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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
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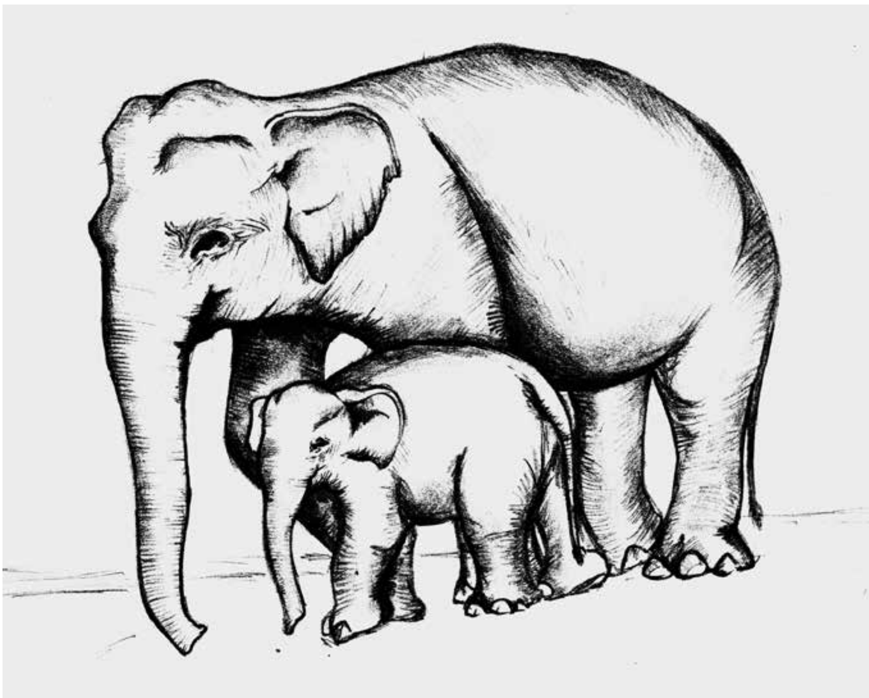
General introduction



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].

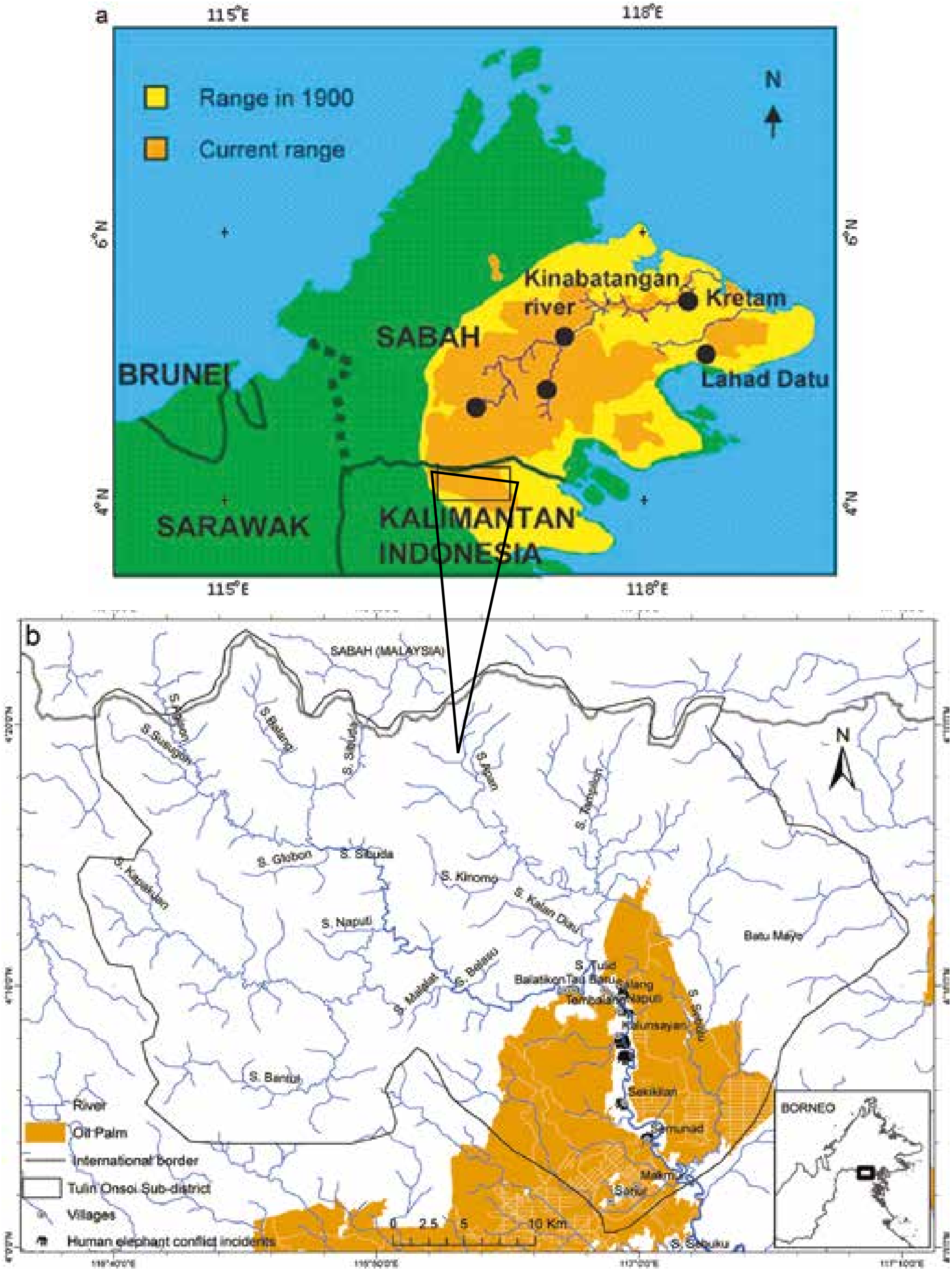


Figure 1-1
Natural range of Bornean elephants (Fernando *et al*. 2003) [a] and map of Tulin Onsoi Sub-district, North Kalimantan Province as part of Bornean elephant ranges [b]

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.

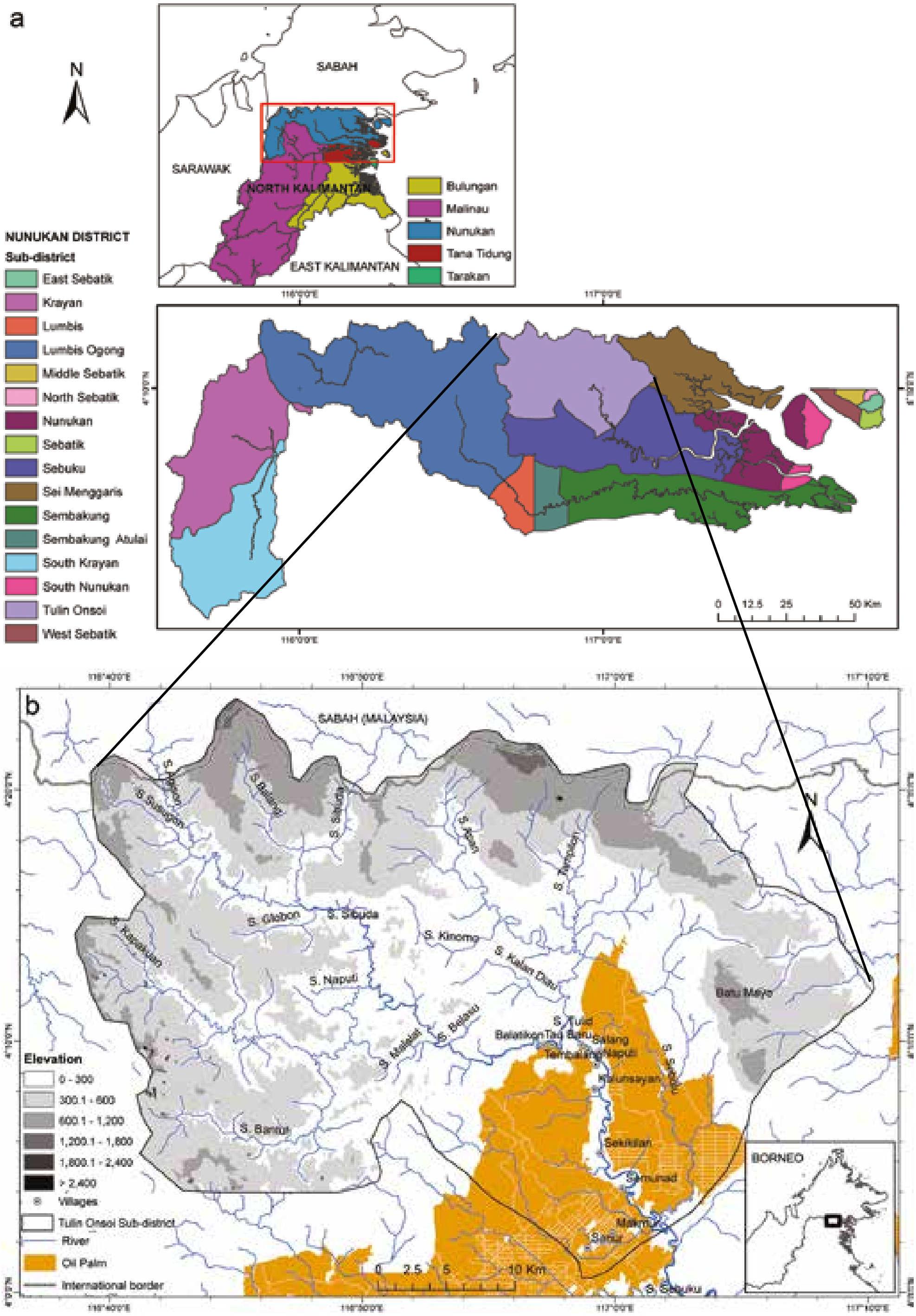


Figure 1-2
Map of North Kalimantan Province, with Nunukan District and Tulin Onsoi Sub-district

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.

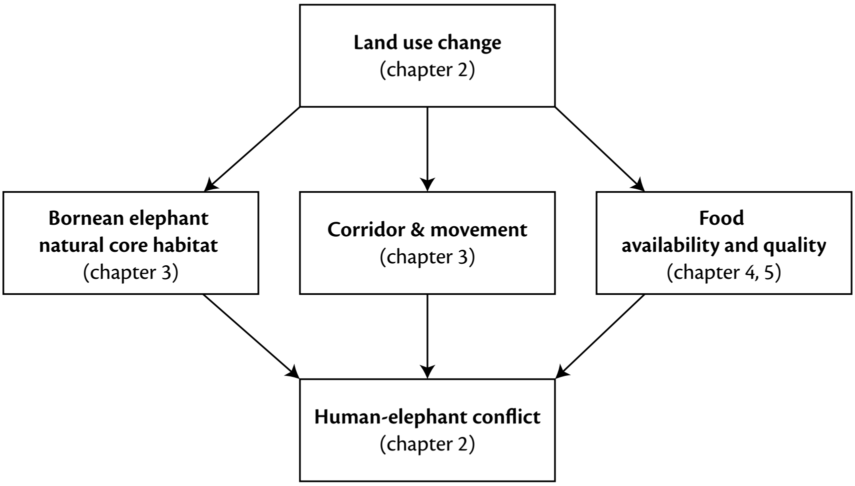


Figure 1-3
The conceptual research framework of impact of land use changes on the human-elephant conflict in relation to feeding ecology and movements of the Bornean elephant in the Sebuku forest

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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