Impact of land use changes on the human-elephant conflict; Bornean elephant (Elephas maximus borneensis) movements, feeding ecology and associated habitat requirements in North Kalimantan, Indonesia

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Identifying potential corridors for Bornean elephant *Elephas maximus borneensis* in the Sebuku forest

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Abstract

The natural range and habitats of Bornean elephants have decreased significantly during the last decade due to agricultural and oil palm development, both in Sabah (Malaysia) and in Indonesian North Kalimantan. This study aims to identify Bornean elephant movement habitat in the Sebuku forest area in order to assess the impact of future land-use. We distinguish two types of corridors for different goals, i.e. dispersal corridors for herds (habitat recommendation) and crop raid corridors for solitary bulls (HEC alleviation). Our study has shown that a least-cost model, validated by field-based approaches (village interviews and transect counts), provides an effective tool for the identification of such corridors for Bornean elephant conservation. Two functional elephant dispersal corridors have been identified along the Agison River and the Upper Sibuda River, which were confirmed to direct to the elephant movements into a natural core habitat in the Upper Apan of the Sebuku forest. The presence of scattered small-holders' oil palm plantations and crop fields surrounded by shrublands enhanced landscape connectivity for solitary bulls, forming crop raid corridors and connecting their natural core habitat with crop raiding zones. Conserving the remaining patches of natural forest and preventing further encroachment of this critical habitat are considered as the most fundamental prerequisites for human-elephant conflict alleviation.

Keywords

village interviews, field-based approach, least-cost model, dispersal corridor, crop-raid corridor

3.1 Introduction

In Indonesian Kalimantan, Bornean elephants occur only in the northernmost parts of the province, in the Sebuku forest area [Figure 3-1] (Olivier 1978; Payne *et al.* 1994; Yasuma 1994; MacKinnon *et al.* 1996). The group of elephants represents a small sub-population of around 20-60 individuals, which is connected to the main populations in Sabah, Malaysia (Wulffraat 2006). Research suggests that the population is also connected with a larger population of 280-330 elephants in Kalabakan, the Central forest of Sabah (Riddle *et al.* 2010; Alfred *et al.* 2011).

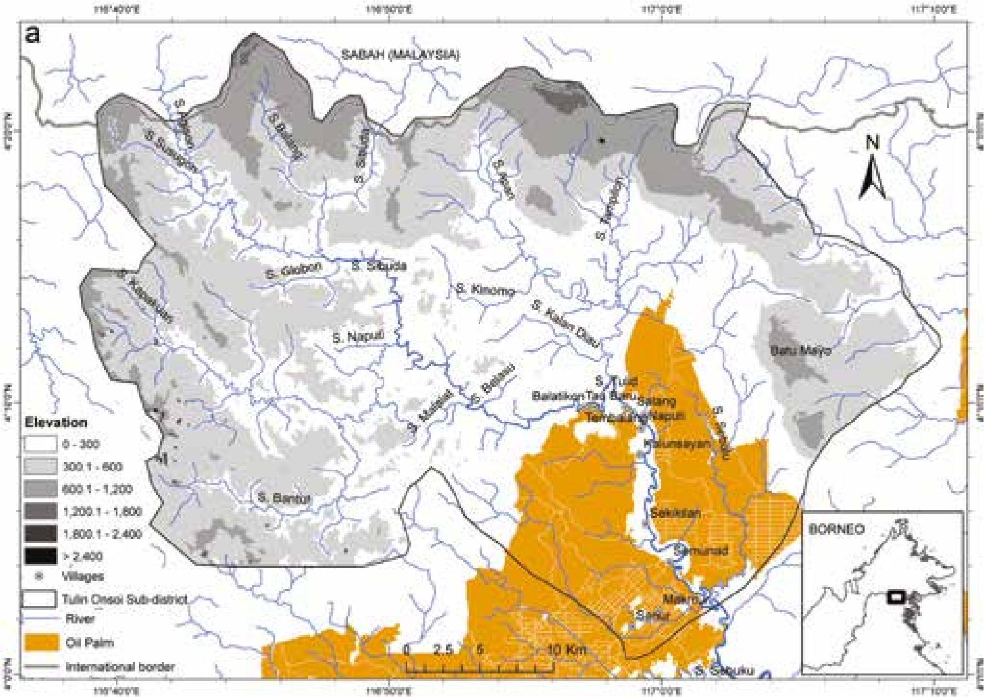
Figure 3-1
Five major Managed Elephant Ranges in Sabah, Malaysia and a small sub-population in the Sebuku forest, North Kalimantan [re-drawn Wulffraat (2006); Alfred *et al.* (2011); georeferenced from Google Earth]

Elephants are generalist herbivores/frugivores that complement their diet with minerals from soil deposits, when available (Sukumar 1989; Matsubayashi *et al.* 2007; Sitompul 2011). Their movements are related to the availability of natural resources, particularly those offering the highest net gain for the lowest costs in terms of energy (Fryxell 1991; Blake & Inkamba-Nkulu 2004). Reliable food resource patches that continue to satisfy Asian elephants' energy needs over multiple visits are important drivers of recursion (Sukumar 1990; English *et al.* 2014). Recursion is a common behavior used by the elephants and its pattern suggests that it may be a foraging strategy for revisiting areas of greater nutritional value (Blake and Inkamba-Nkulu 2004; English *et al.* 2014).

Elephant movement patterns can also be greatly influenced by variation in vegetation cover and topography (Sukumar 1989; Lin *et al.* 2008; Rood *et al.* 2008), as well as human activities/disturbances (Alfred *et al.* 2012; Estes *et al.* 2012; Gubbi 2012). Elephants have a strong preference for forests with a high productivity located within valleys (Rood *et al.* 2010). This pattern has been linked to the fact that landscape depressions are also natural waterways providing a main source of water and natural ranging routes (Rood *et al.* 2010). Elephants prefer flat land or terrains with gentle slopes, elevations below 300 meters and a relatively narrow range of relative ruggedness (Lin *et al.* 2008; Rood *et al.* 2010; Alfred *et al.* 2012; Estes *et al.* 2012). Steeper slopes and highly rugged terrain have been mentioned to restrict elephant movements (Lin *et al.* 2008; Rood *et al.* 2010). Although mountaineering is an energy-expensive, usually avoided by elephants, they have been reported to move through mountainous terrain, particularly in areas where suitable habitat at lower elevations has become occupied by human settlements and farmlands (Lin *et al.* 2008; Rood *et al.* 2008). In several elephant core ranging habitats, elephants have shown to expand and/or shift their home range in response to habitat alterations (Alfred *et al.* 2012; Estes *et al.* 2012).

The deliberate ingestion of soils or geophagy has been observed in Bornean elephants (Matsubayashi *et al.* 2007). The sites where these soils are ingested are called "natural licks" and differ in their geochemical and mineralogical composition from the surrounding soils. Soils at natural licks may be ingested for mineral depletion (Natrium and Magnesium) and for the neutralizing ability of toxic secondary plant compounds, as well as to enhance digestive efficiency (Houston *et al.* 2001). It has been suggested that Bornean elephants' dependency on natural salt licks provide sources for their mineral concentrations may partially determine the limited distribution of Bornean elephants; which could have led to their absence in areas where this type of mineral is not available within a couple of days' walking distance (Payne *et al.* 1994; Wulffraat 2006; Matsubayashi *et al.* 2007; Alfred *et al.* 2011).

Habitat transformation and reduction have influenced Asian elephant distribution and movements across their range (Lin *et al.* 2008; Rood *et al.* 2008; Sitompul *et al.* 2013). In the case of the Bornean elephant, natural range and habitats have decreased significantly during the last decade due to agricultural and oil palm development, both in Sabah and in North Kalimantan. Since the launching of the government program 'one million hectares of oil palms' in 2002, oil palm plantations in the Nunukan District of North Kalimantan have expanded at an alarming rate [Figure 3-2a]. In the Sebuku



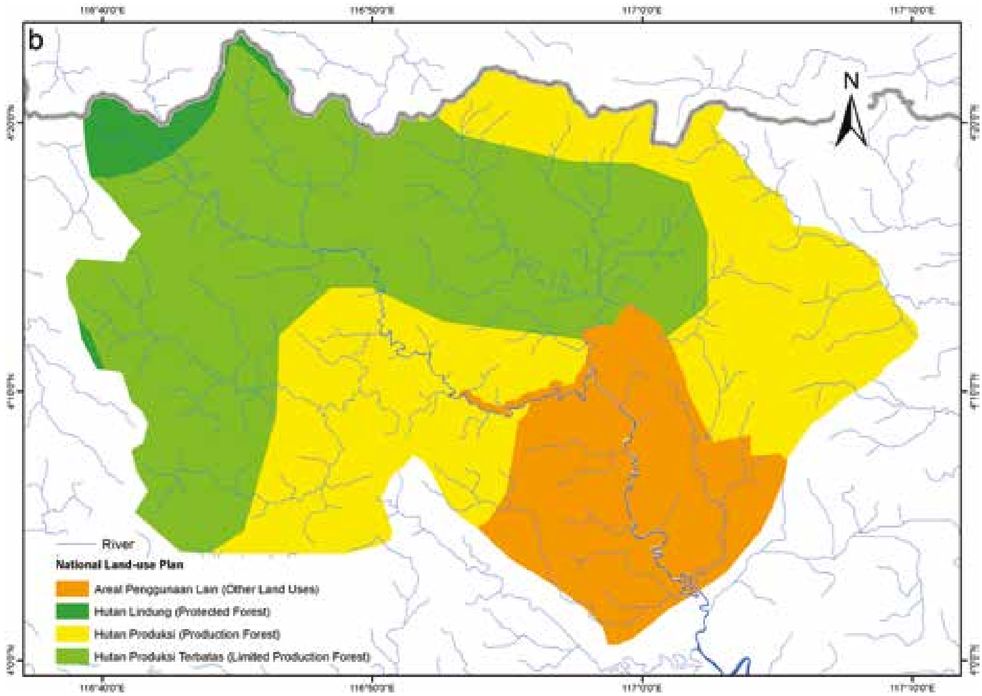


Figure 3-2
Overview of study area showing the location of oil palm plantations and elevation in the Tulin Onsoi Sub-district, North Kalimantan (a) and national land use plan (b)

forest area, plans to destroy the last remaining natural habitat for Bornean elephants in the Indonesian part of Borneo for conversion into timber or oil palm plantations are threatening the survival of this small sub-population (Wulffraat 2006).

Within small-scale farming land, elephants move between refuges and feeding grounds at night and at high speed to avoid people (Sukumar 1989; Nyhus *et al.* 2000; Chiyo *et al.* 2005; Galanti *et al.* 2006; Kumar *et al.* 2010; Webber *et al.* 2011; Gubbi 2012). This type of dispersal is categorized as transient and corresponds with a mostly solitary behavior (Cote *et al.* 2016). It is therefore not surprising that incidents of crop raiding by elephants in the Sebuku area are generally associated with solitary male elephants rather than herds (Suba, pers. obs.). In fact, there are no known records of multiple elephants disturbing agricultural fields here, whereas several male individuals are suggested to have increased the frequency in which they visit some of the village gardens and fields (Wulffraat 2006). Since such behavioral traits are important indicators of habitat use and movement patterns, they should be carefully investigated to ensure corridors are delineated in the right way. For the Sebuku area, hence, I looked at a corridor for solitary bulls with the potential to successfully alleviate crop raiding impacts; henceforth referred to as 'crop raid corridors' (following Pittiglio *et al.* 2014).

The present study aims to map Bornean elephant movements in the Sebuku forest area in order to assess the impact of future land-use and identify potentially suitable habitat for the development of elephant corridors. Two types of corridors are distinguished for different goals, i.e. dispersal corridors for herds (habitat recommendation) and crop raid corridors for solitary bulls (HEC alleviation). Three sequential approaches were used: (1) Participatory research (Kemmis & McTaggart 2000) to gather information on the existing elephant movements based on observations by the local people; (2) field surveys/transect counts of elephant signs to evaluate information from village interviews (3) Least cost (LC) modeling of satellite-based maps to delineate optimal corridor routes (Cushman *et al.* 2013; Van de Perre *et al.* 2014), using some of the observations as reference points. LC modeling uses a combination of geographical information and biological preferences to determine movement probability in between habitat patches of the focal species in a landscape mosaic (Cushman *et al.* 2013).

3.2 Methods

3.2.1 Study area

This study was conducted in the Sebuku forest area which is part of Tulin Onsoi Sub-district of North Kalimantan Province (Figure 3-2a). The Sebuku forest contains an almost complete range of habitats that characterize lowland landscapes of northeastern Borneo (Jepson *et al.* 2002). The lowland Dipterocarp forests of the Sebuku area are among the most species-rich forests of Borneo. Due to logging activities in the past, the primary forest has been replaced by secondary forest. Consequently, in these places, the canopy is more open and the proportion of trees from families such as the Euphorbiaceae, Moraceae, and Lauraceae is higher than in primary forest (MacKinnon *et al.* 1996). Only a few areas of primary hill Dipterocarp forests remain in the upper north and west of the Sebuku forest area (Wulffraat 2006).

The central part of the study area still consists of a good quality lowland forest. The Tulid River [Figure 3-2a] is the major river in this area, bordered in the west by a wide complex of mountains and hills that in general have steep slopes. In the south, it is separated by a vast lowland landscape with a flat to undulating topography where most of the oil palm plantations have been developed. The northern part of the study area primarily consists of hilly terrain, marking the international boundary between Malaysia and Indonesia. Several tributaries of the Tulid River have their origin in Sabah. The Agison River has more than 20 km of its upper course flowing inside Sabah. The river valleys of the Sibulu, Tampilon, Apan, Agison, and Kapakuan Rivers cross the landscape at low elevations into the surrounding mountains and hills (Wulffraat 2006). All areas and nearly half of the area around the Tulid and Upper Tulid river respectively is categorized as 'other land uses' [Areal Penggunaan Lain (APL)] which includes areas allocated for non-forest purposes (e.g. oil palm plantations) (Figure 3-2b). The remaining habitat for Bornean elephants around the Tulid River banks consists of shrublands and fragmented secondary forests, which could still provide an important marginal habitat with sufficient food sources for Bornean elephants.

Due to seasonal monsoons, field visits were only possible part of the year. The study area receives about 2,600 mm of rainfall annually (data from Meteorology and Geophysics Bureau in Nunukan), most of which falls between April and September [Figure 3-3]. February to March and October to November mark two periods with less heavy rainfall, although monthly data averages between 2005 to 2011 show that rain occurs evenly throughout the year (with 15 to 20 rain days each month).

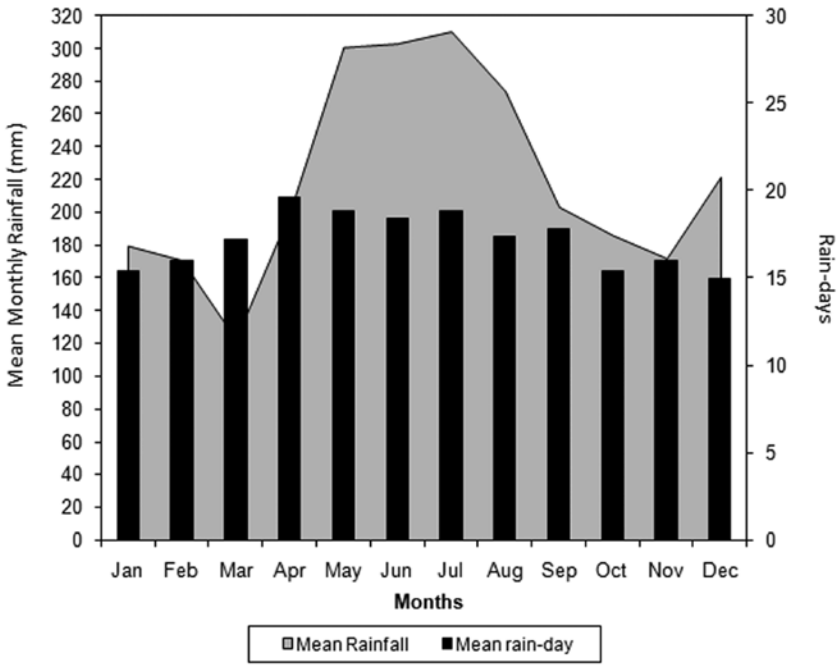


Figure 3-3
Mean monthly rainfall for 2005-2011 and number of rainy days per month (rain-days) in the study area [Source: Meteorology and Geophysics Bureau in Nunukan District, North Kalimantan, 2014]

3.2.2 Village interviews

An interview survey was conducted of a systematic sample of 214 households (between 31.7% and 84.8%; average = 56.8%) in ten villages of the Tulin Onsoi Sub-district [Figure 3-2], of which 213 (99.5%) were completely answered. of the households in the ten villages were sampled [Table 3-1]. The interviews started with a number of predefined, open questions, intended to start a discussion or a new question, depending on the respondents' response (Appendix 3-1). Villagers were asked if they knew a 'path or route used by elephants' existed anywhere in the Sebuku area, but specifically in their own village and if so, whether they could point out its location on a map. Villagers who indicated to have seen elephants were asked about the time of year and location (on a map if possible) of their observation. Respondents were also asked about potential factors preventing elephant movements. The locations gathered from the interviews served as a template to arrive at a preliminary elephant corridor.

Table 3-1
Human population size, number of households and respondents in the ten surveyed villages

Village	Population size	Total households	Total main households	Number of respondents	Percentage
Semunad	553	135	61	26	42.6
Sekikilan	487	126	68	28	41.2
Kalunsayan	311	94	41	31	75.6
Tembalang	345	84	22	17	77.3
Salang	351	91	33	28	84.8
Naputi	316	79	51	23	45.1
Tinampak I	346	108	24	15	62.5
Tinampak II	245	79	24	17	70.8
Tau Baru	340	94	41	14	34.1
Balatikon	362	94	41	14	34.1
Total	3656	984	406	213	
Average					56.8

3.2.3 Field surveys

Based on the collected information from the interviews and older records locations frequently visited by elephants (Wulffraat 2006), repeated reconnaissance surveys were conducted in the Sebuku forest during January-April 2012, January-April 2013, February-April 2014 and May-July 2015. During 14 travel reconnaissance walks (see Walsh & White 1999; Blake 2002), observations of all elephant signs (dung, feeding signs, foot prints and trails) visible from the reconnaissance path were recorded. In addition, observations on elephant presence were recorded in the ten villages, crop fields, and adjacent areas, as well as on raided farms.

3.2.4 Modeling

Data preparation
Five variables were used to predict corridors for Bornean elephants across the landscape: land cover, elevation, slope, terrain ruggedness index (TRI) and distance from villages as a proxy measure for the degree of human disturbance. The variables were selected according to the references to elephant ecology [Appendix 3-2], and were then transformed into GIS layers in ESRI ArcGIS 10.2.2. Appendix 3-3 indicates the source of GIS layers used.

Least cost modeling

Least cost path (LCP) analysis was used to quantify the ease with which elephants could disperse across the landscape based on the habitat resistance model. Least-cost modeling [LC, we used Cost-Distance in ArcGIS 10.2.2 (ESRI 2014)] allows the selection of the least costly route between the two areas according to a number of variables based on detailed geographical information and behavioral aspects of the research subjects (Adriaensen *et al.* 2003; Larkin *et al.* 2004; Rouget *et al.* 2006; Cushman *et al.* 2013; Van de Perre *et al.* 2014). LCPs are calculated using a cost raster, where each pixel of the raster has a value assigned according to the level of impedance represented by that pixel. The LC analysis determines the shortest path across the cost raster that accumulates the minimal possible cost (see Appendix 3-4 for details).

Each layer represented specific aspects of the landscape that may be relevant for the movement of Bornean elephants through the area. Cost values were assigned on a pixel by pixel basis for each layer, representing the permeability of the variable class for the movement of an elephant. The cost values form a link between the non-ecological GIS information and the ecological-behavioral aspects of the mobility of the research subject (Adriaensen *et al.* 2003). Assigning cost values to specific variables should ideally be based on empirical data on dispersal of the focal species through all possible landscape elements (cf. Zeller *et al.* 2012; Cushman *et al.* 2013). As such information is largely lacking for the Bornean elephant, dispersal cost values were assigned to one of five conceptual resistance categories ranging from prime movement habitat to full barrier, based on the available references [Table 3-2]. Grid cells (30 x 30 m) representing each dispersal category were assigned cost values of 1, 10, 50, 100 and 500 respectively. To control for landscape characteristics that would decrease the suitability of the land cover (e.g. steep slopes, rugged terrains, high elevation areas, and areas with high levels of human activity), habitat suitability scores were assigned in a non-linear fashion (Larkin *et al.* 2004; Wikramanayake *et al.* 2004). Although in most cases subjective in nature, such an approach provides more biologically realistic costing of grid cells than simple equal interval ranked values (Larkin *et al.* 2004). Beier *et al.* (2008) found that when assigning cost values to a set of landscape elements, the rank order of the cost values is the most important factor.

Table 3-2
Bornean elephant dispersal resistance categories and dispersal 'cost' values

Rank	Dispersal resistance category	Dispersal cost value
1	Prime movement habitat	1
2	Secondary habitat for movement	10
3	Limited negative influence on movement, but is not preferred either	50
4	Impeding effect on the movement	100
5	Strong impeding effect on the movement (full barrier)	500

The LC value is a measure of the overall landscape resistance of the total trajectory between two patches in the landscape or the effort an individual needs to take to move between both patches (Adriaensen *et al*. 2003; Van de Perre *et al*. 2014). The outcomes of an LC model are two cost layers in which the value of each cell is defined as the least effort (minimal cumulative cost) in moving over the resistance layer to the source point and vice versa. Because LCPs do not give any indication of variation in values around the path or elsewhere in the landscape, a corridor layer (Cushman *et al*. 2013; Van de Perre *et al*. 2014) was calculated. The sum of cost values in two least-cost layers was represented as a percentage of the least-cost value. The corridor was then delineated on the map by dividing the cost values of each grid by the LCP. In this way, the map could be divided into zones with a higher value compared to the value of the LC path. The percentages were grouped in zones with borders at 1, 2, 3, 4, 5, 10, 20, 30, 40 and 50 percent [Appendix 3-4]. When a value was at least 5% above the least cost value it was considered as a potential corridor point (Adriaensen *et al*. 2003; Van de Perre *et al*. 2014).

3.3 Results

3.3.1 Village interviews

Of the 85.4% of respondents (n = 182) who claimed to have seen elephants, 68.8% saw bulls inside the villages areas. About 31.2% of the respondents had observed elephants elsewhere [Table 3-3]: Tulid river, forest area, Agison, Apan, dan Sibuda rivers, estate land, Sabah (Malaysia), and Batu Mayo hill [Figure 3-4a]. 10.7% of these observations were in the vicinity of the three main rivers.

Table III-3
Number of reported elephant sightings during the interview survey for each sighting location in the Tulin Onsoi sub-district

Villages	Elephant sightings by respondents	Semunad	Sekikilan	Kalunsayan	Tembalang	Salang	Naputi	Tinampak I	Tinampak II	Tau Baru	Balatikon	Pembe-liangan
Semunad	31	18	4	1	-	1	-	-	-	-	-	-
Sekikilan	28	-	18	-	-	-	-	-	-	-	-	-
Kalunsayan	35	1	1	24	-	-	-	-	-	-	-	2
Tembalang	21	2	1	1	13	-	-	-	-	-	-	-
Salang	26	1	3	-	-	12	-	-	-	-	-	-
Naputi	29	1	1	1	2	-	17	-	-	-	-	-
Tinampak I	10	-	1	1	-	-	-	3	-	-	-	-
Tinampak II	12	-	2	-	1	-	-	-	4	-	-	-
Tau Baru	13	-	3	2	-	-	-	-	-	0	-	-
Balatikon	11	1	1	1	-	-	1	-	-	-	2	-
	215	24	35	31	16	13	18	3	4	0	2	2
		11.2%	16.3%	14.4%	7.4%	6.0%	8.4%	1.4%	1.9%	0.0%	0.9%	0.9%

Table III-3
continued

Villages	Elephant sightings by respondents	Agison	Sibuda	Apan	Tulid	Forest	Estate Land	Batu Mayo	Malaysia
Semunad	31	–	–	–	5	–	1	–	1
Sekikilan	28	–	–	–	6	3	–	1	–
Kalunsayan	35	–	–	–	6	–	1	–	–
Tembalang	21	–	–	–	1	3	–	–	–
Salang	26	–	–	1	8	1	–	–	–
Naputi	29	2	2	1	1	–	1	–	–
Tinampak I	10	–	–	2	–	2	–	–	1
Tinampak II	12	1	–	1	–	2	–	–	–
Tau Baru	13	4	–	2	–	–	1	–	1
Balatikon	11	3	–	1	–	1	–	–	–
	215	10	2	8	27	12	4	1	3
		4.7%	0.9%	3.7%	12.6%	5.6%	1.9%	0.5%	1.4%

Based on the interviews, two main Bornean elephant dispersal corridors can be identified [Figure 3-4a], both originating in Sabah, Malaysia. One corridor follows the Agison River towards its intersection with the Sibuda River (Figure 3-4a). Herds were observed in the river valley of the Agison River (4.3%). The other corridor starts in the north of Sibuda headwater (hereafter, Upper Sibuda) and continues south along the Sibuda River and its tributaries. Following the Sibuda River, elephant herds may also move to the south, into the valley of the Kapakuan River. From this locality, a potential corridor could lead further towards Upper Apan [Figure 3-4a]. The interviews revealed that elephants did not disperse any further towards the South; they did not reach the Tulid River.

The valley of the Apan River (hereafter, Upper Apan) was indicated by the respondents as a zone where both potential corridors converge. From there, elephants may go South following the Apan River. There were no reports of elephants moving further to the North (along the Tampilon River). Elephant herds were only reported traveling into the valley of the intersection between the Tulid and Apan Rivers, and possibly returning using the same trail. There were also no reports on elephant herds entering the areas south of the Tulid River where the villages are located. Solitary bulls were periodically observed in the valley and surrounding terrains of the Sibulu River, further east from the Tampilon River [Figure 3-4a]. Solitary bulls also often cross the Tulid and Apan Rivers to go further south, thereby sometimes passing through the southern villages. A respondent mentioned solitary bulls that were seen wandering to the East, heading towards the Batu Mayo hill [Figure 3-4a].

Most solitary bull sightings were reported in the village of Sekikilan (16.3% of all sightings) (see Table 3-3). There appears to be a gradient of bull sightings along the villages, increasing from the north towards the south. In the four most northern villages (Tau Baru, Balatikon, Tinampak II, and Tinampak I), only very few elephants were observed (4.2%). More solitary bulls (41.9%) have been observed in the southernmost villages (Kalunsayan, Sekikilan, and Semunad) (Figure 3-4a). 40% of the reported elephant visits took place in two periods with less rain; February-March and August-October.

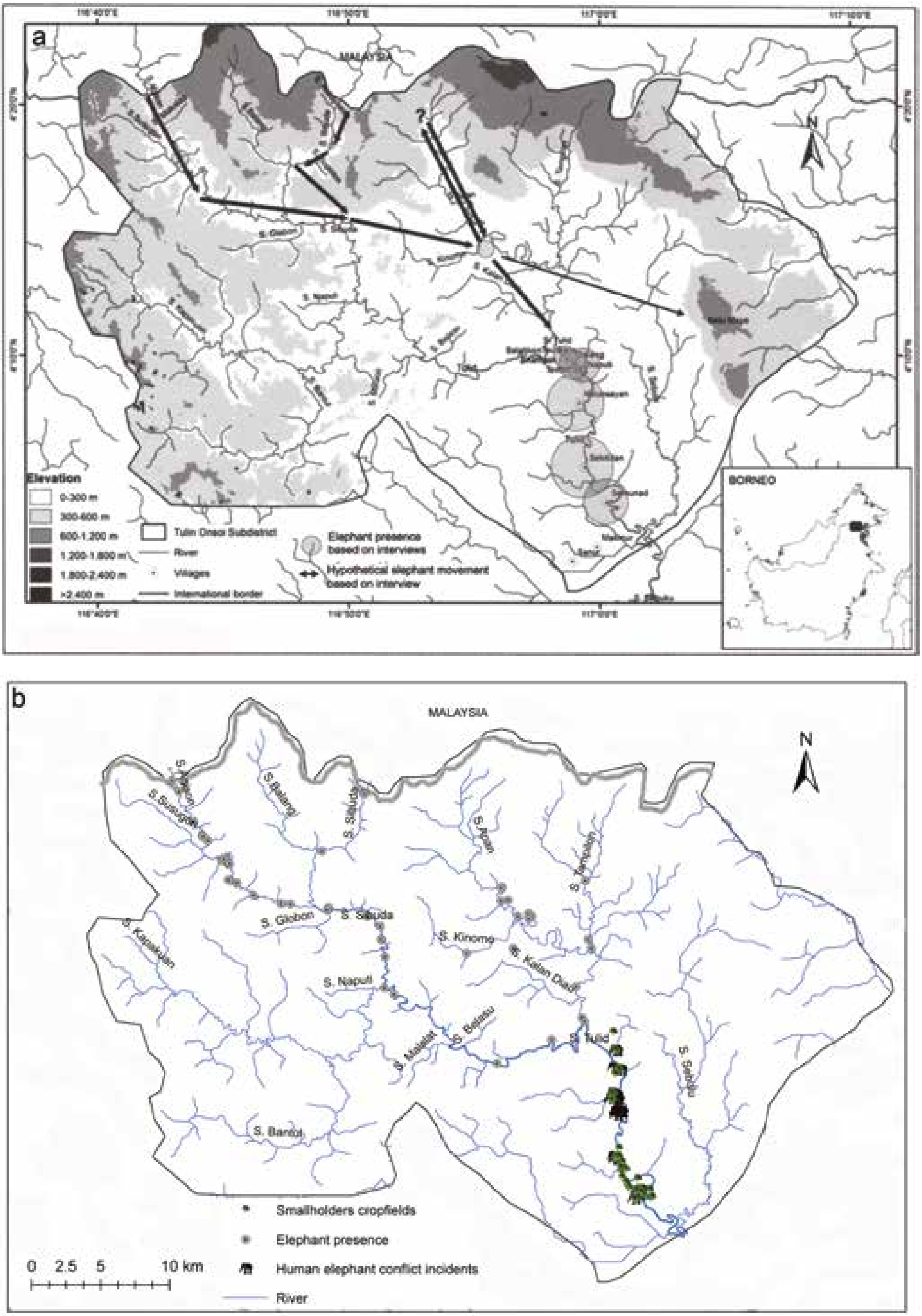


Figure 3-4
Location of elephant sightings based on interview surveys (a) and field surveys (b)

3.3.2 Field surveys

On all reconnaissance paths evidence of Bornean elephant presence was recorded (Figure 3-4b). Of 117 observations in total, 62 were recorded in forest landscape and 55 in village areas (see Appendix 3-5 for details). In accordance with the interview results, the majority of observations was in the three main rivers of the Sebuku forest headwater (Agison, Sibuda, and Apan). During the 2013-2014 surveys, large salt licks were observed in the valley of Agison and Sibuda, which appeared to be frequently visited by elephant herds (Suba, pers. obs.). Elephant presence was further confirmed in two tributaries of the Apan, Tampilon, and Kinomo Rivers. Signs found in the Kapakuan River and the Upper Tulid River indicated the presence of a number of herds (Figure 3-4b), which could represent a frequently used route going from the origin (Agison) to the Kapakuan outfall.

3.3.3 Least-cost model

Cost values and their respective resistance for each Bornean elephant habitat variable used and their categories are summarized in Table 3-4, for both corridors: dispersal and crop raid. By assigning different cost values for oil palm plantations and road networks, both corridors were clearly distinguished. A habitat suitability map was created based on dispersal cost values which were set for categories within each variable (Figure 3-5).

The habitat suitability model shows two dispersal corridors originating in Sabah, Malaysia, leading to the Sebuku forest through the Agison and Upper Sibuda. Both corridors converge at the Agison-Sibuda intersection and head east towards the Upper Apan. Based on our suitability map, both corridors provide a large, contiguous area of highly suitable elephant habitat. As the field surveys revealed that there was hardly any movement between the Upper Apan and the Upper Tulid along the northern part of the Upper Tulid River, two dispersal origins were determined: Sibuda and Kapakuan (Figure 3-5).

For four source areas (Agison, Upper Sibuda, Sibuda, and Kapakuan) and for each LCP, cost-weighted distance and direction rasters were created. LCP was modeled from each of the sources to the locations of four confirmed elephant occurrences based on our field surveys in Upper Apan, Apan, Upper Tulid and Tau 'island' (Figure 3-5). For each of the four locations, the presence of a herd of Bornean elephants was indicated.

Table 3-4
A set of cost value for each variable describing Bornean elephant resistance category for dispersal and crop raid corridors

Variable	Categories	Cost value	
		Dispersal corridor	Crop raid corridor
Land use	Upland forest	1	1
	Shrub land	10	10
	Dry cultivated land	50	50
	Water bodies	50	50
	Oil palm plantation	100	50
	Road network	100	50
	Swamp forest	100	100
	Open area	500	500
	Settlements	500	500
Slope	Level to gentle slopes (0-8o)	1	1
	Moderate slopes (9-15o)	10	10
	Steep slopes (16-30o)	100	100
	Extremely steep slopes (>30o)	500	500
Elevation	0 – 300 m	1	1
	301 – 600 m	50	50
	601 – 1,200 m	50	50
	1,201 – 1,800 m	100	100
	1,801 – 2,400 m	500	500
	>2,400 m	500	500
Terrain Ruggedness	Level (0-80 m)	1	1
	Nearly level (81-116 m)	10	10
	Slightly rugged (117-161 m)	50	50
	Intermediately rugged (162-239 m)	50	50
	Moderately rugged (240-497 m)	100	100
	Highly rugged (498-958 m)	500	500
	Extremely rugged (958-3,384 m)	500	500
Human disturbance (village buffer)	>1,000 m	1	1
	500 – 1,000 m	50	50
	< 500 m	500	500

Solitary bulls were observed spending some time in the area surrounding the southern villages (Figure 3-5). The remaining secondary habitat for elephants in this area is shrubland along the flat lowlands south of the Tulid River, and many of these are essentially highly degraded forest landscape. Shrubs are also a sign of abandoned land and most independent smallholders planted oil palm in this type of land cover. Bornean elephant occurrences in 'human-dominated landscape' (as shown by the fieldwork result) were concordant with the crop raiding events. We modeled LCP that may head to the Tulid River. To create this path, we considered Upper Apan as the origin point and the solitary bull observation as the destination point. We added one point near Batu Mayo Hill and this locality was also mentioned during interviews as a solitary bulls destination heading towards the East (Figure 3-5).

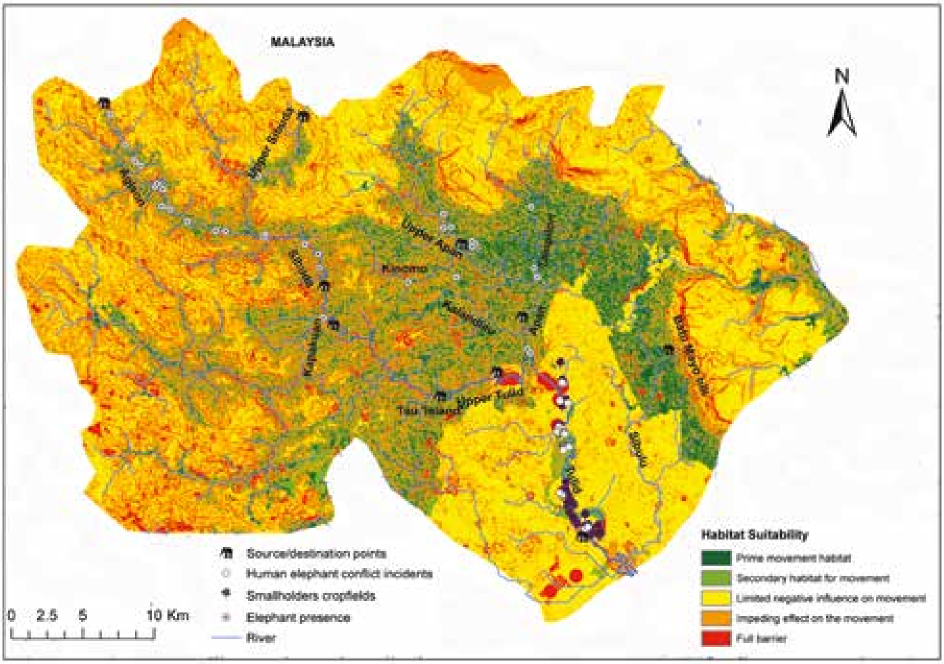


Figure 3-5
Potential elephant source points and habitat suitability

In total, 18 potential dispersal corridors have been created from four river sections (Agison, Upper Sibuda, Apan, and Kapakuan) to four confirmed Bornean elephants localities (Upper Apan, Apan, Upper Tulid, and Tau 'island') (Figure 3-6a represents a 5%-corridor for all combinations; see Appendix 3-6 for details). In addition, three crop raid corridors were created to represent suitable elephant habitat, from solitary bull observations (Figure 3-6b represents 5%-corridor for all combinations; see Appendix 3-6 for details).

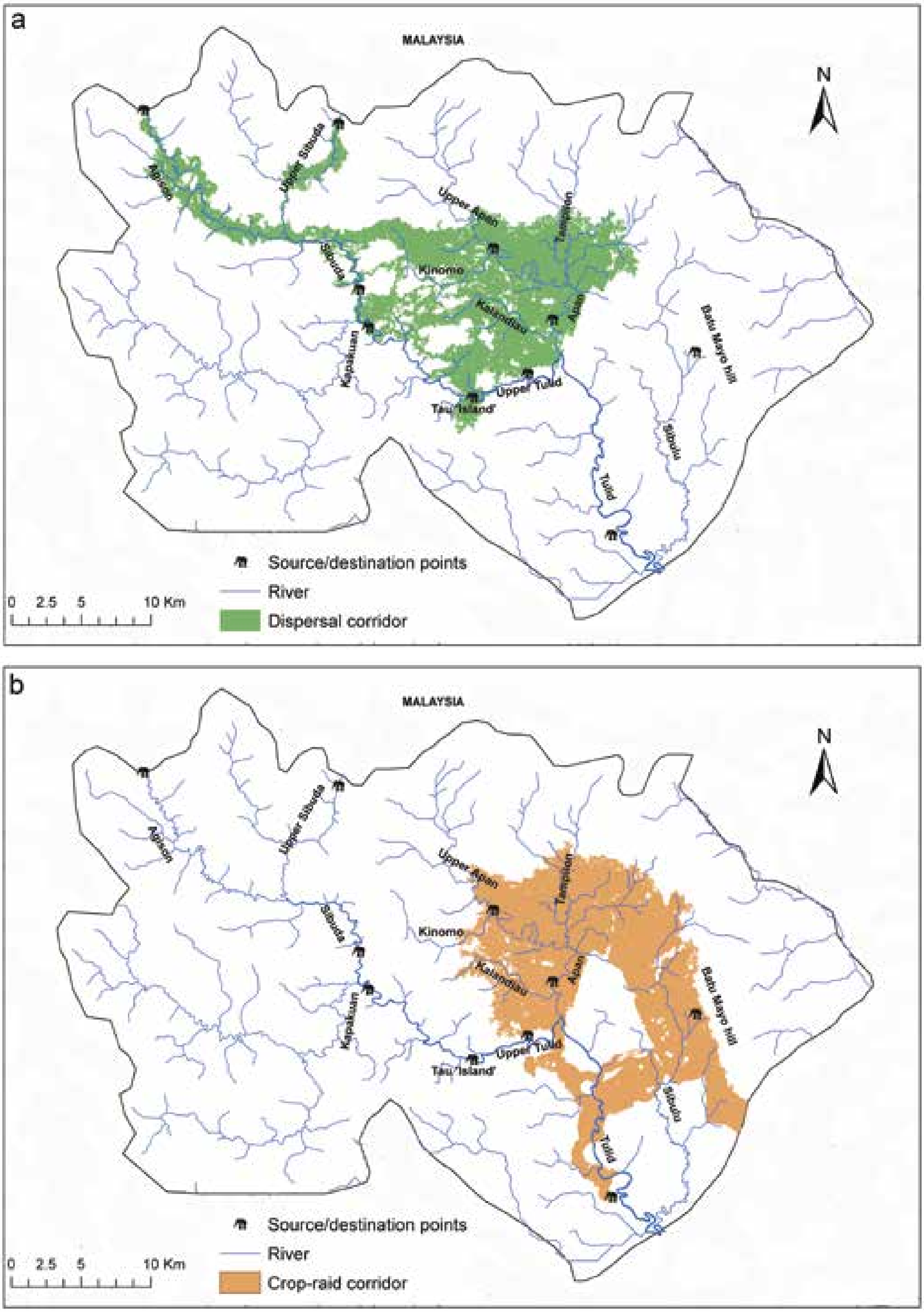


Figure 3-6
Potential elephant (a) dispersal and (b) crop raid corridors (5%) in the Tulin Onsoi Sub-district

3.4 Discussion

3.4.1 Dispersal corridors

As a result of our integrated approach, two functional Bornean elephant corridors have been identified along the Agison River and the Upper Sibuda River. Both corridors could support elephant movements to and from the elephant core habitat in the Upper Apan of the Sebuku forest area, thus providing an important connection between the Indonesian sub-population and the Sabah population.

In contrast to other studies (e.g. Sukumar 1989; Lin *et al.* 2008; Estes *et al.* 2012), the present study shows that slope was not a crucial determinant of elephant movement patterns. This could be due to the patchy and scattered nature of the peaks and steeper slopes in the study area, which have a less pronounced impact on cost layers as opposed to larger interconnected mountainous areas with a more gradual gradient (Adriaensen *et al.* 2003; Van de Perre *et al.* 2014). An exception to this finding was the southern extent of the corridors, which does not reach all the way to the Upper Tulid River but could theoretically form a natural boundary in the Bornean elephant dispersing ranges (Wulffraat 2006). Unlike the potential Agison and Upper Sibuda corridor derived from the interview surveys, the potential corridors derived from the LC model in this area do not always follow the course of the river but included a significant part of a relatively high-cost zone with slopes. Whereas Bornean elephants appear to incorporate both ruggedness and slope, the relative importance of these two variables may shift in response to the availability and accumulation of steeper slopes around the Upper Tulid River. The LC model further shows that the LC corridor covers the areas along the northern part of the river.

Indirect evidence from the interview surveys further suggested the existence of a so-called ‘long-term recursion’ behavior [151-250 days according to English *et al.* (2014)]. Elephants in the Sebuku forest were reported to re-visit some of the southern villages around February-March and August-October. During our field surveys, at least two salt licks have been identified in Upper Agison and Upper Sibuda. These areas were characterized by relative higher occurrences of indirect signs.

The LC models showed that accumulation of lower cost areas north of the Tulid River and the Upper Apan River overlapped with several pathways identified during the field surveys. Based on the evidence found during the field surveys, these areas were particularly favored by herds of Bornean elephants. These herds would never go far to the south of the Tulid River to raid crops, which could be explained by the unfavorable hilly terrain connecting the drainage areas of the Apan, Tampilon, and Sibulu Rivers that are thus forming a ‘dispersal boundary’ for elephant herds.

3.4.2 Crop raid corridor

According to the LC model, elephant herds east of the 'dispersal boundary' do not move far away from the Sibulu upstream, while solitary bulls in this area appeared to have much wider dispersal range. The interview surveys confirmed that solitary bulls are often ranging into the foothills of the Batu Mayo and even further southwest, as far as the oil palm plantations and villages areas. Several historical records of solitary bull observations all the way to the village of Pembeliangan in the south of the Tulin Onsoi sub-district (Wulffraat 2006) theoretically confirm that the Batu Mayo corridor extends further downstream.

The interview survey results further suggest that the shrublands that surrounds scattered small-holders crop-fields (mainly oil palm) could enhance landscape connectivity for solitary bulls, connecting their natural core habitat with crop raiding zones. Secondary re-growth containing elephant food plant species are abundant in these areas, i.e. wild bananas (*Musa borneensis*), bamboo (*Bambusa* sp.), and grass *Saccharum spontaneum*, which could benefit elephants living on the forest – non-forest interface (Sukumar 1990; Zhang & Wang 2003; Rood *et al.* 2010). Along the boundaries of these secondary shrublands, the scattered small-holder crop-fields could thus act as 'stepping stone', increasing the vulnerability of oil palms to destruction by elephants. On the other hand, these stepping stone crop-fields could be suitable as 'crop raid corridors' (Pittiglio *et al.* 2014), especially for solitary bulls.

Several studies in e.g. Sri Lanka (Sukumar 1991; Santiapillai 1996) and Sumatra (Santiapillai & Widodo 1993; Sitompul 2004) demonstrated that mostly solitary bulls are responsible for crop raiding. Bandara & Tisdell (2002) found 43% of the crop-raiding elephants in Sri Lanka were solitary bulls, while 38% were bull groups. In these studies, crop-raiding was suggested to be part of an optimal foraging strategy by solitary bulls during a certain period. Others found a relation between the bull elephant's 'musth' and increased frequency of crop raiding (Jainudeen *et al.* 1972; Sukumar 1991; Webber *et al.* 2011), which could be explained by a general tendency of these bulls to behave more aggressively and thus becoming engaged in risky behavior such as crop raiding.

3.4.3 The impact of future land-use changes on Bornean elephant corridors

To determine possible threats and future conservation strategies for Bornean elephants, we overlaid the dispersal corridors based on our LC model with current National Land Use Plans for the Tulin Onsoi Sub-district as well as existing land use maps in the area [Figure 3-7]. The overlay showed that connectivity between Bornean elephant localities may not be guaranteed. The habitat in the elephant corridors consisted mostly of unprotected forest areas, which are listed as 'production forests'. In these areas, timber is extracted legally by logging companies possessing concession licenses. Logging practices under such licenses are officially designated for sustainable use, aimed at selective logging practices that should maintain a permanent forest cover. Logging under forest and timber certification, e.g. through the principles and criteria of the Forest Stewardship Council (FSC), further encourages logging companies to address biodiversity and social aspects of timber production. The High Conservation Value Forests (HCVFs) concept as part of the FSC standard for certified responsible forestry further aims to identify and manage areas within forest landscapes that contain social, cultural or ecological important values (Brown *et al.* 2013; Senior *et al.* 2014). For companies involved, the costs of meeting their certification obligations however often outweigh the benefits (Dennis *et al.* 2008).

Despite the strict regulations in Kalimantan, natural forest areas carrying a 'production forest' status are frequently being converted into timber plantations when commercial timber stocks have been depleted (Obidzinski *et al.* 2009). Mining companies operating in 'production forests' often do so under so-called 'borrow to use permits for forest areas' (izin pinjam pakai kawasan hutan), that they obtain from the Minister of Environment and Forestry. Although this system is suggested to further undermine current rules and regulations on forest exploitation (Kartodihardjo *et al.* 2015), the government recently issued seven mining exploration permits, while several proposals to convert forest into timber plantations are under review (WWF-Indonesia Kalimantan Program 2011) (Figure 3-7b).

The present study shows that combining field-based approaches (village interviews and field surveys) with LC modeling provides a cost-efficient way to localize elephant corridors. Our integrated approach allows for a detailed assessment of the potential effects of future land-use plans on the survival of an endangered species such as the Bornean elephant. Further clearance either for timber plantation or mining of coal could lead to further deterioration of available dispersal corridors and may ultimately lead to the escalation of HEC in the Tulin Onsoi Sub-district. From this, management actions can be formulated that could ensure the preservation of dispersal corridors and alleviate the risk for HEC.

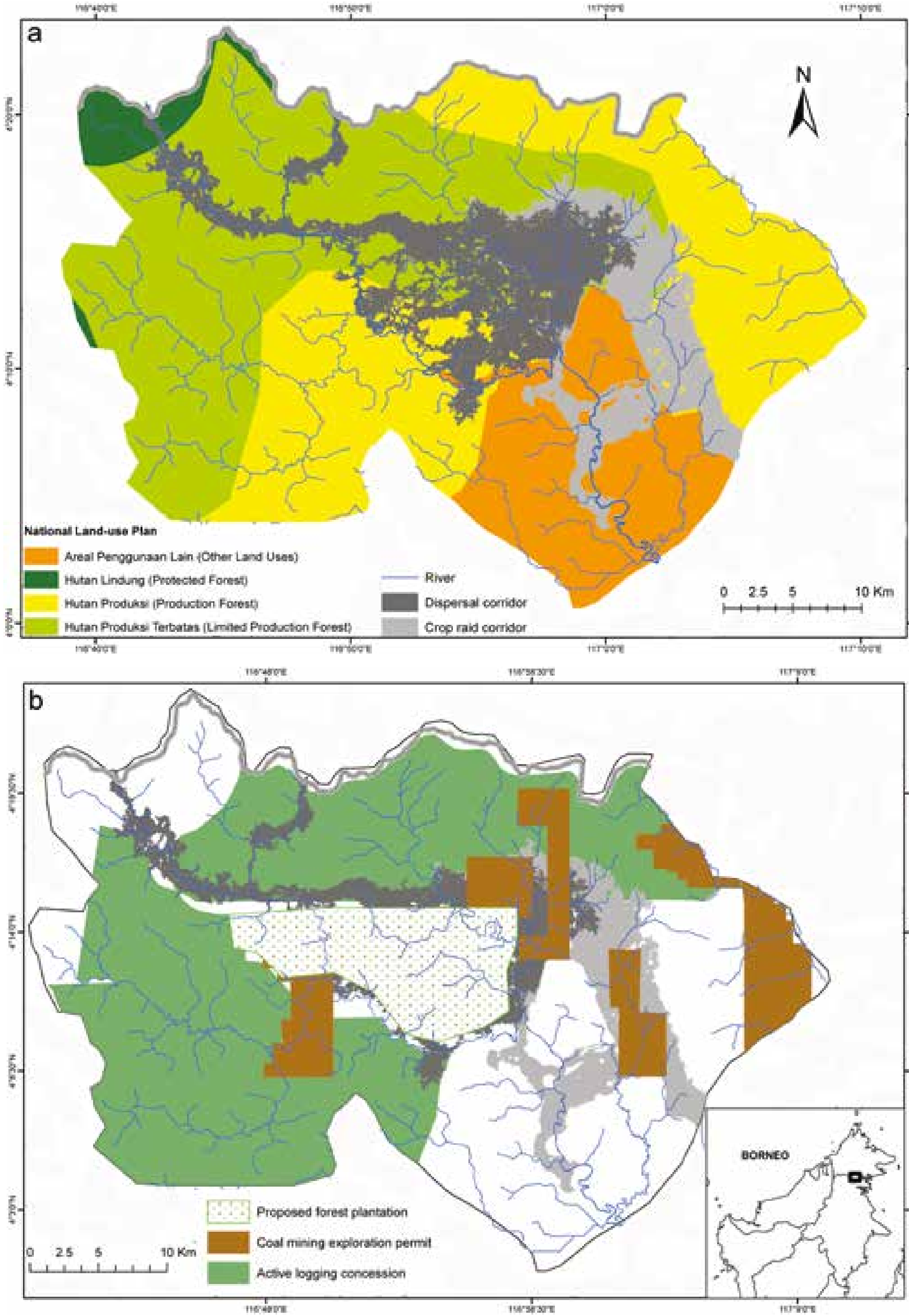


Figure 3-7
Overlay between potential Bornean elephant corridors with current National Land Use Plan and existing land use in the Tulin Onsoi Sub-district

Future land use planning strategies should thus ideally incorporate approaches to conserve remaining patches of natural forest and preventing further encroachment, even if of patchy distribution and coverage quality. Despite difficulties associated with conserving a transboundary elephant population, governments of both Malaysia and Indonesia have committed to the long-term maintenance of natural capital through the Heart of Borneo program. Nevertheless, the coordination between the two countries requires enhanced information sharing and certain land-use reforms that integrate the need for environmental sustainability (Wollenberg *et al*. 2009; Runting *et al*. 2014).

Figure 3-8
Preservation of river bank is necessary for the Bornean elephants in the Tulin Onsoi Sub-district, North Kalimantan, Indonesia

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Appendix 3-1

Summary of the pre-structured questionnaire used in the survey of household heads in the Tulin Onsoi Sub-district

1. Do you have a map of the village? (Can you draw a sketch?)
2. Have you seen elephants? Directly (direct sightings, signs) or indirectly (heard from others)? How many individuals? (single, herds, parents with young)
3. In what time of the year did you see the elephants? (all year around, only in dry/wet season, certain months etc.)
4. How often did you see the elephants? (every time, monthly, once a year, once every certain years, once in a life time etc.)
5. What are the elephants doing (behavior)? (looking for food, only passing by etc.)
6. Have elephants ever visited your crop fields?
7. When was the last time you saw elephants?
8. Where did you see the elephants? Please indicate on a map or describe it! (direction and distance from the village center)
9. Do you think the elephants are passing by or are they resident?
10. Do you think there is a corridor (path along which elephants migrate)?
11. Do you know of any obstructions for elephant to migrate in the Sebuku area?

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Literature study: consulted papers

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Appendix 3-3
GIS theme layers used to construct the basic map

Layer/Variable	Source	Data type
Land use	LDCM/Landsat 8 covered the study area for 2014 was obtained from the USGS Earth Resources Observation and Science center (EROS).[1] Supervised classification technique was used to prepare land use map	Raster
Villages	GPS coordinates were manually digitized	Point
Slope	Slope was calculated from ASTER GDEM[2] elevation data with the Topography tool of ArcGIS 10.2.2 (ESRI, 2014)	Raster
Elevation	Elevation was derived from ASTER GDEM[2] elevation data with the Topography tool of ArcGIS 10.2.2 (ESRI, 2014)	Raster
Terrain ruggedness	Terrain ruggedness was calculated from ASTER GDEM2 elevation data using terrain ruggedness index (TRI) (Riley et al., 1999) with the Topography tool of ArcGIS 10.2.2 (ESRI, 2014)	Raster

[1]Downloaded at http://glovis.usgs.gov
[2]ASTER GDEM is a product of METI and NASA. www.gdem.aster.ersdac.or.jp/

Land use was quantified for the entire study area using remotely sensed satellite images acquired from the USGS Earth Resources Observation and Science Centre (EROS) at http://glovis.usgs.gov (Landsat TM, path 117 row 57, 5 February 2014). A land use classification approach based on a multistage visual technique was implemented in ER Mapper 7.1 and ArcGIS 10.2.2.

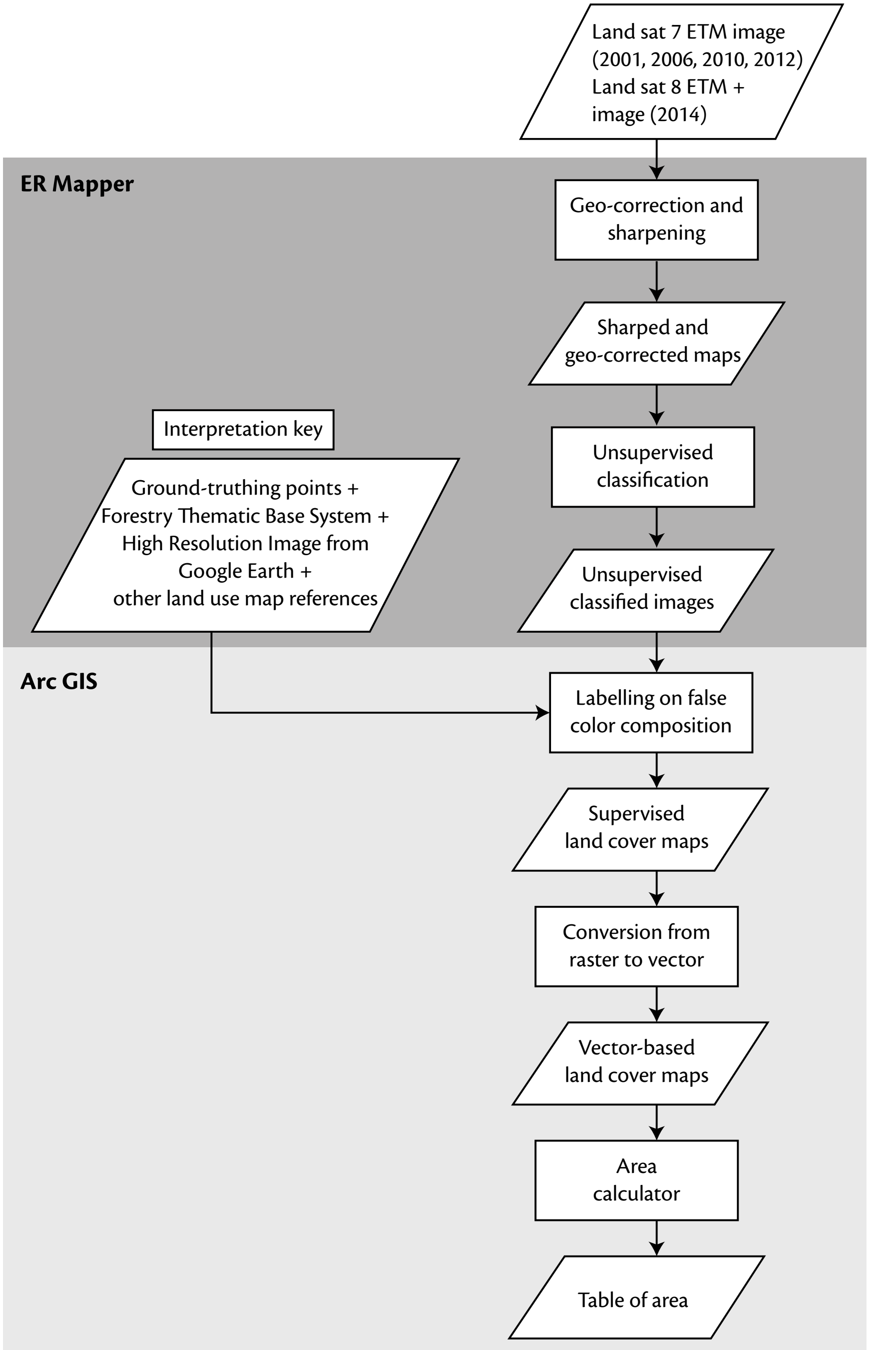


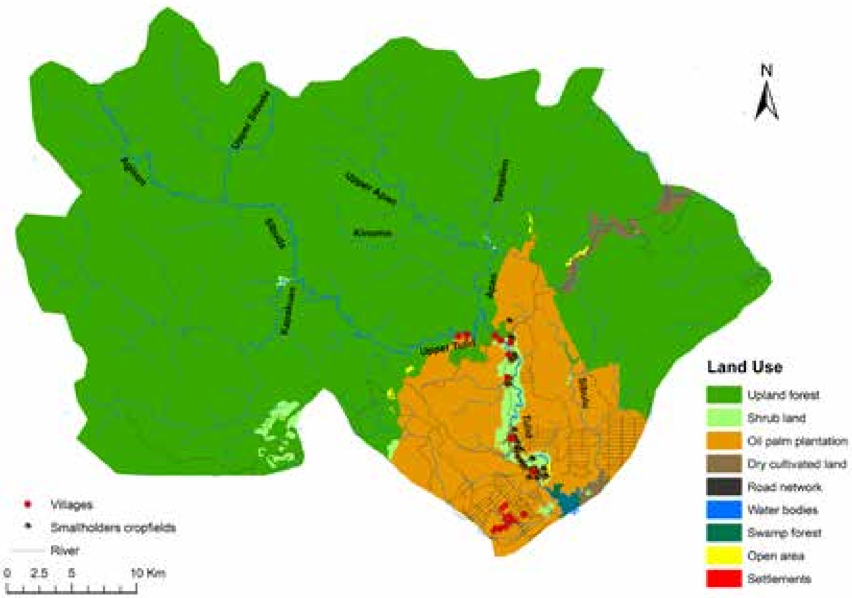
Figure 3-8
Preservation of river bank is necessary for the Bornean elephants in the Tulin Onsoi Sub-district, North Kalimantan, Indonesia

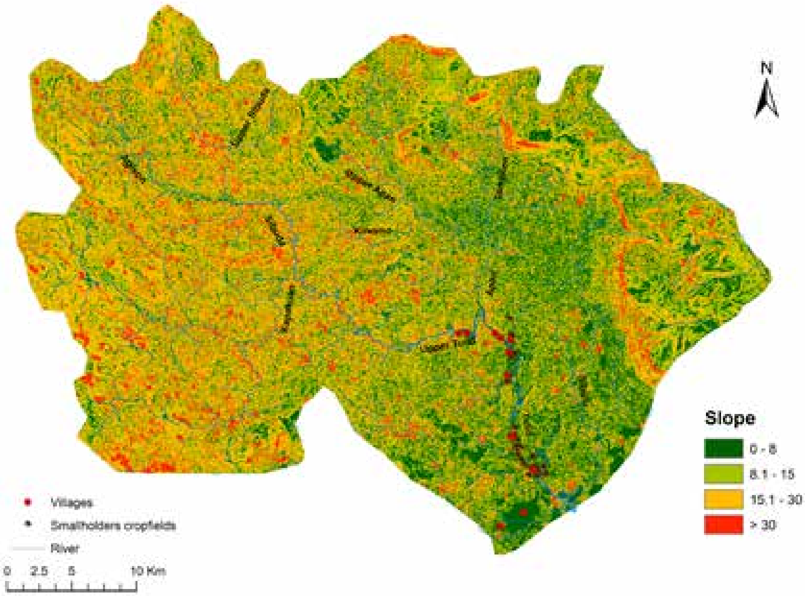
Nine land use categories were assigned: upland forest, shrubland, oil palm plantation, dry cultivated land, road network, water bodies, swamp forest, open area, and settlements, following land use classes defined by MoFRI (2008). All mosaics were then re-sampled to 30 m. Synchronized land-cover classification in the study area as follows:

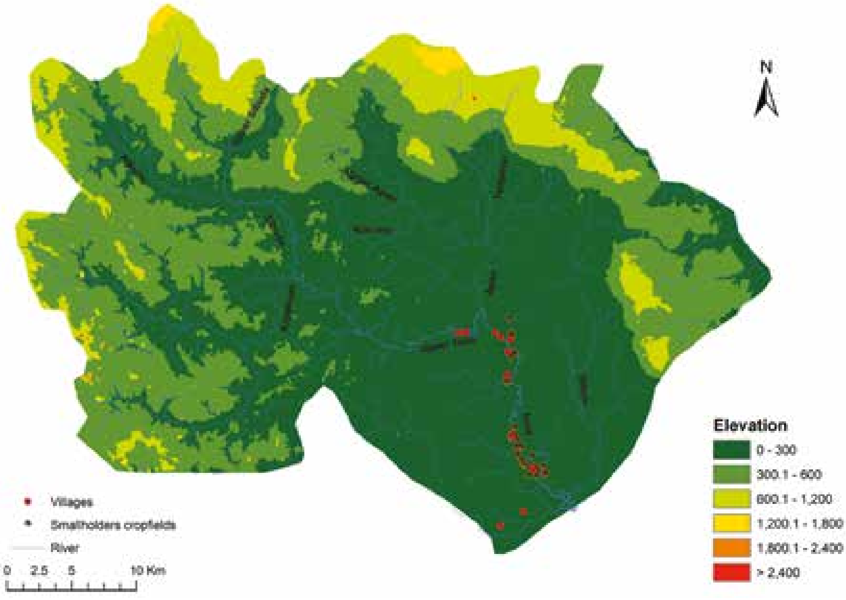
Land Cover Type	Description and Landscape Context
Upland Forest	Natural forest, highly diverse species and high basal area, but in this study, UF actually represents disturbed forest, with evidence of logging (Lusiana *et al*. 2005; Widayati *et al*. 2005), including roads and small clearings typical of logging platform. We excluded undisturbed forest which lack obvious spatial patterns necessary for its identification using satellite imagery were excluded. Often distributed as small patches on hilly terrain, we therefore aggregate them as upland forest.
Shrub Land	Open woody vegetation, often part of a mosaic including forest and grassland. Well drained soils on a variety of landscapes impacted by logging and possibly fire.
Oil Palm Plantation	Large industrial estates planted with oil palm; canopy cover variable depending on age. Regular geometry characterized by discernible rows and internal plantation road network, typically in patches greater than 1000 hectares.
Dry Cultivated Land	Open area characterized by herbaceous vegetation intensively managed for row crops and pasture. Associated with road networks and human settlements.
Road Network	
Water Bodies	Rivers and streams, identified in satellite images by high absorbance in all spectral bands; featuring temporary or permanent inundation.
Swamp Forest	Natural forest with temporary or permanent inundation. Associated with peat domes. Evidence of logging, regular network and small-scale clearings.
Open Area	Exposed soil, recently cleared (deforested) areas, landscapes impacted by fire and portions of estates undergoing replanting procedures.
Settlements	Villages, typically associated with road network. Although distributed in the entire area, settlement could not represented clearly because of the smaller size and intermixing with the background classes, bare soil and cultivated land.

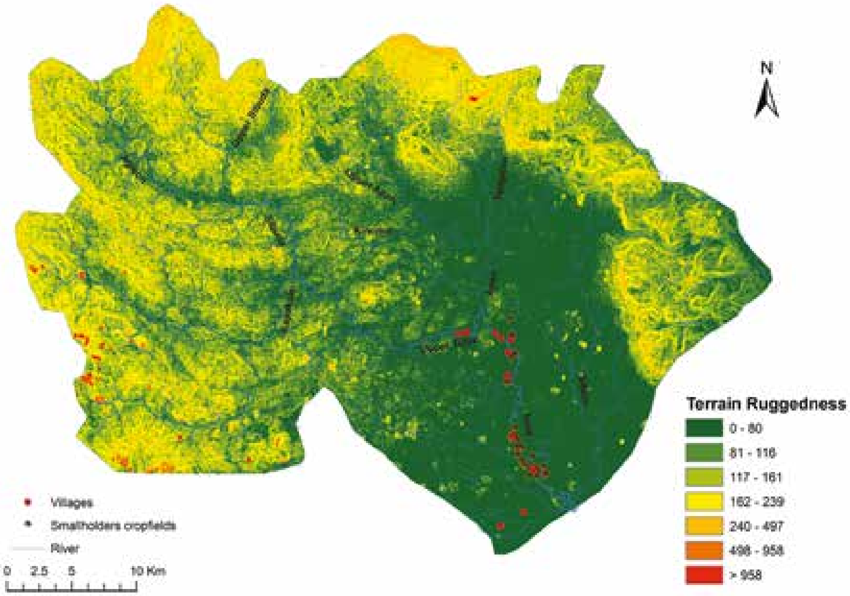
Adapted and modified from elsewhere (Gunarso *et al*. 2013; MoFRI 2008)

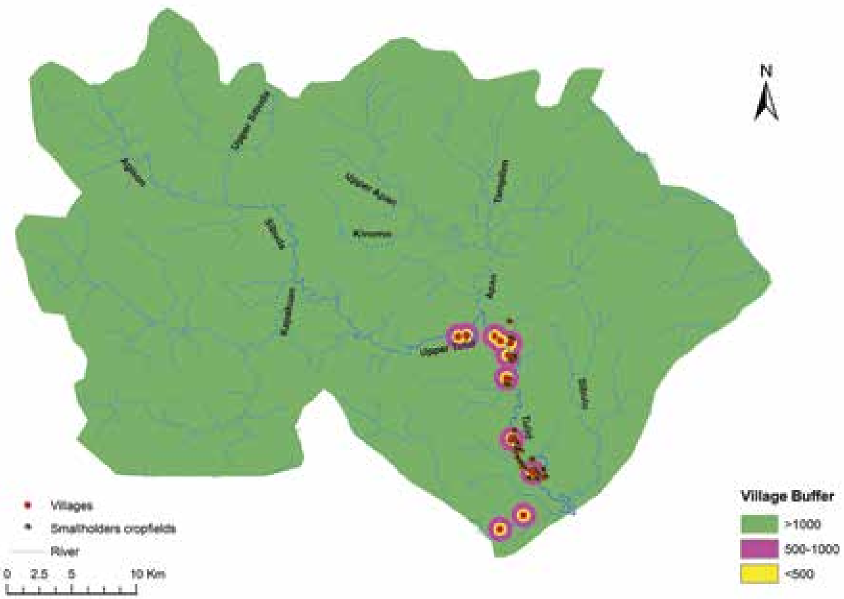
Slope and TRI were derived from a 30 x 30 m digital elevation model. Elevation was categorized into six classes: 0-300, 301-600, 601-1200, 1201-1800, 1801-2400, and >2400 m. The slope was calculated as percent rise and categorized into four classes: level to gentle slopes (0-8°), moderate slopes (9-15°), steep slopes (16-30°), and extremely steep slopes (>30°). TRI was defined as the difference between the ruggedness raster value of a cell and the mean of an 8-cell neighborhood of surrounding cells, with TRI values classified using the categories of Riley *et al.* (1999): level (0-80 m), nearly level (81-116 m), slightly rugged (117-161 m), intermediately rugged (162-239 m), moderately rugged (240-497 m), highly rugged (498-958 m), and extremely rugged (958-3,999 m). Distance to the villages was grouped into three classes: 0-500, 500-1000 and >1000 m, measured from the center of each village and implemented using a multiple ring buffer tool which is available in ArcGIS. All five GIS layers used in this study are described as follows.




N
Slope
0 - 8
8.1 - 15
15.1 - 30
> 30
Villages
Smallholders cropfields
River
0 2.5 5 10 Km


N
Elevation
0 - 300
300.1 - 600
600.1 - 1,200
1,200.1 - 1,800
1,800.1 - 2,400
> 2,400
Villages
Smallholders cropfields
River
0 2.5 5 10 Km


N
Terrain Ruggedness
0 - 80
81 - 116
117 - 161
162 - 239
240 - 497
498 - 958
> 958
Villages
Smallholders cropfields
River
0 2.5 5 10 Km


N
Village Buffer
>1000
500-1000
<500
Villages
Smallholders cropfields
River
0 2.5 5 10 Km

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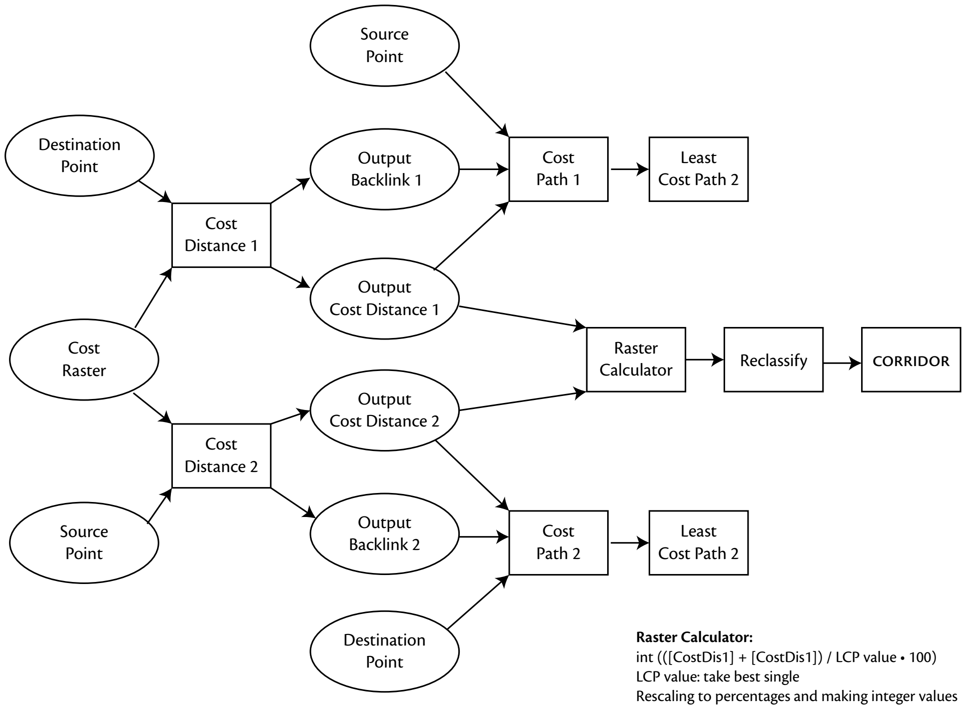
Appendix 3-4

Least cost modeling flow chart

GIS layers of defined variables were combined in one raster map to create an integrated layer of habitat suitability. The layer with the highest cost value determined the resistance class of the grid cell. The habitat suitability model was then used as a cost raster to calculate LCPs between all Bornean elephant localities observed during the reconnaissance surveys. 'Cost distance' in ArcGIS was used to calculate the least accumulative cost distance for each cell to the nearest source over a cost surface which depends on the cost factor. A cost path is a tool in ArcGIS which calculates the most cost-effective route for an animal to go from a source to a destination.



Raster Calculator:
int (([CostDis1] + [CostDis1]) / LCP value • 100)
LCP value: take best single
Rescaling to percentages and making integer values
Percentage from LCP value

Reclassify:
Reclassify calculation so new class can be assigned:
1(100-101), 2(101.1-102), 3(102.1-103), 4(103.1-104), 5(104.1-105), 6(105.1-110), 7(110-120), 8(120-130), 9(130-140), 10(140-150), 11(150-highest value)

Appendix 3-5
Bornean elephant presence in the study area in X and Y coordinates

No.	Observation		X	Y
A	**Forest landscape**			
1	Track	Herd (app. 4 ind)	470834	473597
2	Tracks, feeding sign		481853	468084
3	Track	(Bull) solitary track, *Temadung* river	492737	469791
4	Track	*Sokow* river	492517	469975
5	Track	Abandoned logging road	491063	470949
6	Track	*Bantul* river	490525	470882
7	Track	*Bebulu* river	490602	471878
8	Track	*Lakap-lakap* river	490530	471856
9	Track	*Tampilon* outfall	497092	467443
10	Track	*Kinomo* river	491418	467443
11	Track	(Bull) solitary track	495978	464649
12	Track	*Bosoi* river	496671	472359
13	Track	*Tampilon* river	496864	468105
14	Feeding sign	*Agison* river	471339	472200
15	Track, feeding sign	*Agison* river	470873	472385
16	Track, feeding sign	*Agison* river	470734	472409
17	Track	Trail *Agison*	470754	473592
18	Track	*Agison* river	470742	473608
19	Track	*Agison* river	470579	473929
20	Track	Crossing spot *Agison*	470390	473979
21	Track, feeding sign	Crossing spot and feeding sign *Agison*	470258	473803
22	Track	Track and trail *Dala*	469256	475260
23	Track, feeding sign	Feeding sign *Agison*	469210	475294
24	Feeding sign	Trail *Podos-Dala*	468804	475674
25	Track	Trail *Makalap-Podos*	468178	476694
26	Feeding sign, dung	*Sibuda* river	480606	478743
27	Dung	*Sibuda* river	480580	478713
28	Track, feeding sign	*Agison* river	475229	470669
29	Track, feeding sign	Trail *Balang*	477523	474515
30	Dead infant	*Sibuda* river	481828	468077

31	Track	Trail *Makalap-Podos*	468184	476698
32	Track	Trail *Teludan*	470801	473613
33	Track	Trail *Papaya*	470270	473804
34	Track	Trail *Agison*	469258	475251
35	Feeding sign	Trail *Podos-Dala*	468803	475677
36	Herd tracks	Herd tracks *Teludan*	470834	473597
37	Feeding sign	Herd tracks *Kaduyan*	481853	468084
38	Track	Bull track *Apan*	492737	469791
39	Track	Bull track *Apan*	495978	464649
40	Track	Salt lick *Sibuda*	480627	478688
41	Track	Trail *Papaya*	470413	473984
42	Track	Trail *Titikan*	474547	470700
43	Track, feeding sign	Trail and feeding sign (bamboo) *Globon*	477977	470284
44	Feeding sign	Trail *Globon*	477994	470409
45	Feeding sign	Trail *Sibuda*	480804	469751
46	Track	Trail *Kabatang*	481738	469047
47	Track	Trail *Kaduyan*	481802	468087
48	Herd	Herd (3-6) in *Tau 'island'*	490233	459070
49	Track	Trail at *Sinolop* river	494213	460780
50	Feeding sign	Crossing trail at *Apan* river	496402	462401
51	Track, feeding sign, dung	*Sibuda* river	482108	466806
52	Track		477885	470227
53	Track		472552	471317
54	Track	*Apan* outfall	496605	462121
55	Track	*Kapakuan* outfall	482065	464569
56	Track, feeding sign		482757	464081
57	Track	*Apan* river	492553	469580
58	Track	Trail *Masalui*	468895	475550
59	Track	Trail to salt lick at *Agison* river	466643	479659
60	Feeding sign	*Agison* river	467124	478837
61	Feeding sign	*Kinomo* river	488035	467075
62	Feeding sign	*Apan* river	491740	469774
B	**Agricultural land and villages areas**			

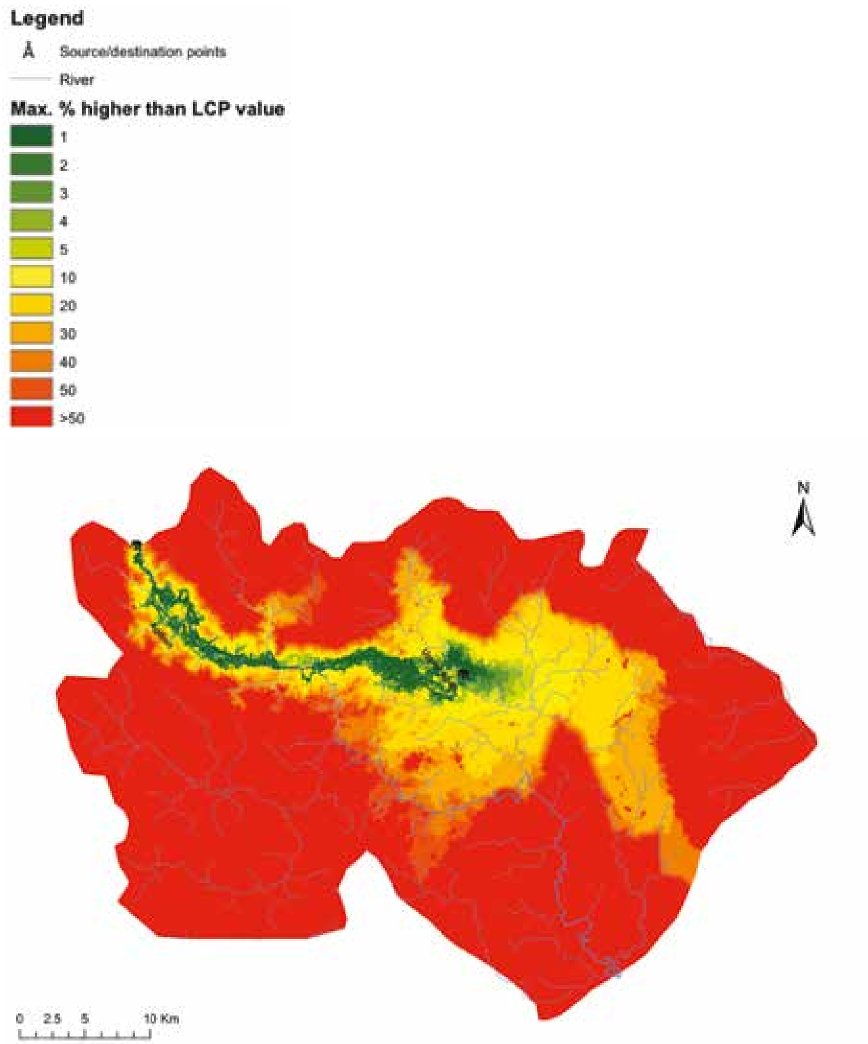
1	Bull encounter	*Semunad* village	500192	449213
2	Bull encounter	*Semunad* village	500400	449779
3	Bull encounter	*Semunad* village	500505	449773
4	Bull encounter	*Semunad* village	500487	449789
5	Bull encounter	*Semunad* village	500651	449902
6	Track	*Sekikilan* village	498785	452115
7	Track	*Sekikilan* village	498844	452154
8	Track	*Sekikilan* village	498842	452184
9	Track	*Sekikilan* village	498670	452311
10	Rubbing tree	Area between *Kalunsayan* and *Sekikilan*	499167	455585
11	Track, feeding sign	Area between *Kalunsayan* and *Sekikilan*	498905	455608
12	Dung	Area between *Kalunsayan* and *Sekikilan*	498873	455602
13	Feeding sign	Area between *Kalunsayan* and *Sekikilan*	498866	455612
14	Track, feeding sign	Area between *Kalunsayan* and *Sekikilan*	498843	455602
15	Bull encounter	*Kalunsayan* village	498612	456941
16	Track	*Tembalang* village	499231	458603
17	Track	*Tembalang* village	498685	458760
18	Bull encounter	*Naputi* village	498905	459985
19	Bull encounter	*Naputi* village	498820	460059
20	Track	Area between *Kalunsayan* and *Sekikilan*	498908	455618
21	Feeding sign	Area between *Kalunsayan* and *Sekikilan*	498927	455634
22	Feeding sign	Area between *Kalunsayan* and *Sekikilan*	498930	455637
23	Track	Area between *Kalunsayan* and *Sekikilan*	498939	455646
24	Feeding sign	Area between *Kalunsayan* and *Sekikilan*	498939	455658
25	Track	Area between *Kalunsayan* and *Sekikilan*	498973	455670
26	Dung	Area between *Kalunsayan* and *Sekikilan*	499003	455668
27	Rubbing tree	Area between *Kalunsayan* and *Sekikilan*	499031	455634
28	Dung	Area between *Kalunsayan* and *Sekikilan*	499053	455599
29	Track	Area between *Kalunsayan* and *Sekikilan*	499145	455599
30	Track	Area between *Kalunsayan* and *Sekikilan*	499189	455578
31	Track	Area between *Kalunsayan* and *Sekikilan*	499223	455570
32	Resting spot	Area between *Kalunsayan* and *Sekikilan*	499263	455591
33	Dung	Area between *Kalunsayan* and *Sekikilan*	499275	455557
34	Dung	Area between *Kalunsayan* and *Sekikilan*	498911	455349

35	Track	Area between *Kalunsayan* and *Sekikilan*	498911	455311
36	Crossing spot	Area between *Kalunsayan* and *Sekikilan*	499312	455544
37	Feeding sign	*Kalunsayan* village	498474	456561
38	Track	*Kalunsayan* village	498476	456567
39	Track, feeding sign	*Kalunsayan* village	498495	456589
40	Track	*Kalunsayan* village	498526	456505
41	Feeding sign	*Kalunsayan* village	498535	456577
42	Track	*Kalunsayan* village	498529	456570
43	Dung	*Kalunsayan* village	498535	456555
44	Track	*Kalunsayan* village	498519	456530
45	Wallow	*Kalunsayan* village	498535	456616
46	Dung	*Kalunsayan* village	498479	456582
47	Track	*Kalunsayan* village	498911	456786
48	Dung	*Kalunsayan* village	498911	456770
49	Feeding sign	*Kalunsayan* village	498967	456598
50	Track	*Kalunsayan* village	498979	456509
51	Dung	*Kalunsayan* village	498930	456515
52	Crossing spot	*Kalunsayan* village	498920	456511
53	Dung	*Kalunsayan* village	498935	456497
54	Feeding sign	*Kalunsayan* village	498982	456444
55	Trail	*Kalunsayan* village	499013	456442

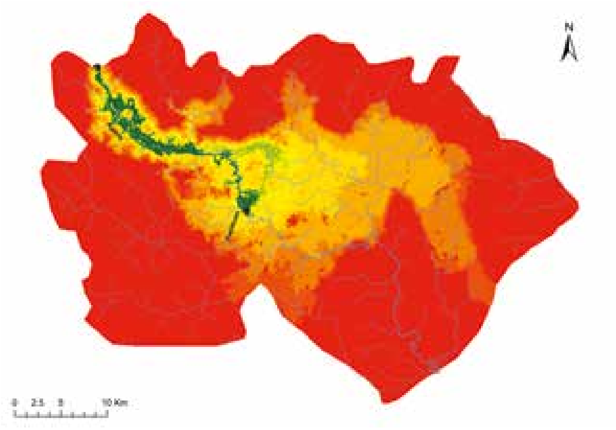
Appendix 3-6

Results of least-cost models with values and length of the least-cost paths of each model. The length is expressed as the number of grid cells (approximately 30 meters)

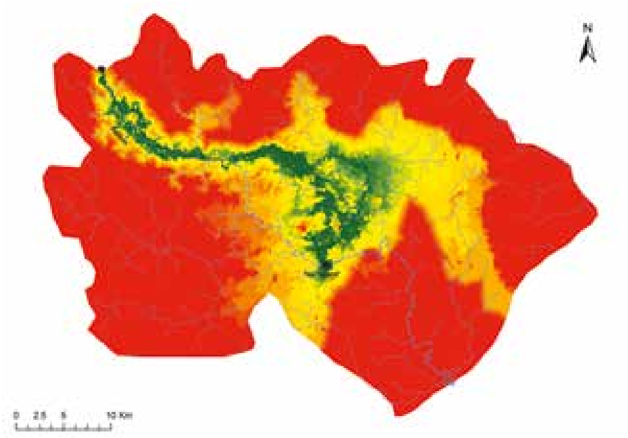
Corridor maps are represented in all models four source areas (Agison, Upper Sibuda, Sibuda, and Kapakuan) in the forest landscape and two sources points (Upper Apan and Batu Mayo Hill) in human-dominated landscape.



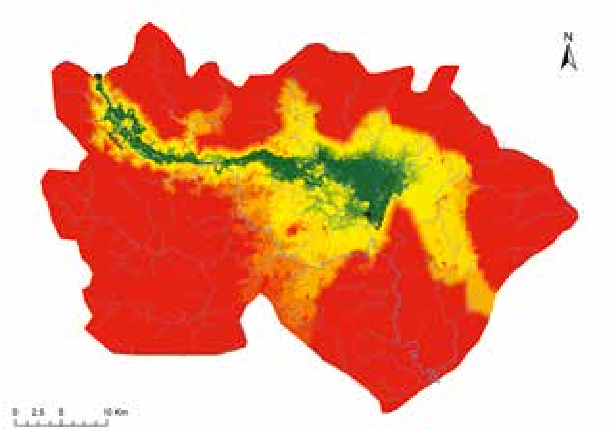
Agison – Upper Apan
Least-cost value : 235173 ; 235173.4
Length least-cost path (# cells) : 1182



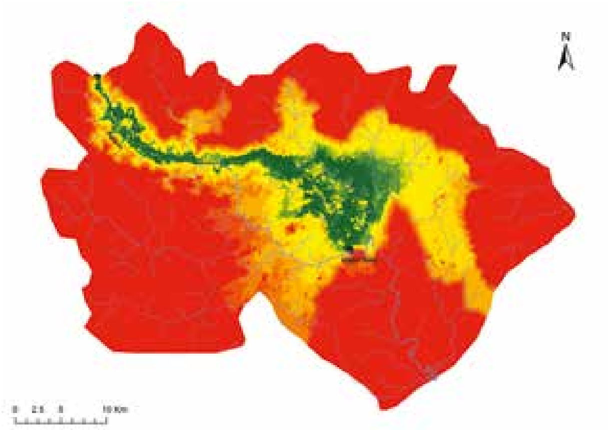
Agison – Kapakuan
Least-cost value : 285149.1 ; 285149.4
Length least-cost path (# cells) : 979



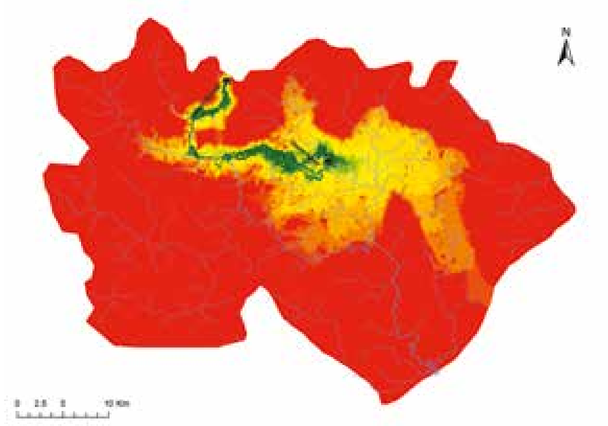
Agison – Tau 'Island'
Least-cost value : 272483.5 ; 272484.1
Length least-cost path (# cells) : 1483



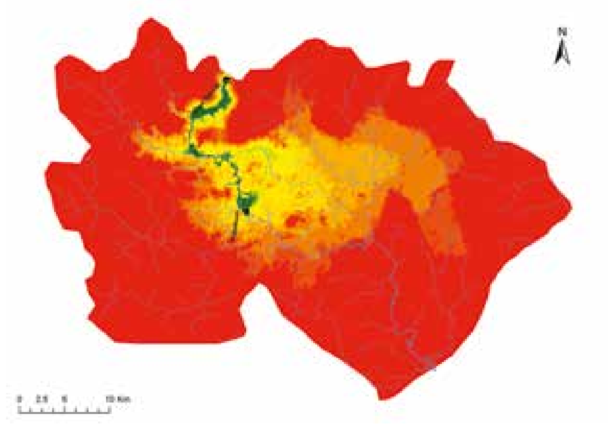
Agison – Apan
Least-cost value : 255729.7 ; 255730.4
Length least-cost path (# cells) : 1467



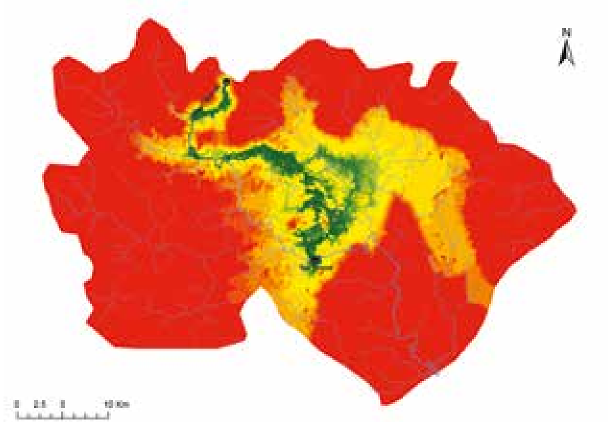
Agison – Upper Tulid
Least-cost value : 273881.8 ; 273882.4
Length least-cost path (# cells) : 1438



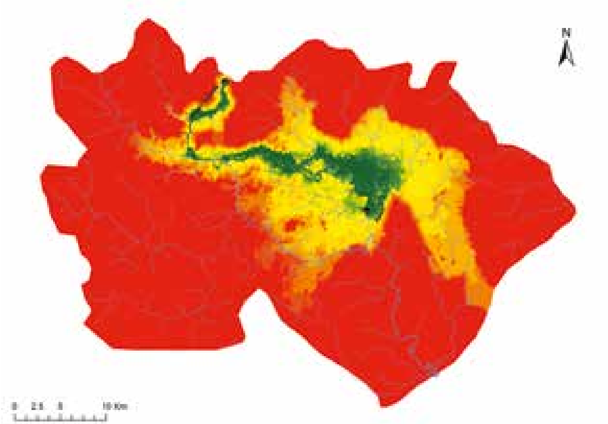
Upper Sibuda – Upper Apan
Least-cost value : 173490.4 ; 173490.7
Length least-cost path (# cells) : 950



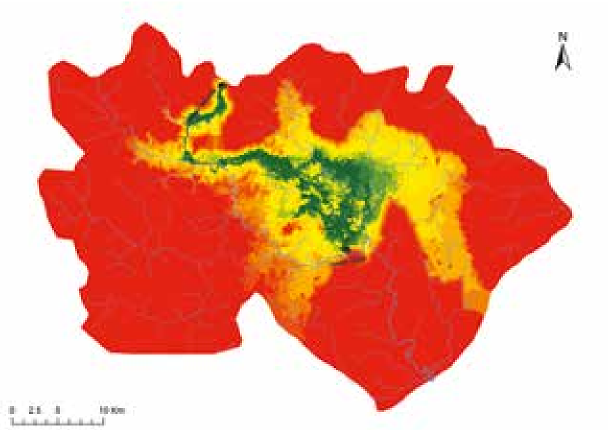
Upper Sibuda – Kapakuan
Least-cost value : 223466.4 ; 223466.7
Length least-cost path (# cells) : 747



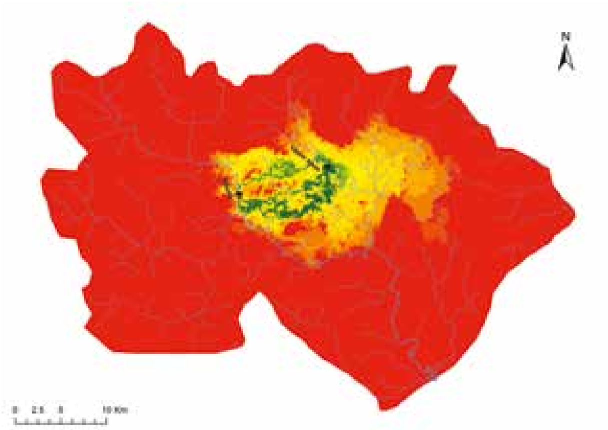
Upper Sibuda – Tau 'Island'
Least-cost value : 210800.8 ; 210801.4
Length least-cost path (# cells) : 1251



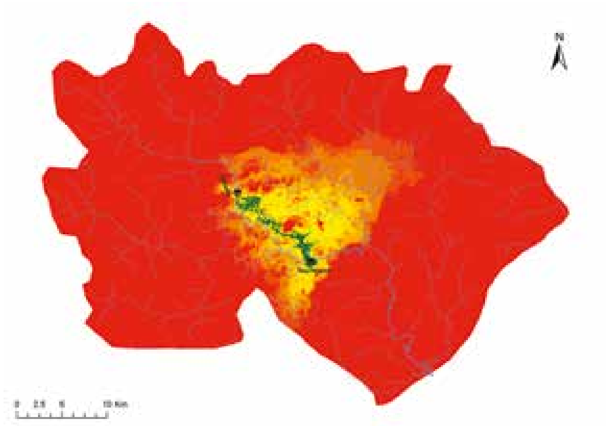
Upper Sibuda – Apan
Least-cost value : 194047.1 ; 194047.8
Length least-cost path (# cells) : 1235



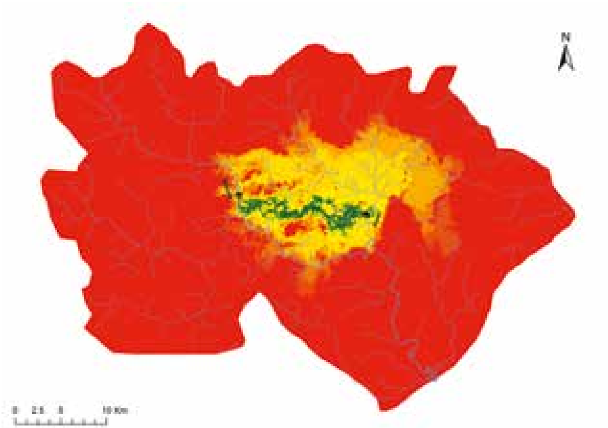
Upper Sibuda – Upper Tulid
Least-cost value : 212199.2 ; 212199.7
Length least-cost path (# cells) : 1206



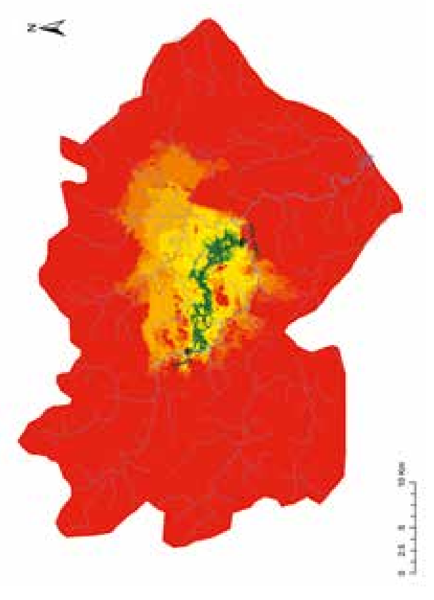
Sibuda – Upper Apan
Least-cost value : 108640.6 ; 108641
Length least-cost path (# cells) : 605



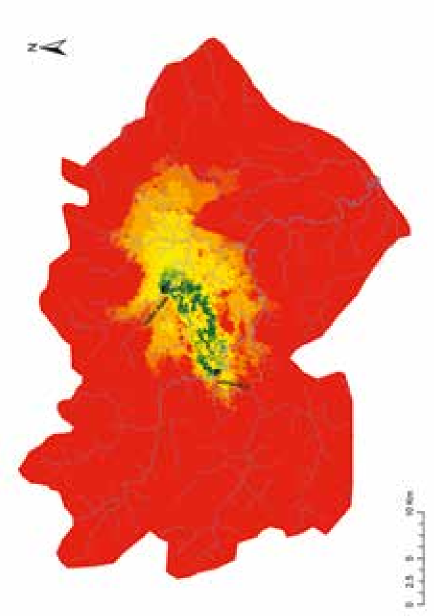
Sibuda – Tau 'Island'
Least-cost value : 114400.9 ; 114401
Length least-cost path (# cells) : 448



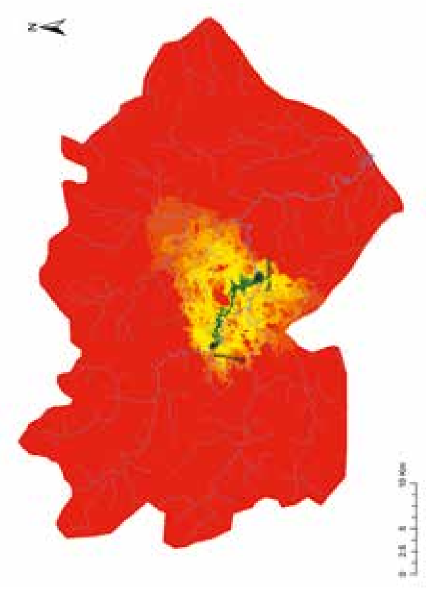
Sibuda – Apan
Least-cost value : 115878.3 ; 115878.7
Length least-cost path (# cells) : 617



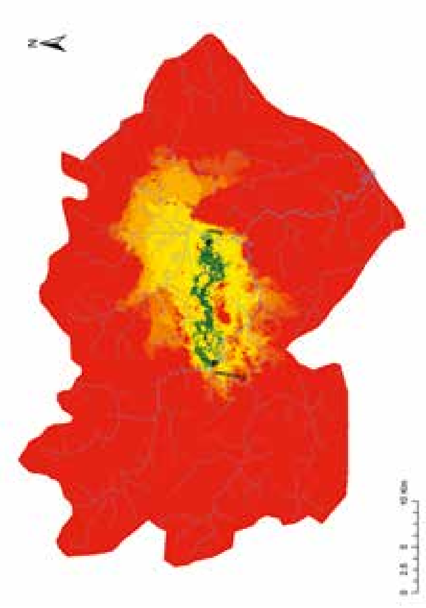
Sibuda – Upper Tulid
Least-cost value : 123524.8 ; 123525.3
Length least-cost path (# cells) : 640



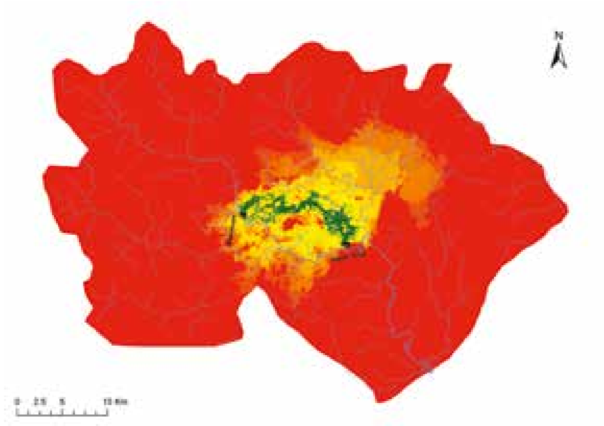
Kapakuan – Upper Apan
Least-cost value : 107327.7 ; 107328.1
Length least-cost path (# cells) : 597



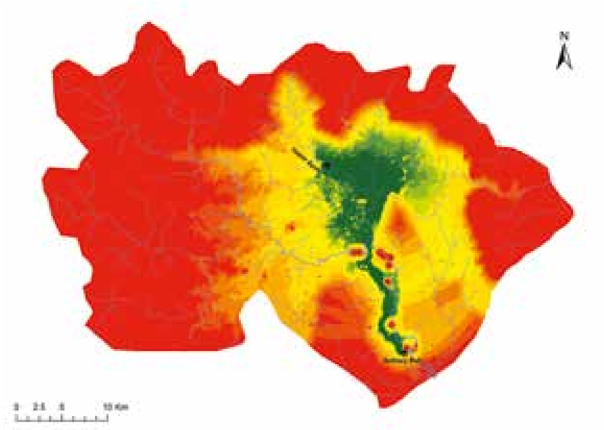
Kapakuan – Tau 'Island'
Least-cost value : 105831.8 ; 105832
Length least-cost path (# cells) : 387



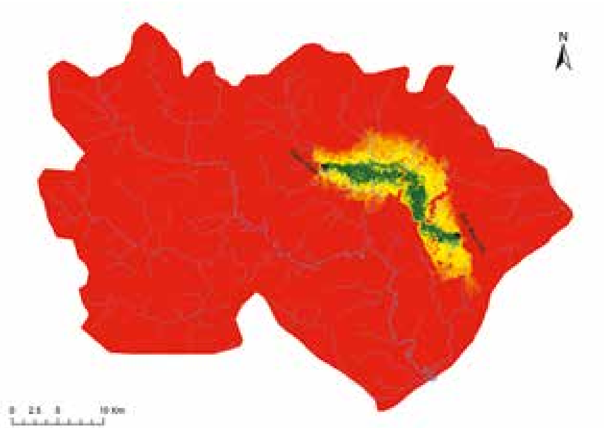
Kapakuan – Apan
Least-cost value : 114565.4 ; 114565.8
Length least-cost path (# cells) : 609



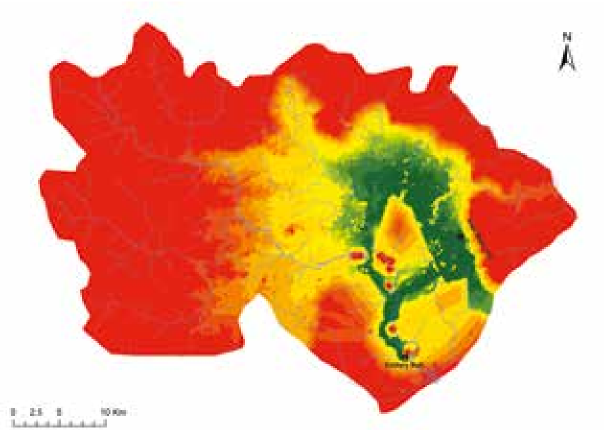
Kapakuan – Upper Tulid
Least-cost value : 122211.9 ; 122212.3
Length least-cost path (# cells) : 632



Upper Apan – Solitary Bull
Least-cost value : 427271.9 ; 427274.6
Length least-cost path (# cells) : 874



Upper Apan – Batu Mayo Hill
Least-cost value : 36094.06 ; 36094.07
Length least-cost path (# cells) : 713



Batu Mayo Hill – Solitary Bull
Least-cost value : 435916.1 ; 435918.1
Length least-cost path (# cells) : 621