Threats to Big Cats in Southeast Asia

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Abstract

Southeast Asia is experiencing rapid rates of habitat conversion as homogenous oil palm plantations are replacing biodiverse areas. These oil palm plantations have exploded over recent decades, altering the landscape for species such as tigers, leopards, and clouded leopards who depend on large tracts of habitat for survival. To understand how to protect these big cats and their habitats, I examined 1) the current state of big cat habitat and habitat connectivity in Southeast Asia, 2) how oil palm plantation expansion would impact remaining habitat, 3) additional threats challenging big cats such as poaching, forest loss, and human population growth, and 4) the overlap between protected areas and threatened habitat. This study found that big cat habitat patches are already isolated from one another. While oil palm was not found to be the biggest threat to big cat connectivity, habitat in Malaysia would suffer most from the expansion of oil palm plantations. Overall, big cats are experiencing the greatest anthropogenic threats to their habitat in Malaysia, Myanmar, and eastern India with over half of the threatened habitat patches falling outside of protected areas.

Introduction

Southeast Asia is experiencing rapid rates of habitat conversion as homogenous oil palm plantations, agricultural expansions, and human developments replace biodiverse areas. Due to rising human populations, the landscape of Southeast Asia is increasingly under anthropogenic stresses and threats. Anthropogenic pressures destroy tracts of forest, and natural vegetation, eliminating the region's wildlife (Sodhi et al. 2004). In Southeast Asia, big cats including tigers, *Panthera tigris*, leopards, *Panthera pardus*, and clouded leopards, *Neofelis nebulosa*, are under pressure due to habitat loss because they rely on sizable habitat patches for survival (Goodrich et al. 2015, Jacobson et al. 2016, Grassman et al. 2016).

Tigers are the largest of these three cats and are listed as endangered by the IUCN Red List because observed populations have declined as much as 30% over the past 14 years and occupy less than 6% of their historic range (Goodrich et al. 2015). Leopards have the widest distribution of any felid but are listed as vulnerable because they reside in approximately 25% of their historic range (Jacobson et al. 2016). Clouded leopards are the smallest of these three big cat species and are arboreal, spending much of their time in trees (Grassman et al. 2016). The clouded leopard's conservation status is also vulnerable because they have lost an estimated 30% of their adult population over the past 20 years (Grassman et al. 2016). All three cats have experienced population declines due to poaching, habitat loss, and fragmentation, as well as additional human pressures (Goodrich et al. 2015, Grassman et al. 2016).

One of the largest contributors to habitat loss in Southeast Asia is the rapidly increasing market for palm oil, a cheaply produced vegetable oil from the oil palm tree, *Elaeis guineensis.* This palm oil is found in processed foods, cosmetics, and cleaning supplies (Vijay et al. 2016). Oil palm plantations are replacing natural forests with homogenous rows of vegetation that support less biodiversity (Yue et al. 2015). Recent studies have found that replacing natural forests with oil palm plantations decreases the species richness and diversity for many mammals in Southeast Asia (Yue et al. 2015). Overall, oil palm plantations have been found to cause a decline in species diversity as animals do not occupy these unnatural forests for extended periods of time (Yue et al. 2015).

Southeast Asia alone is responsible for over 80% of global palm oil production, largely from Malaysia and Indonesia (Bateman et al. 2010). Between 1999 and 2005, 59% of the natural forests in Malaysia were replaced with oil palm plantations, and this trend is only expected to continue (Bateman et al. 2010). Furthermore, the market for oil palm is poised to continue to expand, making the expansion of oil palm plantations one of the greatest threats to wildlife in Southeast Asia (Vijay et al. 2016). Due to the great threat oil palm poses to biodiversity and native forests, a recent study identified regions around the world that would be suitable for the expansion of oil palm plantations to evaluate the threat of future expansion of oil palm (Vijay et al. 2016).

In this study, I apply this new data on areas suitable for oil palm to examine how oil palm expansion would impact big cats in Southeast Asia by addressing the following questions:

1. What is the current state of tiger, leopard, and clouded leopard habitat and its connectivity?
2. How would habitat connectivity change if areas suitable for oil palm plantation expansion were developed?
3. What are additional threats to big cat habitat, and what areas are under greatest anthropogenic pressures?
4. What does the overlap between big cat habitat and protected areas look like? And what is the overlap between threatened habitat patches and protected areas?

Knowledge about the current state of habitat connectivity and the possible impacts from future threats provide a baseline for organizations to make informed decisions about the conservation of tigers, leopards, and clouded leopards in Southeast Asia so these big cats populations can be protected from further decline.

Methods

Study Area

The study area includes Myanmar, Laos, Thailand, Cambodia, Peninsular Malaysia, Singapore, the Indian states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura, and the Yunnan Province of China (**Figure 1**). This extent was selected as it represents a biologically similar region.

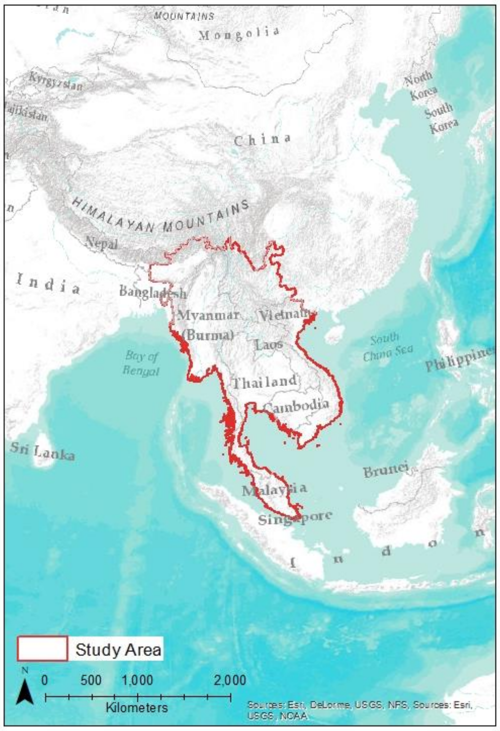

Figure 1: Study area including Myanmar, Laos, Vietnam, Thailand, Cambodia, Peninsular Malaysia, Singapore and the eastern region of India, and the Yunnan province of China.

Within this region, I extracted the most updated extant habitat patches for tigers (Panthera 2015), leopards (Jacobson et al. 2016), and clouded leopards (IUCN 2016), excluding any habitat patch slivers less than 100 km^2 because studies have found areas below this size are not suitable for supporting viable populations of the carnivores (Lynam et al. 2007). I overlapped all three big cat habitat patches to find the areas that support tigers, leopards, and tigers. In addition, I explored the extant habitat patch overlap with protected areas to calculate the percentage of habitat area comprised of designated protected areas (WDPA 2014, Li et al. 2016).

Current State of Habitat Connectivity

All analyses were conducted using ArcGIS 10.5.1 (ESRI 2001), using Asia North Albers Equal Area Conic projection and 330 x 330-meter grain size. This is appropriate because the projection reduces shape and area distortion, and the grain size allows for a more rapid landscape-scale analysis.

To address the first research question, I evaluated the current state of connectivity between habitat patches for tigers, leopards, and clouded leopards by conducting a subnetwork analysis. Subnetworks are groups of functionally connected habitat patches that an animal could possibly travel between given a maximum travel distance for the species. From behavior and tracking literature, I estimated distances that each species would be likely to travel. I found that tigers are likely to travel between 100 and 250 km under normal conditions (Singh et al. 2013), leopards are likely to travel between 80 and 225 km (Fattebert et al. 2013), and clouded leopards are likely to travel between 50 and 100 km (Giordano 2018). The tiger and leopard have been recorded traveling further distances, but these have been influenced by extreme conditions like chasing prey over long distances. I did not use the greatest travel distances recorded in the literature, rather I used conservative distances to prevent overestimation of connectivity.

I buffered extant habitat patches for each species using the two different travel distances listed above for each species. If habitat patches were within the species' maximum travel distance, these patches were considered functionally connected and grouped into a subnetwork. These initial subnetwork analyses only account for the maximum distance traveled by the species and do not incorporate features on the landscape that could also be impacting the animal's ability to travel between patches.

To incorporate these landscape features, I created three species-specific resistance layers including landcover (Globcover 2009), distance to roads (gRoads), and human population density (Asia Population Continental Dataset 2015). A resistance layer is a surface representing how easy or challenging it would be for an animal to move across the landscape. Each cell in the surface has a different cost value with higher values equating to a part of the landscape that would be more difficult to travel through.

I removed large bodies of water (WWF 2004) such as lakes from the landcover data because the cats would not be able to travel through them. Using information about each big cat species, I assigned cost values to different landcover types, different distances to roads, and different human population densities (**A Tables 1-3**).

For instance, tigers prefer areas of dense, natural vegetation to more open areas and agricultural fields (Monirul et al 2007, Rabinowitz 1993). Tigers also tend to avoid human settlements and roads (Joshi et al 2013, Thatte et al. 2018). Using this information, I assigned cost values consistent with these preferences and combined all three landscape features giving landcover type a weight of 0.4, human population density a weight of 0.4, and distance to roads a weight of 0.2.

Leopards also prefer areas of natural, dense vegetation (Hayward et al. 2016), but are a generalist species influenced less by human presence compared to the other big cats due to their high adaptability (Kshettry et al. 2016). However, human disturbance still impacts leopards and areas of agriculture and human developments had lower usage by leopards (Kshettry et al. 2016). Roads act as deterrents to leopards, but they are not barriers to movement, and leopards are not as sensitive to the presence of roads when compared to tigers (Ngoprasert et al. 2007). Therefore, human-influenced landcover types received the lowest costs among the three the cats. Like the tiger, landcover and human population density received a weight of 0.4 and distance to roads was weighted at 0.2.

Clouded leopards are most sensitive to human disturbance of these cats and prefer dense, natural, isolated forests (Borah et al. 2013). Clouded leopards are most associated with semi-evergreen forests but are also observed using grasslands, scrub, and secondary forests (Austin et al. 2007). Due to the greater need for forest habitat, landcover type was given a higher weight of 0.5, human population density was weighted at 0.3, and distance to roads remained at 0.2 weight when creating the final resistance surface. Additionally, human-influenced landcover types like agriculture fields were weighted highest for the clouded leopard.

After creating these landscape resistance layers, I calculated least-cost paths between habitat patches for each species using Linkage Mapper 1.1.1. I selected the least cost paths equivalent to the two estimated distances each cat is likely to travel (tiger 100, 250 km; leopard 80, 225 km; clouded leopards 50, 100 km) to maintain realistic connections between patches. Least cost paths are the direction an animal could take to get from one habitat patch to the other with the least accumulated total cost moving through the landscape. Sometimes these are the shortest route, but not always. I reduced habitat patches by 500 meters around all edges to account for edge effects and calculated the linkages from these habitat core areas. These least cost paths illustrate the easiest routes a big cat could travel between habitat patches and visually represent the connections between habitat patches for each species. For example, a tiger will move through forest habitat rather than through a city to get to one patch to another because forest cover has a lower cost than human developments.

Oil Palm

Area suitable for oil palm expansion data was created in a 2016 study based on oil palm crop requirements such as soil and climate (Vijay et al. 2016). Importantly, Vijay and colleagues (2016) did not calculate suitability within protected areas meaning areas suitable for oil palm expansion could be under-represented. Using the dataset, I subtracted the area suitable for oil palm expansion from existing habitat patches for each species. I also subtracted oil palm area from the areas of habitat patch overlap between all three cats to evaluate how much habitat area would be lost if the area were to be developed into oil palm plantations.

I also re-examined the least cost paths for each of the big cats after incorporating the area suitable for oil palm expansion into the resistance layers. I added the area suitable for oil palm expansion to the landcover data layer and assigned it a high cost for all species to reflect the aversion the cats have to oil palm plantations but without making the oil palm an impenetrable barrier. I combined the landcover, human population density, and distance to roads layers into the final resistance layer in the same manner as before.

After creating new resistance layers incorporating the presence of oil palm plantations, I re-ran the least cost path analysis with the same two distance scenarios for each species to assess any differences in path location or length because of the presence of future oil palm expansion areas.

Additional Threats

Oil palm plantation expansion is not the only major challenge that threatens big cats in Southeast Asia. Anthropogenic influences permeate the landscape, so I examined five additional dangers to each species: poaching, forest loss, human population increase, the risk of agricultural expansion, and landcover change.

I used accessibility to cities raster data (Weiss et al. 2018) as a proxy for poaching threat because habitat patches that are easily accessible, or easy to travel to from major population centers, are at a higher risk for people entering these habitat patches in search of the big cats. I examined forest loss that had occurred from 2000 to 2015 (Hansen et al. 2013) to represent the areas that had experienced the greatest percentage of forest canopy loss. I then assumed that these regions would continue to experience additional forest loss. The threat from human population density was examined by calculating the change in density from 2000 to 2015 (GPW v4). I considered areas of greater population increase to be areas that would likely continue to experience the greatest threat due to population increase. To examine the threat of the land conversion to agriculture risk, I used a dataset that quantified this risk, with higher values illustrating areas of higher risk for conversion (Laurence et al. 2014). I examined landcover change threat by using a recent dataset that calculated landcover change from 1992 to 2015 with higher positive values indicating more recent conversion (ESA 2017). Areas of recent conversion were assumed to be areas of highest risk to the big cats.

I buffered tiger, leopard, and clouded leopard habitat patches by 10 km to capture what was occurring immediately outside of the patch because big cats do not necessarily remain within the bounds of these habitat patches used in the analysis. I calculated the mean, median, minimum, maximum, and sum values for each of the five threat rasters within each species' buffered habitat patches. This resulted in threat values within each habitat patch with patches with higher values indicating a patch experiencing greater threat.

I ranked patches according to their mean values for poaching, population increase, and agricultural expansion risk threats. The three patches with the highest mean for each species were considered the patches under highest risk. For the forest loss and landcover change, patches for each species were ranked according to their sum because of the binary nature of the data. The top three patches for each threat were considered the patches experiencing highest threat.

Looking at the areas of overlap of all three big cat habitat patches, I determined the habitat patches threatened by each of the five different threats using the same manner as above. Because the threats are not mutually exclusive, I combined the top three most threatened patches for each threat into one single map to highlight all threatened patches. Many patches ranked in the top three for more than one threat.

Protected Areas

I examined the overlap of the threatened patches for each species with protected areas to determine which threatened patches do not have the benefit of protected area status. I did the same with the threatened patches for all three big cat range habitat patches. Furthermore, I compared the number of total extant habitat patches to the number of top threatened patches for each species and for all big cat habitat.

Results

Within the study area, the tiger has 33 individual habitat patches and 53.7% of the habitat area overlaps with designated protected areas (**Table 1**). The leopard has 17 habitat patches with 31.4% of the habitat area overlapping with protected areas. There are 23 habitat patches for the clouded leopard with 19.1% overlapping with protected areas. Finally, there are 17 habitat patches that are utilized by all three cats and 50.7% of this habitat area overlaps protected areas.

Table 1: Number of habitat patches and the overlap with protected areas for each cat species and the area of habitat overlap for all big cats.

	Tiger	Leopard	Clouded Leopard	Range Overlap of All Big Cats
Total Number Habitat Patches	33	17	23	17
Habitat Overlap with Protected Areas	53.7%	31.4%	19.1%	50.7%

Current State of Connectivity

The subnetwork analysis using the shorter travel distance estimates for each species resulted in a greater number of subnetworks, indicating a lower level of connectivity between patches. Using the larger travel estimates, there was a greater connection across the landscape because the cat would be able to travel further to nearby patches.

There were 10 separate subnetwork groups of habitat patches for the tiger traveling 100 km and there were 3 subnetworks with the larger travel distance of 250 km. There were 13 subnetworks with the leopard traveling 80 km, and 7 subnetworks if the leopard traveled 225 km. There were 15 subnetworks for the clouded leopard traveling 50 km and 10 when traveling 100 km (**Figures 2A, 2B**). The leopard has a high number of separate subnetworks because habitat patches are largely isolated from one another making it difficult for the leopard to travel between many patches in the study area. The clouded leopard also has a greater number of disjunct subnetwork habitat groups because this cat is the smallest of the three and can travel the shortest distance, limiting its ability to move between different areas of habitat.

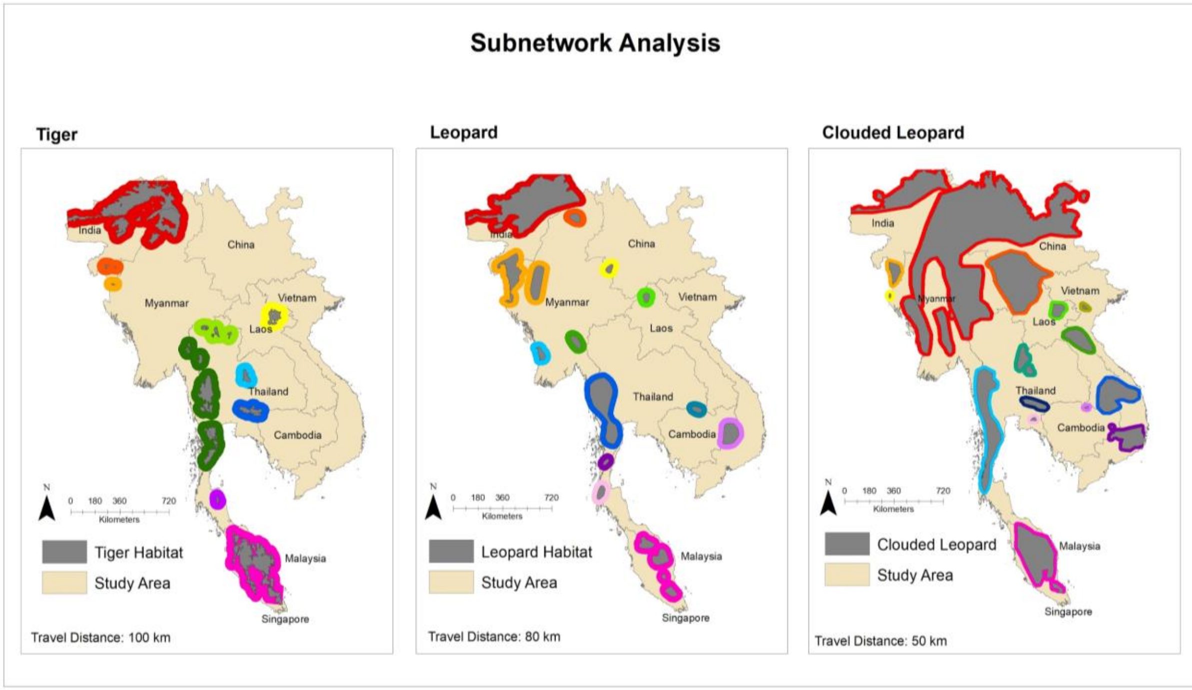

Figure 2A: Habitat patch subnetworks for each species based on a conservative travel distance estimate. Each color buffering the habitat patches indicates a separate subnetwork.

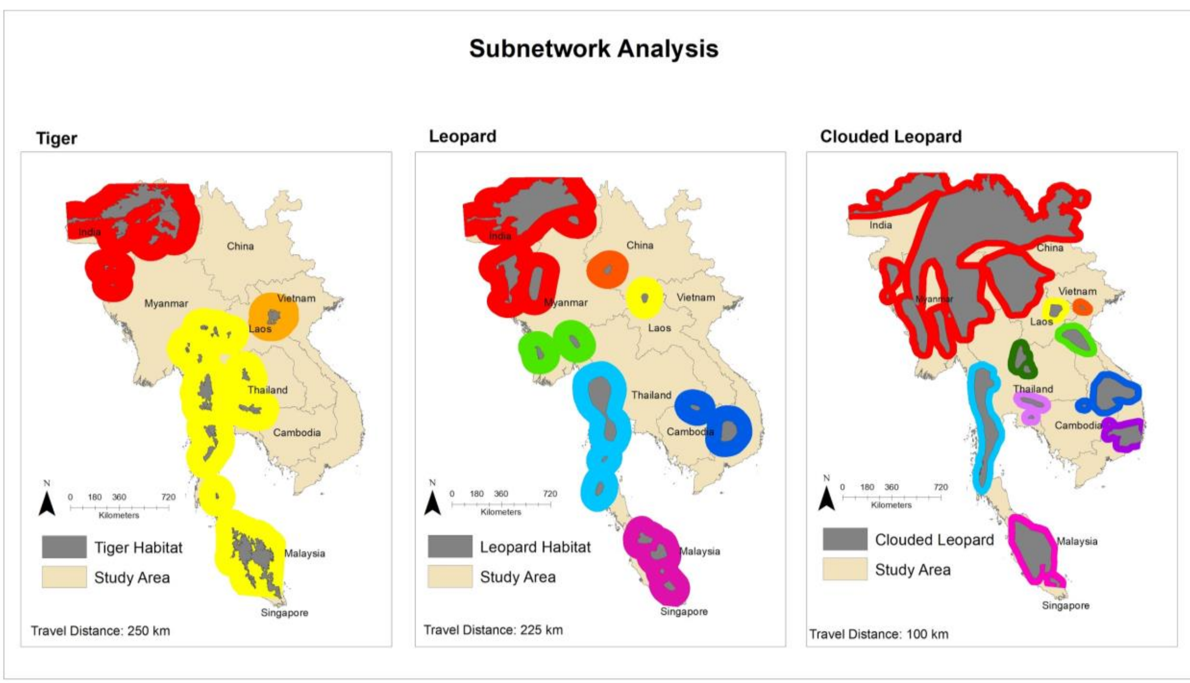

Figure 2B: Habitat patch subnetworks for each species based on a greater travel distance estimate.

Calculating the least cost paths for each species under two different distance scenarios illustrated the easiest traveled routes between habitat patches. For the tiger, there were 25 LCPs at 100 km and 37 LCP at 250 km (**Figure 3**). For the leopard, only 3 LCPs exist at 80 km and 9 at 225 km (**Figure 4)**. For the clouded leopard, 5 LCP exist at 50 km and 9 at 100 km (**Figure 5**). Overall for all species, no connections exist between habitat patches in the Malaysia peninsula and the rest of Southeast Asia.

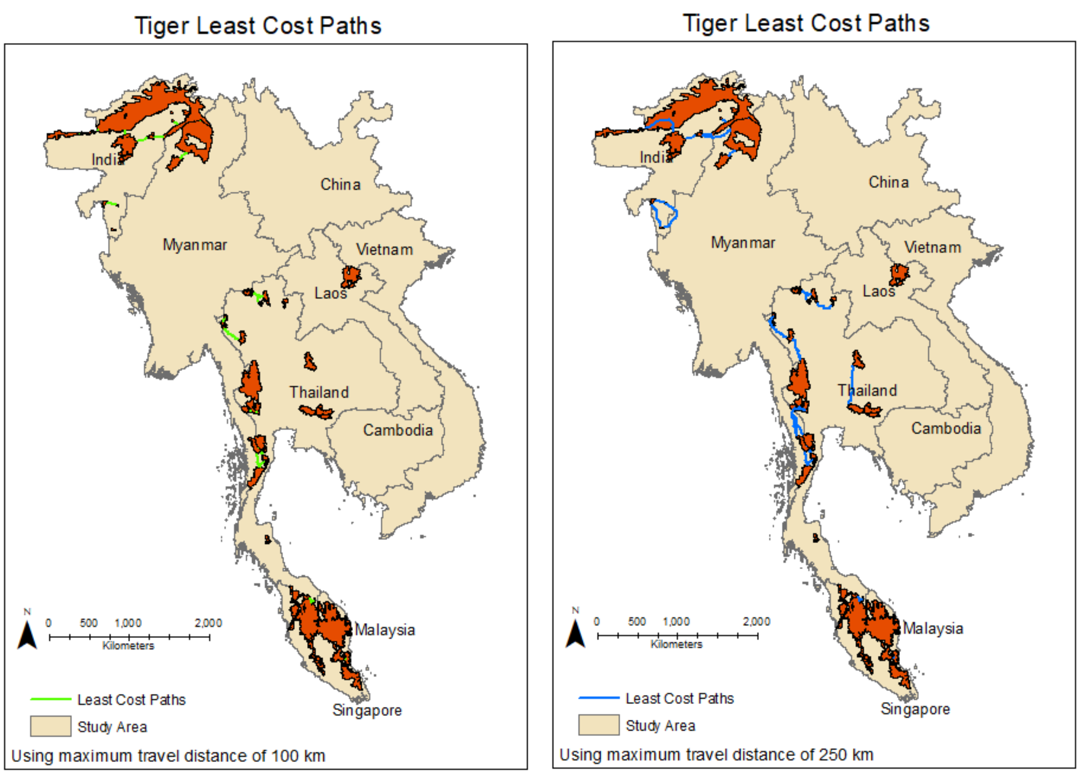

Figure 3: Least cost paths for the tiger with a conservative travel distance of 100 km (left) and a further travel distance of 250 km (right).

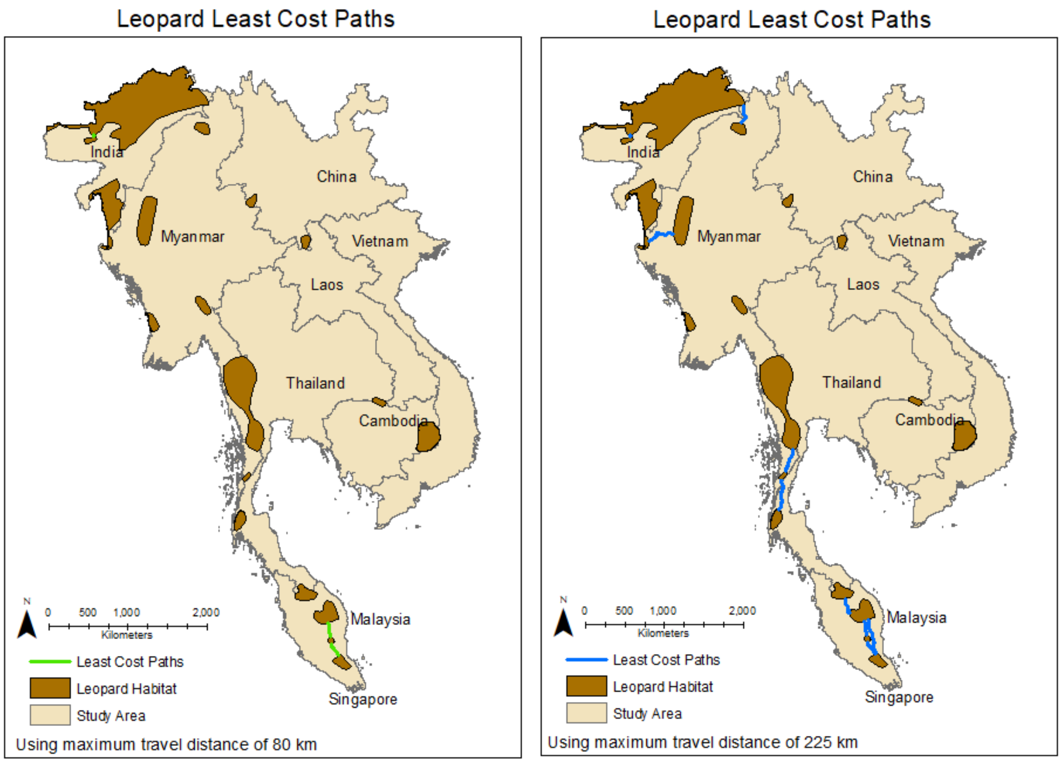

Figure 4: Least cost paths for the leopard with a conservative travel distance of 80 km (left) and a further travel distance of 225 km (right).

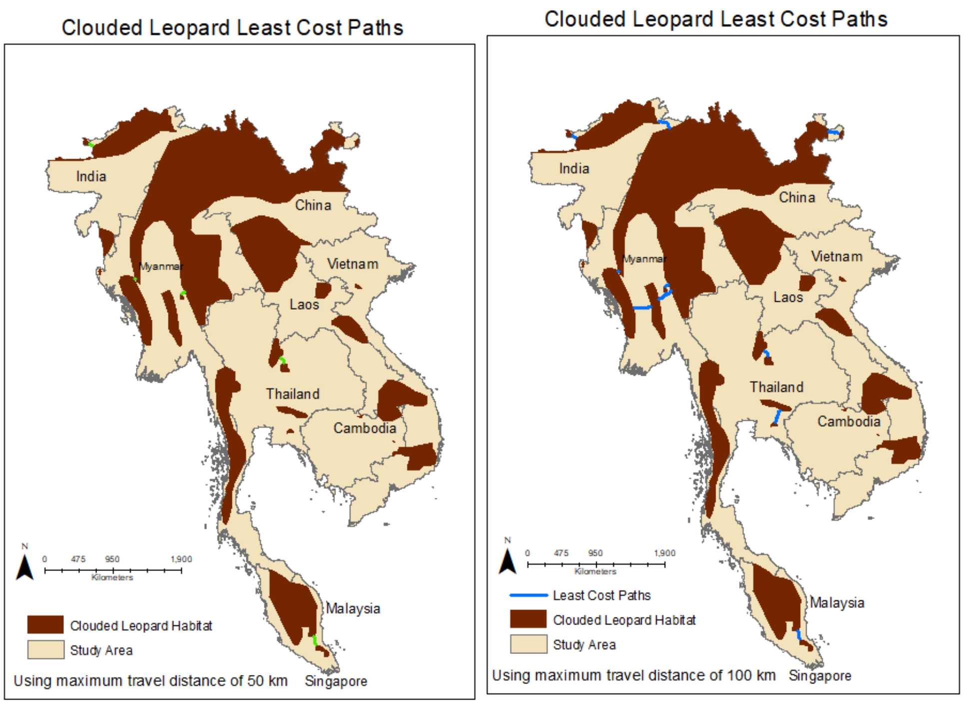

Figure 5: Least cost paths for the clouded leopard with a conservative travel distance of 50 km (left) and a further travel distance of 100 km (right).

Oil Palm

Vijay et al. estimated over 267,000 km^2 would be suitable for future expansion of oil palm in the study area (Vijay et al. 2016). If these areas suitable for oil palm expansion were developed and converted into palm plantations, it would cause a reduction in habitat across the study area for all species. The tiger would experience the greatest loss in current habitat with a decrease of 9.1% (**Table 2**). Much of the habitat decrease would occur in Malaysia where there is a large overlap of oil palm with existing extant tiger habitat (**Figure 6**). The leopard would experience the second greatest loss of habitat at 4.0% with most of the habitat loss occurring in Malaysia as well as Cambodia (**Figure 6**). The clouded leopard would experience the least at 3.6% loss of total habitat area, again with most occurring in Malaysia but also in northern Myanmar and in Laos. When all big cat ranges are overlapped, there would be a 3.7% reduction in habitat area if oil palm were to be expanded with all habitat loss happening in Malaysia (**Figure 7**).

Table 2: Percent area of habitat lost if area suitable for oil palm expansion were to be developed with oil palm plantations.

	Tiger	Leopard	Clouded Leopard	Range Overlap of All Big Cats
Area Lost to Oil Palm Expansion	9.1%	4.0%	3.6%	3.7%

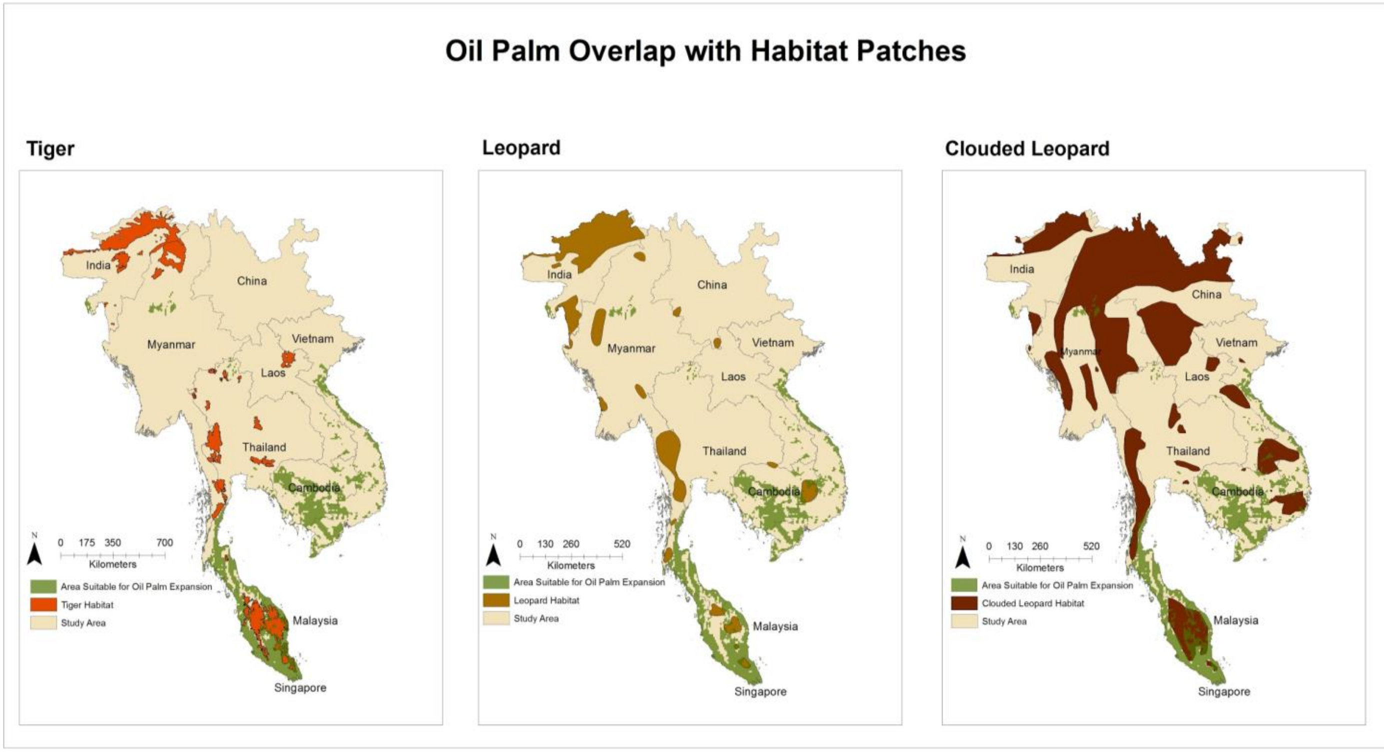

Figure 6: Area suitable for oil palm expansion overlap with each big cat habitat patches.

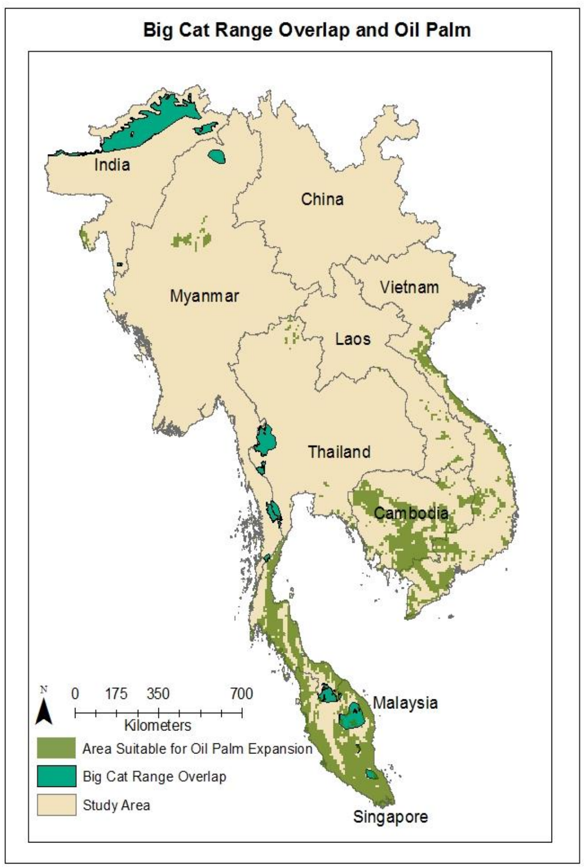

Figure 7: Area suitable for oil palm expansion overlay with big cat range overlap.

Incorporating the areas suitable for future oil palm into the resistance layers did not cause much change in the least cost paths for each species because most of least cost paths occurred in areas that are not suitable for oil palm expansion. However, there was one least cost path for the tiger and the clouded leopard in both travel distance scenarios that would be disrupted by the presence of oil palm. The leopard had two LCPs that would be impacted by the oil palm development at 80 km and three at 225 km (**Table 3**).

Table 3: Least cost paths present for each species under two different travel distance scenarios and how many least cost paths would be impacted by the presence of oil palm.

	Tiger		**Leopard**		**Clouded Leopard**	
Travel Distance	**100 km**	**250 km**	**80 km**	**225 km**	**50 km**	**100 km**
# LCP	25	37	3	9	5	11
# LCP Disrupted by Oil Palm	1	1	2	3	1	1

Additional Threats

The top three most threatened patches in each of the five threats examined were identified (poaching **A Figures 1, 2**, forest loss **A Figures 3, 4**, human population increase **A Figures 5,6**, conversion to agriculture risk **A Figures 7, 8**, and landcover change **A Figures 9, 10**). These top threatened patches were then mapped together to illustrate the patches under greatest threat for each species. For the tiger, the threatened patches were concentrated in eastern India, Northern and southern Myanmar, Laos, and Malaysia (**Figure 8**). For the leopard, threatened patches occurred throughout most of the study area in India, Myanmar, Thailand, and Malaysia (**Figure 8)**. For the clouded leopard, top threatened patches occurred in every country in the study area except Malaysia and Singapore (**Figure 8**).

When all big cat ranges are overlapped, the habitat patches experiencing the highest threats occurred in India, Myanmar, and Malaysia with a majority of these threatened patches occurring in India and Malaysia (**Figure 9)**.

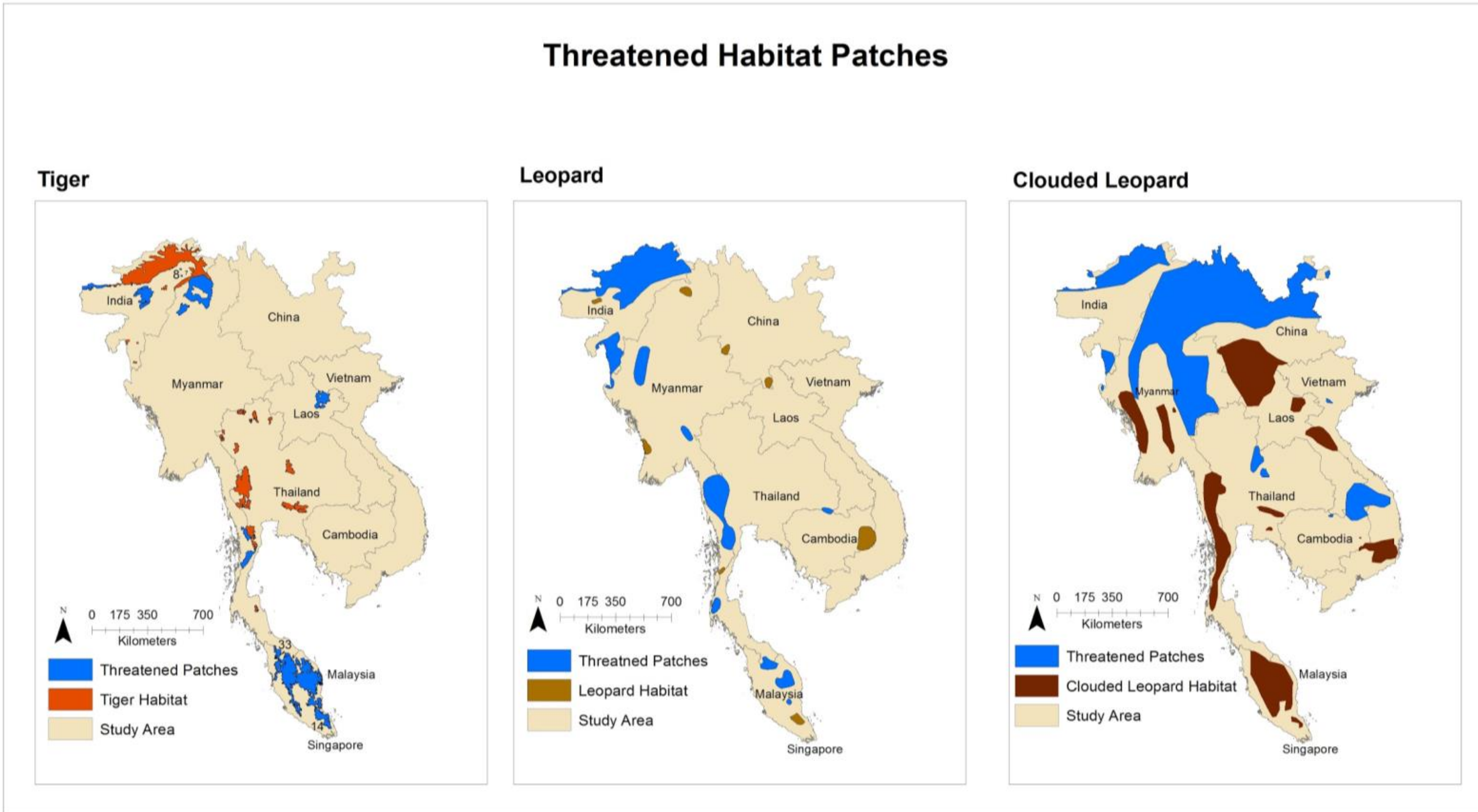

Figure 8: Habitat patches experiencing the most threats for each species.

Comparing the number of total extant habitat patches to the number of top-ranked threatened patches for each species found that 36.4% of tiger habitat patches are threatened (**Table 4**). Of the leopard's habitat patches, 58.8% are threatened and 47.8% of the clouded leopard's patches are threatened. For all big cat habitat, 64.7% of the patches rank as top threatened patches.

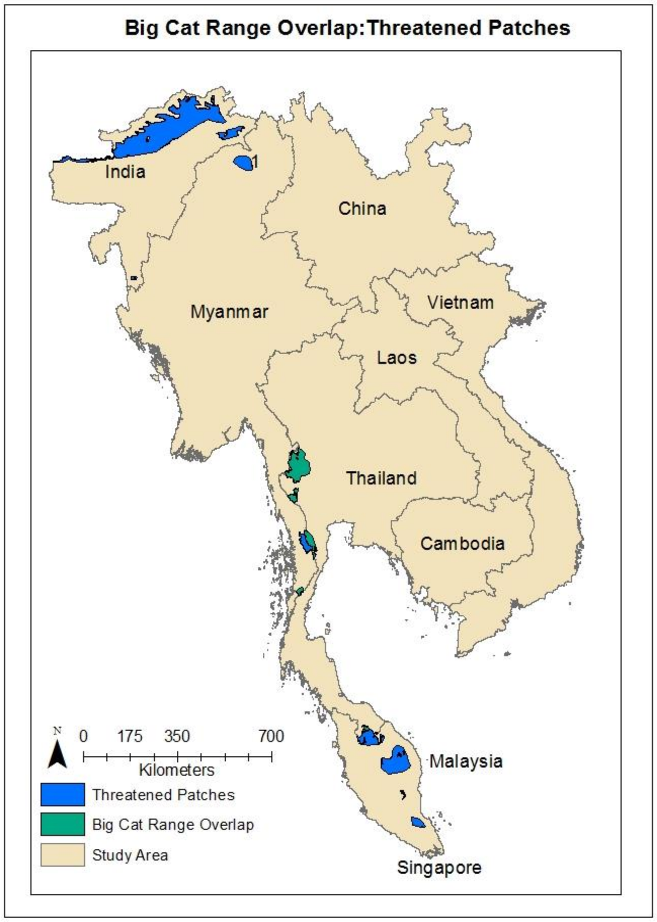

Figure 9: Habitat patches for all big cats experiencing threats.

Table 4: Habitat patches under threat from other disturbances.

	Tiger	Leopard	Clouded Leopard	Range Overlap of All Big Cats
Total Number Habitat Patches	33	17	23	17
Total Number of Threatened Patches	12	10	11	11
% Patches Threatened	**36.4**	**58.8**	**47.8**	**64.7**

Protected Areas

When examining the overlap of protected areas with habitat, the tiger's habitat patches overlap most with protected areas at 53.7% (**Table 4**), with only habitat in India, Laos, and Malaysia not falling within protected areas (**Figure 11**). The leopard had 31.4% overlap between protected areas and habitat. Habitat patches in every country overlap in some ways with protected areas. Yet, unlike the tiger where many habitat patches fall completely in protected areas, leopard habitat patches are much larger than the protected area sections, leaving portions unprotected and at risk for fragmentation (**Figure 10**). The clouded leopard has the smallest amount of overlap of habitat with protected areas at 19.1%. Like the leopard, each patch overlaps with protected areas, but there are large portions of habitat beyond the protected areas (**Figure 10**). For the big cat range overlap, there was a 50.7% overlap with protected areas with a small portion of Malaysia not under protection and much of India not protected (**Figure 11**).

Furthermore, 53.8% of the tiger's most threatened patches do not overlap with protected areas (**Table 5**). 73.2% of the leopard's most threatened patches and 87.3% of the clouded leopards top threatened patches are without the safeguard of protected areas. When overlapping all big cat habitat ranges, 67.3% of the top threatened patches do not overlap with protected areas.

Table 5: Percent area of habitat overlap with protected areas.

	Tiger	**Leopard**	**Clouded Leopard**	**All Big Cats**
Habitat Overlap with Protected Areas	53.7%	31.4%	19.1%	50.7%
Threatened Habitat Without Protected Area Status	53.8%	73.2%	87.3%	67.3%

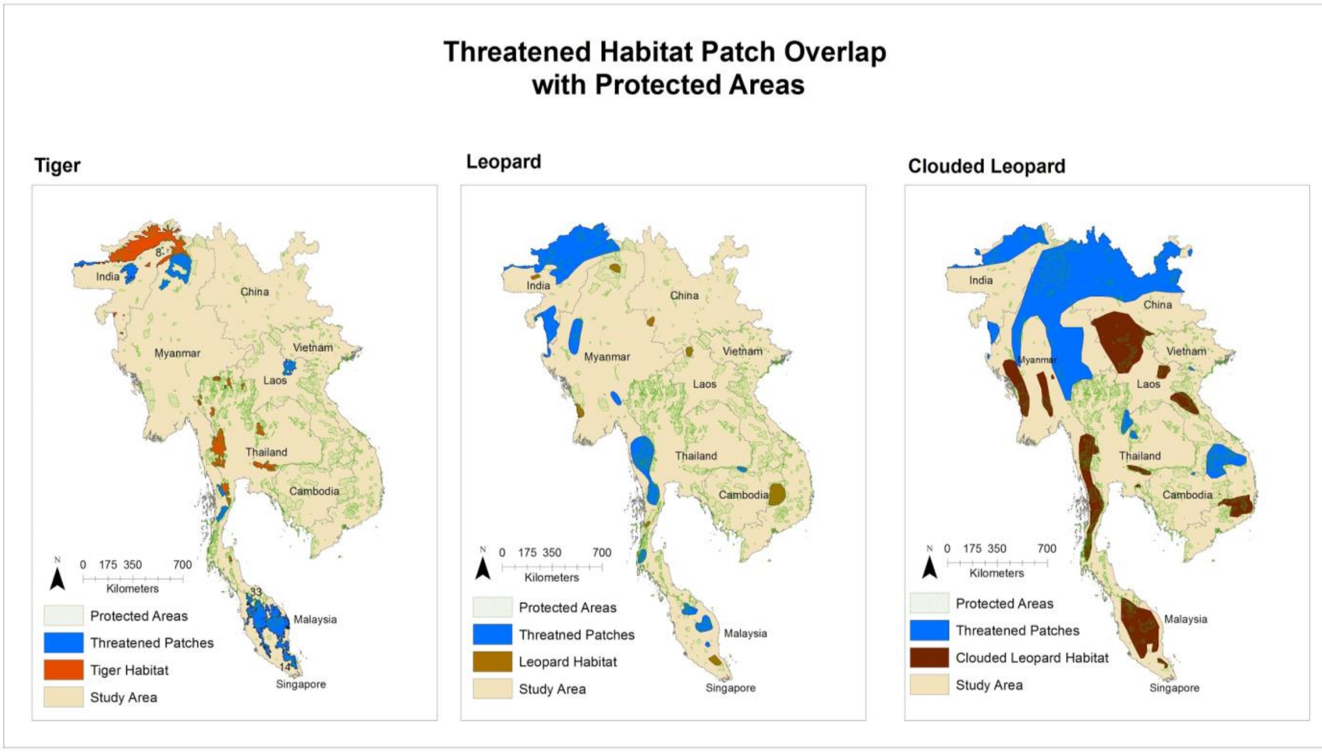

Figure 10: Big cat habitat patch overlap with protected areas.

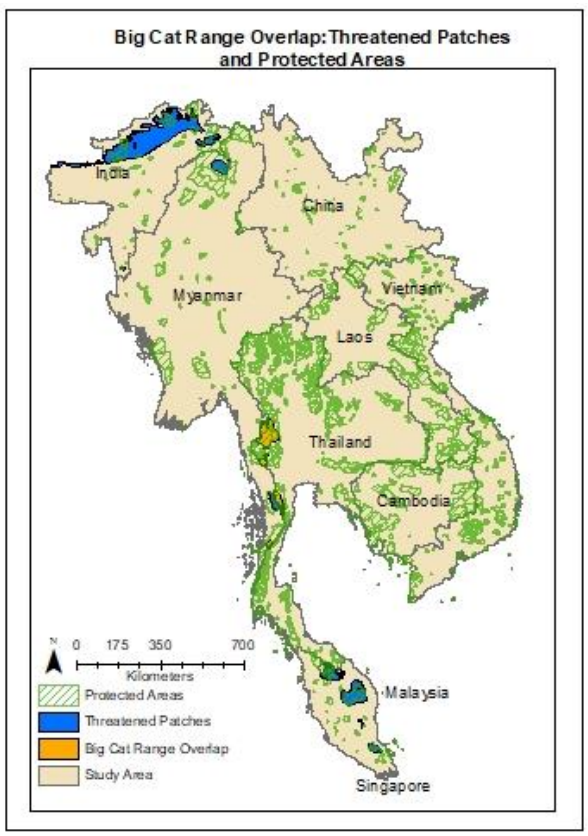

Figure 11: Protected area overlap with all big cat range habitat patches and those patches that have been identified as being most threatened.

Discussion

When examining the extent of habitat patches for the tiger in the study area, the largest areas of habitat exist in eastern India, northern Myanmar, and in Malaysia. There are also smaller habitat patches scattered throughout the remaining countries with none falling within the Yunnan province of China. The largest habitat patches for the leopard occur in India and in Southern Myanmar. The rest of the habitat patches are small and spread across the study area. The clouded leopard's largest patches occur in the north of the study area stretching across India, Myanmar, and China, with other patches throughout the area. When all three cat habitat patches are overlapped, the habitat utilized falls in India, northern and southern Myanmar, Southern Thailand, and Malaysia.

Of the tiger habitat patches, 53.7% of the area overlaps with protected areas, the highest of all three cats meaning more than half of the tiger's habitat is within designated protected areas. Leopard habitat has a 31.4% area overlap with protected areas, and the clouded leopard has a 19.1% overlap meaning these two cats are less reliant on protected areas to provide habitat. Finally, the habitat patches where all three cats exist have a 50.7% overlap with protected areas. It is reasonable then to assume that protected areas play a large role in providing these cats with areas of habitat, with this being most true for the tiger.

Isolated Habitat Patches

My research shows that big cat extant habitat patches in Southeast Asia are largely isolated from one another. However, habitat patch connectivity is dependent on the cat's travel distance because there is greater connectivity when using a larger travel distance. Isolated habitat patches put wildlife at risk for inbreeding, degradation of genetic diversity, and a higher chance for local extinction, so maintaining connections between habitat patches is essential for these big cats (Thatte 2018).

Least cost paths provide a visualization of the easiest travel route between habitat patches. This, in turn, illustrates habitat patches that are clustered together into functionally connected subnetworks and areas that are isolated where species have a lower likelihood of traveling to other patches. In this study, while there are some habitat patches connections particularly under greater travel distance scenarios, the habitat patches for all big cats remain largely isolated from one another as illustrated by the low number of LCPs across the landscape. Overall, habitat patches in Peninsular Malaysia are disconnected from habitat patches further north in the study area.

Few studies have documented travel distances of the big cats in the study region, so this study is limited to using studies of only a few individuals studied in other landscapes or based on expert's best estimates. This is important because there is limited information about the dispersal of these three big cats, and these travel distances differ from normal movement patterns that have been documented for felids such as the of African lion (Elliot et al. 2014). Therefore, the resistance surfaces were utilized to best estimate big cat movement between habitat patches by incorporating landscape features that impact their movement behavior (Zeller 2012).

No Primary Threat from Oil Palm

Oil palm expansion is primarily limited to the southern portion of the study area in Malaysia, and southern Cambodia and Vietnam, barring changes to the plant or from climate change. Only small patches of suitable big cat habitat exist in these regions predicted to be suitable for oil palm expansion. Therefore, this study found only a small portion of habitat would be lost to the development of oil palm and very few least cost path connections would be disrupted. Hence, oil palm is not the biggest threat to big cat habitat and connectivity when considering the entire study area. Yet, habitat for all big cats is under the greatest threat from future oil palm expansion in Malaysia because this is where most least cost paths and habitat patches overlapped with areas suitable for oil palm.

However, this analysis examining the differences in the least cost paths before and after the development of oil palm is a limited way to illustrate the impacts of oil palm on the connectivity in the region because least cost paths only illustrate one travel route between habitat patches. In reality, there are numerous ways a cat could travel between patches that could be impacted by the development of oil palm, but it is not captured here.

In addition, the area suitable for oil palm expansion is limited because it excluded protected areas (Vijay et al. 2016). Countries have different definitions and enforcement policies that could change given certain political pressures. Changes in protected area status could mean area considered ‘protected’ could be developed into oil palm, so the area of oil palm expansion is likely under-represented here causing the threat to big cats to be underestimated.

Identifying Most Threatened Areas

Additional threats to big cats include poaching, forest loss, human population increase, conversion to agriculture, and landcover change. Tiger habitat patches are most threatened in eastern India, northern and southern Myanmar, Laos, and all habitat patches in Malaysia. Leopard habitat is threatened throughout the landscape in India, Myanmar, on the border between Thailand and Cambodia, in Thailand, and in Malaysia. Clouded leopard habitat is most threatened in the northern region of the study area in India, China, Myanmar, Thailand, Vietnam, and Cambodia. Malaysia is not one of the top ranking threatened patches for the clouded leopard, unlike the tiger and leopard, because other clouded leopard habitat patches have experienced greater forest loss than the patch in Malaysia. For instance, habitat in Vietnam and Thailand have experienced greater amounts of forest loss and these are areas where tiger and leopard habitat patches do not exist. Finally, for all big cats, most threatened patches are in eastern India, northern and southern Myanmar, and throughout Malaysia.

When looking at the total number of extant habitat patches for each species and the percentage of patches ranking as most threatened, the leopard has the greatest amount of threatened habitat patches with over half of the patches being under threat. The clouded leopard's habitat patches are just under 50% threatened, and the tiger has the lowest percentage of habitat patches under threat at 36%. When all big cat habitat is overlapped, almost 65% of the habitat utilized by all three cats ranks as most threatened. This illustrates that the majority of almost all big cat habitat is highly threatened by various anthropogenic pressures.

These most threatened patches are indications of areas that have experienced either the greatest change in the past several years or currently are experiencing the greatest anthropogenic influences. This information can be used to inform decisions about what areas should be prioritized for habitat protection for each species or for all three species. While most threatened is different from highest priority, information about the areas experiencing greatest threats is a critical component when deciding areas of highest conservation priority. Additional information about the political situation of the country, resources available, and stakeholder preferences are also important when making decisions about conservation priority areas.

Threatened Habitats Lack Protection

Information about the overlap of habitat patches and the most threatened patches with protected areas also provides decision-makers with valuable information about the prioritization of protection of these areas. More than 50% of the tiger's most threatened patches do not lie within protected areas leaving over half of the tiger's extant habitat in Southeast Asia without protection from encroachment from humans. The leopard has almost three-quarters of its threatened habitat without protected area overlap, and the clouded leopard has lover 80% of its threatened habitat patches lacking protected area status. When overlapping all big cat ranges, 67% of the threatened habitat is lacking this overlap with protected areas. This information about the lack of overlap of threatened patches with protected areas can inform decisions about what areas are most threatened and where protection should be extended.

Previous research examining the past impact of oil palm on wildlife in Southeast Asia have been specific to individual countries or regions within one country. This research not only looks at a larger, landscape view of Southeast Asia, it also examines the future impact of oil palm expansion. Since this area has not yet been developed into oil palm, this information could assist in the halting of further deforestation due to the expansion of oil palm. Although oil palm was not identified as the major threat to big cats in this region, oil palm development would still cause a decline in habitat for species that have already experienced tremendous habitat loss. Therefore, information about the impact of future oil palm expansion and additional threats to the big cats provides valuable knowledge for conservation efforts for protecting tigers, leopards, and clouded leopards from additional anthropogenic influences.

Recommendations

Given the habitat loss in Malaysia that would result from the development of oil palm, we recommend that efforts should be made to protect this region from further expansion of oil palm plantations.

If threat conditions are maintained, we would also recommend that habitat in India, Myanmar, and Malaysia be protected because these areas support all three big cat species and are under greatest anthropogenic threat.

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Appendix

A Table 1: Values used to assign cost values to different landcover types according to each species habitat preferences.

ID	Landcover	Tiger Cost Values	Leopard Cost Values	Clouded Leopard Cost Values
0	No data			
1	Oil palm expansion area	900	900	900
10	Cropland, rainfed	800	700	800
11	Cropland, rainfed	800	700	800
12	Cropland, rainfed	800	700	800
20	Irrigated cropland	900	800	900
30	Mosaic cropland >50%/ natural vegetation	500	400	600
40	Mosaic natural veg/ cropland <50%	400	300	500
50	Tree cover, broadleaved, evergreen, closed to open	1	1	1
60	Tree cover, broadleaved, deciduous, closed to open	1	1	1
61	Tree cover, broadleaved, deciduous, closed to open	1	1	1
62	Tree cover, broadleaved, deciduous, closed to open	1	1	1
70	Tree cover, needle-leaved, evergreen, closed to	1	1	1

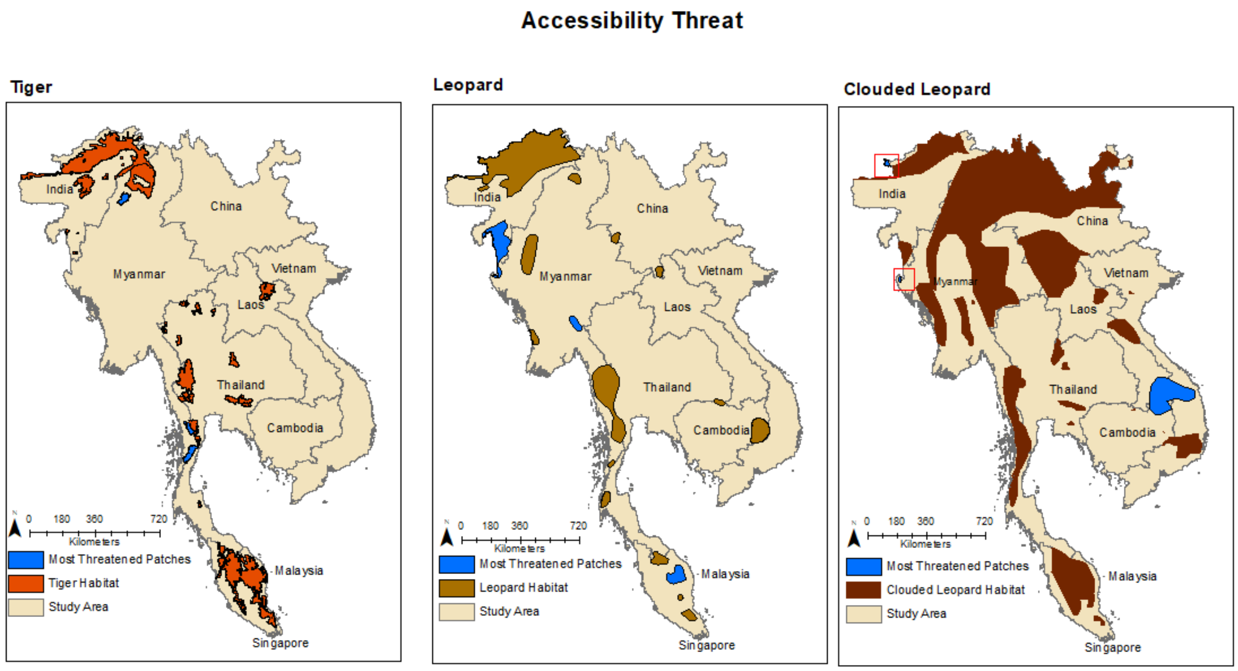
	open			
71	Tree cover, needle-leaved, evergreen, closed to open	1	1	1
72	Tree cover, needle-leaved, evergreen, closed to open	1	1	1
80	Tree cover, needle-leaved, deciduous, closed to open	1	1	1
81	Tree cover, needle-leaved, deciduous, closed to open	1	1	1
82	Tree cover, needle-leaved, deciduous, closed to open	1	1	1
90	Tree cover, mixed leaf type	1	1	1
100	Mosaic tree and shrub > 50%/ tree and shrub <50%	100	50	200
110	Mosaic herbaceous cover >50%/ tree and shrub <50%	100	50	300
120	Shrubland	100	50	200
121	Shrubland	100	50	200
122	Shrubland	100	50	200
130	Grassland	100	100	200
140	Lichens and mosses			
150	Sparse vegetation (tree, shrub, herbaceous)	100	50	300
151	Sparse vegetation (tree, shrub, herbaceous)	100	50	300
152	Sparse vegetation (tree, shrub, herbaceous)	100	50	300
153	Sparse vegetation (tree, shrub, herbaceous)	100	50	300
160	Tree cover, flooded, fresh or brackish	400	500	600
170	Tree cover, flooded, saline water	600	600	600
180	Shrub or herbaceous cover, flooded, fresh-saline or brackish	700	700	700
190	Urban	1000	1000	1000
200	Bare areas	600	600	600
201	Bare areas	600	600	600
202	Bare areas	600	600	600
210	Water	300	300	600
220	Permanent snow and ice	800	800	800

A Table 2: Values used to assign a cost to different distances to roads for each species.

Distance (m)	Tiger Cost	Leopard Cost	CL Cost
0-100 m	1000	1000	1000
100-200	900	900	900
200-300	900	900	900
300-400	900	900	900
400-500	800	800	800
500+	1	1	1

A Table 3: Values used to assign a cost to different human population densities for each species.

Density (people/1km2)	Tiger Cost	Leopard Cost	CL Cost
0-5	1	1	1
5-10	100	100	100
10-20	300	300	300
20-25	700	700	700
25+	1000	1000	1000



A Figure 1: Habitat patches under greatest threat from poaching accessibility.

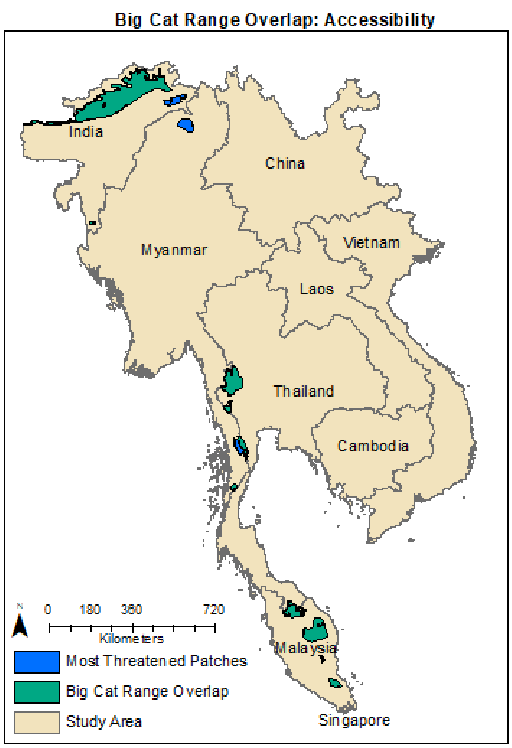
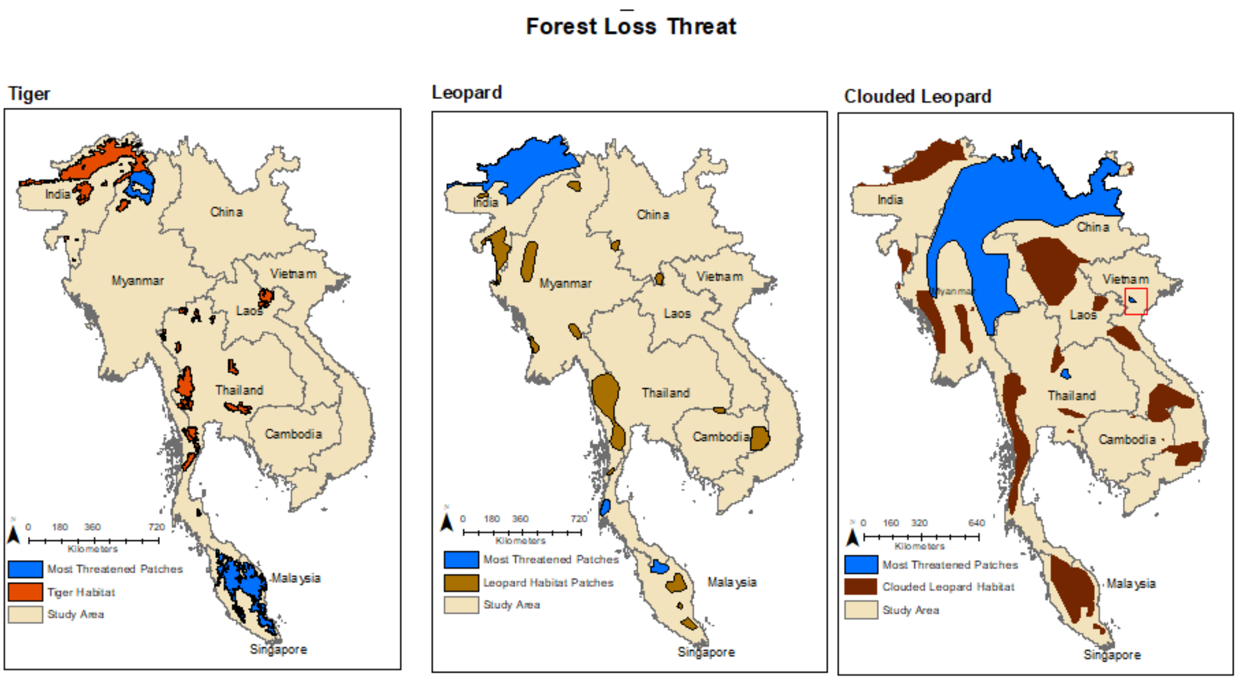
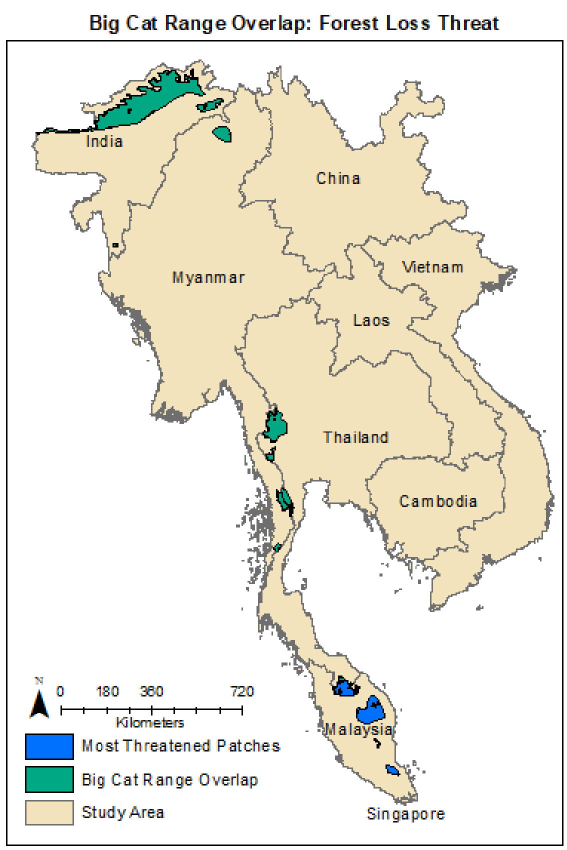


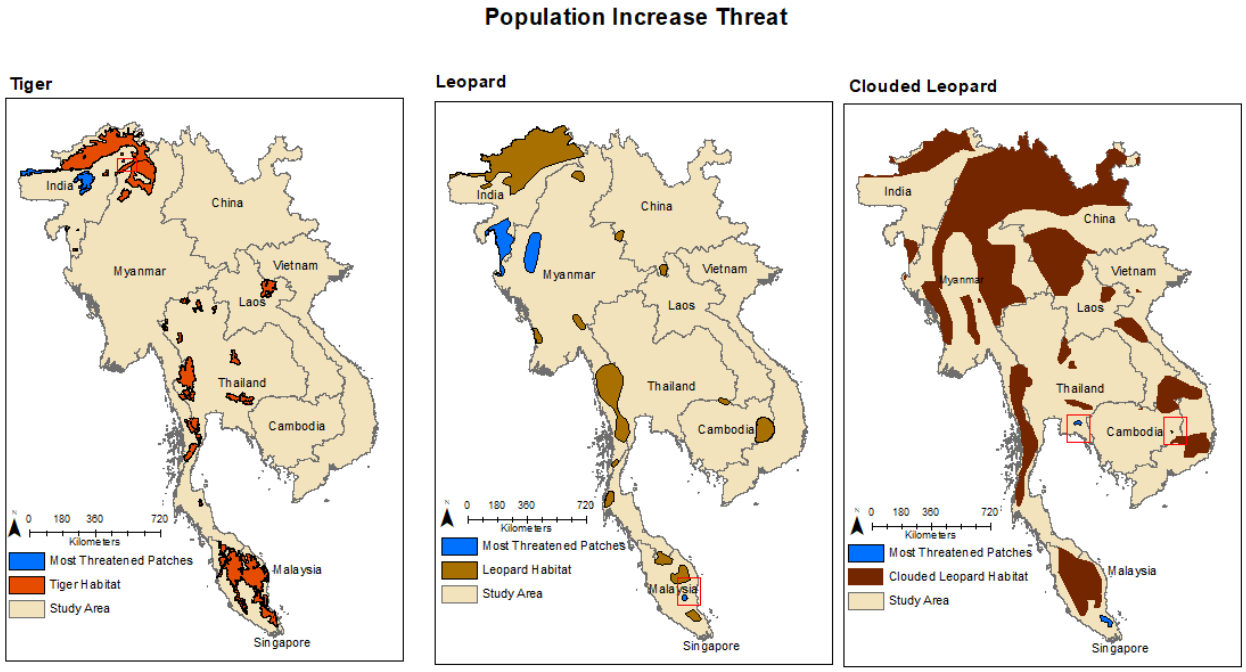
Figure 2: All big cat range overlap patches under the greatest threat due to accessibility used as a proxy for poaching.



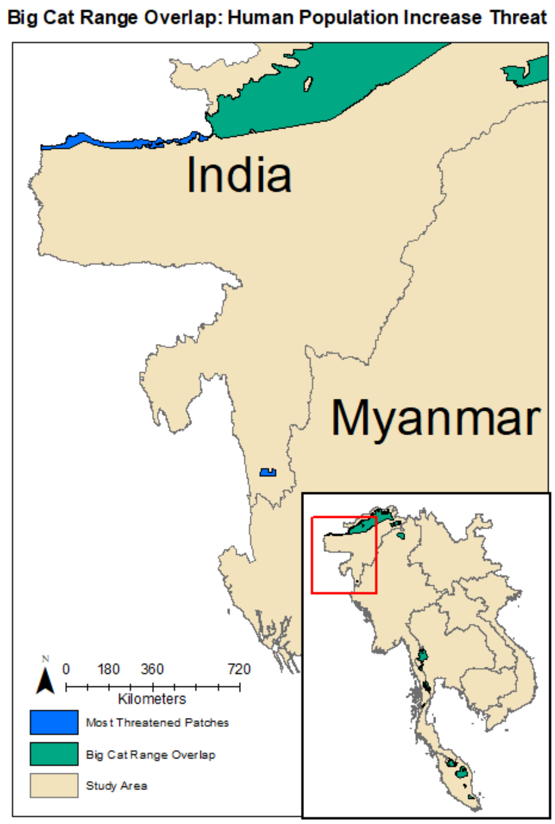
A Figure 3: Habitat patches under greatest threat from forest loss.



A Figure 4: All big cat range overlap patches under the greatest threat due to forest loss.

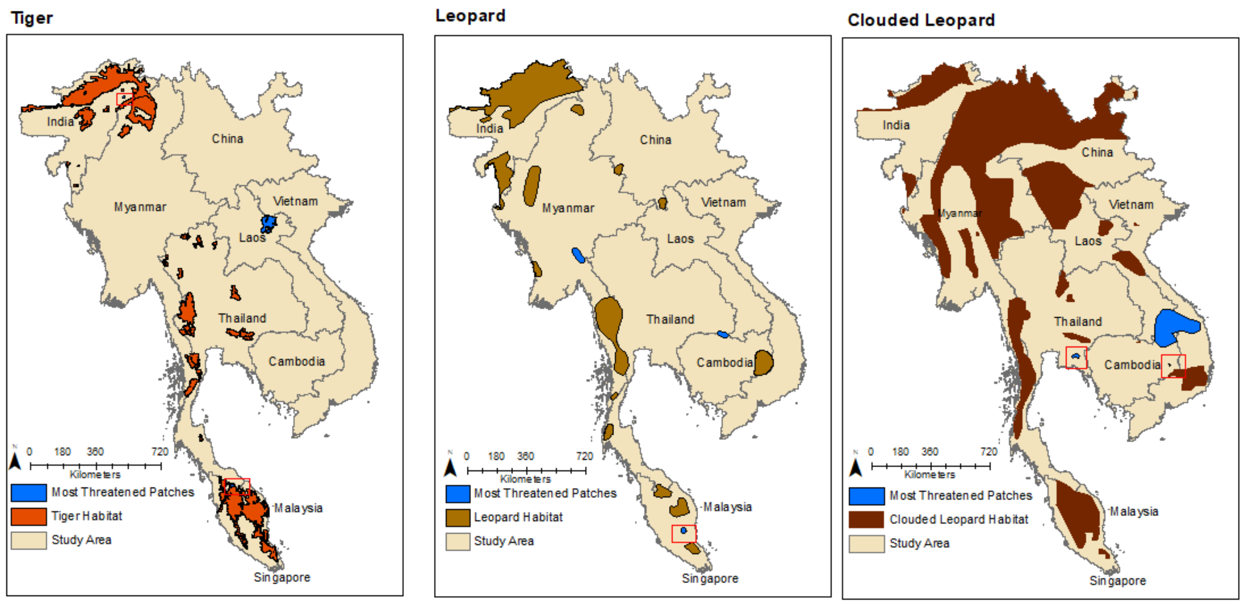


A Figure 5: Habitat patches under greatest threat from human population increase.



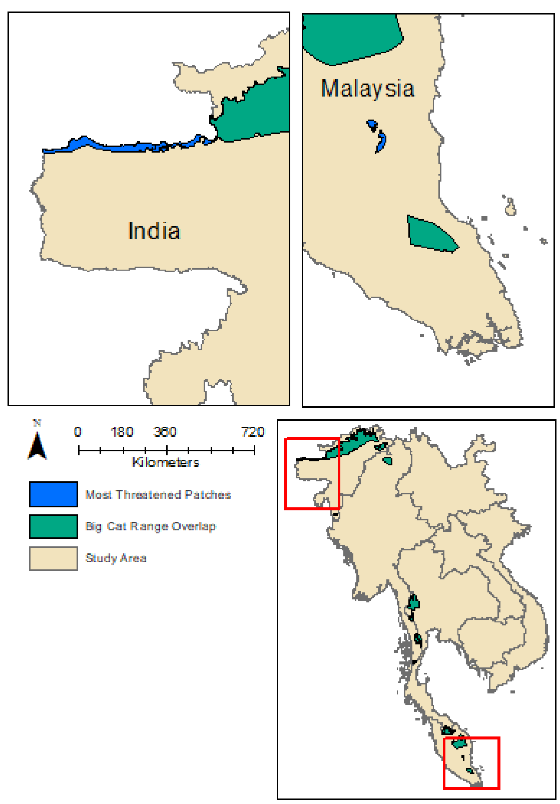
A Figure 6: All big cat range overlap patches under the greatest threat due to human population increase.

Agriculture Expansion Threat

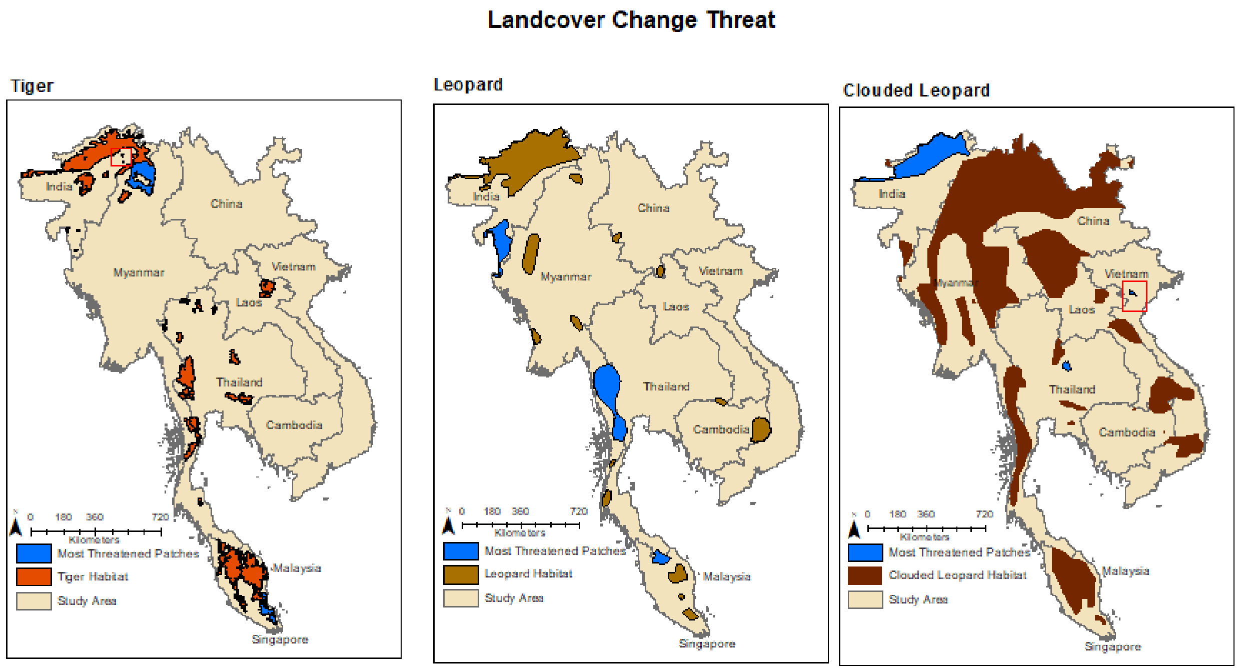


A Figure 7: Habitat patches under greatest threat from agricultural expansion.

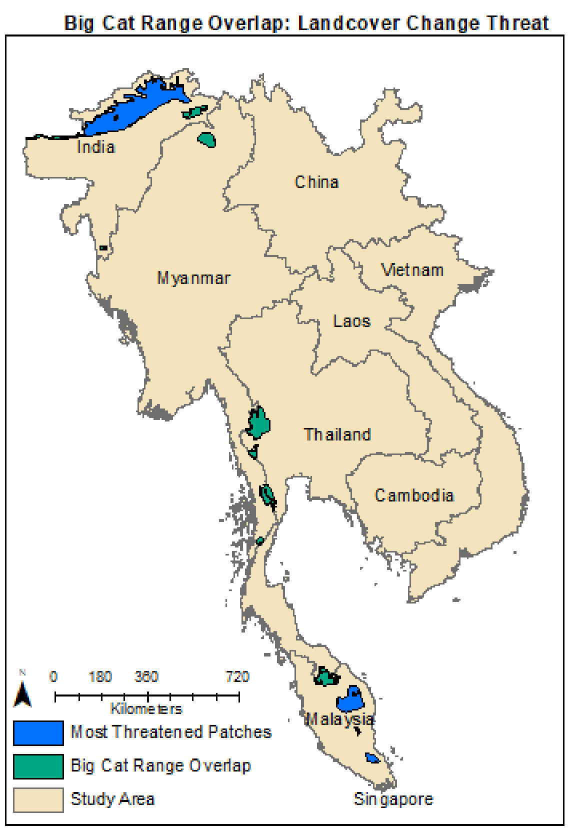
Big Cat Range Overlap: Agriculture Expansion Threat



A Figure 8: All big cat range overlap patches under the greatest threat due to conversion to agriculture.



A Figure 9: Habitat patches under greatest threat from landcover change.



A Figure 10: All big cat range overlap patches under the greatest threat due to conversion to agriculture.