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An assessment of habitat connectivity for the endangered Malayan tapir in Thailand

Damisa Kaminsin and Naparat Suttidate*
Walailak University, Department of Biology, School of Science, Thasala District, Nakhon Si Thammarat, Thailand
Corresponding author e-mail: naparat.st@wu.ac.th*

Abstract: The Malayan tapir (Tapirus indicus) is threatened by habitat loss and fragmentation, causing populations to become small and isolated. An assessment of habitat connectivity patterns is crucial for the survival of the species because connectivity facilitates species movement and gene flow. Our goal was to identify habitat connectivity networks for the Malayan tapir in Thailand. We first defined suitable habitat for tapirs using satellite data: evergreen and deciduous forest patches with the minimum patch size of 13 km2 (average home range size), elevation, slope, and mean annual precipitation. We then applied circuit theory analysis to assess potential dispersal corridors using Circuitscape software. We identified 38 suitable habitat forest patches and 13 potential dispersal corridors for tapirs in Thailand. We found that Khlong Saeng-Khao Sok forest complex was well connected with average habitat patch size of 2,247.78 km2. In contrast, Chumphon forest complex was the most fragmented forest complex with the highest number of suitable habitat patches and potential dispersal corridors. In addition, we found ten potential dispersal corridors within the forest complexes, while there were three potential dispersal corridors between Western – Kaeng Kra Chan, Kaeng Kra Chan – Chumphon and Chumphon – Khlong Saeng – Khao Sok. The results provide better understanding of the current pattern of habitat connectivity networks and a guideline for priority areas for conservation planning. We highlight that an assessment of habitat connectivity pattern can be applied as a wildlife management tool to assist conservation efforts for the Malayan tapir and other endangered mammals in the region.

Keywords: Circuit theory, Conservation, Corridor, Habitat connectivity, Mammal

Introduction

The Malayan tapir (Tapirus indicus) is a globally endangered species (IUCN, 2016). It is also listed as an endangered species in the Wild Animal Reservation and Protection Act, B.E. 2535 of Thailand and as Appendix I status in the Convention on International Trade in Endangered Species (CITES) appendices (CITES, 2017). The Malayan tapirs is a frugivore and is one of the most important seed dispersal mammals in tropical forest ecosystems. Malayan tapirs help to decrease plant competition, increasing survival rates of seeds, and decreasing the impacts of disease. Therefore, the Malayan tapir plays a crucial role in plant communities and tropical biodiversity. Currently, tapir populations have declined rapidly due to anthropogenic activities, such as habitat loss and fragmentation, caught by chance, hunting, and road accidents (Corlett, 2007; Holden et al., 2003). Specifically, habitat loss and fragmentation can fracture a population into at-risk sub-populations. A small, isolated sub-population within a habitat patch is more likely to become locally extinct due to limited movement between suitable habitats and low genetic variation among sub-populations (de la Torre, et al., 2017). Thus, the survival of Malayan tapirs in fragmented landscapes depends upon maintaining connectivity between isolated populations (Fahrig & Merriam, 1985; Noss et al., 1996; Taylor et al., 1993).

Habitat connectivity is the connectedness between patches of suitable habitats to facilitate movement for a given species (Lindenmayer & Fischer, 2013). The importance of habitat connectivity is to maintain a specie's home range, enhance gene flow among sub-populations, increase the opportunity for adaptation in response to environmental changes, and mitigate the risk of extinction (Brodie et al., 2015; McRae et al., 2008; Sulistyawan et al., 2017). In addition, connectivity plays a crucial role in conservation planning where the goal is often to preserve resilient habitat networks, and design linkages of high-quality habitat (i.e., dispersal corridors) between remnant patches or protected areas (Soule & Terborgh, 1999). Habitat connectivity has been successfully applied in conservation planning for species in many regions, such as deer (Odocoileus hemionus) in California and Arizona (Beier et al., 2006), jaguars (Panthera onca) in Mexico (de la Torre et al., 2017), and pandas (Ailuropoda melanoleuca) in China (Sulistyawan et al., 2017; Wang et al., 2014). Despite the advancements in theory and application, the assessment of habitat connectivity for Malayan tapirs has not yet been studied in Thailand which hampers conservation efforts (Lynam et al., 2012). Broad-scale conservation planning for Malayan tapirs cannot be successful without identifying suitable habitat patches, dispersal corridors, and an effective assessment of a connectivity network that can maintain the viability of tapir populations and facilitate gene flow among populations (Lynam et al., 2012).

The goal of our study was to identify habitat connectivity networks for the Malayan tapir in Thailand. First, we defined suitable habitat patches for Malayan tapirs, and then evaluated the patterns of habitat connectivity using circuit theory.

Materials and Methods

Study area

Our study area included 35 protected areas in seven forest complexes, Thailand where the Malayan tapir populations occupy: (1) Western forest complex (Kamphaeng Phet, Tak, Nakhon Sawan, Kanchanaburi, Suphan Buri, and Uthai Thani Provinces); (2) Kaeng Kra Chan forest complex (Prachuap Khiri Khan, Ratchaburi and Phetchaburi Provinces); (3) Chumphon forest complex (Pratap Khiri Khan, Ranong and Chumphon Provinces); (4) Khlong Saeng-Khao Sok forest complex (Surat Thani, Ranong, Phang Nga, Chumphon and Ranong Provinces); (5) Khao Luang forest complex (Nakhon Si Thammarat Province); (6) Khao Banthad forest complex (Phattalung, Trang, Satun and Songkhla Provinces); and (7) Hala Bala forest complex (Yala, Narathiwat, and Pattani Provinces) (Kanchanasaka 2015). Preferred forest habitat areas for the Malayan tapir are evergreen and deciduous forests with an approximate total area of 22,803 km^2 (Figure 1).

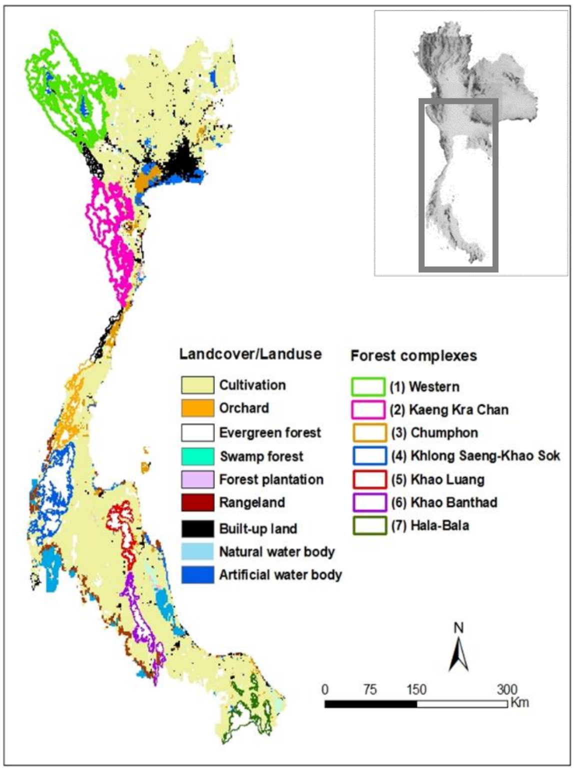

Figure 1. Study area covered evergreen and deciduous forest patches with an average area greater than 13 km^2 was shown in white with seven forest complex boundaries.

Identifying Malayan tapir's habitat patches

To identify habitat patches for Malayan tapirs in Thailand, we employed four habitat requirement variables from satellite data: habitat types, elevation, slope, annual precipitation. we defined suitable habitat patches as the following criteria:

(1) Evergreen forest and deciduous forest patches with a minimum habitat patch size of 13 km^2 based on average home range size for tapirs in Thailand (Lynam et al., 2012; Williams & Petrides, 1980). Evergreen forest and deciduous forest data were obtained from the land use and land cover map of Thailand for the year 2016 derived by the Land Development Department, Thailand.

(2) Suitable elevation for the Malayan tapir was < 1,500 meters. We derived elevation data from the CGIAR - Consortium for Spatial Information (http://srtm.csi.cgiar.org)

(3) Suitable slope for the Malayan tapir was from 0° to 30°. We derived the slope data by transforming the elevation data to degree slope using spatial analyst tool in ArcGIS version 10.2.1.

(4) Annual precipitation for the Malayan tapir differed among regions in Thailand. Accordingly, we assigned mean annual precipitation in southern forest complexes (i.e., Chumphon FC, Khlong Saeng - Khao Sok FC, Khao Luang FC, Khao Banthad FC, and Hala Bala FC) to a minimum of 3,500 mm. On the other hand, mean annual precipitation in western forest complexes (Kaeng Kra Chan FC and Western FC) was assigned to a minimum

of 2,500 mm. Annual precipitation was obtained from WorldClim version 2 (http://worldclim.org/version2) (Fick & Hijmans, 2017).

We prepared all habitat data in raster format with 1-km resolution because it is a proper resolution for spatial analysis of mammals in Thailand (Lynam et al., 2012). We analyzed suitable habitat patches for the Malayan tapir using ArcGIS program version 10.2.1.

Assessing habitat connectivity for Malayan tapirs

To evaluate potential dispersal corridors for the Malayan tapir, we used Circuitscape software version 4.0 (McRae et al., 2008). Circuitscape applies electrical circuit theory and random walk theory to calculate pairwise resistances and create maps of current flowing between focal nodes (McRae et al., 2008). Circuitscape requires two inputs: (1) a resistance map (i.e., land use and land cover with a degree of movement resistance for Malayan tapirs); and (2) a focal node map (i.e., forest habitat patches). We prepared the resistance map by assigning resistance values to each land use and land cover raster, ranking from 1 to 100. We assigned lowest resistance values to forest habitat: evergreen and deciduous forest patches. Higher resistance values were assigned to other natural habitats: swamp forest, rangeland, marsh and swamp, and small natural water body. Highest resistance values were assigned to agricultural areas, such as forest plantation, and orchards (Table 1). For complete barriers, we assigned them as no data areas (i.e., settlements, roads, perennial agricultural areas, and large water bodies). Circuitscape created current maps between pairs of forest patches using pairwise analysis and iterated all pairs into focal nodes (McRae, et al., 2013).

Table 1. Resistance values assigned to create the resistance map.

Category	Resistance score
Evergreen forest	1
Deciduous forest	1
Swamp forest	20
Forest plantation	30
Rangeland	40
Marsh and swamp	50
Small natural water body	60
Agricultural areas	100

Result & Discussion

We identified 38 potential suitable forest patches in seven forest complexes with approximately an area of 23,731 km^2 and average patches size of 625 km^2 (Table 2). Chumphon forest complex had the highest number of forest habitat patches, while Khao Luang and Khlong Saeng - Khao Sok had the lowest number of forest habitat patches. Additionally, we found large forest habitat patches (> 625 km^2) in Western, Kaeng Kra Chan, Khao Luang and Khlong Saeng-Khao Sok forest complexes. In contrast, we found many small forest habitat patches (< 625 km^2) in the Chumphon, Hala-Bala, and Khao Banthad forest complexes (Table 2). In addition, we found that Western and Kaeng Kra Chan forest complexes had seven forest patches which included both evergreen and deciduous forest habitat types. On the other hand, we found that suitable forest habitat patches in the south of Thailand were only evergreen forests due to high rainfall and humidity (Kanchanasaka, 2015; Lynam et al., 2012).

We also identified 13 potential dispersal corridors: 10 dispersal corridors within the forest complexes (Table 3), and three dispersal corridors between forest complexes: (A)Western forest complex – Kaeng Kra Chan forest complex; (B) Kaeng Kra Chan forest complex – Chumphon forest complex; (C)Chumphon forest complex – Khlong Saeng – Khao Sok forest complex (Figure 2).

Table 2. Suitable forest patches for the Malayan tapir in Thailand.

Forest complex	Number of patches	Mean patches size (km^2)
Chumphon	9	169.07
Hala Bala	8	241.04
Western	7	998.70
Kaeng Kra Chan	6	915.41
Khao Banthad	3	504.34
Khao Luang	3	596.47
Khlong Saeng – Khao Sok	2	2,247.78
Total	38	625

Table 3. Potential dispersal corridors within forest complexes for the Malayan tapir in Thailand.

Forest complex	Number of corridors
Chumphon	4
Namtok Ngao NP - Lam Nam Kraburi NP	
Namtok Ngao NP - Tungraya-Nasak WS	
Tungraya-Nasak WS - Prince Chumphon Park (South) WS	
Prince Chumphon Park (South)WS-Prince Chumphon Park (North) WS	
Kaeng Kra Chan	2
Kuiburi NP (Patch 1) - Kaeng Kra Chan NP	
Kuiburi NP (Patch 1) - Kuiburi NP (Patch 2)	
Khao Luang	2
Tai Rom Yen NP - Namtok Si khid NP	
Namtok Yong NP - Khao Luang NP	
Hala Bala	2
Budo-Sungai Padi NP (Patch 2) - Budo-Sungai Padi NP (Patch 3)	
Hala Bala WS - Budo-Sungai Padi NP (Patch 1)	
Khao Banthad	0
Western	0
Khlong Saeng – Khao Sok	0
Total	10

** NP: Natural Park, WS: Wildlife Sanctuary*

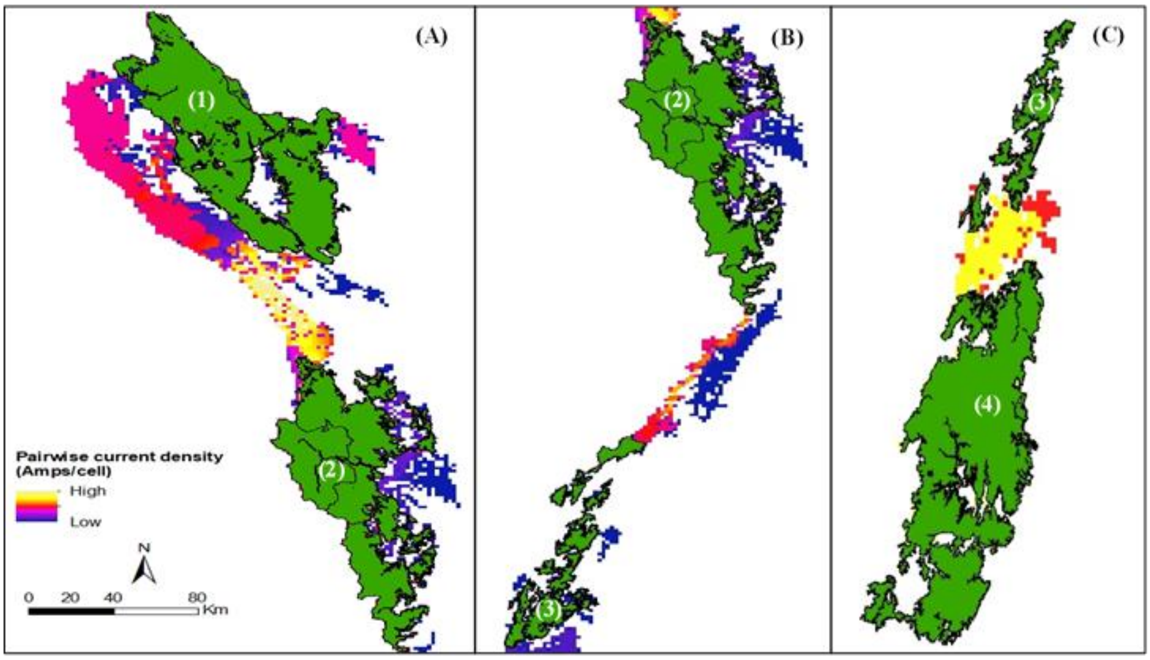

Figure 2. The results showed pairwise current flow density (Amps/cell) between three forest complexes: (A) Western forest complex (1) and Kaeng Kra Chan forest complex (2); (B) Kaeng Kra Chan forest complex (2) and Chumphon forest complex (3); (C) Chumphon forest complex (3) and Khlong Saeng – Khao Sok forest complex (4). The highest current density (shades of yellow) indicated areas of potential dispersal corridors. Areas, where connectivity was most difficult were shown in purple. Evergreen and deciduous forest habitat patches with an area greater than 13 km^2 were shown in green.

Discussion

Our goal was to identify habitat connectivity networks for the Malayan tapir in Thailand. We assessed patterns of potential forest habitat patches and dispersal corridors within and between forest complexes. Our results provide important baseline information for Malayan tapir conservation planning. Especially, the Malayan tapir populations are at risk of locally extinct primarily due to habitat loss and fragmentation (Lynam et al., 2012). Recent estimate Malayan tapir abundance in Thailand is approximately 538 – 720 individuals, occupying seven forest complexes: Western, Kaeng Kra Chan, Chumphon, Khlong Saeng-Khao Sok, Khao Luang, Khao Banthad and Hala Bala forest complexes (Kanchanasaka 2015).

Our results demonstrated that Chumphon, Hala Bala, Khao Banthad, and Khao Luang forest complexes were more fragmented than other forest complexes. These forest complexes experience changes in land use and land cover from anthropogenic activities, such as perennial crop, field crop, orchard, built-up areas, and artificial water bodies. Malayan tapir populations are more likely to be separated in those forest complexes, and occupy small proportions of the available forest habitat patches (Lynam et al., 2012; Clements et al., 2012). Malayan Tapirs avoid human-made landscape and anthropogenic activity because they are nocturnal and solitary, and also prefer wetter places in denser forest habitat (Clements et al., 2012). Malayan tapirs may also avoid natural water bodies, if such areas were used by human activities (Lynam et al., 2012; Kanchanasaka 2015). In addition, Chumphon forest complex had the lowest mean patches size, indicating that forest habitat patches in this forest complex become more fragmented and degraded. This might due to geographical location and topography where Chumphon forest complex is located along the western border of Thailand and potentially vulnerable to human disturbance (Lynam et al., 2012; Kanchanasaka 2015).

We found that Chumphon forest complex had the highest number of potential dispersal corridors, indicating habitat fragmentation and degradation. However, there was no potential dispersal corridor in Western forest complex, and Khlong Saeng – Khao Sok forest complex because such forest complexes are well connected and most of protected areas in each forest complex are adjacent to each other (Lynam et al., 2012; Kanchanasaka 2015). The current flows among adjacent forest patches were substantially higher than the current flows in nonadjacent forest patches, indicating that short distance dispersal corridors can facilitate tapirs' movement better than the long-distance corridors. The analyses revealed that potential dispersal corridors with low resistance mostly were evergreen forest and deciduous forest.

The results showed that there were more potential dispersal corridors within the forest complexes than between the forest complexes. Also, corridors within the forest complexes were connected to larger forest habitat patches. Similarly, the study of habitat connectivity for Pumas (*Puma concolor*) in the southwestern United States (Arizona and New Mexico) demonstrates that maximum current flow corridors are more likely to be located within close proximity to high quality habitat (Dickson et al., 2013). Furthermore, we found that forest patches in Hala Bala forest complex were more isolated with the long-distance potential corridors than other forest complexes due to conversion of natural habitat to perennial crops. We found no potential dispersal corridors in Khlong Saeng-Khao Sok forest complex and Western forest complex because the complexes have the largest forest patch size with adjacent patches. Conversely, we found that forest patches in Khao Banthad forest complex were threatened by agricultural areas that resulted in no connectedness between patches.

We suggest that Western forest complex and Khlong Saeng-Khao Sok forest complex had the lowest habitat fragmentation with high quality habitat for Malayan tapir populations. This forest complex could potentially be an important source for habitat connectivity network.

Conclusions

An assessment of potential suitable habitat patches and dispersal corridors for Malayan tapirs in Thailand provides preliminary information to assist conservation planning and management for the Malayan tapir in Thailand. Specifically, less fragmented and well-connected evergreen and deciduous forest patches can potentially be an important refuge for the endangered Malayan tapir in Thailand. Habitat connectivity is crucial to maintain the viability of Malayan tapirs and can help conservation management for other endangered species in the regions.

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