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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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**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 *Arennga 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.