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Using Circuit Theory, Connectivity Analysis and Least-Cost Path to Model the Potential Ecological Corridors of Malayan Tapir (*Tapirus indicus*) at Chini-Bera Forest Complex in Pahang, Peninsular Malaysia

(Penggunaan Teori Litar, Analisis Ketersambungan dan Laluan Kos Minimum untuk Memodelkan Potensi Koridor Ekologi Tapir Malaya (*Tapirus indicus*) di Kompleks Hutan Chini-Bera, Pahang, Semenanjung Malaysia)

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ABSTRACT

In Peninsular Malaysia, the Master Plan of Ecological Linkages has proposed ecological corridors at Chini-Bera forests complex to connect the forest patches. However, the proposed corridors have been determined arbitrarily without evaluating the reliability of the landscape structure which may cause liability in conservation effort. Therefore, the objective of this study was to determine the potential ecological corridors by considering the reliability of landscape structure in Chini-Bera forests complex using Malayan tapir (*Tapirus indicus*) as a focal species. The tapir was chosen because it is one of the target large mammals in the master plan. In this study, three landscape structures, i.e., patch size, patch distance and landscape resistance were used as parameters in modelling the potential ecological corridors for tapirs. In the modelling, circuit theory, connectivity analysis and least-cost path were integrated using the geographic information systems and remote sensing platforms. The model has identified a total of 35 potential ecological corridors for tapir of which over 50% connect the large core areas while the other 25% connect the small core areas. Meanwhile, four corridors can be considered as priority corridor as their effective resistance below 1000 which indicate easy movement and high connectivity. The findings showed the importance to consider the reliability of the patch size, patch distance dan landscape resistance in determining the potential ecological corridors of wildlife to avoid liability in conservation effort. In addition, the integrated modelling approach contributes to a more concrete assessment of ecological corridors for effective wildlife conservation planning.

Keywords: Central forests spine; circuit theory; ecological corridor; least-cost path; sustainable development; wildlife conservation

ABSTRAK

Di Semenanjung Malaysia, Pelan Utama Rangkaian Ekologi telah mencadangkan koridor ekologi di kompleks hutan Chini-Bera untuk menghubungkan gugusan hutan. Walau bagaimanapun, koridor yang dicadangkan telah ditentukan sewenang-wenangnya tanpa menilai ketersediaan struktur landskap yang boleh menyebabkan liabiliti dalam usaha pemuliharaan. Oleh itu, objektif kajian ini adalah untuk menentukan koridor ekologi yang berpotensi dengan mengambil kira ketersediaan struktur landskap di kompleks hutan Chini-Bera menggunakan tapir Malaya (*Tapirus indicus*) sebagai spesies tumpuan. Tapir dipilih kerana ia merupakan salah satu mamalia besar sasaran dalam pelan utama. Dalam kajian ini, tiga struktur landskap, iaitu saiz gugusan, jarak gugusan dan rintangan landskap digunakan sebagai parameter dalam memodelkan koridor ekologi yang berpotensi untuk tapir. Dalam pemodelan, teori litar, analisis ketersambungan dan laluan kos minimum telah disepadukan menggunakan sistem maklumat geografi dan platform penderiaan jauh. Model ini telah mengenal pasti sejumlah 35 koridor ekologi yang berpotensi untuk tapir dengan lebih 50% menghubungkan kawasan teras besar manakala 25% lagi menghubungkan kawasan teras kecil. Sementara itu, empat koridor boleh dianggap sebagai koridor keutamaan kerana keberkesanan rintangannya di bawah 1000 yang menunjukkan kemudahan pergerakan dan ketersambungan yang tinggi. Hasil kajian menunjukkan kepentingan untuk mempertimbangkan ketersediaan saiz gugusan, jarak gugusan dan rintangan landskap dalam menentukan potensi koridor ekologi hidupan liar untuk mengelakkan liabiliti dalam usaha pemuliharaan. Di samping itu, pendekatan pemodelan bersepadu menyumbang kepada penilaian yang lebih tepat terhadap koridor ekologi untuk perancangan pemuliharaan hidupan liar yang berkesan.

Kata kunci: Koridor ekologi; laluan kos minimum; pembangunan mampan; pemuliharaan hidupan liar; teori litar; tulang belakang hutan tengah

Introduction

In 1946, about 77% of Peninsular Malaysia was covered by forests (Jomo, Chang & Khoo 2004) but declined to 39.7% in 2014 (Tan et al. 2017). This trend is closely related to rapid land use development due to economic and population growth (Abdullah & Hezri 2008; Jomo, Chang & Khoo 2004). Most of the forest areas have been converted to various land uses such as agricultural plantations particularly oil palm and rubber, urban areas and other infrastructures. As a result, only a few large-intact forests remained while many become fragmented and isolated. This occurred mainly to forests at the lowland but since the past three decades the land use developments gradually intrude to the hilly sites. In this regard, forest loss and fragmentation are prevailing to threaten the survival of wildlife especially large mammal species as their habitats become disconnected. In conservation planning, the disconnected habitats must be linked to minimize the negative impact of forest loss and fragmentation on wildlife (Sodhi et al. 2010).

In fragmented landscapes, development of ecological corridors to connect the habitats is the most recommended approach (Jain et al. 2014). Generally, ecological corridor is a linear landscape element that connects two or more patches of habitat (Soule 1991). Hedgegrows, fencerows, plantations, remnant roadside vegetation and streamside riparian vegetations can function as ecological corridor to connect the main or large habitat patches. Similarly, a strip of natural vegetation can also be functioned as ecological corridor at the landscape, regional or even continental scales, for examples, the Baltic Ecological Networks, the Vilcabamba-Amboro Conservation Corridor, the Tri-Dom, the Mesoamerican Biological Corridor and the Yellowstone to Yukon (Y2Y) Conservation Initiative (Bennett 2004). Ecological corridor is certainly important for the structure and function or ecological integrity of a landscape. Through ecological corridors, wildlife movement is enhanced which is important to conserve them (Cook 2002). Enhancing the connectivity through ecological corridor has been suggested for more than three decades to conserve biodiversity (Forman 1995; Hampson & Peterken 1998). However, ecological corridor depends on the landscape structure of the area such as patch size and distance between habitat patches or patch distance (Wiens, Schooley & Weeks Jr. 1997). Connectivity between habitat patches also depends on how organisms interact with the spatial structures (Rizkalla & Swihart 2007; Wiens, Schooley & Weeks Jr. 1997). In fact, Saura and Torné (2009) cited that many literatures agreed that connectivity is species-specific. This means that a functional perspective which considers the dispersal distances and/or preference of the focal species to the landscape structure should be considered in developing ecological corridors (Adriaesen et al. 2003; Ruiz-González et al. 2014). As such, it is crucial that the habitat preferences and dispersal capacities be considered to ensure functional connection is maintained between habitat patches, especially for the conservation of wildlife that are highly susceptible to fragmentation that caused the loss of connectivity between habitat patches.

In Peninsular Malaysia, the Central Forest Spine (CFS) concept which embedded in the first National Physical Plan was introduced in 2005 (DTCP 2005). The CFS is a complex of forests that form the backbone of the environmentally sensitive areas of Peninsular Malaysia (DTCP 2005). This is a government initiative to protect and conserve biodiversity in implementing the country's sustainable land use planning. Following this, the Ecological Linkages Master Plan was introduced in 2009 specifically to establish linkages between the forest complexes for large mammal conservation (DTCP 2009). In the master plan, the linkages have been identified as primary and secondary linkages. However, the linkages or ecological corridors have been identified arbitrary without considering the spatial structures of the landscape which means without evaluating the reliability of the forest patches, distance between patches or patch distance, and landscape resistance (i.e., land uses) between patches. As such, considering the reliability of the landscape structure to identify potential ecological corridors for wildlife is important to avoid liability in the conservation effort. Therefore, the objective of this study was to determine potential ecological corridors by considering the reliability of landscape structure in Chini-Bera forests complex with Malayan tapir (*Tapirus indicus*) was selected as a focal species. The Malayan tapir is one of the target large mammal species (others are elephants, tigers, and gaurs) in the master plan. This species is also categorized as endangered under the IUCN Red List (Traeholt et al. 2016). With the potential ecological corridors, the planners and other related stakeholders can identify the relative high-quality habitats and choose the best opportunities to develop and/or restore connectivity.

MATERIALS AND METHODS

STUDY AREA

The study site is Chini-Bera forests complex which is located in the state of Pahang, Peninsular Malaysia. It is one of the main forest complexes identified as the backbone of environmentally sensitive areas in Peninsular Malaysia as enshrined in the National Physical Plan for sustainable land use planning (DTCP 2005). The forest complex is also one of the areas that has been identified to have ecological linkages or corridors as stated in the Master Plan for Ecological Linkages to improve connectivity between the forest complexes for large mammal conservation (DTCP 2009). In the master plan, the area of forest complexes including the Chini-Bera forests complex is only depicted in a segment of square without having a clear demarcation. Without a clear demarcation is a constraint that can affect the analysis and the reliability of the output data. To address the constraint, we systematically defined the boundary of Chini-Bera forests complex by taking into account the boundaries of districts, sub-districts, roads and rivers (Figure 1). Based on the defined border the total area of Chini-Bera forests complex is 419,074 ha.

LAND USE MAP OF CHINI-BERA FORESTS COMPLEX

In this study, satellite images of Landsat TM 8 for 2020 with path/row 126/57, 126/58, 127/57 and 127/58 that covered the state of Pahang were selected to develop land use map of the study area. These satellite images were obtained from United States Geological Survey (USGS) which downloaded freely from www.earthexplorer.com. The GeoTIFF images of individual bands for each path/row were converted into the ERDAS raster format. Then, layer stacking was used to combine separate image bands into a single multispectral image file. Geometric correction was carried for each path/row to ensure the satellite image projected accurately using georeferenced image of the same area.

The four scene of Landsat images were geocoded and mosaicked into a single image. The mosaiced image was subset into the state of Pahang boundary. After that, image enhancement and band combination of spectral bands were carried out using false colour composite (FCC). The combination of 6-5-4 (red-green-blue) was selected because this combination provides clear image which is suitable to distinguish each land use type in the state of Pahang. The maximum likelihood of supervised classification was applied to the obtained land use types of Pahang in 2020. The supervised classification identified seven type of land uses: built-up area, cleared land, commercial agriculture, forest, other agricultures, waterbody and wetland. The classification was compared to google earth map to obtained its accuracy. The overall classification accuracy is 91.02% while the overall Kappa statistic is 0.8733, which indicates that the land use classification is acceptable (Table 1). After that, the land use map of the state of Pahang was subset into Chini-Bera forests complex boundary to generate land use map of the study area (i.e., Chini-Bera forests complex).

CONNECTIVITY MODELLING FOR POTENTIAL ECOLOGICAL CORRIDORS

We identified high-priority or core areas for Malayan tapir conservation in Chini-Bera forests complex by using circuit models, connectivity analysis and the least-cost model. The big core areas are crucial as the home for most species, the largest populations, and the best likelihood of preserving intact biological processes (relatively unaltered disturbance regimes). The small core areas are also important in protecting biodiversity and preventing the conversion of land, the exploitation of resources and extensive motorized recreation in national or regional conservation habitat (Belote et al. 2016).

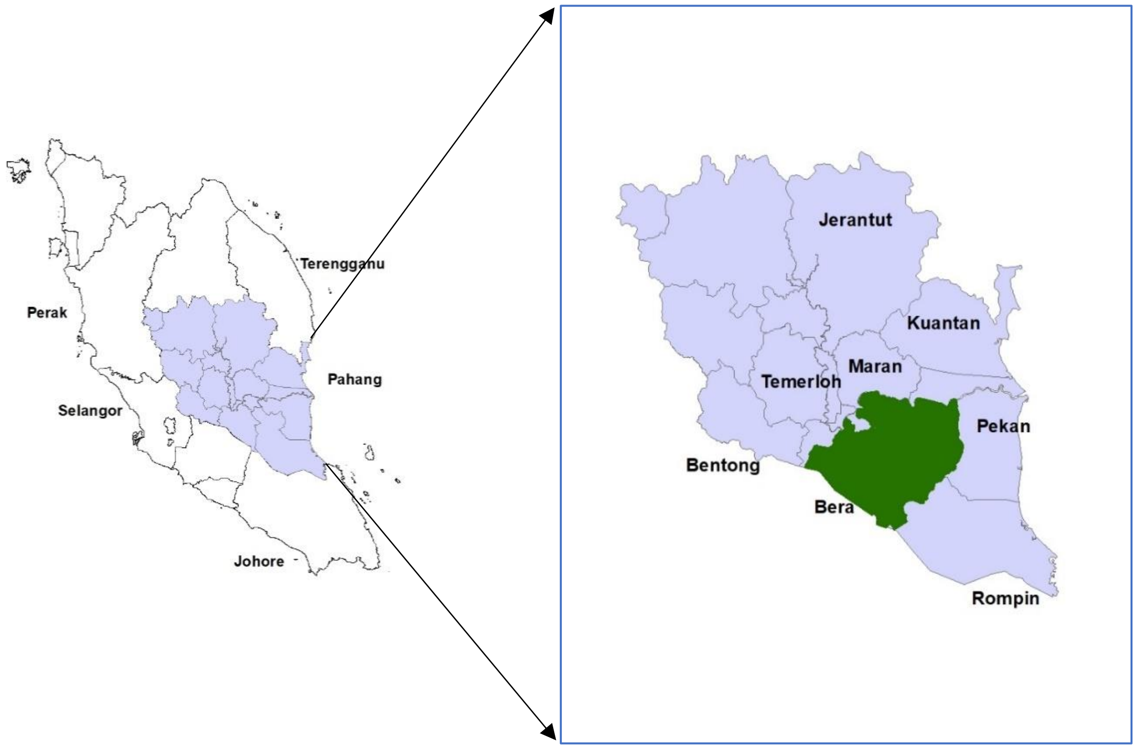

FIGURE 1. The Chini-Bera forests complex (in green) as defined by the boundaries of districts, sub-districts, roads and rivers located at the southern part of the state of Pahang, Peninsular Malaysia

TABLE 1. The matrix table shows that the user's and producer's accuracy is compatible to the overall accuracy value. This means that the distribution of exclusion and inclusion errors is equal between classes and is reliable for classifications to be used in the subsequent analyses

Land use class	Reference totals	Classified totals	Number correct	Producer's accuracy	User's accuracy
built-up area	26	29	22	84.62%	100.00%
cleared land	10	10	10	75.86%	100.00%
commercial agriculture	100	108	97	97.00%	89.81%
forest	88	81	78	88.64%	96.30%
others agriculture	12	8	7	58.33%	87.50%
waterbody	8	9	8	100.00%	88.89%
wetland	11	11	11	100.00%	100.00%
Total	255	256	233		
Overall classification accuracy: 91.02%					
Overall Kappa statistics: 0.8733					

Circuit Models

In modelling, the connectivity to develop the potential ecological corridor for Malayan tapir using circuit models, two main analyses were conducted: modelling resistance surface and modelling hypothetical dispersal corridors. Circuit models that based on circuit theory were developed using Circuitscape software (McRae & Kavanagh 2011). The software enables the analysis of maps resistance and least-cost flow pathways and used to model a species' movement across land use types (McRae, Shah & Mohapatra 2013). Landscape resistance and patch sites were converted into ASCII raster using the Export to Circuitscape extension for ArcGIS. For the purpose of simulating the connection between all pairs of patch sites, circuit models for the studied species were developed using the paired mode. As part of the paired operation (i.e., significant habitat patches) in the landscape, all pairs of identified 'focal nodes' are repeatedly tested for 'current flow' (i.e., connection). Three datasets were used: landscape resistance data, focal node position files, and short-circuit area files. Parameter selections were made in accordance with the following criteria: i) landscape resistance values; ii) identification of focal nodes; and iii) identification of short-circuit regions. A cumulative current density map was produced by combining the results of all the pairwise current density maps.

Modelling Resistance Surface

The land use map of Chini-Bera forests complex in raster format was used as the material source for modelling resistance surface. In this analysis, the landscape resistance values were determined. The resistance values given to each land use type were justified based on literature related to the ecology of Malayan tapir. We assigned landscape resistance values to map cells in the raster map of the study area in the proportion to their occurrence in the area based on the reference of expert studies of Malayan tapir preference (Table 2). The range of the resistance value is from 1 to 100 and with the highest resistance is mainly related to the presence of built-up area (Leonard et al. 2017; McRae, Shah & Mohapatra 2013). This analysis produced a landscape resistance value map of the forest complex.

Modelling Hypothetical Dispersal Corridors

In this analysis, the reliability of landscape structures was evaluated. The parameters of landscape structures used were landscape resistance value map (i.e., represent land uses), patch size and patch distance (i.e., distance between patches). Using the same file of landscape resistance map the focal nodes or key habitat patches were identified based on the patch size. The identification of focal nodes was based on the home range size of Malayan tapir which is between 52 ha and 73 ha obtained from a study by Khadijah-Ghani (2010). Using the lower limit (i.e., 52 ha) and upper limit (i.e., 73 ha) of the home range size, all the forest patches in the landscape resistance map were classified as 'not suitable' (weight: 0), 'less suitable'

TABLE 2. Landscape resistance value of each land use type for Malayan tapir (*Tapirus indicus*) and the justification that based on literatures of the tapirs' ecology

Land use types	Resistance value	Justification
Commercial agriculture	70	Less endangered Asian tapirs were recorded in the commercial agriculture (Adila et al. 2017).
Forest	1	Tapirs are found higher in the large, fragmented forest landscapes in Peninsular Malaysia (Samantha et al. 2020)
Wetland	10	Tapirs are riverine animals and they inhabit dense vegetation and swamp forests (Dudgeon 2000).
Others agriculture	50	They are found in the adjacent agricultural areas (Reza, Rafaai & Abdullah 2022).
Built up area	100	No endangered Asian tapirs were recorded in the built-up area (Adila et al. 2017).
Waterbody	5	Tapirs need to remain close to permanent water bodies (Samantha et al. 2020).

(weight: 1), 'suitable' (weight: 2) and 'highly suitable' (weight: 3) for Malayan tapir. The corresponding weight for each suitability class is as follows: 0: < 52 ha, 1: 52 ha and 63 ha (between lower and median size of home range), 2: 63 ha and 146 ha (between median and twice the upper size of home range) and 3: >12400 ha (above twice of upper size of home range). However, in this analysis only forest patches with size above 63 ha (i.e., suitable [weight – 2] and highly suitable [weight – 3]) were selected as focal nodes. Then, using the same file (containing the landscape resistance value and focal nodes) the short-circuit regions were identified. Short-circuit region represent areas that the focal species can travel and traverse freely with no cost. The identification was based on the assumption that the large suitable patch would act as a source and destination for wildlife movement. While the smaller patches do not act as source and destination but rather act as low-cost for movement between larger patches (McRae, Shah & Mohapatra 2013; Nor et al. 2017).

Least Cost Model (Potential Ecological Corridors)

Pinchpoint Mapper 1.0 (McRae, Shah & Mohapatra 2013), which is part of the Linkage Mapper toolkit, was used to create models combining least-cost and circuit methods. By constraining the current flow to the least-cost corridors identified, the combined method was able to highlight least-cost corridors and to assess the connectivity via the least-cost distance and least-cost path length metrics. Then, by running the Circuitscape software within the least-cost corridors, the tool assessed the connectivity via the effective resistance metric and mapped existing pinchpoints (critical connections) within least-cost corridors (Abouelezz et al. 2018; Hilty et al. 2020; Kong et al. 2021).

RESULTS

Land use of CHINi-Bera forests complex

The distribution of land uses in Chini-Bera forests complex is shown in Figure 2. It contains six land use types; built-up area, commercial agriculture, forest, other agricultures, waterbody and wetland. In terms of proportion, the forest complex is dominated by commercial agriculture which covered about 68.3% of the total area (Figure 3). This followed by forest (29.3%) while the other land uses were very least which is less than 1% of the total area of the forest complex (Figure 3). Generally, the forest complex contained forest patches with various sizes. Several patches are considerably well intact while others are small, fragmented and surrounded by commercial agriculture particularly oil palm and rubber plantations. It also contains two large natural freshwater lakes (i.e., wetlands) in Peninsular Malaysia, that is Tasik Chini and Tasik Bera.

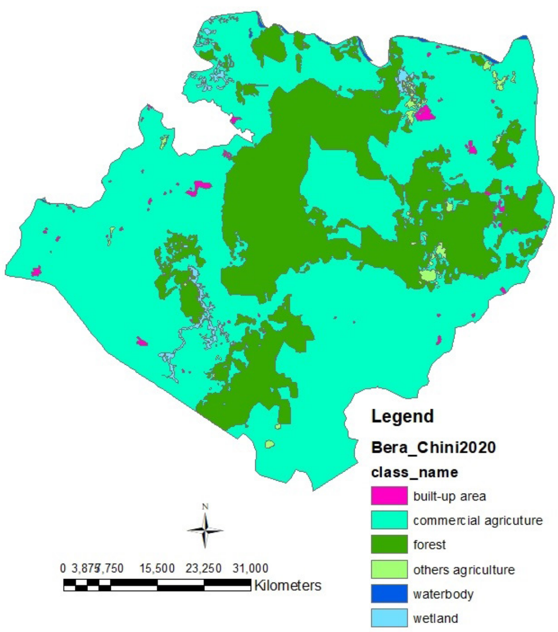

FIGURE 2. The distribution of the six land use types in Chini-Bera forests complex in 2020 which mainly covered by commercial agriculture and forest

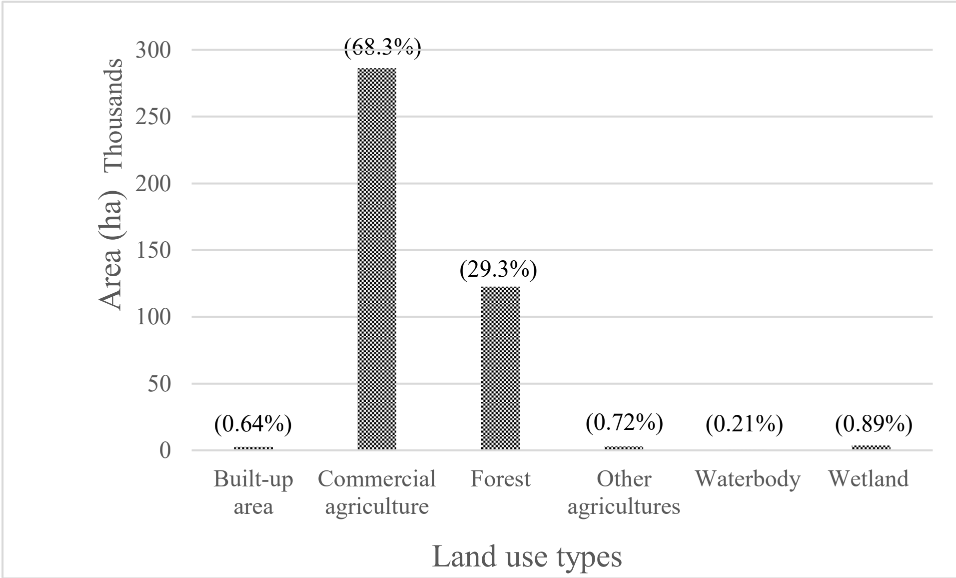

FIGURE 3. The proportion of each land use type in Chini-Bera forests complex that shows the domination of commercial agriculture over the natural forest while the other land uses were very least

CONNECTIVITY MODELLING FOR POTENTIAL CORRIDORS

LANDSCAPE RESISTANCE

Landscape resistance map shows the low value that defines less resistance of the landscape and easy for movement while high value is vice versa (Figure 4). The resistance map will provide guidance options for conservation and management plans to preserve and improve habitat connectivity. For example, high value of resistances helps to identify corridors, barriers in built up area, commercial agriculture and others agriculture and to produce a map of landscape resistance to tapir movement. Figure 5 shows the current density for Malayan tapir within the focal area in Chini-Bera forests complex. Cell with highest cumulative cost represent by red colour showing the area of high resistance, least connectivity and barrier for tapir movement which highlight the critical connections within them. While the green colour represents the lowest cumulative cost showing the less resistance of the landscape and easy for movement. The lowest cumulative cost was found to the north of the forest complex which is the largest fragmented forest there. However, the highest cumulative cost found adjacent to commercial agriculture and the border of Chini-Bera forests complex shows the less preference of Malayan tapir in that particular area because of difficult movement and hard to survive for shelter and food.

Least cost model (potential ecological network)

Results showed that the most important core areas and corridors are concentrated at the north of Chini-Bera forests complex. Over 50% of the least cost path link are connecting the large core area in the north of the forest complex while the other 25% are connecting small core areas in the east and west of Chini-Bera forests complex (Figure 6). The low value of least cost path link for Malayan tapir represents less resistance, easy movement and high connectivity while the highest value represents high resistance, difficult movement and low connectivity (Figure 6). Table 3 shows the combined models of current density within corridors identified in the least cost models and provide values of effective resistance which is a connectivity measure complementing least cost path length. For example, patch core 18 and 21 showed the lowest effective resistance showing where species are more likely to move, less of barrier and high connectivity. While patch core 17 and 22 showed highest effective resistance meaning that there is barrier and resistance to move freely and less connectivity of patch site.

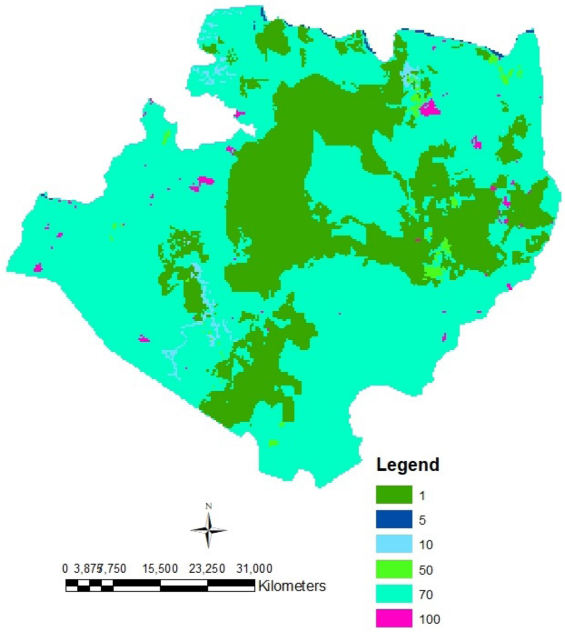

FIGURE 4. Landscape resistance map for Malayan tapir (*Tapirus indicus*) in Chini-Bera forests complex with the resistance values range from 1 (lowest: dark green) to 100 (highest: purple)

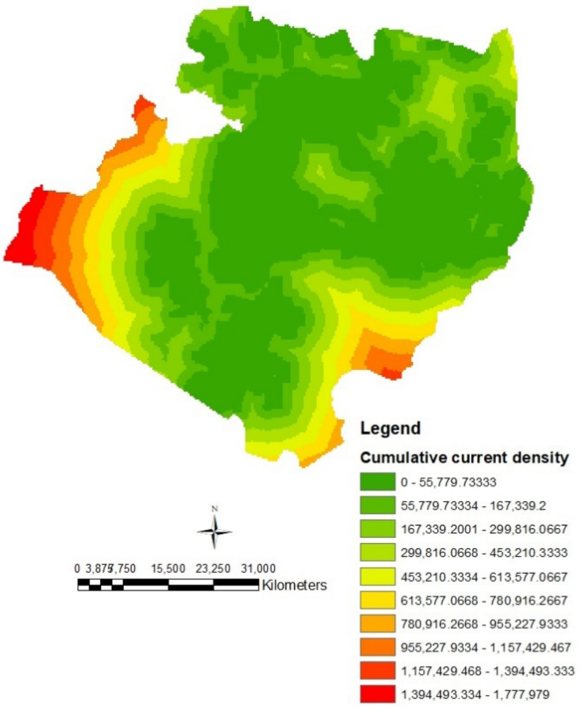

FIGURE 5. Cumulative current density for Malayan tapir (*Tapirus indicus*) in Chini-Bera forests complex with the red legend represents the highest cumulative cost and resistance

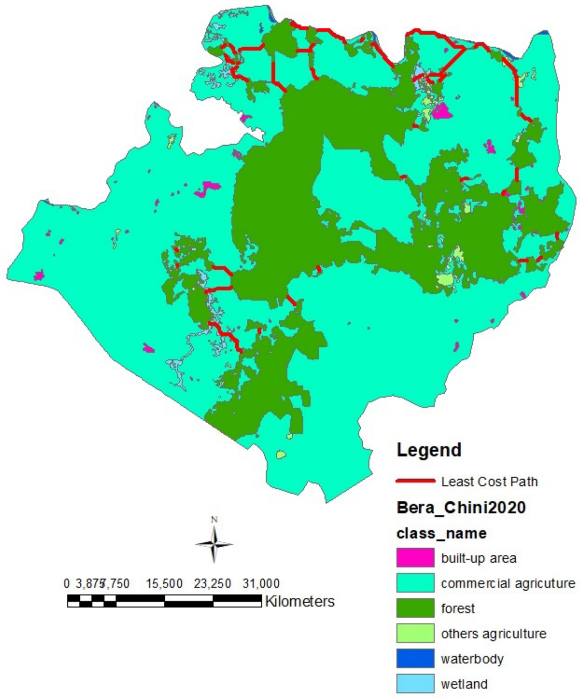

FIGURE 6. Least cost path link that determined the potential ecological corridors for Malayan tapir at Chini-Bera forests complex

DISCUSSION

Identifying the priority areas for potential ecological corridors and core habitat is of great importance for biodiversity conservation and landscape planning (Dong et al. 2020). Ecological corridors are crucial geographic landscape structure for the evaluation of biodiversity and biological protection. Visual interpretations of movement patterns (i.e., functional corridors) or habitat maps are used to identify and map corridors (i.e., structural corridors) (Vogt et al. 2007). The potential ecological corridors by connecting habitat patches play an important role in providing ecological services as well as providing space for wildlife to move at shorter distances and provide adequate resources such as food and survival or reproduction. The connection between species and the landscape is considered to be at the core of ecological corridors. Additionally, ecological corridors offer ecological benefits including water conservation, pollution control, and a reduction in the heat island effect. Ecological corridors improve connectedness between isolated populations by enabling animal and plant movement between habitat areas (Ye, Yang & Xu 2020). Therefore, creating corridors to link isolated habitat areas is necessarily important to reduce the adverse effects of habitat fragmentation.

It is challenging to protect large-ranging wildlife like Malayan tapir under increasing pressure of human development. This study identified and assessed optimal corridors for ecological network in forest environments under present development scenarios in Peninsular Malaysia using an integrated approach, with the goal of filling in the gaps as existing protected areas only cover less than one-fourth of predicted core habitats in Asia (Long et al. 2021). This will help to provide a more technically robust foundation for Malayan tapir habitat conservation prioritization. The integrated modelling approach combining circuit theory, connectivity analysis and least-cost path was used to identify the potential ecological corridor to connect Malayan tapir habitat within the focal area in Chini-Bera forests complex. In such a rapidly evolving, heterogeneous and highly fragmented landscapes of the forest complex the identification of ecological corridors which should be prioritised is important to better design, preserve and can

TABLE 3. Comparative table of the least-cost path lengths (LCP length) and effective resistances (EffResist) resulting from the combined models for every link path. The effective resistance value revealed that four links can be considered as primary link as their value is between 100 and 230 (highlighted in gray)

OBJECTID	Link_ID	From_Core	To_Core	Euclidean distance	LCP_Length	Effective resistance
1	43	18	21	226.00	320	102.52
2	10	5	7	174.00	320	187.45
3	9	4	7	164.00	452	226.27
4	57	24	27	320.00	452	226.27
5	18	9	26	90.00	640	1160.87
6	39	16	26	1295.00	1997	1795.67
7	5	2	26	84.00	772	4071.39
8	7	3	26	907.00	1280	5503.18
9	20	10	26	705.00	1092	5746.36
10	17	8	26	377.00	772	7276.13
11	30	14	16	997.00	1545	8945.12
12	54	23	25	512.00	772	10704.20
13	22	11	26	721.00	772	12045.60
14	13	6	26	547.00	960	13215.30
15	50	20	29	1598.00	1920	14443.20
16	16	8	12	1557.00	1920	15148.90
17	38	16	17	1390.00	2052	16019.40
18	49	20	28	749.00	1092	16685.30
19	45	18	25	1317.00	1677	17811.30
20	4	1	30	438.00	640	22720.00
21	44	18	23	1045.00	2185	22783.80
22	23	12	13	1418.00	1997	29923.60
23	48	20	26	1653.00	1997	31345.20
24	6	3	6	475.00	905	32130.90
25	15	7	26	2891.00	3410	32415.50
26	37	15	29	2847.00	3200	37215.60
27	52	21	29	3638.00	4237	37344.90
28	36	15	26	1425.00	2130	46559.10
29	11	5	26	4026.00	4557	51292.70
30	33	15	18	2345.00	4635	60772.80
31	31	14	17	828.00	1357	63809.30
32	64	28	29	1539.00	3090	75908.20
33	46	19	22	1813.00	2770	86691.00
34	3	1	26	1635.00	1810	95487.70
35	41	17	22	4431.00	4978	317236.00

improve ecological networks as a whole. This ecological network of multifunctional ecosystems is undoubtedly crucial for nature conservation and human well-being as well, since they support biodiversity, ecological processes, and services in heterogenous and fragmented landscapes.

This study used circuit theory which was parameterised with landscape structures (i.e., landscape resistance or land use, patch and patch distance) to optimise ecological corridor effectiveness for Malayan tapir. This approach aims to optimise the continuity and conditions of forest within the forest complex, thus opportunities for individual passage may be maximised for a wide range of species. The model is significant in predicting wildlife habitat continuity based on the use of circuit theory and connectivity to build a spatially explicit model to understand habitat factors on biodiversity. The landscape structure factors can give an indication of the conditions of surrounding matrix and possible future change surrounding forest patches. Uezu and Metszger (2016) demonstrated that species differ in their responses to fragmentation, and abundance are related to the structural of landscape and patch size factors. This study emphasised the importance of considering species preference of landscape, especially functional connectivity, in developing priority corridors of ecological networks.

Circuit theory was selected because of its ability to provide rapid, repeatable results using the simple connectivity measure of resistance distance (distance metric) as the effective resistance between a pair of nodes. A convenient property of the resistance distance is that it incorporates multiple pathways connecting nodes, with resistance distances measured between node pairs decreasing as more connections are added. The use of the model was also favoured as it evaluates sites on the basis of their ability to support a wide range of species, not only in areas containing significant habitat but also in sites currently lacking vegetation. In this study, the model has proven that the circuit theoretic model was able to overcome the limitation of the least-cost model by simultaneously considering different suitable routes. This major advantage over the least-cost model has also been mentioned by other studies (Beaujean et al. 2021; Kwon, Kim & Ra 2021). The circuit model was also able to spot critical connections that contribute the most to ecological network and to identify corridors with optimal connectivity (Figure 6). The least-cost model was the first and most popular method studied. Throughout the study, this has proven to be an effective way to calculate distances and to identify the most optimal routes between source sites (Table 3). This method also provides an easily understandable assessment of connectivity via the least-cost path length metric, which is a much easier way to interpret than accumulated-cost in terms of dispersal distance. Nevertheless, the study has demonstrated that the least-cost model also has some constraints such as not considering all possible routes that could contribute to connectivity or providing connectivity assessments that are only related to a single, most cost-efficient route identified in a given landscape.

The selection of appropriate landscape structure in this model will allow many applications, ease of calculation, functional basis, and simplicity of interpretation by a range of specialist and non-specialist stakeholders. Regardless, there continues to be a need for landscape metrics to calculate landscape structure because they are seen by many land managers and stakeholders as simple, intuitive tools for assessing and monitoring changes in landscape pattern and, by extension, the effects on underlying ecological processes. Future needs include: (1) the development of more user-friendly landscape analysis software that can simplify analyses and visualization; and (2) studies that clarify the strengths and weaknesses of different approaches, including the potential limitations and biases in modelling connectivity. In the future, they could be related to other datasets to provide a complete interpretation of ecological processes and phenomena. By replicating the methodological approach presented in this study, these results could also be used as initial data to predict how future developments might affect the landscape connectivity in rapidly expanding regions in Peninsular Malaysia, either for Malayan tapir or other animal species.

CONCLUSIONS

This study has presented an integrated approach to assess and model potential ecological corridor for tapir in Chini-Bera forests complex in order to provide priority corridors for ecological network. This study has: (1) developed predictive connectivity models for Malayan tapir based on least-cost and circuit models; and (2) identified priority corridors and assessed their connectivity and highlighted critical connections within them. The model used in this study has complementary approaches that can contribute to a more concrete assessment of the connectivity for biodiversity conservation and forest planning especially in fragmented landscape. The circuit model has also shown its ability to highlight priority corridors similar to the ones identified by the least-cost model under rapid land use development. The combined model is an effective way of highlighting critical connections within the priority corridors identified by the least-cost model. It allows for the maintenance and improvement of existing corridors or for the creation of ecological networks in future planning. This study can help wildlife conservation and planning decisions to maintain or design appropriate ecological networks. The findings showed the importance of considering the reliability of the patch size, patch distance dan landscape resistance in determining the potential corridors of wildlife to avoid liability in conservation effort.

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