Global Ecology and Conservation 53 (2024) e03015

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: www.elsevier.com/locate/gecco

Original research article

Identifying wildlife corridors to restore population connectivity: An integration approach involving multiple data sources

Naruemon Tantipisanuh [a], Somporn Phakpian [b], Pornpimon Tangtorwongsakul [a], Supagit Vinitpornsawan [b], Dusit Ngoprasert [a,c,*]

[a] Conservation Ecology Program, Pilot Plant Development and Training Institute, King Mongkut's University of Technology Thonburi, Bangkok 10150, Thailand

[b] Department of National Parks, Wildlife and Plant Conservation, Bangkok 10900, Thailand

[c] Natural Resource management and Sustainability, School of Bioresources and Technology, King Mongkut's University of Technology Thonburi, Bangkok 10150, Thailand

A R T I C L E I N F O

Keywords:
Bayesian Belief Network
Dong Phayayen-Khao Yai Forest Complex
Fragmentation
Management scenario testing
Ursus thibetanus
Thailand

A B S T R A C T

Identification of wildlife corridors usually prioritizes ecological data while often overlooking the perspectives of local communities despite their relevance. This oversight may contribute to human-wildlife conflicts in surrounding areas. This study aims to demonstrate how multiple data sources and aspects can be integrated to identify wildlife corridors using the Dong Phayayen-Khao Yai Forest Complex as a case study. Suitable areas serving as additional wildlife corridors for the Asiatic black bear were identified, and appropriate management strategies to enhance the overall suitability of the wildlife corridor were determined. Firstly, road segments having the potential to serve as additional wildlife corridors were selected based on four criteria related to physical barriers. Then a Bayesian Belief Network was developed to assess the corridor suitability for each proposed road segment by including data from various sources and aspects (ecological data, the human dimension and landscape characteristics). Afterward, eight scenarios were tested to evaluate how they could impact the overall suitability. From seven potential road segments, only three segments showed high suitability to be additional wildlife corridors. Within the assessed 58 km^2 area, 13 km^2 (22 %) were identified as highly suitable for wildlife corridors under current situations. Improving human attitudes toward wildlife corridor construction emerged as the scenario that could increase the overall suitability the most (from 13 to 29 km^2) while increasing human threats (hunting, wildlife pet trade, and vehicle collisions) was the scenario that reduced overall suitability the most (from 13 to 4 km^2). Our framework in this study is practical, adaptable, and flexible for various decision-making processes. It can also be adapted to other areas and focal species by making relevant adjustments to align with specific landscapes and contexts.

1. Introduction

The expansion of road and highway networks has caused adverse impacts on wildlife populations. Construction of roads results in

* Corresponding author at: Conservation Ecology Program, Pilot Plant Development and Training Institute, King Mongkut's University of Technology Thonburi, Bangkok 10150, Thailand.

E-mail address: ndusit@gmail.com (D. Ngoprasert).

https://doi.org/10.1016/j.gecco.2024.e03015
Received 19 February 2024; Received in revised form 26 May 2024; Accepted 27 May 2024
Available online 28 May 2024

the direct removal of habitats and the increase of fragmentation level (Liu et al., 2019; Zellmer and Goto, 2022). Roads create physical impediments to the movement and migration of wildlife, making animals reluctant to cross and, as a result, wildlife populations between patches become isolated (Koivula and Vermeulen, 2005; Kramer-Schadt et al., 2004; Watabe and Saito, 2021). Collisions with vehicles pose a serious threat to wildlife, especially nocturnal species, facilitated by higher traffic speeds and volumes (Baskaran and Boominathan, 2010; Filius et al., 2020; Kioko et al., 2015). Moreover, roads allow humans access to natural resources inside the forest, consequently increasing the risks of poaching and illegal pet collection (Coffin, 2007). Increased mortality rates due to roadkill and hunting exert pressure on the viability of wildlife populations.

To alleviate the effects of habitat fragmentation and isolation, conservation networks, consisting of natural core areas connected through conservation corridors, are essential to maintain landscape connectivity (Beier and Noss, 1998; Hofman et al., 2018). This is crucial because isolated populations are more likely to experience random genetic drift, inbreeding depression, and limited gene exchange (Corlatti et al., 2009; Ralls et al., 2020; Sawaya et al., 2019; Willi et al., 2007). Crossing structures such as overpasses (roads above tunnels), underpasses (paths below elevated roads), and tunnels help facilitate population dispersal between isolated patches. This helps sustain gene flow for a wide range of species, increasing long-term population viability (Corlatti et al., 2009; Hofman et al., 2018; Jackson and Griffin, 2000).

Many complex tools have been developed to prioritize which patches to be linked as mitigation tools for wildlife crossings. When corridors are designated, habitat suitability for focal species is often used to predict connectivity (Bond, 2003). Various techniques are used to predict connectivity networks from empirical data, with the most frequently used ones being graph theory (Urban et al., 2009) and least-cost path models (Beier et al., 2008). Although these tools are useful in determining crossing locations, they often overlook the perspectives of local communities (Dutta et al., 2022; Ghoddousi et al., 2021; Hairong et al., 2022; Xu et al., 2020). Consequently, conflicts between humans and wildlife arise, especially for those who live close to forests (Ahmed et al., 2012).

Bayesian Belief Network (BBN) is a graphical model that can incorporate data from various sources, such as results from species distribution modeling, data from literature reviews, and data from interviews, and can construct models based on expert opinions (Marcot et al., 2006; Tananantayot et al., 2022; Tantipisanuh et al., 2014). Thus, BBN allows for a comprehensive assessment that covers a range of factors, including ecological considerations, aspects related to human dimensions, and landscape characteristics, thereby making it possible to develop models that better capture the reality and complexity of the situation being studied. In addition, by incorporating interview data, local people's perspectives can be combined with the suitability model, making the results more acceptable to communities around the corridor areas. Moreover, the possibility to predict outcomes from different scenarios makes BBN a more applicable tool for management decision support (Bennett et al., 2021; Johnson et al., 2013; Ortega-Argueta, 2020).

This study aimed to (1) identify suitable areas to serve as additional wildlife corridors for the focal species, the Asiatic black bear *Ursus thibetanus* (hereafter black bear) within the Dong Phayayen-Khao Yai Forest Complex World Heritage site, and (2) determine appropriate management strategies that can enhance the overall suitability of wildlife corridors. A recent study on black bear populations clearly demonstrated a limited exchange of genetic material (low gene flow) between two separate forest patches because of the barrier effect of highways, increasing the risk of genetic erosion (Vaeokhaw et al., 2020). The Asiatic black bear was chosen as the focal species due to its globally threatened status (designated as "vulnerable" by IUCN), its potential as an umbrella species (Penjor et al., 2024), and its tendency to avoid roads (Doko et al., 2011; Garshelis and Steinmetz, 2020; Hairong et al., 2022). In this study, we applied BBN to incorporate data from multiple sources (empirical data, social science survey, and landscape characteristics) to identify suitable areas for a new proposed wildlife corridor in Dong Phayayen-Khao Yai Forest Complex and evaluate various management scenarios to determine the most appropriate strategies to increase overall suitability.

2. Materials and methods

2.1. Study area

Dong Phayayen-Khao Yai Forest Complex (hereafter DPKY) represents one of the largest contiguous forests in the northeastern part of Thailand. This forest complex comprises five protected areas, including Khao Yai National Park (2,168 km^2) and Dong Phayayen Forest (3,987 km^2) (UNESCO, 2015). DPKY has been inscribed in the UNESCO World Heritage list since 2005. The area contains more than 800 fauna species, including 112 species of mammals, 392 species of birds, and 200 reptiles and amphibians. Some of these are recognized as globally threatened species, such as the Asian elephant *Elephas maximus*, Indochinese tiger *Panthera tigris*, dhole *Cuon alpinus*, gaur *Bos gaurus*, pileated gibbon *Hylobates pileatus*, lar gibbon *Hylobates lar*, Sunda pangolin *Manis javanica*, banteng *Bos javanicus*, Asiatic black bear *Ursus thibetanus*, and sun bear *Helarctos malayanus* (UNESCO, 2015). Evergreen forest occupies all five protected areas, with elevations ranging from 100 to 1,350 m asl. The DPKY area is utilized and disturbed by hunting and forest product collection (Ngoprasert and Gale, 2019).

Highway 304 was initially constructed in 1956 as a two-lanes paved road, with each lane measuring 12–15 m in width (Department of Highways, 2006). This road bisects a continuous forest that separates Khao Yai from Dong Phayayen. To reduce traffic congestion, the Department of Highways undertook an expansion project in 2005, converting Highway 304 into four lanes (Wildlife Research Division, 2012). Despite this expansion, the volume of traffic more than doubled from 7488 vehicles/day in 2006–16,573 vehicles/day in 2015. However, there have still been reports of wildlife crossing and roadkill incidents (Silva et al., 2020; Vaeokhaw et al., 2020). The majority of land use along both sides of Highway 304 includes human habitation, agricultural areas, and abandoned areas, with varying proportions of each land-use type observed at different road parts (Fig. 1).

Since 2019, both overpasses and underpasses have been incorporated into Highway 304, creating a wildlife corridor between Khao Yai and Dong Phayayen to facilitate the movement of wildlife between the two forest patches. For the overpass, camera surveillance systems were set up at multiple points by the Department of National Parks, Wildlife and Plant Conservation to monitor the corridor use of wildlife. Small to medium-sized ungulates, including barking deer *Muntiacus muntjak*, serow *Capricornis sumatraensis,* and sambar deer *Rusa unicolor*, were captured by the camera traps in 2019. However, there is no evidence that large carnivores such as tigers or black bears use this corridor, raising concerns that the current dimensions and positioning of the wildlife corridor may not be adequate to support and encourage the movement of large landscape species between Khao Yai and Dong Phayayen.

2.2. Physical barriers and stepping stone identification

As not all parts of the road are suitable to be a wildlife corridor, three criteria for physical barriers were used to identify road segments for the next-step assessment. Firstly, the polygon of Highway 304 between Khao Yai and Dong Phayayen was manually digitized from a high-resolution satellite image taken in 2021, available on Google Earth. Then we drove along the highway to record road and potential physical barriers, applying three criteria: (1) the height of the road barriers (i.e., concrete, fences) along the road and at the middle of the road must be <90 cm, as a high barrier can obstruct bear movement; (2) the slope of the surrounding area along the roadside must be < 60 degrees, in line with the maximum steepness recommended by Phuyal (2018); and (3) surrounding

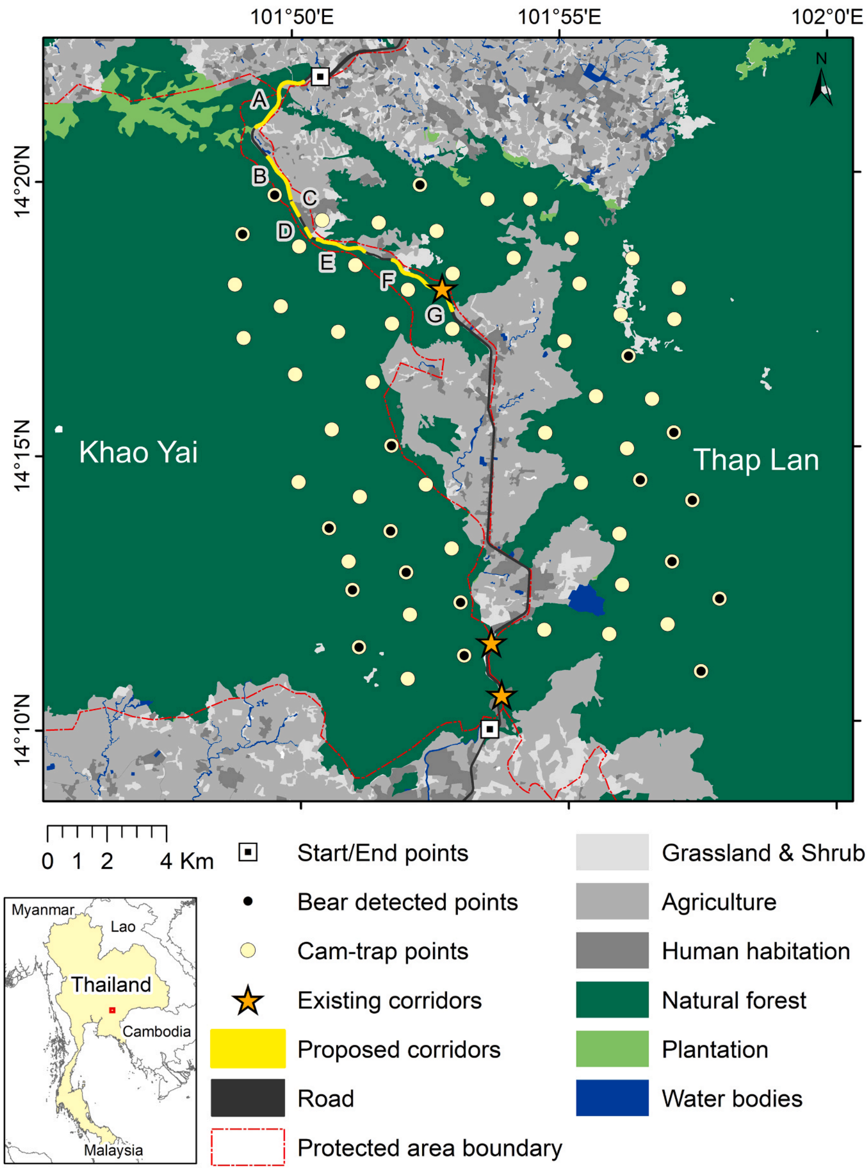

Fig. 1. Study area map showing the start/end points of the driving survey, existing corridors, and seven road segments (A-G) that meet specific criteria: (1) the height of barriers along the road and at the middle of the road is <90 cm, (2) the slope of the area along the road is < 60 degrees, (3) land-use type around the area, and (4) the availability of forest patches as stepping-stones.

areas should not be highly dominated by humans, as wildlife might be disturbed or hunted, leading to human-wildlife conflict. The width of road segment was not included as the criteria because the width of all road parts in this study are quite similar (between 4 and 5 lanes). No significant road width difference has been observed while we drove along the highway. However, in other areas where road widths are quite different in each road part (e.g. range from 4 to 8 lanes), the width of road segment should be included as another criteria.

In addition, due to the law in Thailand that allow local people to still be able to utilize the lands inside the protected areas if their family were there before the protected area designation, converting those lands into a part of corridor cannot be done if they refuse. Therefore, one more criterion was added to identify potential road segments: adjacent forest patches that can serve as a crucial stepping stone to connect and facilitate wildlife movement between the two sides should be available. These adjacent forest patches will at least guarantee that those areas can be used as corridor if the area is selected.

In total, seven road segments (Segments A – G) that passed the criteria, following a 30 km drive along Highway 304, were included in the study (Fig. 1). Among them, Segment A is the longest (2.6 km), followed by Segment F (2.0 km), Segments B and E (1.7 km), Segment G (700 m), Segment C (500 m), and Segment D (300 m). However, as good corridors should concern with the availability of the core area to reduce edge effect and wider is better (King et al., 2009; Proctor et al., 2015), we select only the road segments longer than 1.5 km. The length 1.5 km comes from the mean daily movement of Sun bear (Wong et al., 2004) since daily movement of black bear is unavailable, but the scale of movement of these two species are similar (Ngoprasert et al., 2012). The segment shorter than 1.5 km might cause the edge effect problem for bear species. Consequently, only four segments selected: Segment A, B, E and F.

2.3. Corridor suitability assessment

We assessed areas suitable for wildlife corridors by examining a 2-km buffer around the identified road segments. This distance was chosen based on the observed scale of movement for both the black bear and sun bear, derived from the spatial capture-recapture model (Ngoprasert et al., 2012). Within this zone, we overlaid 100×100 m (1 ha) grids (6,200 grids in total), evaluating the suitability for each grid using a BBN. The model consists of three elements: (1) 'nodes' – independent (parent node) and dependent (child node) variables (see Fig. 2 for example), (2) 'arrows' – indicating causal relationships between parent and child nodes, and (3) a 'conditional probability table' – determining the belief of each node in specific states (Oliver and Smith, 1990). To construct the BBN,

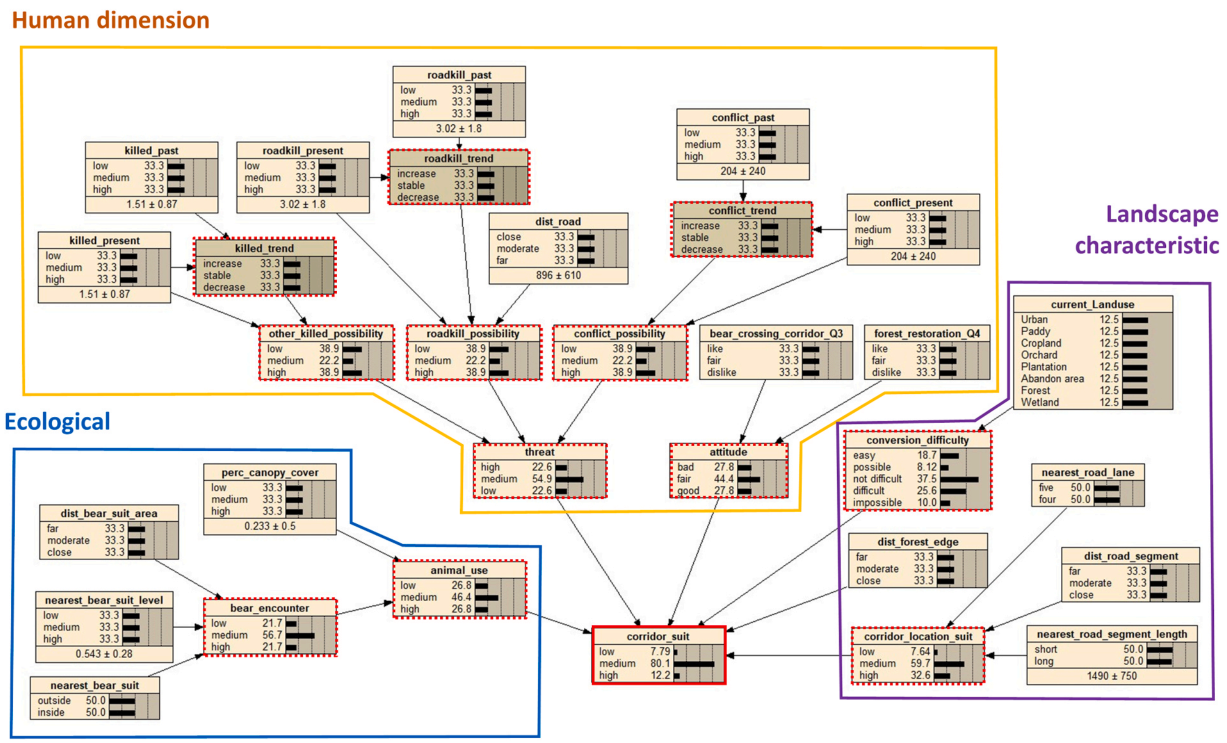

Fig. 2. Bayesian Belief Network of the corridor suitability model. The model covers three aspects: ecological, human dimension, and landscape characteristics. The explanation of each node is provided in Appendix II. The nodes with black border are the parent node, and the one with red border is the child node. The nodes with red dot border are the nodes that are both the parent and child nodes. The numbers shown in each child node for each state represent the probability of being in that state, which varies depending on the input of each parent node. For example, for the 'corridor_suit' node, with the current input for all parent nodes, there is a 7.79 % probability for corridor suitability to be low, 80.1 % to be medium, and 12.2 % to be high. All states of each parent node have equal probability as they are not affected by other nodes, and so the probabilities are set as equal due to the unknown of prior knowledge.

we initially drafted a conceptual model, which was then validated by two experts from the Department of National Parks, Wildlife and Plant Conservation and a non-governmental organization, both having extensive experience in wildlife management in Thailand. Next, the model was constructed using Netica software version 4.02 (Norsys, Vancouver, British Columbia, Canada) and re-evaluated by the same set of experts to finalize the model. Probability values for the Conditional Probability Table of each node were obtained from 21 additional experts in wildlife management with more than 10 years of experience. Relative corridor suitability levels were determined from six variables covering three aspects: (1) ecological (bear habitat use), (2) human dimension (threat level, human attitude), and (3) landscape characteristics (difficulty of land conversion into corridors, distance from forest edge, suitability of corridor location) (Fig. 2). The affiliations of all experts who contributed to BBN development are listed in Appendix I.

2.3.1. *Ecological data*

Black bear distribution model – This model was based on bear habitat suitability and the percentage tree cover. We used passive infrared digital camera-traps to determine the presence and absence of black bears in areas along the forest edge between two forest patches throughout the entire area (Fig. 1). Each trap location had a single camera mounted on trees, with a distance of 1.5–2 km between each location. To lure the bears, 500 ml of fish oil was applied to the tree trunks in front of the camera traps. To prevent black bears from getting close to the villages, cameras were installed at least 500 m from the forest edge, extending up to 3–4 km inside the protected areas. We set 60 camera trap locations between December 2020 and May 2021 (27 locations in Khao Yai and 33 locations in Dong Phayayen). Although the cam-trap survey was conducted in dry season, the bear habitat use should be able to represent for a whole year. According to Sun Bear data from telemetry study within the same area (Ngoprasert unpublished data), their home range size in wet season is smaller than in dry season, and the size in dry season is similar to the annual home range size. We did not have telemetry data for Asiatic Black Bear, but we assume that this should be similar for black bear as the fruit abundance in dry season is lower and thus bears need to move in further distance. The cameras were set to take multiple pictures without delay between triggering and be active 24 h per day. We carried out monthly inspections of cameras, involving the replacement of batteries and memory cards, and the application of lure. The total trapping effort (measured in trap days) was calculated based on the operational duration of each camera.

Logistic regression was used to test which variables influenced the habitat use by black bears. We analysed the following variables: 1) distance to Highway 304, 2) distance to agricultural areas, 3) distance to urban areas, 4) distance to abandoned areas (area with no active human activity and/or abandoned agricultural area), 5) slope and 6) elevation. We assessed outliers and correlations among variables prior to data analysis. All continuous variables were standardized before analysis by subtracting each variable's mean and dividing by its standard deviation (z-score). Variance Inflation Factor (VIF) was used to evaluate multicollinearity in each model, and a VIF value of 5 was used as the cut-off for considering multicollinearity between variables in the model (Zuur et al., 2010). We used the "*performance*" package to estimate the variance inflation factor (Ludecke et al., 2021). We addressed unequal camera-trap survey efforts at each location by using an offset in the model formula. This is equivalent to including survey effort (trap-days) as a regression predictor but with its coefficient fixed to 1 (Gelman and Hill, 2007). Data analysis was performed in R software (R Core Team, 2022). We tested model assumptions (i.e. spatial autocorrelation, residuals) by using the "*DHARMa*" package (Hartig, 2022). We compared models using AIC and AIC weights to identify the best model explaining the probability of bear habitat use (Akaike, 1973). The model predictability was evaluated by calculating the area under the receiver-operating curve (AUC). An AUC value $\leq$0.5 indicates prediction performance equivalent to random expectation, while a value of 1 indicates excellent predictability (Hosmer and Lemeshow, 2000). Model evaluation was performed using the "*PresenceAbsence*" package (Freeman and Moisen, 2008).

Forest cover – For assessing the tree cover percentage in 2022, the NDVI map was used as a surrogate. We tested for correlations between NDVI and percentage tree cover and found a highly significant correlation ($r = 0.8$). The percentage tree cover map for the year 2000 was obtained from Hansen et al. (2013), while NDVI maps for the years 2000 and 2022 were generated from Landsat Satellite Images downloaded from https://earthexplorer.usgs.gov/.

2.3.2. *Human dimension*

For threat level and human attitude, both variables were assessed through interviews with the local people. Between February and March 2022, 150 grids within the assessed area were randomly selected, and one household was sampled per grid. The questionnaire consisted of two sections. The first section delved into wildlife threats within the past five years (2017–2021), categorized into two periods: before (2017–2019) and during covid-19 situation (2020–2021). Three threats were assessed, including the number of animals that died from human persecution, vehicle collisions, and other causes (hunting, trapping, pets, electric fences). The second section considered human attitudes toward wildlife corridor construction and the recommendations for government agencies to mitigate local resistance toward corridor construction. Two questions were used to assess their attitudes: (1) the acceptance level for the presence of bears walking past their areas after wildlife corridor construction, and (2) the acceptance level if the government were to restore their areas as wildlife corridors, with the government taking responsibility for all construction costs, and local people retaining access to and collect of non-timber forest products from that area. The acceptance levels were divided into five categories, ranging from 1 (totally unacceptable) to 5 (totally acceptable). Data from the interviews were used to generate threat level maps and human attitude maps, using spatial IDW interpolation techniques in ArcGIS 10.8.

2.3.3. *Landscape characteristics*

In this part, three factors involved: land conversion difficulty, distance from the forest edge and suitability of the corridor location. The difficulty of converting land into corridors was assessed by 21 experts based on eight land-use types: urban areas, paddy fields, cropland, orchards, plantations, abandoned areas, forest areas and wetlands. The land-use map, obtained from the Land Development

Department (2018–2019), was manually updated by our team between December 2020 and January 2021 to match the current land-use. Secondly, the distance from the forest edge was calculated as the distance between specific grids and the forest edge, with data sourced from the earlier mentioned land-use map. Lastly, the suitability of the corridor location considered lane number, length of the nearest road segments, and distance from particular grids to the nearest road segment. All distance values were calculated using the 'Euclidean Distance' toolbox in ArcGIS 10.8. Appendix II provides explanations for all nodes included in the BBN.

Following the complete construction of the BBN, the values of each factor were extracted for each grid to generate a case file. A case file is the input file that contain the values of all parent nodes for each grid (one line per grid) which will be processed through the BBN. Then the 'process case' function in the BBN was then executed with the prepared case file to obtain probabilities in each state (low, medium, or high) of the final output node for each grid (Fig. 2). These probabilities were subsequently used to calculate the corridor suitability of each grid, divided into four levels: unsuitable (0–25 %), low suitability (25–50 %), moderate suitability (50–75 %), and high suitability (75–100 %). The equation below was employed.

$$p(\text{corridor suitability}) = 0*p(\text{low}) + 50*p(\text{medium}) + 100*p(\text{high})$$

2.4. Road segment identification

After corridor suitability was assessed, we calculated the overall suitable corridor areas for the current situation. Then each road segment was evaluated on its potential to serve as a wildlife corridor based on the suitability level of the surrounding grids. Potential road segments were identified as those with more than 25 % of the surrounding areas (within a 2 km buffer around each road segment) classified as highly suitable for a corridor. Wildlife is more likely to frequent and utilize corridors in areas characterized by higher corridor suitability.

2.5. Management strategy and priority for connectivity

Various scenarios were tested to identify management strategies that could maximize suitable corridor areas (Scenarios #1–4) and predict future situations that might reduce suitable corridor areas (Scenarios #5–8) compared to the current state. The first four scenarios were designed to evaluate how each management strategy could improve overall suitability. These were: Scenario #1—better human attitudes toward wildlife corridor construction, Scenario #2—a 20 % increase in forest cover, Scenario #3—a decrease in hunting, wildlife pet trade, and vehicle collisions, and Scenario #4—a decrease in human-wildlife conflicts. Then, four more scenarios were tested to evaluate the overall decrease in suitability if adverse situations were to occur. These included: Scenario #5—worse human attitudes toward wildlife corridor construction, Scenario #6—a decrease in forest cover by 20 %, Scenario #7—an increase in hunting, wildlife pet trade and vehicle collisions, and Scenario #8—an increase in human-wildlife conflict. The method of how each scenario was tested was shown in Table 1. Overall suitable corridor areas were calculated and the road segments having potential to serve as a wildlife corridor were identified for each scenario.

3. Results

3.1. Black bear habitat use

Elevation emerged as the best predictor of black bear habitat use, based on the model with the lowest AIC value and highest AIC weight. The probability of black bear occurrence was high in areas with higher elevation ($\beta = 0.61 \pm SE\ 0.30$). The occurrence probability attained a 50 % chance when elevations were higher than 465 m. This indicates that black bears exhibit a preference for healthy forests over secondary forests along the forest edge, usually found at lower elevations close to the village. The model demonstrated acceptable discrimination between detected and non-detected black bears with AUC = 0.74.

Table 1
The method for all scenario testing (how each node changed).

Scenario	Node changed	Change applied
1) better human attitudes toward wildlife corridor construction	Bear_crossing_corridor_Q3 Forest_restoration_Q4	Improve attitude one level (from Dislike → Fair and Fair → Like)
2) a 20 % increase in forest cover	Perc_canopy_cover	Add 20 %
3) a decrease in hunting, wildlife pet trade, and vehicle collisions	Killed_present	Change all to Low level
4) a decrease in human-wildlife conflicts	Conflict_present	Change all to Low level
5) worse human attitudes toward wildlife corridor construction	Bear_crossing_corridor_Q3 Forest_restoration_Q4	Downgrade attitude one level (from Like → Fair and Fair → Dislike)
6) a decrease in forest cover by 20 %	Perc_canopy_cover	Reduce 20 %
7) an increase in hunting, wildlife pet trade and vehicle collisions	Killed_present	Change all to High level
8) an increase in human-wildlife conflict	Conflict_present	Change all to High level

3.2. Corridor suitability assessment

The overall suitability within the assessed area (58 km^2) is distributed as follows: 13 km^2 (22 %) of highly suitable areas, 36 km^2 (62 %) of moderately suitable areas, 8 km^2 (14 %) of low suitable areas, and 1 km^2 (1 %) of unsuitable areas (Fig. 3).

For the suitability of each grid, only one road segment that have high potential to be wildlife corridors which is segment F (Table 2). For all other road segments (A, B and E), although they did not pass the criteria, the percentage of grids identified as high corridor suitability were not that low (between 20 % and 23 %). Segment A even has highly suitable grids connecting Khao Yai and Dong Phayayen patches. The majority of surrounding area (within 2-km buffer around each road segment) of all four segments are classified as moderately suitable corridor (between 59 % and 72 %)

3.3. Management strategy and priority for connectivity

Among the four scenarios designed to explore how each management strategy could improve overall suitability, Scenario #1—improvement in human attitudes toward wildlife corridor construction, emerged as the most effective, resulting in a substantial increase in overall suitability (areas with a high suitability rating increased from 13 km^2 to 29 km^2). This was followed by Scenario #4—a decrease in human-wildlife conflicts, which showed a 4 km^2 increase in highly suitable areas (Fig. 4). Both scenarios identified all four road segments to have high potential to be wildlife corridor (Table 2). Scenario #3—a decrease in human threats (hunting, wildlife pet trade, vehicle collisions, led to the smallest improvement, with an increase of less than 1 km^2 from the current situation,

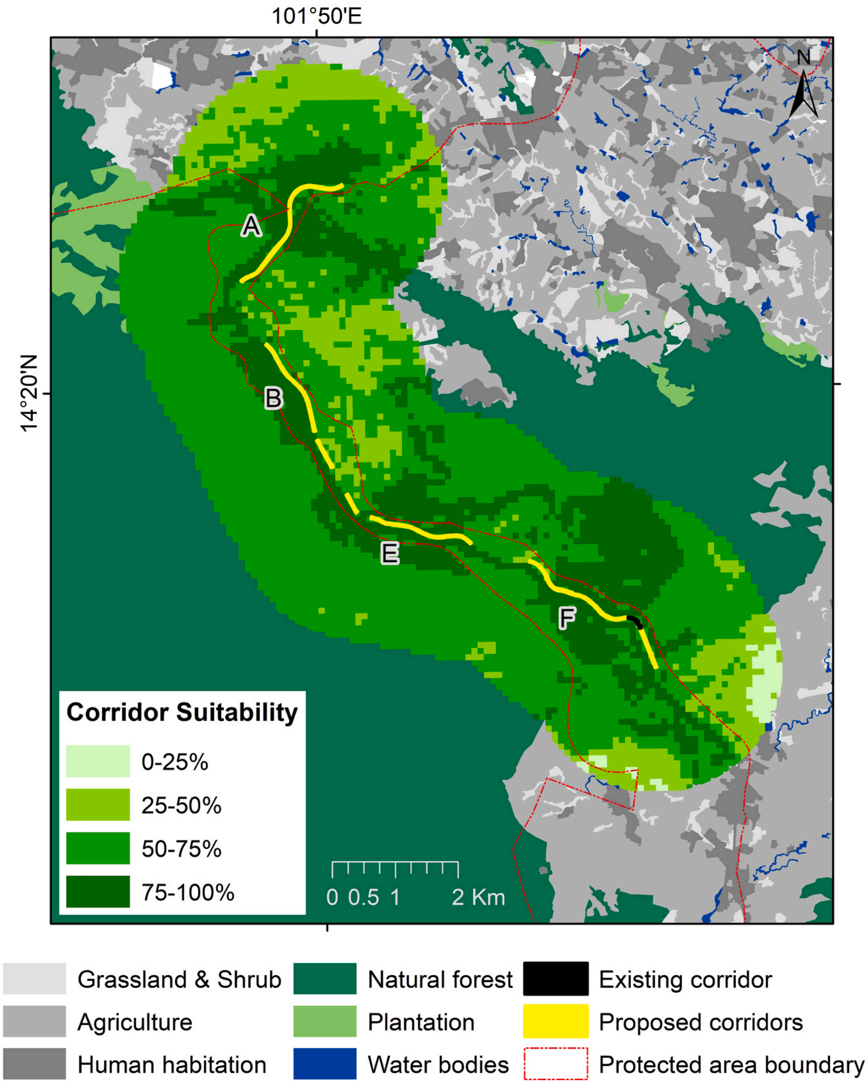

Fig. 3. The corridor suitability of four road segments (A, B, E, F) under the current situation. The road segments connect Khao Yai and Dong Phayayen patches.

Table 2
Percentage of surrounding area in each corridor suitability level for four potential segments. Scenario (1) improvement in human attitudes toward wildlife corridor construction, (2) a 20 % increase in forest cover, (3) a reduction in hunting, wildlife pet trade, and car accidents, (4) a decrease in human-wildlife conflicts, (5) deterioration in human attitudes toward wildlife corridor construction, (6) a 20 % decrease in forest cover, (7) an increase in hunting, wildlife pet trade, and car accidents, and (8) an increase in human-wildlife conflicts.

		corridor suitability			
	Segment	unsuitable	low	medium	high
Current situation	A	0	20	59	20
	B	0	13	67	20
	E	0	5	72	23
	F	0	6	62	32
maximize suitable corridor areas					
Scenario 1	A	0	7	45	48
	B	0	2	52	46
	E	0	0	44	56
	F	0	1	29	70
Scenario 2	A	0	10	65	25
	B	0	3	74	23
	E	0	1	73	26
	F	0	1	61	38
Scenario 3	A	0	20	60	20
	B	0	12	68	20
	E	0	5	72	23
	F	0	6	62	32
Scenario 4	A	0	13	54	33
	B	0	6	64	30
	E	0	3	70	27
	F	0	3	57	40
reduce suitable corridor areas					
Scenario 5	A	0	24	59	17
	B	0	14	67	19
	E	0	5	73	21
	F	0	9	74	18
Scenario 6	A	1	35	58	6
	B	0	38	59	3
	E	0	30	68	2
	F	0	21	74	5
Scenario 7	A	4	36	53	8
	B	1	32	61	6
	E	0	23	70	7
	F	0	19	72	9
Scenario 8	A	2	26	58	13
	B	0	22	69	9
	E	0	21	71	9
	F	0	14	74	12

and only segment F that have high potential to be wildlife corridor (Table 2).

Conversely, among the four scenarios that might reduce overall suitability, Scenario #7—escalation of human threats such as hunting, wildlife pet trade, and vehicle collisions, stood out as the most detrimental, reducing highly suitable areas from 13 km^2 to 4 km^2. Meanwhile, a decrease in forest cover by 20 % (Scenario #6) and an increase in human-wildlife conflicts (Scenario #8) resulted in a reduction in highly suitable areas from 13 to 6 km^2 (Fig. 5). The scenario with the least impact on overall suitability was the worsening of human attitudes toward wildlife corridor construction (Scenario #5), leading to a reduction in highly suitable areas from 13 km^2 to 9 km^2. No road segment was identified as high potential to be wildlife corridor for all of these four scenarios (Table 2).

4. Discussion

This study used a structured decision-making model to identify potential wildlife corridors between isolated forest patches and tested various positive and negative scenarios that could impact overall suitability probabilities. Our approach, utilizing multiple data sources within BBN, is flexible and incorporates anthropogenic resistance, directly integrating a human dimension into the model.

From the models, only one road segment (Segment F) has been identified as potential wildlife corridor, while other three (Segment A, B, E) have less potential. Improving human attitudes toward wildlife corridors is a strategy that can maximize overall suitability for connectivity, while escalating human threats (hunting, pet, vehicle collisions) represent a major threat to the overall suitability. Among all four segments, Segment A is the longest and the only segment that has areas with high corridor suitability, serving as a long-range connection between Khao Yai and Dong Phayayen patches (Fig. 3). The disadvantage of Segment A is its proximity to villages, which may cause adverse impacts (e.g., increased human-wildlife conflicts) in the future, potentially lowering its suitability. For Segment B, although areas along the segment on Khao Yai side are natural habitats, all land-use on Thap Lan side are agriculture and so

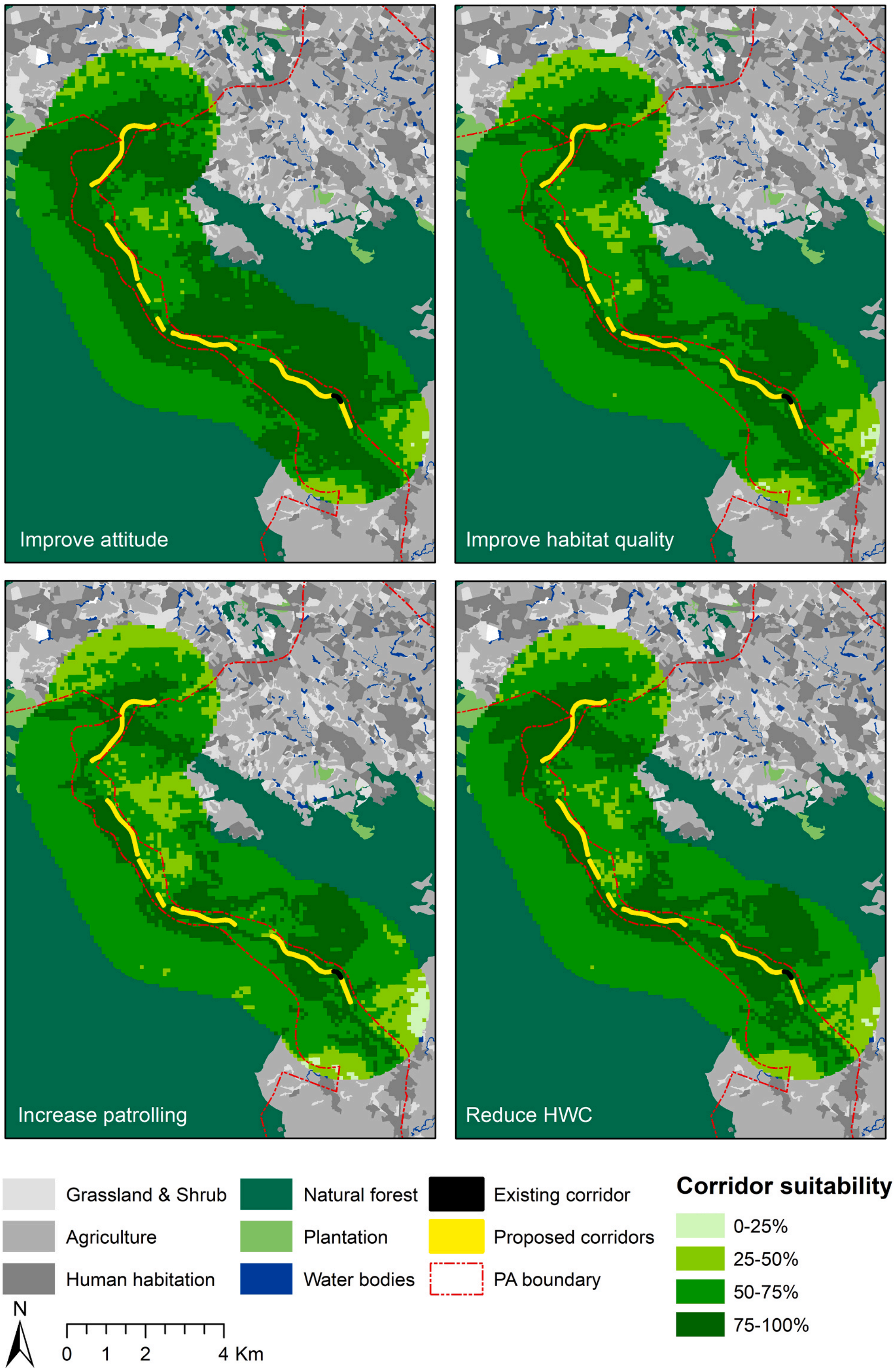

Fig. 4. Overall suitability results from four management strategies: (1) improvement in human attitudes toward wildlife corridor construction, (2) a 20 % increase in forest cover, (3) a reduction in hunting, wildlife pet trade, and car accidents, and (4) a decrease in human-wildlife conflicts.

the suitability on this side are low to moderate. For Segment E and F, these two segments are surrounded by natural habitats, so the impact may be lower. However, the areas adjacent to Khao Yai for both segments have moderate corridor suitability as these areas are mostly secondary forests, leading to lower food availability for wildlife. Therefore, the corridor suitability for Segment E and F can be improved by restoring these secondary forests. Additionally, Segment F has another advantage of being connected with an existing

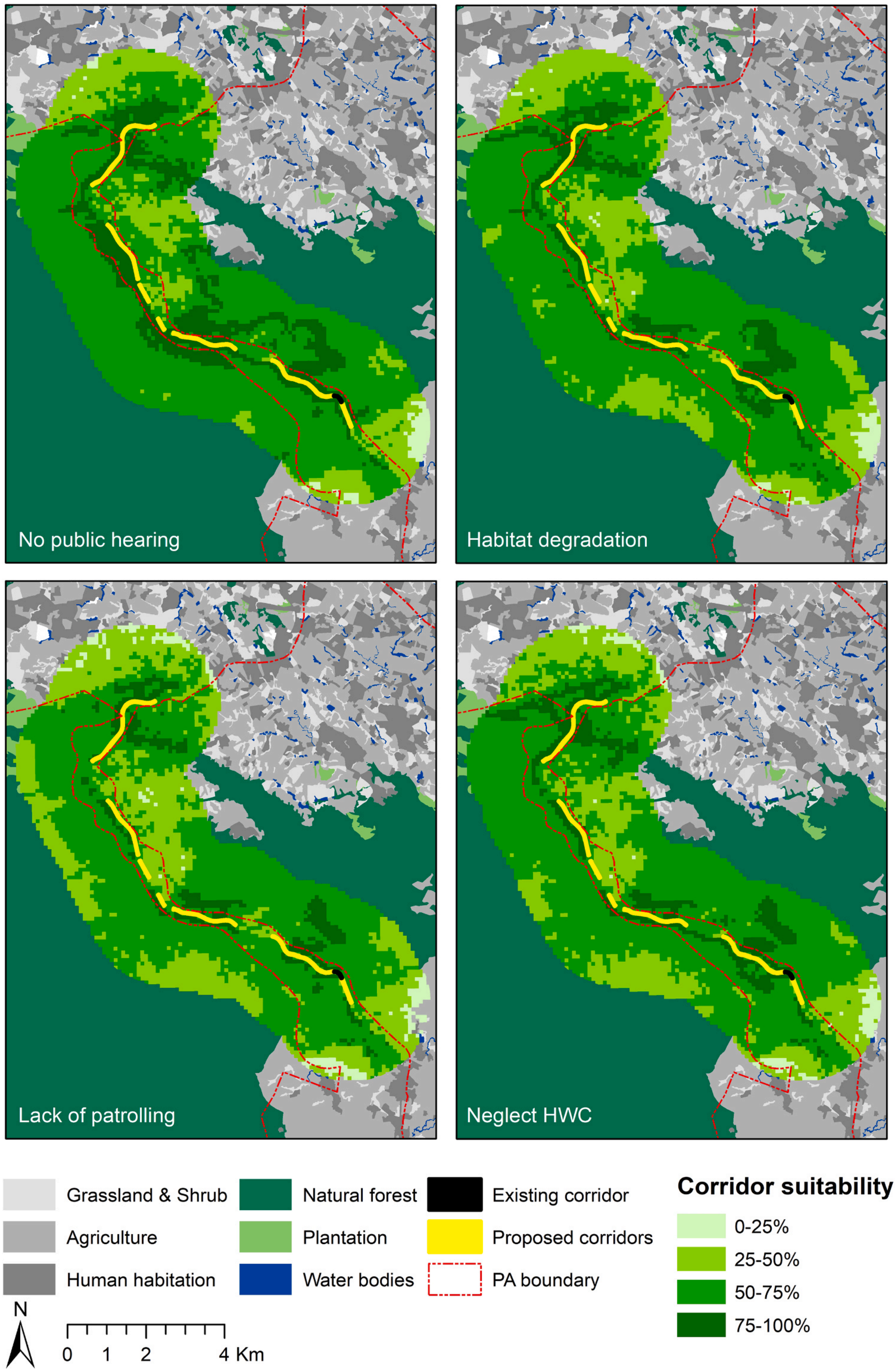

Fig. 5. Overall suitability results from four adverse scenarios: (5) deterioration in human attitudes toward wildlife corridor construction, (6) a 20 % decrease in forest cover, (7) an increase in hunting, wildlife pet trade, and car accidents, and (8) an increase in human-wildlife conflicts.

underpass wildlife corridor (Fig. 1).

Among the four management scenarios tested, improving human attitudes toward wildlife corridors proved the most effective strategy for increasing overall suitability. This highlights the importance of integrating community engagement in wildlife corridor management strategies, particularly in the face of increasing urbanization globally. We observed that a significant proportion of local people hold negative attitudes toward wildlife corridors, with most villages located inside protected areas (Fig. 3). According to interviews, about 60 % of respondents still cannot accept the idea of wildlife walking through their areas owing to fears of possible attacks and crop damage. Moreover, 80 % do not agree with the restoration of parts of their land for wildlife corridors, even if it involves cropland conversion into agroforestry, despite the government overseeing all restoration activities, and individuals still being able to use the land as usual. To address these attitudes, the implementation of a public hearing process is very important. However, trust-building within the local community can take a long time to accomplish. An additional strategy that might be feasible to apply along with attitude improvement is the use of compensation programs such as payments for ecosystem services to compensate individuals or communities for increasing suitable corridor areas and reducing community resistance (Jack et al., 2008; United Nations Environment Programme, 2008).

For the testing of adverse scenarios, we found that the escalation of human-induced threats (hunting, wildlife pet trade, and vehicle collisions) emerged as the scenario with the most potential to substantially reduce overall suitability. Therefore, measures should be taken to ensure that this situation does not happen. During the camera trap survey covering 297 km^2, we detected 15 illegal activities, including snaring (targeting wild pigs, gaurs, elephants, muntjac, and galliforms), gun traps, armed hunters, hunter camps, and the collection of non-timber forest products (such as bamboo and mushrooms). Surveillance by rangers both inside the forest and near the forest edge should be continuously supported to maintain or, if possible, increase the frequency of surveillance to ensure that hunting levels do not increase. At the same time, penalties for keeping or trading wildlife as pets should be promoted and communicated, so the locals can understand their severity. In addition, law enforcement should also be more effective in conveying the strictness of government measures. Physical barriers between the parks and main roads should be repaired, strengthened, or expanded to prevent wildlife from crossing roads outside the corridor. The maintenance of these barriers should also be conducted routinely. However, the construction should minimize the use of physical barriers and landscape modification, keeping the corridor as open as possible. Many species, especially large carnivores, are sensitive to these changes and might avoid such areas (McClure et al., 2017; Naha et al., 2023). Moreover, we recommend that managers consider extending corridor widths as much as the landscape allows to facilitate the dispersal and movement of multi-species, especially for large carnivores. Sex-biased dispersal (short and gradual female natal dispersal) tends to reduce the ability of large female carnivores to cross suitable connectivity areas (Proctor et al., 2012, 2015; Smith, 1993).

In this study, factors incorporated in the BBN to assess corridor suitability covered three aspects: ecological, human dimension, and landscape characteristics. However, to make the results more practical and helpful for managers and stakeholders when making decisions, several other factors, like construction costs, should be considered (although this is outside the scope of this research). Each corridor option will have different initial and maintenance costs depending on the surrounding environment. Some options (e.g., Segments E and F) might have lower initial costs for constructing the corridor as these segments are mostly surrounded by natural areas with just a small portion of residential/agricultural patches. In contrast, Segment A and B, like any other options, can have higher initial costs, as these segments mostly run through residential and agricultural areas, necessitating the construction of long physical barriers to prevent wildlife intrusion into human habitation areas. The difference in barrier length can also affect long-term maintenance costs, with longer barriers incurring higher maintenance costs. Furthermore, the possible future impact of each option needs to be considered, as well as the severity of such impact. For example, for Segment A and B, more than half of these segments connect with residential/agricultural areas, increasing the chance that wildlife crossing the corridor might inadvertently enter human areas, escalating human-wildlife conflicts. All these factors, including costs and impact, should be presented to stakeholders when making decisions regarding corridor construction to help in choosing the most practical options.

Our framework in this study is practical, flexible, and adaptable for various decision-making processes that require knowledge and/or human-animals interaction. Additionally, managers need to consider human tolerance in surrounding areas and the mortality risk to wildlife. The BBN model can be adapted for application in other areas with similar ecosystems. It can also be minimally modified for different models implementing a multi-species approach when identifying wildlife corridors. However, several parts need to be adjusted to match specific landscapes, contexts, and target species. For example, the criteria for road segment identification may differ for different species of interest. Moreover, the focal species should be those sensitive to habitat alterations caused by humans, such as large carnivores. These species would serve as good "indicator species" for identifying corridors, as they will only use the corridor if it is suitable. If these species use the corridor, it can be inferred that other species will also use that particular corridor. Different kinds of threats may be added or removed from the BBN depending on data availability. Management scenario testing will also depend on the context/policy of each area. Moreover, if possible, cost-effective assessments should be incorporated into the BBN (whether in the model itself or conducted afterward) to increase usability when presenting solutions to stakeholders. Although our recommendation for further improvement of the model might make this modelling to look complicated, we would like to stress that the BBN still be an advance on corridor planning and should be applied more widely in other contexts as the modeling also consider the anthropogenic aspects in addition to animal ecology (Dutta et al., 2022).

CRediT authorship contribution statement

Somporn Phakpian: Writing – review & editing, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Naruemon Tantipisanuh:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Dusit Ngoprasert:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Supagit Vinitpornsawan:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Pornpimon Tangtorwongsakul:** Writing – review & editing, Investigation, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Acknowledgements

We extend our gratitude to the entire staff of Dong Phayayen-Khao Yai Wildlife Research Station for their invaluable assistance during the field survey. Special thanks to Chadaporn Saenset and Kiratikan Kongkiatsiri for their contributions to the interview survey. We also wish to acknowledge Anak Pattanavibool for his assistance in developing the conceptual model and express our gratitude to the other 21 experts involved in model parameterization. We are grateful to Robert Steinmetz for providing constructive comments on earlier drafts, and Oscar Nnaemeka Obidiegwu for proof reading the final draft. We also thank two reviewers for their constructive and helpful comments to improve our manuscript. This project received grant support from the National Science and Technology Development Agency (grant number P-19-52257).

Appendix I. Qualifications of experts involved in BBN development

Involved process	Organization	Position	Number
Conceptual model development (draft & validate)	Department of National Parks, Wildlife and Plant Conservation	Forestry specialist	1
	WCS Thailand	Director	1
CPT calculation	King Mongkut's University of Technology Thonburi	Lecturer/Researcher	4
	Chulalongkorn University	Veterinary	1
	Kasetsart University	Lecturer/Researcher	2
	Mahidol University	Lecturer/Researcher	2
	Khon Kaen University	Lecturer/Researcher	1
	Walailak University	Veterinary	1
	WWF Thailand	Project manager	1
	Panthera Thailand	Project manager	1
	Panthera Thailand	Veterinary	1
	Zoological Park Organization of Thailand	Veterinary	4
	Department of National Parks, Wildlife and Plant Conservation	Forestry specialist	2
	Chiang Mai Zoo	Veterinary	1

Appendix II. Description of each node in Bayesian Belief Network shown in Fig. 1

Node	Description	Parent nodes
Dist_bear_suit_area	Nearest distance of the specific grid from suitable habitat areas for bears	-
Nearest_bear_suit_level	The level of suitability of the bear habitat in closest proximity to the specified grid	-
Nearest_bear_suit	The protection status (whether inside or outside protected areas) of the suitable bear habitat in closest proximity to the specified grid	-
Bear_encounter	The likelihood of encountering bears in that particular grid	Dist_bear_suit_area, Nearest_bear_suit_level, Nearest_bear_suit
Perc_canopy_cover	The percentage canopy cover in that particular grid	-
Animal_use	The probability of wildlife utilizing that particular grid	Bear_encounter, Perc_canopy_cover
Killed_present	The extent of wildlife mortality from trapping, hunting, wildlife pet trade, or electrocution between 2020 and 2021 (during the Covid-19 situation) in that particular grid	-
Killed_past	The extent of wildlife mortality from trapping, hunting, wildlife pet trade, or electrocution between 2017 and 2019 (before the Covid-19 situation) in that particular grid	-
Killed_trend	The trend in wildlife mortality from trapping, hunting, wildlife pet trade, or electrocution before and during the Covid-19 situation in that particular grid	Killed_present, Killed_past
Other_killed_possibility	The possibility of wildlife mortality from trapping, hunting, wildlife pet trade, or electrocution in that particular grid	Killed_present, Killed_trend
Roadkill_present	The extent of wildlife mortality from roadkill between 2020 and 2021 (during the Covid-19 situation) in that particular grid	-

(continued on next page)

(*continued*)

Node	Description	Parent nodes
Roadkill_past	The extent of wildlife mortality from roadkill between 2017 and 2019 (before the Covid-19 situation) in that particular grid	-
Roadkill_trend	The trend in wildlife roadkill before and during the Covid-19 situation in that particular grid	Roadkilled_present, Roadkilled_past
Dist_road	Distance to highway	-
Roadkill_possibility	The possibility of wildlife mortality from vehicle accidents in that particular grid	Roadkill_trend, Dist_road
Conflict_present	The level of wildlife mortality from human persecution between 2020 and 2021 (during the Covid-19 situation) in that particular grid	-
Conflict_past	The level of wildlife mortality from human persecution between 2017 and 2019 (before the Covid-19 situation) in that particular grid	-
Conflict_trend	The trend in wildlife persecution before and during the Covid-19 situation in that particular grid	Conflict_present, Conflict_past
Conflict_possibility	The possibility of wildlife persecution in that particular grid	Conflict_present, Conflict_trend
Threat	The overall threat level for all threats in that particular grid	Other_killed_possibility, Roadkill_possibility, Conflict_possibility
Bear_crossing_corridor_Q3	Attitudes of local people regarding the prospect of bears traversing through their areas after wildlife corridor construction in that particular grid	-
Forest_restoration_Q4	Attitudes of local people toward restoring their areas for use as wildlife corridors in that particular grid	-
Attitude	The overall attitude of local people toward wildlife corridor construction in that particular grid	Bear_crossing_corridor_Q3, Forest_restoration_Q4
Current_landuse	The current major land-use type in that particular grid	-
Conversion_difficulty	The difficulty to convert each land-use type into wildlife corridor	Current_landuse
Dist_forest_edge	The distance to forest edge in that particular grid	-
Nearest_road_lane	The number of lanes in the nearest road segment to that particular grid	-
Dist_road_segment	The nearest distance from the road segment to that particular grid	-
Nearest_road_segment_length	The length of the nearest road segment to that particular grid	-
Corridor_location_suit	The suitability of that particular grid as a wildlife corridor with respect to the nearest road segment	Nearest_road_lane, Dist_road_segment, Nearest_road_segment_length
Corridor_suit	The suitability of that particular grid as a wildlife corridor, combining all pertinent factors	Animal_use, Threat, Attitude, Conversion_difficulty, Dist_forest_edge, Corridor_location_suit

References

Ahmed, R.A., Prusty, K., Jena, J., Dave, C., Das, S.K., Sahu, H.K., Rout, S.D., 2012. Prevailing human carnivore conflict in Kanha-Achanakmar corridor, Central India. World J. Zool. 7 (2), 158–164.

Akaike, H. (1973). Information theory and an extension of the maximum likelihood principle. Pages 267-281 in *International Symposium on Information Theory*, Budapest, Hungary.

Baskaran, N., Boominathan, D., 2010. Road kill of animals by highway traffic in the tropical forests of Mudumalai Tiger Reserve, southern India. J. Threat. Taxa 2 (3), 753–759.

Beier, P., Majka, D.R., Spencer, W.D., 2008. Forks in the road: choices in procedures for designing wildland linkages. Conserv. Biol. 22 (4), 836–851.

Beier, P., Noss, R.F., 1998. Do habitat corridors provide connectivity? Conserv. Biol. 12 (6), 1241–1252.

Bennett, E.L., Underwood, F.M., Milner-Gulland, E.J., 2021. To trade or not to trade? Using Bayesian belief networks to assess how to manage commercial wildlife trade in a complex world. Front. Ecol. Evol. 9, 587896.

Bond, M., 2003. Principles of wildlife corridor design. Cent. Biol. Divers. 4.

Coffin, A.W., 2007. From roadkill to road ecology: a review of the ecological effects of roads. J. Transp. Geogr. 15 (5), 396–406.

Corlatti, L., Hackländer, K., FREY-ROOS, F., 2009. Ability of wildlife overpasses to provide connectivity and prevent genetic isolation. Conserv. Biol. 23 (3), 548–556.

Doko, T., Fukui, H., Kooiman, A., Toxopeus, A.G., Ichinose, T., Chen, W., Skidmore, A.K., 2011. Identifying habitat patches and potential ecological corridors for remnant Asiatic black bear (Ursus thibetanus japonicus) populations in Japan. Ecol. Model. 222 (3), 748–761.

Dutta, T., Sharma, S., Meyer, N.F.V., Larroque, J., Balkenhol, N., 2022. An overview of computational tools for preparing, constructing and using resistance surfaces in connectivity research. Landsc. Ecol. 37, 2195–2224.

Filius, J., van der Hoek, Y., Jarrín-V, P., van Hooft, P., 2020. Wildlife roadkill patterns in a fragmented landscape of the Western Amazon. Ecol. Evol. 10 (13), 6623–6635.

Freeman, E.A., Moisen, G., 2008. PresenceAbsence: an R Package for Presence-Absence Model Analysis. J. Stat. Softw. 23, 1–31. ⟨http://www.jstatsoft.org/v23/i11⟩.

Garshelis, D., & Steinmetz, R. (2020). *Ursus thibetanus* (amended version of 2016 assessment). The IUCN Red List of Threatened Species 2020: e.T22824A166528664. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T22824A166528664.en. Accessed on 20 September 2023.

Gelman, A., Hill, J., 2007. Data Analysis Using Regression and Multilevel/Hierarchical Models. Cambridge University Press, NY, USA.

Ghoddousi, A., Buchholtz, E.K., Dietsch, A.M., Williamson, M.A., Sharma, S., Balkenhol, N., Kuemmerle, T., Dutta, T., 2021. Anthropogenic resistance: accounting for human behavior in wildlife connectivity planning. One Earth 4 (1), 39–48.

Hairong, D., Xiaoliang, Z., Minghai, Z., Xiangdong, R., Lee, T.M., 2022. Spatial distribution and conservation strategies of large carnivores in human-dominated landscape: a case study of asiatic black bear in Jilin, China. Front. Ecol. Evol. 10, 882282.

Hartig, F. (2022). DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models. R package version 0.4.6, ⟨https://CRAN.R-project.org/package=DHARMa⟩.

Hofman, M.P., Hayward, M.W., Kelly, M.J., Balkenhol, N., 2018. Enhancing conservation network design with graph-theory and a measure of protected area effectiveness: Refining wildlife corridors in Belize, Central America. Landsc. Urban Plan. 178, 51–59.

Hosmer, D.W., Lemeshow, S., 2000. Applied Logistic Regression, second edition. John Wiley & Sons, Inc., USA.

Jackson, S.D., Griffin, C.R., 2000. A strategy for mitigating highway impacts on wildlife. Wildlife and highways: seeking solutions to an ecological and socio-economic dilemma. Wildl. Soc. 143–159.

Jack, B.K., Kousky, C., Sims, K.R.E., 2008. Designing payments for ecosystem services: lessons from previous experience with incentive-based mechanisms. Proc. Natl. Acad. Sci. 105, 9465–9470.

Johnson, S., Marker, L., Mengersen, K., Gordon, C.H., Melzheimer, J., Schmidt-Küntzel, A., Nghikembua, M., Fabiano, E., Henghali, J., Wachter, B., 2013. Modeling the viability of the free-ranging cheetah population in Namibia: an object-oriented Bayesian network approach. Ecosphere 4 (7), 1–19.

King, D.I., Chandler, R.B., Collins, J.M., Petersen, W.R., Lautzenheiser, T.E., 2009. Effects of width, edge and habitat on the abundance and nesting success of scrub–shrub birds in powerline corridors. Biol. Conserv. 142 (11), 2672–2680.

Kioko, J., Kiffner, C., Jenkins, N., Collinson, W.J., 2015. Wildlife roadkill patterns on a major highway in northern Tanzania. Afr. Zool. 50 (1), 17–22.

Koivula, M.J., Vermeulen, H.J., 2005. Highways and forest fragmentation–effects on carabid beetles (Coleoptera, Carabidae). Landsc. Ecol. 20 (8), 911–926.

Kramer-Schadt, S., Revilla, E., Wiegand, T., Breitenmoser, U.R.S., 2004. Fragmented landscapes, road mortality and patch connectivity: modelling influences on the dispersal of Eurasian lynx. J. Appl. Ecol. 41 (4), 711–723.

Liu, J., Coomes, D.A., Gibson, L., Hu, G., Liu, J., Luo, Y., Yu, M., 2019. Forest fragmentation in China and its effect on biodiversity. Biol. Rev. 94 (5), 1636–1657.

Ludecke, D., Ben-Shachar, M.S., Patil, I., Waggoner, P., Makowski, D., 2021. performance: an R Package for Assessment, Comparison and Testing of Statistical Models. J. Open Source Softw. 6, 3139 https://doi.org/3110.21105/joss.03139.

Marcot, B.G., Steventon, J.D., Sutherland, G.D., McCann, R.K., 2006. Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation. Can. J. For. Res. 36 (12), 3063–3074.

McClure, M.L., Dickson, B.G., Nicholson, K.L., 2017. Modeling connectivity to identify current and future anthropogenic barriers to movement of large carnivores: a case study in the American Southwest. Ecol. Evol. 7 (11), 3762–3772.

Naha, D., Periquet, S., Werner Kilian, J., Kupferman, C.A., Hoth-Hanssen, T., Beasley, J.C., 2023. Fencing affects movement patterns of two large carnivores in Southern Africa. Front. Ecol. Evol. 11, 1031321 https://doi.org/10.3389/fevo.2023.1031321.

Ngoprasert, D., Gale, G.A., 2019. Tiger density, dhole occupancy, and prey occupancy in the human disturbed Dong Phayayen – Khao Yai Forest Complex, Thailand. Mamm. Biol. 95, 51–58.

Ngoprasert, D., Reed, D.H., Steinmetz, R., Gale, G.A., 2012. Density estimation of Asian bears using photographic capture-recapture sampling based on chest marks. Ursus 23, 117–133.

Oliver, R.M., Smith, J.Q., 1990. Influence Diagrams, Belief Nets and Decision Analysis. Wiley, Chichester, UK.

Ortega-Argueta, A., 2020. Improving recovery planning for threatened species through Bayesian belief networks. Biol. Conserv. 241, 108320.

Phuyal, S., 2018. Habitat preference, threats and distribution of Himalayan black bear (Ursus thibeatanus). Apee Nampa Conservation Area Office, Darchula.

Proctor, M.F., Nielsen, S.E., Kasworm, W.F., Servheen, C., Radandt, T.G., Machutchon, A.G., Boyce, M.S., 2015. Grizzly bear connectivity mapping in the Canada–United States trans-border region. J. Wildl. Manag. 79 (4), 544–558.

Proctor, M.F., Paetkau, D., McLellan, B.N., Stenhouse, G.B., Kendall, K.C., Mace, R.D., Strobeck, C., 2012. Population fragmentation and inter-ecosystem movements of grizzly bears in western Canada and the northern United States: Fragmentation de la Population et Mouvements Inter-Ecosystèmes des Ours Grizzlis dans L'ouest du Canada et le Nord des États-Unis. Wildl. Monogr. 180 (1), 1–46.

R Core Team, 2022. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. ⟨https://www.R-project.org/⟩.

Ralls, K., Sunnucks, P., Lacy, R.C., Frankham, R., 2020. Genetic rescue: a critique of the evidence supports maximizing genetic diversity rather than minimizing the introduction of putatively harmful genetic variation. Biol. Conserv. 251, 108784.

Sawaya, M.A., Clevenger, A.P., Schwartz, M.K., 2019. Demographic fragmentation of a protected wolverine population bisected by a major transportation corridor. Biol. Conserv. 236, 616–625.

Silva, I., Crane, M., Savini, T., 2020. High roadkill rates in the Dong Phayayen-Khao Yai World Heritage Site: conservation implications of a rising threat to wildlife. Anim. Conserv. 23, 466–478. https://doi.org/10.1111/acv.12560.

Smith, J.L.D., 1993. The role of dispersal in structuring the Chitwan tiger population. Behaviour 124 (3-4), 165–195.

Tananantayot, J., Agger, C., Ash, E., Aung, S.S., Baker-Whatton, M.C., Bisi, F., Ngoprasert, D., 2022. Where will the dhole survive in 2030? Predicted strongholds in mainland Southeast Asia. Conserv. Sci. Pract. 4 (11), e12831.

Tantipisanuh, N., Gale, G.A., Pollino, C., 2014. Bayesian networks for habitat suitability modeling: a potential tool for conservation planning with scarce resources. Ecol. Appl. 24 (7), 1705–1718.

UNESCO. (2015). UNESCO World Heritage Centre. ⟨http://whc.unesco.org/en/list/590⟩. Accessed 8 Feb 2022.

United Nations Environment Programme. (2008). Payments for ecosystem services getting started: A primer. Forest Trends, The Katoomba Group and United Nations Environment Programme, Washington, DC, USA.

Urban, D.L., Minor, E.S., Treml, E.A., Schick, R.S., 2009. Graph models of habitat mosaics. Ecol. Lett. 12 (3), 260–273.

Vaeokhaw, S., Ngoprasert, D., Swatdipong, A., Gale, G.A., Klinsawat, W., Vichitsoonthonkul, T., 2020. Effects of a highway on the genetic diversity of Asiatic black bears. Ursus 2020 (31e3), 1–15.

Watabe, R., Saito, M.U., 2021. Effects of vehicle-passing frequency on forest roads on the activity patterns of carnivores. Landsc. Ecol. Eng. 17, 225–231.

Wildlife Research Division, 2012. Biodiversity, Abundance and Habitat Suitability of the Wildlife In Habitat Corridor between Khao Yai National Park and ThapLan National Park, First edition. Department of National Parks, Wildlife and Plant Conservation, Bangkok, Thailand.

Willi, Y., Van Buskirk, J., Schmid, B., Fischer, M., 2007. Genetic isolation of fragmented populations is exacerbated by drift and selection. J. Evolut. Biol. 20 (2), 534–542.

Wong, S.T., Servheen, C.W., Ambu, L., 2004. Home range, movement and activity patterns, and bedding sites of Malayan sun bears *Helarctos malayanus* in the rainforest of Borneo. Biol. Conserv. 119 (2), 169–181.

Xu, H., Zhao, G., Fagerholm, N., Primdahl, J., Plieninger, T., 2020. Participatory mapping of cultural ecosystem services for landscape corridor planning: a case study of the Silk Roads corridor in Zhangye, China. J. Environ. Manag. 264, 110458.

Zellmer, A.J., Goto, B.S., 2022. Urban wildlife corridors: Building bridges for wildlife and people. Front. Sustain. Cities 4, 954089.

Zuur, A.F., Ieno, E.N., Elphick, C.S., 2010. A protocol for data exploration to avoid common statistical problems. Methods Ecol. Evol. 1 (1), 3–14.