Integrative Zoology 2018; 13: 2–20 doi: 10.1111/1749-4877. 12283

LETTER TO THE EDITOR

Foraging ecology and diet of Bornean elephants (*Elephas maximus borneensis*) in the Sebuku forest area, North Kalimantan Province of Indonesia: Do the choices matter?

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INTRODUCTION

The Bornean elephant (*Elephas maximus borneensis* Deraniyagala, 1950) is a genetically distinct subspecies 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). *E. maximus* has been listed as an endangered species (EN) on the IUCN Red List since 1986 (IUCN 2016). Under Indonesian law (Government Regulation No. 7/1999 for Preservation of Fauna and Flora), the Bornean elephant is also listed as an endangered species (Azmi & Gunaryadi 2011). This status emphasizes 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 (Fig. 1) (Wulffraat 2006).

Around 2000 Bornean elephants are estimated to live in the wild, of which the majority are found in Sabah. 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 (Alfred *et al.* 2011). Around 20–60 elephants are believed to occasionally enter the Sebuku area (Wulffraat 2006).

The population of Bornean elephants in Kalimantan was rediscovered in the 1990s (Payne *et al.* 1994; MacKinnon *et al.* 1996). In 2005, they drew the attention of the 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). In the Nunukan District, with the Sebuku Sub-district as one of the main centers of the oil-palm plantation program, crop-raiding incidents with elephants have at least partly been caused by the implementation of the "one million hectares of oil-palm" program in 2002. Under this program, forests have been converted to agricultural lands, particularly large oil-palm plantations. Nevertheless, efforts to stop land-use conversion have further increased until the end of 2015.

This study uses feeding sign observations and local community knowledge on plants to provide a detailed description of the foraging ecology and diet of Bor-

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nean elephant. This objective is addressed in the following two questions. First, which plant species are included in the Bornean elephant diet? Second, 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 target specific plant groups) could provide key insights into ecological requirements relevant for the management of wild elephant populations and their habitats (Himmelsbach *et al.* 2006; Campos-Arceiz *et al.* 2008). A detailed description of the methods is available in the Supplementary Material.

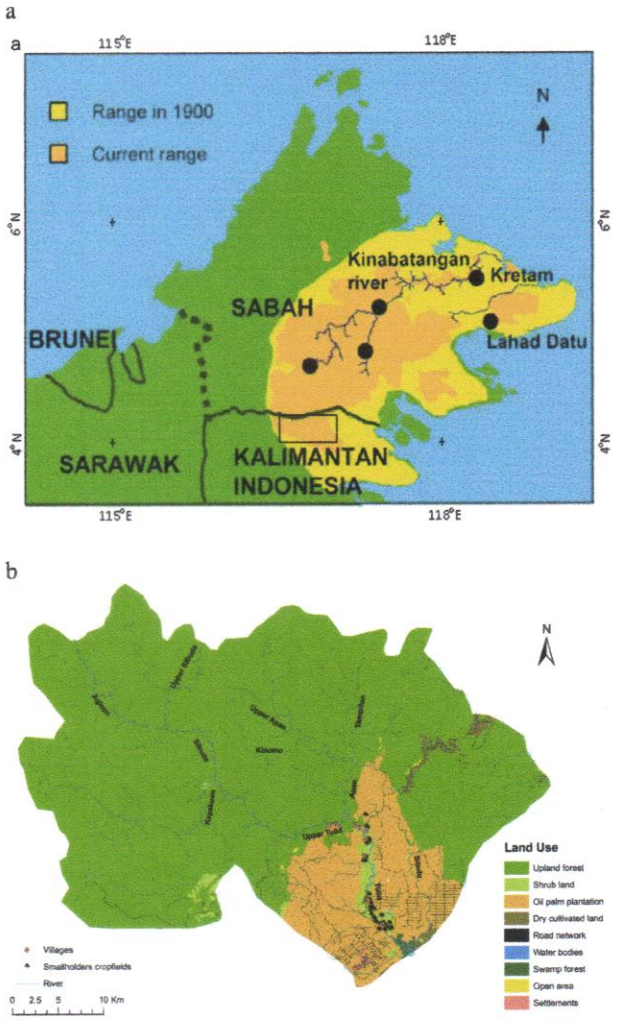

Figure 1 Natural range of Bornean elephant (Fernando *et al.* 2003) (a) Map of Tulin Onsoi Sub-district, North Kalimantan Province, as part of Bornean elephant ranges with existing land-use (b)

QUALITY AS A DETERMINANT FACTOR

Thirty-eight food plant species were identified from interviews with villagers and included palm, rattan, ginger and a few other herbaceous plant species, as well as fruit-tree species (Table S2). Based on feeding signs, 52 food plants were distinguished, representing 18 families. Among the identified food plant species, 45 were wild species and 7 were cultivated crops (Tables S5 and S6). 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 have reported over 100 plant species included in the diet (Chen *et al.* 2006; Himmelsbach *et al.* 2006; Campos-Arceiz *et al.* 2008; Baskaran *et al.* 2010; Sitompul 2011; Roy & Chowdhury 2014). The plant families to which the identified food plants belong do, however, largely overlap with the abovementioned 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 2011).

A restriction to a certain group of plants for the main part of the diet was confirmed by this study. In accordance with 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 (*Bambusa* spp., *Dendrocalamus* sp., *Schizostachyum* sp.), wild banana (*Musa borneensis*), an arrowroot species (*Donax canniformis*), all species of rattan and palms, as well as plants of the ginger family are important in the diet of Bornean elephants. Monocots are suggested to be one of the driving factors of dietary preference by elephants due to their relatively high carbohydrate content (Van Soest 1994). Elephants, as energy maximizers, have a strong preference for energy rich plants (Demment & Van Soest 1985; Jachmann 1989; Rode *et al.* 2006; Sitompul 2011; Pretorius *et al.* 2012).

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, allelo-chemicals, such as condensed tannin, have been shown to influence food selection due to their deleterious properties (Freeland & Janzen 1974; 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 nitrogen 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). *Mallotus* sp. and *Artocarpus heterophyllus* were

eaten from bark. 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 has been 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 1994; Hiscocks 1999).

Selection in favor of high-quality parts was also apparent in the Bornean elephant; they fed mostly on nutrient-rich younger plant parts (e.g. young shoots and stems) (Sukumar 1992; Koricheva & Barton 2012). Depending on nutritional requirements, selective feeding behavior may also vary seasonally (Sukumar 1992). In Borneo, however, where rainfall is common throughout the year, the effect of seasonality is suggested to be less pronounced (MacKinnon *et al.* 1996; English *et al.* 2014). However, the wet tropical forests of Borneo 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 mast-fruiting Dipterocarpaceae. 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 confirmed in this study (*Durio* spp. and *Artocarpus* spp.) are rich in water, carbohydrates, protein and 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 limit their reproduction to mast fruiting events (Cannon *et al.* 2007). During mast fruiting periods, high quality fruits should be abundant. 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 2011) and other large mammals, such as sun bears (*Helarctos malayanus*), orang utans (*Pongo pygmaeus*), gibbon (*Hylobates* spp.), leaf monkey (*Presbytis* spp.) and macaque (*Macaca fascicularis* and *Macaca nemestrina*) (MacKinnon *et al.* 1996; Meijaard *et al.* 2005; Fredriksson *et al.* 2006).

In the Sebuku forest, elephants were found to select particular pioneer plants, mainly for twigs and young leaves (i.e. *Ficus* spp., *Fordia splendidissima* [Fabaceae], and most species from families of Euphorbiaceae, Melastomataceae and Myrtaceae). Many pioneer plants in gap areas are known to store the products of photosynthesis and to provide mechanical protection against foraging by herbivores to achieve a higher growth rate (Coley 1983; Coley *et al.* 1985; Whitmore 1998). In foraging for 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 2011]), 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* spp. (Moraceae) and *Syzygium* spp. (Myrtaceae) as possible examples in the present study.

IMPLICATIONS FOR CONSERVATION

The present study is an initial step towards a detailed identification of the Bornean elephant's diet. Knowledge of the feeding preferences of Bornean elephants is important for the preservation of natural habitats. Maintaining the needs of elephants from inside their habitat requires preserving habitat and food resources (Oelrichs *et al.* 2016). Most of the wild food plants in the Sebuku forest are consumed by the Bornean elephants and appear to be adequate to support their nutritional requirements. Therefore, keeping the habitat under forest cover is essential for the conservation of this species in the Sebuku forest. The disturbed landscape consisting of shrublands and secondary forests still contains a substantial quantity of food plants, such as bamboo (*Bambusa* sp.), wild bananas (*Musa borneensis*) and grass species (*Saccharum spontaneum*). Preservation of such remaining areas in this landscape is necessary for elephant conservation and should be integrated into management planning.

ACKNOWLEDGMENTS

We thank the Indonesian Ministry of National Education and Culture (through a DIKTI scholarship/Directorate General of Higher Education) and the Institute of Environmental Sciences (CML), Leiden University, the Netherlands for supporting the study and providing a doctoral scholarship and a completion scholarship for Rachmat B. Suba. We are grateful to Mulawarman Uni-

versity (Samarinda, Indonesia) for administrative support and for the study permit for Rachmat B. Suba. This project was also partially supported by funds to Rachmat B. Suba from the Nagao Environmental Foundation, Japan. We would like to thank the field assistants (Arie Prasetya, Toni Salsius, Raymoon Silaban and Sanjaya), who provided us support during the fieldwork and interviews. We are grateful to all the local villagers for logistical support and helping in the data collection. We are also grateful to Dr Chandradewana Boer, from the WWF-Indonesia East Kalimantan Program, as well as to Dr Benoit Goosens, of the Danau Girang Field Center in Sabah, for their advice. Professor Peter van Bodegom (Institute of Environmental Sciences, Leiden University) provided helpful comments on the manuscript draft. Finally, we would like to thank Dr Barbara Croes for her service in revision of the English language of the paper.

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SUPPLEMENTARY MATERIALS

Materials and Methods, Supplementary Figures and Tables

Cite this article as:

Suba RB, Beveridge NGP, Kustiawan W, De Snoo GW, De Iongh HH (2018). Foraging ecology and diet of Bornean elephants (*Elephas maximus borneensis*) in the Sebuku forest area, North Kalimantan Province of Indonesia: Do the choices matter? *Integrative Zoology* **13**, xx–xx.