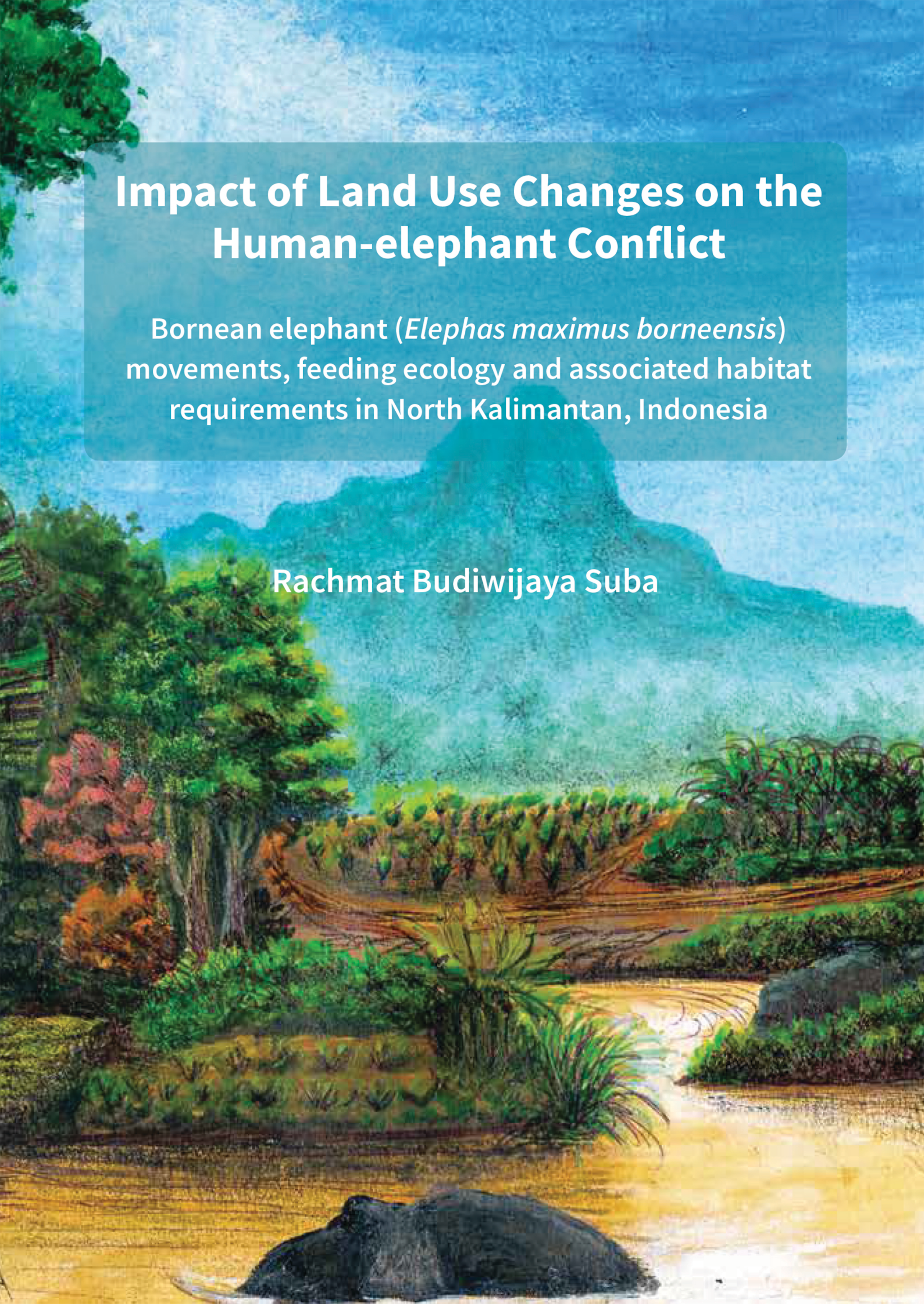
Author: Suba, R.B.
Title: Impact of land use changes on the human-elephant conflict; Bornean elephant (Elephas maximus borneensis) movements, feeding ecology and associated habitat requirements in North Kalimantan, Indonesia
Issue Date: 2017-06-01



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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Cover photos:	Albert L. Manurung
Photos:	Arie Prasetya, Brian Martin
Lay out:	Sjoukje Rienks, Amsterdam
Language corrections:	Barbara Croes

ISBN 978-90-5191-

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PROEFSCHRIFT

ter verkrijging van
de graad van Doctor aan de Universiteit Leiden
op gezag van de Rector Magnificus prof. mr. C.J.J.M. Stolker
volgens besluit van het College voor Promoties
te verdedigen op donderdag 1 juni 2017
klokke 15.00 uur

door

Rachmat Budiwijaya Suba

Geboren te Tarakan, Indonesië
in 1976

Promotores:	Prof.dr. G.R. de Snoo Prof.dr. W. Kustiawan (Mulawarman University)
Copromotor:	Prof.dr.ir. H.H. de Iongh (Universiteit Leiden/Universiteit Antwerpen)
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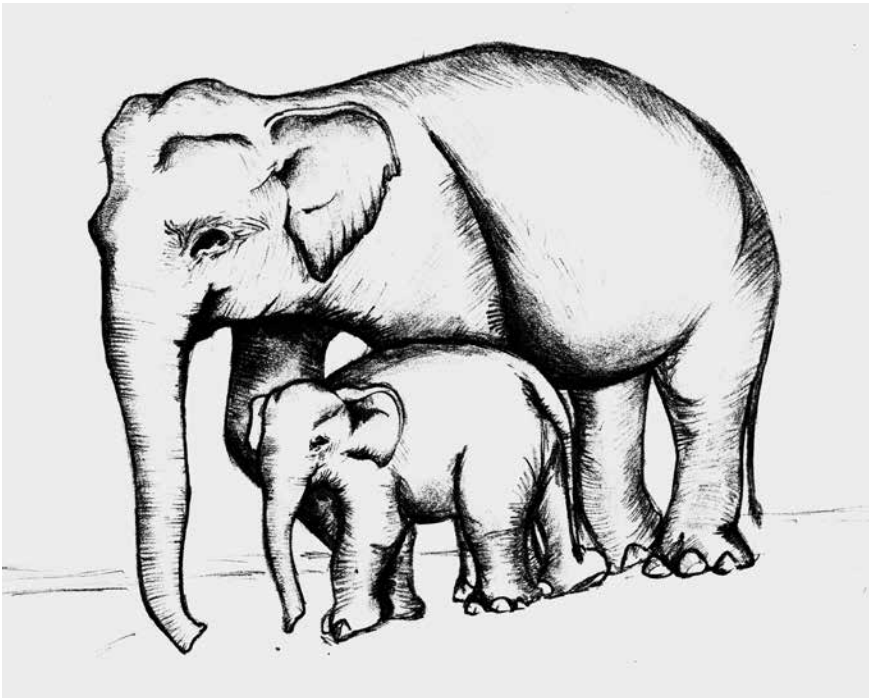
General introduction



1.1 Theoretical background

Asian elephants (*Elephas maximus*) are the largest living land mammal in Asia and are found in 13 range countries nowadays. There are presently four subspecies of Asian elephant recognized, i.e. *Elephas maximus indicus* in mainland Asia, *Elephas maximus maximus* in Sri Lanka, *Elephas maximus sumatrensis* in Sumatra, Indonesia, and *Elephas maximus borneensis* in Borneo. Recent estimates indicate a population size of 30,000 to 50,000 Asian elephants (Riddle *et al.* 2010), although their numbers are declining due to fragmentation and destruction of their habitat.

Around 2,000 Bornean elephants (*Elephas maximus borneensis*) are estimated to be left in the wild, of which the majority is found in Sabah (Alfred *et al.* 2011). The species is however severely threatened by habitat loss, degradation, and fragmentation (Choudhury *et al.* 2008). Since 1986, *Elephas maximus* has been listed as an endangered species (EN) on the IUCN Global Red List (IUCN 2016). Under Indonesian Law (Government Regulation Nr. 7/1999), the Bornean elephant is also listed as an endangered species (Noerdjito and Maryanto 2001).

It was commonly believed that Bornean elephants were introduced to North Borneo by local rulers or *Sultans* which would explain their limited distribution on Borneo (Hooijer 1972). However, a recent publication by Fernando *et al.* (2003) demonstrated the genetic distinctiveness of the Bornean elephant and the genetic distance to elephant populations on the Sundaic continent. Fernando *et al.* (2003) recognizes the Bornean elephant as a separate evolutionary significant unit and confirms that Bornean elephants have been isolated from Asian elephant populations on the continent, at least from the last glacial maximum, around 18,000 years ago, when land bridges last linked the Sunda Islands and the mainland (MacKinnon *et al.* 1996). At the same time, Cranbrook *et al.* (2008) support the hypothesis that Bornean elephants may consist of remnant survivors of the extinct Javan elephant following the disappearance of the Java-Borneo connection. Fernando *et al.* (2003) also suggested a low heterozygosity in the remaining population of Bornean elephants. Since the Bornean elephant is considered as a separate subspecies, conserving their populations has become the main priority (MacKinnon *et al.* 1996; Fernando *et al.* 2003). The Bornean elephant distribution is limited to only 5% of the island of Borneo and further extends to eastern and southern parts of Sabah, Malaysia, and the upper northern part of East Kalimantan, Indonesia, known as the Sebuku forest (Wulffraat 2006) [Figure 1-1a]. A group of 20-60 elephants regularly moves through this area from the Kalabakan Forest Reserve in Sabah, Malaysia (Wulffraat 2006; Alfred *et al.* 2011). My research focused on a small pocket habitat of the Bornean elephant in the Indonesian part of Borneo, the Sebuku forest, which is part of the Tulin Onsoi Sub-district, in North Kalimantan Province [Figure 1-1b].

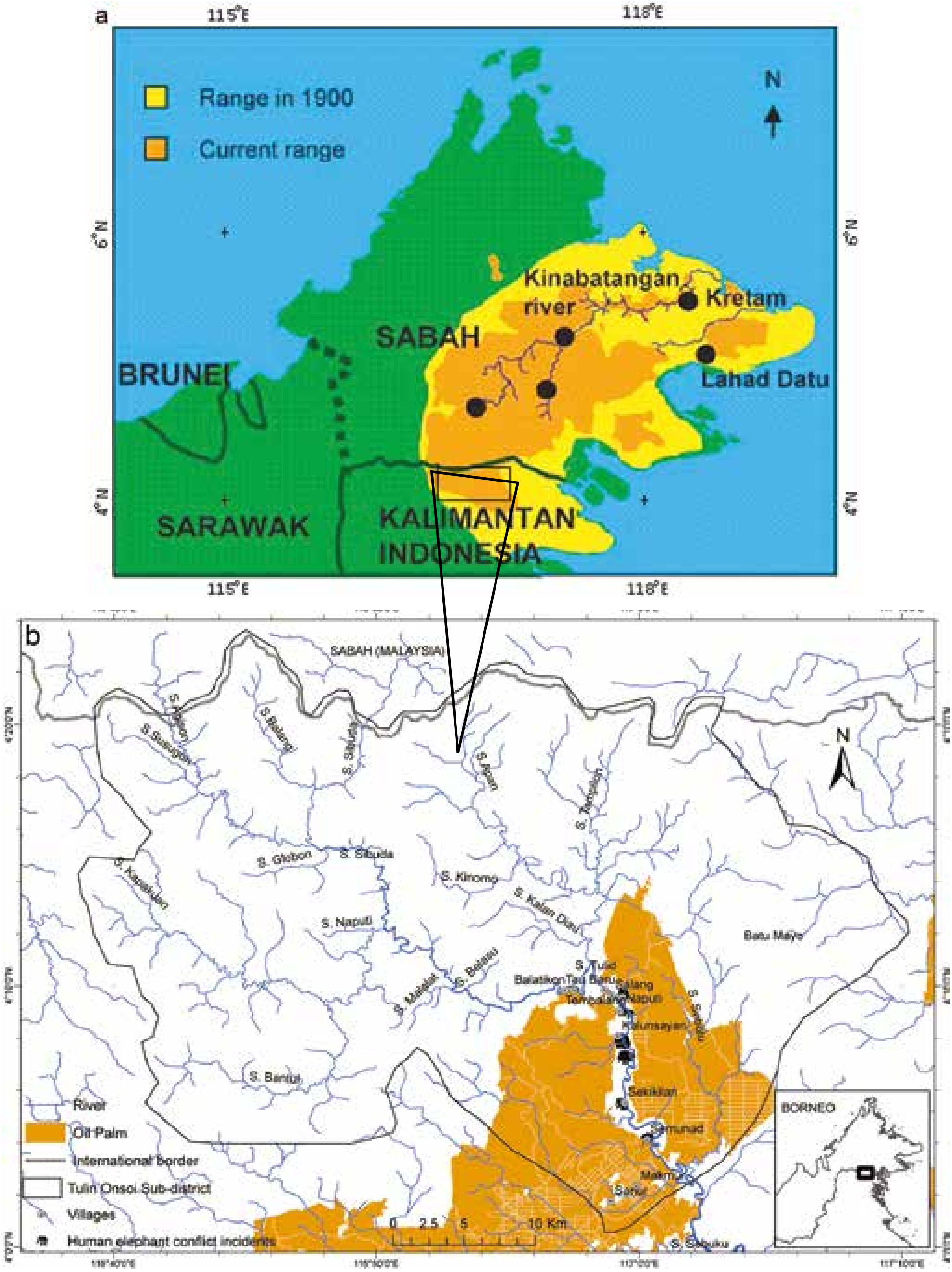


Figure 1-1
Natural range of Bornean elephants (Fernando *et al*. 2003) [a] and map of Tulin Onsoi Sub-district, North Kalimantan Province as part of Bornean elephant ranges [b]

Based on the existing forest area and the present elephant distribution, five major Managed Elephant Ranges (MERs) have been identified in Sabah (Alfred *et al.* 2010). The MERs cover an area of more than 50,000 ha, which is considered suitable as elephant core habitat (Alfred *et al.* 2011). MERs within Sabah include Tabin, Lower Kinabatangan, Central Forest Range (including Ulu Segama, Danum Valley, Malua, Kuamut, Gunung Rara, Kalabakan), North Kinabatangan Range (including Deramakot, Tangkulap, Segaliud Forest Reserve [FR]) and Ulu Kalumpang Range [Table 1-1]. Outside these five main ranges, there are several smaller, scattered and fragmented groups of fewer than 20 individuals. The long-term viability of these small groups is doubtful (Alfred et al. 2011).

The elephant population in the Sebuku forest in North Kalimantan is contiguous with the elephant population in the Kalabakan FR as part of the elephant range in the central forest of Sabah (Riddle *et al.* 2010). The elephant population within the Kalabakan FR is estimated to consist of 280-330 individuals. The suitability of the Sebuku area (about 49,500 ha), which is occasionally visited by 20-60 elephants (Wulffraat 2006; Alfred *et al.* 2011) needs further investigation. The present research will address some of the gaps that still remain in our knowledge of the Bornean elephant on the Indonesian side. Whether the few remaining elephants inhabiting the Sebuku forest could be conserved or could even become a viable population remains arguable, but the fact that Bornean elephants have occurred here for thousand of years and that the area is connected to an important elephant habitat in Sabah (Olivier 1978; Payne *et al.* 1994; Yasuma 1994; MacKinnon *et al.* 1996; Jepson *et al.* 2002; Riddle *et al.* 2010) would at least render such conservation efforts justified.

1.1.1 Local threats and human-elephant conflict

Increasing human populations and changes in land use have brought fierce competition for space and resources between people and wildlife (Hoare 2000; Kinnaird *et al.* 2003; Dublin & Hoare 2004; Nyhus & Tilson 2004; Woodroffe *et al.* 2005; Clements *et al.* 2010). Among all large mammal species, elephants are one of the most vulnerable to land use change due to seasonal migrations (Santiapillai & Widodo 1993; Hoare 1999; Leimgruber *et al.* 2003; Hedges *et al.* 2005; Rood *et al.* 2008; Saaban *et al.* 2011). It has been suggested that, even if all forests within an elephant's range would be completely cleared for agricultural purposes, elephants still follow their traditional migratory routes and may cause considerable damage to agricultural fields (Sukumar 1989; Santiapillai & Widodo 1993; Rood *et al.* 2008). While loss of habitat is one of the main problems facing elephants, consequent human-elephant conflicts (HECs) are considered a major issue affecting elephant populations in Africa

Table 1-1
Size and status of key Managed Elephant Ranges associated with elephant numbers for each forest reserve in Sabah, Malaysia (Alfred *et al*. 2010; Alfrred *et al*. 2011)

No.	Elephant range	Total area size (ha)	Size of the key habitat area used by elephant (ha & %)	Elephant number parameter				Current land use activities
				Nr. of ind.	Stand. error	95% CI		
1	Tabin Range (Tabin Wildlife Reserve)	140,601	56,910 (40.48%)	342	158.13	152	774	Wildlife reserve
2	Lower Kinabatangan Range	58,809	13,815 (23.49%)	298	115.84	152	581	Fragmented forest reserve
3	Central forest of Sabah (Ulu Segama, Danum Valley, Malua, Kuamut, Gunung Rara Kalabakan and Sapulut Forest Reserves)	910,007	95,345 (10.48%)	1,132	322.85	748	1,713	Commercial forest (logging on-going, forest conversion to mono-plantation, silviculture and restoration on-going
4	North Kinabatangan Range (Deramakot, Tangkulap and Segaliud Forest Reserves)	170,521	45,830 (26.88%)	258	101.81	131	511	Commercial forest (logging, silviculture and restoration on-going)
5	Ulu Kalumpang Range (Ulu Kalumpang Forest Reserve)	79,408	9,160 (11.54%)	10	9.95	1	73	Protected forest (encroached by oil palm plantations)
	Total	1,359,346	221,060 (16.26%)	2,040	~	1,184	3,652	~

and Asia, as well as local farmers (Sukumar 1989; Tchamba 1996; De Iongh *et al.* 1999; Hoare 2001; Zhang & Wang 2003; Gubbi 2012). HEC may result in injury and death of humans, crop raiding, damage to villages' infrastructure and an increased negative attitude towards elephants among local communities (Tchamba 1996; De Boer & Baquete 1998; Hedges *et al.* 2005; Fernando *et al.* 2005, 2008). However, there are no customary penalties for killing an elephant; ultimately it is someone's own risk.

In the last two decades, the situation in Asia has worsened because forest is not only lost to small-scale subsistence agriculture but also to large-scale conversion of vast natural forest areas into industrial plantations for sugar, tea, rice, and oil palm (Sodhi *et al.* 2004; Koh & Wilcove 2008; Sheil *et al.* 2009). Although an increase in forest fragmentation does not explicitly lead to an increase of crop raiding, the incidence of crop raiding by elephants may increase as the remaining forest patches are being cleared for agricultural expansion (Rood *et al.* 2008). Continuous forest clearance and habitat degradation will ultimately lead to an increased encounter rate between humans and wild elephants, and consequently to an intensification of HEC. This situation is particularly true for the island of Sumatra, Indonesia, where over the past three decades development of estate crop plantations, mainly comprised of oil palm and rubber plantations, and the establishment of subsistence gardens has forced elephants to compete with humans for available space (Santiapillai & Widodo 1993; Rood 2010). As a consequence, HEC has become widespread in Sumatra, e.g. in Aceh (Rood *et al.* 2008; Rood 2010), Bengkulu (Sitompul 2011) and Lampung (Nyhus *et al.* 2000; Hedges *et al.* 2005; Sitompul *et al.* 2010).

As the only remaining suitable habitat for Bornean elephants in North Kalimantan, the Sebuku forest is currently subject to a conflict over land-use claims by the government (central, province and local), the private sector and other stakeholders. Within the framework of the government-supported 'one million hectares of oil palms' program since 2002, oil palm plantations have been established in the Nunukan District, North Kalimantan (East Kalimantan Provincial Government 2015; Bureau of Estate of East Kalimantan 2015). As the Sebuku Sub-district, together with the Sub-districts of Sembakung and Lumbis, are quickly becoming the main centers of the oil palm plantation program, conversion of large parts of the Sebuku forest into oil palm is ongoing and therefore considered as the major threat to the local elephant population (Wulffraat 2006).

The Asian elephant has a specific value in the history, religion, and folklore of local people (Santiapillai & Jackson 1990; Santiapillai 1997; Fernando *et al.* 2005). Although this cultural significance place the elephant as a potential flagship species in efforts to maintain remaining tropical rain forests (Nyhus *et al.* 2000), increased negative perceptions towards elephants could negatively impact their conservation (De Boer & Baquete 1998; Hill 1998;

Gubbi 2012). Even if the overall impact of HEC is relatively low, its effect can be significant to individual farmers (Naughton-Treves 1998). Incidents of poisoning and electrocution of elephants are increasing as local people attempt to protect their livelihoods (Perera 2009). Recent conflicts with oil palms farmers in the Malaysian state of Sabah in February 2013 resulted in the poisoning of 14 Bornean elephants (Hance 2013). In 2005 the Kalimantan population of Bornean elephants drew the attention of the government when local media reported on a few incidents of solitary males that had entered village gardens and disturbed crops in the Sebuku area (Wulffraat 2006).

1.1.2 Habitat use and movements

Elephant movement patterns are associated with both food availability and quality of food plants (Sukumar 1989; Blake & Inkamba-Nkulu 2004; Rood *et al.* 2010; Alfred *et al.* 2012; Estes *et al.* 2012). Recent studies also show that elephant movement is driven by human disturbance. Agriculture, fallow land, and settlements are land use classes that can limit elephant movements (Lin *et al.* 2008; Graham *et al.* 2009; Joshi *et al.* 2011; Epps *et al.* 2013) and roads adversely affect large forest mammal, including elephant (Newmark *et al.* 1996; Laurance *et al.* 2006).

Elephants may spatially shift among sites to explore resources and temporally move between a set of foraging areas (Bailey *et al.* 1996; English *et al.* 2014). The multiple scales of spatial and temporal heterogeneity over which resources are distributed would determine the most efficient foraging strategy for elephants, which in turn would drive the formation of trails and the return by elephants to previously utilized foraging sites, so-called recursion. The temporal pattern of site recursion can be a reflection of elephant movement patterns. Since trails are formed as a result of repeated movement towards important resources, it is predicted that trails and the pattern of recursion would link those resources offering the highest net energy gain for the lowest energy costs (McNaughton 1985; Gordon & Lindsay 1990; Fryxell 1991; Bailey *et al.* 1996; Bergman *et al.* 2001; Blake 2002; English *et al.* 2014).

Bornean elephants spend most of their time in mixed secondary or or previously logged forests that contain grassy areas. Water availability, e.g. the presence of rivers, is also a major predictor for elephant presence (Brashares *et al.* 2001; Fahrig 2007; Epps *et al.* 2011; Epps *et al.* 2013). Elephants have a strong preference for forests with a high productivity, which are often located in valleys (Rood *et al.* 2010) and other landscape depressions. These natural waterways provide a main source of water and as such often become elephant migration routes (Pan *et al.* 2009; Shannon *et al.* 2009).

Steep slopes have been mentioned to constrain elephant movements (Lin *et al.* 2008; Pan *et al.* 2009). Terrain ruggedness also seems limit elephant movements to some extent, with lower frequencies of elephant occurrence in highly rugged terrain and higher elephant presence occurring over a relatively narrow range of relative ruggedness (Rood *et al.* 2010). Bornean elephants in Sabah preferred flat land or areas with gentle slopes below 300 meters elevation (Estes *et al.* 2012). Wulffraat (2006) suggested that the combination of elevation and slope plays an important role in the movement of Bornean elephants in the Sebuku forest.

1.1.3 Foraging ecology and diet

Large body size is generally associated with high metabolic requirements. Due to their long digestive system, elephants, as non-ruminant hind gut fermenters, have a faster digestive passage, thus allowing them to tolerate food of lower nutritional quality (Bell 1971; Demment & van Soest 1985; Clauss *et al.* 2003). Elephants developed a number of traits that maximize energy intake from low digestible forage fractions. They are known for instance to expand their diet to include even low-quality plant species and increase the bulk of dietary food ingestion (Demment & van Soest 1985; Owen-Smith 1992). Elephants use symbiotic microbes to digest cellulose in the large caecum and the colon (Sukumar 2006), and their characteristic trunk and high-crowned molar teeth (structured for grinding fibrous materials) allow them to exploit a wide range of plant resources.

Despite these adaptations, elephants selectively feed on high-quality forage when given the opportunity. As the availability of good quality forage varies with geographic region and is subject to seasonality, which results in seasonal variation in dietary composition (Sukumar 1989; Nyhus *et al.* 2000; Rode *et al.* 2006). The time spent foraging and the composition of plants consumed are subject to seasonality. In dry tropical forests for example over 70% of the diet is browsed, while (tall) grasses comprise the majority of the diet in the wet season when they are plentiful. However, in the tropical wet forests (i.e. rainforest) the diet may almost entirely consist of browse and fruit. During periods of the mast in tropical forests elephants are known to feed mainly on fruits (Sukumar 2006).

Dietary mineral concentrations also vary on a seasonal basis (Sukumar 1992; Nyhus *et al.* 2000; Rode *et al.* 2006). Depending on the plant species availability and the time of the year, elephants may selectively forage to meet their dietary mineral requirement (Sukumar 1990; Rode *et al.* 2006). Many studies have found over 100 plant species included in Asian elephants' diet (Himmelsbach *et al.* 2006; Chen *et al.* 2006; Campos-Arceiz *et al.* 2008; Baskaran *et al.* 2010; Sitompul *et al.* 2013; Roy & Chowdury 2014). Withonly c. 40-50% of the forage being digested, elephants may spend 12-18 hours a day feeding, during which they can consume up to 150 kg of vegetation (Sukumar 2006). In Peninsular Malaysia, palm and grass constitute about 75% of their diet. Overall, Fabaceae (legumes), Poaceae (grasses), Cyperaceae (sedges), Arecaceae (palms), Euphorbiaceae (spurges), Rhamnaceae (buckthorn) and Malvales (mallows, sterculias, and basswoods) account for most of the Asian elephant's diet (Sukumar 2006; Campos-Arceiz *et al.* 2008; Sitompul 2011). Thus, although comparing the quality of dietary species may provide useful insights, explaining dietary composition in terms of mineral composition is also of importance (Chen *et al.* 2006), especially considering that plants are not the only possible source of these minerals.

1.1.4 Primary determinants of food preference

The optimal foraging theory suggests that herbivores maximize on energy and/or total Nitrogen (Pyke *et al.* 1977; McNaughton 1979; Demment & Van Soest 1985; De Iongh 1996). Plant material is made of chemical components that react differently to digestive enzymes of different digestive systems. Sugars, protein, and carbohydrates form the active fraction of plant metabolism and these can be digested directly by vertebrate enzymes or fermented rapidly by microbes. Complementary to the active fraction, the cell-wall fraction of plants is composed of lignin and fibers (Neutral Detergent Fibers or NDF) which provide the structural matter of the plant. This fraction is digested slowly and exclusively by microbial symbiotes (Demment & Van Soest 1985). The quality of forage will therefore generally be increased by sugars, proteins, and carbohydrates, and decreased by fibers and lignin. Allelochemicals (e.g. condensed tannin) have been shown to influence food selection by herbivores, due to their deleterious properties (Rosenthal & Janzen 1979; Jachman 1989). In contrast to small herbivores and foregut or ruminant herbivores that have the ability to ingest toxins proportionally (Freeland & Janzen 1974), larger herbivores and hindgut fermenters such as elephants are less well adapted to deal with these secondary compounds. In order to reduce the negative effect of secondary compounds, elephants diversify their diet composition (Clauss *et al.* 2003).

Whereas the old model of food selection by ruminants suggested that ruminants can taste and smell most nutrients and toxins in plants while foraging, which would allow them to select nutritious food while avoiding potential harmful food (Provenza 1995), this could be debated because the taste, smell, and texture of each food are results from a unique chemical compound that makes the flavor of each food unique (Bartoshuk 1991). The latest model, the learning model of foraging, assumes that diet selection is a result of flexibility to select nutritious diets in a situation where diets vary in concentrations of nutrients and toxins (Provenza & Balph 1990; Provenza & Cincotta 1993). The nutritional and toxicological consequences of food selection are related to the individuals' morphology and physiology. Neurally mediated interactions between the sense (i.e. taste and smell) and the viscera enable ruminants to sense the consequences of food ingestion, and these interactions may occur but may also substantially affect the hedonic value of food through the sensational experience from smell and taste. Furthermore, post-ingestive feedback from nutrients and toxins can enable animals to select nutritious food and limit intake of toxic food (Provenza 1995).

Nutritional value of selected food is not the only determinant of diet composition. Behavioral preferences which can reflect the most desirable components that the animal perceives in relation to what is available is also suggested to be of influence (Loehle & Rittenhouse 1982). Evidence suggests that food selection involves interactions between the senses of taste and smell and mechanisms to sense the consequences of food ingestion, such as satiety (experienced when animals ingest adequate kinds and amounts of nutritious food) and malaise (experienced when animals ingest excesses of nutrients or toxins or experience nutrient deficits) (Provenza 1995). Taste, smell, and sight could also interact, i.e. a taste cue could potentiate a visual cue (Provenza 1995). Garcia (1989) suggested that taste is the most powerful arbiter of what is fit to eat, the smell comes after.

With their strongly developed sense of taste (Joshi 2009; Garstang 2015), elephants are expected to use taste to select preferable food plant species. Recursion is a common behavior used by elephants and its pattern suggests it may be a foraging strategy for revisiting areas of greater value. Innate foraging decisions associated with the spatial and temporal availability of resources (English *et al.* 2014) and associative learning have also been associated with certain elephant foraging strategies. Acquired behavior within elephants is likely as they remember areas containing their preferred food and revisit those areas after sufficient time has elapsed, searching for resources for replenishment (English *et al.* 2014). As highly social and long-lived species with large home ranges, elephants may thus develop a spatial and temporal memory that allows them to select preferred food (Hart *et al.* 2008).

1.2 Study area

1.2.1 Nunukan District and Tulin Onsoi Sub-district

The Nunukan District is located in the most northeastern part of North Kalimantan Province (East Kalimantan has been separated from North Kalimantan since 2012). It covers approximately 14,264 km^2 and is situated between 3°15’00”-4°24’55” north latitude and 115°33’30”-118°30’54” east longitude. The area of Nunukan District consists of two parts. The first part is situated on the mainland of Borneo, a long and narrow area stretching from the Sulawesi Sea in the East to deep into the central Borneo Mountains in the West. It borders the Districts of Malinau and Bulungan to the South, and Malaysia’s Sabah and Sarawak to the North and West. The second part is the island known as Nunukan, where the district capital is located. It has a surface area of 1,586.77 km^2 or 11.9% of the total area of the district. This island lies adjacent to Malaysia's Tawau city. Its regional position, in the borderlands of Indonesia and Malaysia, makes Nunukan District an important strategic area for inter-state traffic (Wahyuni 2011).

The Nunukan District was formed in 1999 when the large Bulungan District was split and sub-divided into five sub-districts. In 2008, Nunukan District was divided into nine sub-districts, i.e. Krayan, South Krayan, Lumbis, Sebuku, Sembakung, Nunukan, South Nunukan, Sebatik, and West Sebatik. Finally, since August 2011, Nunukan District has 16 sub-districts [Figure I-2a]. The Tulin Onsoi Sub-district, one of the new sub-districts has been split from Sebuku Sub-district [Figure I-2b]. It is located in the north part of the Nunukan District. Administratively, Tulin Onsoi Sub-district is divided into 12 villages that are located along the Tulid River. The central administration of Tulin Onsoi Sub-district is located in Sekikilan.

The present study includes ten villages located along the Tulid River: Balatikon, Tau Baru, Tinampak II, Tinampak I, Salang, Naputi, Tembalang, Kalunsayan, Sekikilan, and Semunad. These villages are known to be visited by Bornean elephants. The majority of inhabitants of the Sebuku Sub-district belongs to the Agabag, an indigenous ethnic group. The human population in Tulin Onsoi Sub-district is unevenly distributed. The total human population number in this district is estimated at 4,832 people with 1,142 family heads (2010). The most densely populated village is Makmur with 1,591 people. Makmur and Sanur are transmigration villages which were established after the estates entered the area.

The Tulin Onsoi Sub-district is currently one of the main target areas of the provincial oil palm plantation program (Bureau of Estate of East Kalimantan 2015) [Figure 1-2b]. Two main oil palm estates are operating in the Tulin Onsoi Sub-district: the *Karangjoang Hijau Lestari* (*KHL*) Group and the *Tirtamadu Sawit Jaya* (*TSJ*) Group, with respectively 20,000 and 7,892.18 ha of oil palms (Bureau of Estate of East Kalimantan 2015). The predominant livelihood strategy in the Tulin Onsoi Sub-district is small-scale subsistence farming, nowadays complemented with wage labor for oil palm companies. Crops grown in the area include cassava (*Manihot esculenta*), the staple food crop of Dayak Agabag, rice (*Oryza sativa*), corn (*Zea mays*), legumes, coconut (*Cocos nucifera*), banana (*Musa* spp.), sugar cane (*Saccharum officinarum*), vegetables, fruits, and spice trees. Most oil palm is cultivated in a so-called Nucleus Estate and Smallholder (NES) scheme. In this scheme, villagers transfer a proportion of their land to an oil palm company in return for financial compensation (Sheil *et al*. 2009; Rist *et al*. 2010). In other cases, people sell their land directly to a company.

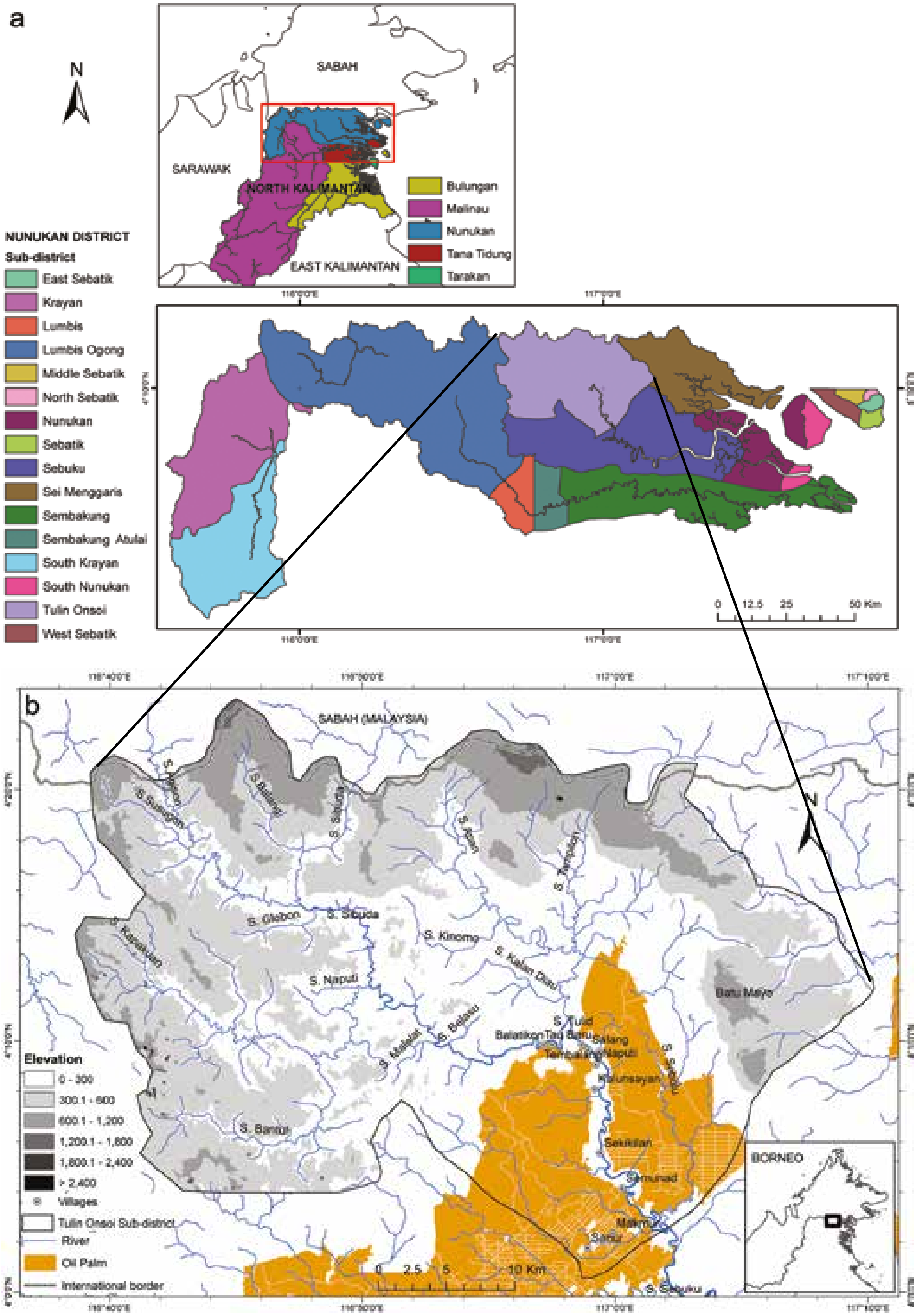


Figure 1-2
Map of North Kalimantan Province, with Nunukan District and Tulin Onsoi Sub-district

1.2.2 Sebuku forest

The Sebuku forest is located inside the Sebuku Sembakung Nature Reserve (SSNR), which was supposed to be the most recent addition to Indonesians list of proposed National Parks since 1998 (Momberg *et al.* 1998; Jepson *et al.* 2002). Designating SSNR as a national park was expected to compensate for the loss of biodiversity-rich habitats in other areas in Kalimantan, due to the wide range of biodiversity components that are contained inside and which characterize the lowland ecosystems of northeastern Borneo. Compared to other areas in East Kalimantan province, the SSNR has some unique features in terms of wildlife abundance and supports viable populations of large mammal species (Payne *et al.* 1994; Yasuma 1994; MacKinnon *et al.* 1996; Momberg *et al.* 1998). According to survey efforts conducted by WWF (World Wide Fund for Nature) Indonesia in 2000, there are 44 species of mammals, of which 22 are protected by Indonesian law (Jepson *et al.* 2002; WWF 2013). Some of them are endemic to Borneo island, e.g. Proboscis Monkey (*Nasalis larvatus* ssp. *orientalis* Chasen 1987), Bornean Yellow Muntjac (*Muntiacus atherodes* Groves & Grubb 1982), Bornean Gibbon (*Hylobates muelleri* ssp. *funereus* I. Geoffroy 1850), Grey Leaf Monkey (*Presbytis hosei* ssp. *sabana* Thomas 1893), Maroon Leaf Monkey (*Presbytis rubicunda* ssp. *ignita* Dollman 1909) and Bornean Clouded Leopard (*Neofelis diardi* ssp. *borneensis* Wilting *et al.* 2007) (Jepson *et al.* 2002; WWF 2013; IUCN 2016).

Jepson *et al.* (2002) nevertheless pointed out several constraints in relation to the establishment of the Sebuku forest that could create potential problems in the future: (1) park establishment would require the government to resolve the issue of illegal logging across the Indonesian border from Malaysia, which may be difficult politically, e.g. since the Indonesian military proposed to clear the forest near the border with Malaysia for security reasons; (2) the Sebuku forest covers lowlands areas with a potential for conversion to estate crops; (3) the power of state and central government has declined markedly since the fall of the New Order regime and previous conditions that implied provincial and district administrations to follow central government policies and directives, are no longer guaranteed. In fact, the proposal has been declined and most of the Sebuku forest is currently unprotected and listed as 'production forests' under the Indonesian land-use planning regulations.

The Sebuku forest shares its western boundary with the Kayan Mentarang National Park, which is characterized by an undisturbed sequence of all major habitats in Kalimantan, ranging from mangrove tidal swamp forests, freshwater swamp and peat swamp forests, riverine forests and lowland forests of Sebuku Sembakung up to hill and mountain habitats of Kayan Mentarang. The western area of the Sebuku watershed comprises forested hills with limestone areas and outcrops. The central part of the forest is a good quality lowland forest including flat lowland plains supporting the only known elephant population in Kalimantan.

A very large part of the Sebuku forest has elevations lower than 100 m above sea level (asl). The entire western section consists of lowlands and marshlands with very low elevations (Wulffraat 2006). Towards the East and upper North, elevations start to rise gradually. The northern boundaries are formed in most locations by high mountains, or otherwise by complexes of connecting hills. These hills have elevations ranging from less than 100 m to more than 500 m altitude, with several high peaks of more than 700 m altitude. The slopes of this hill complex are generally very steep (MacKinnon *et al.* 1996; Jepson *et al.* 2002). The international border between Sabah and Indonesia does not always follow the watershed. Several tributaries of the Sebuku River have their origin in Sabah. The Agison river, for instance, has more than 20 km of its upper course flowing in Sabah. The westernmost high altitude area is covered by the Mayo Hills, which. form the eastern boundary of the major elephant habitat. The river valleys of, from East to West, the Sibulu, Tampilon, Apan, Agison, and Kapakuan Rivers are rather flat and have low elevations, stretching far into the mountains and hills. The river plains of the Tulid river, the main river in the Sebuku forest, and the surrounding landscape have low elevations stretching for tens of kilometers. The foot slopes of the western mountain complex rise only gradually with little steepness. The western mountain complex consists of wide slope areas, gradually connecting to central mountain ridges. The elevations of the wide slope areas are generally below 500 m asl, while the central mountain ridges are considerably higher, reaching elevations well above the 1000 m asl. The lower slopes of the northern mountains are generally steeper than in the West. Upper slopes are wider areas with elevations above 700 m (Wulffraat 2006).

The Sebuku lowland forest used to be one of the most species-rich forests of Borneo (MacKinnon *et al.* 1996; Jepson *et al.* 2002), but has been logged to a great extent in the 1990s. Between 1996 and 2003, primary forest decreased from 915,183 ha to 697,695 ha; a 24% decline in 7 years (Lusiana *et al.* 2005; Widayati *et al.* 2005). The proportion of trees from families such as the Euphorbiaceae, Moraceae, and Lauraceae is higher in these logged forests than in primary forest (MacKinnon *et al.* 1996). The herbaceous layer is also more pronounced in the logged areas. There are still areas of primary hill Dipterocarp forests in the upper North and West (Wulffraat 2006) and riverine forests stretching in narrow strips along the larger streams and rivers. The vegetation is typically composed of dominant *Dipterocarpus oblongifolius* and several other species that are more or less restricted to this habitat. Degraded riverine vegetation in the lowlands is often dominated by *Saccharum* grasses (Wulffraat 2006). The canopy height in this forest ranges from 20 to 40 meters, but giant emergent trees can reach a height of more than 60 meters. Densities of non-woody plants on the forest floor depend largely on light penetration. In primary forests this group of plants is usually less abundant because the closed canopy prevents light from reaching the forest floor (Whitmore 1998).

1.3 Research objectives and research questions

As is the case in other areas of the elephant's distribution range, human-elephant conflicts (HECs) in the Tulin Onsoi Sub-district are associated with land use changes (Wulffraat 2006). Local land use planning policies, however, are currently mostly driven by immediate economic gains, rather than by sound management approaches aimed at social equity, environmental sustainability, and protection of wildlife habitat (Wich *et al.* 2012; Wollenberg *et al.* 2007). The present research will provide a basis for defining elephant conservation priorities by identifying the quantity of available suitable habitat in the study area (see Figure 1-3) and studying relations between elephant behavior and human response.

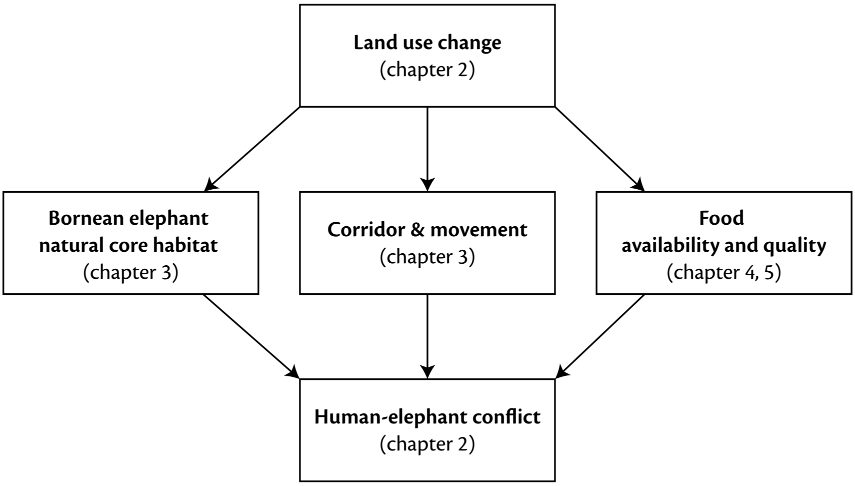


Figure 1-3
The conceptual research framework of impact of land use changes on the human-elephant conflict in relation to feeding ecology and movements of the Bornean elephant in the Sebuku forest

The main objective of my study is to investigate the impact of land use changes on HEC in relation to the feeding ecology and movements of the Bornean elephant in the Sebuku forest in North Kalimantan, Indonesia. The main questions of this research are:

1. What are the patterns and trends in land use change in relation to HEC? [Chapter 2]
2. How does HEC influence the local people's perceptions on and attitudes towards the conservation of the Bornean elephant? [Chapter 2]
3. What is the extent of Bornean elephant movement in relation to habitat between Sabah in Malaysia and the Sebuku forest in North Kalimantan? [Chapter 3]
4. Which foraging strategies could be identified for Bornean elephants in relation to major food plants in their diet? [Chapter 4]
5. What is the quality of wild food plants compared to crops? [Chapter 4 and Chapter 5]
6. Which compounds in Bornean elephant diets determine dietary preference? [Chapter 5]

1.4 Outline of this thesis

The present thesis describes the results of research on the impact of land use changes on human-elephant conflicts (HECs), and on movements and feeding ecology of the Bornean elephant in the Sebuku forest in North Kalimantan, Indonesia. Chapter 2 describes the most prominent land-use changes in the area and investigates patterns and trends in HEC. Chapter 2 further analyzes how HEC is influencing local people's perception and attitudes towards the conservation of the Bornean elephant. Chapter 3 covers the results of three sequential approaches [interviews, field surveys/observations and least cost (LC) modeling] on the identification of Bornean elephant movements and use of corridors as part of the Sebuku forest habitat and provides an assessment of the impact of future land-use on these corridors. The diet of Bornean elephants is described in Chapter 4. Chapter 4 and 5 present the results of a comparison of nutritive value between crops and wild food plants. In chapter 5, I also investigate the use of different methodological approaches to analyze non-essential and possible secondary compounds in elephant diets which may be associated with the dietary preferences of Bornean elephants. Chapter 6, finally, summarizes the importance of available Bornean elephant habitat in the Sebuku forest of North Kalimantan in terms of feeding ecology and movements and includes recommendations for habitat management for elephant conservation in relation to existing land use.

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2

Rapid expansion of oil palm is leading to human-elephant conflicts

Submitted as
"Rapid expansion of oil palm is leading to the human-elephant conflict in North Kalimantan Province of Indonesia" to Tropical Conservation Science, 25 February 2017 (manuscript number: TCR-17-0020)
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Abstract

Crop raiding by Bornean elephants (*Elephas maximus borneensis*) is increasing rapidly in North Kalimantan, mainly due to a rapid conversion of swiddens and secondary forest into oil palm plantations. In the Tulin Onsoi Sub-district, the area used by oil palm plantations has grown from 3,302.71 ha in 2001 to 21,124.93 ha in 2014. Particularly from 2006 to 2010 the area covered by oil palm plantations increased rapidly (418%). Preventing further encroachment of, oil palm plantations in elephant habitat and regulating land-use change are keys to stop further population declines and make way for the re-establishment of a viable elephant population in Kalimantan. Crop raiding is a strong determinant of the local people's perceptions of elephants, and risks eroding cultural values that enabled people to coexist with elephants. People's perception and attitude towards elephants are generally negative. Nevertheless, negative attitudes have not led to cases of retaliation in the Tulin Onsoi Sub-district. Public education at the community level could strengthen cultural values and foster coexistence between humans and elephants.

Keywords

Bornean elephant, North Kalimantan, oil palm, human-elephant conflict, crop raiding, human-elephant coexistence

2.1 Introduction

Historically, elephants have played an important role in cultural heritage and local traditions. In local stories, elephants would, for instance, lead people that are lost in the forest back to their homes. Elephants are said to be God's creation and regarded as guardians of humans. Elephants are often called grandparents ('*yaki*' for male or '*yadu*' for female), not only as a sign of respect but also because people believe that they descended from elephants. Attempts to observe elephants in the wild are nevertheless considered to be disrespectful, which proved to oppose a few challenges during the present research.

Changes in land use have however brought fierce competition for space and resources between people and wildlife in Southeast Asia (Kinnaird *et al*. 2003; Nyhus & Tilson 2004; Clements *et al*. 2010), and elephants are particularly vulnerable to land use change (Leimgruber *et al*. 2003; Hedges *et al*. 2005; Rood *et al*. 2008; Rood 2010; Saaban *et al*. 2011). On the Indonesian island of Sumatra, the development of oil palm (*Elaeis guineensis*) and rubber plantations has forced elephants to increasingly compete with humans for available space (Nyhus *et al*. 2000; Rood 2010; Sitompul *et al*. 2010; Sitompul 2011). The human-elephant conflict (HEC) may result in injury and death of humans, damage to crops and infrastructure, and lead to negative attitudes towards elephants among local people (Nyhus *et al*. 2000; Fernando *et al*. 2005; Hedges *et al*. 2005).

Land use change in Borneo is mainly driven by the expansion of large-scale oil palm plantations (Sheil *et al*. 2009; Wicke *et al*. 2011; Gunarso *et al*. 2013). Oil palm plantations in East Kalimantan[1] increased from 116,887.5 ha (since 2000) to 1,102,632 ha (since 2013) (East Kalimantan Provincial Government 2015). The Sebuku area, a part of Tulin Onsoi Sub-district [Figure 2-1], is currently one of the main target areas of the provincial oil palm plantation program (Bureau of Estate of East Kalimantan 2015). Two main oil palm estates are operating in the Tulin Onsoi Sub-district: the *Karangjoang Hijau Lestari* (*KHL*) Group and the *Tirtamadu Sawit Jaya* (*TSJ*) Group, with respectively 20,000 and 7,892.18 ha of oil palms (Bureau of Estate of East Kalimantan 2015). Most oil palm is cultivated in a so-called Nucleus Estate and Smallholder (NES) scheme. In this scheme, villagers transfer a proportion of their land to an oil palm company in return for financial compensation (Rist *et al*. 2010). In other cases, people sell their land directly to a company.

1 East Kalimantan has been split to North Kalimantan Province since 2012.

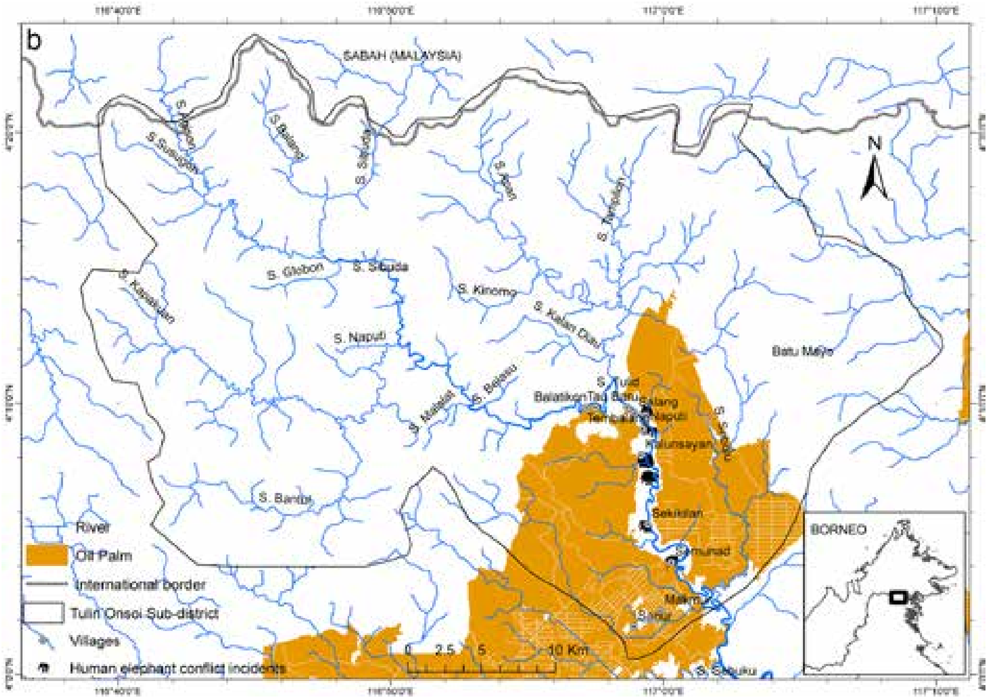

Figure 2-1
Map of the study area showing the Tulin Onsoi Sub-district, North Kalimantan Province and the area that has been allocated for oil palm plantations where human-elephant conflict incident exists

The Asian elephant has a specific significance in the region's history, religion and folklore, which makes it a potential flagship species for forest conservation (Nyhus *et al.* 2000; Fernando *et al.* 2005). However, HEC can undermine these cultural values and erode local support for conservation efforts (Hedges *et al.* 2005). In most cases, the total costs of crop raiding are relatively low, but its impacts on individual farmers can be significant (Naughton-Treves 1998). This chapter identifies patterns and trends in HEC in the Tulin Onsoi Sub-district, specifically in relation to the rapid development of oil palm plantations. The chapter provides a description of current land use changes and analyzes how HEC influences local people's perceptions of and attitudes towards the conservation of the Bornean elephant.

2.2 Methods

2.2.1 Study area

This study was conducted in the Tulin Onsoi Sub-district (split from the Sebuku Sub-district since 2011), which is part of the Nunukan District of North Kalimantan Province (Figure 2-1). The Sebuku forest is one of the most species-rich forests of Borneo in terms of botanical diversity (Jepson *et al.* 2002). However, the forest was logged in the 1990s. Between 1996 and 2003, primary forest decreased from 915,183 ha to 697,695 ha; a 24% decline in 7 years (Lusiana *et al.* 2005; Widayati *et al.* 2005).

This study focused on ten villages in the Tulin Onsoi Sub-district, inhabited by indigenous Agabag Dayak: Balatikon, Tau Baru, Tinampak II, Tinampak I, Salang, Naputi, Tembalang, Kalunsayan, Sekikilan, and Semunad [Figure 2-1]. Around 3,650 people inhabit these ten villages (Profil Daerah Kecamatan Sebuku 2013). The predominant livelihood strategy in these villages is small-scale subsistence farming, nowadays complemented with wage labor for oil palm companies. Crops grown in the area are cassava (*Manihot esculenta*), the staple food crop of Dayak Agabag, rice (*Oryza sativa*), corn (*Zea mays*), legumes, coconut (*Cocos nucifera*), banana (*Musa* spp.), sugar cane (*Saccharum officinarum*), vegetables, fruits, and spice trees.

2.2.2 Data collection and analysis

Land use and land cover change

Remote sensing techniques were used for quantifying land use and land cover changes. Both ground truthing (in February-April 2014 and March-April 2015) and 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) were used for this purpose. Land cover images for the years 2001, 2006, 2010 and 2014 served as a reference to evaluate oil palm land coverage.

We used a land use classification approach based on multistage visual techniques, using ER Mapper v. 7.1 and ArcGIS v. 10.2.2. Following the land use categories defined by Indonesian Ministry of Forestry (MoFRI 2008), ten land-cover categories were identified: upland forest, shrubland, oil palm plantation, dry cultivated land, road network, water bodies, swamp forest, open area, settlements and mixed tree crops (MoFRI 2008). Change matrices were created by comparing maps from different timelines pixel by pixel to identify small scale changes. Patterns in land use change in the study area were also determined through interviews with village heads, traditional leaders, and village elders in the ten villages of Tulin Onsoi Sub-district.

HEC survey

Several social scientific methods were used to assess HEC, and document local people's perceptions of and attitudes towards elephants [Table 2-1]. Household surveys were carried out between January and April 2013 using a pre-structured questionnaire [Table 2-2]. Questions were written and asked in Bahasa Indonesia. The presented results only include interview data for which the respondents have given their consent. Surveys consisted of a systematic sample of 214 households in ten villages of Tulin Onsoi Sub-district. Between 31.7% and 84.8% (average = 56.8%) of the households in the ten villages were sampled. The Agabag represent 77% of all respondents.

Table 2-1
Data collection techniques used for the HEC assessment in the Tulin Onsoi Sub-district

Emphasis of data collection	Method
Village description, settlement history and land use	Interviews with village heads and traditional leaders
Traditional cultural knowledge and value about elephant	Interviews with traditional leaders and village elders, using a snowball sample
Socio-economic and demography	Household survey (systematic sample) and documentation from village heads
Knowledge of and attitudes towards elephants, and information about HEC	Interviews of c. 30 min with one individual (18 years or older) in each household

*Modified from Chartier *et al*. (2011), Nyhus *et al*. (2003), and Sheil *et al*. (2006)

For yes/no questions [Table 2-2, questions no. 12-14], a logistic regression analysis was performed (Freedman 2009; Soto-Shoender & Main 2013), with the ethnic group, age, educational background, year of residence, and prior elephant crop damages as independent variables. The odds of an affirmative answer were modeled to each question for all categories of respondents. Statistical significance was calculated using the Wald χ^2 statistic. Statistical significance was calculated at $P < 0.05$ for all analyses using SPSS v. 23.0.

Table II-2
Summary of the questionnaire used in the interview survey

1. Have you seen elephants? Directly (direct sightings, signs) or indirectly (heard from others)?
2. When and where did you see elephants?
3. Did you recognize elephant's sex?
4. Did elephants ever visit your crop fields?
5. How did you respond?
6. Since when and how often have your crop fields been frequented by elephants?
7. What crops were raided by elephant? What kind of damage did they cause?
8. What could be the reasons for elephants to enter your crop fields?
9. Did elephants cause any other problems?
10. What could cause the decrease of elephant population?
11. How do you feel about elephants?
12. Do you think elephants and humans can live together in harmony? Yes/No/ Don't know; Why?
13. Do you know that elephants are protected by local customs or rights? Yes/ No; How does it work?
14. Do you know that elephants are protected by Indonesia law? Yes/No; How does it work?

2.3 Results

2.3.1 Land use changes

The multi-temporal analysis spanning from 2001 to 2014 shows a rapid expansion of industrial-scale oil palm plantations in the Tulin Onsoi Sub-district [Figure 2-2a-d]. From 2006 to 2010, the area covered by oil palm plantations increased significantly (418%) [Table 2-3]. 77% of these oil palm plantations were converted from the upland forest.

Table II-3
Land cover classes and their surface area in Tulin Onsoi Sub-district from 2001 to 2014 [Total land size approximately 153,000 ha]

Land cover class (ha)	2001	2006	2010	2014
Upland forest	144,526.96	146,597.02	128,713.09	126,520.57
Shrub land	1,771.99	760.60	3,899.94	2,451.65
Mixed tree crops	2,340.22	–	–	–
Dry cultivated land	–	1,500.77	795.64	1,322.68
Oil palm plantations	3,302.71	3,573.50	18,516.89	21,124.93
Other	1,442.11	1,018.71	1,137.53	1,583.60

Description and landscape context (Gunarso *et al*. 2013; MoFRI 2008):
Upland forest: natural forest, highly diverse species and high basal area, but in this study, upland forest actually represents disturbed forest, with evidence of logging.
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.
Mixed tree crops: mosaic of cultivated and fallow land with canopy cover between 5-60%.
Dry cultivated land: Open area characterized by herbaceous vegetation intensively managed for row crops; associated with road networks and human settlements.
Oil palm plantations: 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.
Other: swamp forest, bare soil, settlements, and water bodies

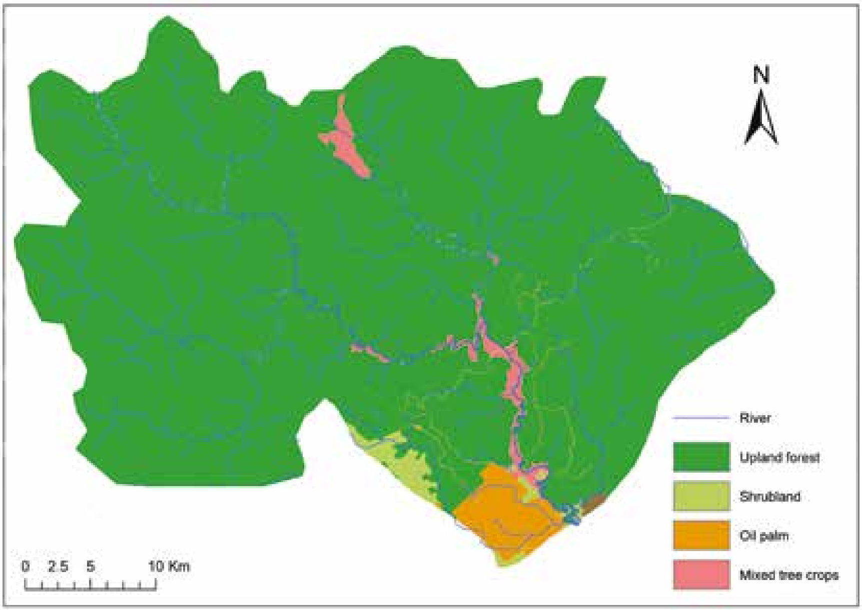

Figure 2-2a
2001 land cover map of Tulin Onsoi Sub-district

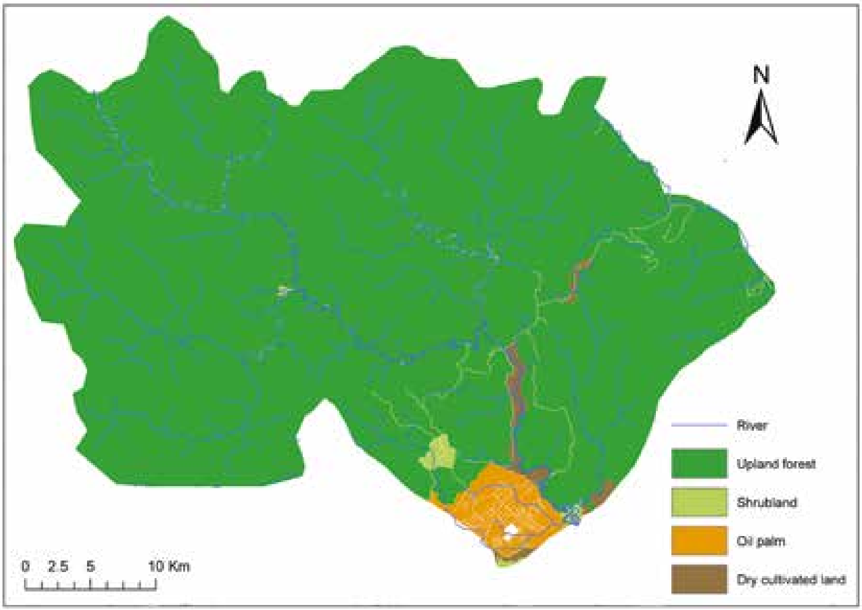

Figure 2-2b
2006 land cover map of Tulin Onsoi Sub-district

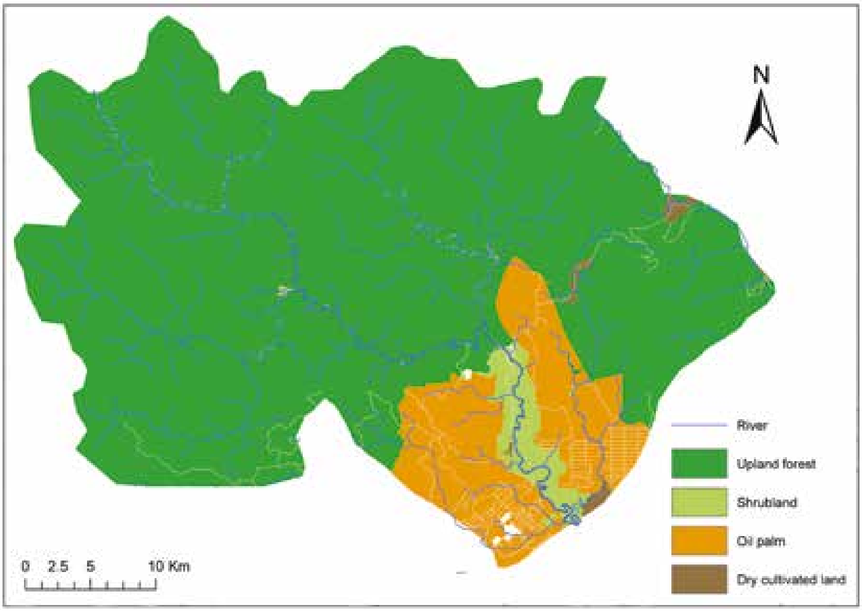

Figure 2-2c
2010 land cover map of Tulin Onsoi Sub-district

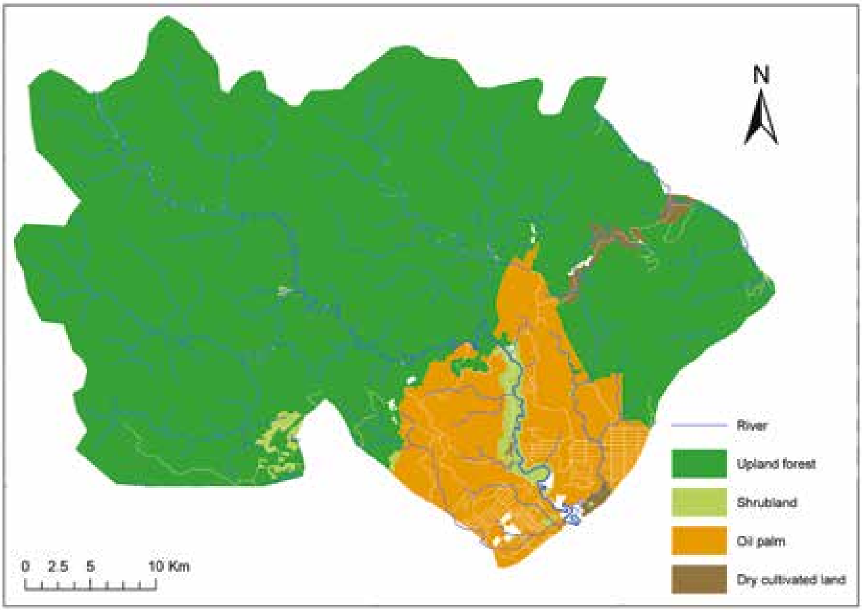

Figure 2-2d
2014 land cover map of Tulin Onsoi Sub-district

In addition to the intensification of several forms of land use [Table 2-3], a general shift in cultivation practices was observed. Between 2001 and 2006, traditional slash-and-burn agriculture adjacent to rivers and streams (the 'mixed tree and crops') was gradually replaced by 'dry cultivated land' which is characterized by an open area with herbaceous vegetation intensively managed for row crops and associated with road networks and human settlements. This was confirmed through our interviews; 52.7% of the respondents indicated that they had changed their traditional farming system to practice sedentary farming instead, and had integrated oil palm in their farming systems at the time of the interview, compared to 6.6% before 2005. The majority, however, transferred their land to the oil palm company in the NES scheme (32.5%) or sold their land directly to the company (14.8%).

The cultivation of important food crops has decreased, such as cassava (from 64.3% to 43.4%), legumes (28.1% to 13.8%), vegetables (17.1% to 9.1%) and rice (21.4% to 7.1%). Insufficient revenue from their traditional crops was given as the main reason for this general decline (54.7%). People stressed they needed to earn more money, and were forced to look for alternative incomes. Other reasons mentioned were government incentives, including local cultivation schemes that provide with seeds and fertilizers to farmers (23.1%); estate incentives that offer a profit-sharing scheme (7.4%); and the proximity to an oil palm mill (7.4%). Some disincentives were mentioned as well, specifically crop raiding by elephants (7.4%).

2.3.2 Elephant sightings and crop raiding

70.6% of the respondents had seen elephants in the wild at some time in their lives. 14.8% had only ever seen indirect evidence of their presence, i.e. tracks, trails, dung, or damage caused by elephants; 14.6% had never seen an elephant. A single individual was observed surrounding village areas in most cases (68.8%) confirming that only solitary bulls raid oil palms [Figure 2-3]. Villagers indicated to observe two peak periods during which elephants visit their village; February-March and August-October. One or two family groups were reported in the vicinity of three main rivers: Apan, Agison and Sibuda in the Sebuku Forest [Figure 2-1]. There is no information of elephant groups that move south of the Tulid River, where most villages are located.

Figure 2-3
Two solitary males of Bornean elephant were spotted during the fieldwork in Semunad village, the Tulin Onsoi Sub-district (left) while feeding on wild bananas, and while crossing the river (right) [Photos by Rachmat B. Suba (author) (left) and Arie Prasetya (right)]

According to the respondents, elephants rarely visited the cultivated lands surrounding the villages before the start of the oil palm program in 2002. Since then, the number of crop-raiding incidents has consistently increased [Figure 2-4]. Out of 215 elephant sightings, 49.3% occurred in villages with oil palm plantations (Tembalang, Kalunsayan, Sekikilan, and Semunad) and 18.6% occurred in villages that are surrounded by other crop types or natural habitat (Salang, Naputi, Tinampak I, Tinampak II, Tau Baru, and Balatikon). According to the respondents (n = 176), oil palm is by far the most frequently raided crop by elephants (59%). When villagers (n = 213) were asked about the reason why they thought elephants enter their fields, 51.3% would refer to some kind of habitat loss, e.g. 'elephants are looking for food'; 'the forest has been depleted'; and 'the forest has been destroyed by the oil-palm estates'.

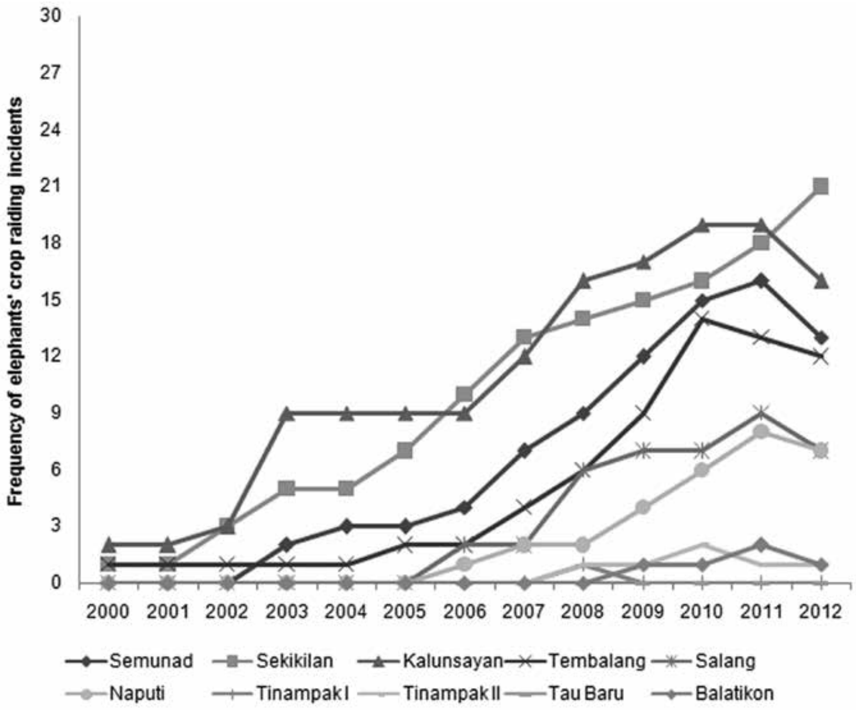

Figure 2-4
Reported frequency of elephants' crop-raiding incidents in the ten villages of Tulin Onsoi Sub-district based on interviews

2.3.3 Attitudes towards elephants

43.2% of the respondents expressed an outright negative attitude towards elephants, with 'loss of crops' (15.5%) as the main motivation for this negative attitude. 79% of all respondents say that oil palm expansion is the main cause of HEC. About 21% also mention logging operations in the area as a cause of HEC. They claim that logging operations have destroyed some of the natural salt licks in the area and disrupted elephant movements in the Sebuku Forest.

Table 2-4
Percentage of responses (yes, no and don't know) to the question whether elephants and humans can live together in harmony and the elaborated explanation or requirement

Response	Percentage of responses (n=213)
Yes	**32.4**
Folklore (ancestor): 'we need each other'; 'we are related'	9.0
'But elephants should be tamed'	7.1
'If they cause no trouble'	5.7
No further comments; don't know; other	5.4
'They should be respected'; 'if forest destruction stops'	5.2
No	**43.2**
Elephants damage the crops	15.5
People are scared of elephants	11.3
Elephants are wild animals, not pets	8.5
No further comments/other	7.9
Don't know	24.4

32.4% of the respondents believe humans can live in harmony with elephants but only under certain conditions [Table 2-4]. 43.2% believe coexistence is difficult as elephants raid crops. Affirmative answers to our questions regarding human-elephant coexistence are significantly influenced by crop damage (P = 0.008). The odds of affirmative answers to whether elephants and humans can live together in harmony were 2.53 times higher for people whose fields were not damaged by elephants [Table 2-5].

73.8% of the respondents answered 'yes' to the question 'do you know that elephants are protected by local customs or rights?' Dayak Agabag are significantly more knowledgeable on elephant protection legislation than other ethnic groups (P = 0.004 and P = 0.02, respectively) [Table 2-5]. The odds of an affirmative answer to whether they knew about local customs or rights and laws for elephant protection were 3.84 and 4.80 times higher, respectively, for Dayak Agabag as opposed to other ethnic groups. Although the majority of respondents are supportive of elephant conservation in the Tulin Onsoi Sub-district, they claimed that it is currently not directly benefitting them. Most respondents acknowledge that elephants are an integral part of their culture, but people also mention that elephants are causing problems, e.g.: 'the elephants are giving us a hard time nowadays' and that these problems should be tackled by government: 'If government wants to protect elephants, it should implement measures to prevent them from raiding our crops.'

Table II-5

Logistic regression analysis, with Wald χ^2 statistical test, for answers to survey questions 12, 13 and 14 [N (total respondents/households) = 213; n = affirmative answer]

Question/predictor variable	Test statistics					
	Estimate	SE	$\chi2$	df	P	Odds ratio estimate
12 Do you think elephants and humans can live together in harmony? (n = 69)						
Ethnic group (n = 46 Dayak Abagag, n = 23 other)	-0.67	0.53	1.57	1	0.21	0.51
Age	-0.001	0.02	0.002	1	0.97	0.51
Educational background (n = 17 with no education)						
Basic education (n = 37)	0.78	0.54	2.14	1	0.14	2.19
Further education (n = 15)	0.45	0.43	1.12	1	0.29	1.57
Year of residence	0.003	0.17	0.03	1	0.87	1.00
Prior elephant crop damage (37 absent, 32 present)	0.93	0.35	7.06	1	0.008	2.53
13 Do you know that elephants are protected by local customs or rights? (n = 156)						
Ethnic group (n = 131 Dayak Abagag, n = 25 other)	1.35	0.46	8.47	1	0.004	3.84
Age	0.008	0.02	0.22	1	0.64	1.01
Educational background (n = 34 with no education)						
Basic education (n = 88)	-0.12	0.49	0.06	1	0.80	0.88
Further education (n = 34)	0.37	0.39	0.89	1	0.35	1.45
Year of residence	0.00	0.02	0.00	1	0.99	1.00
14 Do you know that elephants are protected by Indonesia law? (n = 192)						
Ethnic group (n = 154 Dayak Abagag, n = 38 other)	1.57	0.65	5.92	1	0.02	4.80
Age	0.002	0.03	0.007	1	0.93	1.00
Educational background (n = 45 with no education)						
Basic education (n = 105)	0.87	0.73	1.44	1	0.23	2.39
Further education (n = 42)	0.88	0.54	2.59	1	0.11	2.40
Year of residence	-0.01	0.02	0.22	1	0.64	0.99

2.4 Discussion

Negative perceptions of elephants are mainly caused by crop damage. This is supported by Kellert *et al.* (1996) who mention that attitudes towards wildlife may be influenced by past and present interaction. In line with this, human and elephant coexistence in the Tulin Onsoi Sub-district was historically enforced through traditional shifting cultivation systems that allowed for resource partitioning (see Fernando *et al.* 2005; Kumar *et al.* 2010; Pastorini *et al.* 2013). Between 2001 and 2014, the total land area covered by oil palm plantations in the Tulin Onsoi Sub-district increased more than 5 times, from 3,302.71 ha in 2001 to 21,124.93 ha in 2014, leading to increased elephant crop-raiding incidents. As a result, HEC has become a significant problem in the Tulin Onsoi Sub-district and attitudes towards elephants have become negative, despite the deeply rooted respect for elephants throughout history. Efforts to save the elephant and its habitat in the future depend on a local support (Nyhus *et al.* 2000; Fernando *et al.* 2005). HEC can hinder efforts to save the species (Infield 1988), although negative attitudes towards elephants have not yet led to cases of retaliation in the Tulin Onsoi Sub-district. People do worry about the costs associated with damage by elephants and are frustrated about the lack of measures that would protect them from the 'government's animals'.

Providing the needs of elephants from inside their habitat requires restoring habitat and food resources (Oelrichs *et al.* 2016). Therefore, to effectively protect the Bornean elephants and to avoid more severe HEC, it is, therefore, essential to prevent further expansion of oil palm plantations. Improving oil palm yield through better management practices could reduce pressure for expansion (Sheil *et al.* 2009). Maintaining 'buffer zones' between forested areas and human agricultural fields is suggested to aid in the mitigation of HEC (Rood *et al.* 2008; Perera 2009). In the Tulin Onsoi Sub-district, such 'buffer zones' have been assigned at 100 m buffer on each side of the Tulid River (according to the Presidential Decree No. 32/1990 about Management of Reserved Areas). Although mostly degraded, the shrublands and secondary forests of these buffer zones contain a variety of potential food plants for elephants, such as bamboo, wild bananas *Musa borneensis* and grasses *Saccharum spontaneum* (personal observation) [Figure 2-5]. Such plant species could thus serve as 'lure' plants (Nyhus *et al.* 2000) to switch elephants' attraction from raiding agricultural fields. Local conflict mitigation efforts should, therefore, include management of these buffer zones, thereby ensuring that any type of cultivation will be prohibited in such areas, although complicating factors linked to Indonesian legislative issues regarding land ownership and compensation would have to be tackled (Fredriksson 2005). While paying compensation could increase the tolerance level of local farmers towards elephants, it is open to considerable abuse (Tchamba 1996). Successful implementation of any compensation scheme entails careful monitoring of the economic value of crop losses by elephants (Zhang & Wang 2003; He *et al*. 2011) to avoid over-estimation of crop damage.

Figure 2-5
Degraded forest landscapes dominated by wild bananas in the Tulin Onsoi Sub-district could benefit elephants living on the forest – non-forest interface [Photos by Rachmat B. Suba (author)]

The timing of crop raiding and its relation to environmental factors are also important considerations in the design of effective short-term strategies to mitigate HEC (Chiyo *et al*. 2005). By knowing this, early warning and vigilant response can be applied in community-based guarding systems to reduce HEC (Hedges & Gunaryadi 2009; Oelrichs *et al.* 2016). Efforts by WWF-Indonesia to deter elephants from crop raiding in the Tulin Onsoi Sub-district using noise cannons made of bamboo filled with carbide [Figure 2-6] have shown promising results and could thus be integrated into future HEC mitigation strategies. Using a special local elephant control team has shown to be effective in minimizing crop damage during elephant visits to village areas in the Sekikilan village (WWF 2011). Although this method is widely used, it requires specialized training and well-regulated night watch shifts to minimize the risks that arise from direct confrontations with elephants.

Fostering cultural values that enable people to live in close proximity to elephants could help to support elephant conservation (Fernando *et al.* 2005). Education as a tool in the prevention of HEC (Zhang & Wang 2003;

Fernando *et al.* 2008; He *et al.* 2011; Jayewardene 2011) could also assist local mitigation efforts. Reinvigorating the local traditional knowledge and perceptions on elephants could at least serve as a basis to reinstate a sense of common responsibility for the protections of elephants.

Figure II-6
Bamboo cannons filled with carbide are used to deter elephants in the Tulin Onsoi sub-district [Source: WWF-Indonesia Kalimantan Program]

2.5 Implications for conservation

Our study shows that crop raiding by elephants is a significant and growing problem in the Tulin Onsoi Sub-district. Effective mitigation measures are urgently required and if local support fails to actually target the villagers' concerns, attitudes toward elephants could become even more negative and fear could turn into frustration. Traditional beliefs and local knowledge values will then no longer protect the elephants.

Preventing further encroachment of oil palm plantations in elephant habitat is a key to stop further population declines and make way for the re-establishment of a viable elephant population in Kalimantan. Hence the Indonesian Government (national and local) assisted by conservation organizations should ensure that policies that regulate land use change are compatible with the conservation of the Bornean elephant. The recently developed 'Conservation Strategy and Action Plan of Bornean Elephants' includes promising ideas on collaborative protection efforts between the regional government and policy makers in the Nunukan District [The 2011 Workshop on Conservation Strategy and Action Plan of Bornean Elephants in Nunukan District].

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3

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

Submitted as "Identifying potential corridors for Bornean elephant *Elephas maximus borneensis* in the Sebuku forest, North Kalimantan Province of Indonesia"
to Oryx, 17 January 2017 (manuscript number: Oryx-17-A-0016)
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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

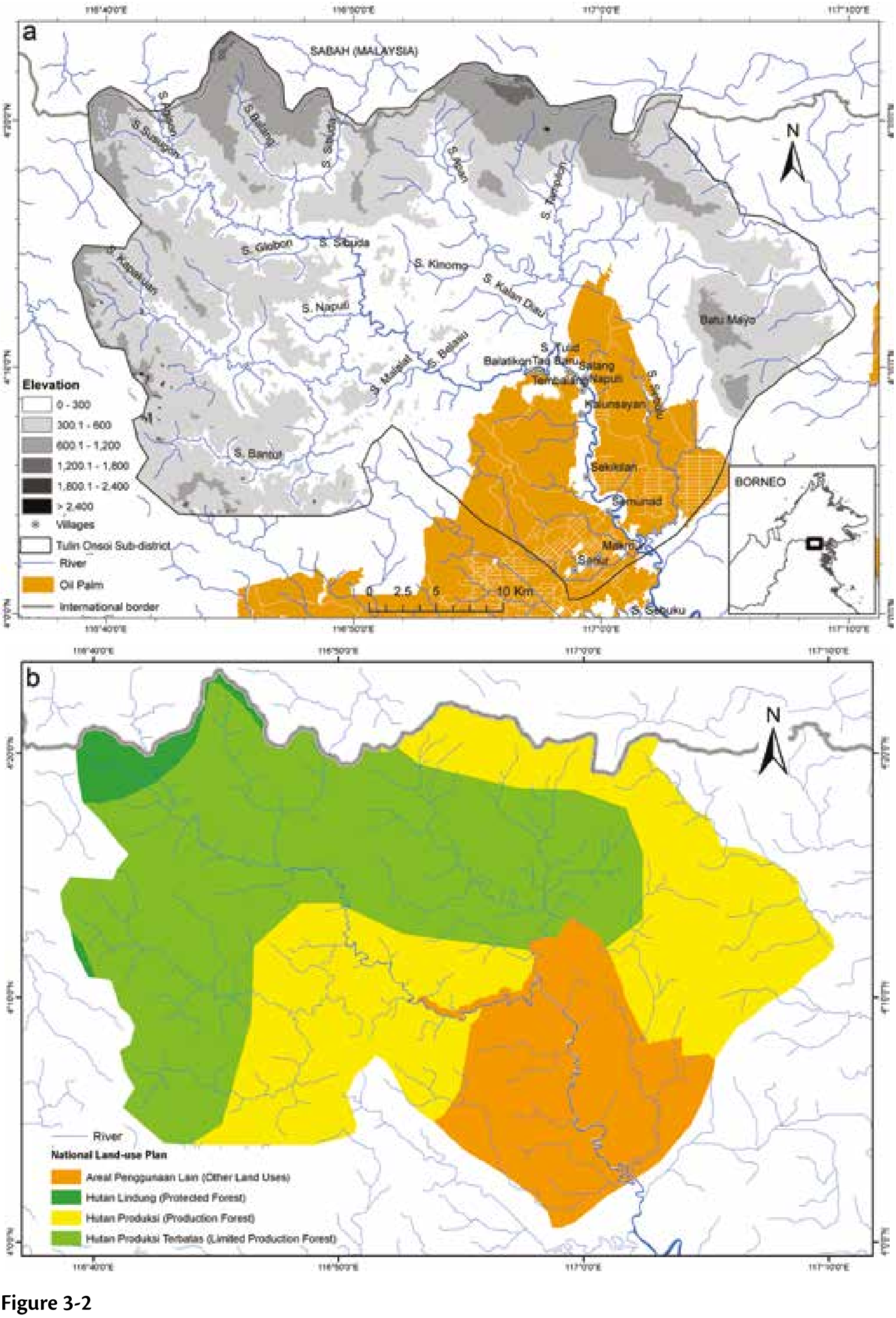

Figure 3-2
Overview of study area showing the location of oil palm plantations and elevation in the Tulin Onsoi Sub-district, North Kalimantan (a) and national land use plan (b)

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).

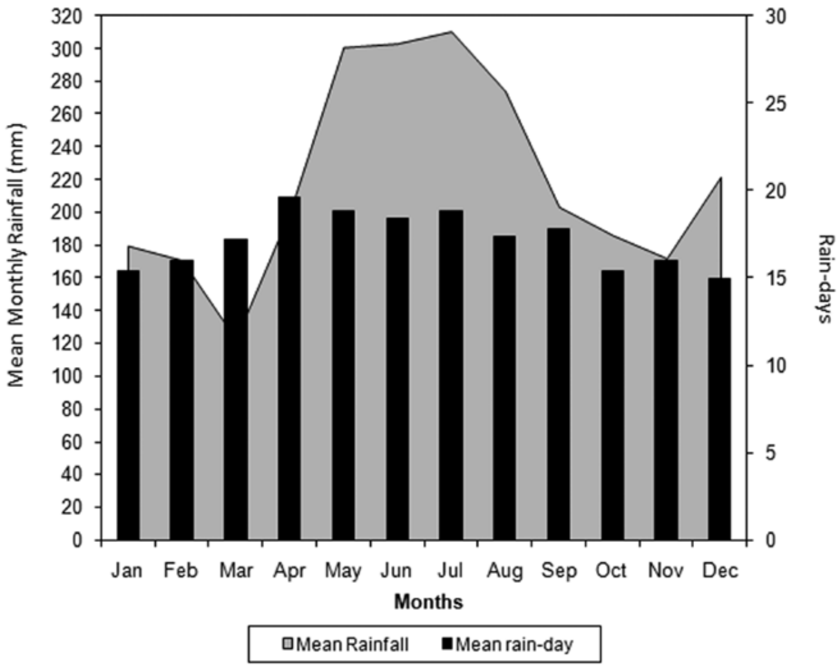

Figure 3-3
Mean monthly rainfall for 2005-2011 and number of rainy days per month (rain-days) in the study area [Source: Meteorology and Geophysics Bureau in Nunukan District, North Kalimantan, 2014]

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.

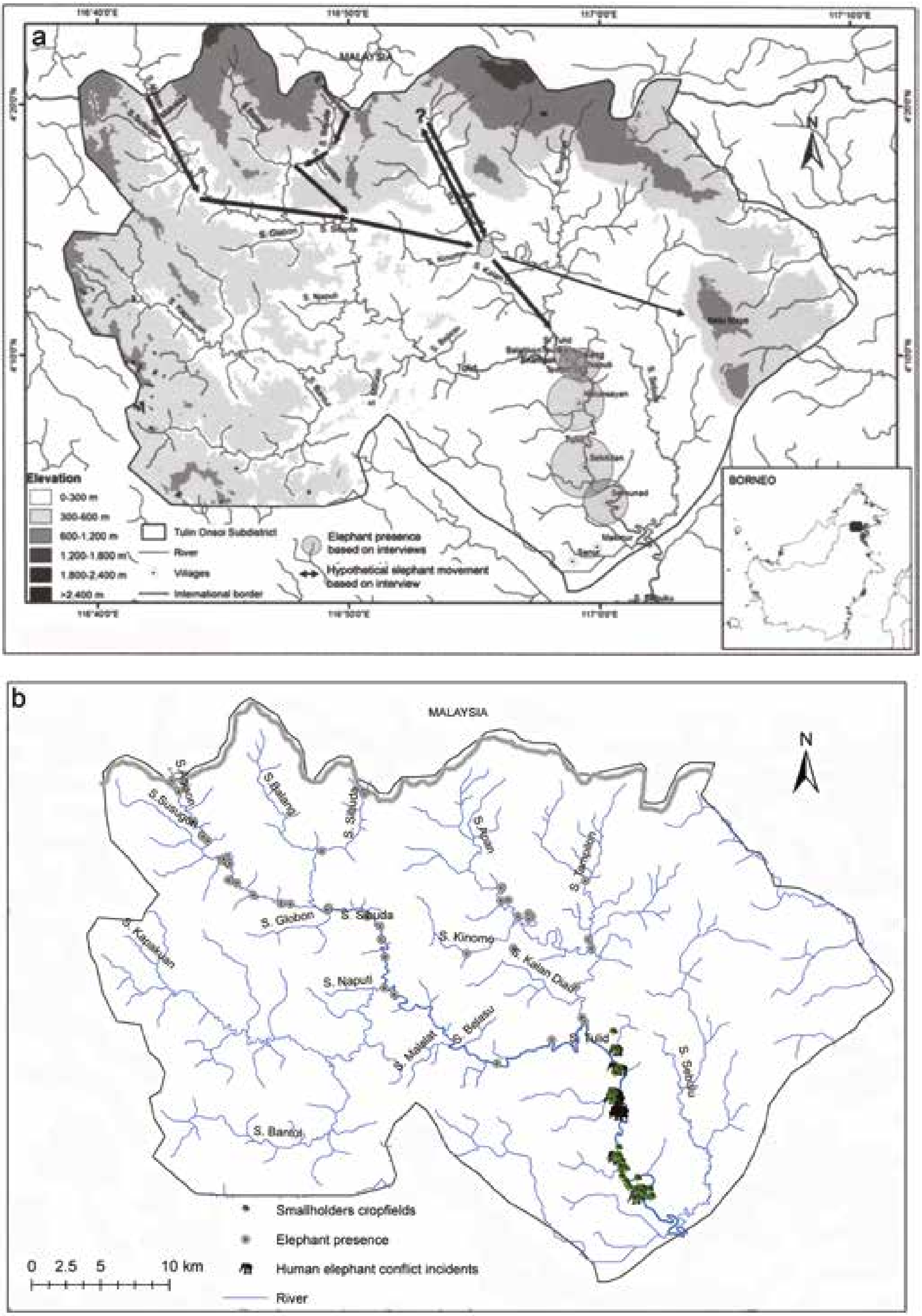

Figure 3-4
Location of elephant sightings based on interview surveys (a) and field surveys (b)

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).

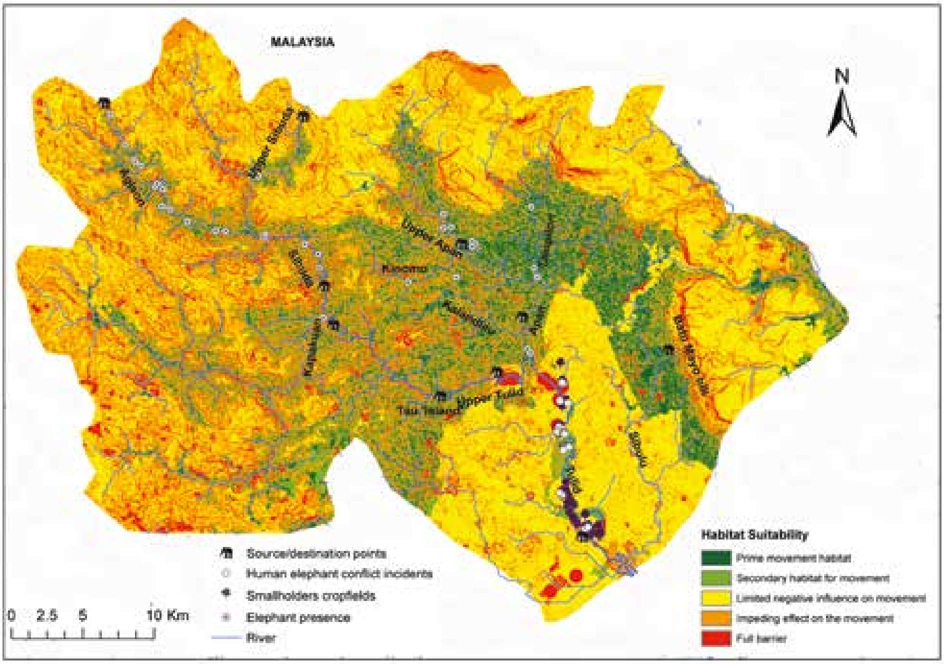

Figure 3-5
Potential elephant source points and habitat suitability

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).

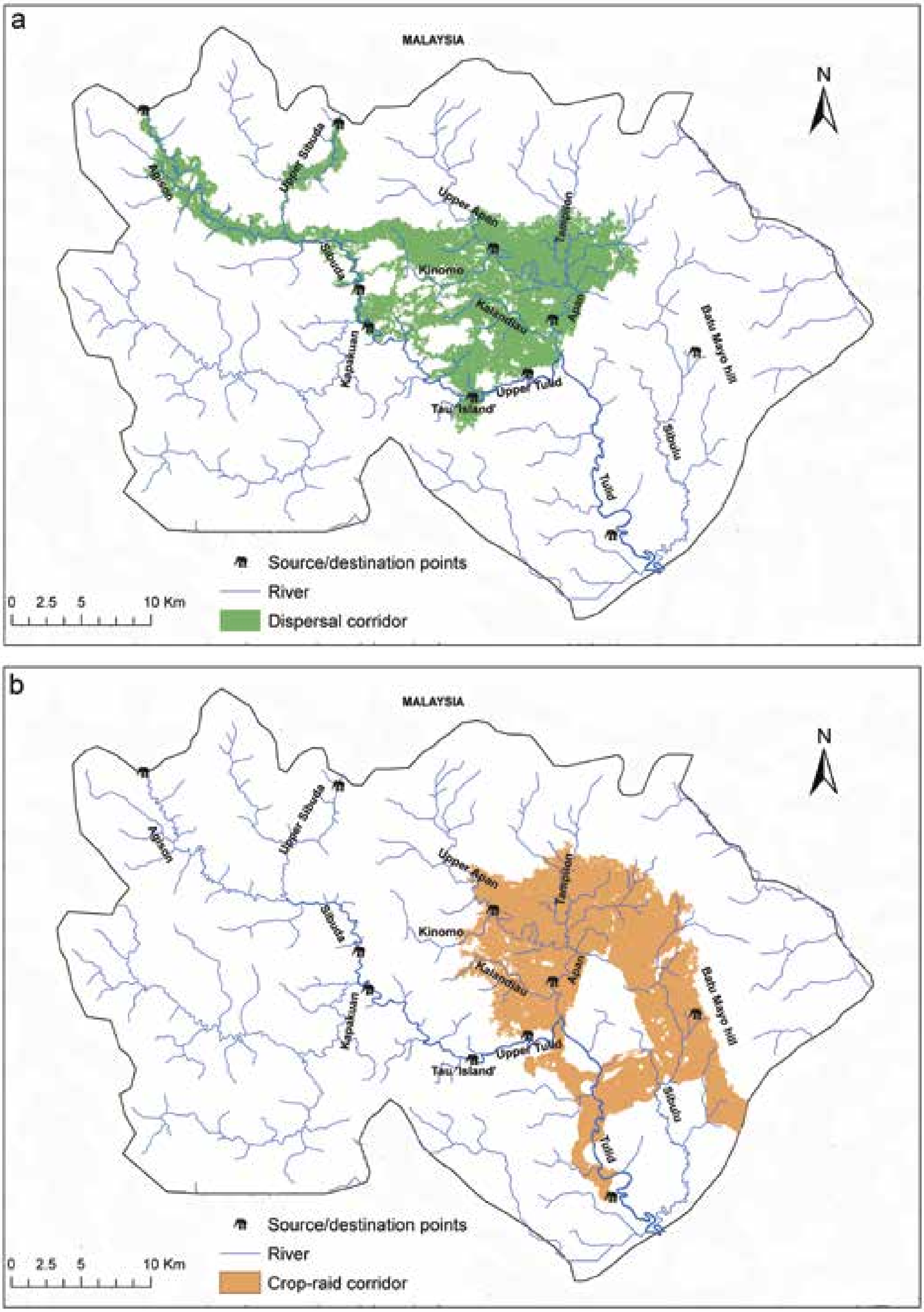

Figure 3-6
Potential elephant (a) dispersal and (b) crop raid corridors (5%) in the Tulin Onsoi Sub-district

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.

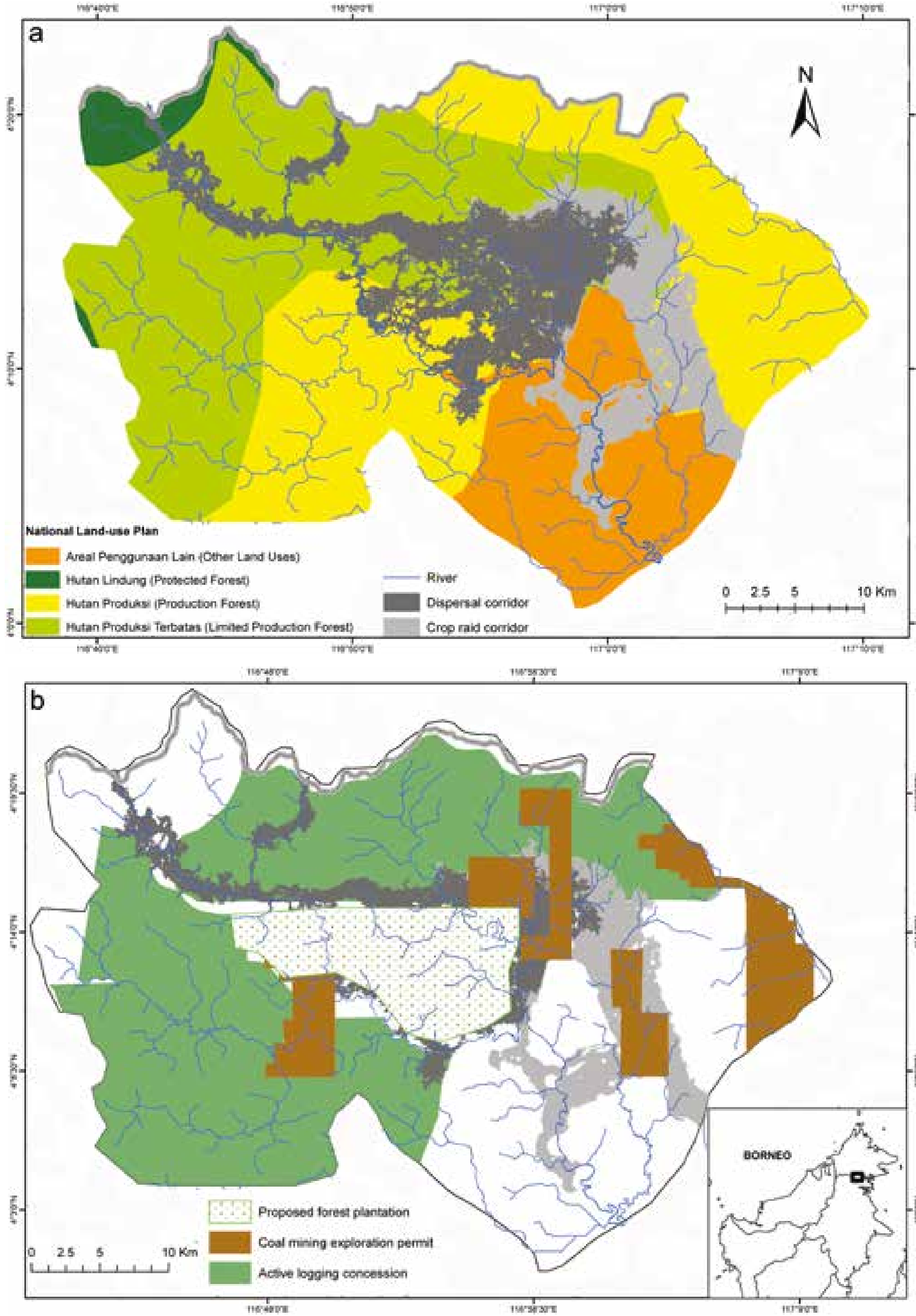

Figure 3-7
Overlay between potential Bornean elephant corridors with current National Land Use Plan and existing land use in the Tulin Onsoi Sub-district

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.

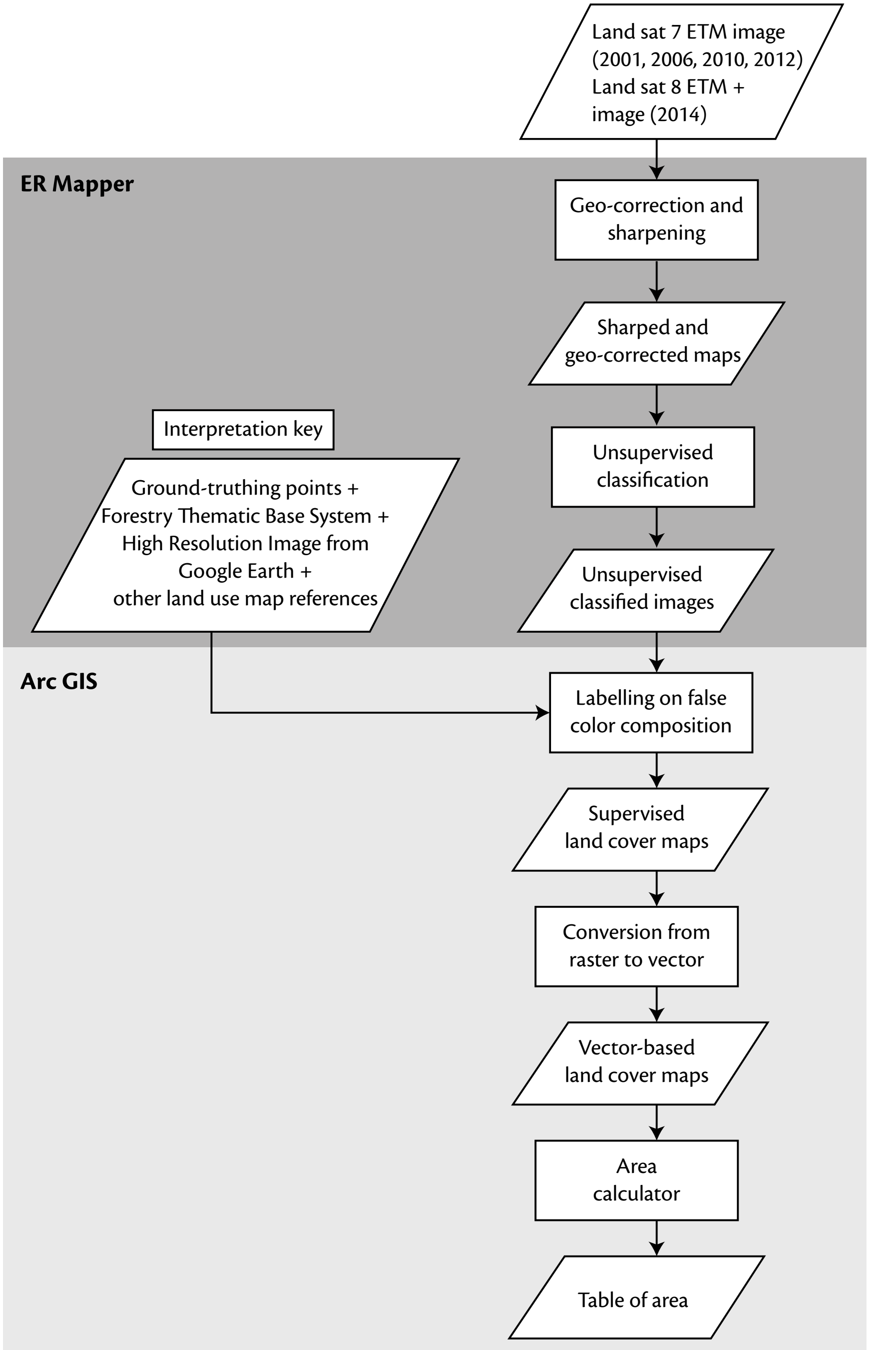


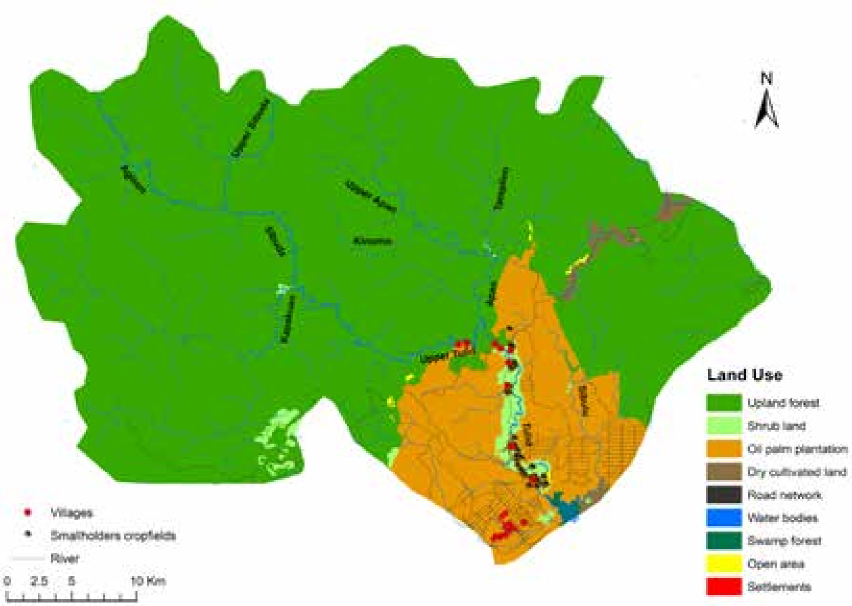
Figure 3-8
Preservation of river bank is necessary for the Bornean elephants in the Tulin Onsoi Sub-district, North Kalimantan, Indonesia

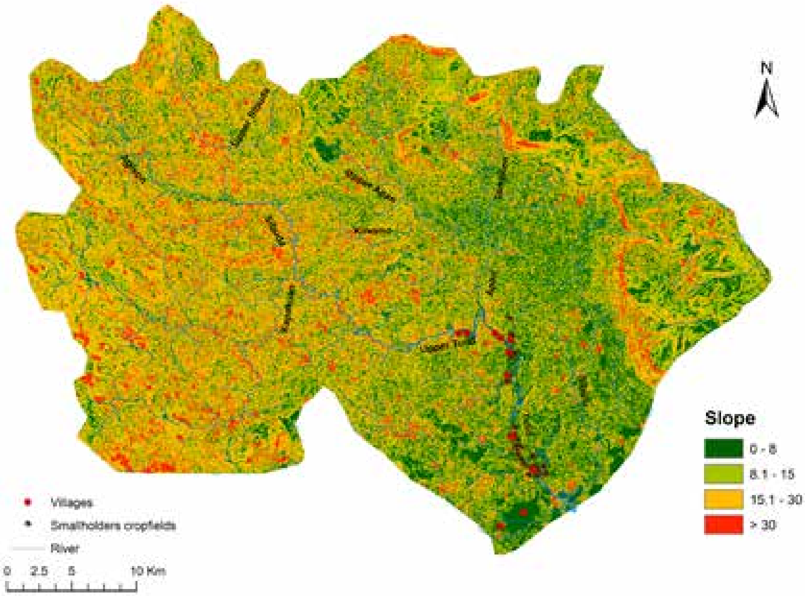
Nine land use categories were assigned: upland forest, shrubland, oil palm plantation, dry cultivated land, road network, water bodies, swamp forest, open area, and settlements, following land use classes defined by MoFRI (2008). All mosaics were then re-sampled to 30 m. Synchronized land-cover classification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

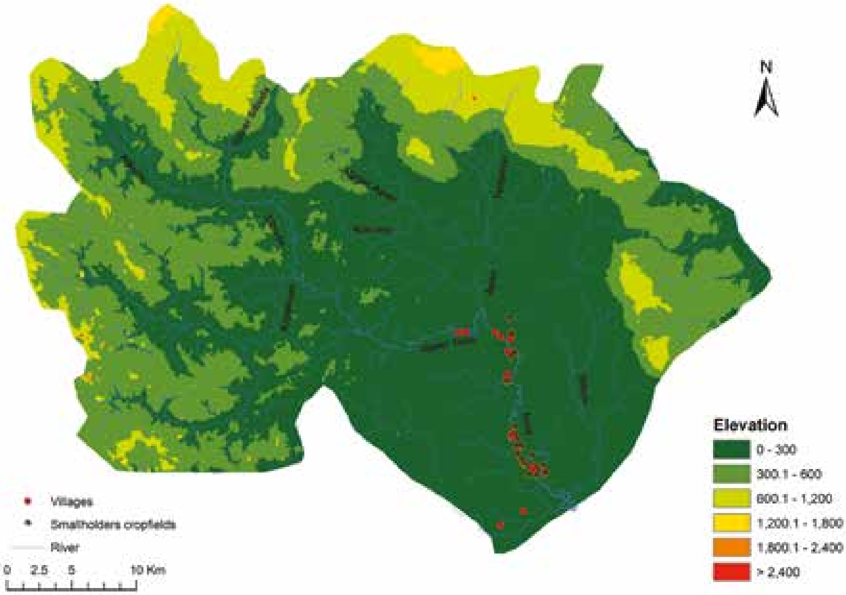
Land Cover Type	Description and Landscape Context
Upland Forest	Natural forest, highly diverse species and high basal area, but in this study, UF actually represents disturbed forest, with evidence of logging (Lusiana *et al*. 2005; Widayati *et al*. 2005), including roads and small clearings typical 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.

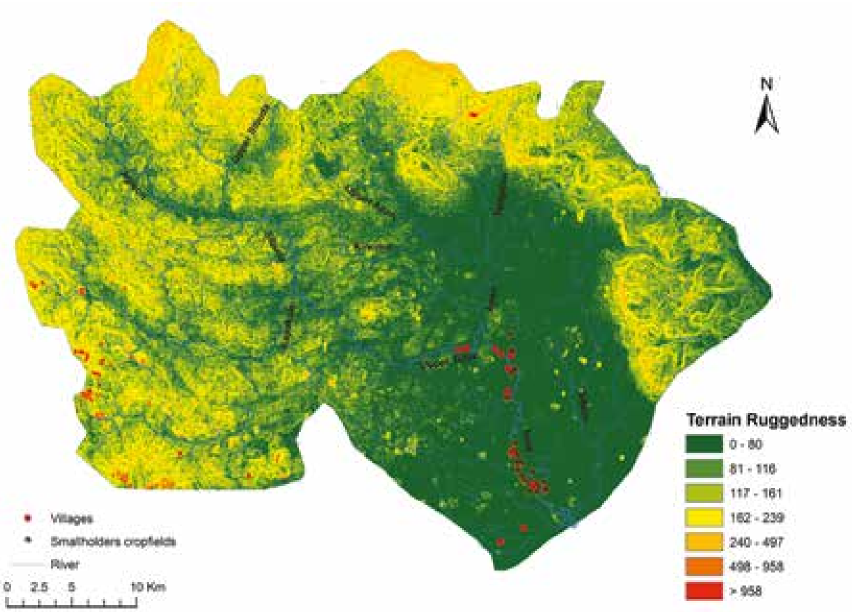
Adapted and modified from elsewhere (Gunarso *et al*. 2013; MoFRI 2008)

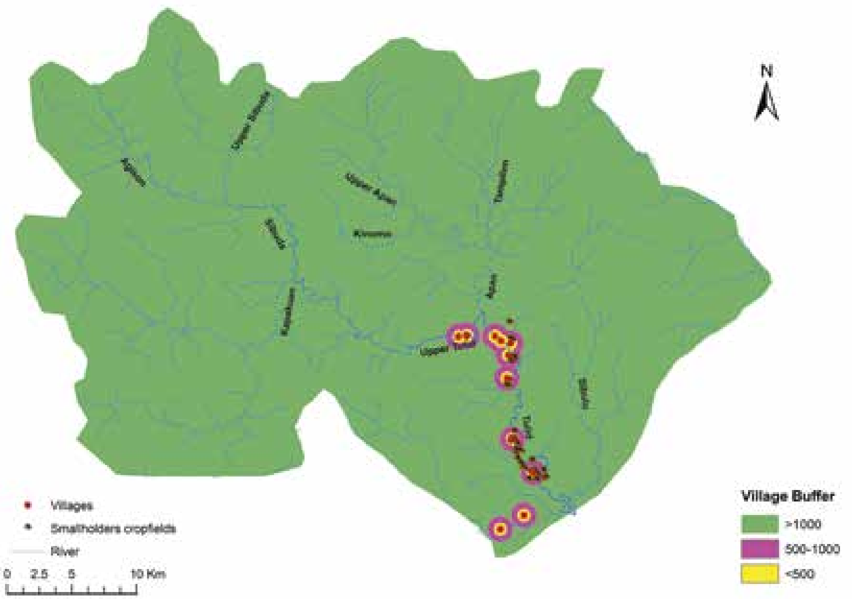
Slope and TRI were derived from a 30 x 30 m digital elevation model. Elevation was categorized into six classes: 0-300, 301-600, 601-1200, 1201-1800, 1801-2400, and >2400 m. The slope was calculated as percent rise and categorized into four classes: level to gentle slopes (0-8°), moderate slopes (9-15°), 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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Lusiana B, Shea GA, van Noordwijk M (2005) Introduction: Why Monitor Carbon in Nunukan? In: Lusiana B, van Noordwijk M, Rahayu S (eds) Carbon Stocks Monitoring in Nunukan, East Kalimantan: A Spatial and Modeling Approach. World Agroforestry Centre (ICRAF), Bogor, Indonesia.

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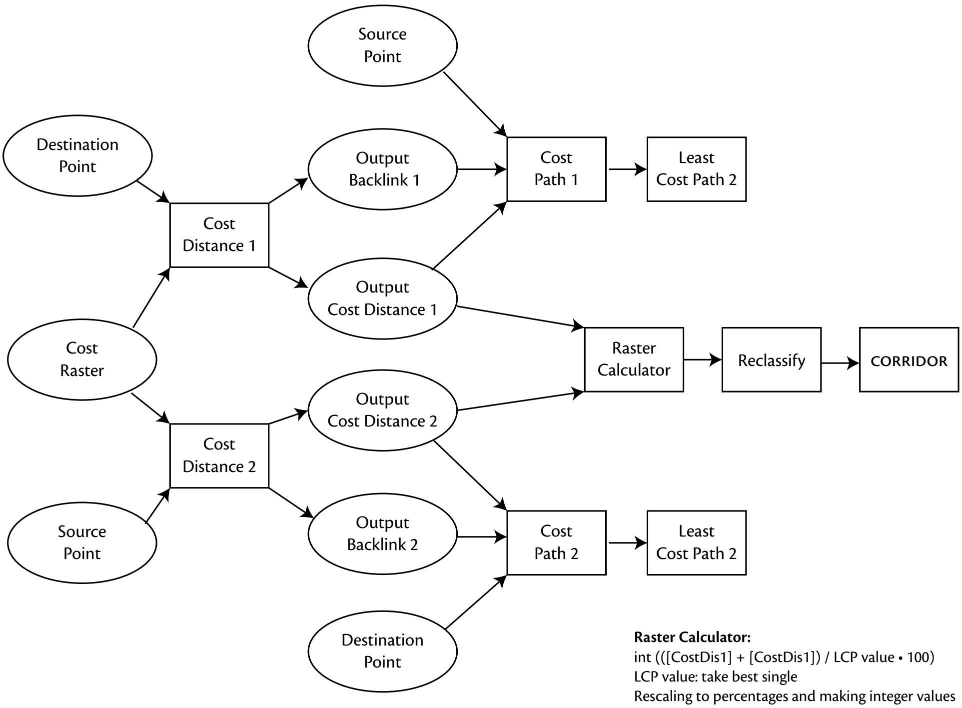
Appendix 3-4
Least cost modeling flow chart

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**			

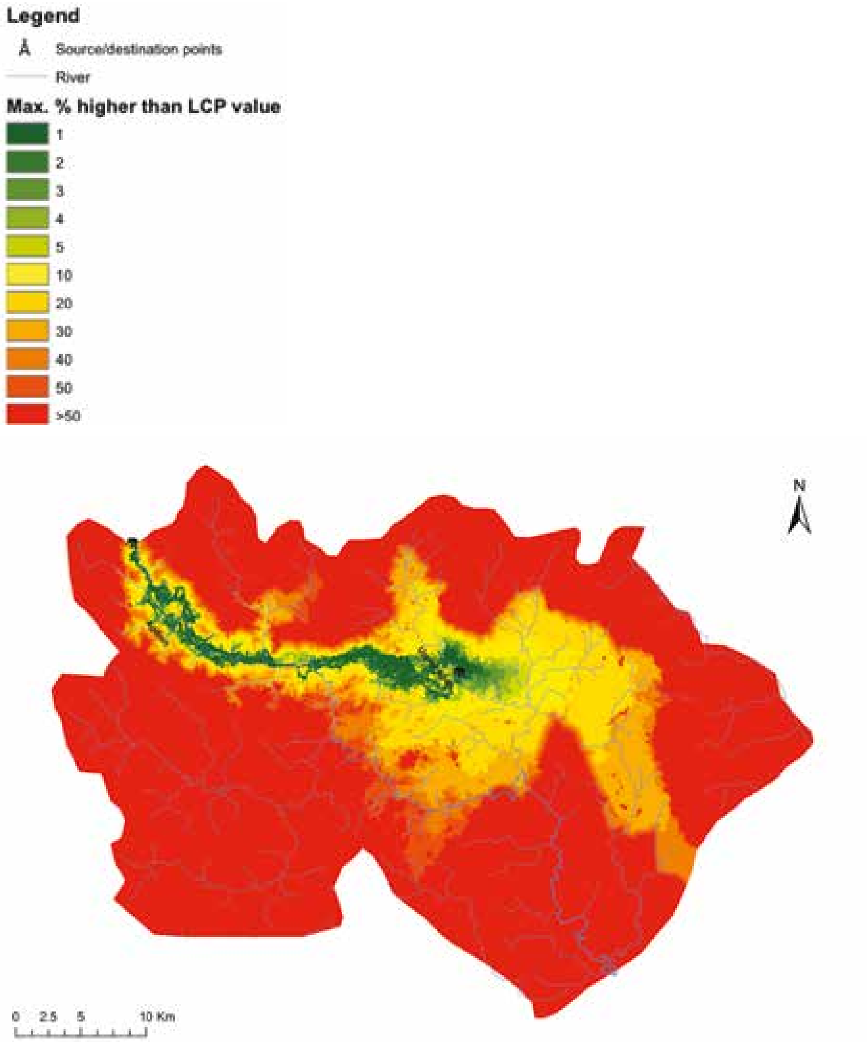
1	Bull encounter	*Semunad* village	500192	449213
2	Bull encounter	*Semunad* village	500400	449779
3	Bull encounter	*Semunad* village	500505	449773
4	Bull encounter	*Semunad* village	500487	449789
5	Bull encounter	*Semunad* village	500651	449902
6	Track	*Sekikilan* village	498785	452115
7	Track	*Sekikilan* 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

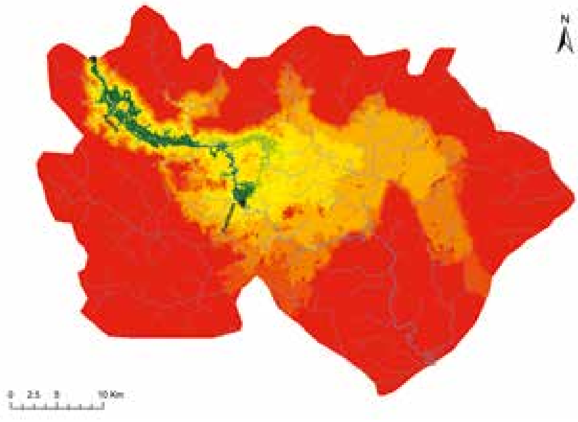
Appendix 3-6

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)

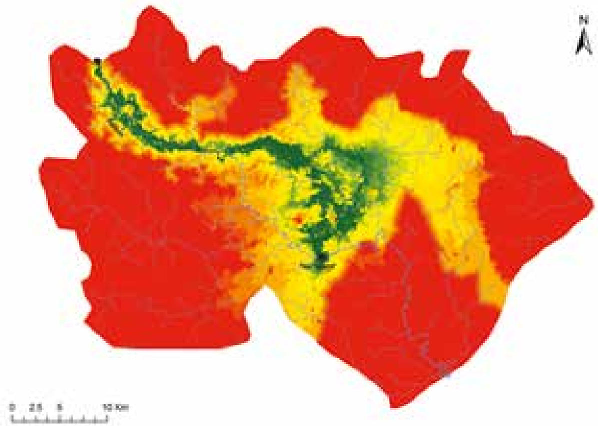
Corridor maps are represented in all models four source areas (Agison, Upper Sibuda, Sibuda, and Kapakuan) in the forest landscape and two sources points (Upper Apan and Batu Mayo Hill) in human-dominated landscape.



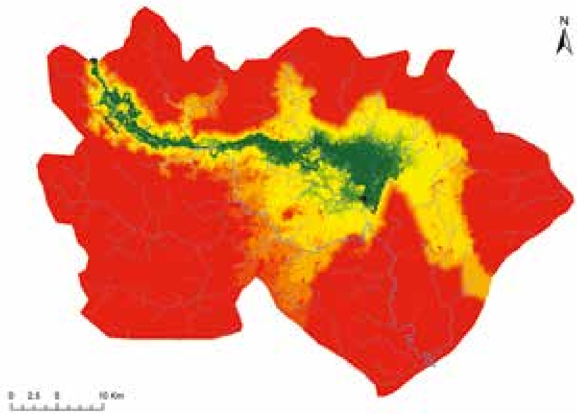
Agison – Upper Apan
Least-cost value : 235173 ; 235173.4
Length least-cost path (# cells) : 1182



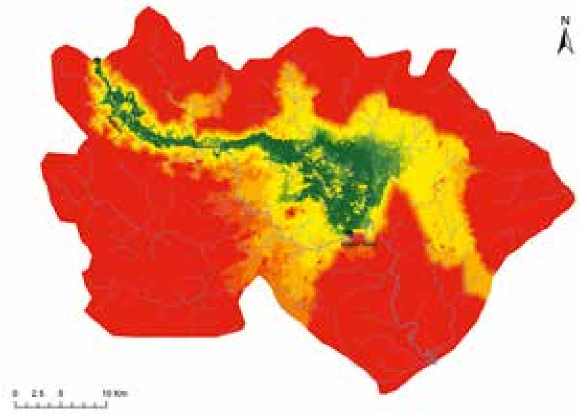
Agison – Kapakuan
Least-cost value : 285149.1 ; 285149.4
Length least-cost path (# cells) : 979



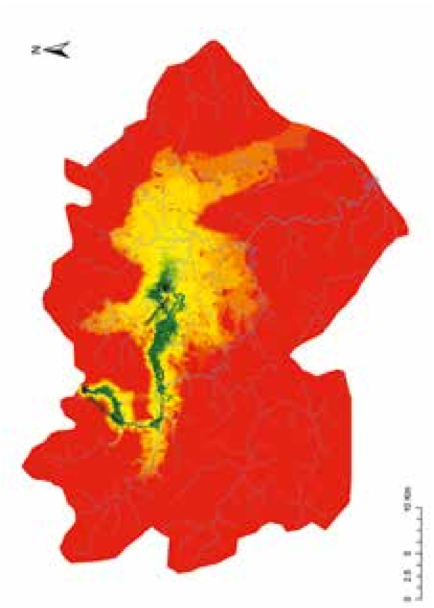
Agison – Tau 'Island'
Least-cost value : 272483.5 ; 272484.1
Length least-cost path (# cells) : 1483



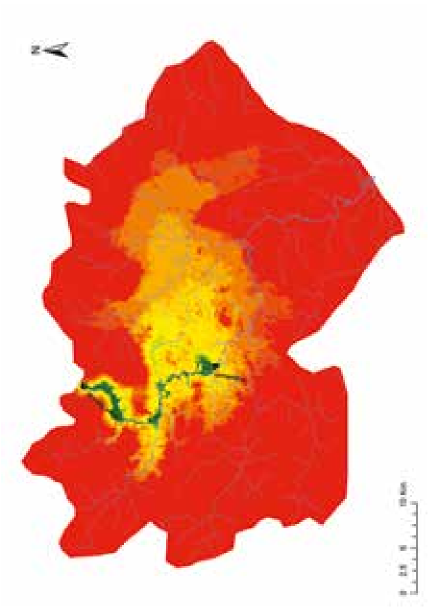
Agison – Apan
Least-cost value : 255729.7 ; 255730.4
Length least-cost path (# cells) : 1467



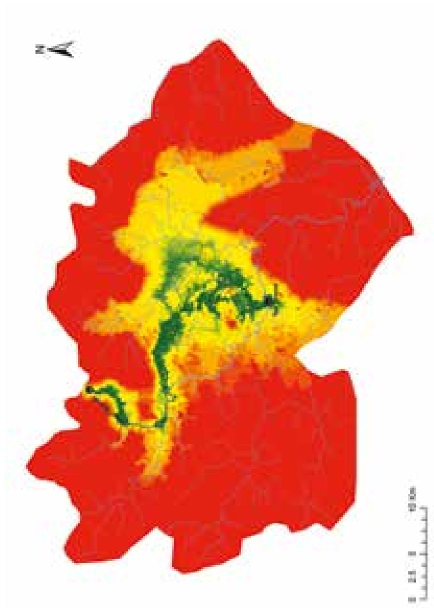
Agison – Upper Tulid
Least-cost value : 273881.8 ; 273882.4
Length least-cost path (# cells) : 1438



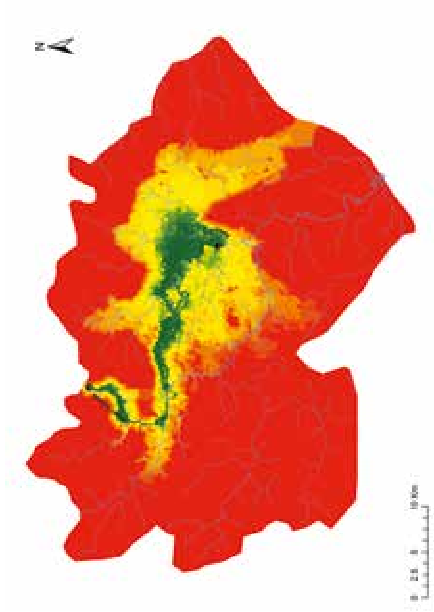
Upper Sibuda – Upper Apan
Least-cost value : 173490.4 ; 173490.7
Length least-cost path (# cells) : 950



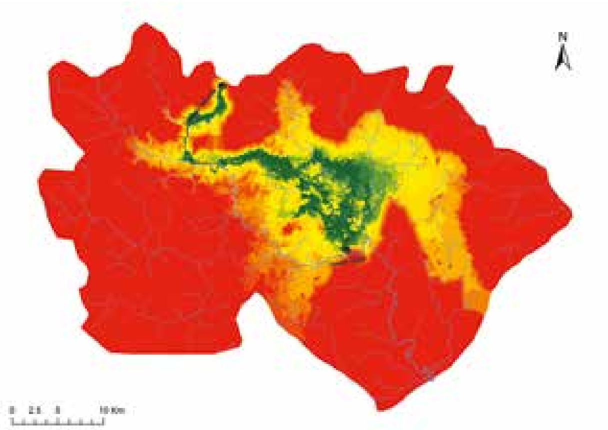
Upper Sibuda – Kapakuan
Least-cost value : 223466.4 ; 223466.7
Length least-cost path (# cells) : 747



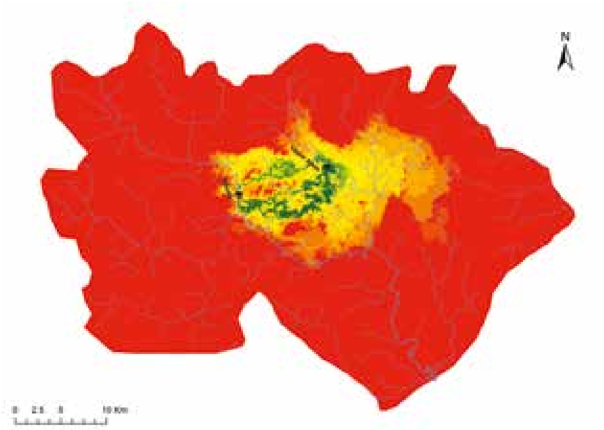
Upper Sibuda – Tau 'Island'
Least-cost value : 210800.8 ; 210801.4
Length least-cost path (# cells) : 1251



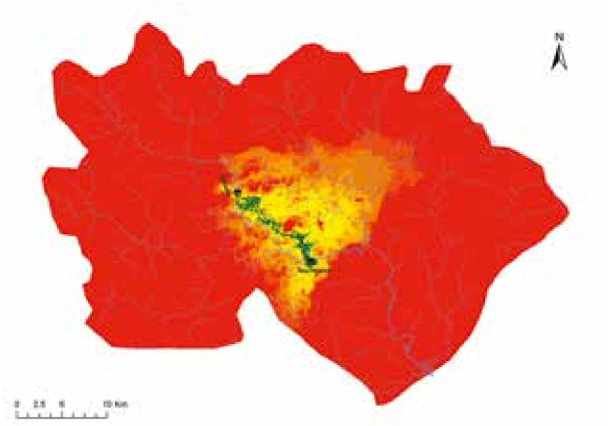
Upper Sibuda – Apan
Least-cost value : 194047.1 ; 194047.8
Length least-cost path (# cells) : 1235



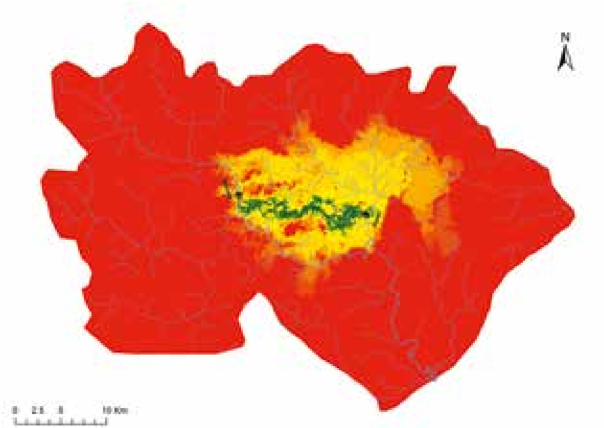
Upper Sibuda – Upper Tulid
Least-cost value : 212199.2 ; 212199.7
Length least-cost path (# cells) : 1206



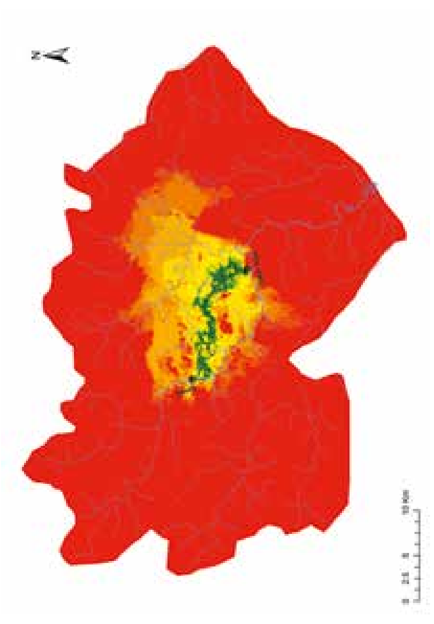
Sibuda – Upper Apan
Least-cost value : 108640.6 ; 108641
Length least-cost path (# cells) : 605



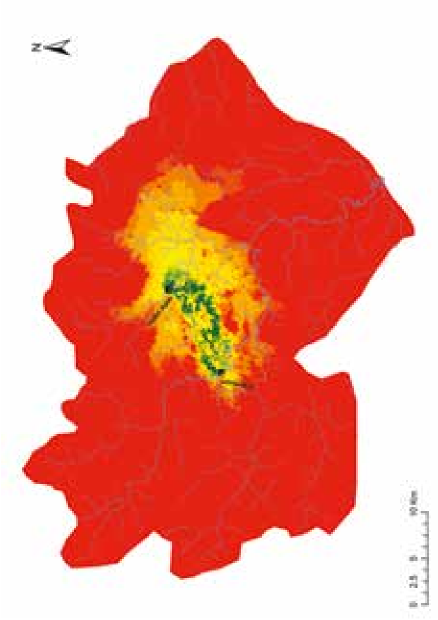
Sibuda – Tau 'Island'
Least-cost value : 114400.9 ; 114401
Length least-cost path (# cells) : 448



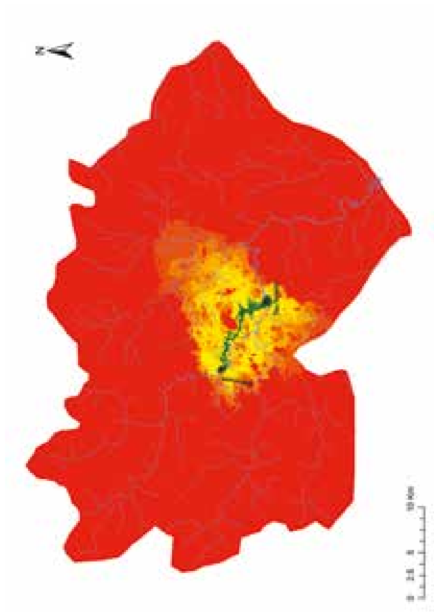
Sibuda – Apan
Least-cost value : 115878.3 ; 115878.7
Length least-cost path (# cells) : 617



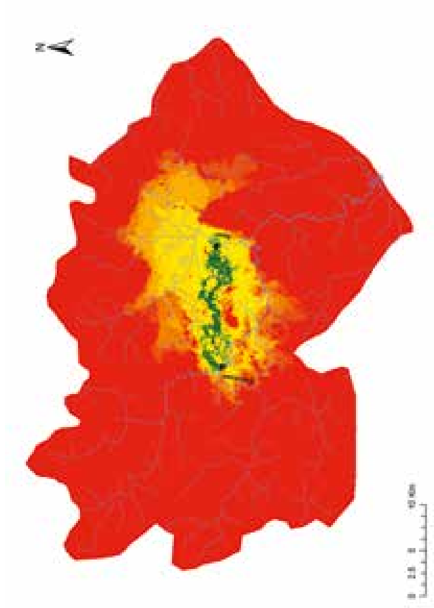
Sibuda – Upper Tulid
Least-cost value : 123524.8 ; 123525.3
Length least-cost path (# cells) : 640



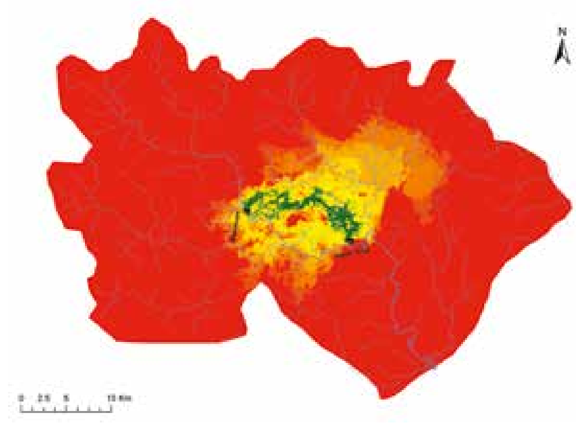
Kapakuan – Upper Apan
Least-cost value : 107327.7 ; 107328.1
Length least-cost path (# cells) : 597



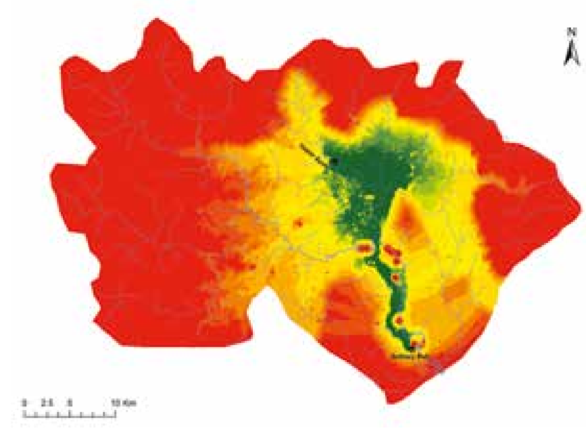
Kapakuan – Tau 'Island'
Least-cost value : 105831.8 ; 105832
Length least-cost path (# cells) : 387



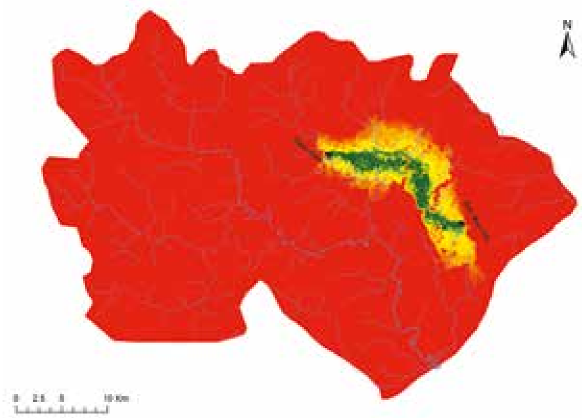
Kapakuan – Apan
Least-cost value : 114565.4 ; 114565.8
Length least-cost path (# cells) : 609



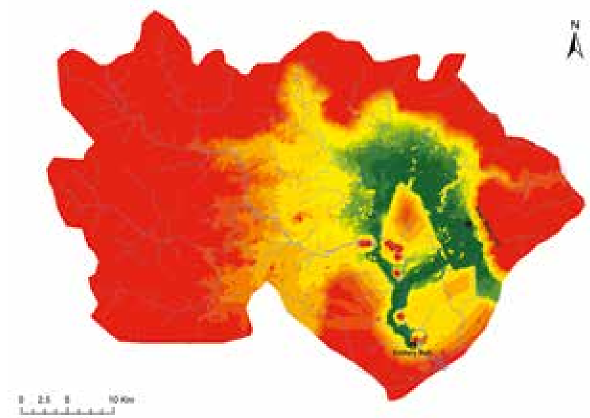
Kapakuan – Upper Tulid
Least-cost value : 122211.9 ; 122212.3
Length least-cost path (# cells) : 632



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

4

Foraging ecology and diet of Bornean elephants

Submitted as "Foraging ecology and diet of Bornean elephants *Elephas maximus borneensis* in the Sebuku forest area, North Kalimantan Province of Indonesia" to Integrative Zoology, 26 February 2017 (manuscript number: INZ-2017-02-029)

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Abstract

To gain a better understanding of the dietary preference of Bornean elephants (*Elephas maximus borneensis*), we studied their foraging ecology and dietary species composition. Fifty-two dietary plant species were recorded based on feeding signs. In addition, we found 38 additional species based on interviews. Of the plants consumed, Arecaceae, Poaceae, Moraceae, and Euphorbiaceae, overlap with those suggested in previous studies on Asian elephants. The interviews also revealed that several plant families may constitute all species to be potentially consumed by elephants, i.e. Arecaceae (rattan and palm), Poaceae (especially bamboo), and fruit sources (Myrtaceae, Malvaceae, Moraceae, Anacardiaceae, Phyllanthaceae, Euphorbiaceae, Ebenaceae, and Clusiaceae). Bornean elephants show a sophisticated selection of food items which most likely based on different nutritional properties. A restriction to a certain group or food plant spectrum for the main part of the diet is confirmed by this study. Monocots, such as bamboos, bananas, an arrowroot species (*Donax canniformis*), rattan, palms, and plants of the ginger family, were found to be important in the diet of Bornean elephants. In this study, 33 dicots were potentially consumed by elephants, and 23 of these were fruit producing species.

Keywords

Bornean elephant, foraging strategy, dietary species composition, feeding signs, interviews

4.1 Introduction

The Bornean elephant (*Elephas maximus borneensis*) was recently identified as a genetically distinct sub-species of the Asian elephant (*E. maximus*) (Fernando *et al.* 2003), possibly related to the Javan elephant, which became extinct following the disappearance of the Java-Borneo connection at the last glacial maximum (Cranbook *et al.* 2008). Although not yet listed as Endangered on the Global IUCN Red List, in future evaluation the sub-species would probably be qualified as such. This status would emphasize the urgency to conserve the Bornean elephant as an evolutionarily significant unit (Fernando *et al.* 2003; Alfred *et al.* 2011). The distribution of the Bornean elephant is limited to only 5% of the island, comprising the eastern and southern parts of Sabah, Malaysia, and the Sebuku forest in the most northern part of North Kalimantan Province, Indonesia (Wulffraat 2006). Around 2,000 Bornean elephants are estimated to be left in the wild, of which the majority is found in Sabah (Alfred *et al.* 2011). The elephant population in the Sebuku forest area is contiguous with the elephant population in the central forest of Sabah which is estimated at 280-330 individuals that utilize forests in the two adjacent countries (Sabah Wildlife Department 2011). Only 20-60 elephants are believed to occasionally enter the Sebuku area (Wulffraat 2006; Alfred *et al.* 2011).

The population of Bornean elephants in Kalimantan was rediscovered in the 1990's (Payne *et al.* 1994; MacKinnon *et al.* 1996). In 2005, they drew the attention of government as a result of local media reporting on incidents with solitary males that had entered village gardens and agricultural fields in the Sebuku area (Wulffraat 2006). Nevertheless, efforts to stop land use conversion and thus incidents with crop raiding elephants have further increased in recent years. In the Nunukan District, crop raiding incidents with elephants have at least partly been caused by the implementation of the "one million hectares oil palm program" in 2002. Under this program, forests have been converted to agricultural lands, particularly large oil palm plantations (Wulffraat 2006; Alfred *et al.* 2011). As the Sebuku Sub-district is also becoming one of the main centers of the oil palm plantation program (Bureau of Estate of East Kalimantan 2015), conflicts arising from crop raiding elephants are expected to aggravate in this area as well.

Encroachment and destruction of elephant habitat and migration routes are currently considered to be the main threat to wild elephants. From these human-induced threats, an additional problem could arise when elephants can no longer satisfy their nutritional needs. Humans generally select their food crops based on considerations of digestibility, the absence of toxins (condensed tannins), productivity and nutritive value, i.e. high levels of carbohydrates and protein (Santiapillai & Widodo 1993; Sitompul 2004; Rode *et al.* 2006).

Elephants, on the other hand, are non-ruminant hind-gut fermenters that digest cellulose in the large caecum and the colon through symbiotic microbes (Sukumar 2006) and are using specialized traits (such as their trunk and high-crowned molar teeth) to exploit a wide range of plant resources. With only 40-50% of the forage being digested, they may spend 12-18 hours a day feeding during which they can consume up to 150 kg of vegetation or 10% of their body weight (Sukumar 2006). Studies have found that over 100 plant species comprise the diet of the Asian elephant, with only a few plant species accounting the main part of their diet (Chen *et al.* 2006; Himmelsbach *et al.* 2006; Campos-Arceiz *et al.* 2008; Baskaran *et al.* 2010; Sitompul *et al.* 2013; Roy & Chowdury 2014). Overall, Fabaceae (legumes), Poaceae (grasses), Cyperaceae (sedges), Arecaceae (palms), Euphorbiaceae (spurges), Rhamnaceae (buckthorn), and Malvales (mallows, sterculias and basswoods) account for most of the Asian elephants diets (Sukumar 2006; Campos-Arceiz *et al.* 2008; Sitompul 2011).

Asian elephants are generalist herbivores that often select plants proportional to the availability of plant species within their feeding habitats (Sukumar 1990; Baskaran *et al.* 2010; Roy & Chowdhury 2014). Although mostly classified as bulk feeders, elephants have the ability to vary their feeding habits depending on their state of physiology, the season and individual taste (Jachmann & Bell 1985; Sukumar 1989; Price 1991; Dhakal & Ojha 1995; English *et al.* 2014). In general, high-quality parts of plants generally form smaller food items than do the low-quality parts. In the case of Bornean elephants, food plant selection is not always related to the relative abundance of plant species (English *et al.* 2014).

In regions where residents have long histories of exploiting local resources, knowledge of animals and their habitats, in particular, have high value for research and conservation (Philips & Gentry 1993; Nyhus *et al.* 2003). This study intends to use feeding sign observations and local knowledge on plants to provide a detailed description of Bornean elephant foraging ecology and diet, and how this relates to human-elephant conflict (HEC). This objective is addressed in the following questions: 1) Which plant species comprise the Bornean elephant diet? 2) Which parts of those plant species are consumed by Bornean elephants? Understanding what elephants feed on and the way they select their food (e.g. they may not always select plants proportional to their availability, but only certain kind of plant groups) could provide key insights into ecological requirements relevant for the management of wild elephant population and their habitats, as well as for the mitigation of HEC (Himmelsbach *et al.* 2006; Campos-Arceiz *et al.* 2008).

4.2 Methods

4.2.1 Study area

This study was conducted in the Sebuku area of the Nunukan District, located in the northeast of the Province of North Kalimantan, Indonesia (Figure 4-1). The forest area has an almost complete range of biological components that are characteristic of lowland forests of Borneo. The Sebuku drainage area is bounded by mountains and hills with mostly steep slopes to the north of the international border with Sabah (Malaysia). Several tributaries in the Sebuku forest area have their origin in Sabah. The main rivers of the Sebuku drainage area are the Tikung in the north (Malaysia) and the Tulid to the south, which later comes together in the Sebuku River. The Tulid river has several tributaries (Agison, Sibuda, Tampilon, and Apan) flowing through elephant habitat. The rivers in the North that are favored by elephants are located in flat areas of low elevation (Wulffraat 2006).

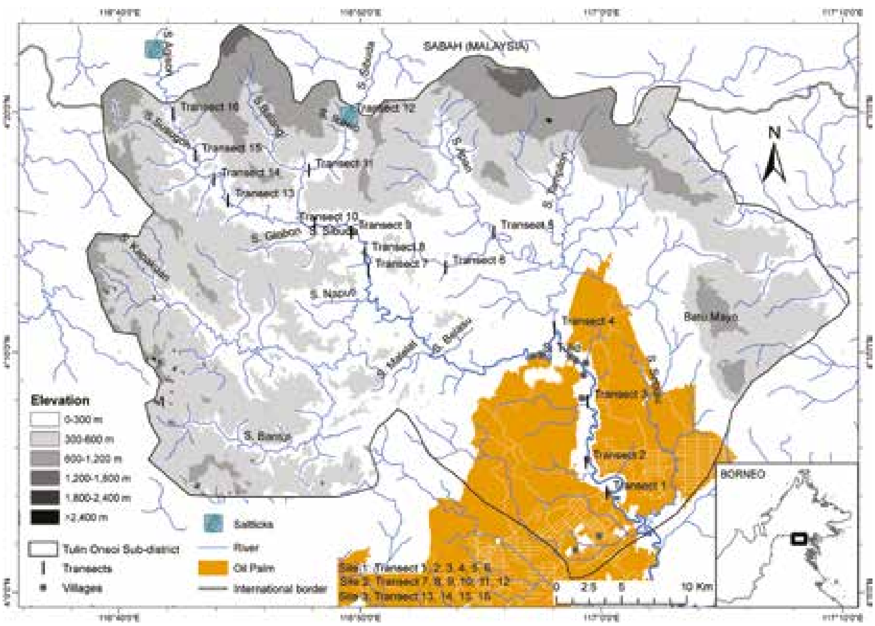

Figure 4-1
Map of the study area showing transects containing feeding signs of Bornean elephant in the study area in Tulin Onsoi Sub-district, North Kalimantan Province

Oil palm (*Elaeis guineensis*) introduced to the area in 2002, is grown by villagers either on a benefit shared scheme with the estates or in a small-scale farm of 0.5 to 2 ha (WWF 2010). Some forest areas have been converted to make it accessible for oil palm plantations. The two major oil palm estates in the area are *Karangjoang Hijau Lestari (KHL)* Group and *Tirtamadu Sawit Jaya (TSJ)* Group which have production areas of 20,000 ha and 7,892.18 ha respectively (Bureau of Estate of East Kalimantan 2015). Agricultural fields, other than oil palm, are generally located close to the primary village area. Crops grown in these areas include cassava (*Manihot esculenta*), rice (*Oryza sativa*), corn (*Zea mays*), coconut (*Cocos nucifera*), banana (*Musa acuminata*), sugar cane (*Saccharum officinarum*), legumes, vegetables, fruits and spice trees (Wulffraat 2006).

The climatic conditions of the study area reflect the patterns of a tropical zone of high humidity (an average of 80%), an average temperature of 23.4o-32.6oC, and low wind speed (0.7-8 knots). The average annual temperature is 26°C and the maximum temperature is between 22.6° and 35°C. The study area receives about 2,645.6 mm of rainfall annually (data from Meteorology and Geophysics Bureau in Nunukan), most of it between April and September. Whereas February and March, as well as October to November, are generally dry periods, monthly averages between 2005 and 2011 showed that the rain occurs evenly throughout the year (15-20 days).

4.2.2 Data collection

Data was collected during three field visits during January-April 2012, January-April 2013, and February-April 2014 (Figure 4-1), by the principle author (RBS), a botanist and two local guides. Sampling sites were selected randomly throughout the known Bornean elephant's home range, so as to cover as many known feeding paths as possible. Sampling sites were searched from the main rivers within the home range (Tulid, Apan, Sibuda, and Agison).

Considering site conditions, logistical issues and technical purpose (i.e. the distance between transects), within three different sites, sixteen transects were selected, ranging from 2 to 5 km in length. 12 transects were located in the natural or primary forest and 4 transects in disturbed landscape passing through villages, crop fields, adjacent shrublands and secondary forests (Figure 4-1). All feeding signs observed, of any age, which could still be recognized as Bornean elephant feeding signs, were recorded within a strip width of 20 m. Food plants were identified by the botanists to species level if possible. Browsing sign observations were often derived from associated signs, such as footprints, digging or broken vegetation. Signs of bark stripping and feeding on wood were usually easy to distinguish by scarring of trees and chewed wood. Positive identification up to species level of feeding on leaves was often difficult because 1) elephants frequently pull up or damage plants without feeding on them; 2) other animals may have fed on plant parts that had been made available by elephants; 3) trampling and feeding often occurred together, particularly in muddy sites, and sometimes it was impossible to tell which species had been eaten; 4) fruits are primarily picked up from the ground, which does not leave any feeding sign. Particularly for fallen fruits, we recorded fruit as eaten if the transects with elephants feeding trails passed underneath one or more fruiting trees with fallen ripe fruits.

Food plant species were assigned to life forms and taxonomic criteria (Table 4-1). Several life forms were distinguished within these three major groups, based on taxonomic criteria and growth form. Throughout this study, each plant species was assigned to one of the following three life forms (Eichhorn *et al.* 2006; Arbainsyah *et al.* 2014): (1) Trees defined as non-climbing woody species of which the mature individuals had a stem diameter > 10 cm; (2) Saplings defined as all herbaceous, non-climbing woody species and climbing woody species of which the mature individuals had a stem diameter < 10 cm and were on average more than 1.5 m tall; and (3) Seedlings defined as all herbaceous species, non-climbing woody species and climbing woody species of which the mature individuals were on average less than 1.5 m tall.

These three life forms (trees, saplings, and seedlings) were systematically recorded along each line transect. For this purpose each line transect was divided into 10 plots of 20 × 20 m at an interval of ~100 m, to count all trees with a diameter at breast height (dbh) > 10 cm. Within each plot, a subplot of 5 × 5 m for saplings and 2 × 2 m for seedlings were established and counted for food plant species. These subplots were positioned alternately to the left and right of the transects.

Table 4-1
List of life-forms used in this study and the taxa, growth form and size class they represent [Source: Arbainsyah *et al.* 2014]

Life-form	Taxa	Growth form and size
Trees (woody non-climbers with stem diameter ≥ 10 cm)		
Palms-trees	Monocotyledonae (Palmae)	Woody non-climbers, height >1.3 m
Dicots-trees	Dicotyledonae	Woody non-climbers, height >1.3 m
Saplings (herbs, shrubs, climbers, woody non-climbers with diameter < 10 cm)		
Monocots-other herbs	Monocotyledonae	Herbaceous, non climbers, height > 1.5 m
Dicots-trees	Dicotyledonae	Woody non-climbers, height >1.5 m
Palms-lianas (rattans)	Monocotyledonae (Palmae)	Climbers, height >1.5 m
Palms-palmlets	Monocotyledonae (Palmae)	Woody non-climbers, height >1.5 m
Dicots-lianas	Dicotyledonae	Climbers, height > 1.5 m
Dicots-shrubs	Dicotyledonae	Woody non climbers, with many branches from the ground, height > 1.5 m

Seedlings (herbs, shrubs, climbers, woody non-climbers < 1.5 height)		
Palms-lianas (rattans)	Monocotyledonae (Palmae)	Climbers, height <1.5 m
Palms-palmlets	Monocotyledonae (Palmae)	Woody non-climbers, height <1.5 m
Monocots-small lianas	Monocotyledonae	Climbers, height <1.5 m
Monocots-other herbs	Monocotyledonae	Herbaceous, non-climbers, height < 1.5 m
Monocots-grass-like	Poaceae	Herbaceous, leaves linear
Dicots-small treelets	Dicotyledonae	Woody non-climbers, height <1.5 m
Dicots-small lianas	Dicotyledonae	Climbers, height < 1.5 m
Dicots-small shrubs	Dicotyledonae	Woody non climbers, with many branches from the ground, height < 1.5 m
Fern-small lianas	Filicopsida	Climbers
Ferns-herbs	Filicopsida	Herbaceous, non climbers

4.2.3 Data analysis

The frequency of selected plant species was calculated to describe plant species preference for Bornean elephants. For this, a formula was adapted from the quadrate method for Importance Value Index (Mueller-Dumbois & Ellenberg 1974). The ratio of certain plant groups selected by the Bornean elephant and food plant availability (p_i) was calculated by comparing each frequency.

$$\text{Frequency (F)}_{selected} = \frac{\text{Number of plots containing feeding signs of a certain species}}{\text{Total number of plots}} \times 100\%$$

$$\text{Frequency (F)}_{available} = \frac{\text{Number of plots containing food plant species}}{\text{Total number of plots}} \times 100\%$$

$$p_i = \frac{F_{selected}}{F_{available}}$$

For selected and available comparison, food plant species were grouped into 14 plant spectrums according to plant types, habitus, and life-form categorization (see Table 4-2).

4.3 Results

Overall utilization of food plant spectrums by the Bornean elephants (Table 4-2) revealed maximum utilization (ρ = 1) of bamboo, banana, shrub-arrowroot which was represented by one species of Marantaceae (*Donax canniformis*), and rattan. The next groups were palms (ρ = 0.86) and ginger (ρ = 0.85). Two woody plant spectrums, tree sapling, and tree, seemed to be most abundant, but they were not taken by the elephants in the same proportion as the other groups mentioned earlier. Tree-sapling (ρ = 0.81) and trees (ρ = 0.62) mainly provided twigs and young leaves for the elephants.

Table 4-2
The ratio of the food plant spectrum selected by the Bornean elephant and food plant availability in the Sebuku area [$\rho = F_{selected}/F_{availability}$]

Food plant spectrum	$F_{available}$ (%)	$F_{selected}$ (%)	p	Remarks
Fern-seedling	5.8	1.7	0.29	2 ferns
Herb-ginger-seedling	16.7	14.2	0.85	3 species of Zingiberaceae
Herb-grass-seedling	32.5	25.0	0.77	3 species of Poaceae (1 native species and 2 cultivated species)
Herb-bromelids-seedling	2.5	2.5	1.00	1 species; only found in 1 sub-plot
Herb-arrowroot-seedling	12.5	4.2	0.33	1 species (*Stachyphrynium borneense*)
Shrub-arrowroot-seedling	11.7	11.7	1.00	1 species (*Donax canniformis*)
Rattan-seedling	21.7	20.8	0.96	8 species
Rattan-sapling	5.0	5.0	1.00	2 species
Herb-banana-sapling	17.5	17.5	1.00	2 species of Musaceae (1 native species and 1 cultivated species)
Bamboo-sapling	18.3	18.3	1.00	5 species
Palm-seedling	20.0	17.5	0.88	2 cultivated species (oil palm and coconut)
Palm-sapling	15.0	12.5	0.83	5 species
Tree-sapling	33.3	25.8	0.81	10 species
Tree	35.0	21.7	0.62	8 species

Figure 4-2
Some feeding signs found in the study area

Based on feeding signs, 52 food plants were distinguished (Table 4-3 and Table 4-4), representing 18 families: Arecaceae (15 species), Poaceae (8 species), Melastomataceae (5 species), Euphorbiaceae (4 species), Myrtaceae (4 species), Moraceae (3 species), Zingiberaceae (3 species), Phyllantaceae (2 species), Marantaceae (2 species), Musaceae (2 species), Blechnaceae (1 species), Bromeliaceae (1 species), Dennstaedtiaceae (1 species), and Fabaceae (1 species). 45 of identified food plant species were wild species and 7 species were cultivated crops. 38 additional food plant species were identified from interviews (Table 4-5) and included palm, rattan, ginger, and a few other herbaceous plant species, as well as fruit-tree species such as Myrtaceae (*Syzygium* sp.), Malvaceae (*Durio* sp. and *Neesia* sp.), Moraceae (*Artocarpus* sp.), Anacardiaceae (*Mangifera superba* and *Spondias mombin*), Phyllanthaceae (*Baccaurea* sp.), Euphorbiaceae (*Drypetes* sp.), Ebenaceae (*Diospyros borneensis*), and Clusiaceae (*Garcinia* sp.).

48.4% ($\rho = 0.94$) of elephant feeding signs were found in shoots of monocots (rattan, palms, bamboo, and banana). Elephants fed from the shoots of early growth stage of *Cocos nucifera* and *Elaeis guineensis*, while also feeding on the stem piths of palms and banana trees. Elephants consumed all parts of two species of fern, as well as of the ginger family (Zingiberaceae), and arrowroot family (Marantaceae). Elephants fed on the twigs and young leaves of bamboo, two figs, *Fordia splendidissima* (Fabaceae), and most species from families of Euphorbiaceae, Melastomataceae, and Myrtaceae. Elephants also picked young leaves of herbaceous plants from families of Poaceae and Musaceae. The root of *Aporosa* sp. constituted a small portion of the elephant diet in the Sebuku area. Feeding signs on bark, twigs, young leaves, fruits, and shoots were found on a tree of cultivated tree species, *Artocarpus heterophyllus* (jackfruit), which had been felled by a solitary bull.

Table 4-3
List of food plant species, frequency of feeding signs (F) and plant parts eaten by Bornean elephants [N = number of subplots; N_{total} = 120; F = Frequency; $\rho = F_{selected}/F_{availability}$]

No.	Species	Habitus	Life form categorization	Clade	Family	$N_{available}$	$F_{available}$ (%)	$N_{selected}$	$F_{selected}$ (%)	p	Plant parts
1	*Blechnum orientale*	Fern	Seedling	Pteridophytes	Blechnaceae	1	0.8	1	0.8	1.0	All parts
2	*Pteridum caudatum*	Fern	Seedling	Pteridophytes	Dennstaedtiaceae	6	5.0	1	0.8	0.2	All parts
3	*Alpinia ligulata*	Herb	Seedling	Monocots	Zingiberaceae	3	2.5	3	2.5	1.0	Root, stem
4	*Amomum maximum*	Herb	Seedling	Monocots	Zingiberaceae	3	2.5	2	1.7	0.7	All parts
5	*Etlingera* sp.	Herb	Seedling	Monocots	Zingiberaceae	14	11.7	12	10.0	0.9	All parts
6	*Stachyphrynium borneense*	Herb	Seedling	Monocots	Marantaceae	15	12.5	5	4.2	0.3	All parts
7	*Donax canniformis*	Shrub	Seedling	Monocots	Marantaceae	5	4.2	5	4.2	1.0	All parts
8	*Calamus saga*	Rattan	Seedling	Monocots	Arecaceae	2	1.7	2	1.7	1.0	Shoots
9	*Ceratolobus subangulatus*	Rattan	Seedling	Monocots	Arecaceae	2	1.7	2	1.7	1.0	Shoots
10	*Daemonorops sabut*	Rattan	Seedling	Monocots	Arecaceae	1	0.8	1	0.8	1.0	Shoots
11	*Daemonorops* sp.	Rattan	Seedling	Monocots	Arecaceae	3	2.5	3	2.5	1.0	Shoots
12	*Korthalsia ferox*	Rattan	Seedling	Monocots	Arecaceae	2	1.7	2	1.7	1.0	Shoots
13	*Korthalsia paucijuga*	Rattan	Seedling	Monocots	Arecaceae	2	1.7	2	1.7	1.0	Shoots
14	*Korthalsia* sp.	Rattan	Seedling	Monocots	Arecaceae	3	2.5	3	2.5	1.0	Shoots
15	*Calamus manau*	Rattan	Sapling	Monocots	Arecaceae	2	1.7	2	1.7	1.0	Shoots
16	*Calamus* sp.	Rattan	Seedling	Monocots	Arecaceae	11	9.2	10	8.3	0.9	Shoots
		Rattan	Sapling	Monocots	Arecaceae	4	3.3	4	3.3	1.0	Shoots
17	*Licuala spinosa*	Palm	Sapling	Monocots	Arecaceae	3	2.5	3	2.5	1.0	Shoots and stem pith of new clump
18	*Bambusa multiplex*	Bamboo	Sapling	Monocots	Poaceae	3	2.5	3	2.5	1.0	Shoots, twigs, young leaves

19	*Bambusa oldhamii*	Bamboo	Sapling	Monocots	Poaceae	12	10.0	12	10.0	1.0	Shoots, twigs, young leaves
20	*Bambusa vulgaris*	Bamboo	Sapling	Monocots	Poaceae	3	2.5	3	2.5	1.0	Shoots, twigs, young leaves
21	*Dendrocalamus* sp.	Bamboo	Sapling	Monocots	Poaceae	2	1.7	2	1.7	1.0	Shoots, twigs, young leaves
22	*Schizostachyum* sp.	Bamboo	Sapling	Monocots	Poaceae	2	1.7	2	1.7	1.0	Shoots, twigs, young leaves
23	*Aporosa grandistipula*	Tree	Sapling	Dicots	Phyllanthaceae	3	2.5	2	1.7	0.7	Root
24	*Aporosa nitida*	Tree	Tree	Dicots	Phyllanthaceae	3	2.5	2	1.7	0.7	Root
25	*Ficus obscura*	Tree	Sapling	Dicots	Moraceae	1	0.8	1	0.8	1.0	Twigs, leaves, fruits
26	*Ficus pubilimba*	Tree	Tree	Dicots	Moraceae	2	1.7	2	1.7	1.0	Twigs, leaves, fruits
27	*Fordia splendidissima*	Tree	Sapling	Dicots	Fabaceae	2	1.7	2	1.7	1.0	Twigs, leaves
28	*Mallotus echinatus*	Tree	Sapling	Dicots	Euphorbiaceae	1	0.8	1	0.8	1.0	Twigs
29	*Mallotus paniculatus*	Tree	Sapling	Dicots	Euphorbiaceae	3	2.5	3	2.5	1.0	Twigs
30	*Drypetes kikir*	Tree	Tree	Dicots	Euphorbiaceae	2	1.7	1	0.8	0.5	Twigs, leaves, fruits*
31	*Drypetes longifolia*	Tree	Tree	Dicots	Euphorbiaceae	8	6.7	1	0.8	0.1	Twigs, leaves, fruits*
32	*Melastoma affine*	Tree	Sapling	Dicots	Melastomataceae	1	0.8	1	0.8	1.0	Twigs, leaves
33	*Melastoma polyanthum*	Tree	Sapling	Dicots	Melastomataceae	2	1.7	2	1.7	1.0	Twigs, leaves
34	*Pternandra azurea*	Tree	Sapling	Dicots	Melastomataceae	4	3.3	2	1.7	0.5	Twigs, leaves
35	*Pternandra echinata*	Tree	Sapling	Dicots	Melastomataceae	4	3.3	2	1.7	0.5	Twigs, leaves
36	*Pternandra rostrata*	Tree	Sapling	Dicots	Melastomataceae	4	3.3	3	2.5	0.8	Twigs, leaves
37	*Syzygium pendens*	Tree	Sapling	Dicots	Myrtaceae	6	5.0	6	5.0	1.0	Twigs, leaves, fruits*
38	*Syzygium alyxifolium*	Tree	Tree	Dicots	Myrtaceae	1	0.8	1	0.8	1.0	Twigs, leaves, fruits*
39	*Syzygium curtisii*	Tree	Tree	Dicots	Myrtaceae	1	0.8	1	0.8	1.0	Twigs, leaves, fruits*
40	*Syzygium tetrapterum*	Tree	Tree	Dicots	Myrtaceae	1	0.8	1	0.8	1.0	Twigs, leaves, fruits*

*based on interviews

Table 4-4

List of food plant species, frequency of feeding signs (F) and plant parts eaten by Bornean elephants [N = number of subplots; N_{total} = 40; F = Frequency; $\rho = F_{selected}/F_{availability}$]

No.	Species	Habitus	Life form categorization	Clade	Family	Native or cultivated	$N_{available}$	$F_{available}$ (%)	$N_{selected}$	$F_{selected}$ (%)	ρ	Plant parts
1	*Donax canniformis**	Shrub	Seedling	Monocots	Marantaceae	Native	3	7.5	3	7.5	1.0	All parts
2	*Arenga undulatifolia*	Palm	Sapling	Monocots	Arecaceae	Native	1	2.5	1	2.5	1.0	Shoots and stem pith of new clump
3	*Arenga pinanga*	Palm	Sapling	Monocots	Arecaceae	Native	1	2.5	1	2.5	1.0	Shoots and stem pith of new clump
4	*Caryota mitis*	Palm	Sapling	Monocots	Arecaceae	Native	1	2.5	1	2.5	1.0	Shoots and stem pith of new clump
5	*Licuala spinosa**	Palm	Sapling	Monocots	Arecaceae	Native	2	5.0	1	2.5	0.5	Shoots and stem pith of new clump
6	*Elaeis guineensis*	Palm	Seedling	Monocots	Arecaceae	Cultivated	5	12.5	4	10.0	0.8	Shoots (early stage plant) and stem pith of new clump
7	*Cocos nucifera*	Palm	Seedling	Monocots	Arecaceae	Cultivated	3	7.5	3	7.5	1.0	Shoots (early stage plant) and stem pith of new clump
8	*Saccharum officinarum*	Herb	Seedling	Monocots	Poaceae	Cultivated	3	7.5	3	7.5	1.0	Stem, leaves
9	*Saccharum spontaneum*	Herb	Seedling	Monocots	Poaceae	Native	6	15.0	4	10.0	0.7	Stem, leaves
10	*Zea mays*	Herb	Seedling	Monocots	Poaceae	Cultivated	4	10.0	3	7.5	0.8	Cob, leaves
11	*Musa acuminata*	Herb	Sapling	Monocots	Musaceae	Cultivated	3	7.5	3	7.5	1.0	Shoots, stem pith, leaves
12	*Musa borneensis*	Herb	Sapling	Monocots	Musaceae	Native	4	10.0	4	10.0	1.0	Shoots, stem pith, leaves
13	*Ananas comosus*	Herb	Seedling	Monocots	Bromeliaceae	Cultivated	1	2.5	1	2.5	1.0	Fruits
14	*Artocarpus heterophyllus*	Tree	Tree	Dicots	Moraceae	Cultivated	2	5.0	2	5.0	1.0	Bark, twigs, young leaves, fruits, shoots

*also found on forest transects

Table 4-5
List of plants and plant parts potentially eaten by Bornean elephants based on interviews

No.	Plant species	Habitus	Family	Potential plant parts
	Monocots			
1	*Oncosperma* sp.	Palm	Arecaceae	Shoots and stem pith of new clump
2	*Borassodendron borneense*	Palm	Arecaceae	Shoots and stem pith of new clump
3	*Caryota rumphiana*	Palm	Arecaceae	Shoots and stem pith of new clump
4	*Daemonorops longipes*	Rattan	Arecaceae	Shoots
5	*Daemonorops mollis*	Rattan	Arecaceae	Shoots
6	*Daemonorops collarifera*	Rattan	Arecaceae	Shoots
7	*Khortalsia flagellaris*	Rattan	Arecaceae	Shoots
8	*Khortalsia echinometra*	Rattan	Arecaceae	Shoots
9	*Calamus discolor*	Rattan	Arecaceae	Shoots
10	*Calamus muelleri*	Rattan	Arecaceae	Shoots
11	*Calamus rotang*	Rattan	Arecaceae	Shoots
12	*Panicum trigonum*	Herb	Poaceae	Stem, leaves
13	*Commelina* sp.	Herb	Commelinaceae	Twigs, leaves
14	*Costus speciosus*	Herb	Zingiberaceae (ginger)	Leaves, stem
15	*Globba* sp.	Herb	Zingiberaceae (ginger)	All parts
16	*Curculigo latifolia*	Herb	Amaryllidaceae	All parts
17	*Scindapsus pictus*	Herb	Araceae	All parts
	Dicots			
18	*Mangifera superba*	Tree	Anacardiaceae	Fruits
19	*Spondias mombin*	Tree	Anacardiaceae	Fruits
20	*Garcinia parvifolia*	Tree	Clusiaceae	Fruits
21	*Artocarpus rigidus*	Tree	Moraceae	Bark, twigs, leaves, fruits, shoots
22	*Artocarpus elasticus*	Tree	Moraceae	Bark, twigs, leaves, fruits, shoots
23	*Artocarpus lanceifolius*	Tree	Moraceae	Bark, twigs, leaves, fruits, shoots
24	*Artocarpus anisophyllus*	Tree	Moraceae	Bark, twigs, leaves, fruits, shoots
25	*Artocarpus odoratissimus*	Tree	Moraceae	Bark, twigs, leaves, fruits, shoots
26	*Uncaria cordata*	Liana	Rubiaceae	Twigs, leaves
27	*Gardenia tubifera*	Tree	Rubiaceae	Bark, twigs, leaves
28	*Polyalthia* sp.	Tree	Annonaceae	Root
29	*Croton argyratus*	Tree	Euphorbiaceae	Bark
30	*Diospyros borneensis*	Tree	Ebenaceae	Fruits
31	*Durio graveolens*	Tree	Malvaceae	Fruits

32	*Durio koetejensis*	Tree	Malvaceae	Fruits
33	*Durio oxleyanus*	Tree	Malvaceae	Fruits
34	*Neesia* sp.	Tree	Malvaceae	Fruits
35	*Baccaurea parviflora*	Tree	Phyllanthaceae	Fruits
36	*Baccaurea stipulata*	Tree	Phyllanthaceae	Fruits
37	*Baccaurea macrophylla*	Tree	Phyllanthaceae	Fruits
38	*Baccaurea sumatrana*	Tree	Phyllanthaceae	Fruits

4.4 Discussion

The total of 90 food plant species identified during the present study, suggests that elephants in the study area have a diverse diet, although studies on Asian elephants reported over 100 plant species included in the diet (Himmelsbach *et al.* 2006; Chen *et al.* 2006; Campos-Arceiz *et al.* 2008; Baskaran *et al.* 2010; Sitompul *et al.* 2013; Roy & Chowdhury 2014). The plant families to which the identified food plants belonged, did however largely overlap with above-mentioned studies, with Arecaceae, Poaceae, Moraceae, and Euphorbiaceae as the main families (Himmelsbach *et al.* 2006; Chen *et al.* 2006; Campos-Arceiz *et al.* 2008; Sitompul *et al.* 2013). A restriction to a certain group or food plant spectrum for the main part of the diet was confirmed by this study. In accordance with other studies on Asian elephants in China (Chen *et al.* 2006) and Myanmar (Himmelsbach *et al.* 2006; Campos-Arceiz *et al.* 2008), the present study further revealed that monocots, such as bamboo, banana, an arrowroot species (*Donax canniformis*), rattan, palms, and plants of the ginger family, are an important seem to be important part of the diet of Bornean elephants.

Elephants, as energy maximizers, have a strong preference for energy-rich plants (McCullagh 1969; Pyke *et al.* 1977; McNaughton 1979; Demment & Van Soest 1985; Jachmann 1989; Rode *et al.* 2006; Sitompul 2011; Pretorius *et al.* 2012). It is therefore not surprising that elephants have a clear preference for monocots, which is a high-energy food source, with relatively high carbohydrates contents. Monocots are even suggested to be one of the driving factors of dietary preference by elephants (Van Soest 1982).

The relatively high proportion of bamboo in the elephant's diet could be related to the low tannin levels of this plant (Easa 1989; Wang *et al.* 2009). In other herbivores, allelochemicals such as condensed tannin have been shown to influence food selection due to their deleterious properties (Freeland & Janzen 1974; Rosenthal & Janzen 1979; Jachman 1989). Elephants are known to switch between plant species and plant parts to sequester the greatest amount of digestible protein per unit time (O'Connor *et al.* 2007), which is a behavioral adaptation to cope with declines in N content (Mattson 1980). By doing so, elephants may acquire fatty acids (McCullagh 1973) and minerals such as manganese, iron, boron, copper, and calcium (Bax & Sheldrick 1963; Dougall *et al.* 1969). *Mallotus* sp. and *Artocarpus heterophyllus* were eaten from barks. Debarking of certain food plants by elephants has been observed in the tropics (Olivier 1978). Tree bark is selected because of its high protein content (Foguekem *et al.* 2011). Tree bark also contains minerals and fiber and may prevent colic (Sukumar 1992). Bornean elephants in the Sebuku forest were found to feed on the roots of the woody plant *Aporosa* sp. (Euphorbiaceae) and most of the ginger family. *Spondias mombin* (Anacardiaceae) and *Polyalthia* sp. (Annonaceae) could also be potentially included as root sources for the elephant in the Sebuku Forest, as was observed for Asian elephants in China (Chen *et al.* 2006), Vietnam (Varma *et al.* 2008), and Myanmar (Campos-Arceiz *et al.* 2008). Roots are also known to contain relatively high carbohydrate and nitrogen levels (Mattson 1980; Van Soest 1982; Hiscocks 1999).

The compositions of plants consumed and the availability of good quality forage are subject to seasonality and plant phenology (Sukumar 1989; Nyhus *et al.* 2000; Rode *et al.* 2006; Sukumar 2006). Asian elephants may switch their diet preferences from grass to browse depending on seasonal changes in plant quality. In dry tropical forests, for example, over 70% of the diet is browse, while grasses comprise the majority of the diet in the wet season when they are plentiful (Sukumar 2006; Baskaran *et al.* 2010). In the tropical rainforest, the diet predominantly consists of browse and fruit (Sukumar 2006).

In general, high-quality forage for herbivores is rare, whereas low-quality forage is more abundant. When plants mature, the fiber and lignin content increase. Thus young shoots and stems rather than mature parts of plants are higher in quality (Koricheva & Barton 2012), with the exception of storage and reproductive organs; when these are separated from their protective hulls, they have low fiber contents but are high in quality. Most elephant feeding signs were found in young/growing tissues, i.e. shoots, stem pith of new clump, twigs, and young leaves.

Matsubayashi *et al.* (2006) found that Bornean elephants in the Deramakot Forest Reserve, Sabah, Malaysia often fed on pioneer plants *Macaranga* sp. In the Sebuku forest, however, elephants were found to select 'tree-saplings' of other pioneer plants, mainly for twigs and young leaves, i.e. *Ficus* sp., *Fordia splendidissima* (Fabaceae), and most species from families of Euphorbiaceae, Melastomataceae, and Myrtaceae. The difference in preference of pioneer plants between the two study sites could be related to the season, i.e. data collection in the Deramakot Forest Reserve took place during the dry season when *Macaranga* sp. were flowering/bearing fruits. Another reason for the difference in preference for *Macaranga* sp. involves a difference between the level of forest disturbance at the two sites. *Macaranga* sp. is well known as a pioneer species in primary succession of rainforest, being the first to colonize cleared and vacated areas after disturbance, e.g. due to logging or fire. It grows rather fast, out-competes other species and is well equipped to grow in habitats where sunlight often reaches the forest floor (Whitmore 1998).

Many pioneer plants in gap areas are known to store the products of photosynthesis: secondary metabolite production and/or provide mechanical protection against foraging by herbivores to achieve a higher growth rate (Coley 1983; Coley *et al.* 1985; Whitmore 1998). By foraging on leaves in forest gaps, elephants often open up foraging habitat for other herbivores thus acting as ecosystem engineers in tropical rain forests (Matsubayashi *et al.* 2006). As in other studies, e.g. in Myanmar (Campos-Arceiz *et al.* 2008) and Sumatra (Sitompul *et al.* 2013), fruit trees bordering gaps in rainforests were found to be an important food source, because of their relative abundance (Brokaw 1987; Brandani *et al.* 1988) and continuous production (Whitmore 1998), with *Ficus* sp. (Moraceae) as an example in this study.

The wet tropical forests of Kalimantan are characterized by irregular mast fruiting events. Certain fruit trees have a distinct reproductive pattern that causes them to flower and fruit synchronously at intervals of 2-10 years (Fredriksson *et al.* 2006). The canopy of these forests is dominated by trees of the Dipterocarpaceae, the most extreme in their specialization on mast fruiting behavior. Other mast fruiting species producing succulent fleshy fruits also restricted their reproduction to mass fruiting events (Fredriksson *et al.* 2006; Cannon *et al.* 2007). The main mast fruit genera found in this study (*Durio* spp. and *Artocarpus* spp.) are rich in water, carbohydrates, protein, fat and could provide elephants with necessary vitamins, carotenoids, amino acids, and minerals (Hoe & Siong 1999). The other fruit sources, *Diospyros* spp. (Ebenaceae) and *Syzygium* spp. (Myrtaceae) also limited their reproduction to mast fruiting events (Cannon *et al.* 2007). During mast fruiting periods, high-quality fruits are abundant, followed by extended periods of low food availability. In this study, of 33 dicots that were potentially consumed by elephants, 23 were fruit-producing species, all belonging to fruit tree families that are common in the Sebuku forest area. In other study areas, these fruits were also found to be preferred by elephants (Campos-Arceiz *et al.* 2008; Sitompul *et al.* 2013), and other large mammals such as Sun Bear, Orang Utan, Gibbon, Leaf Monkey, and Macaque (MacKinnon *et al.* 1996; Meijaard *et al.* 2005; Fredriksson *et al.* 2006). These fruits provide sufficient reserves or could restore lost energy reserves from the prolonged inter-mast periods when few fruit resources are available (Fredriksson *et al.* 2006) since they are higher in caloric content than non-mast fruits (Leighton 1993; Knott 1998; Hoe & Siong 1999; Fredriksson *et al.* 2006).

Food crops grown by humans are selected for their digestibility, the absence of toxins (e.g. condensed tannins), productivity and nutritive value, i.e. high levels of carbohydrates and protein (Santiapillai & Widodo 1993; Sitompul 2004; Rode *et al*. 2006). Because elephants selectively feed on high-quality forage when given the opportunity, these advantages are suggested to be an incentive for elephants to raid crops (Sukumar 1990; Santiapillai & Widodo 1993). The percentage of crop species that contributed to the overall dietary plant of Bornean elephants in the Sebuku forest was 10.6%. The overall frequency of crop species present in the study area reached 48% in some locations and varied between species depending on the type of cultivation. Crop raiding was most frequently found on oil palm (*Elaeis guineensis*), followed by sugar cane (*Saccharum officinarum*), coconut (*Cocos nucifera*), cultivated banana (*Musa acuminata*), corn (*Zea mays*), jackfruit (*Artocarpus heterophyllus*), and pineapple (*Ananas comosus*). The frequency of crop-raiding was seasonal and appeared to be proportional to their availability, which is also in agreement with Sukumar (1990). As was found in other studies (Jainudeen *et al*. 1972; Sukumar 1991; Santiapillai & Widodo 1993; Sitompul 2004; Santiapillai 1996; Bandara & Tisdell 2002; Webber *et al.* 2011), adult bulls rather than elephant herds are more often responsible for crop-raiding. With the abundance of food during mast fruiting years, the number of crop raiding events is expected to be lower than in-between mast years. It has been proposed that crop-raiding can ultimately be an extension of the male elephant's optimal foraging strategy, driven by a push factor caused by temporal low nutritional levels in forest food plants, e.g. in-between mast fruiting events.


Bambusa oldhamii
Daemonorops longipes
Donax canniformis
Saccharum spontaneum

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Appendix 4-1

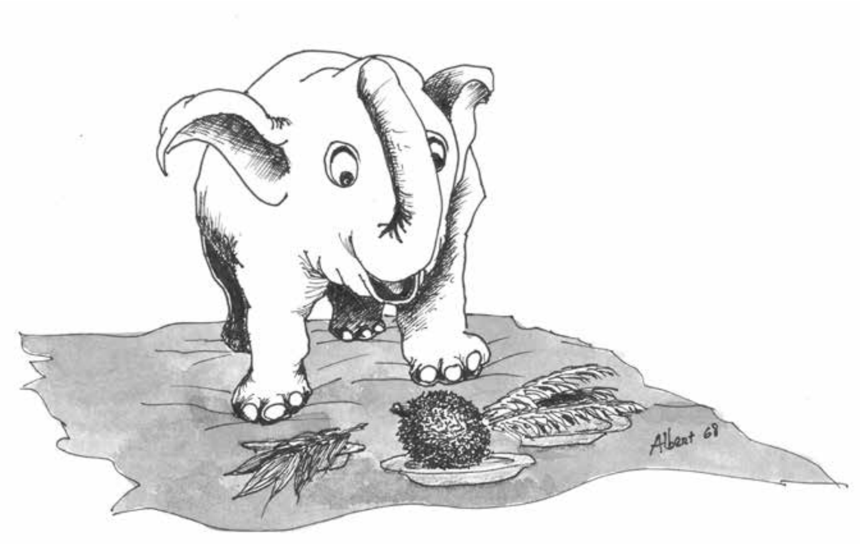
List of food plants found in village and forest transects in the Sebuku area of North Kalimantan

No.	Species	Habitus	Life form categori-zation	Clade	Family	Native or cultivated	Transects															
							Village				Forest											
							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Blechnum orientale	Fern	Seedling	Pteridophytes	Blechnaceae	Native														x		
2	Pteridum caudatum	Fern	Seedling	Pteridophytes	Dennstaedtiaceae	Native							x									
3	Alpinia ligulata	Herb	Seedling	Monocots	Zingiberaceae	Native																x
4	Amomum maximum	Herb	Seedling	Monocots	Zingiberaceae	Native													x	x		
5	Etlingera sp.	Herb	Seedling	Monocots	Zingiberaceae	Native							x		x	x			x			
6	Stachyphrynium borneense	Herb	Seedling	Monocots	Marantaceae	Native							x		x				x	x	x	
7	Donax canniformis	Shrub	Seedling	Monocots	Marantaceae	Native	x		x			x			x	x						
8	Calamus saga	Rattan	Seedling	Monocots	Arecaceae	Native												x			x	
9	Ceratolobus subangulatus	Rattan	Seedling	Monocots	Arecaceae	Native					x						x					
10	Daemonorops sabut	Rattan	Seedling	Monocots	Arecaceae	Native															x	
11	Daemonorops sp.	Rattan	Seedling	Monocots	Arecaceae	Native							x	x	x							
12	Korthalsia ferox	Rattan	Seedling	Monocots	Arecaceae	Native						x								x	x	
13	Korthalsia paucijuga	Rattan	Seedling	Monocots	Arecaceae	Native						x									x	
14	Korthalsia sp.	Rattan	Seedling	Monocots	Arecaceae	Native							x	x	x							
15	Calamus manau	Rattan	Sapling	Monocots	Arecaceae	Native													x		x	
16	Calamus sp.	Rattan	Seedling	Monocots	Arecaceae	Native								x	x				x			x
		Rattan	Sapling	Monocots	Arecaceae	Native					x		x									
17	Licuala spinosa	Palm	Sapling	Monocots	Arecaceae	Native			x										x			
18	Arenga undulatifolia	Palm	Sapling	Monocots	Arecaceae	Native	x															
19	Arenga pinanga	Palm	Sapling	Monocots	Arecaceae	Native			x													
20	Caryota mitis	Palm	Sapling	Monocots	Arecaceae	Native			x													
21	Elaeis guineensis	Palm	Seedling	Monocots	Arecaceae	Cultivated	x	x	x	x												
22	Cocos nucifera	Palm	Seedling	Monocots	Arecaceae	Cultivated	x	x	x													
23	Bambusa multiplex	Bamboo	Sapling	Monocots	Poaceae	Native										x				x	x	x

24	Bambusa oldhamii	Bamboo	Sapling	Monocots	Poaceae	Native										x			x	x	x	
25	Bambusa vulgaris	Bamboo	Sapling	Monocots	Poaceae	Native					x											
26	Dendrocalamus sp.	Bamboo	Sapling	Monocots	Poaceae	Native											x		x			
27	Schizostachyum sp.	Bamboo	Sapling	Monocots	Poaceae	Native											x		x			
28	Saccharum officinarum	Herb	Seedling	Monocots	Poaceae	Cultivated	x	x	x													
29	Saccharum spontaneum	Herb	Seedling	Monocots	Poaceae	Native	x	x	x	x												
30	Zea mays	Herb	Seedling	Monocots	Poaceae	Cultivated	x	x	x													
31	Musa acuminata	Herb	Sapling	Monocots	Musaceae	Cultivated	x	x	x													
32	Musa borneensis	Herb	Sapling	Monocots	Musaceae	Native	x	x	x	x												
33	Ananas comosus	Herb	Seedling	Monocots	Bromeliaceae	Cultivated		x	x													
34	Aporosa grandistipula	Tree	Sapling	Dicots	Phyllanthaceae	Native									x							x
35	Aporosa nitida	Tree	Tree	Dicots	Phyllanthaceae	Native								x					x		x	
36	Ficus obscura	Tree	Sapling	Dicots	Moraceae	Native							x	x			x		x			
37	Ficus pubilimba	Tree	Tree	Dicots	Moraceae	Native														x		x
38	Fordia splendidissima	Tree	Sapling	Dicots	Fabaceae	Native									x				x			
39	Garcinia parvifolia	Tree	Sapling	Dicots	Clusiaceae	Native									x						x	
40	Mallotus echinatus	Tree	Sapling	Dicots	Euphorbiaceae	Native							x	x								
41	Mallotus paniculatus	Tree	Sapling	Dicots	Euphorbiaceae	Native														x	x	x
42	Drypetes kikir	Tree	Tree	Dicots	Euphorbiaceae	Native								x								
43	Drypetes longifolia	Tree	Tree	Dicots	Euphorbiaceae	Native									x							
44	Melastoma affine	Tree	Sapling	Dicots	Melastomataceae	Native													x	x		
45	Melastoma polyanthum	Tree	Sapling	Dicots	Melastomataceae	Native													x	x		
46	Pternandra azurea	Tree	Sapling	Dicots	Melastomataceae	Native								x					x			
47	Pternandra echinata	Tree	Sapling	Dicots	Melastomataceae	Native								x					x			
48	Pternandra rostrata	Tree	Sapling	Dicots	Melastomataceae	Native							x						x	x		
49	Syzygium pendens	Tree	Sapling	Dicots	Myrtaceae	Native								x	x			x				
50	Syzygium alyxifolium	Tree	Tree	Dicots	Myrtaceae	Native															x	
51	Syzygium curtisii	Tree	Tree	Dicots	Myrtaceae	Native											x					x
52	Syzygium tetrapterum	Tree	Tree	Dicots	Myrtaceae	Native													x	x	x	x

5

Bornean elephant food preference based on Nuclear Magnetic Resonance (NMR) metabolic profiling techniques



Submitted as “Investigation of food preference of the Bornean elephant, *Elephas maximus borneensis*, using Nuclear Magnetic Resonance (NMR)-based metabolic profiling techniques”
to Journal of Tropical Ecology, 31 December 2016 (manuscript number: JTE-16-300)
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Abstract

Preference to feed on certain plant species may relate to animal behavior, reflecting the most desirable components that the animal perceives in relation to what food plant is available. Food preference of Bornean elephants (*Elephas maximus borneensis*) was studied, with analytical data on the primary and secondary metabolites of several food plant species that are known to be eaten by Bornean elephants. Chemical properties of Bornean elephant diets were determined to analyze the content of four crop species and nine wild plant species. Plant preference for each consumed plant was described by frequency of feeding signs. All samples were analyzed for nutritional value and data on their metabolite composition was obtained using nuclear magnetic resonance spectroscopy. These data were subjected to multivariate data analyses to identify the common components. Bornean elephants tend to follow a strategy to maximize the energy of their intake by selecting food items rich in sugar and crude protein and to minimize fibrous elements. The fact that they also prefer food items with high glutamate suggests that 'taste' plays a role and this element may be a 'cue' for Bornean elephants to assist foraging and searching for palatable food.

Keywords

Bornean elephant, cue, feeding sign, glutamate, Nuclear Magnetic Resonance (NMR), nutritional value, plant preference

5.1 Introduction

A large body size requires increased metabolic rates and longer ingesta passage rates in comparison to small body size. Together, these are a pre-requisite for the evolution of gut structures, which result in greater digestibility of slowly digestible fractions of forage (Demment & Van Soest 1985; Claus *et al.* 2003). Mega-herbivores such as elephants have evolved non-ruminant hindgut fermentation that allows them to meet their energy requirements through slowly digestible forage in a long intestinal track. Elephants have a faster digestive passage, thus allowing them to tolerate food of lower nutritional quality (Bell 1971). Based on its body size and metabolism, the elephant thus represents the upper end of a tolerance class, tolerating lower-quality food compared to smaller herbivores and ruminants. As hindgut fermenters, elephants more efficiently extract high fiber food per unit time, whilst ruminants have more efficient extraction rates per unit material (Jachmann & Bell 1985).

To extract sufficient energy, hindgut fermenters expand the range of dietary food plants to include high-quality plant species and increase the bulk of food ingestion (Demment & Van Soest 1985; Sukumar 1990). Thus, elephants are not only bulk feeders but also select smaller parts of high-quality food (Jachman & Bell 1985; Price 1991). An adult Asian elephant (*Elephas maximus*) can consume between 150 and 350 kg in wet weight per day (Shoshani & Eisenberg 1982). Elephants exploit a wide range of plant resources (Sukumar 2006), due to their ability to digest cellulose through the present of symbiotic microbes in their large caecum and colon, and by enhanced grinding of fibrous materials with their specialized trunk and high-crowned molar teeth. As a result, more than 250 plant species of over 60 plant families have been reported to be consumed by Asian elephants (Sitompul 2011), but only certain kinds are especially preferred (Shoshani & Eisenberg 1982).

Whenever available, elephants show a preference for high-quality food, that is easy to digest and high in energy, protein, and minerals, but low in certain secondary compounds such as saponins and lignin due to their limiting effects on digestibility. A combination of these food components may make plant parts particularly attractive to elephants (Jachman 1989; Sukumar 1990). There are also certain deficiencies in elephants' diets, e.g. calcium, phosphorus, sodium, iodine and essential fatty acids (Lihong *et al.* 2007). In addition, allelochemicals (e.g. condensed tannins) have been shown to influence food selection, due to their deleterious properties (Rosenthal & Janzen 1979; Jachman 1989). Larger herbivores and hindgut fermenters are less well adapted to deal with these secondary compounds than foregut or ruminant herbivores, although they are known for the ability to reduce the negative effect of these compounds by diversifying diet composition (Clauss *et al.* 2003). The choices made by herbivores may, therefore, reflect both the concentration of secondary compounds and nutrients in available food plants (McArthur *et al.* 1993) and are suggested to be part of an 'optimal foraging strategy' (McNaughton 1979). Besides nutritional values, preference for certain food plant species may also be based on perception; some animals select food components based on what they find most desirable, in relation to what is available (Loehle & Rittenhouse 1982). Such behavioral preferences are driven by a range of stimuli, which may be 'patch-specific' (smell, taste, sight, touch or sound) (Bell 1991; Blake & Inkamba-Nkulu 2004). Due to their highly developed sense of taste (Joshi 2009; Garstang 2015), elephants have been suggested to select in favor of 'better tasting' food plant species.

5.2 Methods

Using multiple approaches, feeding preferences of Bornean elephants were studied during the period of 2012-2014 in Indonesia (Chapter 4). Four crop species and nine wild plant species which could represent utilization level of food plant spectrums by the Bornean elephants in the study area were collected and analyzed [Table 5-1]. Five biological replicates of each plant were randomly represented by location (forest or village), transect and individual plant.

5.2.1 Chemical analysis

Chemical profiles were obtained by comprehensive, qualitative and quantitative analysis, referred to as 'Metabolomics' (Kim *et al.* 2010). In metabolomics, Nuclear Magnetic Resonance (NMR) is considered to be a suitable method to carry out such an extensive analysis because it allows the simultaneous detection of diverse groups of secondary metabolites (flavonoids, alkaloids, terpenoids, etc.) besides abundant primary metabolites (sugars, organic acids, amino acids, etc.), both essential and non-essential components.

Nutritional analysis

Chemical properties of elephant diets were determined by content analyses of the plant samples. To determine the major chemical attributes on which preference was based, all samples were analyzed for dry matter (DM), organic material (OM), crude protein (CP), four fibrous components [the total structural carbohydrate content/neutral detergent fiber (NDF), cellulose plus lignin/acid detergent fiber (ADF), hemicellulose (NDF-ADF) and acid detergent lignin (ADL)], as well as five mineral elements [Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg) and Sodium (Na)]. This analysis was performed at the Laboratory of the Resource Ecology Group at Wageningen University and Research Centre, The Netherlands as follows.

Table 5-1
Thirteen Bornean elephant food samples based on frequency (F) of feeding signs found in the study area arranged according to overall preference by Bornean elephants [N = number of subplots; N_{total}-forest = 120; N_{total}-village = 40; Frequency $(F)_{selected} = N_{selected}/N_{total}$]

No.	Elephant food	Symbol	Family	Life Form	Wild plants (W) or Crop (C)	Transect	$N_{selected}$	$F_{selected}$ (%)	Plant parts sampled	Sample Identity [Location (F=Forest, V=Village); Transect (T); Individual plant/part (n-th)]
1	*Calamus sp.*	C	Arecaceae	Palm	W	Forest	14	11.6	Shoots	F-5-1, F-7-1, F-8-1, F-9-1, F-13-1
2	*Donax canniformis*	Dc	Marantaceae	Shrub	W	Forest	5	4.2	All parts	F-6-1, F-9-1, F-10-1
						Village	3	7.5	All parts	V-1-1, V-3-1
3	*Elaeis guineensis*	Eg	Arecaceae	Palm	C	Village	4	10.0	Shoots (early stage plant)	V-1-1, V-2-1, V-3-1, V-3-2, V-4-1
4	*Etlingera sp.*	E	Zingiberaceae	Herb	W	Forest	12	10.0	All parts	F-7-1, F-9-1, F-10-1, F-10-2, F-13-1
5	*Musa borneensis*	Mb	Musaceae	Herb	W	Village	4	10.0	Stem pith and shoots	V-1-1, V-1-2, V-2-1, V-3-1, V-4-1
6	*Saccharum spontaneum*	Ss	Poaceae	Herb	W	Village	4	10.0	Stem and leaves	V-1-1, V-2-1, V-2-2, V-3-1, V-4-1
7	*Bambusa oldhamii*	Bo	Poaceae	Bamboo	W	Forest	12	10.0	Shoots	F-10-1, F-13-1, F-13-2, F-14-1, F-15-1
8	*Saccharum officinarum*	So	Poaceae	Herb	C	Village	3	7.5	Stem and leaves	V-1-1, V-1-2, V-2-1, V-2-2, V-3-1
9	*Cocos nucifera*	Cn	Arecaceae	Palm	C	Village	3	7.5	Shoots (early stage plant)	V-1-2, V-2-1, V-2-2, V-2-2, V-3-1
10	*Artocarpus heterophyllus*	Ah	Moraceae	Tree	C	Village	2	5.0	Fruits	V-1-1, V-1-2, V-2-1, V-2-2, V-2-3
11	*Licuala spinosa*	L	Arecaceae	Palm	W	Forest	3	2.5	Shoots and stem pith of new clump	F-13-1, F-13-2
						Village	1	2.5	Shoots and stem pith of new clump	V-3-1, V-3-2, V-3-3,
12	*Caryota mitis*	Cm	Arecaceae	Palm	W	Village	1	2.5	Shoots and stem pith of new clump	V-3-1, V-3-2, V-3-3, V-3-4, V-3-5
13	*Arenga pinanga*	Ap	Arecaceae	Palm	W	Village	1	2.5	Shoots and stem pith of new clump	V-3-1, V-3-2, V-3-3, V-3-4, V-3-5

Plant samples were sieved through a 1 mm mesh and analyzed for chemical composition on a dry matter basis. N, P, K, Ca, Mg, and Na contents were measured after destruction with a mixture of H_2SO_4, salicylic acid, H_2O_2 and Selenium (Se) and with a Skalar Sanplus autoanalyzer (Novozamsky *et al.* 1983). The percentage of CP was obtained by multiplying the total N by 6.25 (%CP = %N x 6.25). NDF and ADL were determined according to Van Soest *et al.* (1991) using the ANKOM Technology Technique.

NMR analysis

Other metabolites were analyzed using NMR protocols (Kim *et al.* 2010). This analysis was conducted at Natural Products Laboratory at Leiden University, The Netherlands as follows.

50 mg dried powder was extracted by ultrasonication for 20 min with a 1.5 ml mixture of KH_2PO_4 buffer (pH 6.0) in D_2O containing 0.005% trimethyl silyl propionic acid sodium salt (ww^{-1}) (TMSP) and methanol-d_4 (1:1). Extracts were centrifuged at 13000 rpm for 10 min at 25°C and the supernatant (300 μL) was transferred to a 3 mm-NMR tube.

Nuclear magnetic resonance spectroscopy was performed using the parameters explained in Kim *et al.* (2010). Briefly, ^1H NMR spectra were recorded at 25°C on a Bruker 600MHz AVANCE II NMR spectrometer (Bruker, Karlsruhe, Germany) operating at a proton NMR frequency of 600.13 MHz. Methanol-d_4 was used as the internal lock. Each ^1H NMR spectrum consisted of 64 scans requiring 4 min and 26 s acquisition time with the following parameters: 0.16 Hz/point, pulse width (PW) = 30°(11.3 μs), and relaxation delay (RD) = 1.5 s. A pre-saturation sequence was used to suppress the residual H_2O signal with low power selective irradiation at the H_2O frequency during the recycle delay. FIDs were Fourier transformed with LB = 0.3 Hz. The resulting spectra were manually phased and baseline corrected, and calibrated to TMSP at 0.0 ppm, using XWIN NMR (version 3.5, Bruker).

5.2.2 Statistical analysis

The mean and standard error for each nutritional value of consumed plants was calculated. Different chemical characteristics of Bornean elephant food items were compared to detect differences among consumed plants and differences between consumed wild and crop plants in general.

The ^1H NMR spectra were automatically reduced to ASCII files. Spectral intensities were scaled to TMS signal (δ 0.0) and reduced to integrated regions of equal width (δ 0.04) corresponding to the region of δ 0.0-10.0. The regions of δ 4.85-4.95 and d 3.2-3.4 were excluded from the analysis because of the residual signal of D_2O and CD_3OD, respectively. Bucketing was performed by AMIX software (Bruker) with scaling to the internal standard region (TMSP, from 0.02 to -0.02).

The projections to latent structures (PLS), an extended form of principal component analysis (PCA), are normally used to establish the relationship between two data sets i.e. X (predictors) and Y (response). For the present study, the X-data represent the nutritional values and metabolomics data and the Y-data represent the predictive preference level based on relative frequency of feeding signs of each food plant. PLS modeling was primarily used to predict the chemical shifts from nutritional values and metabolomics data, which are responsible for the food preference of the Bornean elephants. The score plot of PLS with two components shows the samples grouped on the basis of preference. PLS and orthogonal PLS (OPLS) with scaling based on Unit Variance were performed with the SIMCA-P+ software (v. 14.1, Umetrics, Umeå, Sweden).

Since structured noise present in the X-data set could cause systemic variation, this was eliminated by extension of the PLS method known as orthogonal PLS (OPLS). OPLS modeling determines relationships between the two data blocks and divides the systemic variation of X into two model parts: the predictive or parallel part which correlates the X and Y-data, and the orthogonal part which indicates the variation in X-data unrelated to Y-data set (Eriksson *et al*. 2006; Trygg & Wold 2002). By applying the OPLS method, the samples with different preference levels were separated by the predictive component with positive and negative scores.

5.3 Results

5.3.1 Food preference

Feeding signs on three wild food plant species were solely detected on the forest transects (i.e. *Calamus* sp., *Etlingera* sp., and *Bambusa oldhamii*), while two wild food plant species were represented on both forest and village transects (i.e. *Donax canniformis* and *Licuala* sp.), and four wild food plant species on the village transect only (i.e. *Musa borneensis*, *Saccharum spontaneum*, *Caryota mitis*, and *Arenga pinanga*). Four crop plant species had feeding signs on the village transects (i.e. oil palm *Elaeis guineensis*, sugarcane *Saccharum officinarum*, coconut *Cocos nucifera* and jackfruit *Artocarpus heterophyllus*) [Table 5-1].

Plant preference level was predicted by frequency of feeding signs (F) found in the study area for each food plant species [Table 5-1]. *Calamus* sp. and *Donax canniformis* appeared to be the most preferred species (F = 11.6%), followed by five species with F = 10.0%, i.e. *Elaeis guineensis*, *Etlingera* sp., *Musa borneensis*, *Saccharum spontaneum*, and *Bambusa oldhamii*. The less preferred species were indicated by lower frequency respectively, i.e. *Saccharum officinarum* and *Cocos nucifera* (7.5%), *Artocarpus heterophyllus* and

Licuala sp. (5% respectively), *Caryota mitis* and *Arenga pinanga* (2.5% respectively).

5.3.2 Nutritional value of individual plants

Nutritional value of plants varied across species. Table V-2 shows the content of the crude protein, fiber, and lignin. *Calamus* sp., the most preferred wild plant, contained the highest value of CP (33.4-34.6%). Other wild food plants with a relatively high CP value were *Bambusa oldhamii* (18.5-19.1%), *Saccharum spontaneum* (14.6-15.7%) and *Musa borneensis* (13.7-14.7%). Low-level ADL was found in wild plant species which were assumed to be more preferred (based on Jachmann 1989), i.e. *Saccharum spontaneum* (2.1-3.8%), *Donax canniformis* (6.4-6.9%), *Bambusa oldhamii* (5.1-8.2%) and *Calamus* sp. (5.4-8.0%). *Calamus* sp. and *Bambusa oldhamii* were among wild food plants which were low in ADF (17.4-19.2% and 20.9-22.9%, respectively). *Elaeis guineensis* was identified as high in CP (16.7-17.0%), but relatively low in ADF (23.6-25.4%) and ADL (8.5-8.7%). *Saccharum spontaneum* (wild plant) and *Saccharum officinarum* (crop) were high in hemicellulose (27.5-29.0% and 26.7-28.1%, respectively).

Table 5-2 also shows the content of mineral microelements in plants. *Calamus* sp. and *Elaeis guineensis* had the highest content of P (0.60-0.62% and 0.56-0.58%, respectively). The highest level of K was found in *Musa borneensis* (7.0-7.4%), followed by *Donax canniformis* (4.2-4.6%), *Saccharum spontaneum* (4.0-4.5%) and *Elaeis guineensis* (3.9-4.5%). In general, *Elaeis guineensis* had a higher concentration of the analyzed minerals than most of the wild food plants. Ca and Na were less abundant in the most preferred food plants and more abundant in the food plants with lower level preference. *Arenga pinanga* (wild plant) and *Cocos nucifera* (crop plant) had the highest concentration of Na (0.3-0.4% and 0.2%, respectively). *Caryota mitis* had the highest content of Ca (1.1-1.2%).

Figure 5-1a shows the OPLS score plot with the correlation between nutritional data and food preference. In the OPLS model, two orthogonal components explained 52% variation of the total and the cross-validation predictive ability $Q^2(y)$ was 0.40, indicating a good predictability of the model. Y-related (food preference) variables are shown in Figure V-1b. Crude protein, P, K, and hemicellulose (HC) appeared to be positively correlated with preference while fibrous components (ADF and ADL) were negatively correlated with preference. In contrast, Ca and Na, although also significant in their level of separation, were negatively correlated with predictive preference [Figure 5-1b].

Table V-2
Nutrient and mineral composition of Bornean elephant's wild and crop food. [Mean and S.E. (standard error) in parentheses]

Plant species	Wild plants (W) or Crop (C)	W (%)					C (%)				
		CP	NDF	ADF	Hemi	ADL	P	K	Ca	Mg	Na
Calamus sp.	W	34.0 (0.60)	39.2 (0.82)	18.3 (0.88)	20.9 (0.51)	6.7 (1.28)	0.61 (0.01)	3.02 (0.03)	0.44 (0.00)	0.29 (0.01)	0.03 (0.02)
Donax canniformis	W	2.1 (0.07)	72.0 (2.36)	49.3 (1.81)	22.7 (0.54)	6.7 (0.21)	0.08 (0.00)	4.37 (0.21)	0.07 (0.01)	0.14 (0.00)	0.01 (0.01)
Elaeis guineensis	C	16.8 (0.15)	48.7 (1.25)	24.5 (0.90)	24.2 (0.48)	8.6 (0.06)	0.57 (0.01)	4.18 (0.28)	0.82 (0.03)	1.18 (0.09)	0.11 (0.07)
Etlingera sp.	W	3.3 (0.14)	65.1 (2.58)	43.1 (2.42)	22.0 (0.16)	14.7 (1.97)	0.06 (0.00)	3.41 (0.17)	0.26 (0.05)	0.51 (0.06)	0.02 (0.01)
Musa borneensis	W	14.2 (0.51)	61.6 (0.74)	36.9 (0.43)	24.7 (0.32)	11.9 (0.24)	0.35 (0.02)	7.18 (0.23)	0.28 (0.03)	0.29 (0.02)	0.00 (0.00)
Saccharum spontaneum	W	15.2 (0.56)	55.8 (2.45)	27.6 (1.73)	28.2 (0.76)	2.9 (0.81)	0.39 (0.02)	4.27 (0.23)	0.57 (0.06)	0.45 (0.04)	0.03 (0.02)
Bambusa oldhamii	W	18.8 (0.28)	44.4 (0.29)	21.9 (1.00)	22.5 (0.71)	6.7 (1.56)	0.39 (0.01)	3.54 (0.06)	0.14 (0.02)	0.15 (0.01)	0.00 (0.00)
Saccharum officinarum	C	2.8 (0.18)	60.4 (0.80)	33.0 (0.30)	27.4 (0.72)	7.4 (0.30)	0.08 (0.00)	1.87 (0.05)	0.12 (0.00)	0.17 (0.01)	0.00 (0.00)
Cocos nucifera	C	5.9 (1.72)	54.6 (1.14)	34.3 (1.11)	20.4 (0.07)	10.7 (1.36)	0.23 (0.05)	2.39 (0.15)	0.40 (0.06)	0.30 (0.05)	0.21 (0.00)
Artocarpus heterophyllus	C	11.2 (0.26)	42.1 (0.44)	32.5 (0.28)	9.6 (0.27)	17.3 (0.45)	0.15 (0.01)	1.84 (0.03)	0.43 (0.01)	0.17 (0.00)	0.04 (0.01)
Licuala sp.	W	4.8 (0.02)	79.3 (0.03)	56.2 (0.07)	23.1 (0.04)	14.4 (0.19)	0.05 (0.00)	1.26 (0.07)	0.00 (0.00)	0.13 (0.00)	0.00 (0.00)
Caryota mitis	W	14.6 (0.50)	47.5 (2.51)	29.2 (1.15)	18.3 (1.38)	11.8 (0.51)	0.39 (0.03)	3.71 (0.06)	1.13 (0.04)	0.54 (0.01)	0.00 (0.00)
Arenga pinanga	W	15.3 (0.30)	56.5 (6.72)	35.7 (5.07)	20.8 (1.66)	7.7 (0.53)	0.48 (0.01)	4.47 (0.09)	0.69 (0.09)	0.56 (0.01)	0.36 (0.02)

W: weight percentage; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; Hemi: hemicellulose; ADL: acid detergent lignin; C: concentration; P: phosphorus; K: kalium (potassium); Ca: calcium; Mg: magnesium; Na: natrium (sodium)

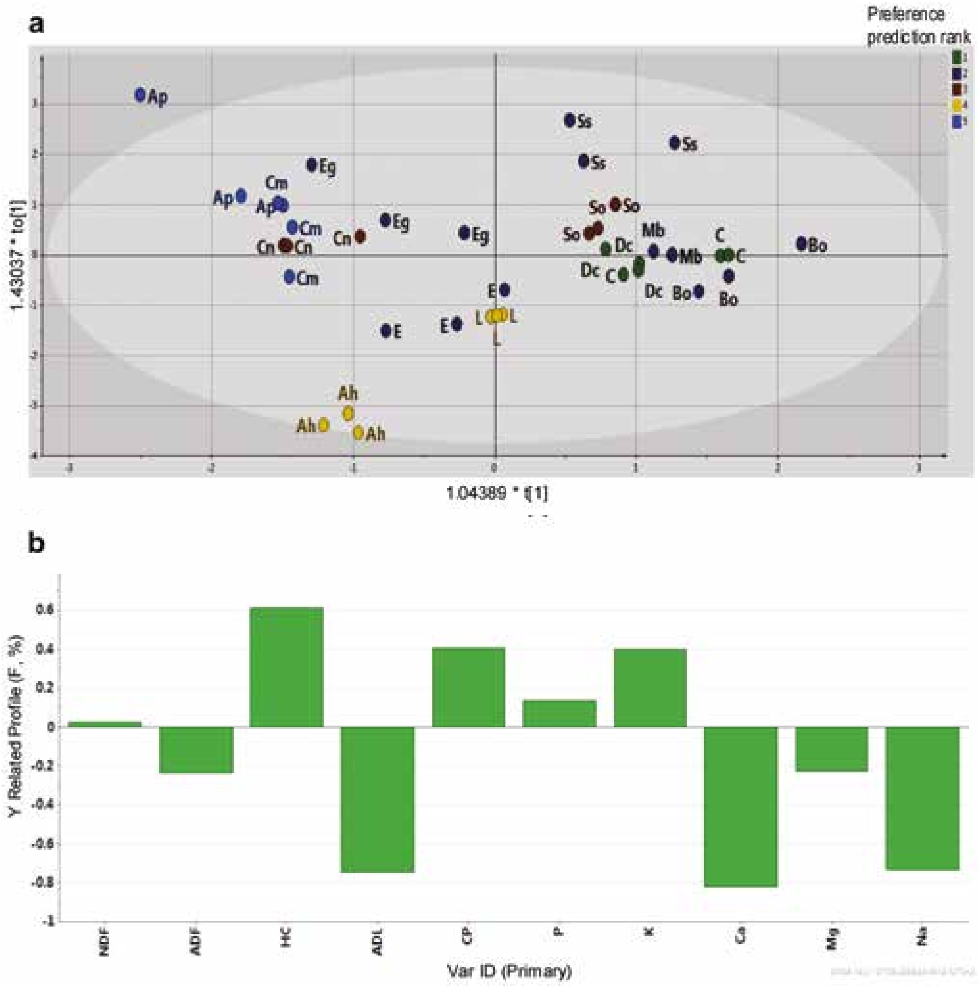

Figure 5-1
The orthogonal projections to latent structures (OPLS) score plot (a) showing separation of nutritional values among the samples. [C = *Calamus* sp., Dc = *Donax canniformis*, Eg = *Elaeis guineensis*, E = *Etlingera* sp., Mb = *Musa borneensis*, Ss = *Saccharum spontaneum*, Bo = *Bambusa oldhamii*, So = *Saccharum officinarum*, Cn = *Cocos nucifera*, Ah = *Artocarpus heterophyllus*, L = *Licuala* sp., Cm = *Caryota mitis*, Ap = *Arenga pinanga*] The y-related profile (b) showing signals that are positively and negatively correlated to the preference prediction. [NDF = Neutral detergent fiber, ADF = Acid detergent fiber, HC = Hemicellulose, ADL = Acid detergent lignin, CP = Crude protein, P = Phosphorus, K = Potassium, Ca = Calcium, Mg = Magnesium, Na = Sodium]

5.3.3 NMR analysis and correlation with food preference

Mostly large metabolites (protein, fiber) and inorganic components were subjected to nutritional composition analysis. During ^{1}H-NMR spectroscopy, all proton containing compounds were detected, providing broader profiles of all metabolites present in the plant. A typical ^{1}H-NMR spectrum of one of the plant species is shown in Figure 5-2. Resonances were assigned according to an in-house library (Chemomx 7.0). Various metabolites such as amino acids, organic acids, sugars and other secondary metabolites (flavonoids, phenolics, tannins) were detected. Due to the great variation in plant profiles, it was necessary to apply chemometric tools such as PCA, partial least squares PLS or orthogonal projections to latent structures (OPLS) to quantify the differences between the spectra and extract latent spectral information correlated to a feeding preference.

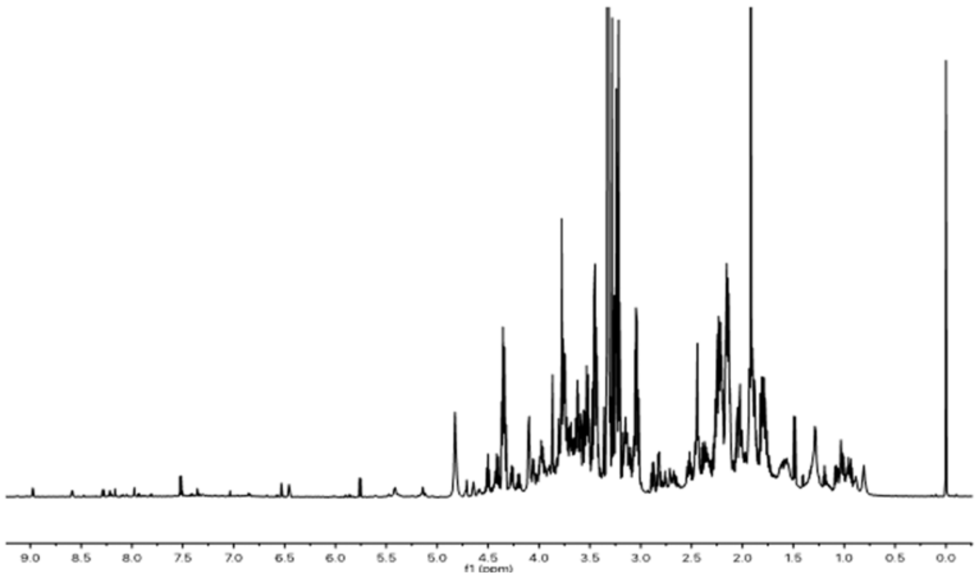

Figure 5-2
^{1}H-NMR spectrum of *Donax canniformis*

No separation was found between crop plants and wild plants based on PCA and PLS-DA (data not shown). However, when applying the OPLS method, the plants with high and low preference are well separated and a clear correlation of the preference was observed [Figure 5-3a]. The OPLS model was constructed using the NMR data as X variables and the food preference (F, %) as Y variable. Two orthogonal components that explain 70% variation of the total were calculated for the model to remove the variation in the NMR spectra unrelated to feeding preference. Validation of the model was performed through cross-validation (CV)-ANOVA with $p < 0.01$, resulting in a cross-validation predictive ability $Q^2(y)$ of 0.65, indicating a good predictability of the model. The R^2, which represents the total explained variation for X, was approximately 28%. Samples with different preference were well separated along the first component indicating that NMR-based profiles could reveal characteristic metabolites in plants from high and low feeding preference.

Since OPLS concentrates all showed discriminating information into the first component, it is sufficient to plot the S-line which allows the visualization of both the covariance and the correlation structure between X-variables (NMR data) and predictive scores. The most dominant resonances responsible for separation were identified as glucose (δ 5.20, d, J = 3.4 Hz, α-glucose; δ 4.65, d, J = 8.0, β-glucose), glutamate (δ 2.10, m, δ 2.36, m) and glutamine (δ 2.14, m, δ 2.46, m) [Figure 5-3b]. In contrast, the presence of gallic acid derivatives (δ 7.10, δ 6.80) made the plant less preferable as a food.

Glucose and glutamate/glutamine appear to be determinant components in the food preference of Bornean elephants. In contrast, the presence of tannin-derivatives reduced the feeding preference of the plants, which is in accordance with previous reports on tannins acting as allelochemicals due to their deleterious properties (Freeland & Janzen 1974; Rosenthal & Janzen 1979; Jachman 1989). For the other nutritional values, the OPLS showed that crude protein, phosphorus, potassium, and hemicellulose were positive discriminants in the Bornean elephant food preference. Other fibrous elements (ADF and lignin) showed a negative correlation.

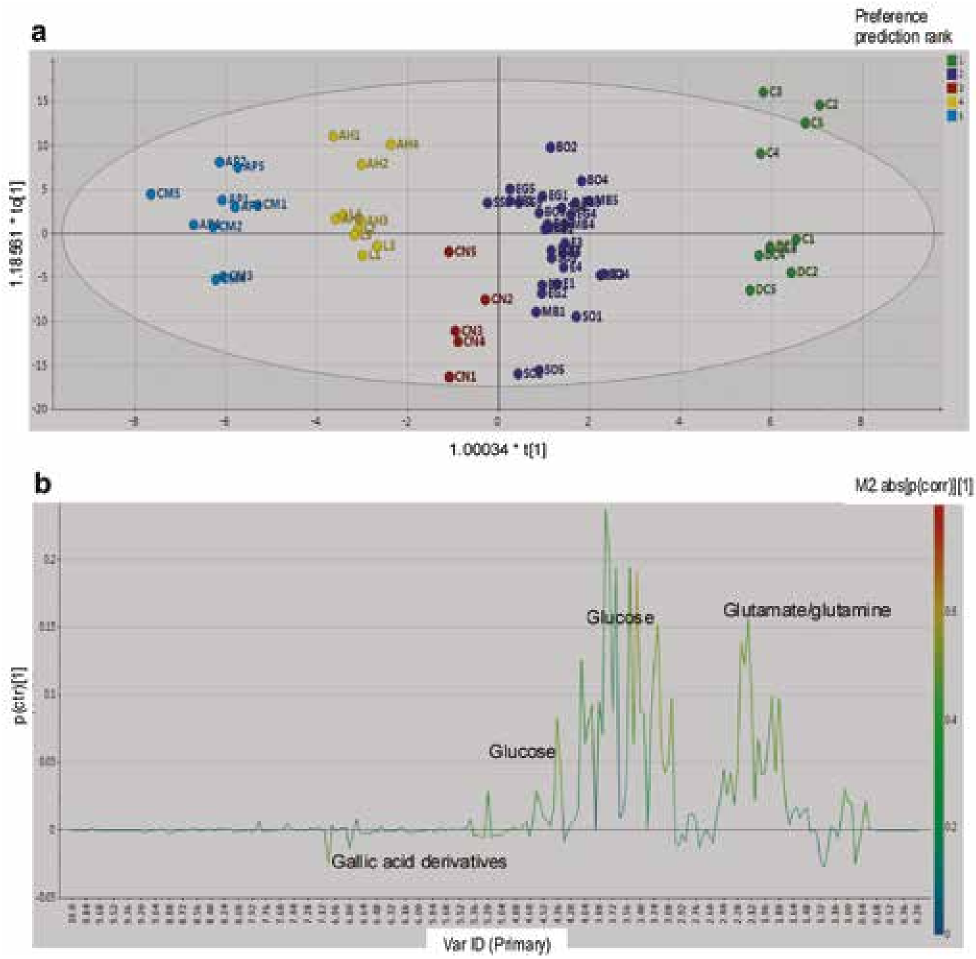

Figure 5-3
The OPLS score plot (a) showing the correlation between ^{1}H NMR data and Bornean elephant predictive food preference level. The loading coefficient plot (b) showing the signals that are positively (on the positive y-axis) and negatively (negative y-axis) correlated to the preference prediction. [C = *Calamus* sp., DC = *Donax canniformis*, EG = *Elaeis guineensis*, E = *Etlingera* sp., MB = *Musa borneensis*, SS = *Saccharum spontaneum*, BO = *Bambusa oldhamii*, SO = *Saccharum officinarum*, CN = *Cocos nucifera*, AH = *Artocarpus heterophyllus*, L = *Licuala* sp., CM = *Caryota mitis*, AP = *Arenga pinanga*]

5.4 Discussion

The results confirm that Bornean elephants follow a strategy to maximize energy intake by selecting food items rich in sugar, protein, and hemicellulose. Glucose is one of the most important carbohydrates used as a source of energy. Hemicellulose, a support material in the cell wall, belongs to a group of heterogeneous polysaccharides. This is in accordance with several other studies demonstrating that elephants are energy maximizers (McCullagh 1969; Pyke *et al.* 1977; McNaughton 1979; Demment & Van Soest 1985; Jachmann 1989; Rode *et al.* 2006; Sitompul 2011; Pretorius *et al.* 2012). This study showed that food preference is also correlated with crude protein, which is in agreement with Pyke *et al.* (1977) and Sitompul (2011). Plant material consists of chemical components that react differently to digestive enzymes within the digestive tract. Protein, sugars, and carbohydrates constitute the active fraction of plant metabolism and can rapidly be digested directly by vertebrate enzymes or fermented rapidly by microbes (Demment & Van Soest 1985). This study further revealed that Bornean elephants optimize their diets for low fiber concentrations, which appears to be common across several elephant populations (Jachmann 1989; Omondi 1995; Nakamura 1996). A lower fiber concentration in the food is likely to have significant effects on diet digestibility. Lignin reduces the digestibility of cell wall matter, and its negative effect on elephant food selection is obvious (Jachmann 1989). In addition, glutamate may intensify the meaty, savory flavor of food, which is suggested to be favored by elephants, thus enhancing palatability (Bellisle 1999; Forde & Lea 2007).

Selection in favor of high-quality plants was also apparent in Bornean elephants; they fed mostly on nutrient rich younger plant parts (e.g. young shoots and stems) (Sukumar 1990; Koricheva & Barton 2012). Depending on nutritional requirements, selective feeding behavior may also vary seasonally (Sukumar 1989, 1995). In Borneo, however, rainfall is common throughout the year (English *et al.* 2014:a), the effect of seasonality is suggested to be less pronounced.

Not only the quality of forage varies between different seasons. Both plant community composition and dietary mineral concentrations vary by season (Sukumar 1992; Nyhus *et al.* 2000), leading to seasonal variations in plant species selection by elephants to meet their dietary mineral requirements (Sukumar 1990; Rode *et al.* 2006). Dietary composition could, therefore, vary based on mineral compositions of plants and their seasonal availability (Chen *et al.* 2006), although plants are not the only possible source of minerals.

Sodium and protein are inversely related because plants that accumulate sodium typically contain low concentrations of protein (Masters *et al.* 2001), e.g. *Cocos nucifera*. The consumption of young/growing tissues increases potassium intake (Jachmann 1989), which at surplus concentrations will be excreted, followed by excretion of sodium. The wild food plant *Arenga pinanga* in this study was found to have a high sodium concentration. This plant had, however, a lower relative frequency and abundance in the preference prediction. This confirms the fact that the sodium availability of elephants may be very critical and in general, sodium concentrations of elephant food plants throughout their ranges in Asia and Africa are extremely low (Weir 1972; Jachmann 1989; Sukumar 1989; Holdo *et al.* 2002; Rode *et al.* 2006).

Two crops in this study were identified as a source of sodium, i.e. coconut (*Cocos nucifera*) and oil palm (*Elaeis guineensis*), and were part of the elephants' diet. Crop raiding could thus be part of an optimal foraging strategy by Bornean elephants. Findings of other studies suggesting that elephants select crops (Jachmann & Bell 1985; Holdo *et al.* 2002; Rode *et al.* 2006) because of a high sodium content, which is generally also associated with increased digestibility, confirm this assumption. The higher percentage of sugar (hemicellulose) in cultivated crops is also likely to be an important incentive for elephants to raid crops.

The ingestion of sodium through sodium rich plants (Jachman 1989; Omondi 1995; Nakamura 1996; Holdo *et al.* 2002; Rode *et al.* 2006) as well as through soils (geophagy) has been widely observed in elephants (Houston *et al.* 2001; Chandrajith *et al.* 2009). At locations where high sodium concentrations are provided through so-called "natural licks", geochemical and mineralogical compositions differ from the surrounding soils. In the study area, at least two natural licks were frequently visited by elephants (Figure 4-1). Besides as a mineral replenishment source (especially sodium and magnesium), natural licks have been suggested to serve as a neutralizer of toxic secondary plant compounds and as a digestive stimulus (Jachman 1989). Clay minerals and in particular kaolinite [$Al_2Si_2O_5(OH)_4$] are absorptive agents of toxic compounds (Houston *et al.* 2001; Chandrajith *et al.* 2009) and elephants that have access to such minerals may be able to feed on a wider range of forest plant species (Houston *et al.* 2001). The presence of natural salt licks in Borneo has even been suggested to partially determine the limited distribution of Bornean elephants (Wulffraat 2006; Matsubayashi *et al.* 2007).

The concept that the presence of glutamate/glutamine in food allows a human consumer to use less salt and decrease their sodium intake while still enjoying palatable food (Bellisle 1999) might also apply to elephants. As greatly social and long-lived species with large home ranges, elephants could also develop a spatial and temporal memory that allows them to select 'tasty' food (Hart *et al.* 2008) and to go back to certain areas after sufficient time has elapsed, in search for resources that could provide replenishment (English *et al.* 2014:b). The NMR-based metabolomics approach revealed a high amount of glutamate in most of the wild food plants preferred by Bornean elephants. This preference suggests that 'taste' plays a role in the selection of food and could influence food searching behavior and thus movement patterns of Bornean elephants.

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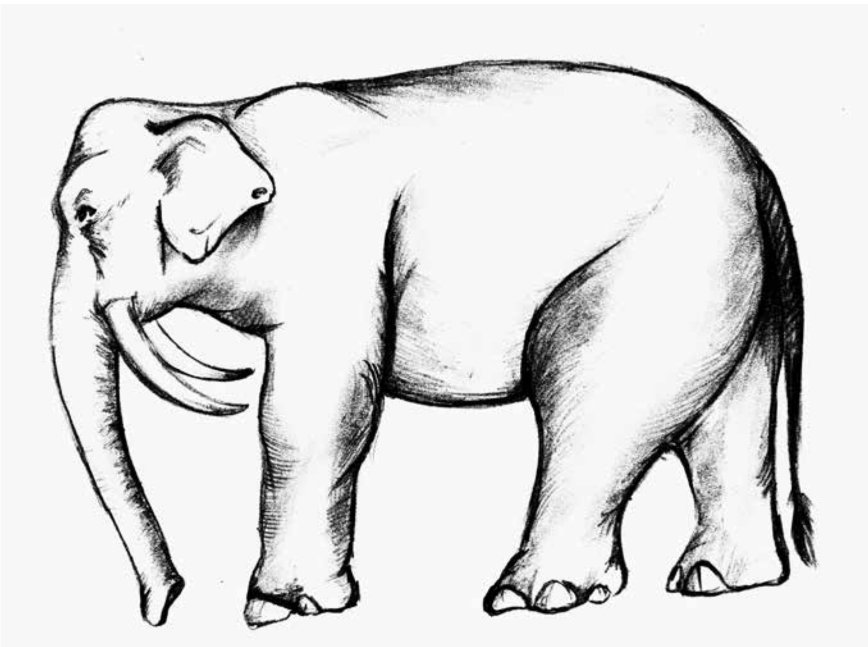
6

Synthesis, conclusions and recommendations



6.1 Patterns and trends in human elephant conflict

Are there any patterns and trends in human-elephant conflicts (HECs) in the Tulin Onsoi Sub-district, and what are the drivers?

My research results show that crop raiding by Bornean elephants is rapidly increasing in the Tulin Onsoi Sub-district, mainly due to rapid conversion of swiddens and secondary forest into oil palm plantations. A multi-temporal analysis covering 2001 to 2014 shows a rapid expansion of industrial-scale oil palm plantations in the area, from 3,302.71 ha in 2001 to 21,124.93 ha in 2014. From 2006 to 2010, the area covered by oil palm plantations increased significantly (418%). 77% of these oil palm plantations were converted from the upland forest. Since 2002, the area has been allocated to oil palm plantations by the government for two main oil palm estates, the *Karangjoang Hijau Lestari* (*KHL*) Group and the *Tirtamadu Sawit Jaya* (*TSJ*) Group.

Land use changes in the study area are particularly related to changes in cultivation practices. Whereas the traditional farming system was based on slash-and-burn agriculture adjacent to rivers and streams (landscape type 'mixed tree and crops'), between 2001 and 2006 this type of landscape has become gradually replaced by 'dry cultivated land'; i.e. open areas with herbaceous vegetation intensively managed for row crops, associated with road networks and human settlements. These land use changes are in accordance with the results of an interview survey, indicating that 85.2% of the villagers now grow oil palm in the NES (Nucleus Estate and Smallholder) scheme (Sheil *et al*. 2009; Rist *et al*. 2010); compared to 6.7% before 2005. My interviews confirmed that HEC was rare in the villages before the start of the oil palm program in 2002 and that the expansion of oil palm plantations is considered as the main cause of the recent increase in crop raiding by elephants.

6.2 Local people's perceptions of and attitudes towards conservation of the Bornean elephant

How does HEC influence local people's perception of and attitudes towards the conservation of the Bornean elephant?

42.3% of the interview respondents had an outright negative attitude towards elephants, which was associated with the extent of crop damage. Despite these negative attitudes towards elephants, no cases of retaliation have been reported so far in the Tulin Onsoi Sub-district. In Sabah, conflicts resulted in the poisoning of 14 Bornean elephants in February 2013 (Hance 2013) and conflict retaliation measures are urgently required to prevent similar incidents in Kalimantan in the future. The losses suffered by villagers due to elephant raids could have long-lasting social impacts (Karanth & Madhusudan 2002). My study reveals that the local people generally have a good knowledge of elephant behavior and the legislation under which elephants are currently protected. The majority of respondents are supportive of elephant conservation in the Tulin Onsoi Sub-district although they feel frustrated about the absence of any government incentives. People are confused why they have to bear the costs associated with the 'government's animals'.

As long as individuals or communities that have been economically impacted by elephants cannot fully support the idea of elephant conservation, HEC incidents could hinder efforts to conserve them (Infield 1988). Efforts to save the elephant and its habitat in the future thus strongly depend on the local support (Infield 1988; Nyhus *et al.* 2000; Fernando *et al.* 2005). Reinforcing traditional practices, perceptions and attitudes of the past could help to achieve this (Fernando *et al.* 2005). As villagers of the Tulin Onsoi Sub-district still emphasize that elephants are part of their history and deserve the people's respect, Bornean elephant conservation should focus on reinvigorating people's traditional knowledge regarding elephants.

6.3 Movement patterns and migration

What is the extent of Bornean elephant movement in space and time in relation to habitat between Sabah in Malaysia and the Sebuku forest of North Kalimantan in Indonesia?

My study has shown that least-cost (LC) modeling, validated by village interviews and field survey, provides a suitable method to identify migration corridors for Bornean elephant conservation. Two types of migration corridors have been identified: (i) dispersal corridors for herds and (ii) crop raid corridors for solitary bulls. Two functional Bornean elephant dispersal corridors have been delineated along the Agison River and the Upper Sibuda River, connecting elephant core habitat in Sabah with the Upper Apan of the Sebuku forest area. These two main corridors together could provide a long term connective stretch of 13.4-44.5 km between the Indonesian sub-population and the Bornean elephant population in Sabah.

Both corridors show an overlap of 'lower cost factors' in the areas North of the Tulid River and the Upper Apan River. These areas are favored by Bornean elephants, especially family herds. The drainage areas of the Apan, Tampilon, and Sibulu rivers are bounded by hilly terrain in the North and Northeastern Tulin Onsoi sub-district which form the 'dispersal boundary' of elephant herds. Elephants have large range requirements which include high-quality habitat composed of core forest areas (Olivier 1978; Sukumar 1992; Kinnaird *et al.* 2003). The estimated core habitat for family herds based on the extent of the dispersal corridor was 186.75 km^2. Using approximate home range requirements for elephant families (60-170 km^2: Olivier 1978; Sukumar 1992), I estimate that the Sebuku forest currently provides a core forest area for 1-2 elephant families.

The dispersal range of solitary bulls in the study area is larger than that of elephant herds. Solitary bulls move further southwest towards the oil palm plantations and village areas. My research results demonstrate that scattered small-holder crop-fields (mainly oil palm) surrounded by shrublands enhanced landscape connectivity for solitary bulls, connecting their forest refuges with crop raiding zones. Secondary re-growth containing elephant food plant species is abundant in these areas, e.g. wild bananas (*Musa borneensis*), bamboo (*Bambusa* sp.), and grass species (*Saccharum spontaneum*). The presence of these food plants could benefit elephants inhabiting the forest – non-forest interface (Sukumar 1990; Zhang & Wang 2003; Rood *et al*. 2010). The scattered small-holder crop-fields act as a 'stepping stone' and increase the vulnerability of oil palm plantations along the boundary of these corridors. Pittiglio *et al.* (2014) also found that crop-fields provide 'crop raiding corridors' for solitary bulls, even across areas with 'high energy cost' and thus 'high resistance', such as typically human-induced land use, at close distance to the village and at steeper slopes. These high resistance areas are compensated by the accessibility of 'easy food' from oil palms and crops in the stepping stone.

As was found in other areas of the elephant's distributional range in Asia, mostly solitary bulls are engaged in crop raiding and often during a certain period of the year. Crop raiding elephants in the areas along the Tulid River were solely solitary bulls and the LC model showed an 'extension' of the dispersal corridors to the South forming the crop raid corridors. The ability of Bornean elephants to adapt their behavior to exploit preferred habitat elements within human-dominated landscapes supports the high correlation between the areas under smallholder land and the presence of elephant dispersal corridors.

Reliable food resource patches that continue to provide a reward for Asian elephants over multiple visits are an important factor driving recursion (Blake & Inkamba-Nkulu 2004; English *et al*. 2014;a). Recursion patterns shown by the corridors in my study suggest that it may be a foraging strategy to revisit areas of great nutritional value and other critical resources such as salt licks. During our fieldwork, at least two sites in Upper Agison and Upper Sibuda have been identified as salt licks, sites that seem to be visited regularly by the Bornean elephants during their movements in the Sebuku forest. In Borneo, it has been proposed that natural salt licks provide sources of high mineral concentrations and that the demand for such minerals or salt licks may partially determine the limited distribution of Bornean elephants, and they might not be able to live in areas where this type of mineral is not available within a couple of days' walk (Payne 1992; Payne *et al.* 1994; Matsubayashi *et al.* 2007; Alfred *et al.* 2011).

6.4 Foraging ecology and major food plants in the diet of Bornean elephants

What is the foraging ecology of Bornean elephants in relation to major food plants in their diet?

52 food plant species were found in the Bornean elephant diet based on feeding signs and 38 additional food plant species based on interviews. Of the plants consumed, species from the Arecaceae, Poaceae, Moraceae, and Euphorbiaceae have also been reported as part of the Bornean elephant's diet in previous studies (Sukumar 1990; Himmelsbach *et al.* 2006; Chen *et al.* 2006; Campos-Arceiz *et al.* 2008; Baskaran *et al.* 2010; Sitompul *et al.* 2013; Roy & Chowdhury 2014). A restriction to a certain group or food plant spectrum for the main part of the diet is confirmed by this study. My study showed that monocots, such as bamboo, banana, and arrowroot species (*Donax canniformis*), rattan, palms, and plants of the ginger family, are important in the diet of Bornean elephants, as suggested in other diet studies of Asian elephants in China (Chen *et al.* 2006) and Myanmar (Himmelsbach *et al.* 2006; Campos-Arceiz *et al.* 2008).

I conclude that Bornean elephants show a sophisticated selection of food items, based on different nutritional properties. Especially carbohydrates contents may be a driving factor in dietary preference by elephants (Van Soest 1982), which could explain their preference for monocots in the study area. Allelochemicals (e.g. condensed tannin) have been shown to influence food selection by herbivores due to their deleterious properties (Freeland & Janzen 1974; Rosenthal & Janzen 1979; Jachman 1989) and bamboo is known as elephant diets with low tannin levels (Easa 1989; Wang *et al.* 2009). Elephants are known to switch between plant species and plant parts to sequester the greatest amount of digestible protein per unit time (O'Connor *et al.* 2007) and this is a behavioral adaptation to cope with declines in N content (Mattson 1980). By doing so, elephants may acquire fatty acids (McCullagh 1973) and minerals such as manganese, iron, boron, copper, and calcium (Bax & Sheldrick 1963; Dougall *et al.* 1964). As in other tropical regions (Olivier 1978), debarking of certain food plants by elephants was observed, i.e. from *Mallotus* sp. and *Artocarpus heterophyllus*. Tree bark is selected for protein (Foguekem *et al.* 2011), minerals, fiber, and preventing colic (Sukumar 1992). Roots are known to contain relatively high carbohydrate and nitrogen levels (Mattson 1980; Van Soest 1982; Hiscocks 1999). In the Sebuku area, elephants fed on the roots of the woody plant *Aporosa* sp. (Euphorbiaceae) and most of the ginger family. *Spondias mombin* (Anacardiaceae) and *Polyalthia* sp. (Annonaceae) can be potentially included as root sources for the elephants in the Sebuku Forest as was also observed for Asian elephants in China (Chen *et al.* 2006), Vietnam (Varma *et al.* 2008), and Myanmar (Campos-Arceiz *et al.* 2008). Most elephant feeding signs were found in young/growing tissues, i.e. shoots, stem pith of new clump, twigs, and young leaves which are known to be higher in quality (Koricheva & Barton 2012). This study further demonstrated the importance of graze (grasses) in Bornean elephant diet despite their living in a tropical rainforest, which is in agreement with e.g. English *et al.* (2014:b). My study period was in the dry season when browsing material was abundant but still, the Bornean elephant was observed to feed on a native 'herb-grass', *Saccharum spontaneum*.

Of 33 dicots potentially consumed by elephants in the study area, 23 were fruit-producing species. Fruits of woody plants from families of Moraceae (5 species), Phyllanthaceae (4 species), Myrtaceae (4 species), Malvaceae (4 species), Euphorbiaceae (2 species), Anacardiaceae (2 species), Clusiaceae (1 species), and Ebenaceae (1 species) are common fruit-families in the Sebuku forest area. Some of the fruit-producing species found in this study are so-called mast fruiting species, e.g. *Durio* spp., *Artocarpus* spp., *Diospyros* spp. (Ebenaceae) and *Syzygium* spp. (Myrtaceae). They are known to be rich in water, carbohydrates, protein, fat, and may contain important nutrients such as vitamins, carotenoids, amino acids, and minerals (Hoe & Siong 1999) and limit their reproduction to mast fruiting events (Cannon *et al.* 2007). During mast fruiting periods, high-quality fruits are abundant, followed by extended periods low food availability. It has been proposed that crop-raiding can ultimately be an extension of the male elephant's optimal foraging strategy and I assume that there is a push factor caused by temporal low nutritional levels in forest food plants, e.g. in-between mast fruiting events.

The percentage of crop species that contributed to the overall dietary plant of Bornean elephants in the Sebuku forest was 10.6%. Crop plants comprised up to 48% of the diet, and species varied depending on the time of year and cultivation surface area. Crop raiding was most frequently found on oil palm (*Elaeis guineensis*), followed by sugar cane (*Saccharum officinarum*), coconut (*Cocos nucifera*), cultivated banana (*Musa acuminata*), corn (*Zea mays*), jackfruit (*Artocarpus heterophyllus*), and pineapple (*Ananas comosus*). The frequency of crop-raiding was seasonal and appeared to be proportional to their availability, which is also in agreement with Sukumar (1990).

6.5 Quality of wild food plants and crops

Chemical properties of the elephant's diet were determined by content analyses of plant samples. To determine the major chemical attributes on which preference was based, all samples were analyzed for dry matter (DM), organic material (OM), crude protein (CP), four fibrous components [the total structural carbohydrate content/neutral detergent fiber (NDF), cellulose plus lignin/acid detergent fiber (ADF), hemicellulose (NDF-ADF), and acid detergent lignin (ADL)], and five mineral elements [Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), and Sodium (Na)]. Due to sample availability and adequacy in the feeding signs, 13 plant species with sufficient amounts were analyzed, i.e. 9 wild plant species and 4 crop species. The plant preference level was predicted based on the frequency of feeding signs found in the study area in the following decreasing order: *Calamus* sp. (w) and *Donax canniformis* (w) > *Elaeis guineensis* (c), *Etlingera* sp. (w), *Musa borneensis* (w), *Saccharum spontaneum* (w), and *Bambusa oldhamii* (w) > *Saccharum officinarum* (c) and *Cocos nucifera* (c) > *Artocarpus heterophyllus* (c) and *Licuala* sp. (w) > *Caryota mitis* (w) and *Arenga pinanga* (w).

What is the quality of wild food plants compared to crops?

Bornean elephants select different food items for different nutritional properties. Nutritional value of plants varied across species. *Calamus* sp. contained the highest value of CP (33.4-34.6%), followed by *Bambusa oldhamii* (18.5-19.1%), *Saccharum spontaneum* (14.6-15.7%), and *Musa borneensis* (13.7-14.7%). Low-level lignin was found in wild plant species which were predicted to be more preferred, i.e. *Saccharum spontaneum* (2.1-3.8%), *Donax canniformis* (6.4-6.9%), *Bambusa oldhamii* (5.1-8.2%) and *Calamus* sp. (5.4-8.0%). *Calamus* sp. and *Bambusa oldhamii* were among wild food plants which were low in fiber (17.4-19.2% and 20.9-22.9%, respectively). Similar to what was found for preferred wild plants, oil palm (*Elaeis guineensis*) was identified as high in crude protein (16.7-17.0%), relatively low in fiber (23.6-25.4%) and lignin (8.5-8.7%). *Saccharum spontaneum* (wild plant) and *Saccharum officinarum* (crop) were high in hemicellulose (27.5-29.0% and 26.7-28.1%, respectively). The results of my research support the hypothesis that Bornean elephants follow a strategy to maximize on energy by selecting food items rich in sugar and also by maximizing the digestion rate of the protein. Elephants in the study area appeared to optimize their diets for low concentration of fiber which is common across several elephant populations (Jachmann 1989; Omondi 1995; Nakamura 1996).

Calamus sp. and *Elaeis guineensis* had the highest content of phosphorus (0.60-0.62% and 0.56-0.58%, respectively). The highest level of potassium was found in *Musa borneensis* (7.0-7.4%), followed by *Donax canniformis*

(4.2-4.6%), *Saccharum spontaneum* (4.0-4.5%), and *Elaeis guineensis* (3.9-4.5%). In general, *Elaeis guineensis* had a higher concentration of the analyzed minerals than most of the wild food plants. Calcium and sodium were less abundant in the most preferred food plants and more abundant in the food plants with lower level preference. *Arenga pinanga* (wild plant) and *Cocos nucifera* (crop plant) had the highest concentration of sodium (0.3-0.4% and 0.2%, respectively). *Caryota mitis* had the highest content of calcium (1.1-1.2%).

Plants that accumulate sodium typically contain low concentrations of protein (Masters *et al.* 2001), e.g. *Cocos nucifera*. The consumption of young/growing tissues generally increases potassium (Jachmann 1989). When potassium concentrations in plants reach a certain level, surplus potassium is excreted, which followed by excretion of sodium. Magnesium content is known to follow the concentration of sodium (Jachmann & Bell 1985). The wild food plant *Arenga pinanga* in this study was found to have a high sodium concentration. This plant had, however, a lower relative frequency and abundance in the preference prediction. Two crops species in this study, i.e. coconut (*Cocos nucifera*) and oil palm (*Elaeis guineensis*), on the other hand, were identified as a source of sodium. This confirms that the sodium availability of elephants may be very critical despite the fact that sodium concentrations of elephant food plants throughout their ranges in Asia and Africa are generally low (Weir 1972; Jachmann 1989; Sukumar 1989; Holdo *et al.* 2002; Rode *et al.* 2006).

Humans have selected their food crops based on considerations of digestibility, the absence of toxins (condensed tannins), productivity and nutritive value, i.e. high levels of carbohydrates and protein (Santiapillai & Ramono 1993; Sitompul 2004; Rode *et al.* 2006). These advantages are likely to be an important incentive for elephants to raid crops. It comes to no surprise that elephants selectively feed on high-quality forage when given the opportunity. Minerals have been a driving factor in the selection of crop species (Sukumar 1990; Rode *et al.* 2006). McNaughton *et al.* (1988) and McDowell (1997) found that copper and sodium exhibited low concentrations in elephant food, and are included as two of three most limiting nutrients (along with phosphorus) for herbivores. Deficiencies of these minerals are common in tropical environments and may result in reduced fitness. The importance of sodium in elephant behavior (Jachmann & Bell 1985; Holdo *et al.* 2002; Rode *et al.* 2006) suggests that this element along with the increased digestibility associated with certain crops could contribute to crop-raiding behavior. The higher percentage of sugar (hemicellulose) in cultivated crops is also likely to be an important incentive for elephants to raid crops.

6.6 Bornean elephant diet preference in response to variation in nutrient reward and plant secondary compounds

Food preference was studied by obtaining analytical data on the primary and secondary chemistry of food plant species that are known to be eaten by Bornean elephants. Chemical profiles were obtained by comprehensive, qualitative and quantitative analysis, referred to as 'Metabolomics' (Kim *et al.* 2010). Nuclear Magnetic Resonance (NMR) was used for the simultaneous detection of diverse groups of secondary metabolites (flavonoids, alkaloids, terpenoids, etc.) and the most abundant primary metabolites (sugars, organic acids, amino acids, etc.), both essential and non-essential components. Comprehensive chemical profiles were performed on the plant species using different methods to analyze compounds in elephant diets which may be associated with dietary preference by the Bornean elephant.

Which compounds in Bornean elephant diets determine dietary preference?

Bornean elephants show a sophisticated selection of food items based on different nutritional properties. NMR spectroscopy identified glucose and glutamate/glutamine as determinant components in the food preference of Bornean elephants. In contrast, the presence of tannin-derivatives reduced the feeding preference of the plants, which is in accordance with the previous report on tannins that could act as allelochemicals due to their deleterious properties (Freeland & Janzen 1974; Rosenthal & Janzen 1979; Jachman 1989). For the other nutritional values, OPLS modeling showed that crude protein, phosphorus, potassium, and hemicellulose were positive discriminants in Bornean elephant food preference while other fibrous elements (ADF and lignin) were negatively correlated.

The interaction between the sensory properties of food plants (i.e. taste and smell) and their post-ingestive consequences is thought to be an important mechanism by which browsing herbivores learn about the toxic and nutritional properties of food (Provenza, 1995; Ginane *et al.* 2005). The fact that Bornean elephants prefer food items with high glutamate suggests that 'taste' plays a role in food selection. Glutamate may intensify the meaty, savory flavor of food which results in a good taste and thus enhances palatability (Bellisle 1999; Forde & Lea 2007). My study confirms that glutamate may act as an important stimulus for to assess nutrient awards of food plants, which could consequently drive their foraging behavior. Based on these findings, acquired behavior is likely to occur within Bornean elephants. As they remember areas containing their preferred food choices, they revisit those areas after sufficient time has passed for resources to replenish (English *et al.* 2014:a). Ginane *et al.* (2005) suggested that in a complex situation with many stimuli, animals may need additional pre-ingestive cues to perceive the whole value of the food. My study also suggests that glutamate could support Bornean elephants' sodium requirements, particularly through preferred wild food plants, i.e. *Calamus* sp., *Donax canniformis*, *Etlingera* sp., *Musa borneensis*, *Saccharum spontaneum*, and *Bambusa oldhamii*.

6.7 General synthesis and recommendations

Preventing further expansion of oil palm plantations in elephant habitat is urgently required to protect the current small population of Bornean elephants in Kalimantan from extinction. Further land use changes could lead to more HEC, either by increased intensity or more elephants involved in crop raiding [Chapter 2]. Oil palm yield improvements through better management practices could reduce pressure for expansion of oil palm fields (Sheil *et al.* 2009), although such measures require strict legislation and follow-up. Appropriate land use planning measures should recognize the Bornean elephant's core habitats and their ecological requirements in terms of feeding ecology and movement, and keeping these under forest cover are key to the conservation of Bornean elephants in the area [Chapter 3].

Feeding signs and tracks of elephants show that two functional corridors could provide sufficient suitable habitat for approximately 1-2 elephant families [Chapter 3]. Wild food plants in the Sebuku forest appear to adequately support the nutritional requirements of Bornean elephants, especially for family herds [Chapter 4 and 5] although certain crops are favored for their sodium, i.e. oil palm (*Elaeis guineensis*) and coconut (*Cocos nucifera*). Sodium has been mentioned as a driving factor for crop raiding behavior (Rode *et al.* 2006). On the other hand, glutamate could partly substitute the need of Bornean elephants for sodium which was found in most of the wild food plants [Chapter 5].

Two functional Bornean elephant dispersal corridors have been confirmed along the Agison River and the Upper Sibuda River which could direct elephants to and from their core habitat in the Upper Apan of the Sebuku forest. These corridors are considered to secure important ranging habitat for the Bornean elephant population, providing connectivity between the Indonesian sub-population and the Bornean elephant population in Sabah [Chapter 3]. Previous research suggests that the small population of Bornean elephants in the Sebuku forest is connected with a larger population of 280-330 elephants in the Kalabakan forest of Sabah (Wulffraat 2006; Riddle *et al.* 2010; Alfred *et al.* 2011). To secure the future of this migrating transboundary population, governments of both Malaysia and Indonesia should collaborate. Although both governments have committed to the long-term maintenance of natural capital through the Heart of Borneo Program, effective coordination between the two countries requires enhanced information sharing and land-use reforms that integrate the need for economic growth, as well as environmental and social sustainability (Wich *et al.* 2012; Runting *et al.* 2014).

Only solitary bulls are involved in crop raiding [Chapter 2 and 3], which could be partly explained by their higher energy requirements due to their larger body mass. Crop-raiding is suggested to be part of an optimal foraging strategy by solitary bulls during periods of 'low' food nutritional quality and availability. Seasonal food shortage in between mast fruiting years may force bulls to feed on crops to satisfy their energy requirements. Interview results suggesting that bulls usually visit the southern villages around February-March and August-October when fruits are rare, confirm this assumption [Chapter 4]. The influence of environmental factors, such as periodicity of mast fruiting years on elephant crop raiding behavior and frequency should, therefore, be considered carefully in the implementation of future HEC mitigation strategies. Follow-up research on this issue is recommended. Although the remaining habitat for Bornean elephants around the Tulid River banks consists primarily of shrublands, this type of marginal habitat provides important food plants for Bornean elephants. The high correlation between the areas under smallholder land within the elephant dispersal corridors confirms the ability of Bornean elephants to adapt their behavior to exploit habitat elements within human-dominated landscapes. Conserving the remaining patches of natural forest within smallholder farms and preventing further encroachment of this critical habitat, even with a patchy distribution and coverage, are important for the future conservation of Bornean elephants [Chapter 3]. National Land Use Plans should be translated into local policies at the lower governmental level, thereby ensuring social equity and environmental sustainability (Wollenberg *et al.* 2007). A combination of such an 'advanced' Land Use Plan and the application of HEC mitigation measures may secure the future existence of Bornean elephants in the Tulin Onsoi Sub-district.

Traditional history acknowledged by local communities in the Tulin Onsoi Sub-district used to emphasize their tolerance toward elephants [Chapter 2]. Therefore, conservation should focus on reinvigorating this traditional history. Conservation education should reinforce people's knowledge regarding elephants. Re-instating WWF efforts to build functional night watch teams as part of village traditions could also be part of initiatives to involve local people in HEC mitigation. Paying compensation could increase the tolerance level of local farmers towards elephants. However, compensation is open to considerable abuse (Tchamba 1996). This method needs a careful assessment to be implemented. The systematic monitoring of the economic value of crop losses by elephants needs much more attention (Zhang & Wang 2003; He *et al.* 2011) to avoid over-estimation of crop damage.

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Summary

My PhD covers the impact of land use changes on human-elephant conflicts (HECs), the feeding ecology and movements of the Bornean elephant (*Elephas maximus borneensis*) in North Kalimantan, Indonesia.

I identified two functional Bornean elephant dispersal corridors in the study area along the Agison River and the Upper Sibuda River which provide a connection between elephant core habitat in the Upper Apan of the Sebuku forest and the Bornean elephant population in Sabah, Malaysia. Although the population of elephants in the Sebuku forest is small, conservation efforts could secure its presence when important habitat of this forest keystone species is adequately protected. Although no retaliation in response to HEC has occurred in the study area, the frequency of crop-raiding incidents is increasing and the forest is being converted at an alarming rate. Current plans for the conversion of remaining forest into timber plantations or oil palm are posing a serious threat to the future of this small sub-population.

Elephant movement patterns represent temporal patterns of site recursion amongst foraging sites. Recursion patterns showed via corridors suggest that it may be part of a foraging strategy to revisit areas of great nutritional value. I recorded fifty-two dietary plant species based on feeding signs of elephants and 38 additional food plant species based on interviews with local communities. Of the plants consumed, food plants from the families of Arecaceae, Poaceae, Moraceae, and Euphorbiaceae, overlap with those suggested in the previous studies on the Asian elephants. My results confirm that there is a restricted number of food plants which form the main part of the elephant diet. Monocots, such as bamboos, bananas, an arrowroot species (*Donax canniformis*), rattan, palms, and plants of the ginger family, were found to be important in the diet of Bornean elephants. In my research, 33 dicots were potentially consumed by the elephants, and 23 of these were fruit-producing species. Some of the fleshy fruit-producing species restrict their reproduction to mass fruiting events. As a result, there are temporally low nutritional levels in forest food plants, e.g. in-between mast fruiting events. Therefore, I recommend follow-up research on the influence of the periodicity of mast fruiting years on the frequency of crop raiding by elephants. These patterns should provide meaningful insights to determine the factors affecting these crop-raiding events more precisely.

Based on Nuclear Magnetic Resonance (NMR) metabolomics was confirmed that Bornean elephants have a sophisticated selection of food items, which is assumed to be based on different nutritional properties. Bornean elephants follow a strategy to maximize energy and total Nitrogen intake by

selecting food items rich in sugar, protein, and hemicellulose. My research also confirmed the selection in favor of food plants with low fiber concentrations and low lignin content. This preference can be explained by the negative impact of fibers and lignin on the digestibility of cell wall matter. My research also confirmed that Bornean elephants showed a preference for glutamate. From literature, it is known that glutamate may intensify the meaty, savory flavor of food and can enhance palatability. This suggests that 'taste' may play a role in the selection of food. Glutamate could also partly satisfy sodium requirements of Bornean elephants. The preference of elephants for certain food plant I found was correlated with the high amount of glutamate in most of the wild food plants, i.e. *Calamus* sp., *Donax canniformis*, *Etlingera* sp., *Musa borneensis*, *Saccharum spontaneum* and *Bambusa oldhamii*. The functional corridors that have been identified indicate that Bornean elephants repeatedly visit particular sites where abundant food plants are found or where salt licks are present. They spent more time at these sites relative to others. Such site could thus represent high-quality areas for elephants in terms of food and other critical resources (such as minerals). Salt licks have been identified to be scattered in the Sebuku forest, and they are visited regularly by elephants. In Borneo, the scarcity of minerals in salt licks may even partially determine the limited distribution of Bornean elephants.

The relatively low frequency of the wild food plant *Arenga pinanga* (which is rich in sodium) based on my preference prediction, suggests that food plants are probably not the main source of sodium for elephants in the study area. I did find two crops with higher levels of sodium; coconut (*Cocos nucifera*) and oil palm (*Elaeis guineensis*), which could provide an incentive for elephants to raid on these crops. The fact that only solitary bulls were found to raid oil palms in the areas around Tulid River where the villages are located could be due to the higher energy requirements of these bulls due to their larger body mass. Crop-raiding is suggested to be part of an optimal foraging strategy by these solitary bulls during certain periods of 'low' food nutritional quality and availability, in between mast fruiting events, when wild food sources are scarce.

Scattered small-holders crop-fields (mainly oil palm) surrounded by shrublands enhanced landscape connectivity for solitary bulls, connecting their core areas with crop raiding zones. These areas are generally flat and dominated by level to gentle slopes. 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 in return could benefit elephants living along the forest – non-forest interface. My research suggests that the scattered small-holder crop-fields act as 'stepping stone' for solitary bull elephants, increasing the vulnerability of oil palm plantations to crop raiding elephants. These stepping stone crop-fields provide 'crop raid corridors' for solitary bulls, even across areas with high resistances, associated with typical human-induced land use, close distance to villages and steeper slopes. The ‘easy food’ provided in these high resistance areas are suggested to compensate for this.

I concluded that the number of conflicts between elephants and humans has increased with the increasing surface of oil palm plantations. Therefore, preventing further expansion of oil palm plantations into elephant habitat is essential to protect current elephant population from extinction and policy makers as well as government should urgently target these issues. As a migrating transboundary population, the successful conservation of Bornean elephants largely depends on an effective partnership between Malaysia and Indonesia. Appropriate land use planning measures should recognize the Bornean elephant’s core habitats and their ecological requirements in terms of feeding ecology and movement, for which the results (e.g. the dispersal corridors) of my study could provide a decent basis.

Although shifting cultivation systems of local communities traditionally allowed human and elephant coexistence through resource partitioning, farming systems have changed rapidly and shifting cultivation has now been largely abandoned. Most local people integrated oil palm in their cultivation practices. Crop raiding by Bornean elephants is increasing rapidly in North Kalimantan, mainly due to a rapid conversion of swiddens and secondary forest into oil palm plantations. In the Tulin Onsoi Sub-district, the area used by oil palm plantations has expanded from 3,303 ha in 2001 to 21,125 ha in 2014, a factor 5 increase. Local people perceive the expansion of oil palm plantations as the main cause of crop raiding by elephants. Their perception and attitude towards elephants is generally negative and the interviewed villagers often expressed their frustration, asking why they have to bear the costs associated with the ‘government’s animals’. Nevertheless, these negative attitudes have not yet led to cases of retaliation in the Tulin Onsoi Sub-district. Public education in terms of coexistence between human and elephants at the community level, thereby reinstating traditional knowledge of elephants could help turning local prejudices and regaining respect for the elephants.

Samenvatting

Mijn PhD onderzoek betrof de impact van veranderingen in landgebruik op de Borneose olifant (*Elephas maximus borneensis*) in Noord Kalimantan, Indonesia. In mijn onderzoek heb ik twee functionele verbindings routes ontdekt langs de Agison rivier en de Boven Sibuda rivier die de core habitat van olifanten in Sabah verbindt met het Sebuku bos reservaat in Noord-Kalimantan. Mijn onderzoek bevestigde dat deze corridors van groot belang zijn voor de verbinding tussen Sabah en Kalimantan. Hoewel de olifanten populatie in Sabah relatief klein is, is het van groot belang deze populatie te beschermen, omdat olifanten beschouwd worden als een sleutelsoort in het tropische bos. Het feit dat olifanten migreren tussen Sabah en Kalimantan maakt dat deze populatie beschouwd kan worden als een gedeelde populatie tussen Maleisië en Indonesië. Dit gegeven is een complicatie voor de beschermingsplannen van zowel Maleisië als Indonesië. Het is van belang dat verdere expansie van oliepalmplantages in de habitat van de olifanten voorkomen wordt, zodat er een levensvatbare populatie olifanten aanwezig blijft. Een verdere expansie van menselijk landgebruik zal resulteren in meer conflicten tussen boeren en olifanten als gevolg van een toename van de schade aan gewassen. Landgebruiksplanning en ruimtelijke ordening zullen rekening moeten houden met de aanwezigheid van olifanten, hun habitat en de ecologische behoeften van olifanten, zoals voedselvoorkeur en migratie. Het intact houden van het natuurlijke bos is een prioriteit voor de bescherming van de Borneose olifant.

In mijn onderzoek bleken de migraties van olifanten een regelmatig patroon te vertonen, gebonden aan seizoenen, langs steeds dezelfde plekken en corridors. Borneose olifanten vertonen een complexe selectie van voedselplanten, gebaseerd op de voedingswaarde van de planten. De olifanten bleken vooral een strategie te volgen van maximalisatie op energie en totale stikstof, waarbij ze voedselplanten prefereerden die rijk waren in suiker, koolhydraten, eiwit en hemicellulose. Mijn onderzoek gaf aan dat olifanten ook selecteren op lage gehaltes aan vezels. Van lignine is bekend dat het de verteerbaarheid van celwanden reduceert, en dit heeft duidelijk een negatief effect op de voedselvoorkeur van olifanten. Borneose olifanten vertoonden in mijn onderzoek een voorkeur voor glutamate. Glutamaat kan invloed hebben op de smaak; het is een smaakversterker. In mijn onderzoek identificeerde ik 66 planten die gegeten warden door olifanten. Daarnaast vond ik nog 24 voedselplanten gebaseerd op interviews. Van de planten die gegeten worden door olifanten was er een overlap met ander onderzoek in Azië van planten uit de families Arecaceae, Poaceae, Moraceae en Euphorbiaceae. Interviews met lokale bewoners toonden ook aan dat er genera van andere families zijn waarvan de plantendelen gegeten worden door olifanten, bijvoorbeeld Areceae (rottan en plamen), Poaceae (speciuaal bamboo), en vruchten (*Syzygium* sp, *Durio* sp, *Artocarpus* sp. en *Ficus* sp.). De resultaten van mijn onderzoek tonen ook aan dat olifanten een duidelijke voorkeur hebben voor een beperkte groep planten. Monocotylen zoals bamboe, bananen en pijlwortelsoorten (*Donax canniformis*), rotan, palmen en gembersoorten blijken tot deze groep te behoren. In mijn onderzoek bleek dat van de 33 soorten dicotylen die gegeten waren door olifanten, 23 vruchten-producerende soorten waren. Sommige planten met vruchten beperken hun vruchtproductie tot zogenaamde "mast "jaren. Hierdoor is er een lager voedselaanbod voor olifanten in de periodes tussen de mast jaren in. Ik vond ook dat olifanten een voorkeur tonen voor voedsel met een hoog gehalte natrium. Dit soort planten kwamen echter weinig voor in de lijst van voorkeursvoedselplanten. De plant *Arenga pinanga* had bijvoorbeeld een hoog gehalte aan natrium, maar deze plant kwam toch weinig voor in de lijst van gegeten planten. De voorkeur voor planten met een hoog gehalte aan natrium bevestigt dat olifanten een tekort kunnen hebben aan natrium omdat natrium gehaltes in de meeste voedsel planten erg laag zijn. Twee andere voedselplanten waren geïdentificeerd als een bron van natrium; *Cocos nucifera* (kokospalm) en oliepalm. Het belang van natrium voor olifanten bevestigt dat de aanwezigheid van natrium in bepaalde gewassen zoals kokospalm en oliepalm, mede een aanleiding kan zijn tot het vernielen van dit soort gewassen. Ook het hoge gehalte van suikers in gecultiveerde gewassen kan een belangrijke aanleiding zijn. Daarom kan het vernielen van gewassen door olifanten beschouwd worden als een onderdeel van een voedselstrategie die maximaliseert op energie, eiwit en mineralen zoals natrium gedurende perioden van een laag natuurlijk voedselaanbod.

De functionele corridors die ik heb gevonden geven aan dat olifanten regelmatig migreren langs dezelfde routes en plekken. Langs deze routes verblijven ze langer op bepaalde plekken. Dit kan een indicatie vormen voor de aanwezigheid van plekken met een hoge kwaliteit in het voedselaanbod. Planten zijn daarbij niet de enige bron van mineralen van belang voor olifanten. Natuurlijke zout *licks* zijn ook een rijke bron van mineralen. De aanwezigheid van deze zout *licks* zou wel eens de verspreiding van olifanten kunnen bepalen. Er zijn verschillende zout *licks* aanwezig in het Sebuku bos reservaat, die regelmatig door olifanten worden bezocht. Vanuit het onderzoek naar humane voeding is bekend dat de aanwezigheid van glutamaat of glutamine in voedsel de consument stimuleert minder zout te consumeren, omdat het voedsel toch smakelijk blijft. Hiermee wordt de suggestie gedaan dat de aanwezigheid van glutamaat een substituut kan vormen voor de afwezigheid van natrium. In mijn onderzoek was de voedselvoorkeur voor bepaalde planten gerelateerd aan de aanwezigheid van glutamaat; bijv in *Calamus* sp, *Donax* *canniformis*, *Etlingera* sp, *Musa borneensis*, *Sacharum spontaeum*, en *Bambusa oldhamii*. De technieken gebaseerd op NMR in het metabolomics laboratorium geven inzicht in de voedselvoorkeur van olifanten in relatie tot de aanwezige stoffen in de geconsumeerde planten. Het feit dat olifanten een voorkeur hebben voor voedselplanten met een hoog gehalte aan glutamaat bevestigt dat smaak een belangrijke rol speelt in de voorkeur.

Dit is wellicht ook een verklaring waarom olifanten nooit verder naar het Zuiden trekken dan de Tulid rivier voor het plunderen van gewassen. Alleen oude mannetjes olifanten brengen schade toe aan oliepalm in het gebied rond de Tulid rivier waar zich dorpen bevinden. Een verklaring hiervoor kunnen de hogere energiebehoeftes zijn van deze oude mannetjes olifanten, vanwege hun grote lichaamsgewicht, zeker in de periode voor de bronst. Het consumeren van gewassen kan daarom beschouwd worden als een onderdeel van een optimale voedselstrategie van de mannetjes olifanten gedurende periodes van voedsel schaarste. De verspreide akkers van boeren die omgeven zijn door secundair bos vormen een toegankelijke corridor voor de oude mannetjes olifanten, die een verbinding vormen tussen hun centrale habitat en de gebieden waar ze gewassen eten. Deze gebieden zijn over het algemeen tamelijk vlak met niet al te steile hellingen. In deze gebieden is een overvloed aan secundair bos met voedselplanten voor olifanten, zoals wilde bananen (Musa borneensis), bamboe (Bambu sp.) en grassen (Sacharum spontaneum). Deze planten komen de olifanten die in deze overgangsgebieden leven ten goede. De verspreide akkers van boeren zijn zodoende een "springplank", waardoor de kwetsbaarheid van de oliepalmplantages wordt vergroot voor schade door olifanten. Deze springplanken vormen dan ook corridors voor de oude mannetjes olifanten, zelfs over gebieden die een hoge weerstandsfactor hebben voor olifanten migratie, zoals nederzettingen en steile hellingen. Deze gebieden van hoge weerstand worden dan gecompenseerd door de aanwezigheid van een hoge kwaliteit aan voedselgewassen.

Schade aan gewassen door Borneose olifanten vertoond een snelle stijging in Noord Kalimantan, vooral als gevolg van de snelle uitbreiding van het areaal aan oliepalmplantage de afgelopen jaren. In het subdistrict van Tulin Onsoi is het areaal aan oliepalm toegenomen van 3.302 ha in 2001 tot 21.124 ha in 2014, een toename van zeker een factor 5. Lokale bewoners geven aan dat de toename van het areaal aan oliepalm de belangrijkste oorzaak is van de toename van schade door olifanten aan gewassen. Schade aan gewassen door olifanten beinvloedt duidelijk de houding en mening van lokale bewoners t.o.v. de olifanten, waardoor culturele waarden kunnen veranderen die het mogelijk maakten voor lokale bewoners om samen te leven met olifanten. Mensen en olifanten hebben in het Tulin Onsoi subdistrict altijd in harmonie kunnen overleven. Het traditionele systeem van zwerflandbouw leek goed te kunnen bestaan in de aanwezigheid van olifanten door het delen van natuurlijke hulpbronnen. De landbouwsystemen zijn echter snel aan het veranderen. De meeste lokale bewoners hebben nu oliepalm geïntegreerd in hun landbouwsysteem. De aanwezigheid van een negatieve houding t.o.v. olifanten hebben in het Tulin Onsoi subdistrict nog niet geleid tot het doden van olifanten. Lokale bewoners vragen zich echter steeds vaker af waarom zij de kosten moeten dragen van de aanwezigheid van olifanten op hun akkers, die beschouwd worden als eigendom van de staat. Traditionele waarden stimuleerden de tolerantie t.o.v. olifanten in het verleden. Het is van belang dat deze traditionele warden in ere worden hersteld.

Acknowledgements

A Ph.D. thesis is supposed to prove one's competence in an independent scientific inquiry. Many people have contributed in one way or another to help me achieve this goal. During my work at the Institute of Environmental Sciences (CML), Leiden University, The Netherlands, I have been supervised by Prof. Dr. Geert de Snoo and Prof. Dr. Hans H. de Iongh. They have patiently guided me over the past year with their valuable advice and suggestion and contributed a great deal to my development as a scientist and a person for which I am thankful. I thank the Indonesian Ministry of Research Technology and Higher Education (through DIKTI scholarship) and CML for supporting the study and providing a doctoral scholarship and a completion scholarship. I would further like to acknowledge NEF (Nagao Environment Foundation), Japan for their financial support to my fieldwork. I am grateful to CML, especially Prof. Arnold Tukker, and Mulawarman University (UNMUL) in Indonesia for the administrative support. I hope CML and UNMUL will continue working together in the coming years. I thank Prof. Peter van Bodegom (CML) and Prof. Wawan Kustiawan (UNMUL) who much initiated this Ph.D. program as part of a collaboration between UNMUL and Leiden University.

I would like to thank people who have been involved in collecting and analyzing data, as well as giving comments and co-writing chapters in this Ph.D. thesis: Dr. Jan van der Ploeg (WorldFish), Frederik van de Perre, M.Sc. (University of Antwerp Belgium), Dr. Hye Kyong Kim and Dr. Young Hae Choi (Natural Product Laboratory, Institute of Biology, Leiden University), Ing. Maarten van't Zelfde and Dr. Wil Tamis (CML), Dr. Sipke van Wieren (Resource Ecology Group, Wageningen University), and three former Master of Biology students of Leiden University: Nils Beveridge, M.Sc., Thomas Wissingh, M.Sc. and Yee Wah Lau, M.Sc., as well as several anonymous reviewers. Prof. Peter van Bodegom, Prof. Wawan Kustiawan, and Prof. Gerard Persoon (Faculty of Social and Behavioural Sciences, Leiden University) also provided helpful comments to the thesis draft. I would also like to thank Dr. Barbara Croes for her service in revision of the English language.

I am grateful to the staff at CML, particularly Jory Sjardin, Susanna van den Oever, Esther Philips, and Joyce Glerum for facilitating my works at CML. Thanks to my fellow Ph.D. researchers who became my friends, my working days at CML were never dull. I consider myself lucky to have had the opportunity with such diverse people from around the world.

I would like to express my gratitude to all of my UNMUL colleagues, especially Dr. Chandradewana Boer and Ir. Ibrahim, WWF-Indonesia East Kalimantan Program, as well as Dr. Benoit Goosens of Danau Girang Field Center in Sabah for their advice. I would like to thank the field assistants (Arie Prasetya, Toni Salsius, Yunus Dayken, Juanisa Andiani, Raymoon Silaban, Sanjaya, and Atma Wahyu) and Ir. Arbain, the botanist, who provided me support during the interviews and field surveys. Finally, I am grateful for all the local guides, local communities, and particularly the village heads for their logistical support and facilitating the data collection.

I would like to dedicate this thesis to my wife (Yeni Anggraini), my daughters (Tari and Tyara) and my whole family, who always support me during my study abroad.

Curriculum Vitae

Rachmat Budiwijaya Suba was born on the 28th of October 1976 in Tarakan, Indonesia. He studied at the Senior High School 1 in Tarakan, Indonesia between 1991 and 1994. In 1999 he obtained his Bachelor of Forestry degree from the Forestry Faculty at Mulawarman University (UNMUL), Samarinda. Following his graduation, he has been employed by his almamater as a lecturer and researcher at the Laboratory of Forest bology. He mainly participated in research on wildlife conservation and monitoring. He lectures to BSc students on fields related to wildlife ecology, biodiversity conservation and management of protected areas. He pursued an MSc in Biology at Leiden University, The Netherlands, between 2004 and 2007 with funding from the Ford Foundation through the International Fellowhip Program (IFP). His MSc project was on The impact of hunting and habitat degradation on population size, structure and relative densities of Bornean *Sambar Deer Cervus unicolor brookei*', supervised by Prof.Dr. Hans H. de Iongh.

In 2009-2010, Rachmat led a project on Bornean elephant conservation in Nunukan District of North Kalimantan which was research project cooperation between Environmental Bureau of Nunukan District and Tropical Forest Research Centre of UNMUL. This research motivated him to do further research on Bornean elephant. In 2012 he was granted a DIKTI scholarship to pursue a PhD program at the Institute of Environmental Sciences, Leiden University, The Netherlands. His PhD on Bornean elephants in North Kalimantan, Indonesia, was conducted under the supervision of Prof.Dr. Geert de Snoo and Prof.Dr. Hans H. de Iongh. In addition to DIKTI scholarship, he received a research grant from Nagao Environmental Foundation (NEF), Japan, and a fund from Leiden University for his PhD completion. During the course of his PhD, Rachmat participated in the creation of Conservation Strategy and Action Plan of Bornean Elephants in Nunukan District. He is also part of Elephant Research Networking which was initiated in 2012 by Sabah Wildlife Department and Danau Girang Field Centre (DGFC) in Sabah. After completing his PhD, Rachmat plans to continue his career as a lecturer and researcher at the Forestry Faculty of Mulawarman University. He hopes that with his PhD experience a series of applicable recommendations could be developed to improve management of Bornean elephants in North Kalimantan.