort which may be financially or logistically infeasible to obtain. Hence, over large spatial scales, presence-only models may still be the practical modelling option.

3. Aims of the study

The small carnivores of Borneo may be good indicators of forest health and the performance of different forest management and conservation strategies because of their ecological diversity and functional importance (Nakashima et al., 2010). ‘Small carnivores’ here refers to small-bodied members of the order Carnivora, which in Borneo are all species of the order except the Malayan sun bear and the Sunda clouded leopard. However, most Bornean small carnivores are poorly understood. This gap in knowledge is more apparent in disturbed habitat such as logging concessions and monoculture plantations, where very little conservation-related research has been conducted. Gaps in knowledge reaches its peak with tropical highland endemics such as Hose’s civet and Bornean ferret badger, two species for which even traditional ecological (indigenous) knowledge is virtually non-existent.

The objectives of this thesis were to:

1) Use Hose’s civet as a case study of a little-studied highland endemic to assess habitat requirements, distribution and threats across Borneo under current and future environmental change scenarios, thereby identifying key aspects and locations for targeted conservation interventions. As an example of a tropical highland endemic, this study also sought to evaluate whether such species are particularly vulnerable to the effects of climate change, and therefore, to what extent scenarios for future climate change should be considered when formulating conservation management strategies.

2) Understand fine-scale predictors of small carnivore occurrence within the disturbed and modified habitat of a logging concession in Sarawak. This improved understanding could then be translated into management recommendations to enhance carnivore conservation in logging concessions across Sarawak.

3) Identify priority conservation landscapes for carnivores across Borneo, and questions for research and conservation which need more attention. This understanding will hopefully facilitate systematic, holistic conservation planning for Borneo's diverse carnivore community, provide an evidence base for conservation planning and bridge the gap between conservation research and practise.

4. Structure of the dissertation

Following the general introduction (Chapter 1), the dissertation is structured into 5 chapters:

Chapter 2: Hose's civet is one of two tropical highland carnivores endemic to Borneo. The chapter **"Predicted distribution of Hose's civet *Diplogale hosei* (Mammalia: Carnivora: Viverridae) on Borneo"** uses presence-only data from a variety of sources, analyses them with a Maxent analytical framework to predict the distribution of Hose's civet across Borneo and provide recommendations on the most immediate measures needed to ensure the long-term conservation of the species within its current known range.

Chapter 3: Using two distribution modelling frameworks, Maxent and generalised boosting model, the chapter **"Identifying refuges for Borneo's elusive Hose's civet"** uses Hose's civet as a case study to evaluate whether tropical highland endemics are particularly vulnerable to the effects of climate change. The chapter identifies important refugia for the species by predicting suitable habitat under the current climate and future climate change scenarios whilst simultaneously considering likely future land cover and recommends targeted management interventions in and around these refugia.

Chapter 4: Coarse-scale patterns of distribution and abundance of species are the outcome of processes occurring at finer spatial scales, hence the conservation of species depends on understanding their fine-scale ecology. In the chapter **"Fine scale distributions of carnivores in a logging concession in Sarawak, Malaysian Borneo"**, we used occupancy models to understand fine-scale predictors of occurrence of several Bornean carnivores, using data from a logging concession in interior northern Sarawak, the Sela'an Linau Forest Management Unit. We show that logged forests can still benefit carnivore conservation, provided suitable management actions are applied.

Chapter 5: In order to enhance the evidence base for conservation management planning for Bornean carnivores, a systematic, science-based planning framework is required. In the chapter "**Carnivore conservation planning on Borneo: identifying key carnivore landscapes, research priorities and conservation interventions"** we derive species richness maps from single-species predictive habitat suitability index models of 20 Bornean carnivores and highlight areas of conservation importance for carnivores across Borneo. We further highlight fields in which current understanding and conservation efforts are particularly poor and where further research is urgently required

Chapter 6 (**general discussion**) provides a summary and general discussion of the results of this dissertation. In this chapter, general methodological issues of the modelling process are discussed and key findings of the previous chapters are embedded in the broader context of conservation of Borneo's carnivores, both in the Sela'an Linau Forest Management Unit, and over the wider scale across Borneo.

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CHAPTER 2

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Predicted distribution of Hose's civet *Diplogale hosei* (Mammalia: Carnivora: Viverridae) on Borneo

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Author contributions

J.M. and A.W. conceived the ideas; S.K.S and A.W. conducted the analysis; J.M. led the writing; J.M., J.B., A.G. and R.A. collected the data; J.B., J.L.B. and A.W. commented extensively and edited the manuscript.

Abstract

Hose's civet *Diplogale hosei* is one of the world's least known carnivores and is endemic to Borneo. We collected 43 records of which only 20 (Balanced Model) or 24 (Spatial Filtering Model) were used to model potential habitat suitability. We predicted habitat suitable for Hose's civet to be largely restricted to the central spine of the mountainous interior, corresponding to much of the northern half of the 'Heart of Borneo' complex. Although protected areas are scattered throughout this complex, many are poorly managed, facing threats from illegal logging and mining, poaching and encroachment. The surrounding matrix of logging concessions face conversion to monoculture plantations, in which there is no evidence that the species can persist. To ensure the conservation of the species, further research is urgently required, both in-depth ecological studies and basic inventory work using camera-traps across Borneo. More intensive surveys in all habitats are needed to improve current models so they can inform conservation planning more effectively. Pending sufficient information, sensible precautionary measures need to be taken such as increased enforcement including patrolling activities in key protected areas, encouraging sustainable forestry in the surrounding logging concessions and maintaining forested corridors to support movement and gene flow between sub-populations.

Key words: Borneo Carnivore Symposium, Brunei, conservation priorities, habitat suitability index, Heart of Borneo, Indonesia, Malaysia, species distribution modelling, survey gaps

Introduction

Hose's civet *Diplogale hosei* (Thomas), is one of the world's least known carnivores (Yasuma, 2004). Endemic to Borneo, only about 17 museum specimens are known, all collected before 1984 (Van Rompaey & Azlan, 2004). The species was first described by Oldfield Thomas in 1892, from a specimen collected by Charles Hose in north-eastern Sarawak, Malaysian Borneo. Thomas (1892a) initially described it as *Hemigale hosei*, later changed to *Hemigalus hosei* by Trouessart (1898–1899). Thomas (1912) himself subsequently erected for it the distinct genus *Diplogale*, because of differences in the skull, dentition and colouration of pelage from the type species of *Hemigalus* Jourdan, the more common banded civet *H. derbyanus* (Gray). Pocock (1933) and Davis (1958) retained *Diplogale*, although some later authors classified it again as *Hemigalus* (e.g. Medway, 1977; Payne et. al., 1985) until Corbet & Hill (1992) restored *Diplogale*. This nomenclature is now widely accepted (e.g. Hon & Azlan, 2008; Jennings & Veron, 2009) and a recent phylogenetic analysis confirmed the warranting of the monotypic genus *Diplogale* by Wilting & Fickel (2012).

Hose's civet (Figure 2.1) resembles the banded civet in external appearance (Thomas, 1912), having similar size and proportions (Thomas, 1892b), with adults weighing about 1.5 kg (Van Rompaey & Azlan, 2004). Hose's Civet, however, does not share the complex pelage pattern of the banded civet, but instead is bicoloured, with dark smoky brown to blackish upperparts and whitish underparts (Thomas, 1892b; Francis, 2002). Very little is known about the ecology of Hose's civet (Van Rompaey & Azlan, 2004), although morphological adaptations such as the broad, square-fronted muzzle (Thomas, 1892b), long whiskers (Banks, 1931) and partly webbed feet with patches of hair between the footpads (Payne et al., 1985) suggest a specialist forager for small animals such as fish, shrimp, crabs and frogs (Yasuma, 2004) amongst mossy boulders and streams (Payne et al., 1985). Hose's civet is thought to be crepuscular and nocturnal (Mathai et al., 2010a) and largely ground-dwelling, although one of Tom Harrisson's specimens was listed "in jungle (treetops)" (Medway, 1965). It is thought to make dens in holes between rocks and/or tree roots (Yasuma, 2004). Nothing is known of population densities, home-range size or dispersal patterns.

Figure 2.1: Hose’s civet *Diplogale hosei* camera-trapped in the Protected Zone of the Sela’an Linau Forest Management Unit, Upper Baram, northern Sarawak, Malaysia on 19 July 2012. (Photograph by: John Mathai/HOSCAP Borneo.)

On Malaysian Borneo, Hose’s Civet is listed on the Schedules of Totally Protected and Protected Species as ‘Protected’ under the Sarawak Wild Life Protection Ordinance (1998) and the Sabah Wildlife Conservation Enactment (1997), implying limited protection and lenient punishment to offenders. It is not listed as a protected animal in Brunei under the Brunei Wild Life Protection Act (1978) nor on Indonesian Borneo under the Appendix of the Government of Republic of Indonesia Regulation No. 7 (1999), although it was not known to occur in Kalimantan until recently (Samejima & Semiadi, 2012). It is not a CITES-listed species (CITES, 2015), presumably because it is unlikely to occur in international trade, given its rarity and rather plain pelage. Under the IUCN Red List of Threatened Species (Hon & Azlan, 2008), it is listed as Vulnerable, reflecting its naturally highly restricted range and extensive habitat loss within that range. It is possible the species could qualify for a higher threat category once more information is available on its ecology and threats; hence, research is urgent.

Results and discussion

Species occurrence records

Very few Hose’s civet records were available for modelling and hence, the results should be treated with caution. Of the 43 collated, nine were excluded from modelling because of low spatial precision (over 5 km; Categories 4 and 5), but 17 had high precision (within 2 km;

Category 1) and were collected between 2001 and 2011 (Table 2.1). Most records were collected from the mountainous interior of northern Sarawak and Sabah (Figure 2.2); no records from Kalimantan were available at the time occurrence records for the modelling were collated. Only 20 (Balanced Model = M_1) or 24 (Spatial Filtering Model = M_2) records were used for modelling (see Kramer-Schadt et al. [2016], for detailed methodology).

Habitat associations

The respondents of the questionnaire were inconsistent in their assessment of suitable land-cover for Hose's Civet (Table 2.2). Although lower montane forest was ranked overall as very good habitat for the species, individual responses ranged from very poor to very good. Similarly, upland forest and upper montane forest, though overall ranked as good, had individual responses ranging from very poor to very good habitat. This inconsistency in individual responses suggests there is little knowledge on suitable habitat for Hose's civet, and more intensive surveys in all types of habitat are needed to improve current models and inform conservation planning. Lowland forest was ranked marginally suitable (possibly suitable as corridors) whereas forest mosaics (both lowland and highland) were ranked very poor habitat. Respondents were more consistent in their assessment of unsuitable habitat, all agreeing that mangroves and mixed crops were unsuitable, and most agreeing that swamps and young plantations and crops were unsuitable. Old plantations were, overall considered poor habitat, but had individual rankings from unsuitable to good. Based on this habitat assessment and the distribution of occurrence records, predicted core habitat for Hose's civet was restricted to an area of highland forest in the interior of north-eastern Borneo (Figure 2.3). This region, located largely in the central 'Heart of Borneo', a government-led and NGO-supported agreement signed between Brunei Darussalam, Malaysia and Indonesia to manage sustainably the remaining relatively less-encroached band of forests in the centre of the island, is predominantly upland and montane forest. But there are records of the species from lowland forest (e.g. Francis, 2002; Wells et al., 2005; and since this modelling study, Samejima & Semiadi, 2012 in Central Kalimantan), so a focus on elevation in explaining the species's habitat use will probably miss important determinants.

Table 2.1: Summary of occurrence records for Hose's civet *Diplogale hosei* on Borneo.

Spatial precision	Total number of records	No of records in M_1	No of records in M_2	No of recent records 2001–2011
Category 1 below 500 m	17	7	9	17
Category 2 500 m – 2 km	1	1	1	1
Category 3 2–5 km	16	12	14	4
Category 4 above 5 km	9	-	-	3
Category 5 (no coordinates*)	0	-	-	0
Total	**43**	**20**	**24**	**25**

M_1 = Balanced Model; M_2 = Spatial Filtering Model (2 km); *only coarse location description was available

Table 2.2: Land-cover reclassification for Hose's civet *Diplogale hosei* based on the questionnaire results of eight respondents working on carnivores on Borneo.

Land-cover class	Mean of reclassification	Range of reclassifications
Lowland forest	2.00	1–4
Upland forest	2.75	1–4
Lower montane forest	3.39	1–4
Upper montane forest	2.17	1–3
Forest mosaics/lowland forest	1.00	*
Forest mosaics/upland forest	1.13	#
Swamp forest	0.71	0–1
Mangrove	0.00	0–0
Old plantations	0.50	0–3
Young plantations and crops	0.17	0–1
Burnt forest area	0.17	0–1
Mixed crops	0.00	0–0
Bare area	0.00	0–0
Water and fishponds	0.00	0–0
Water	0.00	0–0

*/#Calculated based on the mean of the reclassification of old plantation and *lowland forest or #upland forest, respectively.
Habitat suitability rank ranges from 0 (unsuitable) to 4 (most suitable); further detail, and on land-cover classes, in Kramer-Schadt et al. (2016).

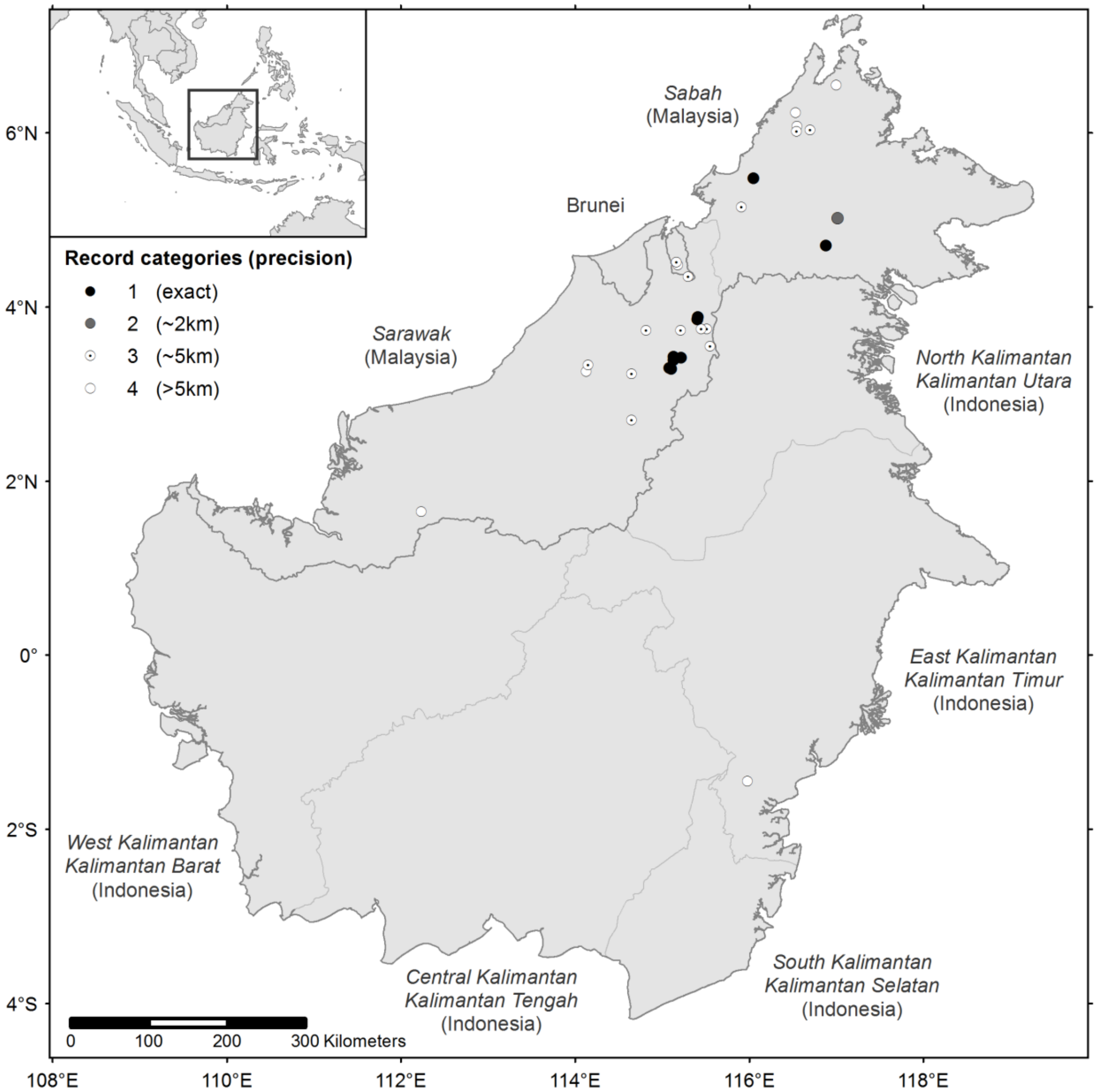

Figure 2.2: Location of Hose's civet *Diplogale hosei* occurrence records across Borneo, showing spatial precision categories as well as countries and state boundaries.

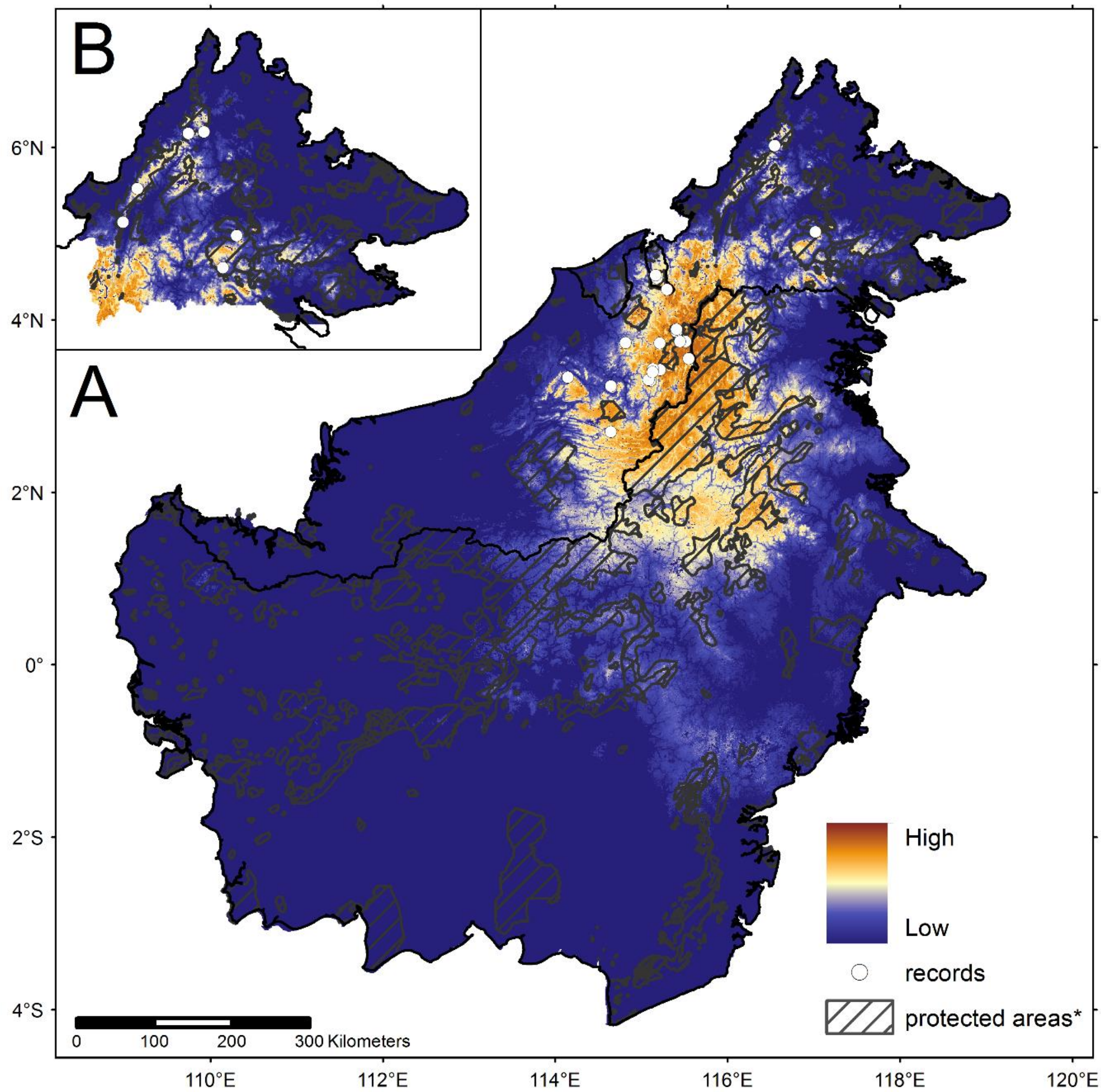

Figure 2.3: Predictive Habitat Suitability Index (HSI) models for Hose's civet *Diplogale hosei* including location records used in models. A, Balanced Model for the island of Borneo; B, Spatial Filtering Model for Sabah, Malaysia. Sources for protected area information: see Kramer-Schadt et al. (2016).

Habitat suitability index (HSI) model

The current distribution predicted by the modelling process suggested the following important localities and conservation actions (see Figure 2.3). Given the paucity of records and lack of understanding the species's ecology, the conservation measures suggested here are preliminary pending additional and better information.

Brunei Darussalam

Much of the remaining forest in Brunei Darussalam is lowland forest and was not predicted to be suitable habitat for Hose's civet. However, search effort in Brunei has been too low to allow conclusion that paucity of records means rarity or unsuitability of habitat. The southernmost tips of Ulu Temburong National Park and the Sungai [=River] Ingei Protection Forest were, however, predicted to be suitable. Ulu Temburong National Park is the largest protected area in Brunei Darussalam, comprising lowland forest, with upland and montane forest in the southern portion. It is the site of the only live capture of a Hose's civet to date (Yasuma, 2004) although the species should not be assumed to be restricted in the country to this site. The forest catchment of the Sungai Ingei in the interior of the Belait district comprises a mosaic of heath forest (kerangas), peat forest and upland forest. Local communities do hunt, although the intensity is thought to be low (Ahmad, 2014); of more concern might possibly be poaching of animals (potentially including Hose's civet, if they came across it) by foreign gaharu [aloewood *Aquilaria* Lam.] collectors (e.g. in Lim & Anak, 2010) who usually hunt during expeditions (Wollenberg, 2001). Increased enforcement (including patrolling) are necessary to protect Hose's Civet and other threatened wildlife in these forest complexes; Sungai Ingei Protection forest, in particular, is located near Sarawak's Mulu National Park, an area predicted by the model to be key habitat for the species, thereby offering critical trans-boundary forest connectivity.

Sarawak, Malaysia

Interior northern Sarawak was predicted to contain habitat important for Hose's civet. Much of this largely upland and montane forest straddling the Kalimantan border is part of the 'Heart of Borneo' complex, comprising a mosaic of totally protected areas (e.g. National Parks), logging concessions (e.g. Forest Reserves), State Land and Native Customary Land. This includes Paya Maga (forest reserve), the Pulong Tau complex (comprising Pulong Tau National Park, the Kelabit Highlands, Tama Abu Range and surrounding forest reserves), Apad Lunan (forest reserve and native customary land), the Mulu–Gunung [=Mount] Buda complex (comprising Mulu National Park, Gunung Buda National Park and surrounding forest reserves), Linau Danum (forest reserve), Usun Apau complex (comprising Usun Apau National Park and the surrounding mosaic of forest reserves, state land and native customary land) and Gunung (= Mount) Dulit (forest reserve), while the Hose–Laga mountains (comprising the proposed Hose Mountains National Park, the proposed Batu Laga Wildlife Sanctuary and surrounding forest reserves and native customary land) was considered marginally suitable habitat for the species.

The Kelabit Highlands in the Pulong Tau complex provided the largest series of collected specimens (Davis, 1958) and recent camera-trapping in a nearby logging concession revealed the greatest reported number of Hose's civet encounters to date (Mathai et al., 2010a, b). Logging is ongoing in many of the forest reserves, in some cases followed by conversion to monoculture plantations (e.g. oil palm, acacia or rubber). The species's use of monoculture plantations remains unknown, given the low survey effort inside them. Hunting might be another potential threat given the species's ground-dwelling nature and the indiscriminate use of snares and nets. A further threat is the planned construction of a series of large hydroelectric dams (Sovacool & Bulan, 2013) within the area predicted to contain suitable habitat for the species. The proposed Baram dam alone, situated near the Kelabit Highlands, is expected to inundate an area of forest more than 400 km^2 and displace more than 20,000 indigenous people (Shirley & Kammen, 2013), potentially increasing intensity of shifting agriculture and indiscriminate hunting in the shrinking available habitat. Because of few records and paucity of research on the species, it is difficult to make any evidentiary recommendations other than the need for in-depth ecological studies and further basic inventories. Precautionary measures pending better information seem appropriate and include increased enforcement (including patrolling) activities, control of illegal hunting and snaring, and maintaining landscape connectivity among areas in Sarawak, Ulu Temburong National Park and Sungai Ingei Protection Forest in Brunei Darussalam, Kayan Mentarang National Park in Kalimantan and the Sipitang and Ulu Padas forest reserves in Sabah, all of which were predicted as high suitability areas for Hose's civet and two of which have records of the species (Ulu Temburong National Park (Francis, 2002; Yasuma, 2004) and Ulu Padas Forest Reserve [Brodie et al., 2015)).

Sabah, Malaysia

As in Sarawak, high suitability Hose's civet habitat was predicted along the mountain ranges. This includes Kinabalu Park and Crocker Range Park in the west of Sabah, where camera-trapping has recorded the species (e.g. Wells et al., 2005; AJ Hearn, pers. comm.). Both national parks are surrounded by villages, the inhabitants of which depend, presumably, to a certain extent at least, on forests for their livelihood and on wildlife for their protein. Harvest may therefore be of concern, especially by aloewood collectors (e.g. in Lim & Anak, 2010), who use snares commonly, although the population-level effects of present hunting levels remain unknown. This could be addressed by working with local communities and understanding their traditional use of surrounding forests and Hose's civet response to present harvest levels. A recent proposal to link the two national parks, known as the Kinabalu Ecological Linkage (Kinabalu Eco-Linc), is a promising step for the long-term conservation of wildlife in the area and ensuring connectivity between these two key Hose's civet sites (see also Wilting et al. (2016b) for Borneo Ferret Badger). Moreover, this region, together with Gunung Lumaku and the second major forest complex in Sabah suitable for Hose's civet, the Sipitang–Ulu Padas Forest Reserves in the south, form a continuous trans-boundary forest block with Paya Maga Forest Reserve in northern Sarawak, as part of the 'Heart of Borneo' initiative. The northern reaches of the Sipitang–Ulu Padas forest reserves have been logged and a large portion has been converted to industrial tree plantations (mainly *Acacia* Miller). Nonetheless, with proper management, this area has the potential to be important for Hose's civet conservation. The third key area for Hose's civet in Sabah is the Maliau Basin – Imbak Canyon Conservation Area, located in south central Sabah. Currently managed by Yayasan Sabah for conservation, research, training and education, and nature recreation, this region comprises forest types including tropical heath (kerangas) and cloud forests. Recent camera-trapping has documented Hose's Civet in these areas (Brodie & Giordano, 2011; Matsubayashi et al., 2011). This region is important for many wildlife species and hence, enforcement (including patrolling) needs to be increased to address the potential threat of harvest.

North Kalimantan, Indonesia

In North Kalimantan, the 1.4 million hectare Kayan Mentarang National Park is the largest protected area in Borneo and predicted to contain habitat highly suitable for Hose's civet, although the species was never recorded there, possibly reflecting inadequate survey to date. Kayan Mentarang National Park comprises several forest types and provides trans-boundary connectivity with important Hose's civet sites in Sarawak and Sabah such as the Pulong Tau complex and Ulu Padas Forest Reserve, respectively. However, large parts of the park are neither patrolled nor monitored, resulting in increased pressure from poaching, encroachment, illegal logging, local economic development and expansion of plantations and road networks (e.g. in Nijman, 2005). The Malinau Basin, connected in the north to Kayan Mentarang National Park, was considered marginally suitable for the species. This largely lowland forest is managed for commercial timber and mining and is exposed to numerous threats, similar to those in Kayan Mentarang National Park.

East Kalimantan, Indonesia

The Müller mountains, linking the national parks of Kayan Mentarang in North Kalimantan and Betung Kerihun in West Kalimantan, were predicted to contain marginally suitable habitat for Hose's civet. This mountain range lies between the provinces of East, North, Central and West Kalimantan and is thus an important area for ecological connectivity. Much of the landscape comprises timber concessions where logging is ongoing, ranging from conventional logging to reduced-impact logging practices (Brown et al., 2011). Other areas considered marginally suitable for the species were the hill forests surrounding the headwaters of the Sungai Mahakam, S. Len, S. Segah and S. Kelai. Many of these forests lie within timber concessions and face possible threats from unsustainable logging and poaching. Inventory work using camera-traps is needed to check for presence of Hose's civet; if confirmed in these areas, then ecologically sensitive management strategies and increased enforcement activities are likely to be necessary because these areas could function as corridors improving the overall functionality of these potential conservation sites.

South Kalimantan, Indonesia

South Kalimantan was considered unsuitable habitat for Hose's civet, potentially merely reflecting the extremely low survey and search effort in the province. More intensive surveys are needed, particularly in the Pergunungan [=Mountains] Meratus, to ascertain presence or absence of the species. A possible explanation for the apparent unsuitability of South Kalimantan is its climatic distinctiveness; it is more seasonal than the rest of Borneo, with a pronounced dry season (extracted from Hijmans et al., 2005, 2015). This difference in local climate and the isolation of the province's mountain range from the central spine of interior Borneo make it probably unlikely to hold the species.

Central Kalimantan, Indonesia

Central Kalimantan was generally predicted to contain habitat unsuitable for Hose's civet, probably because of low search effort. However, some areas in the north bordering West Kalimantan, such as the Schwaner mountains and Bukit Baka–Bukit Raya National Park, might contain marginally suitable habitat for the species. Since the records were collated for the model, Samejima & Semiadi (2012) recorded Hose's civet in the Schwaner mountains, underlining the caution required when interpreting the model's results and emphasising the need for more data to improve such models and to inform conservation planning. Logging is ongoing in much of this area and hunting might be a potential threat to wildlife including Hose's civet (Samejima & Semiadi, 2012).

West Kalimantan, Indonesia

West Kalimantan is largely understudied compared with other parts of Borneo and was thus generally predicted to contain habitat unsuitable for Hose’s civet. Nonetheless, the Gunung Niut Nature Reserve in the northwest of the province and Betung Kerihun National Park in the northeast were predicted to contain marginally suitable habitat for the species. Gunung Niut Nature Reserve contains lowland, upland and lower montane forests, but is isolated from other potential Hose’s civet habitat. Hunting is a potential threat as is the expansion of oil palm plantations. Betung Kerihun National Park contains mainly highland ecosystems and provides transboundary connectivity to two protected areas in Sarawak, the Lanjak Entimau Wildlife Sanctuary and Batang Ai National Park. More surveys are needed in this area, as is increased enforcement (including patrolling activities) to reduce the potential threats of illegal logging and mining, poaching and encroachment.

Research priorities

The ecology of Hose’s civet is almost unknown, with most information derived from a few direct sightings and camera-trap images of the species from the mountainous interior of Sarawak and Sabah. More surveys in other habitat types and areas, particularly in Kalimantan, are needed to evaluate the habitat associations of Hose’s civet. A case in point is the recent record of Hose’s civet from a logging concession in the Schwaner mountains, Central Kalimantan (Samejima & Semiadi, 2012): this area was predicted to be only marginally suitable, reflecting modelling constraints in areas with low search effort. This record is at least 500 km from any previous record (e.g. Francis, 2002; Dinets, 2003; Yasuma, 2004; Wells et al., 2005; Mathai et al., 2010a, b; Brodie & Giordano, 2011; Matsubayashi et al., 2011) and, at 325 m above sea level (a.s.l.), is over 100 m lower in elevation than the lowest previous record (in Brunei), at 450 m a.s.l. (Francis, 2002), in itself is regarded as an unusually low record. The site where the species was detected is more than 30 km from the nearest montane area, suggesting that lowland forests may be a part of the main habitat for Hose's civet, at least in this area (Samejima & Semiadi, 2012). Based on the previous piecemeal understanding of the species and the predictive model’s results, it is unlikely that this site would have been selected for deeper ecological research of the species. This highlights the need for further basic inventory work using camera-traps across Borneo, particularly in areas surrounding these lowland records. Ecological studies emphasising fine-scale habitat use are also needed. These can use occupancy methods, with data derived from camera-traps or hair-snares, although Hose's civet has not yet been studied by the latter method. Radio-telemetry would provide more detailed information on habitat selection and potential corridors but it remains unknown how Hose's civet could be successfully trapped (J. Mathai et al., unpublished data).

Another important question regarding Hose's civet is its dispersal abilities. Because the species's distribution appears to be patchy across montane regions, it is unclear if dispersal may be affected by habitat fragmentation as suitable habitat becomes increasingly isolated. It is also unclear whether individuals can disperse through a matrix of logged forest and monoculture plantations to ensure exchange between possibly subdivided populations. Further, it remains unknown how the increase of road networks in the interior of Borneo (Meijaard & Sheil, 2008) will affect dispersal.

General conservation issues and recommendations

Pending sufficient information, precautionary conservation measures are currently sensible. Hose's civet was originally thought to be strictly montane (Payne et al., 1985; Jennings et al., 2013) although records from much lower elevations at 325 m a.s.l. (Samejima & Semiadi, 2012) and 450 m a.s.l. (Francis, 2002) demonstrate that the species can use lower-altitude forests. Similarly, that most records are from undisturbed forests (e.g. Yasuma, 2004; Wells et al., 2005; Brodie & Giordano, 2011; Matsubayashi et al., 2011) suggest a dependency on old-growth forest and intolerance to human-induced change in habitat; a recent modelling study by Jennings et al. (2013) concluded the species to be forest-dependent and restricted to evergreen forests. However, this could also in part reflect wide tendency to survey these habitats rather than modified landscapes (see also Mathai et al., 2016). Moreover, recent images within logging concessions from areas near logging roads (Mathai et al., 2010a, b; Samejima & Semiadi, 2012) might suggest some tolerance to modified landscapes. It remains unclear whether the species can persist in these more modified areas, whether they contain non-productive populations originating from nearby source populations, or whether they are dispersing individuals. Nevertheless, recent records indicate some degree of tolerance to selective logging, particularly in landscapes with large areas of old-growth forest. A precautionary conservation action for Hose's civet would thus be to ensure that forest reserves surrounding key protected areas engage only in sustainable forestry practices such as selective logging. This would help ensure connectivity among sites of predicted high suitability and facilitate collaborative work between conservation biologists and the timber industry, particularly in the development of wildlife management plans, the location of corridors, and the rehabilitation of logged or burnt forests. This is in line with the vision of the 'Heart of Borneo' initiative and Hose's civet would benefit greatly from the implementation of this plan. Currently there is no evidence that the species can persist in monoculture plantations, but further research is needed to understand adaptability and dispersal of the species in monocultures. As a precautionary measure, road expansion through key areas should be minimised, to reduce fragmentation and effects of human access such as poaching, illegal logging and anthropogenic fires. Large strips of protected forest are also needed as habitat corridors between existing protected areas and areas of high suitability, in order to maintain dispersal and gene flow between subpopulations of the species. Committees including park staff and social scientists could work with local communities to enhance their sense of custodianship of the land and wildlife within, with the intent of addressing issues of encroachment and unsustainable wildlife harvest. Of particular concern is the potential killing of Hose's civet in snares and traps set for species such as chevrotains *Tragulus* Brisson, ground birds such as various pheasants, Phasianidae Horsfield, and porcupines, Hystricidae Fischer. Enforcement (including patrols) should be increased in priority sites, possibly by integrating local former hunters into anti-poaching patrols to curb illegal logging, mining and poaching. Another recommendation is to upgrade the status of Hose's civet to Totally Protected in Sarawak and Sabah, and list the species as protected in Brunei Darussalam and Kalimantan. Only through further research, effective management, a commitment to sustainability, and a holistic attitude towards conservation from all stakeholders concerned, can the long-term conservation of the endemic Hose's Civet be ensured.

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CHAPTER 3

Original article: Submitted

Identifying refuges for Borneo's elusive Hose's civet

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J.M., R.S. and A.W. conceived the ideas; J.M., J.N., V.R. and I.H. conducted the analysis; J.M. led the writing; J.M., J.B., A.J.H., J.R., D.M. and J.H. collected the data; J.N., V.R., M.S. and A.W. played a large part in the writing of the manuscript.

Abstract

Environmental changes, particularly climate change, pose a threat to many tropical montane species, making the identification of optimal future habitat a conservation priority. Here we used maximum entropy (Maxent) and boosted regression trees to predict suitable habitat of the threatened Bornean highland endemic Hose's civet (*Diplogale hosei*), currently and for future time periods (2050s and 2080s), considering future land cover and climate change predictions. Next, we identified forest refuges as areas consistently suitable under current and future model predictions. Our analysis predicted that Hose's civet is restricted mainly to the highlands of Borneo to an area less than 20,000km^2 (about 2% of Borneo). Changes in land cover have little impact on predicted suitable area for the species. However, habitat loss due to climate change was approximately 86% by 2080, except for a green economy scenario which showed stable or increasing suitable habitat. Refuges were small, about 11% of 2010 habitat, and mostly restricted to lower montane forest. About 28 – 35% of refuges lie within the current protected area network though much is designated as commercial forests within the proposed Heart of Borneo (HoB). For the conservation of Hose's civet and likely other Bornean highland endemics, we recommend increased enforcement in identified protected refuges and sustainable timber harvesting practices in surrounding commercial forests, both within the HoB and the extensions we identified. Results of our green model showed that efforts to reduce greenhouse gas emissions will likely contribute immensely to the long-term conservation of highland species such as Hose's civet.

Keywords: biomod2, climate change, conservation planning, IPCC, species distribution modelling, Southeast Asia

Introduction

Anthropogenic climate change is one of the major causes of biodiversity loss in the next 100 years (Struebig et al., 2015a; Wiens, 2016). A changing climate is likely to increase variability in precipitation seasonality and temperature (Anderson et al., 2004). The possible impacts of climate change on species persistence remain highly uncertain, due to differences among climate models, varied species responses to climate change, and different hypotheses about species dispersal (Wiens, 2016). Vulnerability to the effects of climate change may be strongest in tropical highland species because their current altitudinal ranges may not overlap with climatically suitable ranges of the future (so-called 'range-shift gaps'), and because warming may push climatically suitable conditions off mountain peaks leading to mountain-top extinction (Colwell et al., 2008). Both processes are further complicated by the decline and fragmentation of available habitat for dispersal (Sheldon et al., 2011). For example, the island of Borneo has lost more than 30% of its total forested area from the 1970s and almost half of the remaining forest is degraded through unsustainable logging practises (Gaveau et al., 2014). Much of the remaining intact forests on Borneo is allocated to be logged and converted to monoculture plantations under current forest-use designations (Gaveau et al., 2014). Moreover, although deforestation on Borneo previously occurred mainly in the lowlands, future land cover models predict additional lowland and increasingly upland forest have the highest probability to get deforested (Struebig et al., 2015a), thus likely reducing the ability of montane species to find and/or disperse to suitable habitat in the future. Species which are physiologically specialised to narrow environmental conditions may be most negatively affected by climate and land cover changes (Colwell et al., 2008). Assessing the impact of climate and land cover change on tropical mountain species in highland areas is thus critical to address their conservation needs.

One such tropical mountain species is the Bornean endemic Hose's civet (*Diplogale hosei)*. *Diplogale* is a monospecific genus and the species is genetically distinct from all other global carnivore forms (Wilting and Fickel, 2012). Hose's civet is listed as Vulnerable on *The IUCN Red List of Threatened Species* (Mathai et al., 2015) and nothing is known about population densities, home-range size or dispersal patterns, making specific conservation interventions difficult.

Earlier species distribution modelling efforts for this species concluded that it is forest-dependent and restricted to the higher elevations of Borneo (Jennings et al., 2013; Mathai et al.

2016a), whereas the latter more comprehensive study also summarised records from lowland forest (e.g. Samejima and Semiadi, 2012) and predicted Hose's civet to be patchily distributed within the highland interior of north-eastern Borneo (Mathai et al., 2016a). Overall the very low number of records (either from museum collections or camera trap surveys) strongly suggests that something renders Hose's civet to occur very localised, at very low density, or both (Mathai et al., 2015). One reason for low population density might be the species' unusual microhabitat needs, as at fine spatial scales, Hose's civet occurrence was positively associated with mossy heath forest ('kerangas') (Mathai et al., 2017), a habitat scattered in distribution (Brunig, 1974). This specialised ecology and restricted core distribution area to highland forests emphasizes how important it is to understand the projected impacts of climate and land cover change on Hose's civet.

Here, we provide projections of habitat suitability for Hose's civet across its complete distribution range using land cover and climate change forecasts for the 21st century. We used a species distribution modelling framework that is based on statistical association between species presence and environmental factors (Elith et al., 2010). We first identified which global parameters (on the scale of Borneo) approximate best the fine-scale occurrence of Hose's civet, as determined by Mathai et al. (2017). Next, these global proxies were used to project the extent of suitable habitat into future time periods, while considering the influence of predicted changes in land cover and climate on the distribution of Hose's civet. We account for uncertainty arising from climate forecasts by using several general circulation models (GCM) and emission scenario combinations. Furthermore, we account for model structural uncertainty by using two different analytical frameworks, Maxent and generalised boosting model (GBM, commonly referred to as boosted regression trees). Our modelling frameworks identified areas that might serve as future refuges and where targeted management interventions could be implemented for Hose's civet in an era of rapid environmental change.

Methods

Species occurrence records used for modelling

We based our models both on records from the Borneo carnivore database (Kramer-Schadt et al., 2016) and more recent camera-trapping records until 2015, beyond which we are unaware of records from new locations. We only used records with a spatial precision of less than 5 km. Rapid deforestation occurs on Borneo (Gaveau et al., 2014) and could potentially lead to mismatch between species presences and current land cover classifications. Therefore, we cross-checked all records collected before 2005 with current land cover data (2010 PALSAR land-cover map validated for Borneo (Hoekman et al., 2009); see Table 3.1 for details) to ensure no records fell within habitat that was anthropogenically modified after the records were collected. This also enabled the direct use of land cover as an input variable for modelling. To reduce inaccuracy in model projections associated with spatial autocorrelation (Veloz, 2009; Kramer-Schadt et al., 2016) and to reduce possible search-effort bias, we applied spatial filtering as suggested in Kramer-Schadt et al. (2013) and used only one record within a radius of 2 km (greater than the assumed home range radii of similar-sized small carnivores on Borneo). We retained records with greatest location accuracy; when data clusters included two or more records with equal accuracy, we randomly selected the record to be retained.

Modelling approach

All analyses were done in R 3.2.0 (R Core Team, 2015) and ArcGIS 10.1 (ESRI, Redlands, CA, USA). All maps used during the analyses (Table 3.1) were resampled to an identical extent and cell size of 450 m. To model current habitat suitability of Hose's civet, we used occurrence records and environmental predictors (Table 3.1), and fitted the model with two algorithms: Maxent and GBM. We did not have 'true absences', and instead used a random sample of pseudo-absences. Models were fitted using the R package biomod2 (Thuiller et al., 2009). The following settings were used: random test percentage = 20; regularisation multiplier = 1; maximum number of background points = 10,000. The fitted model was used to project the habitat suitability to two future time periods (2050s and 2080s). We used three different scenarios for each time period, namely: (1) current climate but future projections for land cover (i.e. 'land cover only'); (2) current land cover but future climate projections (i.e. 'climate only'); and (3) both future projected climate and land cover (i.e. 'climate + land cover'). For each modelled algorithm and scenario, we ran ten replicates (representing ten random samples of absence points, to strengthen predictions) and three cross-validations (to assess model fit), and used the habitat suitabilities averaged across these replicates for further analyses. To identify potential refuges for Hose's civet over the course of the century, we identified forests that were consistently suitable under current and future model predictions. To place our projections into a historical context, we hindcasted habitat suitability to land cover conditions before the 1950s, a time when most data used to quantify current climate were first collected (Hijmans et al., 2005) and before major land cover changes occurred on Borneo (Gaveau et al., 2014).

We used the True Skill Statistic (TSS) as a measure of model performance and accuracy as it is neither affected by the prevalence of occurrence points nor size of the study region (Allouche et al., 2006). Values for this statistic range from 0 to 1, with 1 meaning good performance of the model.

Selection of input variables

We used the two identified fine-scale predictors of Hose's civet occurrence, mean moss cover and kerangas forest (Mathai et al., 2017) to detect corresponding global-scale predictors for the whole of Borneo. As no reliable analogous data exist on the Borneo-scale for these two in-situ recorded variables, we tested 19 bioclimatic layers (Hijmans et al., 2005) and 8 soil property layers (Table 3.1), as candidate global proxies. We used correlation matrices and retained eight global predictors most correlated with the two in-situ predictors: annual mean temperature, mean diurnal (temperature) range, annual precipitation, precipitation seasonality (as global proxies of mean moss cover); percentage of sand, cation exchange capacity, bulk density and soil organic carbon (as global proxies of kerangas soils). In addition to these two fine-scale predictors, distance to roads, topographic position index (TPI) and forest disturbance also influence Hose's civet occurrence to a lesser degree (Mathai et al. 2017). For these we used the following corresponding global predictors: logging road data for Borneo (Gaveau et al., 2014; see Table 3.1) applying a maximum threshold distance of 9km (because few surveys in Borneo have been conducted in isolated areas further than 9km from the nearest logging road); a TPI raster for Borneo derived from a 90m SRTM digital elevation model; and land cover data (modified version of 2010 PALSAR land cover data, see Table 3.1). Hence, a subset of 11 variables was used for final modelling (Table 3.1).

Table 3.1: Full set of variables and the subset used in the final model for the species distribution modeling. Variables were calculated in R v.3.2.0 (R Core Team, 2015) and ArcGIS 10.1 using global GIS datasets. All data were resampled to 450m.

Variables (full set)	Variables (final set)	Source
2010 Land cover/elevation class, in 9 classes: 0. Bare areas; water and fishponds; water; burnt forest 1. Old plantations; young plantations and crops; mixed crops 2. Swamp forest; mangroves 3. Forest mosaics/fragmented or degraded forests, 501 – 1000m 4. Forest mosaics/fragmented or degraded forests, 0 – 500m 5. Upper montane forest above 1500m 6. Lower montane forest 1001 – 1500m 7. Upland forest 501 – 1000m 8. Lowland forest 0 – 500m	2010 Land cover/elevation class, in 9 classes: 0. Bare areas; water and fishponds; water; burnt forest 1. Old plantations; young plantations and crops; mixed crops 2. Swamp forest; mangroves 3. Forest mosaics/fragmented or degraded forests, 501 – 1000m 4. Forest mosaics/fragmented or degraded forests, 0 – 500m 5. Upper montane forest above 1500m 6. Lower montane forest 1001 – 1500m 7. Upland forest 501 – 1000m 8. Lowland forest 0 – 500m	Based on 2010 land cover data derived from 50m resolution PALSAR imagery by SarVision (Hoekman et al., 2009) but updated with DEM data in 500m elevation steps and reclassified into 9 classes.
Distance to logging roads	Distance to logging roads	Based on Gaveau et al., 2014 http://gislab.cifor.cgiar.org/wm/borneo/ but applying a maximum threshold distance of 9km
Bioclimatic maps bioclim variables 1 – 19	Bio 1 (annual mean temperature), Bio 2 (mean diurnal range), Bio 12 (annual precipitation), Bio 15 (precipitation seasonality)	Hijmans et al., 2005; http://www.worldclim.org/bioclim
Soil properties 1. Bulk density 2. Cation exchange capacity 3. Coarse Fragments 4. Organic Carbon 5. pH in H_20 6. % Sand 7. % Silt 8. % Clay	 Bulk density Cation exchange capacity Organic carbon % Sand	http://www.isric.org/content/soilgrids These were given at six depth classes for each soil property. As all depth classes were almost perfectly correlated for every soil property, we took the mean of the top three classes for each property (0 – 5cm, 5 – 15cm, 15 – 30cm).
Topographic Position Index (TPI) (the elevational difference between each cell of the DEM and the mean of its eight neighbours)	TPI	Calculated from the 90-m SRTM digital elevation model (DEM, http://srtm.csi.cgiar.org) using extraction method 'bilinear'

Future projections

For future climate projections, we used eight scenarios to account for potential uncertainty associated with any single GCM and with source environmental data. We used the climate projections for two time periods (2050, 2070), obtained with two GCMs (http://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadgem2, HadGEM2-AO; and Commonwealth Scientific and Industrial Research Organisation, ACCESS1.0) under two emission scenarios (green/intermediate model and worst-case model). For HadGEM2-AO, we used RCP26 (green model which assumes global annual greenhouse gas (GHG) emissions peak between 2010 and 2020 and declines substantially thereafter) and RCP85 (worst case model which assumes global annual GHG emissions continue to rise throughout the 21st century). Because RCP26 was not available for ACCESS1.0, we instead used the intermediate model, RCP45 as our green model (which assumes global annual GHG emissions peak around 2040, then decline) and again, RCP85 for the worst-case model.

For future land cover projections, we used 2050 and 2080 predicted land cover maps for Borneo which assumed no reforestation and constant pace of deforestation typical for the period 2000-2010 (Gaveau et al., 2013; Struebig et al., 2015a, b: Supplementary Material). These scenarios represent the worst case scenario for land cover change against which to compare the influence of climate. For historical land cover, we used a modified version of the 2010 land cover data which was used for current habitat suitability models (Table 3.1), in which all non-forest or mosaic forest classes that were converted from forest were reclassified to their natural forested counterparts (Struebig et al., 2015a).

Refuge identification

To compare the extent of suitable habitat predicted by various models under different scenarios, we converted the habitat suitability predictions into binary predictions (i.e. suitable and unsuitable). We used a 25% threshold, calculated by assigning presence to all cells with suitability higher than 25% of habitat suitability predicted with the model for the current conditions. This threshold reflects a strict representation of primary Hose's civet habitat and was the consensus threshold agreed upon by researchers working on carnivores in the region during the 2015-2016 Red List evaluation for Hose's civet and other Bornean carnivores. Because area estimates are sensitive to threshold choice (Liu, 2005), we additionally provide estimates obtained with a 10% error threshold, a commonly applied criterion in distribution modelling studies (e.g. Pearson et al., 2007) to generate a liberal suitability classification insensitive to outliers and incorporate a larger predicted area (i.e. 90% of possible predicted values). Such a usage of fixed omission thresholds, although arbitrary, provides upper and lower bounds of possible habitat extent that could be reliably applied across environmental projections.

In our conservation planning approach, we wanted to include also areas of moderate suitability and the 25% error threshold, being strict, did not include such areas. Therefore, we used the 10% error threshold to select potential Hose's civet refuges. The use of this moderate threshold is also supported, as previous studies showed that species distribution forecasts under climate change often overestimate negative impacts, because SDMs assume stable ecological niches and do not allow for adaptation of species to changing environmental conditions (Stockwell and Peterson, 2002; Atkins and Travis, 2010).

To investigate the degree of agreement (similarity/dissimilarity) between the species predictions based on the two algorithms used, we overlaid binary threshold maps using Maxent only and GBM only, for each of the 12 models used (Appendix 1, Table S2). For each of these models, we calculated, at both thresholds (10% and 25%), the percentage agreement between pixels i.e. whether both modelling algorithms predicted the pixels as suitable or unsuitable (both either '1' or '0') against pixels that were only supported by one algorithm and not the other (i.e. '1' in one case and '0' in the other). Similarly, to investigate consensus between the species distribution predictions based on the two GCMs used, we overlaid binary threshold maps using HadGEM2-AO only and ACCESS1.0 only. However, because we used RCP26 (for HadGEM2-AO) and RCP45 (for ACCESS1.0) for our green/intermediate model, we compared percentage agreement in GCMs only for the RCP85 worst case scenario (4 models, Table S3).

Results

Species occurrence records

We collected 102 occurrence records for Hose's civet, of which 70 were recorded post-2011 (i.e., were not in the Borneo carnivore database). New records were all camera-trap records with high precision (<2 km). After using the 2 km filter to account for spatial autocorrelation and to reduce clumping, we included 64 records in the modelling, which is a large increase in the number of records compared to previous modelling studies (27, Jennings et al., 2013; 20 for

Balanced Model covering the entire Borneo, Mathai et al., 2016a). Most records were collected from the mountainous interior of northern Sarawak and Sabah (Figure 3.1).

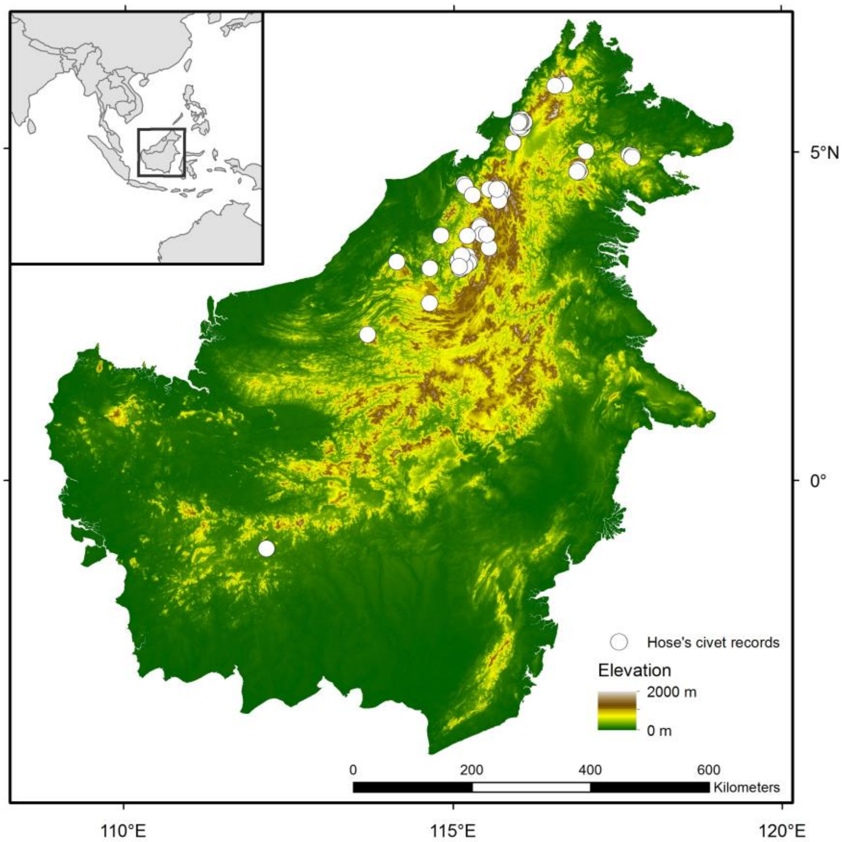

Figure 3.1: Location of Hose's civet *Diplogale hosei* occurrence records used for the modelling study

Present-day model

Models fitted with both algorithms converged well and had good discriminatory power: TSS values for models fitted with Maxent and GBM were 0.855 ± 0.011 and 0.958 ± 0.001, respectively. Environmental parameters which most influenced Hose's civet occurrence using Maxent and GBM were quite consistent, although land cover contributed more in the GBM model: Maxent – annual mean temperature (42%), precipitation seasonality (15%), distance to roads (12%) and annual precipitation (7%); GBM – annual mean temperature (28%), precipitation seasonality (21%), land cover (20%), and distance to roads (16.4%). Much of the central highlands of Borneo exhibited modest to high suitability according to both algorithms. Using the more restrictive 25% error threshold, the ensemble (average of the two algorithms, Maxent + GBM) model predicted approximately 13,000km^2 of Borneo to be currently suitable Hose's civet habitat (Maxent only: 20,000km^2; GBM only: 12,750km^2, Table 3.2). This represented a habitat reduction of approximately 2% of the habitat compared to the models hindcasting to conditions before the 1950s (Table 3.2).

Projected impacts of land cover change

The 2050 and 2080 predicted land cover maps used for future land cover projections only accounts for deforestation and does not include forest degradation e.g. through selective logging in upland forests. Under these projected land cover changes, models showed negligible change in suitable habitat for Hose's civet by the 2080s (Tables 3.2 and S1).

Habitat decline under changing climate

The extent of suitable Hose's civet habitat in future climate conditions varied among the GCMs and emission scenarios used (Tables 3.2 and S1), although there was consensus across models over most of the area (Figure 3.2 and Appendix 1: Tables S2 and S3). Under future climate conditions, models predicted a drastic decline in suitable habitat, approximately 86% loss between 2010 and 2080 at the 25% error threshold (76% at the 10% error threshold: median across all models, including all scenarios and both algorithms, Tables 3.2 and S1). Interestingly, for the green model using the RCP26 scenario, the decline in suitable habitat was much less and predicted suitable habitat even increased, compared to present, for the Maxent and the ensemble (Maxent + GBM) model by 2080 at the 25% error threshold (up to 6.7%, Table 3.2). For all other models which incorporated climate change, huge losses in suitable habitat were projected (Tables 3.2 and S1).

Combined effects of land cover and climate change

There was no major increase in habitat loss resulting from combining future changes in land cover and climate (Tables 3.2 and S1, Figure 3.2). Under this combined environmental change scenario, models predicted an 86% habitat loss at 25% error threshold between 2010 and 2080 (77% at 10% threshold; median across all models, Tables 3.2 and S1).

Table 3.2: Projected change in extent of suitable Hose's civet habitat over Borneo between the 1950s and 2080s under different environmental change scenarios and model predictions. The magnitude of habitat loss is calculated between the 1950s and 2010 for current conditions, and between 2010 and 2080s for the future. Projections are presented for the 25% error threshold.

	GBM			**MAXENT**			**Ensemble (GBM + MAXENT)**		
	Area (km2)		**Suitable habitat loss (%)**	**Area (km2)**		**Suitable habitat loss (%)**	**Area (km2)**		**Suitable habitat loss (%)**
Before major land-cover change (1950s)	13061			20422			13336		
Current (2010)	12755		2.3	20037		1.9	13021		2.3
Time slices	**2050**	**2080**		**2050**	**2080**		**2050**	**2080**	
Land cover only	12725	12723	0.2	19980	19982	0.3	12975	12975	0.3
Climate only									
HadGEM2-AO, green (RCP26)	7454	8402	34.1	19601	20199	-0.8	12342	13890	-6.7
ACCESS1.0, green (RCP45)	2099	1178	90.8	7193	4101	79.5	3307	2038	84.3
HadGEM2-AO, worst-case (RCP85)	3529	885	93.1	10745	4542	77.3	5769	1668	87.2
ACCESS1.0, worst-case (RCP85)	2061	51	99.6	15287	1752	91.3	5780	335	97.4
Land cover + climate									
HadGEM2-AO, green (RCP26)	7466	8413	34.0	19599	20170	-0.7	12318	13865	-6.5
ACCESS1.0, green (RCP45)	2117	1194	90.6	7214	4117	79.5	3331	2062	84.2
HadGEM2-AO, worst-case (RCP85)	3546	904	92.9	10710	4574	77.2	5789	1628	87.5
ACCESS1.0, worst-case (RCP85)	2082	54	99.6	15241	1720	91.4	5877	349	97.3

Consensus between algorithms and GCMs

Variation among model outcomes is to be expected in forecasting studies (Araujo and Peterson, 2012) and our approach uncovered some variation although there was substantial consensus among models. There was 98% consensus between algorithms (96% at 10% error threshold; median across all models, Table S2) with a larger proportion of the area predicted using GBMs within the consensual regions of Ulu Padas – Lawas at the Sabah-Sarawak border, the Kelabit Highlands in Sarawak and the Crocker Range in Sabah. Models using Maxent consistently showed larger suitable areas (see Tables 3.2 and S1). Similarly, there was 99% consensus between the species distribution predictions based on the two GCMs used (Table S3). A larger proportion of area predicted using ACCESS1.0 data was within the consensual regions described above and models using HadGEM2-AO generally showed larger suitable areas (Tables 3.2 and S1).

Hose's civet refuges

By identifying forests that were consistently suitable under current and future model predictions, approximately 2900 km^2 of Borneo (or about 11% of 2010 habitat) was identified as potential refuges for Hose's civet over the course of the century, using the liberal 10% error threshold and the green model (greatest area among all scenarios, calculated from Figure 3.3). This comprised mainly highlands (0% <500 m above sea level, a.s.l.; 7% 500 - 1000 m; 86% 1000 – 1500 m; 7% >1500 m, Table 3.3), particularly the Kelabit Highlands in Sarawak, the Sarawak-Sabah border, and the western Sabah mountain massif. Though 35% of this area was in protected forests (Table 3.3), much lies outside the current protected area network, though largely within the northern regions of the Heart of Borneo (HoB) initiative (a government-led and NGO supported agreement signed between Brunei, Malaysia and Indonesia to manage sustainably the remaining relatively less-encroached band of forests in the centre of the island).

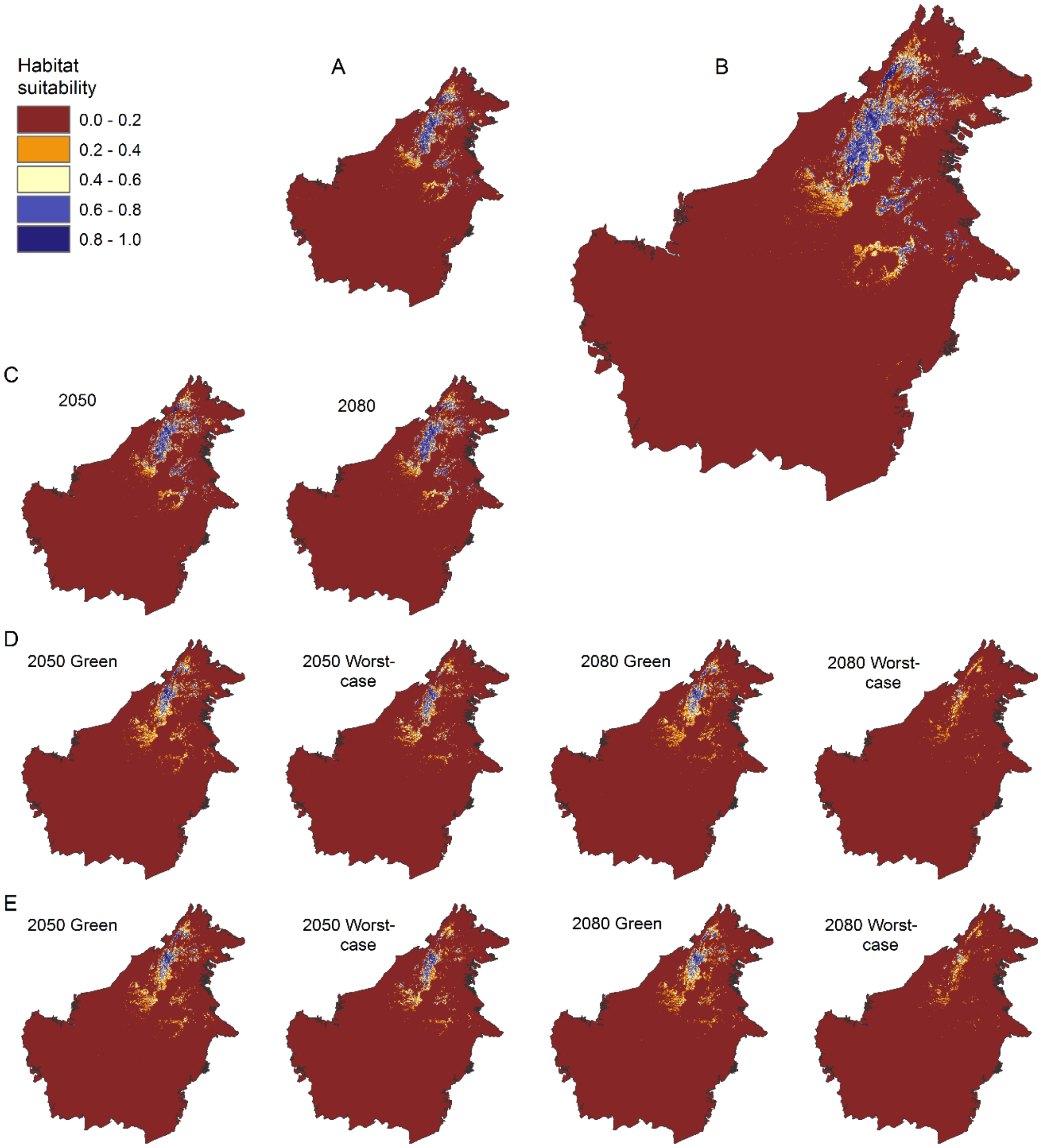

Figure 3.2: Predicted suitable Hose's civet habitat following projected changes in land cover and climate. Suitability models derived from the ensemble model of Maxent and GBM at the strict 25% error threshold. Climate data are from two global circulation models (GCMs, HadGEM2-AO and ACCESS1.0) and two emission scenarios (green/intermediate model and worst-case model, see main text for details). (A) – Former (1950s) (B) – Current (2010) (C) – Land cover only (D) – Climate only (E) – Climate + land cover

Table 3.3: Percentage of area in each elevation class and under protection identified as potential refuges of Hose's civet. Refuge areas are both forested and predicted suitable for Hose's civet between 2010 and 2080 according to 10% and 25% error thresholds, under the green and worst-case scenarios. Percentages are shown if 8 or more models (see legend of Figure 3.3 for model details) were consistent.

Model	Threshold	Consensus in number of overlays	% lowland forest (<500m)	% upland forest (500-1000m)	% lower montane forest (1000-1500m)	% upper montane forest (>1500m)	% under protection
Green model	10%	10	0	7	86	7	35
		9	0	30	62	8	33
		8	0	46	48	6	26
	25%	10	0	1	98	1	31
		9	0	6	86	8	34
		8	0	25	73	2	32
Worst-case model	10%	10	0	0	82	18	28
		9	0	0	85	15	32
		8	0	3	88	9	29
	25%	10	0	0	97	3	28
		9	0	0	95	5	22
		8	0	0	91	9	30

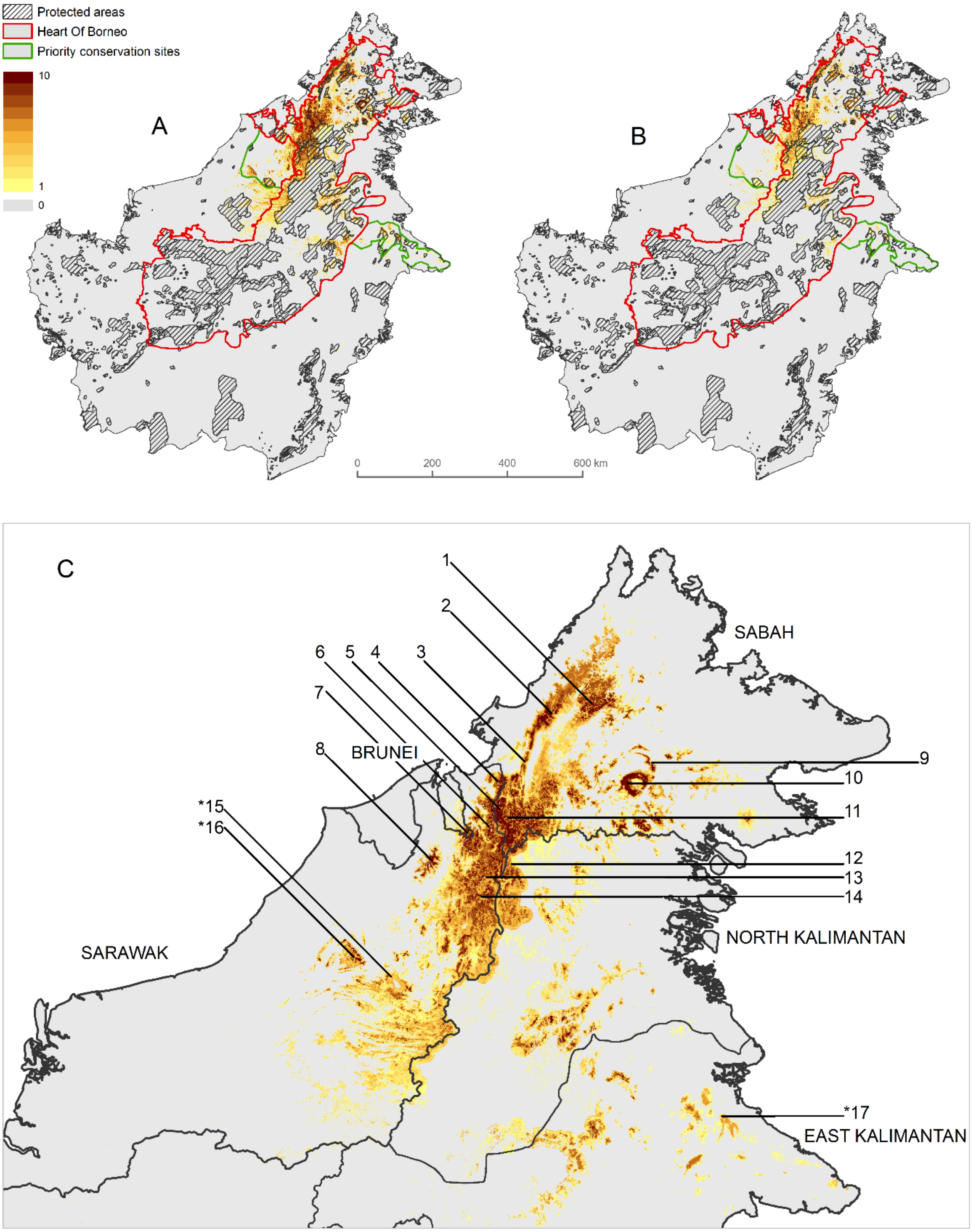

Figure 3.3: Potential refuges for Hose's civet under predictions of both land cover and climate change. Refuge areas are suitable for Hose's civet between 2010 and 2080 according to 10% error (A) and 25% error (B) thresholds for the green/intermediate model (refuges for worst-case model are a subset of these and hence, are not shown here). Consensus among models is based on the overlay of ten models: (1) $\mathrm{GBM}_{\mathrm{Present}}$ (2) $\mathrm{Maxent}_{\mathrm{Present}}$ (3) GBM, $\mathrm{Had}_{(\mathrm{LC+CC})2050}$ (4) GBM, $\mathrm{Access}_{(\mathrm{LC+CC})2050}$ (5) Maxent, $\mathrm{Had}_{(\mathrm{LC+CC})2050}$ (6) Maxent, $\mathrm{Access}_{(\mathrm{LC+CC})2050}$ (7) GBM, $\mathrm{Had}_{(\mathrm{LC+CC})2080}$ (8) GBM, $\mathrm{Access}_{(\mathrm{LC+CC})2080}$ (9) Maxent, $\mathrm{Had}_{(\mathrm{LC+CC})2080}$ (10) Maxent, $\mathrm{Access}_{(\mathrm{LC+CC})2080}$, where Had = HadGEM2-AO, Access = ACCESS1.0, LC + CC = Land cover + Climate change. Consensus is indicated by overlays (red

indicating 100% agreement). The protected area network on Borneo, the Heart of Borneo (HoB) initiative, and two extensions to the HoB, proposed in Mathai et al., 2016, and identified here as important for movement of Hose's civet between refuge habitats, are shown. (C) shows the refuge areas at the 10% error threshold only. Areas numbered 1-14 are within the HoB and areas numbered 15-17 (indicated with *) lie outside the HoB but within the proposed extensions to the HoB (see Table 3.3.4 for the names of the areas).

Table 3.3.4

No.	Political Unit/Location	Refuge
1	Sabah	Trus Madi Forest Reserve
2	Sabah	Crocker Range Park
3	Sabah	Gunung Lumaku Forest Reserve
4	Sarawak	Lawas highlands
5	Sabah	Maligan Virgin Jungle Reserve
6	Sarawak	Paya Maga highlands
7	Brunei	Ulu Temburong National Park
8	*Sarawak*	*Gunung Buda National Park*
9	*Sabah*	*Sungai Imbak Virgin Jungle Reserve*
10	*Sabah*	*Maliau Basin Conservation Area*
11	Sabah	Ulu Padas – Sipitang Forest Reserve
12	*North Kalimantan*	*(higher elevation areas of) Kayan Mentarang National Park*
13	Sarawak	Pulong Tau National Park
14	Sarawak	Kelabit highlands
**15*	*Sarawak*	*Usun Apau National Park*
**16*	*Sarawak*	*Dulit Range*
**17*	*East Kalimantan*	*Sankulirang-Mangkalihat Karst Mountains*

Areas in normal font lie within the core refuge area of Hose's civet. Areas in italics represent forests outside of this core refuge area that might also serve as potentially suitable habitat

Discussion

Very little is known about tropical montane species and their responses to climate and land cover change. Moreover, montane regions, often being remote and difficult of access, are generally less understood and surveyed compared to tropical lowland forests. Hose's civet is one such example of this knowledge gap. Most information in this study was derived from the mountainous interior of Sarawak and Sabah, with few records from Brunei and only one from Kalimantan, mainly due to the paucity of research in these regions. Our models therefore potentially underestimated the true occurrence of Hose's civet, particularly in the central mountain massif in Kalimantan. This is reflected by the fact that our models did not predict the Schwaner mountains of Central Kalimantan (where the sole record from Kalimantan was taken) as suitable habitat. This emphasizes the need for further basic inventory work using camera traps across Borneo, particularly from Kalimantan. Conversely, our models predicted Tawau Hills Park in the southeast of Sabah and species' presence has recently been confirmed by camera traps (AH, unpublished data). However, it seems possible that even within the predicted suitable areas, the actual distribution of the species is likely very discontinuous, as surveys in forest within the documented altitudinal and geographic range yield low encounter rates (if at all, e.g. Cheyne et al., 2016), and native hunters seldom encounter the species (JM, pers. obs.).

Despite methodological limitations, low survey effort from certain regions such as Kalimantan and limited information about the ecology of the species, our results provide new insights into the occurrence and conservation management of this little known, threatened highland endemic. Our models suggest that only 1.7 to 2.7% of Borneo (12,700 to 20,000 km^2) was potentially suitable for Hose's civet in 2010. This figure is less that the area of occupancy (AOO) estimated for the IUCN Red List assessment in 2015 (28,000 km^2, Mathai et al., 2015), emphasizing that the species might be even more threatened than originally thought. Although this shows the importance of conducting further studies on other taxa in montane regions, it is conceivable that our conclusions for Hose's civet could be applied to other montane species for which such comprehensive analysis of potential suitable habitat has not yet been performed.

Projected effects of land cover and climate change

Despite the high rates of deforestation reported on Borneo (Gaveau et al., 2014), our models predicted the trajectory of Hose's civet habitat loss to be negligible under land cover projections alone. This is due to two reasons. First, deforestation currently disproportionately affects the lowlands (<500 m a.s.l.) on Borneo (Struebig et al., 2015b; Mathai et al., 2016b) and under future land cover models, additional lowland and upland forest (500 – 1000 m a.s.l.) have the highest probability to get deforested via conversion to agricultural landscapes (Gaveau et al., 2014; Struebig et al., 2015a). Much of the suitable habitat for Hose's civet, on the other hand, was predicted in the highlands and thus, models did not consider deforestation of higher-elevation forest via conversion as a major threat. However, the deforestation projections regarded montane and upper montane forests, being more rugged, as not suitable for plantations due to higher erosion rates, but potential genetic modifications in cultivars (e.g. of oil palm, Cochard et al., 2005), or warming conditions at higher elevations, could enable cultivation at higher altitudes. This will affect suitable habitat for Hose's civet, as there is currently no evidence that Hose's civet can persist in plantations and agricultural lands. Second, future land cover models only predicted deforestation and did not consider forest degradation. However, higher elevation forests often undergo degradation through intensive and unsustainable selective logging. Though Hose's civet has been found in logging concessions where there are areas of old-growth forest (Samejima and Semiadi, 2012; Mathai et al., 2017), the species' tolerance to more degraded habitat is still unknown. Thus, the inclusion of forest degradation into future land cover models may result in greater habitat loss due to land cover change. It is therefore important that logging practices, particularly within the distribution range of Hose's civet, be conducted in a sustainable manner to reduce potential impacts of forest degradation.

Our assessment of Hose's civet predicted a trajectory of severe habitat loss following anticipated future climate changes. The three climate predictors most affecting Borneo-wide Hose's civet distribution were annual mean temperature, precipitation seasonality, and annual precipitation, all linked to the fine-scale predictor of mean moss cover. How these climate predictors vary and to what degree, depend on GCMs and scenarios used though overall, models predict all three to increase on Borneo. The affinity of Hose's civet towards areas with higher mean moss cover (and hence, cool wet conditions with low seasonality) could be attributed to presence of potential food sources such as earthworms and amphibians, as suggested by Mathai et al. (2017). Projections of higher temperatures and greater seasonality may result in the drying out of such mossy areas, particularly during drier months and in areas which have been deforested, degraded or modified, as microclimate is disturbed due to increased canopy opening. Regarding annual mean temperature, increasingly warmer conditions will mean that individuals may need to move from existing habitats upslope. On Borneo, although altitudes go up to 4100 m, only 4.6% of the land area is above 1000 m (and only 0.6% >1500 m, Mathai et al., 2016b), implying that loss of suitable habitat below 1500 m, due to changing climatic conditions, would restrict distributions to a tiny area, with drastic consequences to population size. The importance of climate has also been emphasized in a recent study of the endangered Bornean orangutan (*Pongo pygmaeus*), which, in contrast to Hose's civet, is a predominantly lowland species. Here, rates of habitat loss under climate change projections were expected to be more than triple those under land cover change projections alone (Struebig et al., 2015a).

An interesting aspect of the predictions is that in the green RCP26 scenario (where global annual GHG emissions peak between 2010 and 2020 and decline substantially thereafter), suitable habitat for Hose's civet increased up to 6.7%, compared to present, by 2080 (for the ensemble (GBM + Maxent) model). This implies that if concerted efforts are made to honour international commitments such as those under the United Nations Framework Convention on Climate Change (UNFCCC), then this will contribute immensely to the long-term conservation of highland species such as Hose's civet.

Potential future refuges for Hose's civet

We defined Hose's civet refuges as intact forests that were consistently suitable under current and future environmental change scenarios. At the 10% error threshold using the green model (the greatest area amongst all modelled scenarios), Hose's civet refuges is worryingly small at only 2900 km^2, consisting of a fairly narrow strip of mainly highland forest in the central spine of the mountainous interior of Borneo, stretching from Crocker Range Park and Trus Madi Forest Reserve in the western Sabah mountain massif to the Kelabit Highlands in northern Sarawak (see Figure 3.3 and Table 3.3.4 for place names and localities). This refuge habitat, though fragmented among protected areas, lies within the larger extent of the HoB complex. Forests that fall under protection within this core refuge area range from approximately 28 to 35%. Forests outside the protected area network within this refuge area are mostly designated as forest reserves, i.e. logging concessions. It is imperative that these logging concessions are managed sustainably, in line with the vision of the HoB initiative, within which the entirety of Hose's civet refuge habitat lies. Not only from the perspective of Hose's civet conservation, but also for other carnivores (Mathai et al., 2016b) and many other Bornean taxa (Beck et al., 2011; Struebig et al., 2015b), the HoB needs to be implemented on the ground and not just remain a well-intentioned vision. We also highlight forests outside of this core refuge area that might serve as potentially suitable habitat. This includes scattered, mainly higher elevation areas in central Sabah, northern central Sarawak, along the Sarawak-Brunei border, and in North and East Kalimantan (see Figure 3.3).

Although we can identify potentially suitable core refuge habitat, it is highly unlikely that the dispersal abilities of Hose's civet would enable individuals to move to these areas within the pace of environmental change predicted. Hence, to maximise the likelihood that Hose's civet could disperse from inferior to highly suitable areas, maintaining connectivity between existing stronghold species populations and the refuge areas we identified is crucial. For this, two conservation priority sites previously proposed as extensions to the HoB in Mathai et al. (2016b), play an important role: the extended Baram complex in Sarawak and the Wehea-Mangkalihat-Sangkulirang Complex in East Kalimantan (see Fig. 4 in Mathai et al., 2016b for all proposed extensions). The former will be critical in linking Usun Apau NP and the Dulit Range in Sarawak to the HoB whereas the latter will enhance connectivity between the Mangkalihat-Sangkulirang Karst Mountains and Wehea forest reserve, both in East Kalimantan, to the HoB, thereby providing connectivity among potential populations of Hose's civet (see Figure 3.3 and Table 3.3.4). These conservation areas or corridors may also be suitable for other threatened species, as recent evaluations in northern Borneo are beginning to demonstrate (Brodie et al., 2015). However, present spatial and development planning in the different regions of Borneo does not yet include ecological principles such as forest connectivity. Consequently, a major change of planning systems and processes is required.

Hunting as a hidden threat

Much of the area identified as Hose's civet refuges is inhabited by indigenous human communities, in which hunting is widespread. Snares and nets are often used (JM, pers. obs.) during hunting activities and being indiscriminate in what they catch, it is suspected that carnivores which spend much of their mobile time on the ground such as Hose's civet, may be affected (Mathai et al., 2016b). Our models did not consider hunting pressure and hence, our predictions represent optimistic estimates. The intensity of hunting should not be under-estimated: regionally, this problem is so severe that trade in wildlife, including parts and derivatives, has been identified as the leading factor threatening species survival (Corlett, 2007; Harrison et al., 2016). In at least some of the logging concessions within Hose's civet refuges, human access, and therefore potential hunting activity, has been shown to negatively affect threatened small carnivores (Mathai et al., 2017). Although hunting levels of carnivores on Borneo are currently presumed lower than in other parts of Southeast Asia, particularly Indochina (Gray et al. 2017, 2018), high demand from China and neighbouring countries like Vietnam, can escalate illegal hunting and trade to become a serious threat (Zhang et al., 2015). Existing wildlife protection laws and ordinances are broadly appropriate on paper but implementation is highly patchy and rectifying this is a priority.

Conclusion

Although our modelling efforts presented here greatly increased our understanding of the distribution of Hose's civet, our models were constrained by two factors: 1) limited understanding of the ecology and the sensitivity of Hose's civet to forest degradation and the inability of incorporating degradation through selective logging in the model; and 2) lack of a spatial overview of hunting pressure on Borneo, which could have been directly included in the model.

The risk of decline or widespread local extinction of Hose's civet under environmental, particularly climate, change, is high. Within the refuge habitats identified in this modelling study, 1) enforcement should be prioritised to curb illegal logging, mining and poaching; 2) road expansion should be minimised to reduce fragmentation and effects of human access such as poaching, illegal logging and anthropogenic fires; 3) conversion of natural forest to plantations and agriculture should not be allowed; and 4) any logging should follow sustainable principles and only apply reduced impact logging strategies. Studies such as this, using range-wide projections of habitat suitability under land cover and climate change forecasts, are essential tools in planning the conservation of threatened species such as Hose's civet. Here we used a little known Bornean carnivore as an example, but a similar pattern of range shifts and contractions of suitable habitat can be expected with other tropical highland endemics and it is likely that areas of conservation priority for Hose's civet are also of conservation relevance for numerous other species on Borneo.

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Supplementary material

Table S1: Projected change in extent of suitable Hose's civet habitat over Borneo between the 1950s and 2080s under different environmental change scenarios and model predictions. The magnitude of habitat loss is calculated between the 1950s and 2010 for current conditions, and between 2010 and 2080s for the future. Projections are presented for the 10% error threshold.

	GBM			**MAXENT**			**Ensemble (GBM + MAXENT)**		
	Area (km2)		**Suitable habitat loss (%)**	**Area (km2)**		**Suitable habitat loss (%)**	**Area (km2)**		**Suitable habitat loss (%)**
Before major land-cover change (1950s)	22188			46839			28152		
Current (2010)	21598		2.7	46151		1.5	27348		2.9
Time slices	**2050**	**2080**		**2050**	**2080**		**2050**	**2080**	
Land cover only	21456	21455	0.7	46208	46364	-0.5	27191	27189	0.6
Climate only									
HadGEM2-AO, green (RCP26)	14587	16064	25.6	41753	38513	16.5	24056	25293	7.5
ACCESS1.0, green (RCP45)	5110	3216	85.1	21960	15758	65.9	9974	6582	75.9
HadGEM2-AO, worst-case (RCP85)	7886	2451	88.7	25308	17606	61.9	13513	5864	78.6
ACCESS1.0, worst-case (RCP85)	5035	234	98.9	32595	11497	75.1	13442	1746	93.6
Land cover + climate									
HadGEM2-AO, green (RCP26)	14559	16012	25.9	41714	38513	16.3	23990	25224	7.8
ACCESS1.0, green (RCP45)	5139	3239	85.0	22018	15760	65.9	9980	6589	75.9
HadGEM2-AO, worst-case (RCP85)	7903	2468	88.6	25341	17544	62.0	13517	5817	78.7
ACCESS1.0, worst-case (RCP85)	5050	237	98.9	32637	11383	75.3	13569	1789	93.5

Table S2: Percentage of similarity (identity) between the two algorithms used, Maxent and generalised boosting model (GBM), for the 12 models at both 10 and 25% error thresholds. Percentage similarity was calculated by overlaying binary threshold maps at the corresponding error thresholds and comparing number of pixels where predictions agreed on (both suitable, '1' or both unsuitable, '0') against pixels that were supported by only one algorithm (i.e. '1' in one case and '0' in the other).

Model	% similarity at the 10% error threshold	% similarity at the 25% error threshold
Historical	96.2	98.0
Current (2010)	96.2	98.1
Landcover only (2050)	96.2	98.1
Landcover only (2080)	96.2	98.1
Climate only (2050, HadGEM2-AO, green)	96.0	97.8
Climate only (2050, ACCESS1.0, green)	97.5	99.1
Climate only (2050, HadGEM2-AO, worst)	97.4	98.8
Climate only (2050, ACCESS1.0, worst)	96.0	98.1
Climate only (2080, HadGEM2-AO, green)	96.4	97.8
Climate only (2080, ACCESS1.0, green)	98.1	99.5
Climate only (2080, HadGEM2-AO, worst)	97.8	99.4
Climate only (2080, ACCESS1.0, worst)	98.4	99.8

Note: For HadGEM2-AO, green model uses RCP26 and worst-case uses RCP85.
For ACCESS1.0, green (intermediate) model uses RCP45, worst-case uses RCP85.

Table S3: Percentage similarity (identity) between the species distribution predictions based on the two Global Circulation Models (GCMs) used, HadGEM2-AO and ACCESS1.0, at the 10 and 25% error thresholds. Results are shown only for the worst-case scenarios as different emission scenarios were used for the green/intermediate model (RCP26 for HadGEM2-AO and RCP45 for ACCESS1.0). Percentage similarity was calculated by overlaying binary threshold maps at the corresponding error thresholds and comparing number of pixels where predictions agreed on (both suitable, '1' or both unsuitable, '0') against pixels that were supported by only one GCM (i.e. '1' in one case and '0' in the other).

Model	% similarity at the 10% error threshold	% similarity at the 25% error threshold
2050 GBM, worst-case	99.3	99.7
2050 Maxent, worst-case	98.1	98.7
2080 GBM, worst-case	99.7	99.6
2080 Maxent, worst-case	98.9	99.6

CHAPTER 4

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Fine-scale distributions of carnivores in a logging concession in Sarawak, Malaysian Borneo

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J.M., R.S., M.E.M. and A.W. conceived the ideas; J.M. and J.N. conducted the analysis; J.M. led the writing; J.M., L.B., S.T.W. and S.A. collected the data; R.S., M.E.M., J.L.B. and A.W. commented extensively and edited the manuscript.

Abstract

Coarse-scale patterns of distribution and abundance of species are the outcome of processes occurring at finer spatial scales, hence the conservation of species depends on understanding their fine-scale ecology. For Bornean carnivores, little is known about fine-scale predictors of species occurrence and it is assumed that the two main threats to wildlife on Borneo, habitat disturbance and hunting, also impact their occurrence. To increase our understanding of the Borneo carnivore community, we deployed 60 cameras in a logging concession in northern Sarawak, Malaysian Borneo, where different landscape covariates, both natural and anthropogenic, were present. We built single-species occupancy models to investigate fine-scale carnivore occupancy. Overall, forest disturbance had a negative effect on Hose's civet (*Diplogale hosei*), banded civet (*Hemigalus derbyanus*) and yellow-throated marten (*Martes flavigula*). Further, banded civet had greater occupancy probabilities in more remote areas. Logging roads had the most diverse effect on carnivore occupancy, with Hose's civet and masked palm civet (*Paguma larvata*) negatively affected by roads, whereas Malay civet (*Viverra tangalunga*), short-tailed mongoose (*Herpestes brachyurus*) and leopard cat (*Prionailurus bengalensis*) showed higher occupancy closer to roads. Canopy height, canopy closure, number of trees with holes (cavities) and distance to nearest village also affected occupancy, though the directions of these effects varied among species. Our results highlight the need to collect often overlooked habitat variables: moss cover and 'kerangas' (tropical heath forest) were the most important variables predicting occurrence of Hose's civet. The preservation of such forest conditions may be crucial for the long-term conservation of this little-known species. Our results confirm that logged forests, when left to regenerate, can host diverse carnivore communities on Borneo, provided less disturbed habitat is available nearby, though human access needs to be controlled. We recommend easy-to-implement forest management strategies including maintaining forest next to logging roads; preserving fruiting trees and trees with cavities, both standing and fallen; and blocks of remote, less disturbed, mid- to high-elevation forest with understorey vegetation.

Keywords: Borneo, Camera trapping, Carnivores, Forest disturbance, Habitat associations

Introduction

The islands of Southeast Asia are recognized as global biodiversity hotspots (Myers et al., 2000) and within insular Southeast Asia, Borneo is recognised as an evolutionary hotspot hosting high levels of mammalian species richness and endemicity (de Bruyn et al., 2014). Borneo currently suffers high levels of deforestation, losing its forest cover at nearly twice the rate of the rest of the world's humid tropical forests. Within the last four decades, over 30% of Borneo's forests were cleared (Gaveau et al., 2014). Of the geopolitical units on Borneo, the Malaysian state of Sarawak has the least proportion of intact forest remaining at 14.6% compared to 19.1% in Sabah, 32.6% in Kalimantan and 56.9% in Brunei (Gaveau et al., 2014). The coverage of protected areas in Sarawak remains low at 4.2% of total land area (DOS, 2011). Much of the forest loss and degradation in Sarawak has been due to logging, as evidenced by the greatest density of logging roads on Borneo (Gaveau et al., 2014). Moreover, only one logging concession in Sarawak is currently certified as sustainably managed by the Malaysian Timber Certification Scheme. In contrast to other provinces on Borneo, no logging concession has been certified by the international Forest Stewardship Council (Mathai et al., 2016a).

In addition to habitat conversion, degradation and fragmentation, hunting is a serious threat to many mammals on Borneo (e.g. Bennett et al., 2000; Brodie et al., 2015a), presumably including carnivores. Hunting may be a larger problem in Sarawak and Kalimantan than in Brunei and Sabah because of larger populations of forest- and wildlife-dependent indigenous communities (Bennett et al., 2000). The effects of hunting and wild meat consumption on Bornean carnivore populations are largely unknown (Mathai et al., 2016a), though illegal hunting and wildlife trade are increasing (Shepherd et al., 2011).

Twenty-five carnivore species occur on Borneo including more endemics than any other island except Madagascar (Shepherd et al., 2011). About half of these carnivores are classified by The IUCN Red List of Threatened Species as globally threatened (IUCN, 2016) with little available information on their basic ecology and tolerance to habitat disturbance (Mathai et al., 2016a). Additionally, most studies conducted in Borneo, and particularly in Sarawak, were focussed on coastal areas and lowland forests due to easier logistics, resulting in little information on highland species. Recently, some understanding of coarse-scale distribution of many carnivore species within Borneo was achieved (Mathai et al., 2016a), but fine-scale predictors of species persistence are lacking, with few studies addressing the effects of physical and anthropogenic covariates on Bornean carnivores. Fine-scale ecological studies provide the context and basis for studying processes and resultant patterns of distribution, abundance, diversity and interactions of species (Landres et al., 1999). Because animals often select resources differently at different scales, habitat associations found in distribution-wide studies cannot necessarily be translated to small-scale distribution of individuals (e.g., Boyce 2006, Mayor et al. 2009). Bornean carnivores are ecologically diverse (i.e. different forest type, trophic niche, response to anthropogenic disturbances) and functionally important (i.e. as seed dispersers (Nakashima et al., 2010) and top predators), and thus, may be good indicators of the performance of different management and conservation strategies.

We analysed fine-scale distributions of carnivores within the Sela'an Linau Forest Management Unit (SL FMU), a logging concession in interior Sarawak, comprising lowland, upland and montane forest, the last two being little-studied forest types. We used an occupancy framework to investigate the role of habitat quality (i.e. vegetation structure) and anthropogenic factors such as logging, forest disturbance, distance to logging roads and human settlements and hunting. We then applied our results to forest management applications to facilitate the long-term conservation of the carnivore community in logging concessions.

Methods

Study area

The SL FMU (3˚11'–29'N; 115˚00'–20'E) is a logging concession of 55,949 hectares in the Upper Baram region of interior northern Sarawak (Figure 4.1A). The FMU's terrain is undulating with elevations from 250 m to 2000 m above sea level (a.s.l.). It receives high rainfall (3,400 – 5,900 mm annually) without distinct seasonality. The FMU supports mixed dipterocarp forest (60%), with some upper montane forest at higher elevations (4%). 'Kerangas' forest, which develops on nutrient-deficient soil and is less suitable for agriculture, covers 21%. This forest type is scattered on Borneo from the coast to more than 1000 m a.s.l (Brunig, 1974, see also Table 4.2); in our site, upland kerangas forests are common. Old and current shifting agriculture ('temuda') covers 15% of the study area. About half the area was logged conventionally (CL, high impact logging typically characterised by destructive log extraction techniques, liberal harvesting limits and rapid rotations) in the 1990s, and since 2003, reduced impact logging (RIL, less detrimental to forest structure and providing economically viable timber harvests over longer time frames; Edwards et al., 2012) was applied. The FMU contains a large tract of forest (about 3000 hectares) that burned during the 1997–1998 El Niño event and where enrichment planting (with commercially-valuable, native species) has since been practised. Logging roads dissect parts of the FMU. The SL FMU lies in the Kelabit Highlands, with Pulong Tau National Park at its north-east border. It is part of the larger Heart of Borneo initiative, a government-led and NGO-supported agreement signed between Brunei, Malaysia and Indonesia to manage sustainably the remaining forests in the centre of the island. The FMU is thus an important area for conservation and has been identified as an important site for carnivores (Mathai et al., 2010, 2016a).

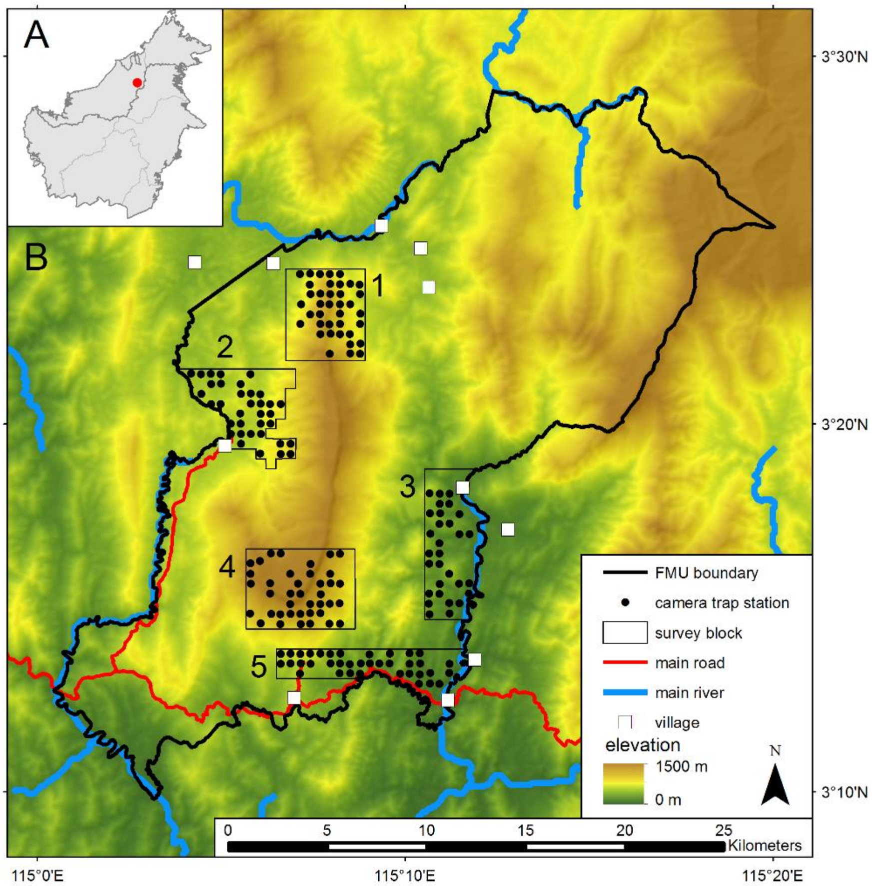

Figure 4.1: Location of the Sela'an Linau Forest Management Unit (FMU) on Borneo (A). Locations of our five study blocks with camera arrays and locations of main roads, rivers and villages (B). Numbering of blocks follows descriptions in Table 4.1.

In the FMU live many indigenous human communities such as the Kayan, Kelabit, Kenyah and Penan, who depend on forest and wildlife for their livelihoods. Local hunters from these communities do not actively target small carnivores, their preferred quarry being ungulates and primates, though indiscriminate hunting techniques e.g. the use of snares and traps, may still impact the more ground-dwelling carnivores (Mathai et al., 2010). The FMU was the first of only two logging concessions in Sarawak to be certified under the old Malaysian certification scheme for sustainable forest management. It lost this certification in 2009, mainly due to unsettled issues with native communities. The concessionaire did not pursue re-certification and logging activities have since declined markedly.

Sampling design

Camera trapping

Field work was conducted between April 2013 and August 2014. Logistical challenges due to remoteness of the forest and difficult terrain, as well as lack of cooperation from some indigenous communities, prevented covering the entire SL FMU as one sampling unit. Therefore, we chose five sampling blocks within the FMU for our camera-trap surveys (Figure 4.1B) representing the range of elevation, logging regime, proximity and density of logging roads and settlements, and differences in forest disturbance and hunting pressure (where forest disturbance was assessed through surveyors' observations and discussions with logging company staff and local communities, considering logging history, extent of shifting agriculture and human settlements, and extent of damage by forest fires; and relative hunting pressure at each block was assessed qualitatively through the surveyors' observations and personal communication with indigenous hunters; see Table 4.1). Each block covered 15 – 20 km^2 and 40 camera trap stations were set up per block at least 500 m apart. We chose 500 m as a compromise between logistical feasibility and satisfying the assumption of spatial independence in occupancy models by exceeding the home range size of most target species (MacKenzie et al., 2006); sun bear *Helarctos malayanus* and Sunda clouded leopard *Neofelis diardi* were excluded from the analysis due to their known larger home ranges. At each block, we sampled 20 points with two Reconyx Hyperfire HC500 cameras (both cameras placed within a 50 m radius of centre point, facing different trails in opposite directions) and the other 20 points with a single camera to optimally use the available 60 cameras and maximise detection probability while accounting for logistical difficulties. We used locally available fish oil as a lure. Because we estimated detection probability for each species in the occupancy models, we did not expect usage of lures to impact our results; lures would only impact detectability and not occupancy itself as it is unlikely that animals could smell the lure greater than 150 m (transect length for vegetation surveys) from the camera trap station. After the last camera set in a block accumulated 45 trap-nights, we moved all cameras to the next block.

Habitat surveys

We characterised the habitat surrounding each camera trap station to assess the general forest structure and disturbance using three 150 m line transects oriented 0˚, 120˚and 240˚ from each centre point and pooled the data of the three transects. Along each transect, we recorded seven measurements of habitat structure and four variables pertaining to predominant forest type/land use history at each station (Table 4.2).

Table 4.1: Survey blocks from the camera trapping study in the Sela'an Linau Forest Management Unit, Sarawak, Malaysian Borneo. Numbering follows Figure 4.1.

Block	Elevation range of cameras (m)	Main forest type and anthropogenic disturbance*
1. Protected Zone LL (PZ LL)	570 - 1200	Unlogged forest, mainly highland kerangas, with low anthropogenic disturbance; surrounded at lower elevations by four indigenous villages along the Tutoh river, with forest affected by shifting agriculture of various ages and moderate to high hunting pressure.
2. C1	500 - 900	Mainly regenerating forest, logged between 2006 and 2008 using RIL methods; old logging roads, one indigenous village, some shifting agriculture and moderate hunting pressure; some highland kerangas.
3. Sel	250 - 560	Unlogged forest; some anthropogenic disturbance due to four indigenous villages and shifting agriculture of various ages, particularly along the Selungoh river, with high hunting pressure.
4. Protected Zone Kel (PZ Kel)	750 - 1550	Unlogged forest, mainly highland kerangas, with low anthropogenic disturbance.
5. BZ	250 - 750	Along the main, active logging road; conventionally logged in the early 1990s and then affected by fires during the 1997-98 El Niño event; some shifting agriculture, silvicultural treatment; high hunting pressure and anthropogenic disturbance.

*anthropogenic disturbance at each block was assessed through surveyors' observations and discussions with logging company staff and local communities, considering logging history, extent of shifting agriculture and human settlements and extent of damage by forest fires; relative hunting pressure at each block was assessed qualitatively through the surveyors' observations and personal communication with indigenous hunters.

Table 4.2: Covariates used for occupancy modeling of carnivores detected in the Sela'an Linau Forest Management Unit, Sarawak, Malaysian Borneo. Covariates were measured in-situ or were calculated in R 3.2.0 using local and global GIS datasets. Covariates in italics were not used in the final model as these were summarised into composite covariates. Covariates that were correlated (slope and ruggedness; d_village and d_access) and those derived from other covariates (d_access from d_village, d_road and d_water) were not used in the same model.

Covariate	Description
Median diameter at breast height, DBH*	All trees > 10cm DBH within 2 m of the transect
Median canopy height, CH*	Measured at 25 m intervals along each transect using clinometer
Mean canopy closure, CC*	Measured at 50 m intervals along each transect using spherical desiometer Canopy closure refers to the proportion of the sky hemisphere obscured by vegetation when viewed from a single point (Jennings et al., 1999).
Mean understorey vegetation density, UVD*	Used (1.5 x 1 m) checkerboard with 150 (0.1 x 0.1 m) cells, with 4 equally spaced dots of identical size within each cell. Checkerboard was photographed at 50 m intervals along each transect at distance 10 m from either side of transect line and number of dots covered by vegetation was expressed as a fraction of total dots.
Mean moss cover, M*	Visual observation along a gradient 0 (no moss) to 4 (full moss cover), recorded at 25 m intervals along each transect.
number of boulders, B*	Number of boulders > 50 cm along each transect
number of trees with holes (cavities), TH*	Number of trees (both standing and fallen) with cavity opening > 20 cm along each transect.
*logged**	*Was forest around a station unlogged, logged by RIL or logged by CL? [3 levels : 'unlogged', 'logged_RIL' and 'logged_CL']*
Logging	Composite variable combining points harvested using both RIL and CL (from covariate 'logged') [2 levels: 'logged' and 'unlogged']
*burnt**	*Was forest around a station affected by forest fires of the 1997–1998 El Niño event (measured within the transect distance of 150m around the station)? [2 levels: 'burnt' and 'unburnt']*
*temuda**	*Was forest around a station formerly subject to shifting agriculture (measured within the transect distance of 150m around the station)? [2 levels: 'temuda' and non temuda]*
Disturbance	Composite variable combining covariates 'logging', 'burnt' and 'temuda' [2 levels: 'disturbed' and 'undisturbed']
Kerangas*	Kerangas means 'land that cannot grow rice' in the native Iban language. It refers here specifically to highland kerangas found on Borneo. These are upland forests characterised by infertile, sandy soils, presence of epiphytic plants (e.g. Nepenthes), streams with reddish water and typically on sandstone outcrops (Brunig, 1974). [2 levels: 'kerangas' and 'non kerangas']
distance to nearest village (d_village) distance to nearest road (d_road)	Euclidean distance to nearest village, road (main/secondary/feeder) and water source (river/stream/lake) from each station. Location data provided

distance to nearest water source (d_water)	by the logging concessionaire
distance to accessibility (d_access)	Composite variable capturing minimum of distance to village, main/secondary road and main river, from each station.
Slope Aspect Ruggedness topographic position index (TPI)	Calculated from the 90 m SRTM digital elevation model (DEM, http://srtm.csi.cgiar.org) TPI is the elevational difference between each cell of the DEM and the mean elevation of its eight neighbours.

*Measured/recorded in-situ

Data analysis

We conducted all analyses in R 3.2.0 (R Core Team, 2015). We used package *camtrapR* (Niedballa et al., 2016) for initial data preparation. We pooled data from camera trap images into 8-day occasions resulting in a minimum of six sampling occasions. In each occasion, we calculated trap effort (number of active camera trap-nights per station per occasion) and where two cameras were placed at a station, we summed the trap-nights for the two cameras, as the two cameras were set on different trails and therefore were operationally independent, though spatially dependent. We constructed detection-nondetection matrices for all stations and occasions. Assuming all carnivore species had similar associations with different habitat variables across the five study blocks, we joined the dataset from all blocks and modelled occupancy for this joint data set. Because there are no strong seasonal differences in Sarawak and no evidence of carnivore migrations on Borneo, we do not expect the timing of the surveys to affect carnivore occupancy or habitat associations. To examine what influenced carnivore occupancy in our landscape, we constructed occupancy models which estimate the probability of occurrence of a species at a station while accounting for imperfect detection (MacKenzie et al., 2006). Both occupancy probability and detection probability can be modelled as functions of covariates. We first modelled variation in detectability by constructing a set of candidate models where the probability of detection of carnivores was modelled as either a function of trapping effort (as defined above) or as a constant. We did not use block as a covariate on detection as it represented differences in forest disturbance, logging history, elevation, distance to roads, rivers and villages and hunting pressure and thus, could have masked the effects of other covariates on occupancy. Conditional on the best detection model (see model selection below), we then modelled carnivore occupancy by testing a set of covariates collected in-situ and covariates derived from regional or global GIS datasets (see Table 4.2 for details), first using covariates individually, then using combinations of important covariates. To investigate the effects of logging, we combined stations that were harvested using both RIL and CL methods because sample sizes were too small to investigate each treatment separately. Similarly, too few stations were affected by forest fires and shifting agriculture and therefore, we created a composite covariate, disturbance. Another composite variable, distance to accessibility (d_access) was created, capturing the distance of each station to the nearest main/secondary logging road, main river or village, whichever was nearest, as a proxy of human access and potential for hunting activity (Table 4.2). Occupancy models were implemented in R using package *unmarked* (Fiske and Chandler, 2011).

We standardised all continuous variables to have mean = 0 and variance = 1. All continuous variables were tested for collinearity using Spearman's rank correlation and were not included in the same model if substantially correlated (coefficient > 0.7; Dormann et al., 2013). For each species, we constructed models representing combinations of the occupancy covariates, ensuring that the ratio of sample size *(n)* to parameters *(k)* was ≥ 10 by considering only models with a limited number of parameters, thereby avoiding overparameterisation (a full list of candidate models can be found in Appendix A). We based model selection on Akaike's information criterion (AIC) using *unmarked* and used AIC differences and Akaike weights to assess the explanatory power of each model relative to the others. We considered all parameters that occurred in models within two units of ΔAIC of the top model of each species as important in explaining occupancy of that species. To visualise habitat associations, we plotted response curves based on the top model for each species, showing standard errors and 95% confidence intervals.

Results

After accounting for camera failure and thefts, we retrieved data from 179 stations. We recorded 498 independent events (photographs of the same species at the same station, where a station consists of either one or two cameras, within 60 minutes, were considered the same 'event') of 15 carnivore species over 14,814 camera trap nights. Of these species, banded civet *Hemigalus derbyanus* was the most commonly recorded and widespread, being detected 142 times at 69 stations (Table 4.3). We had sufficient records to build occupancy models for seven species (Tables 4.3 and 4.4). Banded civet, Hose's civet *Diplogale hosei*, masked palm civet *Paguma larvata*, leopard cat *Prionailurus bengalensis* and yellow-throated marten *Martes flavigula* were detected across almost all blocks, though more often in the less disturbed, higher elevation forests of the Protected Zone (PZ), with Hose's civet records being almost exclusively from the PZ (Table 4.3). Malay civet *Viverra tangalunga* and short-tailed mongoose *Herpestes brachyrus*, though recorded from all blocks, were detected more often in the recently logged C1, with the latter also recorded regularly in the areas affected by forest fires.

Masked palm civet exhibited the highest occupancy (0.64 ± 0.16), whereas yellow-throated marten had the lowest occupancy (0.08 ± 0.05) of the seven species. For all species but masked palm civet, multiple models fell within two units of ΔAIC of the top model, suggesting similar support for these models. In most cases, one or two covariates were consistently represented in these similarly supported models, and consistently had coefficients whose confidence intervals did not include 0, indicating that these factors were important predictors for occupancy (Table 4.4). Banded civet occupancy was strongly related to understorey vegetation density (UVD) and d_access; Malay civet and short-tailed mongoose occupancy was strongly affected by distance to road (d_road) and canopy closure (CC); Hose's civet occupancy responded strongly to moss cover (M) and kerangas. The single top model for masked palm civet (next best model >5 AIC units from top model) included number of trees with holes/cavities (TH), d_road and distance to village (d_village). Leopard cat occupancy was influenced strongly by d_village and UVD; and occupancy of yellow-throated marten was strongly affected by canopy height (CH, Table 4.4). Direction and strength of these covariate relationships are depicted in Figure 4.2. Distance to roads affected occupancy of all species except banded civet (Table 4.4) but the direction of this effect varied between species. Similarly, the directions of effects of other environmental variables (e.g. canopy height, canopy closure, number of trees with holes (cavities)) varied between species. Detailed parameter estimates for models listed in Table 4.4 can be found in Appendix B.

Table 4.3: Carnivore species detected using cameras in the Sela'an Linau Forest Management Unit, Sarawak, Malaysian Borneo from April 2013 to August 2014. Basic information of the records is listed. Occupancy estimates are given for only the seven species for which we had sufficient records to build occupancy models. Occupancy estimates are derived from the top model in Table 4.4 and averaged over all stations.

Species	IUCN Red Listing*	Total number of independent events	Number of independent events in each block (refer to Table 4.1 for block descriptions)					Elevation range (m)	Naïve occupancy	Occupancy (S.E.) [95% C.I.] **
			PZ LL	C1	Sel	PZ Kel	BZ			
Banded civet *Hemigalus derbyanus*	NT	142	48	17	10	41	26	260 - 1500	0.39	0.61 (0.08) [0.44 – 0.75]
Malay civet *Viverra tangalunga*	LC	67	4	29	12	11	11	260 - 1150	0.21	0.31 (0.08) [0.17 – 0.49]
Short tailed mongoose *Herpestes brachyurus*	NT	56	8	19	12	0	17	260 - 1370	0.18	0.24 (0.06) [0.13 – 0.38]
Hose's civet *Diplogale hosei*	VU	53	30	4	1	17	1	370 - 1500	0.16	In Kerangas: 0.32 (0.09) [0.17 – 0.52] In Non Kerangas: 0.07 (0.04) [0.02 – 0.21]
Masked palm civet *Paguma larvata*	LC	46	15	6	5	17	3	280 - 1500	0.18	0.64 (0.16) [0.31 – 0.87]
Leopard cat *Prionailurus bengalensis*	LC	30	1	0	1	22	6	260 - 1500	0.10	0.14 (0.06) [0.05 – 0.31]
Yellow-throated marten *Martes flavigula*	LC	19	6	1	2	7	3	290 - 1470	0.08	0.08 (0.05) [0.02 – 0.23]
Sun bear *Helarctos malayanus*	VU	48	9	12	1	16	10	260 - 1500	0.17	
Binturong *Arctictis binturong*	VU	13	5	1	0	5	2	275 - 1180	0.06	
Collared mongoose *Herpestes semitorquatus*	NT	9	2	0	0	0	7	245 - 1065	0.03	
Banded linsang *Prionodon linsang*	LC	4	0	0	0	4	0	1200 -1550	0.02	

Marbled cat *Pardofelis marmorata*	NT	4	0	2	1	0	1	560 - 700	0.02
Sunda clouded leopard *Neofelis diardi*	VU	3	3	0	0	0	0	1065 -1180	0.01
Bornean bay cat *Catopuma badia*	EN	3	0	0	0	3	0	1040 -1210	0.01
Malay weasel *Mustela nudipes*	LC	1	0	0	0	1	0	860	0.01

*LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered
**Refers to the probability that a station is occupied by the species. S.E. = standard error; C.I. = confidence interval

Table 4.4: Top models for the seven carnivore species detected in the Sela'an Linau Forest Management Unit for which occupancy models were built. Where ΔAIC < 2, all competing models are shown, otherwise only top five models.

	Model	ΔAIC	AIC weight	No. of parameters
Banded civet	p(effort)psi(**UVD** + **d_access** + CH)	0.00	0.143	6
	p(effort)psi(**UVD** + **d_access** + TH)	0.24	0.127	6
	p(effort)psi(**UVD** + **d_access** + TH + Disturbance)	0.41	0.117	7
	p(effort)psi(**UVD** + **d_access**)	0.68	0.102	5
	p(effort)psi(**UVD** + **d_access** + TPI)	1.20	0.079	6
	p(effort)psi(**UVD** + d_access + Kerangas)	1.30	0.075	6
	p(effort)psi(**UVD** + d_access + Disturbance)	1.69	0.062	6
	p(effort)psi(**UVD** + **Dist** + CH)	1.91	0.055	6
Malay civet	p(effort)psi(**d_road** + **CC** + *d_village*)	0.00	0.350	6
	p(effort)psi(**d_road** + **CC** + M)	1.96	0.131	6
	p(effort)psi(**d_road** + **CC**)	2.07	0.124	5
	p(effort)psi(**d_road** + **CC** + ruggedness)	2.48	0.101	6
	p(effort)psi(**d_road** + **CC** + Disturbance)	3.50	0.061	6
Short-tailed mongoose	p(effort)psi(**CC** + **d_road** + ruggedness)	0.00	0.241	6
	p(effort)psi(**CC** + **d_road**)	0.74	0.167	5
	p(effort)psi(**CC** + **d_road** + TPI)	1.53	0.112	6
	p(effort)psi(**CC** + **d_road** + UVD)	2.38	0.073	6
	P(effort)psi(**CC** + **d_road** + d_village)	2.60	0.065	6
Hose's civet	p(effort)psi(**M** + **Kerangas** + TH)	0.00	0.172	6
	p(effort)psi(**M** + **Kerangas** + CC)	0.44	0.138	6
	p(effort)psi(**M** + **Kerangas** + d_road)	0.65	0.124	6
	p(effort)psi(**M** + **Kerangas**)	0.84	0.113	5
	p(effort)psi(**M** + **Kerangas** + Disturbance)	1.57	0.079	6
	p(effort)psi(**M** + **Kerangas** + TPI)	1.93	0.066	6

Masked palm civet	p(effort)psi(**TH** + **d_road** + **d_village**)	0.00	0.806	6
	p(effort)psi(**TH** + **d_road** + CH)	5.54	0.051	6
	p(effort)psi(*TH* + **d_road**)	6.20	0.036	5
	p(effort)psi(**TH** + **d_road** + UVD)	7.07	0.023	6
	p(effort)psi(**TH** + **d_road** + logging)	7.31	0.021	6
Leopard cat	p(effort)psi(**UVD** + **d_village**)	0.00	0.429	5
	p(effort)psi(**d_village** + *d_road*)	1.65	0.188	5
	p(effort)psi(*UVD* + *TH*)	1.97	0.160	5
	p(effort)psi(d_village + TH)	3.28	0.083	5
	p(effort)psi(d_road + **TH**)	4.62	0.043	5
Yellow-throated marten	p(effort)psi(**CH** + *d_village*)	0.00	0.215	5
	p(effort)psi(**CH** + Disturbance)	0.68	0.153	5
	p(effort)psi(**CH** + d_road)	1.51	0.101	5
	p(effort)psi(**CH** + TH)	1.78	0.088	5
	p(effort)psi(**CH** + d_access)	2.27	0.069	5

Bold indicates 95% CI does not include 0 for this variable in this model
Italics indicates 90% CI does not include 0 for this variable in this model
Note: 95% CIs for effort do not include 0 for all species except leopard cat and yellow-throated marten; for these two species, 95% CI includes 0 for all models.

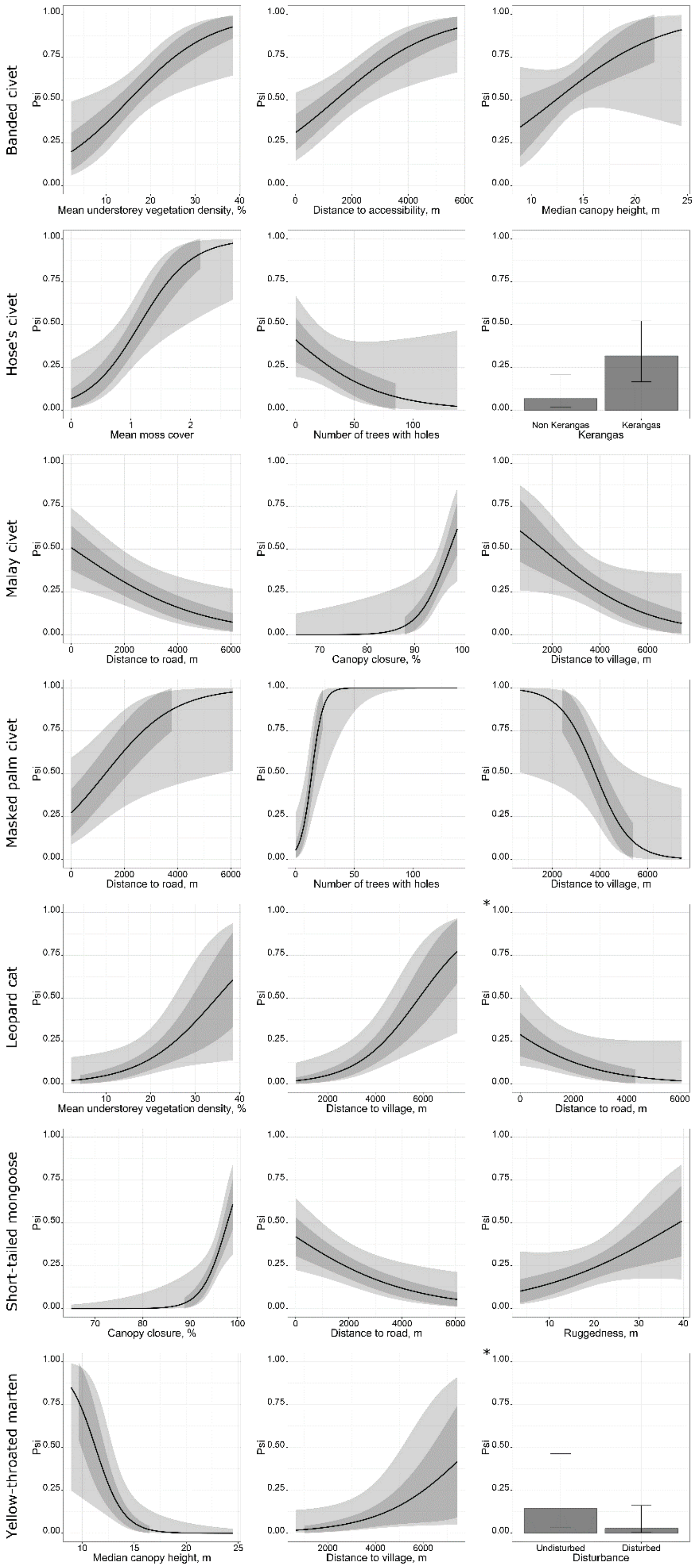

Figure 4.2: Response curves of habitat associations for the seven carnivore species for which occupancy models were built. Curves were based on the top model in Table 4.4. Dark gray shows standard errors and lighter gray represents 95% confidence intervals (CIs). For categorical variables, only 95% CIs are shown.

* indicates response curve for corresponding variable from the second best model for that species (see Table 4.4).

Discussion

Anthropogenic disturbances such as logging alter forest structure and resource availability for mammals (Johns, 1988). This has been associated with changes in abundance of species (Bicknell and Peres, 2010); on Borneo, carnivores are the taxonomic group most negatively affected by logging (Brodie et al., 2015b). In our study, overall forest disturbance adversely affected occupancy of Hose's civet, banded civet, and to a lesser extent, yellow-throated marten, suggesting low tolerance to disturbed habitat, whether logged, or areas subject to shifting agriculture or forest fires. This result confirms current information on Hose's civet (Jennings et al., 2013; Mathai et al., 2016b) and banded civet (Jennings et al., 2013; Ross et al., 2015), but is partially contrary to the suggestion that yellow-throated marten is tolerant of degraded habitat across its range, including Borneo (Hon et al., 2016). Yellow-throated marten was recorded in our study from all forest blocks, including disturbed blocks. However, most records were from the mid- to higher-elevation forests of the Protected Zone (PZ) and at greater distances from villages. This species may experience higher hunting levels caused by higher conspicuousness, being diurnal and often moving in small groups (Grassman et al., 2005). Because the forests of the PZ are both less disturbed and less affected by hunting, our models were possibly unable to separate whether habitat disturbance or hunting impacted occurrence of this species.

Our models suggested that logging had no effect on occupancy of carnivores in our site, similar to Brodie et al. (2015a) and Granados et al. (2016). However, this pattern may have been caused by combining stations harvested using different techniques at different time intervals (six to eight years after RIL and twenty years after CL) as "logged", and similarly, combining undisturbed forests and regenerating shifting agriculture as "unlogged". Further, logging has been reported to negatively impact population densities of small carnivores in Borneo (civets, Heydon and Bulloh 1996), but such effects may be missed when investigating occupancy. As disturbance, partly derived from logging, impacted occupancy of some carnivores in the FMU, further studies in more homogenous logged areas are needed to assess the susceptibility of sensitive carnivores and potential of recovery after logging.

Distance to accessibility affected only banded civet: occupancy was higher in less accessible areas, i.e. areas expected to have fewer hunters. However, logging roads (one of the covariates from which d_access was derived) had a more diverse impact on carnivore occupancy. Occupancy of Hose's civet and masked palm civet were lower at stations closer to roads, but our data did not allow us to tease apart a preference for remote forests and increased hunting pressure facilitated by logging roads (Brodie et al., 2015b; Granados et al., 2016). Interviews (unpublished data) showed that banded civet, and particularly Malay civet and masked palm civet, are opportunistically hunted and consumed in the FMU. Further, snares, traps and nets are used that catch animals indiscriminately, possibly affecting the more ground-dwelling carnivores such as banded civet, Malay civet, masked palm civet and Hose's civet. Occupancy of Malay civet, short-tailed mongoose and leopard cat, however, were higher at stations closer to roads, suggesting that logging roads may ease movement, dispersal and/or hunting for these species (see below).

Apart from these species-specific responses linked to the two main threats of logging (via forest disturbance) and human access, our analyses have helped fill knowledge gaps in our understanding of habitat associations for the following species.

Banded civet

Banded civet occupancy was higher at less accessible stations with higher canopies and denser understory vegetation (Table 4.4, Figure 4.2). The relationship with understory vegetation may reflect the feeding behaviour of this species whose diet consists largely of insects (Davis, 1962), and to a lesser degree, earthworms and other small animals (Ross et al., 2015). Understory vegetation not only provides a more heterogeneous microhabitat for a wide variety of prey, but also offers cover to hunt and subsequently consume prey without being disturbed. Trees with higher canopies are associated with lower- to mid-elevations, suggesting this species may not be so common in the upper elevation forests. Further, the sister species of the banded civet, Hose's civet, had higher occupancy in the mid- to higher-elevation forest, which might indicate intraspecific competition between the two species in this FMU. These results are similar to that of Jennings et al. (2013) who suggest banded civet is mainly found in lowland areas whereas Hose's civet primarily occurs at higher elevations, though there may be some overlap among the two at mid-elevations. To test this hypothesis, additional data would be needed, allowing a two-species occupancy analysis.

Hose's civet

Hose's civet occupancy was greater at stations in kerangas forest and where moss cover was high (Table 4.4, Figure 4.2). Because kerangas forests are generally low in mammalian diversity and abundance, species selecting kerangas forest are thought to be specialised (Brunig, 1974).

Moss cover was high in areas that have constant high humidity, such as closed canopy, undisturbed forests. Our analysis showed that occupancy of Hose's civet may also be greater in undisturbed stations with high canopy closure, more distant from roads, and in areas with a topography of dips and small valleys. Leaves may accumulate in such dips and small valleys, providing more suitable conditions for earthworms, frogs and other invertebrates, which comprise most of the species diet, as stated by personal communications with indigenous people during the surveys. The relationship of occupancy with low number of trees with cavities may either indicate that tree cavities are not limiting for this species or it may be a spurious relationship.

Malay civet

Malay civet occupancy was higher at stations closer to roads and with higher canopy closure (Table 4.4, Figure 4.2). This is not surprising as this species appears to be one of the more tolerant and adaptable of Bornean carnivores (Ross et al., 2016; Mathai et al., 2016a) and may use logging roads to move or hunt. Occupancy was greater at stations closer to villages, possibly explaining why Malay civet is one of the more common carnivores consumed by local communities in the FMU, and could support earlier accounts that suggest this species scavenges food in settlements (Jennings et al., 2010a; Duckworth et al., 2016a). Although found more frequently closer to roads (and villages), Malay civets require forest cover, for example, for rest sites, which are often associated with high canopy cover (Colon 2002; Jennings et al. 2006). In our study site, this did not restrict the species to less disturbed forests as in situ habitat surveys showed that canopy cover can be high in less disturbed and disturbed forest alike. This result corroborates earlier studies in monoculture plantations in Sarawak (Giman et al., 2007), Peninsular Malaysia (Jennings et al., 2010a) and Sumatra (Jennings et al., 2015) which showed this species did not venture far into plantations from surrounding forests and that dense cover and forested patches were important for this species to survive in such modified habitats.

Masked palm civet

Although one of the more widespread civets in Asia, surprisingly little is known about masked palm civet habitat use across much of its range (Belden et al., 2014). Whereas in central south-eastern China it has been reported to use farmland-dominated landscapes with remnant forest fragments (e.g. Wang and Fuller 2003, Zhou et al., 2008), there seem to be no records far from forest within the southern part of its range (Duckworth et al. 2016b). It appears to occur mainly at higher elevations with few records from lowland areas anywhere in its Southeast Asian range

(Belden et al., 2014). This species was detected mainly at higher elevations in the FMU, with greater occupancy at stations more distant from logging roads, though closer to villages, and where the number of trees with cavities was high. This species may avoid roads due to the access provided to hunters; though not perceived as a scavenger or poultry raider like the Malay civet, it is similarly hunted opportunistically. With fruit making up a large portion of its diet (Duckworth et al., 2016b; Semiadi et al., 2016), masked palm civet frequent areas closer to villages to feed in orchards and fruit gardens of local communities. The association with higher number of trees with cavities may be an indication of use as denning sites.

Leopard cat

Leopard cat is the most widespread Asian cat species. Recent genetic analysis suggests species-level distinctions between the Indochinese and Sundaic populations (Luo et al., 2014), with several of the recognised subspecies exhibiting distinct morphological differences (Sicuro and Oliveira, 2015). At least some of these subspecies or populations exhibit different ecological characteristics, which in turn influence the degree to which they are impacted by various threats and thus, require conservation interventions (Izawa et al., 2009). In our study, leopard cat occupancy was higher in stations with denser understorey vegetation and further from villages. Similar to the banded civet, the dependence on understorey vegetation may reflect its entirely carnivorous diet consisting mainly of small mammals, as well as reptiles, amphibians, birds and insects (Rajaratnam et al., 2007). These prey types may be more abundant within the understorey vegetation of forests. That leopard cats prefer less disturbed forests and have higher occupancy away from villages is surprising as earlier studies of leopard cats in the tropics showed the species occurring in plantations such as acacia (Giman et al., 2007), oil palm (Rajaratnam et al., 2007) and sugar cane (Lorica and Heaney, 2013), having higher densities in more disturbed forests and generally preferring more open forests (Mohamed et al., 2013). Our finding that leopard cats prefer to be closer to logging roads (Figure 4.2), however, supports earlier studies showing that leopard cats travel on logging roads and likely use them when hunting (Mohamed et al., 2013).

Short-tailed mongoose

Similar to Malay civet, occupancy of short-tailed mongoose was higher at stations closer to logging roads and with higher canopy closure. Roads possibly enhance movement for this species though the cover of forest is still required. Although many of our records were from more disturbed habitat in the FMU, there is yet no evidence of extensive use of modified habitat, such as monoculture plantations on Borneo, though this species has been recorded close to plantation-forest boundary (Giman et al., 2007; Joanna Ross, personal communication). This species is thought to occur mainly at elevations between 0 and 600 m (Jennings and Veron, 2011) and was recorded only at low elevations (< 160 m) in Peninsular Malaysia (Jennings et al., 2010b), whereas our records (though mainly from lower to mid elevations of 250 -900 m), ranged up to 1300 m. This is similar to recent records from the Crocker Range in Sabah at more than 1400 m (Andrew Hearn and Joanna Ross, personal communication), indicating that occurrence at such altitudes is not unusual in Borneo. Interestingly, albeit not significant, our analysis showed this species may prefer rugged areas, possibly along ridges. In the SL FMU these features also occur at lower elevations.

Yellow-throated marten

Occupancy of this species was higher at stations with lower canopy height and further away from villages. Preference for stations further away from villages is supported by Hon et al. (2016), who reviewed most of the occurrence records across Borneo and concluded that this species may not go near human populated areas. This may be due to higher conspicuity (Grassman et al., 2005), leading to higher probability of being hunted. Our data further suggests this species is restricted to mid to higher elevation forests of the PZ, which supports the recommendation of Hon et al. (2016) for additional surveys in high-elevation forest to better understand yellow-throated marten habitat use.

Conclusion

Knowledge about fine-scale habitat associations of species and their responses to anthropogenic influences is critical for species conservation in rapidly-changing environments. Our findings show that when left to regenerate, logged forests can provide valuable habitat for many carnivore species, as long as less disturbed habitats are available nearby. Broad management recommendations include: maintaining forest cover adjacent to logging roads, both in flat and rugged areas; preserving blocks of less-accessible, mid- to high-elevation forest with understorey vegetation; and preserving fruiting trees and trees with cavities, both standing and fallen. Our results also highlight the need to consider often overlooked habitat variables, for example, moss cover and kerangas were the most important variables for the little-known Hose's civet and the maintenance of such forest types may be important for species persistence. We were unable to investigate the direct effects of hunting and instead used proxies such as distance to roads or accessibility. However, in discussions with local communities, we learned that hunting levels are increasing, particularly due to ease of access provided by roads to outsiders and the increased use of indiscriminate hunting methods such as snares and nets. Thus, quantifying hunting and its effects on carnivore populations is an important next step for future research not only in this FMU but across Sarawak and Borneo.

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Supplementary data

Appendix A: All candidate models for each species, showing AIC and ΔAIC values. Variation in detectability was first modelled as described in text. Conditional on the best detection model, carnivore occupancy was modelled using all covariates individually (see Table 4.2 for details of covariates), then using the combinations of important covariates as presented below.

	Model	ΔAIC	AIC weight
Banded civet	p(effort)psi(**UVD** + **d_access** + CH)	0.00	0.143
	p(effort)psi(**UVD** + **d_access** + TH)	0.24	0.127
	p(effort)psi(**UVD** + **d_access** + TH + Disturbance)	0.41	0.117
	p(effort)psi(**UVD** + **d_access**)	0.68	0.102
	p(effort)psi(**UVD** + **d_access** + TPI)	1.20	0.079
	p(effort)psi(**UVD** + d_access + Kerangas)	1.30	0.075
	p(effort)psi(**UVD** + d_access + Disturbance)	1.69	0.062
	p(effort)psi(**UVD** + **Disturbance** + CH)	1.91	0.055
	p(effort)psi(**UVD** + **Kerangas**)	2.05	0.052
	p(effort)psi(**UVD** + Disturbance + Kerangas)	2.08	0.051
	p(effort)psi(**UVD** + **d_access** + M)	2.22	0.047
	p(effort)psi(**UVD** + **Disturbance**)	2.40	0.043
	p(effort)psi(**UVD** + **Disturbance** + TPI)	3.21	0.029
	p(effort)psi(**UVD** + **M**)	4.44	0.016
	p(effort)psi(**UVD** + CH)	7.30	0.004
Malay civet	p(effort)psi(**d_road** + **CC** + *d_village*)	0.00	0.350
	p(effort)psi(**d_road** + **CC** + M)	1.96	0.131
	p(effort)psi(**d_road** + **CC**)	2.07	0.124
	p(effort)psi(**d_road** + **CC** + ruggedness)	2.48	0.101
	p(effort)psi(**d_road** + **CC** + Disturbance)	3.50	0.061
	p(effort)psi(**d_road** + **CC** + TH)	3.88	0.050
	p(effort)psi(**d_road** + **CC** + UVD)	4.02	0.047
	p(effort)psi(**M** + **CC**)	5.08	0.027
	p(effort)psi(ruggedness + **CC** + **M**)	5.63	0.021
	p(effort)psi(ruggedness + **CC**)	9.67	0.003
	p(effort)psi(ruggedness + **M**)	11.57	0.001
	p(effort)psi(ruggedness + **TH**)	14.84	0.000
Short-tailed mongoose	p(effort)psi(**CC** + **d_road** + ruggedness)	0.00	0.241
	p(effort)psi(**CC** + **d_road**)	0.74	0.167
	p(effort)psi(**CC** + **d_road** + TPI)	1.53	0.112

	p(effort)psi(**CC** + **d_road** + UVD)	2.38	0.073
	p(effort)psi(**CC** + **d_road** + d_village)	2.60	0.065
	p(effort)psi(**CC** + *d_road* + Disturbance)	2.66	0.064
	p(effort)psi(**CC** + **d_road** + TH)	2.67	0.063
	p(effort)psi(**CC** + **d_road** + M)	2.74	0.061
	p(effort)psi(**CC** + *logging*)	3.69	0.038
	p(effort)psi(**CC** + Kerangas)	4.21	0.029
	p(effort)psi(**CC** + Disturbance)	4.38	0.027
	p(effort)psi(**CC** + M)	5.38	0.016
	p(effort)psi(**CC** + M + ruggedness)	5.57	0.015
	p(effort)psi(**CC** + ruggedness)	5.68	0.014
Hose's civet	p(effort)psi(**M** + **Kerangas** + TH)	0.00	0.172
	p(effort)psi(**M** + **Kerangas** + CC)	0.44	0.138
	p(effort)psi(**M** + **Kerangas** + d_road)	0.65	0.124
	p(effort)psi(**M** + **Kerangas**)	0.84	0.113
	p(effort)psi(**M** + **Kerangas** + Disturbance)	1.57	0.079
	p(effort)psi(**M** + **Kerangas** + TPI)	1.93	0.066
	p(effort)psi(**M** + **Kerangas** + UVD)	2.17	0.058
	p(effort)psi(**M** + **Kerangas** + d_access)	2.33	0.056
	p(effort)psi(**M** + **Kerangas** + CH)	2.83	0.042
	p(effort)psi(**M** + **Kerangas** + ruggedness)	2.84	0.042
	p(effort)psi(**M** + **Kerangas** + d_village)	2.84	0.042
	p(effort)psi(**M** + *Disturbance*)	3.30	0.033
	p(effort)psi(**Disturbance** + **Kerangas**)	4.19	0.021
	p(effort)psi(**M** + logging)	5.01	0.014
Masked palm civet	p(effort)psi(**TH** + **d_road** + **d_village**)	0.00	0.806
	p(effort)psi(**TH** + **d_road** + CH)	5.54	0.051
	p(effort)psi(*TH* + **d_road**)	6.20	0.036
	p(effort)psi(**TH** + **d_road** + UVD)	7.07	0.023
	p(effort)psi(**TH** + **d_road** + logging)	7.31	0.021
	p(effort)psi(**TH** + *d_road* + CC)	7.72	0.017
	p(effort)psi(*TH* + **d_road** + ruggedness)	8.17	0.014
	p(effort)psi(**TH** + *d_village*)	9.36	0.008
	p(effort)psi(**TH** + *d_village* + CC)	9.98	0.005
	p(effort)psi(**TH** + TPI)	10.59	0.004
	p(effort)psi(*d_road* + d_village)	11.54	0.003

	p(effort)psi(*TH* + Disturbance)	11.54	0.003
	p(effort)psi(**TH** + CH)	11.77	0.02
	p(effort)psi(*TH* + logging)	12.13	0.002
	p(effort)psi(**TH** + UVD)	12.51	0.002
	p(effort)psi(**TH** + d_access)	12.8	0.001
	p(effort)psi(**TH** + d_access + M)	13.55	0.001
	p(effort)psi(d_road + logging)	14.88	0.000
	p(effort)psi(*Disturbance* + ruggedness)	15.79	0.000
Leopard cat	p(effort)psi(**UVD** + **d_village**)	0.00	0.429
	p(effort)psi(**d_village** + *d_road*)	1.65	0.188
	p(effort)psi(*UVD* + *TH*)	1.97	0.160
	p(effort)psi(d_village + TH)	3.28	0.083
	p(effort)psi(d_road + **TH**)	4.62	0.043
	p(effort)psi(**TH** + d_access)	5.53	0.027
	p(effort)psi(**d_village** + Disturbance)	5.79	0.024
	p(effort)psi(**d_village** + TPI)	5.81	0.023
	p(effort)psi(**TH** + Disturbance)	5.84	0.023
	p(effort)psi(*UVD* + Disturbance)	7.27	0.011
	p(effort)psi(**UVD** + d_access)	8.00	0.008
	p(effort)psi(UVD + TPI)	9.90	0.003
Yellow-throated marten	p(effort)psi(**CH** + *d_village*)	0.00	0.215
	p(effort)psi(**CH** + Disturbance)	0.68	0.153
	p(effort)psi(**CH** + d_road)	1.51	0.101
	p(effort)psi(**CH** + TH)	1.78	0.088
	p(effort)psi(CH + d_access)	2.27	0.069
	p(effort)psi(**CH** + logging)	2.32	0.067
	p(effort)psi(**CH** + UVD)	2.50	0.062
	p(effort)psi(**CH** + TPI)	2.55	0.060
	p(effort)psi(**CH**)	2.93	0.050
	p(effort)psi(**CH** + Kerangas)	3.08	0.046
	p(effort)psi(**CH** + M)	3.21	0.043
	p(effort)psi(**CH** + CC)	4.38	0.024
	p(effort)psi(**CH** + ruggedness)	4.59	0.022

Bold indicates 95% CI does not include 0 for this variable in this model
Italics indicates 90% CI does not include 0 for this variable in this model

Appendix B: Parameter estimates for top models as listed in Table 4.4 for each species.

	Model	Occupancy parameters	Estimate	S.E.	P value
Banded civet	p(effort)psi(**UVD** + **d_access** + CH)	Intercept	0.441	0.347	0.203
		UVD	0.790	0.331	0.011
		d_access	0.808	0.300	0.007
		CH	0.498	0.359	0.166
	p(effort)psi(**UVD** + **d_access** + TH)	Intercept	0.384	0.317	0.226
		UVD	0.779	0.298	0.009
		d_access	1.135	0.395	0.004
		TH	-0.540	0.366	0.140
	p(effort)psi(**UVD** + **d_access** + TH + Disturbance)	Intercept	0.846	0.542	0.119
		UVD	0.730	0.308	0.018
		d_access	0.869	0.432	0.043
		TH	-0.674	0.416	0.105
		Disturbance	-0.928	0.728	0.202
	p(effort)psi(**UVD** + **d_access**)	Intercept	0.411	0.314	0.191
		UVD	0.886	0.306	0.004
		d_access	0.834	0.314	0.008
	p(effort)psi(**UVD** + **d_access** + TPI)	Intercept	0.398	0.314	0.205
		UVD	0.903	0.303	0.003
		d_access	0.872	0.321	0.007
		TPI	0.325	0.276	0.239
	p(effort)psi(**UVD** + d_access + Kerangas)	Intercept	0.016	0.439	0.972
		UVD	0.896	0.313	0.004
		d_access	0.571	0.370	0.123
		Kerangas	0.721	0.616	0.241
	p(effort)psi(**UVD** + d_access + Disturbance)	Intercept	0.718	0.474	0.130
		UVD	0.869	0.314	0.006
		d_access	0.605	0.379	0.111
		Disturbance	-0.628	0.640	0.327
	p(effort)psi(**UVD** + **Disturbance** + CH)	Intercept	1.302	0.632	0.040
		UVD	0.752	0.326	0.021
		Disturbance	-1.444	0.603	0.016
		CH	0.579	0.482	0.230

Malay civet	p(effort)psi(**d_road** + **CC** + *d_village*)	Intercept	-0.815	0.386	0.035
		d_road	-0.782	0.310	0.012
		CC	1.294	0.568	0.023
		d_village	-0.649	0.343	0.059
	p(effort)psi(**d_road** + **CC** + M)	Intercept	-0.756	0.382	0.048
		d_road	-0.715	0.322	0.027
		CC	1.333	0.568	0.019
		M	-0.502	0.361	0.164
	p(effort)psi(**d_road** + **CC**)	Intercept	-0.773	0.368	0.036
		d_road	-0.918	0.301	0.002
		CC	1.421	0.554	0.010
	p(effort)psi(**d_road** + **CC** + ruggedness)	Intercept	-0.792	0.374	0.034
		d_road	-0.857	0.305	0.005
		CC	1.465	0.564	0.009
		Ruggedness	-0.359	0.294	0.222
	p(effort)psi(**d_road** + **CC** + Disturbance)	Intercept	-0.969	0.449	0.031
		d_road	-0.765	0.357	0.032
		CC	1.404	0.567	0.013
		Disturbance	0.539	0.713	0.450
Short-tailed mongoose	p(effort)psi(**CC** + **d_road** + ruggedness)	Intercept	-1.167	0.356	0.001
		CC	1.602	0.614	0.009
		d_road	-0.776	0.310	0.012
		Ruggedness	0.459	0.292	0.116
	p(effort)psi(**CC** + **d_road**)	Intercept	-1.116	0.345	0.001
		CC	1.579	0.600	0.008
		d_road	-0.625	0.275	0.023
	p(effort)psi(**CC** + **d_road** + TPI)	Intercept	-1.153	0.343	0.001
		CC	1.471	0.592	0.013
		d_road	-0.616	0.273	0.024
		TPI	0.295	0.271	0.276
	P(effort)psi(**CC** + **d_road** + UVD)	Intercept	-1.150	0.350	0.001
		CC	1.597	0.596	0.007
		d_road	-0.641	0.275	0.020
		UVD	0.173	0.291	0.552
	P(effort)psi(**CC** + **d_road** + d_village)	Intercept	-1.118	0.346	0.001
		CC	1.642	0.634	0.010

		d_road	-0.668	0.304	0.028
		d_village	0.115	0.315	0.714
Hose's civet	p(effort)psi(**M** + **Kerangas** + TH)	Intercept	-2.623	0.650	0.000
		M	1.445	0.525	0.006
		Kerangas	1.856	0.770	0.016
		TH	-0.549	0.343	0.101
	p(effort)psi(**M** + **Kerangas** + CC)	Intercept	-2.566	0.648	0.000
		M	1.246	0.470	0.008
		Kerangas	1.496	0.753	0.047
		CC	0.797	0.551	0.148
	p(effort)psi(**M** + **Kerangas** + d_road)	Intercept	-2.467	0.652	0.000
		M	0.895	0.412	0.030
		Kerangas	1.523	0.762	0.046
		d_road	0.444	0.300	0.138
	p(effort)psi(**M** + **Kerangas**)	Intercept	-2.490	0.633	0.000
		M	1.050	0.416	0.012
		Kerangas	1.640	0.747	0.028
	p(effort)psi(**M** + **Kerangas** + Disturbance)	Intercept	-2.022	0.738	0.006
		M	0.805	0.427	0.050
		Kerangas	1.459	0.773	0.051
		Disturbance	-0.921	0.826	0.265
	p(effort)psi(**M** + **Kerangas** + TPI)	Intercept	-2.596	0.638	0.000
		M	0.899	0.367	0.014
		Kerangas	1.802	0.764	0.018
		TPI	-0.334	0.329	0.309
Masked palm civet	p(effort)psi(**TH** + **d_road** + **d_village**)	Intercept	0.561	0.697	0.421
		TH	4.631	1.620	0.004
		d_road	1.427	0.638	0.025
		d_village	-1.945	0.916	0.033
	p(effort)psi(**TH** + **d_road** + CH)	Intercept	0.810	0.868	0.351
		TH	3.063	1.366	0.025
		d_road	1.114	0.536	0.038
		CH	-0.867	0.618	0.161
	p(effort)psi(*TH* + **d_road**)	Intercept	0.545	0.839	0.516
		TH	2.489	1.314	0.058
		d_road	0.891	0.435	0.041

	p(effort)psi(**TH** + **d_road** + UVD)	Intercept	0.333	0.656	0.612
		TH	2.318	1.012	0.022
		d_road	0.939	0.423	0.026
		UVD	-0.503	0.473	0.288
	p(effort)psi(**TH** + **d_road** + logging)	Intercept	0.194	0.833	0.816
		TH	2.764	1.262	0.029
		d_road	1.131	0.523	0.031
		Logging	0.937	1.022	0.359
Leopard cat	p(effort)psi(**UVD** + **d_village**)	Intercept	-1.843	0.521	0.000
		UVD	0.868	0.407	0.033
		d_village	1.091	0.383	0.004
	p(effort)psi(**d_village** + *d_road*)	Intercept	-1.927	0.565	0.000
		d_village	1.479	0.458	0.001
		d_road	-0.942	0.532	0.076
	p(effort)psi(*UVD* + *TH*)	Intercept	-1.54	0.572	0.007
		UVD	1.01	0.530	0.057
		TH	1.13	0.684	0.098
	p(effort)psi(d_village + TH)	Intercept	-1.253	0.554	0.024
		d_village	0.843	0.566	0.137
		TH	1.081	0.699	0.122
	p(effort)psi(d_road + **TH**)	Intercept	-1.202	0.598	0.044
		d_road	-0.492	0.472	0.297
		TH	1.831	0.761	0.016
Yellow-throated marten	p(effort)psi(**CH** + *d_village*)	Intercept	-2.525	0.675	0.000
		CH	-1.927	0.737	0.009
		d_village	0.779	0.430	0.070
	p(effort)psi(**CH** + Disturbance)	Intercept	-1.79	0.835	0.032
		CH	-2.14	0.794	0.007
		Disturbance	-1.77	1.090	0.105
	p(effort)psi(**CH** + d_road)	Intercept	-2.594	0.689	0.000
		CH	-1.949	0.667	0.003
		d_road	0.739	0.454	0.104
	p(effort)psi(**CH** + TH)	Intercept	-2.401	0.632	0.000
		CH	-1.565	0.616	0.011
		TH	0.621	0.457	0.174
	p(effort)psi(**CH** + d_access)	Intercept	-2.467	0.677	0.000

		CH	-1.965	0.740	0.008
		d_access	0.588	0.436	0.178

Bold indicates 95% CI does not include 0 for this variable in this model
Italics indicates 90% CI does not include 0 for this variable in this model

CHAPTER 5

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Carnivore conservation planning on Borneo: identifying key carnivore landscapes, research priorities and conservation interventions

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J.M., J.W.D. and A.W. conceived the ideas; J.M. and A.W. conducted the analysis; J.M. led the writing; B.C.C. collected the data; J.W.D., E.M., M.A. and A.W. played a large part in the writing; all co-authors edited the manuscript.

Abstract

Borneo harbours more endemic carnivores than does any other island in the world except Madagascar, and almost half of the Bornean carnivore species have been classified by The IUCN Red List of Threatened Species as globally threatened. Here, a systematic conservation planning framework highlighted key carnivore landscapes, conservation research and intervention priorities, and gaps in current knowledge of Bornean carnivore ecology. All single-species predictive habitat suitability index (HSI) models presented in this issue (20 species, comprising all carnivores on Borneo except otters [Lutrinae] and sun bear *Helarctos malayanus*) were standardised by converting HSI values into binary maps, and combined to derive species richness maps to discuss and delineate areas of conservation priority. The highest predicted carnivore species richness (defined here as the sum of the binary threshold maps), corresponds to interior lowland, upland and lower montane forest, whereas areas with lowest predicted species richness correspond to coastal lowlands already largely converted to oil palm plantations. The 12 proposed areas of conservation importance for carnivores focus on large landscapes and connectivity between subunits, many centred around the tri-national Heart of Borneo initiative, with additional areas for wetland/lowland species. A large proportion of these proposed conservation landscapes are being exploited for commercial purposes (e.g., logging concessions) and would, therefore, improve in conservation value if their management became more sustainable. The most important research priorities for Bornean carnivores are species resilience to altered and fragmented landscapes; under-surveyed regions; and the effects and relative intensity of hunting across the island. The most pressing conservation interventions include conservation research on the most threatened Bornean carnivores: the Bornean ferret badger *Melogale everetti* and Hose's civet *Diplogale hosei* (highland endemics), and the flat-headed cat *Prionailurus planiceps* and otter civet *Cynogale bennettii* (wetland specialists). Targeted conservation research and integration of research findings into decision-making, maintaining and restoring connectivity, raising awareness and improving enforcement and governance are also important conservation interventions. Although more resources are needed for conservation and research, the joint effort of scientists, conservationists and government authorities in the identification of key carnivore landscapes, research priorities and conservation issues which this study presents raises hope that more targeted conservation efforts for Bornean carnivores will follow in the future.

Key words: Borneo Carnivore Symposium, Brunei, conservation priorities, habitat suitability index, Heart of Borneo, Indonesia, Malaysia, species distribution modelling, survey gaps

Introduction

The rapid rate of decline towards global extinction of mammals (Hoffman et al., 2011) has urged the conservation community to accelerate efforts towards a deeper understanding of species distributions, population trends, threats and conservation status (Belant et al., 2013). This growing concern of the species extinction crisis, and the recognition that there are limited conservation funds to address it, should have a profound influence on conservation planning. With a focus on relatively large spatial areas or regions, including areas allocated to both economic exploitation and protection for conservation purposes, there is a need to identify priorities and implement conservation actions within a practical yet science- based planning framework (Groves et al., 2002). A structured framework for conservation planning is necessary to enhance the effectiveness with which science informs conservation by clarifying the social and economic implications of alternative methods or scenarios, and reviewing the effectiveness of political processes for achieving stated biodiversity goals (Margules & Pressey, 2000).

A systematic, science-based conservation planning framework is especially important in the context of Borneo (Runting et al., 2015; Struebig et al., 2015a), identified as an evolutionary hotspot hosting the highest levels of mammalian species richness within South-east Asia (de Bruyn et al., 2014). Borneo has been identified as a global priority for carnivore conservation (Schreiber et al., 1989; Di Marco et al., 2014), with almost 50% of its carnivore species being categorised by The IUCN as globally threatened (i.e. Critically Endangered, Endangered or Vulnerable) (IUCN, 2015), and with more endemic carnivore species than has any other island in the world except Madagascar (Belant & Wilting, 2013). In response to these threats and to the paucity of knowledge, almost 200 national and international scientists, conservationists, naturalists and local stakeholders from the range states of Brunei Darussalam, Malaysia and Indonesia, the three countries comprising Borneo, participated in the Borneo Carnivore Symposium (BCS) in June 2011.

This paper summarises the key achievements of the BCS and the subsequent species distribution analyses, via a community perspective on Bornean carnivore distribution with a focus on threatened species to highlight conservation research and intervention priorities. A unique feature of the BCS was the formation of regional working groups for each of the four main geopolitical units on Borneo: Brunei Darussalam, Sarawak (Malaysia), Sabah (Malaysia) and Kalimantan (Indonesia). Each regional working group proposed areas of conservation importance for carnivores based on available records and results of the predictive models, focusing on large landscapes with an emphasis on connectivity between sub-units. The results of the predictive species distribution modelling and the discussions of these regional working groups are summarised in text boxes 1–4 and emphasise research and conservation actions recommended for and in each proposed carnivore landscape.

Species-level achievements and milestones of the BCS

From the BCS, gaps in knowledge of Bornean carnivores were successfully addressed in some cases, and highlighted in others. The status of two species, the collared mongoose *Herpestes semitorquatus* Gray, and the Bornean ferret badger *Melogale everetti* (Thomas) (one of three currently recognised endemic carnivores on the island), had until the BCS been assessed on The IUCN Red List of Threatened Species as Data Deficient. Information gathered during the BCS allowed categorisation of both species: Bornean ferret badger as Endangered (Wilting et al., 2015) and collared mongoose as Near Threatened (Mathai et al., 2015a). The collection of occurrence records and the predictive models supported previous assumptions of the very small distribution of Bornean ferret badger, lending weight to the hypothesis that the species is endemic to the western Sabah mountain massif and hence has possibly the smallest distribution range of any carnivore in South-east Asia (Wilting et al., 2016b). In contrast, the number of collated occurrence records for collared mongoose was much greater, leading to the prediction that it should be widely distributed across Borneo (Hon et al., 2016).

An unexpected finding was the distribution of the Sunda stink-badger *Mydaus javanensis* (Leschenault, in Desmarest), which models predicted today to be widespread across the lowlands of Sabah, and patchily distributed in north-eastern Sarawak and North Kalimantan, but largely absent from the rest of the island, particularly the southern portion. Reasons for this patchy distribution, whether driven by the species's behaviour, ecology, hunting, or a mix of these, are speculative (see Samejima et al., 2016).

In addition to these species-specific findings, many community-level insights were generated. For example, the full compilation of records further showed even for the more widespread and common species an almost complete lack of records from South Kalimantan and large parts of West Kalimantan (see Kramer-Schadt et al., 2016: Fig. 2). This highlights the urgent need for more surveys in these provinces to gain a better understanding of species distributions in these regions. These community-level aspects form the bulk of this document.

Summary of model results and predicted carnivore diversity across Borneo

Occurrence records were collated for all Bornean carnivores except the sun bear *Helarctos malayanus* (Raffles); based on these records, predictive models were developed for all remaining carnivores except otters (Mustelidae: Lutrinae Bonaparte): altogether, 20 species. Methodology is detailed in Kramer-Schadt et al. (2016). Because of the paucity of occurrence records for the four species of otter known to occur on Borneo, Asian small-clawed otter *Aonyx cinereus* (Illiger), Eurasian otter *Lutra lutra* (Linnaeus), hairy-nosed otter *Lutra sumatrana* (Gray) and smooth-coated otter *Lutrogale perspicillata* (Geoffroy Saint-Hilaire), these species were excluded from modelling and thus do not have species accounts in this supplement. The scarcity of modern records in itself shows that otters are likely to be among the most threatened Bornean carnivores and that, urgently, they need further research and conservation attention. The low number of otter records may reflect several factors. First, few observers are able to tell the different otter species apart under field conditions. Hence, records of otters usually need to be classified as unidentified to species. Second, otters are restricted largely to wetland and riverine habitats, making them vulnerable to the effects of deforestation and degradation: lowlands and wetlands experience the highest deforestation rates on Borneo (Gaveau et al., 2014). Third, their high dependence on semi-aquatic habitat makes them vulnerable to the effects of water pollution, caused by, among others, run-off from oil palm plantations, where fertilisers and pesticides are used commonly, and from mining, where chemicals are used heavily (McCarthy & Zen, 2010). Fourth, few surveys are conducted in wetland and riverine habitat, possibly because of difficult field conditions and lesser interest on the part of decision-makers and researchers in such habitats than in rainforest. Finally, South-east Asian otters are hunted and traded for their skins (Poole, 2003; Shepherd et al., 2011), which perhaps resulted in population declines on Borneo, although there is no evidence yet of such declines.

For the remaining 20 species, individual predictive habitat suitability index (HSI) models were standardised by converting the HSI values into binary maps, separating the predictions into suitable and unsuitable at two different thresholds. The commonly applied 10% and 25% omission error thresholds were used to yield a liberal and a conservative suitability prediction, respectively, allowing for some leeway in interpreting model results. These threshold maps were then combined to map areas with the highest species richness of carnivores. Highest predicted carnivore richness, here defined as the sum of the binary threshold maps, corresponds to interior lowland, upland and lower montane forest (Figure 5.1A [10P, conservative threshold (predicted broader species' distribution)] and 1B [25P, strict threshold (predicted core species' distribution)]; threshold values are explained in more detail in Kramer-Schadt et al. (2016) and Struebig et al. (2015b)). These areas include most of Brunei; large areas of south to central Sabah; much of interior northern and central Sarawak; much of North Kalimantan; the northern parts of East Kalimantan; the northern half of Central Kalimantan; and the interior eastern portion of West Kalimantan bordering Central Kalimantan. Much of this area corresponds to the larger 'Heart of Borneo' (HoB) initiative, a government-led and NGO-supported agreement signed between Brunei, Malaysia and Indonesia to manage sustainably the remaining relatively less-encroached band of forests in the centre of the island, straddling the mountains that run from Gunung [=Mount] Kinabalu in the northeast to the Pergunungan [=mountain range of] Schwaner–Müller in the south-west. The various totally protected areas (TPAs; IUCN protected area categories I and II) scattered throughout this range account for less than 20% of the area. However, when considering all protected areas (PAs; including TPAs and, mainly in Kalimantan, Forest Reserves such as Hutan Lindung [= Protection Forest], as defined in Struebig et al., 2015a: Supplementary Material), this figure corresponds to 38% of the area (see Table 5.1). Most of the area within the HoB is currently licensed as concessions for logging (the dominant industry by area), plantation agriculture (mainly for oil palm, wood and paper-pulp) and mining (although mining currently occurs in only small areas of the HoB, exploration rights have been issued in over 40% of the region; WWF, 2015). To ensure that the HoB initiative conserves carnivores on Borneo, and many other Bornean taxa (Beck et al., 2011; Struebig et al., 2015a), it needs to be implemented on the ground and not just remain a well-intentioned vision.

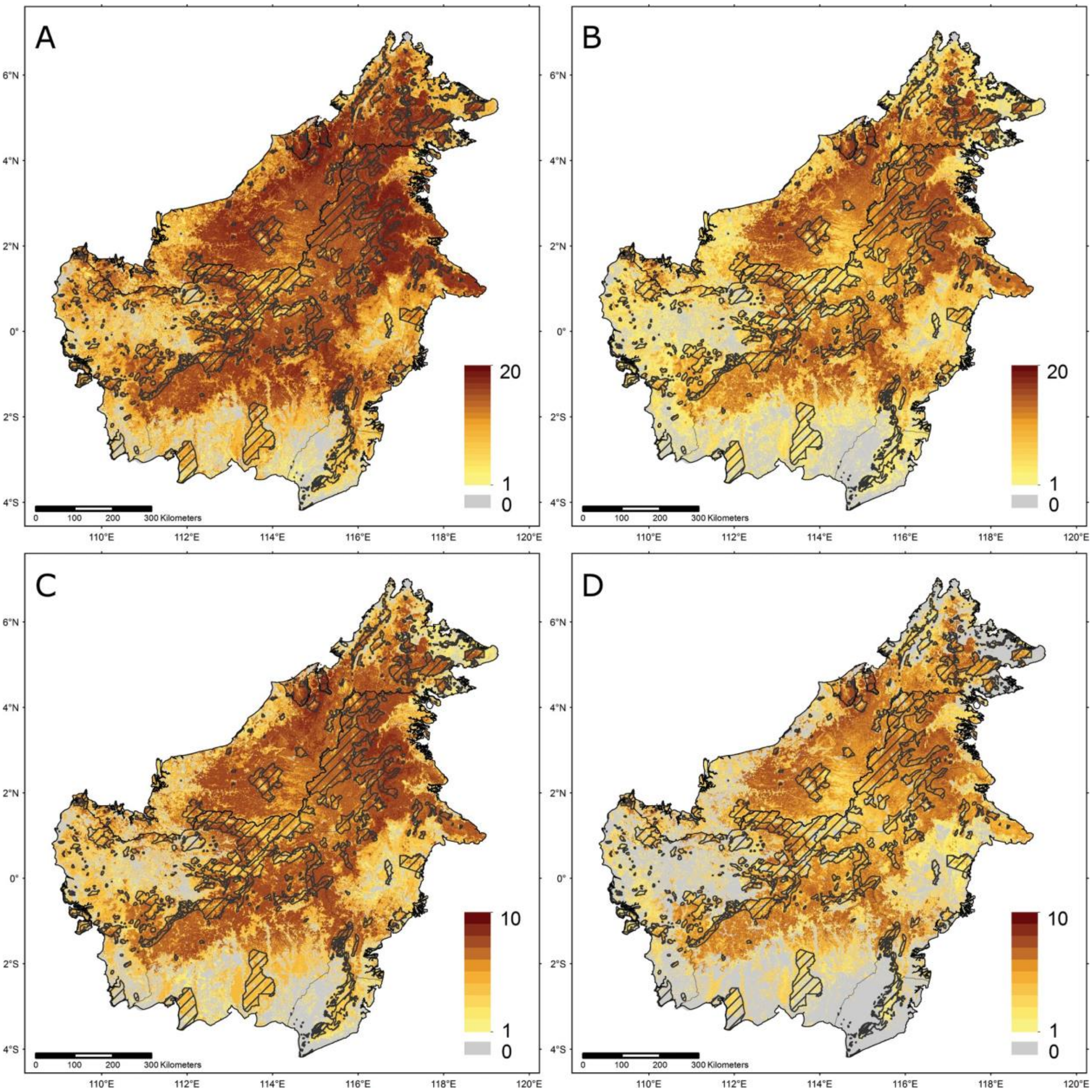


Figure 5.1: Predicted total carnivore species richness (A & B) and globally threatened and Near Threatened carnivore species (BCS priority species) richness (C & D) across Borneo. A (all 20 species) and C (the 10 BCS priority species) show predicted species richness at the 10P (conservative/predicted broader species' distribution) and B (all 20 species) and D (the 10 BCS priority species) show the predicted richness for the strict 25P threshold (predicted core species' distribution).

Table 5.1: Land area for each of the 12 proposed carnivore landscapes across Borneo, according to geopolitical units and percentage protected.

Geopolitical Unit	Proposed Carnivore Landscape	Total Area (km^2)	% Area under TPAs	% Area under PAs
Borneo	HoB (Total)	233,234	18.1	38.1
	All carnivore landscapes, including HoB (Total)	328,412	17.0	35.0
Brunei	HoB (No. 1)	4066	29.5	29.5
Sarawak	HoB (No. 1)	21,834	17	18.7
	Extended Baram Complex (No. 2)	15,900	5	5
	Central Sarawak Complex (No. 3)	10,475	1	15
	Rajang Delta–Saribas–Tanjung Datu Complex (No. 4)	2500	39	39
	All carnivore landscapes	50,709	11	15
Sabah	HoB (No. 1)	39,088	26.9	27.3
	Tabin–Kinabatangan Wetlands (No. 5)	3340	66	66
	All carnivore landscapes	42,428	30	30
South Kalimantan	Pergunungan Meratus (No. 6)	7500	3	53
Central Kalimantan	HoB (No. 1)	30,342	11.7	36.7
	Sabangau Complex (No. 7)	10,380	54	56
	Tanjung Puting NP (No. 8)	5100	60	67
	Arabela–Schwaner Landscape (No. 9)	11,400	0	7
	All carnivore landscapes	58,025	21	37
West Kalimantan	HoB (No. 1)	48,901	20.8	47.5
	Arabela–Schwaner Landscape (No. 9)	6510	0	40
	West Kalimantan Western Wetland Complex (No. 10)	5970	16	30
	All carnivore landscapes	61,381	18	45
East Kalimantan	HoB (No. 1)	37,954	0	36.9
	Wehea–Mangkalihat–Sangkulirang complex (No. 11)	12,180	0	11
	All carnivore landscapes	50,134	0	31

North Kalimantan	HoB (No. 1)	51,049	25.3	48.4
	Sebuku–Sembakung Complex (No. 12)	3120	0	1
	All carnivore landscapes	54,169	24	46

TPAs: totally protected areas; PAs: protected areas.

Information used to identify the proposed carnivore landscapes is described in the text, and descriptions on the landscapes are found in the regional text boxes 1–4. Landscapes are shown in Figure 5.4. Note that other than the Heart of Borneo (HoB) (Carnivore Conservation Landscape No. 1), all other delineated carnivore landscapes are drawn for visualisation purposes only and not defined by provincial or forest reserve borders. Therefore, the percentages under protection shown here are only estimates.

Areas with the lowest predicted carnivore richness were mainly coastal lowlands in South, Central and West Kalimantan. There are several reasons why this pattern is observed. First, deforestation rates have been highest in coastal lowlands where human settlements and plantation agriculture (e.g., oil palm and paper-pulp) have expanded rapidly (see Kramer-Schadt et al., 2016: Fig. 3B); in these human-dominated landscapes, the remaining forests are severely fragmented and only generalist species with a high tolerance to modified landscapes can survive (Fitzherbert et al., 2008). Second, most of Kalimantan, particularly South and West Kalimantan, is generally under-surveyed relative to the rest of the island and the low predicted habitat suitability is likely to reflect this. Third, south-eastern Borneo has a greater seasonal climate variation than elsewhere on the island, including a more pronounced dry season (see Kramer-Schadt et al., 2016: Fig. 3A) and it remains little known (because of low survey effort) which species occur under such climatic conditions.

A similar pattern is found for the subset of the 10 globally threatened and Near Threatened species (hereafter, 'BCS priority species'; Wilting et al., 2016a: Table 1 gives status on IUCN Red List), where interior central Borneo has the highest richness (Figures 5.1C, D). The lower carnivore richness predictions for the coastal lowlands are even more pronounced for the subset of BCS priority species than they were for all carnivore species. For BCS priority species, the low richness is predicted also for converted, degraded and fragmented areas in Sarawak and Sabah. This reflects the lower adaptability of BCS priority species to modified landscapes and fragmentation.

Altitudinal distribution of species across Borneo

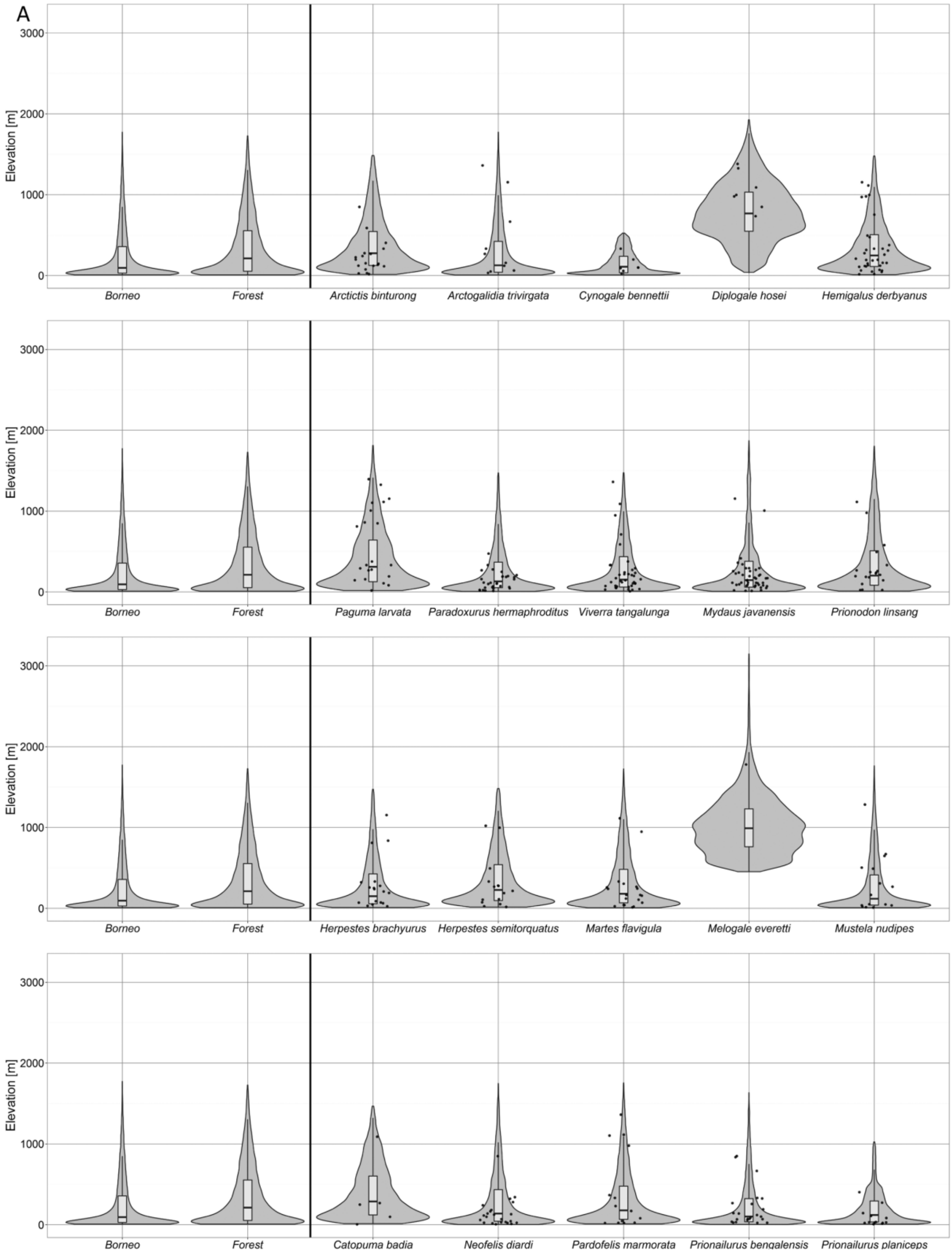
Most of the land in Borneo is in the lowlands: 81.6% of the area lies below 500 m, 13.3% lies between 500 and 1000 m (uplands), 4% lies between 1000 and 1500 m (lower montane) and only 0.6% of the land area is above 1500 m (upper montane; Table 5.2). Within the lowlands, roughly 55% is still forested with some old growth, although mostly logged, forests (lowland, swamp and mangrove forest) and this corresponds to about 72% of the total currently forested area on Borneo; in the upland, lower montane and upper montane altitudinal bands, more than 95% of land remains forested, meaning the percentage of forest that falls within each of these altitudinal classes is higher than the corresponding percentage of land area within that altitudinal class (see Table 5.2). This shows that deforestation disproportionately affects the lowlands and that its effects are smaller at higher altitudes (see also Struebig et al., 2015a). Further, the percentage of forests falling under protection in the highlands is much higher (e.g., for forests above 1500 m, 39.6% lies within TPAs, 63.1% within PAs) than that in the lowlands (only 9% within TPAs, 18.5% within PAs, for forested areas below 500 m; see Table 5.2).

The larger availability of land in the lowlands means that before large-scale anthropogenic land-cover change occurred, the majority of carnivores, except highland specialists, were concentrated in the lowlands of Borneo, simply because this is where most land area is available. This is important for the interpretation and comparison of the elevation ranges of the predicted carnivore distributions, as shown in Figures 5.2A (10P) and 5.2B (25P). Even if the proportion of the predicted area of a species in a high altitudinal band is small, the corresponding land area available in that altitudinal band is also small, suggesting that the species has no altitudinal preferences and that its distribution is rather a reflection of the available land. Besides the available land area, the predominance of observer effort at lower and middle altitudes also influences the altitudinal distributions given in Figures 5.2A & B and therefore, the actual altitudinal breadth of the different species might be divergent.

Table 5.2: Altitude-specific percentages in Borneo for total land area, total land area under protection, total forested area, total forested area protected, and forested area within corresponding altitudinal band.

Altitudinal band (in m)	% of total land area that falls within this band	% of total land area within this band under protection	% of forested area that falls within this band	% of forested area within this band under protection	% of corresponding band that is still forested
Under 500	81.6	6.8 (13.4)	71.7	9.0 (18.5)	54.9
500–1000	13.3	18.2 (42.8)	20.3	17.4 (43.5)	95.1
1000–1500	4.0	31.8 (57.7)	7.0	32.0 (57.5)	98.2
Over 1500	0.6	40.3 (64.2)	1.0	39.6 (63.1)	96.2

Altitudinal levels: lowland (under 500 m), upland (500–1000 m), lower montane (1000–1500 m) and upper montane (over 1500 m). Protection figures are for totally protected areas (TPAs) with those for all protected areas (PAs) in parentheses. TPAs and PAs are defined in the text.


A
Elevation [m]
3000
2000
1000
0
Borneo
Forest
Arctictis binturong
Arctogalidia trivirgata
Cynogale bennettii
Diplogale hosei
Hemigalus derbyanus
Paguma larvata
Paradoxurus hermaphroditus
Viverra tangalunga
Mydaus javanensis
Prionodon linsang
Herpestes brachyurus
Herpestes semitorquatus
Martes flavigula
Melogale everetti
Mustela nudipes
Catopuma badia
Neofelis diardi
Pardofelis marmorata
Prionailurus bengalensis
Prionailurus planiceps

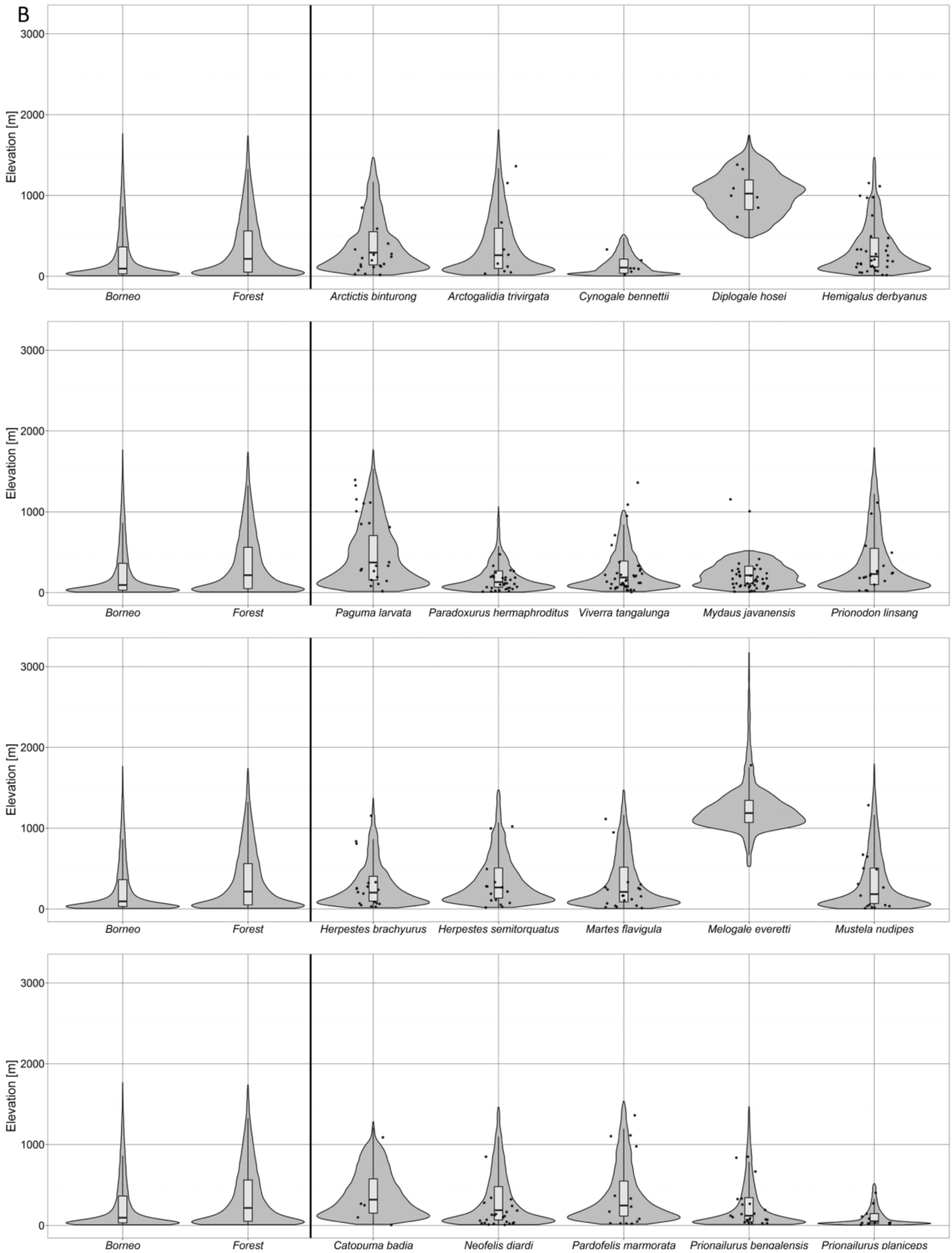


Figure 5.2: Elevation ranges of the predicted species distributions, represented as violin plots at the 10P (conservative/broader altitudinal range; A) and 25P (strict/core altitudinal range; B) thresholds. First two violin plots on each panel represent the elevation ranges of total land area and forested area on Borneo, to facilitate comparison. Violin plots represent kernel density estimates of elevation range of predicted 1 km² grid cells. The median altitudinal preference and interquartile range for each species are shown in the corresponding box plot. Actual records for each species (only category 1, i.e., where precise geographic coordinates were available) are represented as black dots; placement of black dots is arbitrary on either side of the vertical midline.

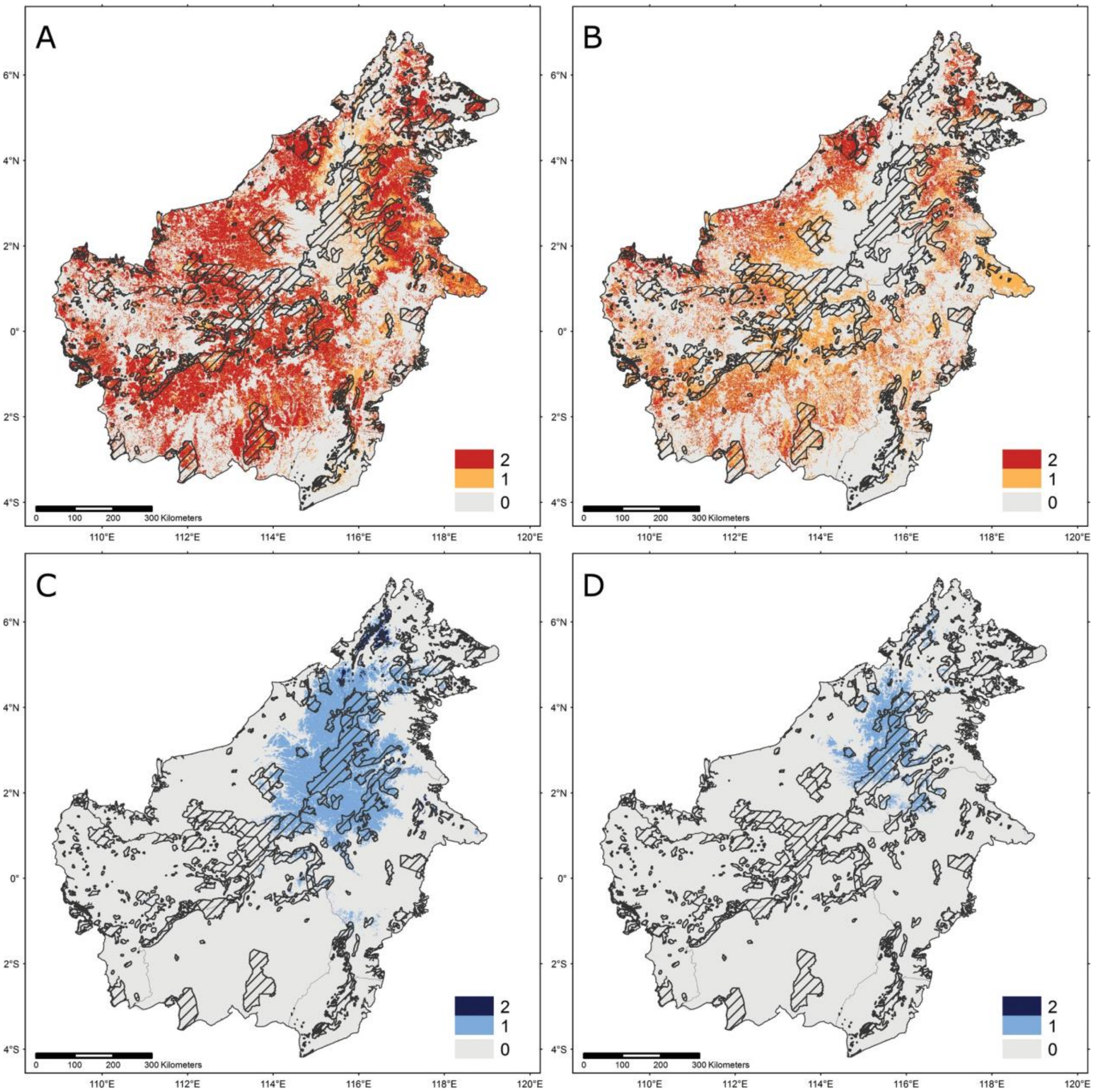


Figure 5.3: Sum of predicted occurrence of wetland/lowland (A, B) and highland (C, D) specialist carnivores across Borneo. A and B show predicted occurrence for wetland/lowland specialist carnivores (flat-headed cat *Prionailurus planiceps* and otter civet *Cynogale bennettii*) at the 10P (conservative/broader species' distribution; A) and 25P (strict/core species' distribution; B) thresholds. C and D show predicted species occurrence for highland specialist carnivores (Bornean ferret badger *Melogale everetti* and Hose's civet *Diplogale hosei*) at the 10P (conservative/broader species' distribution; C) and 25P (strict/core species' distribution; D) thresholds.

Wetlands and lowlands

Models predicted that otter civet *Cynogale bennettii* Gray, and flat-headed cat *Prionailurus planiceps* (Vigors & Horsfield), are strictly wetland (and mostly lowland) specialists favouring peat swamp or lowland forests with many lakes and water bodies. High proportions of these habitats have already been converted to intensive agriculture (e.g., oil palm and other tree plantations, rice fields and aquaculture). Both species appear unable to use such highly modified habitats (Cheyne et al., 2016; Wilting et al., 2016c). From the binary threshold maps of both species, only 8.5% or 15.1% of their distribution range falls under TPAs and PAs respectively, at the 25P threshold. Thus, as well as being among the most habitat-restricted Bornean carnivores, they are also probably the most threatened. There appears some indication that both species may survive in fragmented landscapes as long as forest persists along main rivers and tributaries and hunting pressure is low (see records for the Sungai [=River] Kinabatangan in Wilting et al., 2016c and A.J. Hearn unpublished data). Also, hairy-nosed otter falls in this category of wetland specialists (i.e., associated with peat swamp forest, freshwater swamp forest, mangroves or forested areas around lakes, rivers and their tributaries) and possibly Eurasian otter, at least in tropical Asia; Asian small-clawed otter and smooth-coated otter might similarly be associated with forested wetlands in present-day Borneo. It is unclear whether this association is purely ecological or whether hunting pressure plays a role too, because their non-forest potential range remains poorly surveyed with hunting levels not well known (see Meijaard, 2014). The clarification of ecological preferences and niches of all otter species will be possible only with further field research.

For the six wetland specialist carnivores (including otters) that occur on Borneo, the central HoB forest complex, which was predicted to have the highest carnivore species richness, might not be sufficient to safeguard their long-term survival (see Figures 5.3A & B). Instead, a network of small (under 100 km²) and medium sized (100–1000 km²), often highly fragmented protected areas and unprotected forest areas (often licensed for development), is important (see Figures 5.3A & B and text boxes 1–4 for the wetland priority areas in countries and states). Many of these priority areas are not included in the HoB initiative, are interspersed with plantations and human settlements, face high levels of threats from recurrent fires and deforestation, and thus require special conservation attention (Runting et al., 2015). This could take the form of conservation partnerships which promote forested corridors or reduced impact land-use practices within intervening agricultural mosaics, thereby enhancing connectivity between coastal protected areas and unprotected forest areas. To finance such initiatives, REDD+ (Reducing Emissions from Deforestation and Forest Degradation) or PES (Payment for Ecosystem Services) projects could be initiated because coastal lowlands provide ideal candidate areas through their often high soil-carbon content (especially in peat swamp forests) and their greater perceived threat compared with interior upland forests (Naidoo et al., 2008; Venter et al., 2009).

An additional potential threat faced by wetland specialists is the pollution of water bodies, for example from agrochemicals notably pesticides, use of poison in freshwater fisheries and chemicals in mining (Castilhos et al., 2006; Leong et al., 2007; Dudley, 2009). In this regard, there is a need for further investigation of potential pollution threats to each of these wetland specialists. Following this, awareness programmes need to be designed to sensitise local communities and plantation managers and employees on the susceptibility of these species (if and where relevant) to water pollution as well as the fragility of wetland ecosystems and their conservation importance. Particularly for wetland species, the thorough application of sustainable practices of the oil palm industry is of great importance. Sustainable management, according to the Roundtable for Sustainable Palm Oil (RSPO) guidelines (www.rspo.org), would reduce pollution of freshwater systems and help to restore riverine forests within oil palm plantations, which could function as corridors for wetland species. However, given the area and layout of oil palm, many such within-plantation riverine forest strips do not link large habitat-blocks for these wetland species. If, therefore, the strips themselves can directly support these species (this is not known), this would be an important, perhaps their chief, contribution, for these species. Although large parts of lowland forests and wetlands have already been converted to plantations, collaboration between the palm-oil industry and wetland conservation projects would be a promising start for successful, long-term conservation for Borneo's wetland carnivores.

Uplands and highlands

All three endemic Bornean carnivores, Bornean ferret badger, Hose's civet *Diplogale hosei* (Thomas), and Bornean bay cat *Catopuma badia* (Gray), along with masked palm civet *Paguma larvata* (Smith), were predicted to be associated with higher elevations. The association was much stronger for the former two (see Figures 5.3C & D; Mathai et al., 2016; Wilting et al., 2016b). Both bay cat and masked palm civet are known to occur locally in the lowlands (e.g., Belden et al., 2014). Compared with the two lowland and wetland specialists, the proportion of the predicted distribution range of Bornean ferret badger and Hose's civet which falls under protection is much higher at 46.6% (TPAs) or 54.8% (PAs), because forest conversion and habitat loss occurs mainly in the more productive and easily accessible lowlands. However, climate change could be a very serious threat for upper highland species because potential upslope range shifts are impossible (Struebig et al., 2015a). On Borneo, although altitudes go up to 4100 m, only 0.6% of the land area is above 1500 m; this implies that the loss of suitable habitat below 1500 m for these species would restrict their distributions to a tiny area, with drastic consequences on their population size. For example, potential habitat loss for Hose's civet through climate change alone is projected to be 77% by 2080 (Mathai et al., 2015b) and a similarly worrying outlook is expected for the Bornean ferret badger with its very small distribution range (see Wilting et al., 2016b).

Wide altitudinal range

The remaining species are predicted to be fairly widespread across Borneo, covering a wide altitudinal range and habitat type. Many of them are listed as Least Concern on the IUCN Red List and are tolerant, to a certain degree at least, of habitat degradation, fragmentation and altered landscapes; hence, they do not require urgent or targeted conservation attention. Although many species, for example common palm civet *Paradoxurus hermaphroditus* (Pallas), and Malay civet *Viverra tangalunga* Gray, appeared to prefer lowland forest to other habitat types (see Figures 5.2A & B), these species are so widely distributed that their wider use of lowlands is a simple effect of the greater area of lowland habitat available, and not a genuine preference per se. Six species with wide altitudinal ranges, however, might require attention based on their current IUCN Red List categorisation: sun bear, binturong *Arctictis binturong* (Raffles), banded civet *Hemigalus derbyanus* (Gray), marbled cat *Pardofelis marmorata* (Martin), and Sunda clouded leopard *Neofelis diardi* (Cuvier), all listed as Vulnerable (although banded civet and marbled cat were reclassified to Near Threatened on the latest version of the IUCN Red List, published online in November 2015), and collared mongoose, listed as Data Deficient (reclassified to Near Threatened on the IUCN Red List in November 2015). The two major threats to sun bear are habitat loss (through unsustainable logging, conversion of natural forest to other land uses, and forest fires) and commercial hunting (for its gall bladders and paws), although these threats are not evenly distributed throughout the range of the species (Fredriksson et al., 2008). Binturong is hunted in Borneo for food (Uluk et al., 2001; Murphy, 2007) and is known to be heavily traded in other parts of its global distributional range, mainly as food and on a smaller scale, as living trophies (e.g., Chutipong et al., 2014). Similarly, Sunda clouded leopard and marbled cat are hunted for their pelts and for ritual uses (Puri, 2001;

Shepherd et al., 2011; Rustam et al., 2016) and possibly in the case of Sunda clouded leopard, as fake tiger bones (D'Cruze & Macdonald, 2015). Sunda clouded leopard in particular, but also, to a lesser extent, sun bear, binturong and marbled cat, are assumed to have large spatial requirements and Sunda clouded leopard is known to occur also in very low densities (Cheyne & Macdonald, 2011; Brodie & Giordano, 2012; Wilting et al., 2012). Therefore, large, contiguous forests are needed for these species, particularly because it is not known the extent to which they can disperse through monoculture plantations and tolerate altered and fragmented habitats. The situation for banded civet and collared mongoose is less dire: banded civet has recently been confirmed to have a wider altitudinal range than thought at the time of its 2008 IUCN Red List assessment, whereas collared mongoose is predicted to be widely distributed on Borneo.

Priority carnivore landscapes across Borneo

This study combined four aspects to highlight priority carnivore landscapes across Borneo (Figure 5.4): (i) the summarised results of the predicted habitat suitability assessment for the 20 carnivores; (ii) the distribution of summed carnivore richness of all BCS priority species (globally threatened and Near Threatened species); (iii) the explicit needs of the wetland/lowland and highland specialists, and (iv) respondent opinion, i.e. the knowledge and experiences of the participants of the BCS. Areas not highlighted during this study were often excluded not because they are presently unimportant for carnivores; rather, the selection of priority carnivore landscapes prioritised larger, contiguous and/or currently unprotected areas in dire need of conservation attention in favour of small, scattered and fragmented areas or already protected areas. Highlighted priority carnivore landscapes do not necessarily warrant being gazetted, even in part, as totally protected areas. A flexible approach that integrates the needs of indigenous communities and economic development with those of the conservation and sustainable use of forests and wildlife could retain the carnivore conservation interest of these areas. Many proposed carnivore landscapes are centred around the forests of interior Borneo, earmarked by the tri-national HoB initiative (details about priority carnivore landscapes and needs at the provincial level within the HoB are given in the regional text-boxes 1–4) but additional areas are required to cater for the full range of Bornean carnivores. Some extend the existing HoB to the southwest in Central and West Kalimantan (No. 9), to the north within Sarawak (No. 2) and to the east within East and North Kalimantan (Nos. 11 & 12, respectively; see regional text boxes & Figure 5.4). However, most additional priority carnivore landscapes are located along the coastal wetlands and lowlands. In many cases, these wetland

and lowland priority carnivore landscapes are already highly fragmented and small in size; hence, to maximise the long-term survival chances of Bornean wetland specialists, greater efforts are needed not just to conserve, but also to restore, the remaining habitat (see regional text boxes for details). One priority carnivore landscape which is neither a proposed extension to the HoB nor coastal wetland habitat is the Pergunungan Meratus (No. 6). This area has been only poorly surveyed and its carnivore assemblage is unknown. This knowledge gap, and the different climatic conditions in South Kalimantan compared with the rest of Borneo, might have resulted in unique ecological adaptations of species, highlighting the importance of including the Pergunungan Meratus chain as one of the carnivore research priority landscapes.

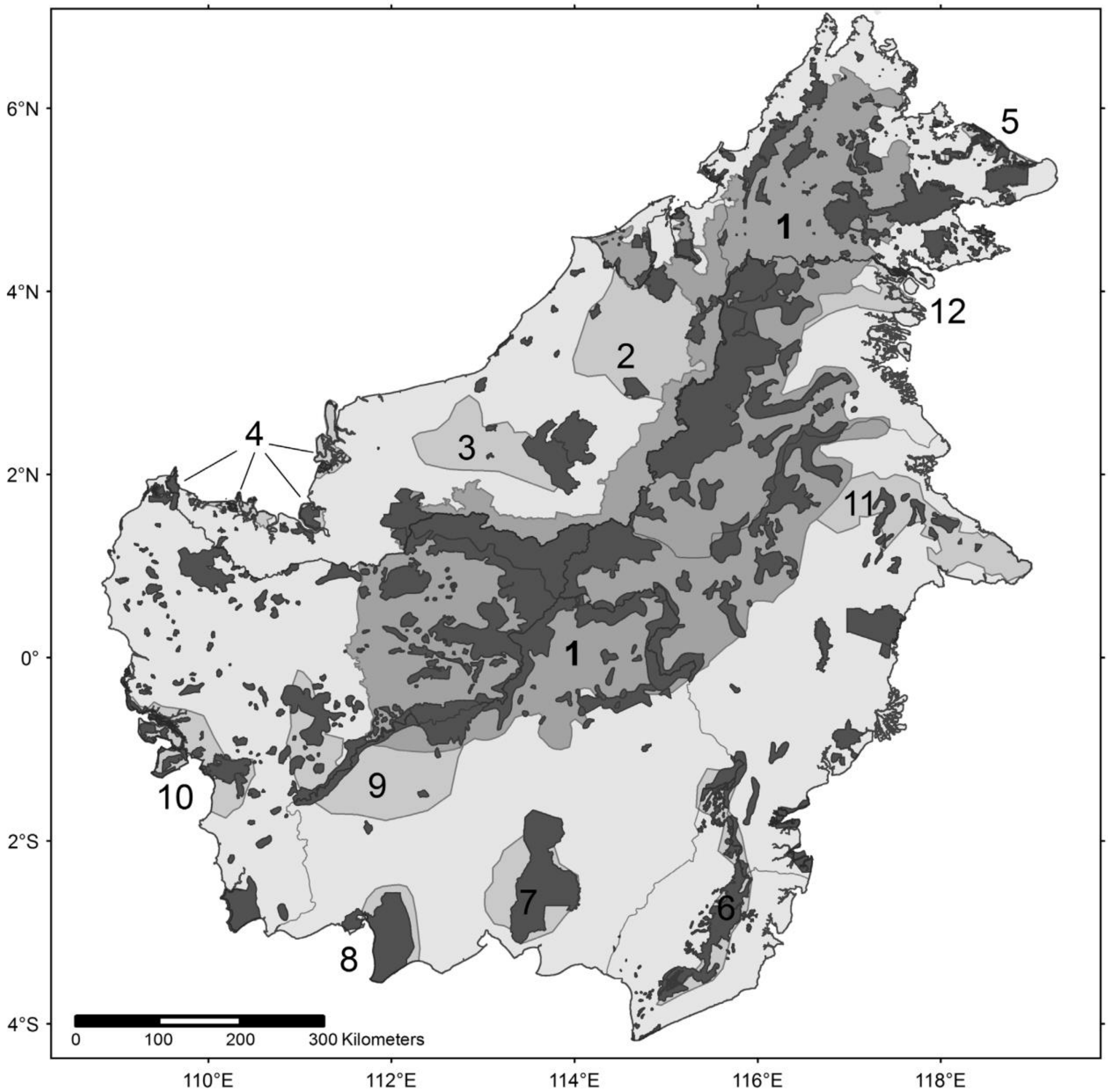


Figure 5.4: Priority carnivore landscapes across Borneo. Information used to identify these landscapes is described in the text and descriptions of the landscapes are found in the regional text boxes 1–4. Three different grey tones represent (from darkest to lightest): (i) protected areas, PAs (note that in Malaysia and Brunei, totally protected areas [TPAs] are shown, whereas mainly in Kalimantan, forest reserves [including protection forests] are also presented [http://gislab.cifor.cgiar.org/wm/borneo/; Struebig et al., 2015a]; this map was updated with latest information provided by Sabah Forestry Department on recently protected areas in Sabah, Malaysia); (ii) the Heart of Borneo (HoB; i.e., Carnivore Conservation Landscape No. 1); (iii) additional proposed Carnivore Conservation Landscapes (numbered 2 to 12). Note that other than the HoB, all delineated carnivore landscapes are drawn for visualisation purposes only and have not been defined by provincial or forest reserve borders.

Conservation research priorities across Borneo

1) Studies on adaptability to disturbed/altered habitat and fragmentation

The protected area network on Borneo will be too small and/or too fragmented to ensure on its own the long-term survival of some, perhaps many, Bornean carnivore species. Hence, in the current era of large-scale modification and conversion of forested areas, conservation research focused on altered and fragmented landscapes is required to inform the integrated approaches of conservation and development that are going to be inevitable over the larger landscapes needed to conserve the carnivore assemblage of Borneo. However, a common denominator amongst all species' respondents was the low understanding of how well carnivores cope with anthropogenic habitat modification, such as selective logging and fragmentation. Further, very few studies focused on monocultures, particularly oil palm plantations. Thus, knowledge of whether, and if so, how each carnivore species uses these areas, is limited, even for the better-known leopard cat *Prionailurus bengalensis* (Kerr) (see Rajaratnam et al., 2007; Bernard et al., 2014; Yue et al., 2015). Although some species certainly use logged forest and plantations, and have some tolerance to habitat fragmentation e.g., leopard cat and Malay civet, the ability, if any, of such disturbed and altered habitat to support populations into the long term is unclear. For example, Wearn et al. (2013) detected all five species of Bornean cat in a highly disturbed commercial forest reserve in Sabah, including substantial populations of Sunda clouded leopard, bay cat and marbled cat; they stressed, however, that it remains to be known if these five species' populations would be viable in the long term and hence, echo previous assertions of the importance of little-disturbed forest. Further, species that are seen even regularly in disturbed habitat might use such landscapes as hunting grounds but still require forested areas for basic needs such as denning sites and breeding (Mohamed et al., 2016).

Considering the above, research relevant for and linked to conservation should move beyond protected areas. Although some of these areas provide comfortable research facilities and easier access, the understanding of carnivore occurrence in such habitats is reasonably complete, with the exception of otters. To influence land-use policy and advise development planning and conservation management, conservation scientists should turn their attention to non-protected areas that are exploited and transformed by various types of production such as forestry, agriculture or mining, and that are fragmented and further degraded by roads and human settlements (Meijaard et al., 2005; Streicher & Ulibarri, 2014). In these non-protected areas, clarifying the impacts that sustainable practices have on carnivore communities (as promoted by various certification schemes such as the Forest Stewardship Council (FSC) for timber exploitation or the RSPO for palm oil production) would inform understanding about how sustainable exploitation of non-protected areas and carnivore conservation could be combined. Research efforts should focus, for example, on riparian buffers of different widths within oil palm plantations and forested islands within logged forests and monoculture plantations, such as studies currently conducted under the SAFE (Stability of Altered Forest Ecosystems) project in Sabah. Studies should investigate the effects and relative intensity of hunting, as well as how infrastructure development, such as the building of road networks, human settlements and dams (notably their power lines) affect movement, whether they become barriers to dispersal and, if so, to what extent.

2) Studies in under-surveyed habitats and areas

A) Wetlands, including peat swamp forest, freshwater swamps, mangroves and forests along lakes, rivers and their tributaries. Because of their often difficult field conditions and relatively low accessibility, wetland habitats are often overlooked by researchers or at best, surveyed only in areas surrounding existing research stations or easily accessible water bodies. More surveys are required in these habitats to understand their use by carnivores. A so-far neglected aspect that requires further study is the effect of pollution on wetland and mangrove systems, caused mainly by run-off from surrounding oil palm plantations, where fertilisers and pesticides are commonly used, and from mining, where chemicals, some toxic, are heavily used (Castilhos et al., 2006; Leong et al., 2007; Dudley, 2009). How, and to what extent this affects carnivores as apex predators, particularly wetland specialists and their prey species, needs to be investigated.

B) Highland forest above 1000 m. About 4.6% of the area of Borneo lies above 1000 m a.s.l. and much of this (roughly 97%), is forested (Table 5.2). Deforestation on Borneo currently affects the highlands less than the lowlands: the percentage of forests above 1000 m a.s.l. is almost double the available land percentage at that altitudinal class, at 8% (Table 5.2). However, very little of this area has been surveyed for carnivores. Nearly all carnivores' uppermost records on Borneo come from lower, sometimes much lower, elevations than that in other parts of their range. It remains uncertain if this is a genuine reflection of low use of these high-elevation forests by Bornean carnivores, or a misleading effect of the limited use, to date, of appropriate survey methods in high-elevation forests on Borneo. Similarly for Bornean birds, a paucity of survey effort in high-altitude habitat meant many montane species had been overlooked (e.g., Brickle et al., 2010). Such highland surveys would potentially find new populations of the two threatened highland specialists, Bornean ferret badger and Hose's civet; and if they did not, they would emphasise the importance of the presently known localities for these species.

C) Under-surveyed regions. South Kalimantan province and surroundings remain hardly surveyed. Indeed many species, including common and wide-ranging ones such as leopard cat, common palm civet and short-tailed mongoose *Herpestes brachyurus* Gray, have no, or only very few, records from South Kalimantan. Kramer-Schadt et al. (2016: Fig. 2) maps all Bornean carnivore occurrence records available to BCS. Areas lacking records can be regarded as under-surveyed. Similarly, large parts of West Kalimantan have not been surveyed. The predictions of the habitat suitability models thus need to be treated with caution for these regions: although search-effort bias has been minimised during the modelling (Kramer-Schadt et al., 2016), these areas might still be underrepresented in the distribution maps because of their climatic distinctiveness (particularly south-east Kalimantan). Unless there are records sufficiently spatially precise to have been used in the model, the predictions cannot accurately reflect the potential of occurrence within these regions, because of the models' high weighting of climatic data. More surveys in these regions would determine whether the lower predictions of suitable habitat are because of the minimal survey effort or reflect a genuine lower suitability of these areas for these species, perhaps because of different climatic conditions or because large areas have been transformed to unsuitable land-cover (Kramer-Schadt et al., 2016: Fig. 3B). Additionally, a number of other scattered localities across Borneo would benefit from further surveys (regional text boxes 1–4 detail these areas).

3) Studies on the effects of hunting

Almost nothing is known about the effects of hunting on carnivore populations on Borneo and therefore, hunting ('hunting' includes here any removal for any purpose of dead or live animals, taken by whatever method, legally or illegally) was discussed at length during regional working group discussions at the BCS. It remains unknown if any carnivores are particularly targeted by hunters, whether any are seriously affected at the population level by the widespread use of snares on Borneo, and what effect poaching by people who travel in remote forest areas (e.g., gaharu [aloewood *Aquilaria* Lam.] collectors, gold prospectors and bird-catchers) have on species populations. Snares often target species such as sambar *Rusa unicolor* (Kerr), bearded pig *Sus barbatus* Müller, chevrotains *Tragulus* Brisson, ground birds such as various pheasants (Phasianidae Horsfield), and porcupines (Hystricidae Fischer), although being indiscriminate in what they catch, carnivores might also be affected. In large parts of Indochina, carnivores are already heavily hunted (Corlett, 2007; Shepherd et al., 2011) and the extensive snaring means that a number of species are even threatened with local extinction (MacMillan & Nguyen, 2013; Coudrat et al., 2014a, b; Willcox et al., 2014). Such high levels of hunting of carnivores have so far not been reported or suspected in Borneo. Illegal hunting and trade is increasing and it is possible that intensive snaring of the sort now commonplace in Indochina might appear in Borneo as the former areas are defaunated (Shepherd et al., 2011). Species that might be targeted by hunters include civets (wild meat trade, pest), specifically palm civets (also for civet coffee [‘kopi luwak’] trade and pet trade), otters (pelts, pest), sun bears (gall bladder, paws, pest), patterned cats (pelts), bigger cats (fake tiger bone), and almost any species for the novelty pet trade. It is suspected that Hose’s civet, Malay civet, banded civet, otter civet, short-tailed mongoose, collared mongoose, Bornean ferret badger, Sunda stink-badger, Malay weasel and some of the cats might be particularly taken as by-catch in snares and other traps, because they spend a lot of their mobile time on the ground. Although some levels of hunting were reported by all regional working groups, hunting appears to be a bigger problem in Sarawak and the Kalimantan provinces than in Brunei (where hunting might have been more common in the past) and Sabah, possibly because in the former two, there are more (often non- Muslim) indigenous communities living in the forest who depend on wildlife for their protein and do not have, or have lost, religious or cultural hunting taboos (see also Bennett et al., 2000; Bennett & Gumal, 2001). Additionally, these local communities are increasingly driven by commercial incentives to hunt for specific items/species (GF pers. obs.) with access to remote areas being eased by logging and mining roads, as well as motorised, affordable, travel over rivers to remote upstream areas.

Scientists should focus on trying to understand how hunting patterns and wild meat consumption affect species populations. Off-take of different species by hunters and those who travel in remote forest areas, such as aloewood collectors, gold prospectors and bird-catchers, needs to be quantified and factors that influence this off-take (such as species’ abundance, hunting methods, intrinsic preference of hunters, legislation and accessibility) need to be determined. Reasons motivating people to hunt, whether it be financial gain, social esteem, enjoyment or subsistence use, should also be assessed. Further, gaps in the awareness of hunters about wildlife protection laws and ordinances need to be understood and rectified (Meijaard et al., 2011). Wildlife trade needs to be monitored to detect and quantify potential increases in demand for wildlife and wildlife products. Such information, specific to Borneo, is critical to design more effective conservation interventions for those Bornean carnivores threatened by hunting.

Necessary conservation interventions across Borneo

1) More targeted conservation research and better integration of research findings in conservation decisions and interventions

Research findings about the distribution and threats of species can improve the allocation of limited conservation resources. Hence, it is important that conservation decisions are based on research findings and that conservation research addresses more effectively the topics relevant to conservation decisions and management. For example, research findings can inform local stakeholders and conservation NGOs on the optimal balance for human and financial resources to reduce hunting pressure between enforcement (e.g., patrolling) activities (and if so, where, when, how and targeting whom in particular), education and awareness programmes (where, when, how and targeting whom), and the provision of alternative activities that meet the offenders' needs (again, where, when, how and targeting whom) (e.g., Davis et al., 2013). Knowledge of many Bornean carnivores' ecology and conservation needs (if any) is so limited that targeted species-specific conservation efforts are currently not applied. Here, joint efforts between local stakeholders (including government agencies) and scientists are needed to (i) generate the necessary understanding, (ii) use this knowledge for more effective conservation initiatives, and (iii) monitor the effectiveness of the initiatives.

2) Maintaining connectivity

The BCS proposed important carnivore landscapes across Borneo, some transcending provincial and international borders (Figure 5.4; regional text boxes 1–4). Connectivity between individual units (e.g. protected areas) within the identified larger carnivore landscapes (habitat blocks) is often lacking, with the protected areas surrounded by plantations and timber concessions that often may not be managed sustainably. Mostly, land-units within the larger carnivore landscapes fall under a variety of management regimes such as protection, logging (both certified and uncertified), plantation agriculture (mainly oil palm and wood), native land and state land and the individual protected areas within these landscapes are frequently too small to function effectively on their own (Table 5.1 gives percentages of each carnivore landscape protected); thus, maintaining and rebuilding connectivity across these disparate landscapes is critical. Such connectivity can be provided by the establishment of wildlife corridors particularly along riparian forests, through reforestation programmes on degraded lands, or through reduced impact land uses in agricultural mosaics.

3) Enforcement including patrolling

The effects of hunting on Bornean carnivore populations are largely unknown: further research is imperative to understand these effects better. All evidence, including experience shared by local stakeholders in the regional working groups, indicates that hunting is a growing threat throughout the Bornean range occupied by carnivores, in both protected and non-protected areas (see also Bennett et al., 2000). This includes hunting by people who travel in remote forest areas, local communities, logging company, plantation and construction workers, urban recreational hunters and foreigners. Regionally, this problem is so severe that trade in wildlife, including parts and derivatives, has been identified as the leading factor threatening species survival (Wildlife Conservation Society and Sarawak Forest Department, 1996; Corlett, 2007). Although hunting levels of carnivores on Borneo are currently presumed to be lower than in some other parts of South-east Asia, high demand from China (and often neighbours like Vietnam) for animals such as pangolins *Manis* Linnaeus, and helmeted hornbill *Rhinoplax vigil* (J.R. Forster) (for casques), shows how quickly illegal hunting and trade can become a serious threat, even in Borneo (Zhang et al., 2015).

Apart from hunting, encroachment into protected areas or other forests is common, by local communities for shifting agriculture and expansion of settlements, by immigrants and by plantation companies (e.g., Santika et al., 2015). In some parts of Borneo, illegal logging is rampant, both within and outside protected areas (by local communities and logging companies) and in logging concessions themselves (by local communities and illegal re-entry into harvesting coupes by concession holders) (Gaveau et al., 2013). Illegal mining, although less extensive, occurs also largely unchecked, particularly in Kalimantan (Obidzinski et al., in prep.). Another problem more severe in the Kalimantan provinces is the use of fire in agriculture, particularly when opening up new areas for plantations. The incidence of forest fires increases near peat swamp forests which have been drained by canal to facilitate expansion of oil palm plantations and logging. Also, impoverished local people use fire for small-scale land clearance, hunting and in disputes over land ownership (Siegert et al., 2001). Intensified use of forest (e.g., for logging) increases fire susceptibility because of the degraded forest condition. In 1997–1998, 5.2 million hectares of land were affected by fires in East Kalimantan alone (Siegert et al., 2001), and 2015 is likely to have been the worst fire year since then (Meijaard, 2015). All these activities result in degradation, alteration or loss of habitat for wildlife, including carnivores.

In summary, there was general consensus that existing wildlife protection laws and ordinances are broadly appropriate on paper but they need to be enforced (see also Crees et al., 2015; Linkie et al., 2015). This can be achieved only through increased political commitment to effective wildlife conservation and strengthened community support. Demonstrating successful conservation and proving that there are social and economic co-benefits would help generate such support.

4) Improved legislation, political will and governance

Ineffective law enforcement is a constant theme in studies of threatened species and protected areas. It is maintained by various combinations of ignorance, tradition, affluence, corruption, greed, low funding, low political will, and low cross-border cooperation (Corlett, 2007). A strong legislative and implementation framework is key to the successful management of forests and wildlife, through effective enforcement. Existing legislation is broadly sufficient in content whereas implementation is highly patchy: rectifying this is the law-related priority. The effectiveness of any legislation depends entirely on its level of implementation, especially on how well it is used as a weapon to deter wildlife criminals.

Recommendations to update existing legislation include mandating all logging concessions and plantations within the carnivore landscapes identified in this study (which are likely also to represent key areas for other animal groups) and the HoB initiative, to be certified for sustainable management. This is to ensure that logging and plantations within these key areas are carried out in a responsible and sustainable manner, as per the guidelines and criteria of certification bodies such as FSC and the RSPO. To retain sustainable carnivore populations across the proposed landscapes, it is not enough if only a few enlightened companies conduct their activities responsibly: governments of all three countries encompassing Borneo should ensure that all forestry and agriculture within these landscapes are conducted sustainably and ethically by incorporating this into legislation and then ensuring the legislation is enforced.

5) Awareness raising

Local communities have much of the necessary knowledge to manage forest resources sustainably (MacMillan &Nguyen, 2013) and can be a key component to manage and conserve Bornean carnivores outside protected areas. However, some investment will be required to build capacity and influence wildlife use in favour of conservation objectives. For example, education programmes to raise hunters' awareness of which species are considered globally threatened as well as respect for wildlife protection laws is often necessary because they may be unaware which species are protected and of protected area boundaries; also, this will ensure there is no possibility that a malefactor's potential ignorance of these matters could be used as an argument to withhold punishment. Such education programmes must be seen as just one component of a much wider programme which involves, among others, ensuring the availability of alternative sources of protein and income, such as animal husbandry programmes (Bennett & Robinson, 2000). Enforcement can also become more effective, particularly in reducing demand for wildlife products, if accompanied by education and awareness programmes, but this is far from widely implemented. Support from local communities is helpful for the long-term viability of protected areas and species populations but conservation programmes still often fail to garner their support on a large scale (Balmford & Whitten, 2003). The hiring of local community members, including former hunters as rangers, guides, or field assistants can help spread the benefits (Lynam et al., 2006; Ancrenaz et al., 2007).

Sustained awareness-raising efforts targeting businesses (e.g., restaurants and traditional medicine shops) and city-based consumers should be conducted also on the illegality of the trade and consumption of carnivores (see The Star Online, 2015). Also, social media can play an important role as an awareness and hunting monitoring tool: recent campaigns against people who uploaded images of the killing of sun bears and leopard cats led to police action and showed how effective social media can be in highlighting conservation problems and getting the legal attention they require (e.g., in Hidayat, 2015; Lajiun, 2015). More efforts should be expended into raising awareness, through social media, school programmes and education centres, to educate the public on Borneo's carnivores, particularly the Bornean endemics – Bornean ferret badger, Hose's civet and bay cat – because many of Borneo's carnivores, with the exception of Sunda clouded leopard and sun bear, are neither well known nor particularly charismatic. Finally, companies (logging, plantation and mining) play an increasing role in wildlife conservation and need to become partners in better management of carnivores. Companies often have the financial means and human resources to enforce anti-hunting laws locally and because of their political connections, they could potentially influence policy-making and implementation. Better management within these concession areas will benefit carnivores, especially those with greater adaptability to non-pristine forest conditions. With the general public taking a relatively negative view of the corporate sector, communication should clarify that good company management can make an important contribution to carnivore conservation.

6) Partnerships for conservation

Priority carnivore landscapes are likely to be managed more sustainably when there is broad participation of all stakeholders. Conservation partnerships should include, where relevant to the area and management approach, local communities, NGOs, government agencies, logging concessionaires, plantation managers, operators of tourism and other businesses within the landscape, and universities and research institutes. Further, such partnerships should include, among others, mechanisms such as certification schemes for sustainable management (e.g., FSC and RSPO, see also Struebig et al., 2015a), international-level awareness campaigns that incorporate better labelling of sustainable products, programmes providing market-based incentives for the protection of forests such as REDD+ and PES, and eco-investments as part of corporate social responsibility (CSR) programmes. These partnerships, and the mechanisms they allow, can ultimately be a powerful force for conservation, leading to market shifts that could benefit forests and wildlife, including carnivores.

Conclusion

The framework of the BCS enabled scientists, conservationists and local stakeholders from the three countries comprising Borneo to share and review knowledge on the current status of carnivores on the island. Species-specific and carnivore-community conservation issues as well as carnivore landscapes were identified and highlighted. Further to these accomplishments, the main achievement of the BCS was to expose gaps in knowledge. A lot more work remains to be done, particularly in terms of understanding species' resilience to the fast changing landscape of Borneo. So far, research has often been conducted in accessible, clearly important protected areas, and avoided landscapes that are highly disturbed, potentially unimportant and/or difficult of access. Although this approach has increased knowledge greatly about some rare species such as bay cat, it has led to disproportionately few data from highly fragmented and degraded landscapes, and from habitats difficult to survey such as peat swamps, mangroves and high-elevation forest. This uneven coverage directly hinders effective conservation: while some of the under-surveyed habitats doubtless do have little to contribute to Bornean carnivore conservation, equally the potential of some is, in general, surely under-estimated.

Further, there is a much larger presence of scientists, both international and local, working in Sabah than elsewhere in Borneo. A reason for this could be that the research permission application system in Sabah is more research- friendly. The paucity of research in other parts of Borneo, particularly some regions in Kalimantan, resulted in a much lower number of records and information. To allow knowledge-based targeted conservation interventions, conservation projects in such regions should be encouraged to start generating information of sufficient quality and quantity to allow them to devise, implement and monitor conservation actions effectively.

The priority carnivore landscapes highlighted in this study warrant due importance by decision-makers and new trans- boundary initiatives of research and conservation. Existing co-operative initiatives such as the HoB need to be pursued as do other conservation measures to ensure the three countries sharing Borneo protect its unique biodiversity and carnivore assemblage. The increasing levels of hunting and trade in wildlife and its derivatives necessitates enforcement cooperation between range countries to combat illegal cross- border hunting and trade. The BCS findings are only one step towards the long-term conservation of Borneo's carnivores. More resources are needed for conservation research, enforcement, training and designing more sustainable approaches for development. However, the joint efforts of scientists, conservationists and government authorities in the identification of key carnivore landscapes, research priorities and conservation issues for these species raises hope that more and better targeted conservation efforts can follow in the upcoming years.

TEXT BOX 1: BRUNEI DARUSSALAM

General remarks. Brunei still maintains substantial forest cover, particularly in terms of lowland forest and peat swamps, and many of these forests are connected to Sarawak. Although few records were collected from Brunei, reflecting generally low survey effort and low response from researchers working in Brunei, models predicted much of Brunei to contain suitable habitat for most carnivores, including globally threatened species and wetland species. Trans-boundary connectivity is an important consideration for Brunei in terms of creating large habitats for carnivores. Within Brunei itself, the priority conservation action should be to create and maintain connectivity between key areas to ensure larger continuous forests from the peat swamps and lowlands to the higher-elevation forests. Another priority is the protection and rehabilitation of Brunei's peat swamps. The peatlands of Brunei, covering almost 20% of the country and found mainly in western Belait district, are still closer to pristine than in other areas on Borneo, but face threats through development, peat drainage and fires.

Conservation research priorities.

A. Inventory surveys in key habitats, for example by camera-trapping.

B. Assessment of hunting levels and their effects on carnivore populations: currently, hunting might be a greater threat in Brunei than are habitat loss and degradation.

Priority conservation interventions.

A. Increase capacity of the Brunei Forest Department, by employing and training more forest rangers to carry out enforcement activities (including patrolling), especially along the boundaries of protected areas and forest reserves.

B. Maintain and enhance connectivity, both between key areas within the country and with upland forested areas in Sarawak.

C. Restore and rehabilitate degraded peatlands, particularly in the Lower Belait Valley.

Priority carnivore landscape.

1. Heart of Borneo [29.5% under both TPA and PA – see Table 5.1 for details on estimation]

i. Areas included:

a) Ulu Temburong National Park (NP),

b) Sungai [=River] Ingei Conservation Forest in Belait district ([a] and [b] connected via Gunung [=Mount] Mulu NP and Gunung Buda NP and the surrounding matrix of forest reserves, state land and native customary land in Sarawak),

c) Tasek [=Lake] Merimbun Heritage Park (at only 62 km², connected to [b] via Ladan Hills Forest Reserve (FR) in Brunei),

d) Bukit [=Hill] Teraja Protection Forest in Belait district,

e) Ulu [=headwaters] Mendaram Conservation Area (at only 78 km², it has already been proposed to be connected to [d] in Labi area of Belait district).

ii. Habitat types: wetlands* [b, c, e]; transitional heath forest (kerangas) [b]; lowland forest [a, c, d]; upland forest [a, b]; montane forest [a].

* habitat type 'wetland' can include peat swamp forest, freshwater swamp forest, mangroves or forested areas around lakes and could include any of these classes, or a combination.

iii. BCS priority species (globally threatened and Near Threatened species as per Wilting et al., 2016: Table 1) predicted to occur: binturong, Otter civet, Hose's civet, banded civet, collared mongoose, bay cat, Sunda clouded leopard, marbled cat, flat-headed cat.

iv. BCS priority species with confirmed records from BCS*: otter civet, Hose's civet, marbled cat, flat-headed cat.

*Records which satisfied the criteria for the BCS Database. Internet and press reports which could not be verified were excluded. From some regions, including Brunei, very few records were provided for the Borneo Carnivore Database. Hence, the number of species is much lower, although it is known that more species, such as the Sunda clouded leopard, occur in the HoB part of Brunei. A low number here, therefore, does not necessarily indicate a low richness of threatened carnivores; rather, it suggests insufficient survey effort and reporting.

v. Threats: illegal logging; unsustainable logging; aloewood collection and hunting (often linked); encroachment from coastal development; drainage of the largest peat dome in Brunei, the Badas peat dome in Belait district, because of industrial infrastructure such as pipelines and road maintenance, resulting in increased susceptibility to forest fires; paucity of PA rangers; lack of connectivity of PAs within the country or with protected areas in Sarawak; forests in potential natural corridors connecting protected areas are designated for development/logging.

vi. Conservation actions recommended: increased enforcement (including patrolling); increased survey effort and systematic faunal surveys; establishment and enhancement of linkage between [c] and Ladan Hills FR as well as between [d] and [e], in addition to links with forested areas in Sarawak; extension of protected area boundaries to include buffer zones to protect core areas; sustainable forest management if new areas are opened for timber exploitation; restoration and rehabilitation of degraded peatlands.

TEXT BOX 2: SARAWAK, MALAYSIA

General remarks. Much of interior northern and central Sarawak was predicted to host carnivore assemblages of high species richness. These areas cover a mosaic of protected areas, logging concessions, plantations, state land and native customary land which comprise lowland forests, highland forests and the unusual habitat of highland swamp forests (in Paya Maga in northern Sarawak). For wetland species, the areas predicted to be most important stretch along the highly fragmented coastal forests, particularly in north-western Sarawak (No. 4), and to a lesser degree, parts of central (No. 3) and northern Sarawak (No. 2).

In terms of trans-boundary conservation of wildlife, Sarawak is poised to play a crucial role: it is the only region linked to all the other regions (except Central and South Kalimantan) within Borneo, and has sizeable tracts of little-encroached forest adjacent to state or international borders. In the north, Pulong Tau NP within the Kelabit Highlands and the matrix of surrounding logging concessions and native land is connected to the largest protected area on Borneo, the Kayan Mentarang NP in North Kalimantan, forming a huge trans-boundary complex within the Heart of Borneo (HoB). Likewise, the Batang Ai–Lanjak Entimau complex in the south is predicted to be an important conservation area for many carnivores and is connected to the Betung Kerihun NP in West Kalimantan, thereby forming the Transborder Rainforest Heritage of Borneo, proposed as the first ever trans-boundary UNESCO World Heritage Site and also part of the HoB.

A general concern for Sarawak is that a great proportion of the land (35%, Sarawak Forest Department, 2015) is designated as Permanent Forest Estate, that is, mainly for logging and some as tree plantations (but Petersen et al. (2015) gave different figures). However, only one logging concession (Anap Muput Forest Management Unit) is currently certified as sustainably managed by the Malaysian Timber Certification Scheme (MTCS) and – in contrast to other provinces on Borneo – no logging concessions have been certified by the Forest Stewardship Council (FSC). In priority carnivore landscapes where logging is carried out, broader application of sustainable forest management would benefit carnivore conservation. In addition to unsustainable logging practices, conversion of natural forest to tree plantations (acacia or eucalyptus) or oil palm plantations is a pre-eminent threat. The total area licensed for the establishment of planted forests (i.e. tree plantations) in Sarawak covers about 7% of the existing area of permanent forest estates (Sarawak Forest Department, 2015), situated mainly in the Planted Forest Zone in central Sarawak; within a Planted Forest concession, up to 20% can be further converted into one cycle of oil palm planting before reverting to tree plantation.

The landscape of Sarawak is set to be altered further by a series of large hydroelectric dams – some of them within or close to the HoB. The Baram dam alone, in northern Sarawak, is expected to inundate more than 400 km² of forest and to displace more than 20,000 indigenous people; plans for its construction have been shelved pending further studies and consultations with relevant stakeholders (see Tawie, 2015). Although the consequences for carnivore conservation prospects are difficult to predict, it is likely that such dams will intensify shifting agriculture and indiscriminate hunting (particularly during the construction phase with the influx of external labour) in a shrinking habitat. Often, such massive development programmes act as a catalyst for further development and thus will increase fragmentation and degradation in Sarawak. The mere process of construction, particularly of powerline routes, can enhance access hugely to formerly remote areas, and the reservoirs improve boat access to large areas formerly accessible only on foot. This increases greatly the range of forest products that are economically viable for commercial extraction. The consequences of such dams, and the associated road networks, on the movement and dispersal patterns of carnivores are unexplored. It is therefore unclear whether they will hinder dispersal and gene flow of wildlife populations (see also Shirley & Kammen, 2015).

Many indigenous communities live in forested areas in Sarawak, whether in protected areas or forest reserves. These communities depend on wildlife for their protein and exercise native customary rights over the land. Any conservation initiative in priority areas in Sarawak needs to work with local communities to understand their use of forest resources and wildlife within and close to protected areas. Conservation initiatives should not seek to bar indigenous communities from hunting but rather, improve their sense of custodianship of the lands and the wildlife within.

Conservation research priorities.

A. Basic inventory surveys in the following areas: along the Sarawak–Sabah border such as Paya Maga, the northeastern highlands of Lawas including Kanaya FR, areas surrounding Long Lopeng, Long Semado and Long Merarap and the forests around the headwaters of the Sungai Tengoa and the Sungai Berayong; Bungo Range Nature Reserve along the southern Sarawak–West Kalimantan border; central Sarawak including the proposed Baleh NP and Hose–Laga

NP, and surrounding logging concessions around the headwaters of the Sungai Baleh and Sungai Balui in the district of Kapit and Belaga, as well as the matrix of remnant peat swamp forest, logging concessions, plantations and native lands around the coastal districts of Mukah and Dalat, and further inland in Selangau, Julau, Kanowit and Song, especially near the Sarawak–Kalimantan border within the HoB.

B. Research in degraded and modified landscapes, particularly tree plantations (for example in the Central Sarawak Complex), to understand carnivore use of such altered and fragmented habitat.

C. Studies on the effects and extent of hunting, bush meat consumption and trade in wildlife and its derivatives.

D. Studies on the effects of dams and associated road networks and how they could potentially hinder movement and dispersal of carnivores.

Priority conservation interventions.

A. Conduct education, sensitisation and awareness programmes targeting local communities, timber camp workers and plantation workers on laws and ordinances pertinent to the protection of wildlife as well as on sustainability practices and the importance of biodiversity conservation.

B. Impress upon government authorities the need for strong, consistent, long-term commitment and political will to enforce wildlife protection laws and ordinances.

C. Recruit and train more rangers to conduct enforcement (including patrolling) exercises in areas that are prone to hunting and encroachment such as along the peripheries of protected areas, logging concessions and plantations and in areas adjacent to human settlements where access has become easier e.g. in Tanjung Datu NP, Similajau NP, Maludam NP and Samunsam Wildlife Sanctuary.

D. Increase dialogue between local government, conservationists and indigenous communities on issues pertaining to the construction of mega-dams. Depending on the scale of the expected biodiversity losses, other areas with good forests and rich biodiversity should be designated for conservation to compensate the expected biodiversity loss caused by the dams.

E. Prepare area-specific, holistic management plans for all priority carnivore areas (listed below) aiming to maintain, and where appropriate, recreate forest connectivity and sustainable use; encourage forest concession areas and plantations to incorporate conservation of key habitats and wildlife within their Forest Management Plan /Planted Forest Management Plans (the protected area network alone is likely to be too small to safeguard Sarawak’s carnivore biodiversity).

Priority carnivore landscapes.

Common threats within the priority carnivore landscapes: illegal logging; unsustainable logging; hunting; infrastructure development (e.g. expansion of large scale plantations, dams); land-use change (including conversion); encroachment from shifting agriculture and expanding plantations.

Common conservation actions recommended within the priority carnivore landscapes: enforcement (including patrolling); awareness and sensitisation programmes for local communities, government, logging staff and plantation company staff on sustainability practices, biodiversity conservation and the importance of wetland conservation; working with local communities to understand their needs and use of land and wildlife close to and within protected areas; engagement with local government, communities, logging companies, plantation owners and other stakeholders on proper land-use planning and management to halt conversion and increase connectivity; ensuring only sustainable practices conducted within the matrix of timber concessions and plantations.

1. Heart of Borneo [17% under TPA; 18.7% under PA – see Table 5.1 for details on estimation]

i. Areas included:

a) The Kelabit Highlands, Tama Abu Range, Pulong Tau NP, and surrounding matrix of logging concessions, tree plantations, state land and native customary land that includes Paya Maga, Layun Forest Management Unit (FMU), Kubaan–Puak FMU, Sela'an Linau FMU, Apad Lunan FR, Linau Danum FR, and others,

b) Gunung Mulu–Gunung Buda NPs and surrounding logging concessions, native lands and state lands,

c) the proposed Baleh NP and surrounding logging concessions, tree plantations, native lands and state land along the headwaters of the Sungai Baleh and Sungai Balui,

d) Batang Ai NP, Lanjak Entimau Wildlife Sanctuary and surrounding logging concessions, tree plantations, state land and native lands.

ii. Habitat types: mainly highlands with swampy highlands in Paya Maga; some wetlands (see Brunei text box for definition) and lowland forest also in [c, d].

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, Hose's civet, banded civet, collared mongoose, Bornean ferret badger.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, Hose's civet, banded civet, collared mongoose.

v. Area-specific threats: planned construction of a series of hydroelectric dams in [a, c] and unsustainable logging and expansion of large-scale plantations (mainly, but not restricted to [a, c]), resulting in fragmentation and low connectivity between individual units.

vi. Specific conservation actions recommended: gazette the Baleh NP; establish corridors to increase connectivity between the (mainly) highland forests in [a, b] and also to connect to the lowlands and wetlands [mainly in c, d] and to Betung Kerihun NP in West Kalimantan through riparian forests within the surrounding logging concessions and plantations; increase survey effort in areas along the Sabah border; investigate the effects of logging on species presence and tolerance of different logging levels.

2. Extended Baram Complex (proposed extension to the Heart of Borneo) [5% under both TPA and PA – see Table 5.1 for details on estimation]

i. Areas included:

a) Usun Apau NP,

b) Loagan Bunut NP,

c) Dulit FR and surrounding matrix of logging concessions, plantations, state land and native customary land.

ii. Habitat types: mainly upland and some lowland forest; wetlands (see Brunei text box for definition) in [b].

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, Hose's civet, banded civet, collared mongoose.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, Hose's civet, banded civet, collared mongoose.

v. Area-specific threats: planned construction of a mega hydroelectric dam on the Sungai Baram (temporarily shelved; Tawie, 2015) and unsustainable logging and expanding oil palm plantations resulting in fragmentation and low connectivity between individual units, especially with the isolated [b]; pollution of wetlands in [b] from upstream oil palm plantations.

vi. Specific conservation actions recommended: establish corridors to increase connectivity with the highland forests in the HoB and to connect to wetlands in [b] through riparian forests within the surrounding logging concessions and plantations; explore the possibility of habitat restoration and reforestation programmes on degraded lands, particularly surrounding the Loagan Bunut wetlands.

3. Central Sarawak Complex [8% under TPA; 15% under PA – see Table 5.1 for details on estimation]

i. Areas included:

a) Anap Muput FMU,

b) Pelagus NP,

c) the proposed Bukit Sarang NP,

d) Bukit Kana NP,

e) northern parts of the proposed Hose Mountains–Batu Laga complex,

f) matrix of logging concessions, plantations (both wood and oil palm), native land and state land around the areas of Selangau, Tatau, Pelagus, Kapit and Song.

ii. Habitat types: wetlands (see Brunei text box for definition), lowland and upland forest.

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

v. Area-specific threats: planned construction of a series of hydroelectric dams on the tributaries of the Sungai Rajang and expansion of large scale plantations, resulting in fragmentation and low connectivity between individual units; mining (both legal and illegal).

vi. Specific conservation actions recommended: establish and enhance connectivity through riparian forests in surrounding plantations and forest reserves within the HoB;

gazette the Bukit Sarang NP and the Hose Mountains–Batu Laga complex; explore the possibility of habitat restoration and reforestation on degraded land, particularly in areas connecting proposed and existing national parks such as along the Sungai Rajang from Kapit to Belaga; increase survey effort and investigate the effects on carnivores of wood plantations and the tolerance of carnivores to fragmentation.

4. Rajang Delta–Saribas–Tanjung Datu Complex [39% under both TPA and PA – see Table 5.1 for details on estimation]

i. Areas included:

a) the proposed Batang Lassa NP,

b) Bruit–Patok NP,

c) Rajang Mangroves NP and surrounding matrix of forest reserves, oil palm plantations, native customary land and state land,

d) Tanjung Datu NP,

e) Gunung Pueh NP,

f) Samunsam Wildlife Sanctuary,

g) Kubah NP,

h) Kuching Wetlands NP and Ramsar site,

i) Bako NP,

j) Sedilu NP,

k) Ulu Sebuyau NP,

l) Gunung Lesung NP,

m) Maludam NP and the intervening matrix of native customary land, state land, logging concessions and oil palm plantations

ii. Habitat types: wetlands (see Brunei text box for definition) and lowland forest; some upland forest in [e].

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** flat-headed cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

iv. Area-specific threats: land-use change (including conversion to aquaculture); fragmentation and very low connectivity between individual units resulting from human development (urban and rural), plantations and forest concessions; construction of flood mitigation channel in [h]; potential of future sedimentation and influx of freshwater into the mangroves of [h]; few carnivore-based surveys carried out; peat dome collapse because of the establishment of drainage canals from surrounding oil palm plantations and illegal logging.

v. Specific conservation actions recommended: establish and enhance connectivity through riparian forests in surrounding plantations and forest reserves and explore the possibility of habitat restoration and reforestation on degraded land; conduct systematic carnivore-based and faunal surveys of other taxa.

TEXT BOX 3: SABAH, MALAYSIA

General remarks. Sabah is the most intensively surveyed of all geopolitical regions on Borneo, resulting in the highest number of occurrence records for almost all carnivores. Despite the large number of local and international researchers working in the state, some areas, particularly those north of the East–West Sabah highway, have not been surveyed. In terms of forestry and wildlife conservation, most areas within Sabah are among the better-managed areas of Borneo. Nevertheless, Sabah experienced the highest deforestation rates on Borneo within the last 40 years and has lost almost 40% of its initial forest cover, mainly because of the conversion of natural forest to oil palm plantations (Gaveau et al., 2014). In addition to these converted areas, a high proportion of the state has been selectively logged (Gaveau et al., 2014). A number of intensive studies in Sabah, however, revealed that in many of these selectively logged forests, a high diversity of Bornean carnivores, including highly threatened species, persists. Hence, large areas of south to central Sabah, which were previously selectively logged, were predicted to support high carnivore species richness.

As in the other parts of Borneo, maintaining connectivity between key carnivore landscapes is of great importance for the conservation of carnivores in Sabah. Three recent initiatives and proposals highlight this need. First, parts of some commercial forest reserves were reclassified as totally protected areas in central Sabah, connecting the already existing totally protected areas of Danum Valley, Maliau Basin and Imbak Canyon; second, the recent proposal to link Kinabalu Park and Crocker Range Park via the Kinabalu Ecological Link (Kinabalu Eco-Linc); and third, the proposed linking of Tabin Wildlife Reserve in the Dent Peninsula to the Lower Kinabatangan–Segama Wetlands Ramsar site via the Kulamba Wildlife Reserve. The Kinabalu Eco-Linc is of particular significance for highland specialists, especially the Bornean ferret badger, which has been recorded only from this massif, whereas the Tabin–Kulamba–Kinabatangan Corridor will create a large contiguous complex of protected areas of particular value to highly threatened wetland carnivores. Ideally, these initiatives should not be tempered with the degazettement of existing protected areas for oil palm and tree plantations because it risks undermining the perceived permanence of other protected areas. This process, however, has begun already in some areas e.g. south-east of the Maliau Basin.

In Sabah, fewer indigenous peoples live in the forests and depend on wildlife and forest products than in other parts of Borneo. Subsequently, although subsistence hunting is still a threat in Sabah, hunting levels are generally lower than in other parts of Borneo. Sport hunting and poaching for the illegal trade in wildlife and its derivatives is, however, on the increase in Sabah (see e.g. Daily Express, 2015a, b; The Star Online 2015). Hence, enforcement (including patrolling) coupled with monitoring programmes are much needed in Sabah.

Conservation research priorities.

A. Intensified research in logging concessions, preferably those applying a range of logging strategies, as well as in non-forest landscapes such as monoculture plantations, to improve understanding of use and tolerance level of carnivores to modified, degraded and fragmented landscapes. Such research should be incorporated into the management plans of forest concessions and plantations to ensure long-term monitoring and thereby increase sustainability.

B. In-depth ecological studies on highland species with a focus on the locally endemic Bornean ferret badger in the Crocker Range Park, Kinabalu Park and the Eco-Linc project.

C. Inventory surveys along the Sarawak and North Kalimantan borders, in areas north of the East–West Sabah highway, and in the coastal wetlands, the latter to identify currently unknown populations of the highly threatened wetland carnivores. (The central Sabah forest complex, Tabin Wildlife Reserve and Kinabatangan Wildlife Sanctuary are already well surveyed.)

D. Research to quantify illegal wildlife trade within Sabah. Despite several confiscations of illegally collected or traded wildlife in the last few years, the degree of illegal hunting and trade is unknown. It is thus uncertain how imminent the threat is for wildlife populations in Sabah.

E. A centralised database of species records within the Sabah Biodiversity Centre (SBC; through which all research projects seek approval) to which all scientists and other interested parties could contribute their data. Such a database would be an extremely valuable resource for conservation planning and help to direct research in the state.

Priority conservation interventions.

A. Enforce laws (including through patrolling) in areas prone to hunting and encroachment such as along the peripheries of parks, and in areas adjacent to human settlements and plantations where access has become easier.

B. Build capacity and train local authorities in standardised enforcement tools to increase the efficiency of enforcement (including patrolling).

C. Raise conservation awareness of local communities, timber camp workers and forest managers, plantation workers and managers, and local government, on sustainability practices and wildlife protection laws and ordinances.

D. Create wildlife corridors connecting adjacent protected areas and existing forest blocks under logging operations and/or plantations.

Priority carnivore landscapes.

Common threats within the priority carnivore landscapes: illegal logging; aloewood collection and hunting (often linked); habitat degradation through unsustainable logging and plantation practices; pollution (e.g. pesticide run-off) from oil palm plantations and palm oil mills.

Common conservation actions recommended at all priority conservation areas: education and awareness programmes and capacity building for plantation managers and staff, local communities and local government in sustainability practices, biodiversity conservation and the importance of wetland conservation; working with local communities to understand their needs and use of land and wildlife close to and within park boundaries.

1. Heart of Borneo [26.9% under TPA; 27.3% under PA – see Table 5.1 for details on estimation]

i. Areas included:

a) Kinabalu Park,

b) Trus Madi FR,

c) Crocker Range Park,

d) Sipitang–Ulu Padas FR,

e) Maligan Virgin Jungle Reserve,

f) Gunung Lumaku Protection Forest Reserve,

g) Danum Valley Conservation Area,

h) surrounding plantations and forest reserves, some of which participate in certification schemes such as Forest Stewardship Council FSC (e.g. Deramakot, Tangkulap, Ulu Segama and Malua FRs) and some which do not (e.g. Segaliud Lokan FR),

i) Imbak Canyon Conservation Area,

j) Maliau Basin Conservation Area.

ii. Habitat types: lowland forest; wetlands (see Brunei text box for definition) [in g, h]; highlands in [a, b, c, d, e, f, i, j].

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, Hose's civet, banded civet, collared mongoose, Bornean ferret badger.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, Hose's civet, banded civet, collared mongoose, Bornean ferret badger.

v. Area-specific threats: habitat degradation through unsustainable logging resulting in inadequate connectivity between individual units; in some areas, hunting and collection of forest products by local communities and plantation workers.

vi. Specific conservation actions recommended: enforcement (including patrolling); development of Forest Management Plans for forest concessions including High Conservation Value Forest identification and management planning; systematic surveys particularly in [b]; maintenance and enhancement of connectivity between individual units and among trans-boundary units, e.g. between [d & e] with Paya Maga and Kanaya FR in Sarawak.

5. Tabin–Kinabatangan Wetlands [66% under both TPA and PA – see Table 5.1 for details on estimation]

i. Areas included:

a) Tabin Wildlife Reserve,

b) Kulamba Wildlife Reserve,

c) Kinabatangan Wildlife Sanctuary,

d) Kuala Maruap FR.

ii. Habitat types: mainly wetlands and lowland forest.

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

v. Area-specific threats: fragmentation and little connectivity between individual units; forest fires; encroachment by local communities and oil palm plantations resulting in further habitat loss; lack of capacity for effective law enforcement.

vi. Specific conservation actions recommended: establish and enhance connectivity through riparian forests (particularly along the Sungai Kinabatangan and Sungai Segama) [This connectivity can be realised only in close collaboration with the oil palm industry because wildlife corridors are needed through the restoration of riparian forests within existing plantations – there is potential to connect this priority area along the Sungai Kinabatangan to the HoB]; capacity building and training of rangers and honorary wildlife wardens to conduct enforcement (including patrolling work).

TEXT BOX 4: KALIMANTAN, INDONESIA

General remarks. There are now five provinces in Kalimantan (the fifth, North Kalimantan, formed in October 2012, was previously part of East Kalimantan), the Indonesian part of Borneo. It covers approximately two-thirds of the island. A large proportion of Kalimantan forests remains either unprotected or is managed inadequately with a high risk of degradation, mainly from economic development pressures (e.g. Gaveau et al., 2014; Runting et al., 2015). Within the last four decades, Kalimantan experienced the second-highest deforestation rate on Borneo, losing over 30% of its initial forest cover, with many areas converted into oil palm plantations (Gaveau et al., 2014). New development projects such as the proposed Trans Kalimantan highway, which would connect the coast of North Kalimantan to the interior highlands through Kayan Mentarang NP to the coast of Sarawak and eventually extend to West Kalimantan, are likely to act as a catalyst for further forest losses. Such development projects are likely also to increase landscape fragmentation and improve access to previously isolated areas, thereby escalating levels of hunting and encroachment.

Apart from forest clearance, degradation of forests is a major threat in Kalimantan. Almost 25% of forests were selectively logged within the last 40 years (Gaveau et al., 2014). In many areas, this logging was conducted unsustainably and/or illegally (Smith et al., 2003). Other serious threats include hunting for bush meat and the illegal wildlife trade, and the lack of capacity and political will to enforce wildlife conservation laws. Furthermore, in many areas, local communities expand their land holdings rapidly, leading to further encroachment for agriculture. In some parts of Kalimantan, mining and pollution associated with it is another threat to wildlife populations.

A conservation concern more severe in Kalimantan than in northern Borneo is forest fires. These are usually started by small-scale farmers and large plantations to open up land for agriculture. The situation is exacerbated by the drainage of peat swamp forests because of the construction of canals to facilitate the expansion of oil palm plantations and logging – the dried up peat swamps are highly susceptible to fires. Areas prone to forest fires include the southern coasts of Central Kalimantan, scattered localities in the south-east and east coast of East Kalimantan (in 1997–1998, 5.2 million hectares of land were affected by fires in East Kalimantan [today's East Kalimantan + North Kalimantan] alone; Siegert et al., 2001), and the south and central west coast of West Kalimantan, corresponding to the distribution of peat swamp forests; wetland specialist carnivores will suffer most from fires in these habitats. At the time of going to press, researchers' data on the extent of the extensive 2015 burning event were yet to be released.

Despite these threats and habitat losses, many parts of Kalimantan were predicted to harbour high carnivore species richness, including much of North Kalimantan, northern East Kalimantan, the Schwaner–Müller range and surrounding areas in the Heart of Borneo (HoB); for wetland species, the most important areas are scattered along the coasts of North, Central and West Kalimantan as well as along the major rivers, the Kapuas, Mahakam and Barito. The habitat suitability predictions were generally lower than in north Bornean states. This was especially true for the provinces of West and South Kalimantan. Kalimantan is overall less well surveyed than is the rest of Borneo. This lower survey effort and correspondingly fewer occurrence records certainly resulted also in lower predictions, despite efforts to correct for uneven sampling across Borneo (Kramer-Schadt et al., 2016). The lack of records biased predictions most strongly in regions with bioclimatic conditions different from the rest of Borneo (e. g. south-eastern Kalimantan; Kramer-Schadt et al., 2016: Fig. 3A). More surveys could evaluate whether the low predicted habitat suitability reflects methodological issues, climatic distinctiveness or because large areas have been transformed into unsuitable land cover such as oil palm plantations (see Kramer-Schadt et al., 2016: Fig. 3A).

Conservation research priorities.

A. Inventory surveys where current carnivore occurrence data are sparse. Of particular importance are surveys in South Kalimantan, especially the Pergunungan [=mountain range of] Meratus and its surrounding areas; in Central Kalimantan, the Arabela–Schwaner landscape; in West Kalimantan, Gunung Niut–Penrisen Nature Reserve and surrounding areas, Bukit Rongga Protection Forest and surrounding areas, and much of Betung Kerihun NP; in East Kalimantan, the proposed Long Bangun Nature Reserve and surrounding matrix of logging concessions, native lands and plantations as well as the Mangkalihat–Sangkulirang peninsula; and in North Kalimantan, regions along the Sabah border such as Buatan–Loetak–Agisan areas, the north-eastern coast including the proposed Sebuku–Sembakung NPs and surrounding areas and parts of the proposed Sungai Kayan NP, including the surrounding matrix of forest reserves, native lands and plantations.

B. Research on the adaptability of species to habitat degradation and fragmentation. A better understanding of the use of these modified landscapes is essential to improve the sustainability of management and to incorporate areas under cultivation and development into conservation measures.

C. Studies on the effects and extent of hunting and trade in wildlife and derivatives.

D. Studies on the effects of roads and human settlements in terms of their potential hindrance of movement and dispersal of carnivores.

E. Studies on the impact of fire on the survival and ecology of carnivores and their prey species.

Priority conservation interventions.

A. Establish and maintain connectivity between fragmented forests to create larger areas within and between provinces (as in Brunei, Sarawak and Sabah, the main priority). Examples are: an inter-provincial conservation area between the Bukit Baka–Bukit Raya NP, adjacent timber concession areas (including the FSC-certified SBK Seruyan–Katingan FR, all in the southwestern portion of Heart of Borneo (No. 1)) and timber concessions within the Arabela–Schwaner Landscape (No. 9) in Central Kalimantan, including the Bukit Perai–Bukit Rongga FRs in West Kalimantan (also No. 9). This area is important not just to ensure the long-term conservation of carnivores, but also of Bornean Orang-utan *Pongo pygmaeus* and other species (e.g. Struebig et al., 2015b).

B. Create awareness among local stakeholders and authorities on the importance of wildlife and forest conservation and on a more sustainable mode of development. Strong governmental support and political will is required to address the major conservation concerns in Kalimantan.

C. Build capacity and train local authorities in standardised enforcement tools such as SMART (Spatial Monitoring and Reporting Tool), to increase the efficiency of law enforcement (including patrolling) to curb illegal hunting, illegal logging, encroachment, the setting of fires and the draining of peat swamp forests. Also, local authorities need to increase their capacities for law enforcement; at present, teams are notoriously understaffed.

D. Build conservation awareness and capacity among local communities, timber camp workers and forest managers, plantation workers and managers, and local government, on sustainability practices, particularly in High Conservation Value Forest planning and management and wildlife protection laws and ordinances.

E. Work with local communities to understand their needs and use of land and wildlife, and to develop management plans.

Priority carnivore landscapes.

Common threats within priority carnivore landscapes: illegal logging; unsustainable logging; hunting; fragmentation; encroachment from shifting agriculture; low capacity among forest managers and local authorities to enforce wildlife laws.

Common conservation actions recommended within the priority carnivore landscapes: enforcement (including patrolling); awareness, education and sensitisation programmes for local communities, local government, and other stakeholders (e.g. logging, plantation and mining company staff) on sustainability practices, High Conservation Value Forest identification and management planning, wildlife laws and ordinances, biodiversity conservation and on the importance of wetland conservation; working with local communities to understand their needs and use of land and wildlife close to and within protected areas; engagement with local government, local communities and other stakeholders (e.g. logging, plantation and mining company staff) on proper land-use planning and management to halt conversion and increase connectivity; insist that only sustainable practices are conducted within the matrix of timber concessions and/or plantations; systematic surveys and long-term monitoring.

Priority carnivore landscapes (South Kalimantan, Indonesia)

6. Pergunungan Meratus [4% under TPA; 54% under PA – see Table 5.1 for details on estimation]

> **i. Areas included:** Meratus Hulu Barabai Nature Reserve and forests along the mountain chain which include the surrounding tree plantations and mining concessions.
>
> **ii. Habitat types:** mainly highlands.
>
> **iii. BCS priority species** (see Brunei text box for definition) **predicted to occur:** marbled cat, binturong, banded civet, collared mongoose and to a lesser extent, flat-headed cat, bay cat, Sunda clouded leopard and otter civet.
>
> **iv. BCS priority species with confirmed records from BCS** (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** none.
>
> **v. Area-specific threats:** isolated; (apparently) no management plan in place; mining; forest fires; lack of awareness amongst forest managers, local government and local communities on the importance of the area being actively protected.
>
> **vi. Specific conservation actions recommended:** most important are inventory wildlife surveys; Forest Management Plans for timber concessions.

Priority carnivore landscapes (Central Kalimantan, Indonesia)

1. Heart of Borneo [11.7% under TPA; 36.7% under PA – see Table 5.1 for details on estimation]

i. Areas included:

a) Bukit Baka–Bukit Raya NP and surrounding logging concessions, some of which participate in certification schemes such as Forest Stewardship Council FSC [e.g. Katingan–Seruyan Block],

b) Bukit Raya Nature Reserve (proposed extension of [a]),

c) the proposed Bukit Batikap I, II and III Nature Reserve,

d) Bukit Sepat Huang Nature Reserve (at the border of Central and East Kalimantan).

ii. Habitat types: mainly lowland and upland forest.

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** flat-headed cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

v. Area-specific threats: illegal mining and associated pollution; proposed nature reserves not yet confirmed; uncertified logging concessions do not follow sustainable principles.

vi. Specific conservation actions recommended: gazette the Bukit Batikap I, II, III Nature Reserve; regular contact and sensitisation programmes for forest managers yet to engage in sustainability practices and the forest certification process; establish and enhance corridor connectivity between logging concessions and protected areas within the complex, and between the protected areas in different provinces, that make up this forest complex and the larger HoB; pursue proposals for Ecosystem Restoration Concession (ERC) licence for REDD and ecotourism projects that involve local communities with appropriate sustainable management plans which prioritise conservation actions and ecological linkages.

7. Sabangau Complex [54% under TPA; 56% under PA – see Table 5.1 for details on estimation]

i. Areas included:

a) Sabangau NP,

b) Mungku Baru and Bawan Forest,

c) parts of the surrounding Mentaya–Katingan and Kalampangan peat swamp forests.

ii. Habitat types: mainly wetlands (see Brunei text box for definition); lowland forest and tropical heath forest (kerangas) in [b].

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, Sunda clouded leopard, otter civet, collared mongoose.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** flat-headed cat, marbled cat, Sunda clouded leopard, otter civet, collared mongoose; since this modelling study, binturong also recorded.

v. Area-specific threats: illegal mining and associated pollution; peat dome collapse because of the establishment of drainage canals from surrounding oil palm plantations and illegal logging leading to increased susceptibility to forest fires; low political will to protect the park; encroachment from surrounding oil palm plantations; low connectivity; land-use change (including conversion).

vi. Specific conservation actions recommended: block drainage channels in swamp forests; prevent forest fires; establish and enhance connectivity through riparian forests in surrounding plantations and forest reserves; pursue REDD+ activities under the Kalimantan Forests and Climate Partnership and the Katingan Peatland Restoration project; pursue proposals for issuance of ERC licenses and/or Hutan Desa (Village/Community Forest) status outside protected areas to encourage the participation of local communities in rehabilitation programmes with appropriate sustainable management plans, prioritising conservation actions and ecological linkages.

8. Tanjung Puting NP [59% under TPA; 67% under PA – see Table 5.1 for details on estimation]

i. Areas included: Tanjung Puting NP and surrounding areas.

ii. Habitat types: Wetlands (see Brunei text box for definition) and lowland forest.

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, Sunda clouded leopard, binturong, otter civet, banded civet.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** flat-headed cat, binturong.

v. Area-specific threats: illegal mining and associated pollution; peat dome collapse because of the establishment of drainage canals from surrounding oil palm plantations and illegal logging leading to increased susceptibility to forest fires; lack of political will to protect the park; encroachment from surrounding oil palm plantations; low connectivity; land-use change (including conversion); limited capacity amongst park staff for conservation management.

vi. Specific conservation actions recommended: block drainage channels in swamp forests; prevent forest fires; establish and enhance connectivity through riparian forests in surrounding plantations and forest reserves; improve boundary demarcation to facilitate patrolling of park boundaries, and capacity building and training of park authorities to conduct enforcement (including patrolling work); pursue the Rimba Raya REDD+ project with a focus on community benefits and involvement via proposals for ERC licenses and/or Community Forest status with appropriate sustainable management plans prioritising conservation actions and ecological linkages.

9. Arabela–Schwaner Landscape (proposed extension to Heart of Borneo) [0% under TPA; 7% under PA – see Table 5.1 for details on estimation]

i. Areas included: mainly logging concessions to the southeast of Bukit Baka–Bukit Raya NP, some of which participate in FSC certification schemes.

ii. Habitat types: mainly lowland and upland forest.

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** flat-headed cat, banded civet, collared mongoose; since this modelling study, Hose's civet also recorded.

v. Area-specific threats: forest degradation through unsustainable logging and common threats as above for most priority carnivore landscapes in Kalimantan.

vi. Specific conservation actions recommended: regular contact and sensitisation programmes for forest managers yet to engage in sustainability practices and the forest certification process; maintain and enhance corridor connectivity between logging concessions and the HoB complex; pursue proposal for REDD+ projects with community participation to finance protection of High Conservation Value Areas (HCVAs) and important ecological corridors; pursue proposal for Village/Community Forest status and ERC license with appropriate sustainable management plans prioritising habitat restoration, conservation actions and ecological linkages.

Priority conservation areas (West Kalimantan, Indonesia)

1. Heart of Borneo [20.8% under TPA; 47.5% under PA – see Table 5.1 for details on estimation]

i. Areas included:

a) Bukit Batutenobang Protection Forest and surrounding mosaic of plantations, production and protection forests, some of which participate in certification schemes such as FSC,

b) Danau Sentarum NP and surrounding oil palm plantations and production forests,

c) Betung Kerihun NP and surrounding oil palm plantations and production forests.

ii. Habitat types: lowland and highland forest [a, c]; wetlands in [b] (see Brunei text box for definition).

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** flat-headed cat, marbled cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

v. Area-specific threats: low awareness amongst local communities, logging and plantation company staff on sustainability and conservation of wetlands and wildlife; low connectivity between individual units because of, in part, surrounding oil palm plantations (mainly in [b]); forest degradation; encroachment from surrounding oil palm plantations; illegal mining, mainly in [c]; planned road construction along the West Kalimantan–Sarawak boundary in [c].

vi. Specific conservation actions recommended: maintain and enhance corridor connectivity between [b] & [c] and Batang Ai–Lanjak Entimau complex in Sarawak thereby enhancing the value of the Transborder Rainforest Heritage of Borneo, proposed as the first ever UNESCO Trans-boundary World Heritage Site; pursue REDD+ projects with community participation to finance protection of HCVAs and important ecological corridors (in [b]); pursue proposal for Village/Community Forest status and ERC license with appropriate sustainable management plans prioritising habitat restoration, conservation actions and ecological linkages (in [b]).

9. Arabela–Schwaner Landscape (proposed extension to Heart of Borneo) [17% under TPA; 18.7% under PA – see Table 5.1 for details on estimation]

i. Areas included: Bukit Perai–Bukit Rongga Protection Forest blocks which consist of a mosaic of production and protection forests, some of which participate in certification schemes such as FSC.

ii. Habitat types: lowland and highland forest.

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** bay cat.

v. Area-specific threats: mining; low awareness amongst local communities, logging and plantation company staff on sustainability and conservation of wildlife; low connectivity between individual units; forest degradation; encroachment from surrounding oil palm plantations.

vi. Specific conservation actions recommended: maintain and enhance corridor connectivity between logging concessions and protected areas in the complex and also with the larger HoB; pursue REDD+ projects with community participation to finance protection of HCVAs and important ecological corridors; pursue proposal for Village/Community Forest status and ERC license with appropriate sustainable management plans prioritising habitat restoration, conservation actions and ecological linkages.

10. West Kalimantan Western Wetland Complex [16% under TPA; 30% under PA – see Table 5.1 for details on estimation]

i. Areas included:

a) Gunung Palung NP,

b) Sungai Putri Forest Block in Ketapang district, comprising forested areas under diverse statuses such as Limited Production Forest, Convertible Production Forest, Permanent Production Forest, oil palm and tree plantations and community lands,

c) Pulau Maya.

ii. Habitat types: mainly wetlands (see Brunei text box for definition); some lowland and upland forest in [a].

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

v. Area-specific threats: encroachment from expanding plantations; low connectivity because of the expansion of oil palm plantations in surrounding forests; low political will to protect and engage in conservation efforts; construction of canal for transportation in [c]; peat drain leading to increased susceptibility to forest fires; no conservation management plan for [b & c]; displacement of local community farming.

vi. Specific conservation actions recommended: block draining of swamp forests; pursue proposal for Kubu Raya REDD+ projects and Payment for Environmental Services (PES) projects within concession borders and in community forest lands to finance protection of HCVAs and important ecological corridors; pursue proposal for ERC license and Village/ Community Forest status with appropriate sustainable management plans prioritising conservation actions and ecological linkages.

Priority conservation areas (East Kalimantan, Indonesia)

1. Heart of Borneo [0% under TPA; 36.9% under PA – see Table 5.1 for details on estimation]

i. Areas included:

a) Bukit Sepat Huang Nature Reserve (at the border of Central and East Kalimantan),

b) the proposed Long Bangun Nature Reserve,

c) the surrounding mosaic of plantations and logging concessions.

ii. Habitat types: mainly lowland and upland forest with some wetlands (see Brunei text box for definition).

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** marbled cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

v. Area-specific threats: the proposed Long Bangun Nature Reserve remains unprotected; forest degradation through unsustainable logging and other common threats as listed above for most areas in Kalimantan.

vi. Specific conservation actions recommended: gazette the Long Bangun Nature Reserve; support sustainable logging and plantation practises.

11. Wehea–Mangkalihat–Sangkulirang Complex (proposed extension to the Heart of Borneo) [0% under TPA; 11% under PA – see Table 5.1 for details on estimation]

i. Areas included:

a) Mangkalihat and Sangkulirang deltas and surrounding oil palm plantations,

b) Mangkalihat–Sangkulirang Karst Mountains and surrounding timber concessions and plantations,

c) Wehea Forest and surrounding logging concessions and plantations.

ii. Habitat types: lowland and upland forest; karst mountains in [b].

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, Hose's civet, banded civet, collared mongoose.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** marbled cat, Sunda clouded leopard, binturong, otter civet, banded civet.

v. Area-specific threats: lack of awareness amongst local communities and government on the importance of conserving biodiversity; cement mining/unregulated mining in [b]; forest fires; insufficient legal protection.

vi. Specific conservation actions recommended: engagement with local government, local communities and other stakeholders for land-use management appropriate to establish and enhance connectivity with the proposed Sungai Kayan NP in North Kalimantan and the greater HoB complex; improved legislation for protection of karst mountains, followed by enforcement (including patrolling).

Priority conservation areas (North Kalimantan, Indonesia)

1. Heart of Borneo [25.3% under TPA; 48.4% under PA – see Table 5.1 for details on estimation]

i. Areas included:

a) Kayan Mentarang NP, the Apo Kayan Highlands,

b) the proposed Sungai Kayan NP and surrounding logging concessions,

c) Malinau Basin.

ii. Habitat types: mainly highlands; lowland forest in [c].

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, Hose's civet, banded civet, collared mongoose.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, banded civet, collared mongoose.

v. Area-specific threats: road network connecting the Kalimantan coast to Kayan Mentarang NP and associated threats through increased accessibility; encroachment from surrounding oil palm and tree plantations; forest fires; mining; lack of political will to engage in conservation efforts.

vi. Specific conservation actions recommended: gazette Sungai Kayan NP; improve enforcement (including patrolling); maintain and enhance corridor connectivity, particularly between [a] and [c] which would not only connect lowland forest with that of the highlands, but also provide trans-boundary connectivity on a larger scale with Pulong Tau NP and the Kelabit Highlands in Sarawak.

12. Sebuku–Sembakung Complex (proposed extension to the Heart of Borneo) [0% under both TPA and PA – see Table 5.1 for details on estimation]

i. Areas included:

a) the proposed Sebuku–Sembakung NP,

b) surrounding forest concessions and oil palm plantations.

ii. Habitat types: mainly wetlands (see Brunei text box for definition) and some lowland forest.

iii. BCS priority species (see Brunei text box for definition) **predicted to occur:** flat-headed cat, marbled cat, bay cat, Sunda clouded leopard, binturong, otter civet, banded civet, collared mongoose.

iv. BCS priority species with confirmed records from BCS (see HoB [No. 1] in the Brunei text box for details on how confirmed species records are treated)**:** Sunda clouded leopard.

v. Area-specific threats: road development; encroachment from surrounding oil palm plantations; lack of political will to engage in conservation efforts; coal mining, both legal and illegal.

vi. Specific conservation actions recommended: gazette Sebuku–Sembakung NP; maintain and enhance connectivity to HoB by restoration of degraded habitat.

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CHAPTER 6

General Discussion

The main purpose of this dissertation was to improve our understanding of the ecology and distribution of Bornean carnivores in disturbed landscapes, focusing on the Bornean endemic Hose's civet. By using Hose's civet as a case study of a little-studied, tropical highland endemic, the dissertation aimed to evaluate whether tropical highland endemics are particularly vulnerable to the effects of climate change and where and which refugia could be identified that are suitable for targeted conservation action when future climate change scenarios are taken into consideration. The dissertation also aimed to provide an improved evidence base, both on a local and Borneo-wide scale, to guide conservation management strategies for carnivores, particularly in identifying key areas for targeted conservation efforts besides raising practical considerations associated with carnivore conservation on Borneo, and possible solutions to address these concerns.

6.1 Hose's civet: a clearer picture, and most pressing conservation research needs

Hose's civet is largely restricted to the central spine of Borneo's mountainous interior, where its distribution appears patchy (Chapter 2). The most important predictors of Hose's civet occurrence are moss cover and *kerangas* (tropical heath forest), suggesting the species may be specialized to live in these forest conditions, possibly because of a restricted diet (Chapter 4). Though Hose's civet shows an apparent tolerance of degraded habitat and occurs across a wide range of altitudes, the core distribution of the species is likely to be in highland forests (Figure 6.1):

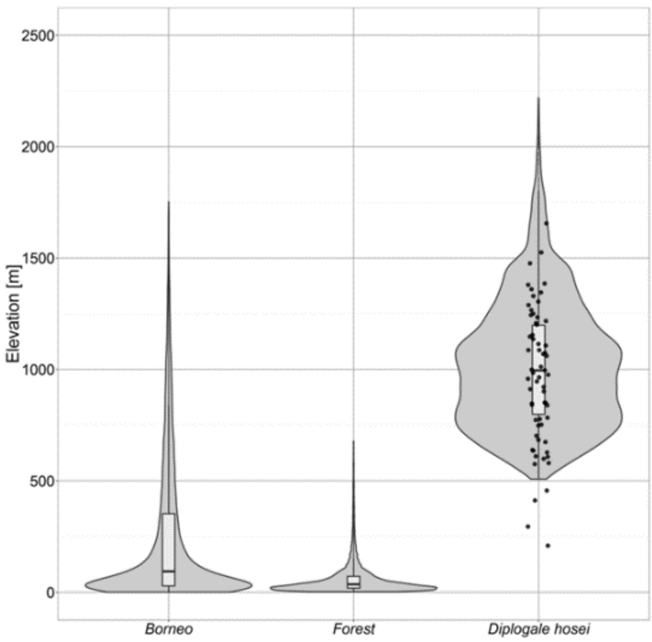

Figure 6.1: Violin plots at the 25P (strict/core altitudinal range) threshold, representing elevation range of the predicted distribution of Hose's civet compared to elevation ranges of the total land area and forested area on Borneo. Further details of violin plots and explanation on thresholds are explained in Chapter 5.

It is thus not surprising that despite the high rates of deforestation reported for Borneo (Gaveau et al., 2014), models predict the trajectory of habitat loss, under land cover change projections alone, to be negligible for Hose's civet (Chapter 3). This is because:

a) deforestation currently disproportionately affects the lowlands on Borneo,
b) future land cover models used in the analysis only predicted deforestation and did not consider forest degradation, which is the greater concern at higher elevations because of the larger areas designated for logging (rather than conversion) in the highlands.

On the other hand, tropical highland specialists such as Hose's civet are vulnerable to the effects of climate change because their current altitudinal ranges may not overlap with climatically suitable ranges of the future (so-called 'range-shift gaps'), and because warming may push climatically suitable conditions off mountain peaks leading to mountain-top extinction (Colwell et al., 2008). Both processes are further complicated by the decline and fragmentation of available habitat for dispersal (Sheldon et al., 2011). Under climate change projections, models predicted a drastic decline in suitable habitat for Hose's civet, more than 86% loss between 2010 and 2080 (Chapter 3). An interesting aspect of the predictions is that in green economy models (where global annual greenhouse gas (GHG) emissions peak between 2010 and 2020 and substantially decline thereafter), suitable habitat for Hose's civet actually show an increase compared to the present (Chapter 3), implying that with concerted efforts by all parties concerned to honour the international commitments made under the United Nations Framework Convention on Climate Change (UNFCCC), then this would substantially improve the long-term conservation of highland species such as Hose's civet.

The most pressing conservation research needs for Hose's civet are similar to that of most carnivore species on Borneo:
a) more surveys across Borneo in different habitat types, particularly in Kalimantan, and in areas surrounding existing lowland records; and
b) assessing tolerance level and dispersal abilities in disturbed forest, especially logged forest and monoculture plantations.

6.2 Methodological considerations during the modelling process

6.2.1 Modelling Borneo-wide distributions of Hose's civet using Maxent, and using Maxent models to derive species richness maps for Borneo-wide conservation planning

For many of Borneo's small carnivores, understanding coarse-scale distribution has only recently become possible because only within the last few years did sufficient data become available that would permit species distribution modelling on a Borneo-wide scale. Because much of this data were sparse, took the form of presence-only locations, was collected using different methodologies and prone to location errors (particularly in the case of museum data), the Maxent analytical framework was the practical modelling option, as it is considered to be robust to such limitations in data (Elith et al., 2006). This is probably why Maxent is one of the most popular tools to model the potential distribution of rare, habitat-restricted or threatened species of conservation concern (Wilting et al., 2010; Clements et al., 2012), and many of Borneo's small carnivores, particularly Hose's civet, fall in this category.

Despite the practicality of Maxent, it has several limitations (Araujo & Guisan, 2006; Yackulic et al., 2013), the most apparent and pertinent to this dissertation being sampling bias, i.e., the bias created by uneven search-effort (Kramer-Schadt et al., 2013). Typical for previous research efforts in Borneo is the very low search effort and therefore the low number of records from Kalimantan, particularly southern and western Kalimantan. It is therefore not surprising that Maxent models predicted low probability of occurrence in Kalimantan for many Bornean carnivores, including Hose's civet, thereby reflecting search effort and not necessarily true species distribution. Consequently, not only species distribution maps for Hose's civet, but also species richness maps derived from these species distribution models need to be interpreted with caution - and so does the carnivore conservation planning across Borneo which relies on them (Chapter 5). Precautions such as spatial filtering were taken to reduce sampling bias (Kramer Schadt et al., 2016), which is a step that is required to produce more reliable model predictions, particularly in the extreme case of no survey effort across large areas on Borneo. Still, unsurveyed areas were mainly predicted as unsuitable for many species. Here, only additional surveys can help improve model predictions.

6.2.2 Using the consensus method implemented in Biomod to project Borneo-wide habitat suitability for Hose's civet into future time periods

Although Maxent models are a popular tool to forecast future distributions under climate change (Struebig et al., 2015a, b), these models are limited in that they underrepresent areas in distribution maps which are climatically different from whence location records stem, due to the models' high weighting of climatic data. In part to deal with this uncertainty in model structure, we used Maxent in this study in combination with generalised boosting model (GBM) to identify future refuges for Hose's civet. This analysis used a consensus method implemented in Biomod, to combine both Maxent and GBM predictions, to yield a final occurrence probability reflecting the majority trend, which usually provides more accurate predictions (Marmion et al., 2009). GBM and Maxent are sometimes referred to as 'enhanced presence-only models' (Senay et al., 2013), and are considered advantageous to pure presence-only models because they use 'background-absence' or 'pseudo-absence' data for model construction (e.g. Zaniewski et al., 2002; Engler et al., 2004), though there is no real use of absence data in the construction of the model.

6.2.2.1 Missing/incomplete information in modelling future projections for Hose's civet

Although modelling efforts provided valuable insight into identifying refugia for Hose's civet, models were constrained by lack of information on issues which could have potentially strengthened and enhanced their utility:

a) Degradation through selective logging

Future land cover models used for the modelling exercise only predicted deforestation and not forest degradation. However, higher elevation forests on Borneo often undergo degradation through intensive and unsustainable 'selective' logging. Though Hose's civet has been found in logging concessions where there are areas of old-growth forest (Samejima & Semiadi, 2012; Chapter 4), the species' tolerance to more degraded habitat is still unknown. There is a possibility that our models may have underestimated the effects of land cover change: if forest degradation were included in future land cover models, it may have resulted in greater habitat loss attributed to land cover change.

b) Spatial overview of hunting pressure on Borneo

The intensity of hunting pressure on Bornean wildlife should not be underestimated: regionally, this problem is so severe that trade in wildlife, including parts and derivatives, has been identified as the leading factor threatening species survival (Corlett, 2007; Harrison et al., 2016). In at least some of the logging concessions within Hose's civet refuges, human access, and therefore potential hunting activity, has been shown to negatively affect threatened small carnivores (Chapter 4). Our models did not consider hunting pressure and hence our predictions are optimistic rather than conservative estimates.

c) Future projections of road networks and human population density

Our models did not consider either future projections of roads or human population density, both of which may have resulted in considerably higher rates of deforestation, degradation and hunting pressure. Again, this may have caused our models to underestimate future habitat loss for Hose's civet.

6.2.3 Using occupancy models to understand fine-scale predictors of carnivore occurrence, focusing on Hose's civet

Records of Hose's civet suggest that the species' distribution might be discontinuous, as surveys in forests within the documented altitudinal and geographic range still yield low encounter rates (if at all, e.g. Cheyne et al., 2016), and indigenous hunters seldom encounter the species (Mathai et al., 2015). This suggests a patchy distribution and a low density of the species.

In order to investigate the possible reasons behind this patchy distribution and increase our understanding of the fine-scale ecology of other small carnivores in disturbed habitats, occupancy models were built for a dataset of small carnivores recorded in a logging concession in the interior of Sarawak. Occupancy models were chosen over the presence-only Maxent and GBM models because occupancy models asess the true distribution of a species whilst simultaneously accounting for the probability of detecting the species (detectability), which, given that the species occurs at a site, is almost always less than 1 (Kery & Schmidt, 2008).

Additionally, the strength of a covariate relationship in a species distribution model will be underestimated whenever imperfect detection is not accounted for, even with constant detectability (MacKenzie et al., 2006) and important habitat predictors may not be identified (Kery et al., 2010).

The resultant occupancy models from this analysis were used to investigate fine-scale predictors of carnivore occurrence in the Sela'an Linau Forest Management Unit (SLFMU) in interior Sarawak and thereby provide recommendations for more carnivore-friendly harvesting techniques in logging concessions. However, it is acknowledged that the extrapolation of model results beyond the boundaries of the SLFMU is usually not considered to be justifiable.

6.3 Local and Borneo-wide issues pertaining to conservation planning approaches for Bornean carnivores

6.3.1 Lessons learnt from the Sela'an Linau Forest Management Unit in the Upper Baram catchment, Sarawak

Many forests of the Upper Baram catchment (about 9000 km^2) are classified as state land, although the numerous indigenous communities inhabiting the area claim Native Customary Rights (NCR) over the land. As in much of Sarawak and indeed, all across Borneo, the state government considers these indigenous lands as "idle" and issues licenses and leases for these lands to logging and plantation companies, often without the knowledge of the indigenous communities, thereby depriving these communities of their livelihoods and violating their rights to their territory as outlined in the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), of which Malaysia is a signatory (Jacquelin-Anderson, 2018). The result is tremendous socio-economic suffering among the indigenous communities, with the semi-nomadic Penan, in particular, being described as the poorest group in Malaysia (Jayasooria, 2013). There is a high level of frustration, anger and desperation among the indigenous communities because of the lack of recognition of the rights to their lands and the lack of consultation during the planning and implementation of government projects claimed to be for their benefit (Jacquelin-Anderson, 2018). This anger and desperation, in turn, sometimes translates to unsustainable and/or illegal harvesting practices, with negative consequences for forests and wildlife.

The forests of the Upper Baram, including those within the Sela'an Linau Forest Management Unit (SLFMU), were gazetted as logging concessions and licensed to be exploited by timber concessionaires since the early 1990s. In 2004, the 560 km^2 SLFMU became the first of only two logging concessions in Sarawak so far to be certified as sustainably managed under the old Malaysian Timber Certification Scheme (MTCS). The SLFMU lost this certification in 2009, mainly because of unsettled issues with indigenous communities. The concessionaire, Samling Global, did not pursue re-certification and logging activities have since markedly declined. In 2011, the Malaysian company Sarawak Energy, with the support of the Sarawak government, announced plans to inundate almost 400 km^2 of forest downstream of the SLFMU as part of the Baram dam project, one of 12 mega dams envisioned in the region by 2020 as part of the larger Sarawak Corridor of Renewable Energy (SCORE) project (Jacquelin-Anderson, 2018). The proposed Baram dam would displace 20,000 indigenous people and would potentially have huge environmental consequences, including massive loss of habitat, increased human-wildlife conflict, inhibition of dispersal and gene flow between wildlife populations and alteration of soil conditions and climate.

6.3.1.1 The need for inclusive conservation by positively engaging indigenous communities

Providing training and increasing awareness

The Hose's Civet and Small Carnivore Project (HOSCAP Borneo) started field work on this dissertation work in the SLFMU in 2012. By positively engaging the local communities, for instance by hiring them as field assistants, guides, porters and boatmen, the project not only provided local people with alternative sources of income, but also trained them to set and operate camera-traps, take field observations and measurements, to read maps and use GPS location devices. Indigenous communities were also taught basic English, informed about their legal rights and educated about wildlife protection laws, including the prohibition of the commercial sale of wildlife and its derivatives as well as the species protected by law and hence prohibited from being hunted. Discussions were also regularly held with indigenous communities to ascertain whether local knowledge of species occurrence and relative abundance matched information from camera-trapping data.

Within just a few months, local communities, particularly the most prolific hunters (who turned out to be the best field assistants), displayed a higher appreciation for wildlife and reduced hunting. There was an observable sense of pride and renewed feeling of custodianship towards the forest and its wildlife. Whereas previously, local hunters often resorted to unscrupulous hunting methods by using traps, snares and poisons and indiscriminately sold wildlife and its derivatives to loggers and city-dwellers, they now mainly used dogs and guns, often reverting to traditional blowpipes and spears, and only hunted species not protected by law. Furthermore, they avoided hunting species that they were told are considered rare or possibly occurring at low densities, as per HOSCAP Borneo's research findings. Moreover, although the commercial selling of wildlife and its derivatives continued, their levels were somewhat reduced, though we did not have the data to quantify this.

Figure 6.2: Hunters from the indigenous Penan community of the Sela'an Linau Forest Management Unit, interior Sarawak.

Understanding local aspirations and supporting communities to stand for their rights

a) Protesting the Baram dam

"What the government is doing when they're flooding all these areas is actually killing the culture, the traditions, of our community. It's basically ethnocide". Mark Bujang, indigenous activist, regarding the Baram dam project.

City dwellers, academics, government authorities and some international NGOs have remained silent on the issue of the construction of the Baram dam. Indigenous people in the Baram opposed this construction. HOSCAP Borneo, along with other local NGOs, provided moral support and information to local communities and assisted them in their efforts to protest against the construction of the dam. After 3 years of protests and 300 days of blockades, the Sarawak government officially terminated the project in March 2016 (Jacquelin-Anderson, 2018). This was a huge success for indigenous communities and the conservation of vital habitat for species-rich wildlife communities, including carnivores.

Figure 6.3: A simple blockade erected across an access road to the site of the proposed Baram dam.

b) Proposal for the Baram Peace Park

Since 2009, local communities have mooted the idea of a community-managed forest within the Upper Baram, initially termed the Penan Peace Park and later renamed the Baram Peace Park. The proposed park, which includes the SLFMU, covers an area of approximately 1,630 km^2, and is envisioned to be jointly managed by local communities and the state government for sustainable development and conservation ("Baram villagers," 2016; "Baram initiative," 2016).

The proposition for the Baram Peace Park was ignored by local government for a long time. In the meantime, with the support of local NGOs, including HOSCAP Borneo, local communities started mapping their traditional lands. Field assistants from HOSCAP Borneo led in this endeavour, having been trained in the usage of GPS units. Furthermore, local communities recorded important cultural and historic sites such as burial and hunting grounds, and with the help of local NGOs prepared a proposal for the Baram Peace Park that will be submitted to the state government. In 2016, the Sarawak government listened, for the first time, to the proposition of the Baram Peace Park and in principle, accepted the proposal ("Baram villagers," 2016), although no concrete action supporting the creation of the park has been undertaken.

6.3.1.2 Engaging decision makers

Regular meetings with the logging concessionaire to advise on wildlife-friendly practices

Since the start of field work in 2012, HOSCAP Borneo held discussions every 2-3 months with Samling Global's Head of Planning and Development Unit, with the objective of briefing him and his team on progress and new insights from ongoing field research. Prior to HOSCAP Borneo's involvement, Samling Global showed little interest towards conservation and was not aware of the species-rich diverse carnivore community within their concession area or the importance of these communities to ensure healthy forest functioning. The management of Samling Global were also oblivious to illegal hunting activities within the concession, often involving their own staff, and the need for increased enforcement.

Quarterly reports were submitted to Samling Global, which included species inventories in sites under different logging management regimes and recommendations to reduce the impact of harvesting on wildlife. Some of these recommendations were previously known to the concessionaire, such as avoiding road construction and harvesting on steep slopes to prevent erosion – such recommendations were ignored as they would have considerably affected operation costs and company profits. Other recommendations, however, were better received. These were (1) prohibiting hunting dogs in all timber camps, (2) avoiding sending large teams into harvesting blocks when conducting pre-and post-harvesting surveys as this will reduce instances of hunting by company staff, (3) retaining fruiting trees and hollow trees to provide food and shelter for wildlife. These recommendations were of a generic nature, did not significantly affect operations and were adopted by the company, thereby improving the viability of wildlife species, including carnivores, in the FMU.

Reports on hunting sent to Sarawak Forest Department

During fieldwork, HOSCAP Borneo field teams often came across traps, snares and nets set in the forest. As these nets were not targeted at specific species but functioned in a very unspecific manner, they are a typical example of by-catch mechanisms (see also Hofer et al., 1993, 1996). Small mammals such as pangolin *Manis javanica* were often found entangled in these nets, and as they are indiscriminate in what they catch, small ground-dwelling carnivores could also be caught by them. It is unclear whether these traps were set by indigenous hunters, city dwellers, loggers, or foreigners. Prior to HOSCAP Borneo's work, it was assumed that only indigenous people hunted in the area, mainly for subsistence, and that hunting was not a major concern. Our work, however, highlighted that (1) lack of enforcement was an issue in the FMU, (2) outsiders, including loggers and city dwellers, were hunting in the FMU, (3) the commercial trade of wild meat was rampant within the FMU and its surrounding areas. Photographs and GPS locations of traps were recorded and the appropriate information communicated to Sarawak Forest Department (SFD), the relevant government authority, for further action. In addition, annual reports were submitted to the SFD to update them on ongoing field research and illustrated the need for increased enforcement.

6.3.1.3 Engaging the larger population

Promoting eco-tourism and alternate sources of livelihood through the Culture and Nature Appreciation School

In 2014, HOSCAP Borneo partnered with the Society for Wilderness Sarawak (SOW Sarawak), a Sarawak-based social NGO, to initiate an eco-tourism project within the SLFMU. The SOW Culture and Nature Appreciation School (CNAS) was established in the village of Long Lellang, Upper Baram, with the objective of bringing in visitors, both local and foreign, to understand and appreciate the customs and aspirations of local communities and raising awareness on ongoing research and conservation issues (Wong et al., 2016; Li-Peng, et al., 2016). Indigenous hunters who were trained by HOSCAP Borneo as field assistants and guides were employed by CNAS as demonstrators, guides, cooks and boatmen. Home-stay facilities were established in the village, all food, in the form of forest vegetables, was sourced locally, and local arts and crafts were promoted and sold. These efforts have succeeded not just in providing alternative livelihoods to local communities and so reduce their reliance on hunting, but also in enhancing their sense of custodianship and pride of forest and wildlife. The project has also served as a platform for further discussions with local government regarding the possibility of changing the designation of the SLFMU from a logging concession to a community-managed forest, complementing conservation initiatives and efforts towards the Baram Peace Park.

Increasing awareness through contemporary publications

Prior to HOSCAP Borneo, few people – and this included indigenous communities – were aware of the existence of Hose's civet. Moreover, Borneo's small carnivores received little attention by conservation organisations, the relevant ministries and government agencies, academic institutions or the general public. Conservation funds and publicity inevitably were focussed on charismatic species such as the Bornean orang utan and Asian elephant, and the only carnivores that garnered any kind of conservation attention and resources were the larger species such as Sunda clouded leopard and the Malayan sun bear.

The website (https://hoscap-borneo.org/) and Facebook page (https://web.facebook.com/HoscapBorneo/) of HOSCAP Borneo reached out to the public to raise awareness of the plight of Borneo's carnivore community. In order to engage the younger, tech-savvy generation, HOSCAP Borneo created a digital comic, 'The Hose's civet of Borneo' which is now being translated into six languages, including three local ones.

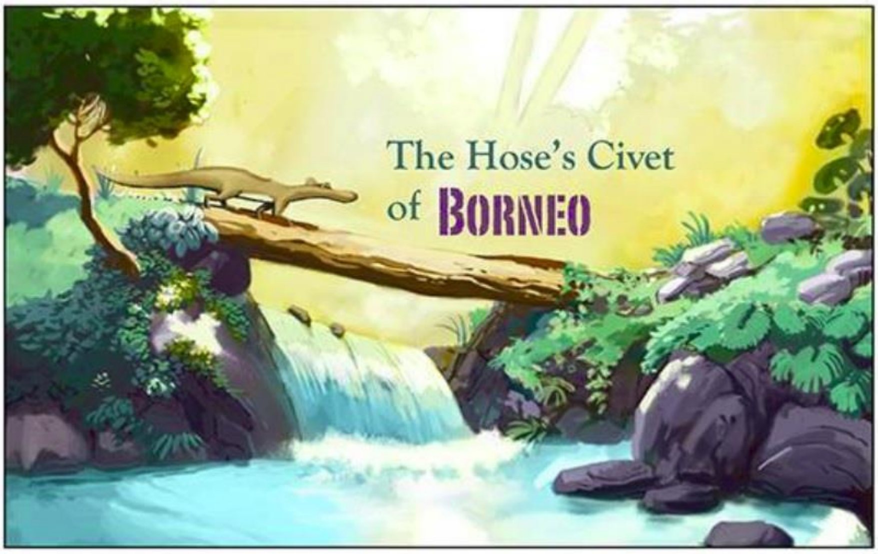

Figure 6.4: First page of the digital comic 'The Hose's civet of Borneo'.

Whichever direction the SLFMU takes in the future, whether as a sustainably managed logging concession within the HoB agreement, a community-managed forest as part of the larger Baram Peace Park, or as a smaller community-managed forest, the involvement and support of all stakeholders, particularly the indigenous communities, is of critical importance.

6.3.2 Borneo-wide issues and possible solutions

Many of the issues pertaining to carnivore conservation on a Borneo-wide scale are the same as those discussed within the SLFMU – only the spatial scale and the degree of complexity differ. This includes the oppression of native communities and disregard of their customary rights, the need for designating additional community-managed forests, unsustainable hunting, lack of enforcement and the need for education and awareness programmes. On top of this, there are additional challenges for large-scale, transboundary planning, as it needs the cooperation and involvement of the governments of Brunei, Indonesia and Malaysia to agree on a plan to provide landscape connectivity and corridors and combat the impacts of climate change.

6.3.2.1 Respecting the rights of indigenous communities and involving them as constructive partners in conservation

The issues and solutions pertaining to indigenous communities as discussed in the SLFMU apply to much of Borneo. Local communities must be engaged in the decision-making process and conservation initiatives should demonstrate social and economic co-benefits for these communities in an effort to garner their support. Besides the approaches highlighted in the SLFMU, such as employment opportunities as rangers, tourist guides or field assistants, and providing alternative sources of protein and income through animal husbandry and eco-tourism projects, governments should play a more active role by institutionalising rehabilitation programmes which encourage the participation of local communities. Such projects include Ecosystem Restoration Concession (ERC) licences, REDD+ (Reducing Emissions from Deforestation and Forest Degradation) or PES (Payment for Ecosystem Services) mechanisms, and issuing of Hutan Desa (Village/Community Forest) status, which transfers responsibility of forest management from solely local government to local communities with the support of local government and the public sector.

6.3.2.2 Hunting and lack of enforcement

Almost nothing is known about the effects of hunting on carnivore populations on Borneo. It remains unknown whether any carnivore species is particularly targeted by hunters, and what the effect of poaching is on population viability. In large parts of Indochina, carnivores are heavily hunted (Corlett, 2007) and the extensive snaring means that a number of species are even threatened with local extinction (Willcox et al., 2014). Such high levels of hunting of carnivores have so far not been reported or suspected in Borneo (Chapter 5). Illegal hunting and trade is increasing, and it is possible that intensive snaring of the sort now commonplace in Indochina might appear in Borneo as the former areas are defaunated (Shepherd et al., 2011). What is needed, therefore, are studies to understand how hunting patterns and wild meat consumption affect population viability of carnivore species and assess the factors that motivate people to hunt and consume wild meat. Such information, specific to Borneo, is critical to design more effective conservation interventions for Bornean carnivores threatened by hunting.

Existing wildlife protection laws and ordinances on Borneo are broadly appropriate on paper but they need to be enforced (see also Linkie et al., 2015; Crees et al., 2016;). This requires increased political commitment to pursue effective wildlife conservation and strengthen support and involvement by local community (e.g. in Sinclair, 2009). The effectiveness of any legislation depends on its level of implementation aided by social control (Sinclair 2009) and the personal costs associated with punishment by legal procedures (Hofer et al., 2000).

Engaging indigenous communities in the fight against unsustainable hunting

In addition to improved enforcement, efforts to engage local hunters and manage wildlife populations through sustainable hunting practices are urgently needed. Funds generated from PES and REDD+ schemes could be used to employ indigenous hunters as forest guards, thereby providing direct benefits and positively predisposing local communities towards such projects. 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 indigenous communities (Robinson & Bennett 2004; Rao et al. 2010). With the genuine support of local communities, it may assist conservation and improve the viability of wildlife populations if legitimate local hunters help police forests against poaching by outsiders and prevent the use of indiscriminate methods such as snares.

Poaching needs to be recognized as a serious crime, and meaningful sentences need to be imposed on hunters and traffickers. Gun-control and ammunition-control legislation must be better implemented and laws introduced to regulate the use and ownership of nets, snares and other tools of indiscriminate hunting. Site-based enforcement is essential for effective conservation, and an increase in the resources dedicated to the basic management of forested areas that includes patrolling and other enforcement efforts is urgently needed (Harrison et al., 2016).

Enforcement against encroachment, illegal logging, illegal mining and the use of fires

Apart from hunting, encroachment into protected areas or other forests is commonplace on Borneo, by local communities, immigrants and plantation companies (e.g. Santika et al., 2015). In some parts of Borneo, illegal logging is rampant, both within and outside protected areas and in logging concessions themselves (Gaveau et al., 2013). Illegal mining, although less extensive, occurs also largely unchecked, particularly in Kalimantan (Santika et al., 2015). The use of fire in agriculture, particularly when opening new areas for plantations, is widespread in Kalimantan (Siegert et al., 2001). Again, enforcement is required to curb these activities.

6.3.2.3 Education, awareness and outreach programmes

Enforcement of conservation-relevant legal stipulations can become more effective, particularly in reducing demand for wildlife products, if accompanied by education and awareness programmes (Harrison, 2011), but this is far from widely implemented. Support from local communities is helpful for the long-term viability of protected areas and species populations (Balmford & Whitten, 2003); it is therefore surprising that conservation programmes often fail to garner their support on a large scale. Education programmes involving local communities ideally is one of several components of a wider development programme which should ensure the availability of alternative sources of protein and income to villagers (Loibooki et al. 2002).

Sustained awareness-raising efforts targeting businesses trading wildlife products, such as restaurants and traditional medicine shops and city-based consumers should be conducted on the importance of conservation, the factors affecting the viability of wildlife, awareness of the protection status of wildlife and the illegality of wildlife trade. More efforts should be expended on raising awareness to educate the public on Bornean carnivores, particularly the Bornean endemics – Hose’s civet, Bornean ferret badger and bay cat *Catopuma badia* – because many of Borneo’s carnivores are little known and deserve more attention.

Linking religious beliefs and conservation goals

A little explored approach which may prove effective on Borneo is the involvement of religious groups to sensitise people to the importance of living in balance with nature and being responsible ‘stewards’ of nature, wildlife and the environment. An example of the power of linking religion and conservation goals occurred in 2014, when Islamic clerics in Indonesia issued a *fatwa* (religious decree) to protect endangered species by forbidding Indonesia’s Muslims, under Islamic law, to participate in wildlife trade and all activities resulting in wildlife extinction (Mcleod & Palmer 2015). Similarly, in 2015, the West Malaysian state of Terengganu issued a fatwa prohibiting the state’s Muslim residents from poaching (Actman, 2015). Christian and Muslim faiths play a large role in the lives of many Bornean residents and hence, this is an avenue worth exploring.

6.3.2.4 Holistic planning for carnivores on Borneo: the need to include disturbed and human-dominated landscapes

The effectiveness of systematic conservation planning comes from its efficiency in using limited resources to achieve conservation goals, its flexibility in the face of competing land uses, and its accountability in allowing decisions to be critically reviewed (Margules & Pressey, 2000). This involves identifying key areas for conservation and allocating limited funds to those areas. On Borneo, such a selection of priority sites for conservation needs to take into account economic pursuits such as monoculture plantations (e.g. oil palm and acacia), logging and mining and consider development issues such as poverty alleviation and alternate sources of livelihoods for local communities. Conservation planning on Borneo will therefore require strategies for managing whole landscapes which incorporate areas allocated to both economic production and protection for conservation.

The protected area network on Borneo is currently too small and/or too fragmented to ensure on its own the long-term survival of some, perhaps many, wildlife species, particularly wide-ranging ones such as carnivores (Proctor et al., 2011; Hearn et al., 2017). Further, the lack of political will and capacity to enforce wildlife conservation laws to curb illegal hunting, illegal logging, encroachment, the setting of fires and the draining of peat swamp forests will exacerbate biodiversity loss not only outside protected areas, but also within protected areas themselves. On top of this, the management plans of many protected areas consider indigenous peoples as threats instead of collaborative partners in conservation. Thus, the concept of protected areas as currently practised in Borneo is unlikely to be effective. Unless more resources are directed towards improving local capacity, transparency and governance, it is unlikely that the protected area network will succeed in achieving its fundamental objective of conserving biodiversity (Watson et al., 2014).

A shift is needed from managing wildlife, including carnivore populations, in isolated protected areas, to the management of populations of threatened species across the broader landscape in which protected areas are one element and wildlife is a component of the human socioecological system. There is a need for greater recognition, by government, NGOs and academics, of the important role of areas outside protected area networks, including secondary forests and multi-use landscapes, to contribute towards conservation goals.

The Heart of Borneo initiative

On Borneo, many of the areas with the highest carnivore richness occur in the region covered by the Heart of Borneo (HoB) initiative. Areas with varying levels of protection constitute about 38% of the HoB, while the rest are licensed as logging concessions (the dominant industry by area), plantation agriculture (mainly for oil palm, wood and paper-pulp) and mining. To ensure that the HoB initiative conserves carnivores and many other Bornean taxa (Beck et al., 2011; Struebig et al., 2015a), it needs to be implemented in practice and not remain a well-intentioned vision.

In practice, the reality of the HoB is messy (Hitchner, 2010). There is no consensus over what HoB actually is, who is involved, or who will bear the costs or reap the benefits. To add to the confusion, multiple decisions are being made by many different actors, and compromises are simultaneously being negotiated at various geographic, political, and institutional scales. Additionally, different actors envision vastly different futures for the HoB, and the area is subject to a multiplicity of overlapping jurisdictions (Hitchner, 2010).

Although there are other key carnivore landscapes on Borneo, it would be advantageous if the HoB initiative lived up to its expectations. Besides increasing enforcement in the existing protected areas, indigenous communities, who make up almost the entire half a million residents within the landscape, should be positively engaged. Furthermore, existing legislation should be updated to mandate all logging concessions and plantations within the HoB to be certified for sustainable management and such legislation strictly enforced.

Similarly, other key carnivore landscapes, many of which include proposed extensions to the HoB (Chapter 5), should also be sustainably managed. It is vital that these key areas be linked via conservation corridors, to allow dispersal of carnivores and other large threatened species (Brodie et al., 2015). Present spatial and development planning in the different regions of Borneo does not yet include ecological principles such as forest connectivity. Consequently, a major change of planning systems and processes is required.

Certification of logging concessions and oil palm plantations

To ensure legal certainty and limit the impact of exploitative activities in non-protected forests, the most obvious step would be to ensure that all such activities are certified as sustainably managed. By clarifying the impacts of sustainable practices, as promoted by certification schemes such as the Forest Stewardship Council (FSC) or the Roundtable on Sustainable Palm Oil (RSPO), on wildlife communities, an improved understanding can be achieved of how exploitation thus regulated will affect wildlife populations and thus either be detrimental to or support conservation. This understanding could then advise and facilitate integrated approaches to conservation management and development planning.

To this end, the Sarawak state government directed the six timber giants in the state (better known as 'the Big Six'), to have at least one licensed area certified by 2017, and that all logging concessions in the Sarawak portion of HoB be certified by 2017 (Cheng, 2016). Although a step in the right direction, until todate, neither target has been achieved, with only a single concession in the state currently certified by the local Malaysian Timber Certification Scheme (MTCS) standard, effectively questioning the sincerity of the Sarawak government in setting these targets. Sabah and Kalimantan, on the other hand, have FSC-certified timber concessions, with almost 30% of Sabah's concessions being FSC-certified (Wulffraat et al., 2017). On top of this, the Sabah government is aiming to have all crude palm oil (CPO) produced in the state to be certified as sustainable as per RSPO standards by 2025, with Kalimantan working towards a similar commitment (RSPO, 2015). Such steps should have positive consequences for carnivore conservation within Sabah and Kalimantan, and it is hoped that Sarawak will follow suit. Areas designated for logging and plantations in Brunei are negligible and are therefore not discussed here.

6.3.2.5 Dealing with climate change

According to a study conducted by the Naturalis Biodiversity Centre (2016), even if global warming was kept below 2°C, no area of Borneo would be left unaffected. If the worst-case scenario of 4°C was reached, then there would be widespread effects, with the whole island severely affected, with serious effects on natural ecosystems (Wulffraat et al., 2017).

Tropical highland specialists such as Hose's civet and Bornean ferret badger will be most vulnerable to these effects of climate change. Our study (Chapter 3) revealed that Hose's civet will potentially lose 86% of its habitat by 2080 due to climate change alone. To mitigate these effects, landscape connectivity should be ensured by maintaining and developing contiguous forest corridors to link existing species habitats with predicted future suitable habitat, i.e., species refugia at cooler elevations. To enable the identification of such refugia and wildlife corridors, analyses that project suitable habitats of species into future time periods, as was conducted for Hose's civet in Chapter 3, should be replicated. These analyses should then be taken into account during land use planning processes.

To reduce the effects of climate change on Borneo, ideally deforestation is halted, although in practise this is unlikely. Therefore, priority for further conversion and development should be confined to areas that are already severely degraded and have low carbon storage. However, degraded areas that are located within key biodiversity areas and are particularly rich in carbon, e.g. peat swamps, should be restored (Budiharta et al., 2018). Particularly in peat swamp areas, forest fires should be prevented through strict law enforcement and quick action on the part of local authorities. This requires responsible long-term planning and reassessment of current land allocation practices.

Conclusion

This dissertation shows that although the conservation of Borneo's diverse carnivore community faces a myriad of challenges, the application of species distribution models, occupancy models and a systematic framework for conservation planning can provide insights, guidelines and methodologies on how to overcome at least some of these issues and optimize the application of limited conservation funds and resources to achieve best possible results.

Our models helped improve our understanding of the coarse-scale distribution, habitat preferences and threats of the Bornean endemic Hose's civet. By projecting the extent of suitable habitat of Hose's civet into future time periods using land cover and climate change forecasts for the 21st century, we highlight how tropical highland endemics such as Hose's civet are most vulnerable to the effects of climate change and how the identification of species refugia should be considered during the spatial planning process of these species. We provide new and novel insights into the fine-scale ecology of many carnivore species, and use this as a basis to provide broad management recommendations for more carnivore-friendly harvesting techniques in logging concessions. Finally, we identify key carnivore conservation landscapes across Borneo and intervention priorities within these landscapes. We emphasize the importance of connectivity between conservation landscapes, and highlight the existing Heart of Borneo (HoB) initiative as a critical landscape that needs to be protected.

There are several limitations with our model predictions because of methodological constraints and lack of information on species ecology as well as issues that are likely to affect model outcomes such as hunting pressure and forest degradation. Additionally, our models were influenced by the general lack of information from some regions of Kalimantan, as well as fragmented and degraded landscapes, and habitats which are difficult to survey such as mangroves and high-elevation forest. Even so, the models presented in this dissertation can provide valuable guidance to ensure the long-term conservation of Borneo’s carnivore assemblage, provided there is sufficient political will, public support and inclusive conservation interventions on the ground.

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SELBSTÄNDIGKEITSERKLÄRUNG

Hiermit versichere ich, dass ich die vorliegende Doktorarbeit eigenständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe.
Berlin,

John Mathai Sankoorikkal