Sumatran elephant *Elephas maximus sumatranus* density and habitat use in relation to forest characteristics in the Leuser Ecosystem, North Sumatra

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Abstract

Forest loss as a result of human activities is causing widespread habitat loss for the critically endangered Sumatran elephant *Elephas maximus sumatranus.* An increase in the global demand for natural resources is believed to be the greatest driver of widespread deforestation throughout the Sumatra and Indonesia, accelerated by the demand of agricultural development and legal and illegal logging. If deforestation continues, remaining populations of Sumatran elephants will become more vulnerable to extinction as their habitat becomes dominated by human landscapes. Continuation of habitat reduction for the Sumatran elephant will likely increase the occurrence of negative human-elephant interactions. Sumatran elephants also remain one of the least understood mammals in regards to their habitat requirements, distribution and population numbers. This study gained a first density estimate of a North Sumatran population residing within Sikundur, a rare lowland forest in the Gunung Leuser National Park and aimed to increase our overall knowledge of elephant habitat use. Ten transects were each walked a minimum of 3 times, totalling 34km. Dung found on the transects were recorded alongside 5m circular vegetation plots that were also undertaken every 125m along the transects. A dung decay rate of 0.0097 was estimated from 14 dung piles residing under different conditions. Elephant density was calculated using the method of McClanahan (1986) & Barnes and Jensen (1987). The density of Sumatran elephants estimated for the lowland forest area of 379km^2 was 71 elephants (0.188 per km^2). Habitat use was determined by comparing vegetation plots near dung piles and those >125m away from dung piles. Ground and understory vegetation and canopy cover did not vary between plots. Tree density was significantly lower and median DBH of trees was greater in areas where dung was present compared to control areas. Elephants were found in all habitat types of the lowland forest, including hill habitats with steep slopes, but were found more often in areas of low elevations (20-55 m.a.s.l). Elephants were found to inhabit areas close to human-dominated landscapes significantly more than areas further away. Elephants also utilised a trail system that exposed them to human traffic but did so less than they used other areas of the forest. Overall, this study brings attention to a previously un-studied elephant population residing in a North Sumatran forest, that remains at risk to habitat loss through on-going deforestation.

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Chapter 1- Introduction

1.1 Background

1.1.1 Tropical Forests Loss and Deforestation

Tropical forests are renowned for being the richest and most biodiverse ecosystems on the planet. These ecosystems are home to a multitude of endemic species and are frequently referred to as 'biodiversity hot spots' (Gentry 1992).A large percentage of the world's tropical forests can be found in South-east Asia. These forests contain an abundance of highly biodiverse ecosystems and contain an array of endemic flora and fauna (FAO 1995, Gentry 1992). At present however, these forests are at most risk to anthropogenic impacts such as large-scale deforestation and biodiversity loss (Kinnaird et al 2003). South-east Asia is at risk of losing more than half of its original forest cover and 13-85% of its biodiversity by 2100 due to dramatically reduced and fragmented forest throughout the region (Achard et al 2002, Sodhi et al 2004). Urbanization and human expansion are the main causes for forest loss, but concessions such as legal and illegal logging, agriculture and monoculture plantations are believed to be the driving force of the rapid widespread deforestation that is occurring today (Sodhi et al 2004).

From 1950, the commercial logging industry was prevalent throughout South-east Asia and as the demand for dipterocarp tree species in Asia increased, many forests were intensely logged (Flint 1994). Although commercial logging has since reduced, legal and illegal logging still occurs in protected areas and elsewhere. Selective logging has been found to alter forest dynamics through the recurrent removal of a specific species (Chapman & Chapman 1997). This modifies forest canopies and can impact the natural mechanisms of tropical forests, negatively affecting species and species diversity (Foody & Cutler 2003, Whitmore 1998, Wilcove et al 2013). Although forest regeneration is possible and has occurred previously in forests that were once logged, successful regeneration depends largely on the degree of logging and can take between 30 and 40 years to show signs of recovery (Okuda et al 2002, Rutten et al 2015). Within the last 30 years, the palm oil industry has become one of the most widespread and destructive concessions within South-east Asia, far exceeding the damage caused by legal and illegal logging. The oil palm (*Elaeis guineensis*) industry has spread rapidly across South-east Asia, growing from only 3.6 million ha in 1961 to 13.2 million ha in 2006 (FAO 2007). Two of the world's largest palm oil countries are currently comprised of Malaysia with 3.6 million ha and Indonesia which holds 4.1 million ha of palm oil plantations (FAO 2007, Margona 2012).

More than half of the expansion of the palm oil industry in Indonesia and Malaysia from the years 1990-2005 is now believed to have occurred to the detriment of biologically rich primary and secondary forests (Koh & Wilcove 2008). Indonesia has experienced the greatest rates of deforestation globally, undergoing a 70% reduction in primary forest cover within the last 60 years and 4.1 million ha of the country has been converted to plantations, far exceeding that of Brazil's deforestation rates (Henders et al 2015, Margona et al 2014, Vijay et al 2016). Land-use change for agricultural or plantation purposes is by far the most intense form of disturbance as often plots of land will be cut down and cleared. The conversion of forests for mono-culture concessions, such as palm oil, are detrimental to biodiversity. This detriment occurs not only through the removal of entire sections of forest, but palm oil has also been found to deplete soil nutrients entirely. This consequently leaves areas of land totally unrecoverable, reducing any hope of restoring it to its original state (Grubb et al 1994, Sodhi et al 2010a). In addition to the potential loss of highly biodiverse and rich ecosystems, South-east Asia's tropical forests also play a key role in the global carbon cycle as they store over half of the world's terrestrial carbon (Sodhi et al 2004). Therefore, as deforestation and forest cover loss continue in the tropics, carbon emissions stored within these forests are quickly being released into the atmosphere, contributing to greenhouse gas emissions and increasing the possibility of serious regional and global consequences (Miettinen et al 2011, van der Werf et al 2009).

1.1.2 History & Current Status of the Sumatran Elephant

As the demand for such concessions continues to rise, the demand for land needed to produce it consequently increases and important habitat for many species is lost (Doyle et al 2010, Koh & Wilcove 2008, Sitompul et al 2013a). Rapid deforestation and growing pressures from human-wildlife conflict are severely affecting wildlife on the Indonesian island of Sumatra, where some of the fastest rates of tropical forest conversion are on-going. As a consequence, many of Sumatra's endemic and endangered species, such as the Sumatran elephant *Elephas maximus sumatranus,* are at risk (Ling 2016, Margona et al 2014, Miettinen et al 2011).

The Sumatran elephant is one of three recognised sub-species of the Asian elephant, endemic to the Indonesian island of Sumatra (Shoshani & Eisenberg 1982, Corbet & Hill 1992). Before the 1900s, the Sumatran elephant was documented as being widespread across Sumatra (Reid 2005). During the 16th and 17th century in the province of Aceh, Sumatran elephants were often used in palace traditions and revered as cultural and ceremonial symbols of status by the sultans, by which a tradition of elephant taming for court and ceremony was undertaken (Lair 1997, van Heurn 1929). When the Dutch colonisation began in 1600, Sumatran elephants were used mainly as draft animals or were captured or killed as development for palm oil, rubber, sugar and tobacco plantations took place (Azmi & Gunaryadi 2011). By 1900, much of Sumatra's primary forest had begun to decrease with the widespread expansion of agricultural settlement and growth in human populations, resulting in the considerable loss of Sumatran forest (Sukumar & Santiapillai 1996). Populations of Sumatran elephants had already decreased significantly by 1931 and the populations continued to decline along with over half of their habitat over the following 60 years, leading to the species being officially listed in Appendix I of the *Convention on International Trade in Endangered Species of Wild Flora and Fauna* (CITES) (Santiapillai & Jackson 1990, Soehartono et al 2007a). In the early 1980s, legal captures of Sumatran elephants occurred in conjunction with government policies to mitigate the rising human- elephant conflict in Sumatra; this resulted in numerous elephant training camps and extraction of wild elephants from their native populations (Azmi & Gunaryadi 2011). In 1985, the first Sumatran elephant survey was undertaken, with the total population estimated at 2800-4800 individuals within 44 populations across Sumatra (Blouch & Haryanto 1984, Blouch & Simbolon 1985). Two decades onwards in 2007, population estimates had reduced by approximately 50%, with 2400-2800 individuals in 25 fragmented populations. However, there is speculation that the populations numbers are much lower at present, with only 1180 individuals thought left to be remaining in the wild (Blake & Hedges 2004, Soehartono et al 2007b, Santiapillai & Sukumar 2006, Sukumar 2006).

Presently, 10% of Sumatra's total area is protected by 11 national parks and reserves, offering moderate protection against illegal activities such as poaching, illegal logging and creation of illegal plantations. Outside of these protected areas an estimated 85% optimal elephant habitat remains, but is left unprotected and at risk (Santiapillai & Jackson 1990). Habitat that does fall under this protection has also been found lacking in enforcement and prosecution (Santiapillai & Jackson 1990, Jepson et al 2001 & Robertson & van Schaik 2001). Populations now remain in very scattered herds across the 8 provinces of Sumatra, but out of all 8 provinces, the distribution of elephants in North Sumatra remains the least understood and most under-studied (Azmi & Gunaryadi 2011, Blouch & Haryanto 1984, Blouch & Simbolon 1985). As a consequence of the human expansion and colonisation in Sumatra over the course of several hundred years, the Sumatran elephant is now classified as critically endangered and declining by the *International Union for the Conservation of Nature* (IUCN) (Azmi & Gunaryadi 2011, Gopala et al 2011, CITES 2017). The Sumatran elephant continues to remain vulnerable to further declines, which may even result in the potential loss of the sub-species in the future if no action is taken to better understand and protect both the elephants and their habitat.

1.1.3 Sumatran Elephant Habitat & Forest Structure

Despite an increase in the research and conservation efforts of the Sumatran elephant in the last three decades, there is still large gaps in our overall knowledge of the sub-species. Difficulties in observing forest elephants directly are often encountered due to dense forest environments and their elusive nature, therefore dung count surveys are a common method used for data collection in relation to density estimates and habitat studies (Mwambola et al 2016). The recce or reconnaissance transect method of Walsh & White (1999) is now a widely adopted approach used when conducting transects. The recce transect method allows for flexibility regarding the compass bearing as the bearing is followed only marginally, dissimilar to the line transect method where a straight line is required throughout. The recce transect method states that the bearing is followed but the path of least resistance should be taken when possible, by means of trails or natural features such as waterways or forest openings (Walsh & White 1999). To estimate elephant density effectively from dung count surveys, data on the rates of elephant defecation and dung-pile decay is required (Hedges & Lawson 2006, Vanleeuwe & Probert 2014). Dung-pile decay rate will vary depending on numerous environmental factors, including rainfall, sunlight exposure, canopy cover and temperature, all of which can greatly vary per season and site (Barnes & Dunn 2002, White 1995). Rates of decay are also dependent on biological factors such as diet composition, which can have overall resulting effects on the composition of dung and how quickly it deteriorates; it is therefore important to conduct individual dung decay studies for per site when undertaking density studies (Hedges & Lawson 2006, White 1995).

As there was previously less data on the diet, ecology and habitat requirements of the Sumatran elephant, the sub-species was often associated with other Asian elephant species due to the lack of specific data, and studies conducted on the sub-species specifically often focused primarily on density estimates, population structure and human elephant conflict and within intensely studied sites in Sumatra. Fortunately, within the last decade, there has been an increase in Sumatran elephant research occurring in the lesser studied areas of Sumatra, focusing on habitat use, suitability and dung decay (Hedges & Lawson 2006, Moßbrucker 2016b, Rizwar et al 2014, Rood et al 2010, Sitompul et al 2013a, Sitompul et al 2013b, Zahrah et al 2014, Sulistyawan et al 2017).

Sumatran elephants have been found to traverse their environment based on the availability of food, water, canopy cover, local climate, seasonality, topography and habitat connectivity (Kumar et al 2010, Sukumar 2006). Previous research has shown that Sumatran elephants will utilise both natural primary forest and disturbed secondary forest, but often prefer secondary forest, despite being exposed to human disturbance such as logging. Secondary forests have been found to contain an abundance of fast growing elephant food and a diversity of mosaic habitats, including edge habitats (Olivier 1978, Hedges et al 2005, Zahrah et al 2014, Rood et al 2010, Seidensticker, 1984, Santiapillai & Suprahman 1995). Elephants are generalist feeders and possess wide-ranging diets, consuming many grass and woody plant species depending on seasonality (Owen-Smith, 1988). Previous studies have shown that Sumatran elephants prefer to consume young and quick growing woody vegetation, between 1-32cm diameter at breast height (DBH), but favour saplings between 2-4cm DBH (Santiapillai & Suprahman 1995, Owen-Smith, 1988). As elephants require large amounts of water to drink, they will often show a preference for alluvial areas such as rivers or streams (Santiapillai 1984, Sukumar 1989 & Chong 2005). The influence of altitude and slope on elephant distribution is frequently debated; in the past elephants were believed to solely favour lowland forests, and have their movements constrained by high slopes and elevation (Hedges et al 2005, Pradhan & Wegge 2007). Studies have shown that elephants occur most frequently between altitudes of 300-500 metres above sea level (m.a.s.l) and below 300 m.a.s.l (Zahrah et al 2014). Sumatran elephants have however been observed occurring in highland and mountainous forests of up to 1600 m.a.s.l (Rood et al 2010). These areas have been found to contain valleys which encompass high productivity forests and natural waterways that elephants utilise (Rood et al 2010, Pan et al 2009). It is therefore likely that, although elephants prefer flat lowland forests, they are not constrained by high elevations such as mountainous areas. Rood et al (2010) did find that the terrain ruggedness of an area will impact general distribution of elephants; therefore areas with steep slopes may be less favourable than areas without.

During the day Sumatran elephants have been observed undertaking most of their activities beneath canopy cover compared to open areas (Sitompul et al 2013). When elephants do venture from underneath canopy cover, it is often to pasture within grassland or scrub areas and occurs predominantly when the weather is cloudier (Sitompul 2011, Zahrah et al 2014). Ideal canopy cover is expected to range between 20%-60% and not above 80% as ground flora and potential elephant food will be greater in areas with a sparser canopy (Zahrah et al 2014). Sumatran elephants have been observed inhabiting forest edges more often than the interior of the forest (Sitompul et al 2013, Rood et al 2010), however, this is contrasted by previous research conducted by Kinnaird et al (2003) which observed elephants avoiding forest edges of up to 3km, suggesting that elephants favour undisturbed forest. Nonetheless, as forest edges are typically rich in new growth of ground flora, they provide elephants with an abundance of food (Sukumar, 1989, 1990; Zhang & Wang, 2003). This abundance of elephant food located around forest edges may explain why elephants are often observed near human-dominated landscapes, however it is unclear whether it is also influenced by lack of food or space within the forest that causes this behaviour. Although elephants are believed to avoid areas with increased human population numbers (Graham et al 2009, Rood et al 2011, Songhurst et al 2015), deforestation and habitat loss may cause an increase in the occurrence of elephants near human landscapes in the search for resources (Granados et al 2012)

1.1.4 Response and Consequences of Habitat Loss

The large-scale conversion of forests to monoculture plantations, farmland and urban areas has drastically reduced the available habitat for many species in Sumatra. As a consequence of habitat and forest reduction, the distribution of many large bodied and wide-ranging species, such as the Sumatran elephant, have been compressed within human dominated landscapes. Elephants require large home ranges, and the Sumatran elephant home range is estimated to be between $275km^2$ and $1352km^2$ (Moβbrucker et al 2016a). However, the increase in human expansion through concession activities such as monoculture plantations is reducing the viable habitat for Sumatran elephants and their contact with humans is increasing. Elephants are known to suffer the costs of habitat loss much more rapidly compared with other species, and therefore populations of the Sumatran elephant are now at an increased risk of becoming fragmented and pushed into ‘pocketed herds’ as viable habitat continues to decrease (Olivier 1978, Santiapillai and Jackson 1990). If population numbers continue to decrease and Sumatran elephants are pushed into small isolated populations, genetic diversity will become an important factor in the survivability of the species (Frankham et al 2002). In previous studies, the minimum viable population of Asian elephants with a high probability of survival was believed to be between 100-200 individuals, but this depends largely on demography, sex ratio and local ecological pressures (Moβbrucker et al 2016b, Sukumar 1993). As numbers of Sumatran elephants decrease, the possibility for skewed sex ratios and inbreeding becomes more prevalent and extinction of the species becomes much more likely in the future (Moβbrucker et al 2016, Vidya et al 2007).

If elephant habitat continues to decline, not only will population numbers drop significantly, resulting in the possible extinction of the species, but resulting effects on their ecosystems could occur. Elephants are firmly recognised as ‘ecosystem engineers’, undertaking important maintenance roles in forest ecosystems and influencing forest dynamics through the modification of the physical environment (Jones et al 1994, Wright & Jones 2006). Elephants have been shown to indirectly influence microhabitat selection of other species through direct and indirect modifications. For example, through the up-rooting or damaging of trees and vegetation, elephants can provide natural trails through the forest that are used by other species, create micro-habitats for smaller species, and can cause an increase of heterogeneity of the forest through creation of tree canopy gaps (Valeix et al 2011, Haynes 2012, Pringle 2008). Elephants are also known to assist in seed dispersal and germination, for example forest elephants in Africa have been widely studied to disperse a high diversity of seeds over large distances, maintaining tree diversity and assisting in ecosystem functioning (Blake et al 2009, Campos-Arceiz & Blake 2011). As elephants are also found to be food species selective, they can greatly influence the overall composition of their environment (Sukumar, 2003, Kitamura, Yumoto, Poonswad, & Wohandee 2007). Although less is known regarding the role of Asian elephants in seed dispersal when compared to their African counterparts, a high proportion of the seeds ingested by Asian elephants are defecated intact, and in viable conditions for germination, therefore they may play a larger role in seed dispersal and forest diversity than is understood (Campos-Arceiz et al 2008). Due to their large home range size, elephants are also appointed as umbrella species within ecosystems. An umbrella species benefits other species through the process of their conservation and the overall protection of their habitat (Entwistle & Dunstone 2000).

1.1.5 Human-Elephant Conflict

Human wildlife conflict (HWC) is defined as an interaction between humans and wildlife that can have adverse negative effects upon one another, with the overall capacity to impact human social, cultural and economic livelihoods and compromise vulnerable species (Conover 2002, Parker 2007). The occurrence of HWC is not perceived as a new phenomenon, interactions between humans and wildlife have been known to occur for millennia, typically taking place when humans live in close proximity to wildlife (Woodroffe et al 2005). However, within recent decades, interactions between humans and wildlife have been observed increasing in frequency and severity due to increased spread of humans, planting of crops and the reduction and fragmentation of habitat for the native wildlife and thus proximity between wildlife and humans is often increasing (Lamarque et al 2009, Perera 2009). Asian elephants are particularly vulnerable to habitat loss and HWC as they possess large home ranges and a preference for lowland forests, which at present are most at risk to deforestation (Hedges et al 2005, Perera 2009, Rood 2010, Sitompul et al 2013). Negative interactions between humans and elephants are currently prevalent on the island of Sumatra, where destruction of Sumatran elephant habitat through conversion of land into agricultural or plantation areas has vastly increased contact between humans and elephants, resulting in reports of crop raiding, poaching and death/injury to both humans and elephants (Doyle et al 2010, Hoare 1999a, Nyhus et al 2000).

Combined with extensive habitat loss, human elephant conflict (HEC) is believed to be one of the major threats faced in the conservation of the Sumatran elephant, reducing local support for the protection of the species by increasing negative perceptions (Suba et al 2017). Negative perceptions have been found primarily to be influenced by recurrent crop raiding incidents, lack of effective mitigation strategies and frustration from lack of compensation when incidents occur (Nyphus et al 2000, Suba et al 2017). The mitigation strategies that have previously been attempted to lessen HEC in Indonesia, and elsewhere, often only bring short term resolution, yielding varying results in effectiveness (Nyphus et al 2000, Hoare 1999b). It is now believed that certain mitigation strategies may even result in greater detriment to the local reputation of the elephants and may contribute to the declining numbers; these include capturing troublesome elephants, translocation, elephant drives and restrictions of range (Fernando & Pastorini 2011).

As habitat for Sumatran elephants decreases due to the expansion of human settlements and monoculture plantations (Achard et al 2002, Sodhi et al 2004), it is more likely that the proximity between humans and elephants will intensify due to habitat loss, understanding how elephants respond are distributed in relation to human-dominated landscapes is therefore crucial in the conservation of the species. It is evident that human-elephant interactions are occurring in Sumatra, but we need a further understanding of the presence of elephants around human-dominated landscapes and what the influencing factors are for this distribution. This understanding could be vital in reducing human-elephant conflict, improving elephant conservation strategies and improve the well-being and livelihoods of the local people that live beside them (Child 1995). Improved enforcement in optimal areas of elephant habitat are similarly in much need of improvement, ideally in both protected and unprotected areas, to reduce poaching and illegal activities at these boundaries. An overall aim to increase our knowledge of elephant distribution around human-dominated areas could help reduce or mitigate the interactions between local people and the elephants, ultimately helping to reduce conflicts and improving the conservation of the Sumatran elephant as a whole.

1.2 Study Species Overview

The Sumatran elephant *Elephas maximus sumatranus* is one of three recognised sub-species of the Asian elephant *Elephas maximus*, alongside the Indian elephant (*Elephas maximus indicus)*, Sri Lankan elephant *(Elephas maximus maximus),* and the Bornean elephant *(Elephas maximus borneensis)* (Shoshani and Eisenberg 1982). Together with their African counterparts, these elephants comprise the few remaining mega-herbivores on Earth (Galetti et al 2017). The Sumatran elephant is endemic to the Indonesian island of Sumatra, defined as an Evolutionary Significant Unit (ESU), and regarded as an evolutionary important sub-species (Flesicher et al 2001). The Sumatran elephant is a generalist feeder that possesses wide-ranging diets, consuming many grass, and woody plant species. They also require large amounts of water to drink, often favouring areas close to water resources, such as rivers or streams (Owen-Smith 1988, Santiapillai 1984, Sukumar 1989 & Chong 2005). Similar to other Asian elephants, Sumatran elephants live within multi-tiered social systems and are comprised of individuals living in matriarchal groups. Family units are often comprised of 4-8 individuals at a time but will often congregate in groups of up to 45 individuals ((Sukumar & Santiapillai 1996). The range of the species is believed to be constrained by the overall availability of viable habitat, which will depend largely on factors including the availability of food and water, canopy cover, climate, human activity and topography (Kumar et al 2010, Sukumar 2006). Only a limited number of studies have been conducted regarding the home range of the Sumatran elephant, but this is likely to range from as low as 95km^2 up to 1352km^2 and will vary depending on the amount of habitat availability and human encroachment (Moβrucker et al 2016a, Sitompul et al 2013 Olivier 1978, Sukumar 2006).

1.3 Focus of Study

The Sumatran elephant is currently classified as ‘critically endangered and declining’ by the IUCN (*International Union for the Conservation of Nature*), having lost over half of their former habitat over the last 60 years (Corbet & Hill 1992, Gopala et al 2011, Santiapillai & Jackson 1990, Shoshani & Eisenberg

1982, Soehartono et al 2007a). Despite an increase in overall conservation effort regarding the Sumatran elephant over the last few decades, there are still large gaps in overall knowledge regarding their distribution, habitat requirements and population numbers (Azmi & Gunaryadi 2011). National population estimates of Sumatran elephants have been attempted in the past, however these estimates are primarily derived from a handful of intensely studied sites within national parks or are now outdated (Hedges et al 2005). Fewer studies have occurred in the northern provinces of Sumatra, such as Aceh and North Sumatra where the Leuser Ecosystem and Gunung Leuser National Park (GLNP) are situated (HAkA 2017, McCarthy 2000). To effectively conserve the Sumatran elephant, it is imperative that we achieve a greater understanding of the current population size of elephants located within lesser studied sites, such as North Sumatra and the Leuser Ecosystem (IUCN/SSC Asian Elephant Specialist Group 2017). It is also crucial to better understand the Sumatran elephant in terms of its habitat preferences, distribution within forests and their distribution in relation to human dominated landscapes as deforestation and human encroachment continues.

1.4 Research Aims, Objectives & Hypotheses

The aim of this study is to gain knowledge on the population status of the Sumatran elephant in the Leuser Ecosystem and attain a greater scientific understanding of the habitat requirements of these elephants to adequately conserve the species. This knowledge will not only enhance our current understanding of the distribution and habitat requirements of the Sumatran elephant, but also provide local Indonesian conservation agencies with the scientific understanding to support their conservation efforts of this critically endangered species. This will be the first study on elephant population density and habitat use of the population in Sikundur, North Sumatra. Habitat use is studied considering the influence of forest characteristics on the overall distribution of the species. These characteristics will not only include forest features, but also proximity to human-dominated landscapes, including villages and intensely used man-made trail systems. The study also aims to classify the dung decay rate of Sumatran elephants for the area of Sikundur, not just for this study but for future studies conducted in the area.

The specific objectives of this study are as follows:

Obj. 1. Identify dung decay rates in different environments to assist in determining population size, such as under canopy/not under canopy, using wild elephant samples and determine the overall dung deterioration rate in Sikundur.

Obj. 2. Establish a first estimate of elephant density in Sikundur by following 1km transects in which elephant dung is counted and its geographic locations recorded via GPS.

Obj. 3. Determine the types of habitat that are associated with the greatest elephant activity in Sikundur by recording various characteristics (such as human activity and landscape modifications, tree, vegetation, habitat type and elevation data) systematically along transects and when signs of elephant presence are encountered. Habitat is also described in view of the use of man-made trail systems and proximity to human-dominated landscapes.

The proposed hypotheses for this research are therefore:

H_1- Forest structure will vary between vegetation plots. As Sumatran elephants are understood to prefer secondary forests, a higher density of trees and a smaller DBH (1-32cm) is expected, along with a mid-range of canopy cover. A preference to a sparser canopy is also expected to be seen.

H_2- Elephants will be found in areas of high elevations, despite presence of steep slopes, but show an overall preference to areas of lower elevations.

H_3- A preference to alluvial habitats will be seen, and elephants will be found more frequently in areas close to water.

H_4- Elephants avoid human-dominated landscapes such as villages, plantations or heavily trafficked human areas, such as trail systems.

Chapter 2- Method

2.1 Study Site

The Sikundur monitoring station is located in the Langkat region of North Sumatra (Figure.1). The area of forest surrounding the monitoring station is located south of the border with Aceh and is encompassed within the Gunung Leuser National Park and the Leuser Ecosystem. The Leuser Ecosystem covers 25,000km^2 of northern Sumatra and is the last refuge for the Sumatran orang-utan *P. abelii*, Sumatran rhinoceros *Dicerorhinus sumatrensis*, Sumatran tiger *Panthera tigris sumatrae* and the Sumatran elephant. The Gunung Leuser National Park spans approximately 7,927km^2 within the Leuser Ecosystem and is a UNESCO World Heritage site, part of the 'Tropical Rainforest Heritage of Sumatra' (TRHS) (UNESCO 2017). The forest surrounding the Sikundur site is classified as a lowland dipterocarp and alluvial tropical rainforest habitat and is one of the last remaining lowland forests in Sumatra. This area is comprised of 3 topographical habitat types: alluvial (floodplain of meandering river with flat to undulating slopes <8%), hills (parallel elongated ridges, 16-25% steep slopes, 450-500 m.a.s.l and plains (flat with undulating slopes <8%) as defined by Laumonier (1997).This area contains both primary and secondary forest that underwent small to large scale logging during 1976 to 1988, and then again in the 1990s. An average of 11 large trees per hectare were felled during this period and substantial amount of forest habitat were lost, however after logging had ceased the forest was left to recover (Knop et al 2004, SOCP 2016). The Sikundur monitoring station was then established in 2013 by the Sumatran Orangutan Conservation Programme (SOCP) and is now used to collect data on orangutans and other primates. Sikundur remains largely under-studied in comparison to other sites in Sumatra, and although the forest is located within the Gunung Leuser National Park and the Leuser Ecosystem, it is under threat from logging and encroachment from monoculture plantations (Gaveau et al 2016).

Figure 1. The location of the Sikundur Monitoring post in relationship to the Gunung Leuser National Park and the Leuser Ecosystem (SOCP 2015).

2.2 Data Collection

2.2.1 Obj 1. Estimating Elephant Dung Decay Rates

With an aim to gather information of the dung decay rate of elephants in Sikundur, dung decay monitoring was undertaken from the start of the project. Previous dung decay publications suggest conducting preliminary dung decay monitoring prior to the dung count surveys, however time restrictions and the lack of previous elephant research at the site meant that only the ‘prospective’ method, termed by Laing et al (2003), was used. As a result, dung decay monitoring was initiated at the same time as the dung count surveys but was conducted in different areas of the forest and 14 dung piles were monitored in-situ. Hedges & Lawson (2006) recommend using only fresh dung piles (<48 hours old) for monitoring purposes, however as no fresh dung was found at the start of the research and was found only towards the end of the data collection, this could not be replicated. Due to time restrictions, the dung monitored from the start of the survey was chosen using the ‘S system’ for dung pile classification with defined stages of decay (Table.1) (Hedges & Lawson 2006). Any dung that could be classified as S1-S3 (Table.1), that contained coherent fragments and could be handled without crumbling, were monitored. Although the ‘S system’ does not provide an estimation of the age of the dung, all monitored dung piles that were not considered to be fresh (<48 hours old) were later compared to data collected when fresh dung piles were found, and a more accurate estimation of age when monitoring of each dung began was possible, and estimated age when found could be added to the data set.

In an aim to monitor dung decay rates within various environments, sites containing dung in various environments (under canopy/not under canopy/swamp) were chosen to gain accurate representation dung decay in all areas of the forest. When found, dung piles were typically left in-situ and not moved, however if it was found upon a logging road or trail path where it is likely to be damaged by human interference (motorcycles), it was moved to the side of the path. Once dung was found, it was marked clearly using tape to ensure it could be found upon every visit. Dung was re-visited a minimum of every 2 weeks, with one month being the largest time frame between visits. Upon each visit, classification of dung was carried out following the ‘S system’ (Table.1) (Hedges & Lawson 2006). Dung was monitored until it had degraded entirely and could be defined as S5 (Table.1)

Table 1. The MIKE ‘S system’ for dung pile classification from the Dung Survey Standards for the MIKE Programme compiled by Hedges & Lawson (2006).

<table>
<tr><th colspan="3">The MIKE ‘S system’ for dung pile classification</th></tr>
<tr><th>Stage</th><th>Definition</th><th>Notes</th></tr>
<tr><td>S1</td><td>All boli are intact</td><td rowspan="5">- A bolus is ‘intact’ if its shape and volume is plausibly the original shape and volume; and it is coherent and can be handled without crumbling.

- A coherent fragment is defined as a fragment (consisting of plant fibres embedded in a matrix of other fecal material) that does not crumble/break-up when handled.

- Plant fibres held together by mud do not count as coherent fragments.</td></tr>
<tr><td>S2</td><td>One of more boli (but not all) are intact</td></tr>
<tr><td>S3</td><td>No boli are intact; but coherent fragments remain (fibres held together by fecal material)</td></tr>
<tr><td>S4</td><td>No boli are intact; only traces (e.g. plant fibres) remain; no coherent fragments are present (but fibres may be held together by mud)</td></tr>
<tr><td>S5 (gone)</td><td>No fecal material (including plant fibres) is present</td></tr>
</table>

2.2.2 Obj 2. Estimating Elephant Densities: Dung Count Surveys

Due to the difficulty in conducting transects and encountering elephant dung in dense tropical forest, the recce or reconnaissance transect method is now a widely adopted approach and was used in this study (Walsh & White 1998). The recce sampling method involves following the path of least resistance along trails and natural features, such as waterways and river banks, and cutting of vegetation is kept to a minimum. The compass bearing is followed only marginally and perpendicular distances to dung piles are not measured as a straight line is not followed throughout. Although the recce method requires less effort than transect sampling, it is recommended to undertake both recce and line transect methods to detect major differences in encounter rate as undertaking recce transects alone may result in increased dung detection and an over-estimate due to following 'elephant paths' and non-random sampling (Walsh & White 1998).

Ten transects were established in the Sikundur field site over a 5-month period (May- September), nine of which were located directly within the forest and one which was located within a plantation adjacent to both the forest and a local village (Figure.7). Due to time constraints, only the recce transect was used and the transect start points were allocated in an aim to ensure maximum coverage of the study site, habitat types (plains, alluvial and hills) and to achieve equal distribution in trail/non-trail areas. If a transect fell too close to another transect or within an impassable area (such as directly within a river/plantation/village), the start points were moved to more ideal locations within a maximum distance of 200m around the initial start point. GPS locations were recorded at the start and end of every transect, and then every 125m metres along the transect. Every fresh elephant dung pile encountered (<1 month old) within 2 metres perpendicular of the transect line was counted. Various habitat variables were recorded on the discovery of dung, (see details in section 2.3.1). An estimation of the decay stage of the dung encountered on the transect was attempted for each dung found using the 'S system' by Hedges & Lawson (2006) (see Table.1, section 2.3.1). Once recorded, the dung piles were then removed from the transect to prevent recounting of dung when repeating transects.

An estimation of the density of Sumatran elephants was attained according to the formula of McClanahan (1986) and Barnes and Jensen (1987):

$$E = (Y \times r / D) \qquad \text{(eq1)}$$

Where E=elephant density was calculated using Y= dung density (obtained through dung count survey methods), D= defecation rate (The defecation rate used for this analysis was derived from a previous study by Tyson et al (2002), which found Sumatran elephants produce 18.15 defecations per 24 h) and lastly r= Dung decay rate (The reciprocal value of mean survival time of all decayed samples).

2.2.3 Obj 3. Elephant Habitat Use

2.2.3.1 Measuring Habitat & Forest Structure

To measure forest structure across the 10 transects of Sikundur, vegetation plots were conducted at every 125m (non-dung plots) and when dung was encountered (dung plots). Although vegetation plots were originally conducted along every interval along the transect (n=80), only non-dung plots that were located 125m away from dung plots were used in the final analysis. Vegetation plots were comprised of 5x5m circular plots in which various forest structure data was collected. Firstly, the number of trees with a circumference at breast height (taken at 1.5m above ground), CBH >10cm were recorded. Percentage of vegetation ground cover (ferns, shrubs, grasses) was then measured; this was accomplished by estimating all ground vegetation (<1m from the forest floor) in relation to bare ground (areas containing no vegetation) as a percentage estimate. The percentage of all understory vegetation (saplings/palm) within the plot was then estimated; this was achieved by estimating the percentage cover by of non-tree vegetation >1m off the forest floor (including saplings, CBH <10cm, large ferns, herbaceous vegetation) in relation to the overall area of the plot and bare ground. Circumference at breast height (CBH) was later converted to DBH using the pie formula (π). To record canopy cover in the vegetation plots, a photograph of the canopy was taken from the centre of the plot a digital camera. To quantify canopy cover percentage, the photographs were subsequently analysed individually using photo editing software Photoshop CC (version 19.0.1). This was achieved by transforming the photographs into black and white monochrome images and editing each individually using the histogram tool to ensure consistency with the original photo of the canopy, and the observed foliage. Then by using the histogram tool, a pixel count was taken, where black pixels represented canopy cover such as foliage, and white pixels were non-canopy. The pixel count allowed for a determination of canopy cover percentage (black pixels) in comparison to non-canopy cover (white pixels). A description of the habitat and surroundings of each plot were recorded when applicable, including presence of a water source (stream/river) or whether the plot was located on a logging road or a slope.

2.2.3.2 Habitat/Forest Types

The study area is comprised of 3 topographical habitat types: alluvial (floodplain of meandering river with flat to undulating slopes <8%), hills (parallel elongated ridges, 16-25% steep slopes, 450-500 m.a.s.l) and plains (flat with undulating slopes <8%) as defined by Laumonier (1997) (Figure.2). A GIS layer of these habitat types was used to determine in which habitat type each of the dung samples and transects were located in and to measure if preferential habitat selection by Sumatran elephants is occurring in these habitat types.

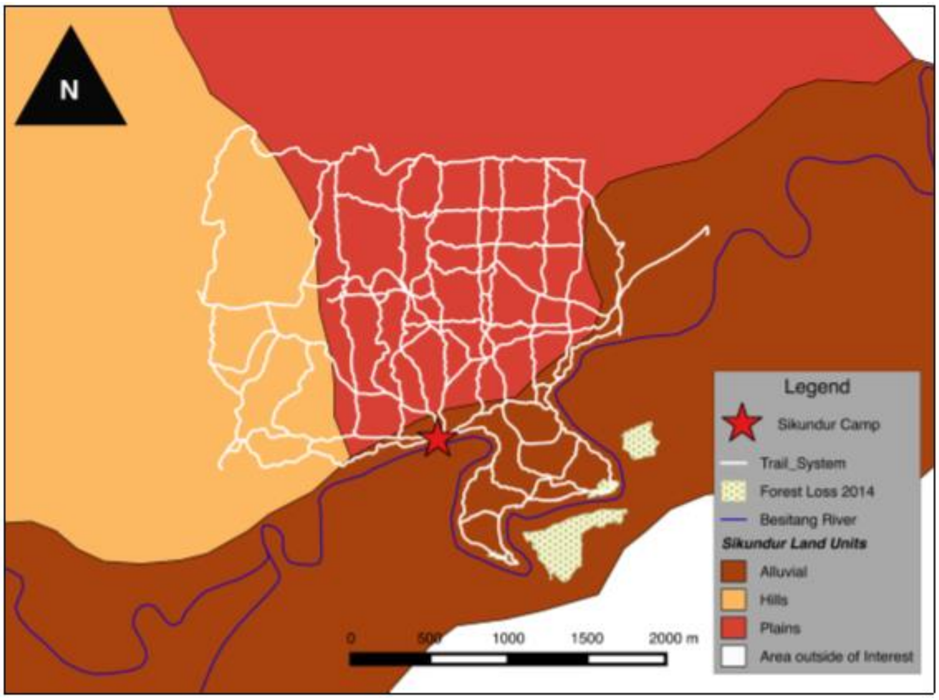

Figure 2. The habitat types of Sikundur, including Alluvial, Hills and Plains (Nowak 2017).

2.3.3.3 Elevation

Elevation data was collected in all vegetation plots across all transects, and recorded using a handheld GPS as meters above sea level. Because GPS elevation measurements are notoriously imprecise, especially in forest habitats, additional elevation data was then compiled using ArcGIS and a 90m resolution digital elevation model from the Shuttle Radar Topography Mission (SRTM) (NASA 2017). Using the SRTM elevation model, a topographical elevation map was created for the survey site, which contained three elevation zones; Zone 1 (20-55m a.s.l), Zone 2, (56-90 m.a.s.l) and Zone 3 (>90 m.a.s.l) (Figure.3). The number of dung samples located inside each zone were analysed to determine whether elephants preferentially use particular elevation zones.

Figure 3. Elevation zones of Sikundur, including Zone 1 (20-55m a.s.l), Zone 2 (56-90 m.a.s.l) & Zone 3 Zone 3 (>90 m.a.s.l) derived from SRTM data (NASA 2017).

2.3.3.4 Distance to Human-Dominated Landscapes and the River

To identify a preference or avoidance to human settlements or rivers, a zonation map outward from these locations was created. The zones were created using the buffer tool in the geospatial software ArcMap 10.6. Human-dominated landscapes were defined as any area of human occupation (urban areas and villages), or areas that have suffered significant loss of forest cover through human activities (farmland and plantations) (Figure.4). Sikundur village was the closest area of human occupation to the forest; and also encompassed surrounding plantations and farmland. The boundary line created to establish the human-dominated landscape area was compared to that of the Landsat derived images of forest cover loss by year from Hansen et al (2014). This comparison showed further forest loss through human activities. The boundary line created to define the river was based on the Besitang River, which runs through the survey area (Figure.5). For both locations (village/river), 3 zones were created outward, and were comprised of: Zone 1 (0-500m), Zone 2 (500-1000m) and Zone 3 (1000-2500m). Initially, the maps were comprised of 5 equal zones, however as not enough dung was located >1000m outward from the human-dominated landscape/river, the three outer zones were merged to create Zone 3. Zone 3 therefore encompasses a bigger area compared to other zones, but nonetheless represents what is occurring in further proximity from the village/river.

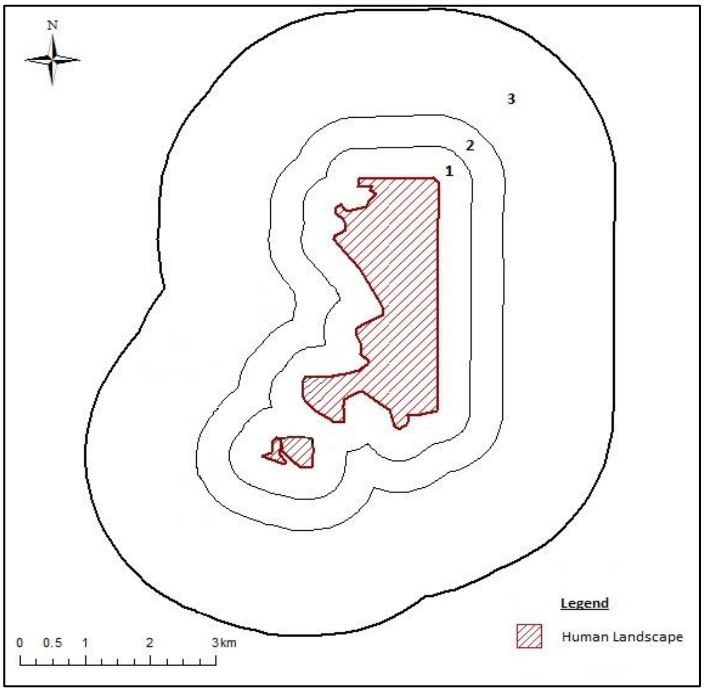

Figure 4. The 3 Zones outward from the human dominated landscapes, including villages and plantations, Zone 1 & 2 (<1000m) and Zone 3

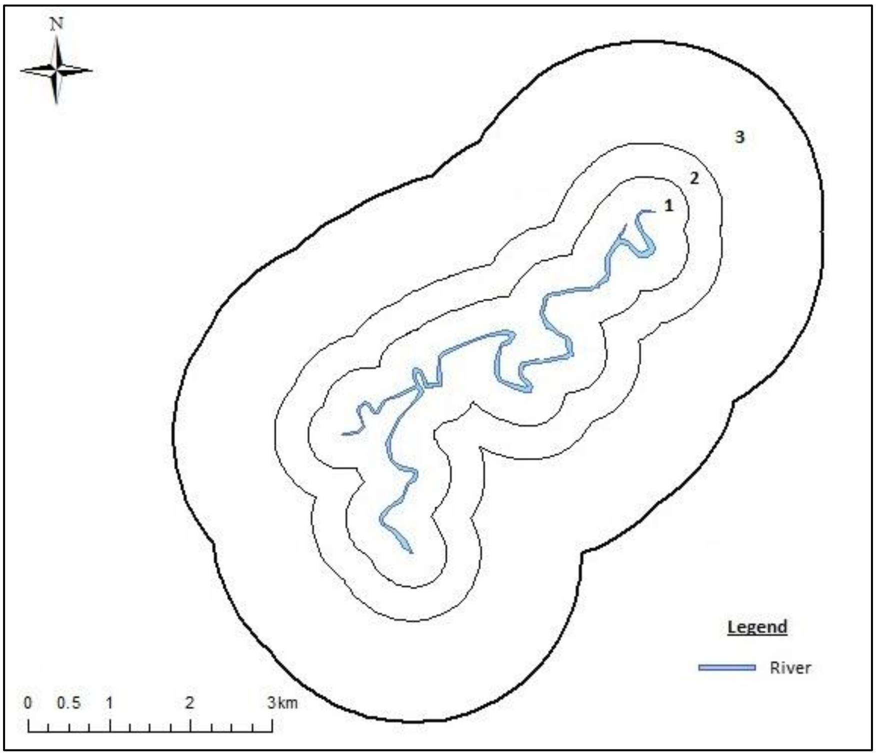

Figure 5. The 3 zones outward from the river, Zone 1 & 2 (<1000m) and Zone 3 (>1000m).

2.3.3.5 Use of Man-made Trail System

The Sikundur trail system consists of defined to semi-defined paths throughout the forest, used primarily for primate surveys by researchers (Figure.6). Although the trail system mostly consists of semi-maintained forest trails, it also contains old logging roads previously used for trucks when the forest was selectively logged from the 1960s until the 1980s (SOCP 2015). The trail system at Sikundur is used more extensively by people than other areas of the forest and consists of forest openings and corridors. To measure whether elephants use the trail system more than other areas of the survey site, transects were spread evenly over trail and non-trail areas of the survey area and dung found both on and off-trail was calculated.

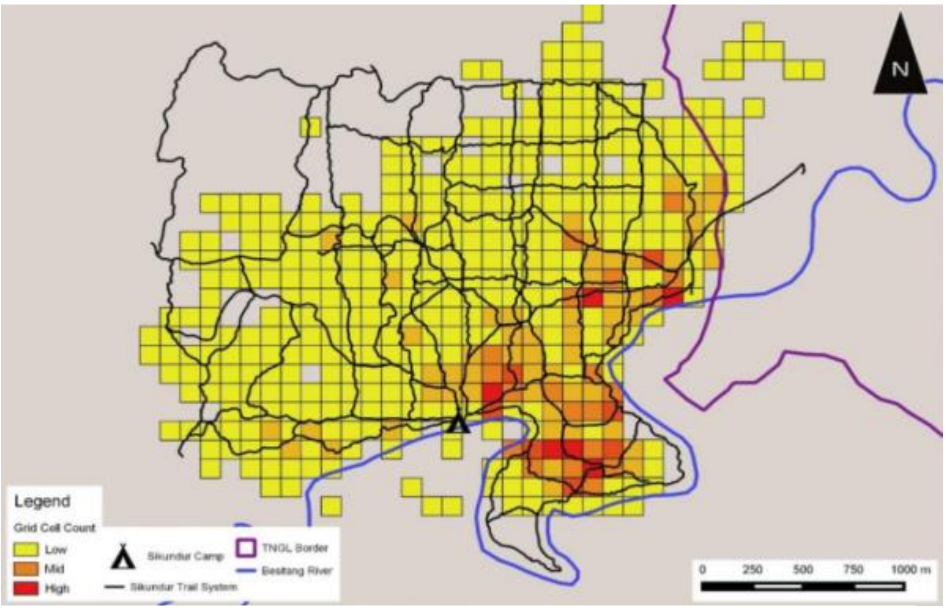

Figure 6. The Sikundur trail system with varying levels of human use (SOCP 2012)

2.3 Data Analysis

2.3.1 Obj 2. Estimating Elephant Densities: Spatial Analysis of Lowland Forest

To first estimate elephant density within a survey area, the total area in km^2 that elephants could inhabit must be identified. Using ArcMap 10.6, the total lowland forest area (km^2) was estimated for the Sikundur area and surrounding lowland forest using a 2008 basemap acquired from Bing (Figure.8). The measurement was based on visual identification of intact forest through aerial imagery; this was achieved using the selection tool on ArcMap 10.6. The selection made was defined by the non-presence of forest cover (plantations or human settlements). The mountainous region to the west was excluded from the area selection as it could not be classified as lowland forest. The density data derived from this study is relevant for a lowland area and should therefore not be used to estimate density across non-lowland regions. The total area of lowland forest was estimated at approximately $426km^2$. This area was then compared to Hansen et al (2014) Landsat derived maps of forest cover loss per year for the area and the selection process was repeated. This allowed for a more accurate and up to date measurement of the remaining lowland forest.

2.3.2 Obj 3. Elephant Habitat Use

All vegetation, habitat variables and GPS elevation data were first tested for normality using Kolmogorov Smirnov test in SPSS 23.0. Due to the small sample size and variables not having a normal distribution, non-parametric tests were then used throughout the vegetation analyses. All tests of significance were two-tailed and alpha was set to 0.05. Mann-Whitney *U* tests were performed in SPSS 23.0 to test for significant differences in vegetation structure collected between non-dung and dung plots, including ground vegetation cover, understory vegetation cover and canopy cover percentages between plots. The same method was then undertaken for tree characteristics, including tree diameter at breast height (DBH) and density between dung and non-dung plots, however the median value was used in analysis of tree DBH due to the occurrence of large emergent trees within the data and an attempt to reduce abnormalities in the data set. By undertaking this analysis we are then able to compare the vegetation structure between plots that contained dung and plots that were absent of dung and determine any significance between them. The median value was used in analysis of tree DBH due to the occurrence of large emergent trees within the data and an attempt to reduce abnormalities in the data set.

To analyse any preference to certain habitat features, including habitat type, elevation, distance from human landscapes and rivers and presence within the trail system, GPS points of dung encountered were input into the geo-spatial programme ArcGIS. A spatial layer was then created for the following zones: habitat type, distance to human landscapes, and distance to river, elevation from SRTM data and on/off trails. The number of dung that fell in to each identified zone was then counted to gain an observed count of dung (O). To generate an expected value of dung in each zone, the mean dung encounter rate retrieved from the dung count surveys (1.41 dung/km) was multiplied by the survey effort conducted within each zone (km walked) (E). Once the observed and expected numbers of dung were calculated, the deviation between observed and expected values could then be obtained by using chi-square analysis:

$$(X^2=\Sigma\ (O-E)^2/E) \qquad \text{(eq2)}$$

O=observed, E=expected (Siegel & Castellann Jr 1988).

By looking at any significant deviation between the observed and expected value of dung found between these areas, we can determine if any preferential habitat selection is occurring.

Chapter 3- Results

3.1 Obj 1. Dung Decay Rate

Fourteen dung piles were monitored over a 7-month period until all samples had decayed entirely (Table.2). As some dung had not decayed by the end of the field data collection, monitoring of samples was continued for an additional 2 months by on-site field researchers to ensure accurate dung decay data. A majority of dung piles persisted for more than 30 days and disappeared through decay, with the exception of dung 12 which was washed away by rising river levels. By incorporating an estimation of the dung age when found and the number of days that had passed from the last visit to the day it was confirmed to have disappeared, minimum and maximum survival time was also estimated with a minimum mean value of 73.64 days and a maximum of 112.5 days in total (Table.2). Mean survival time for all dung piles was found to be 102.8 days in total, the reciprocal value of this was then calculated, which resulted in the mean daily dung decay value of 0.0097.

Table 2. The 14 dung piles monitored for dung decay, estimated age when found, day of confirmed disappearance, minimum & maximum age of dung with mean values of age before disappearance

Dung	Estimated age when found	Minimum age of dung	Day of confirmed disappearance	Maximum age of dung
1	14	98	123	137
2	14	98	124	138
3	14	98	124	138
4	14	98	124	138
5	14	97	124	138
6	14	91	120	134
7	5	86	119	133
8	14	58	84	89
9	5	48	74	88
10	14	110	136	150
11	1	62	126	127
12	1	1	14	15
13	1	10	39	40
14	1	76	109	110
		73.64	**102.8**	**112.5**

3.2 Obj 2. Sumatran Elephant Density

A total of 48 dung piles were recorded on 9 out of the 10 transects in the Sikundur field site over a 5-month period (Table.3, Figure.7). Each transect was walked a minimum of 2 times, with selected transects walked a maximum of 4 times, this resulted in 34km walked overall (Table.3). This equated to a mean encounter rate of 1.41 dung piles per transect and 352.50 piles of dung per hectare. The defecation rate used for this analysis was derived from a previous study by Tyson et al (2002), which found Sumatran elephants produce 18.15 defecations per 24 h (CV = 13.94). The density calculation results in 0.188 elephants per km^2. A lowland forest boundary area was created using ArcMap 10.6 and based solely on visual identification of intact forest from the year 2008 (Figure.8). This was then compared to Hansen et al (2014) Landsat derived maps of forest cover loss per year (Figure.9) and the area of remaining forest was recalculated for a more accurate representation of remaining forest cover. The Landsat map in Figure.9 shows an observable decrease in forest cover when compared to Figure.8. A large proportion of the forest cover loss can be seen occurring between the years 2000-2010, but there are signs of forest cover loss occurring in more recent years within the interior of the forest and at the edges (Figure.9). By using the Landsat data and incorporating significant losses of forest cover, the total lowland forest area was re-estimated at 379km^2. This signifies a forest loss of 47km^2, which cannot be easily identified in Figure.8. By multiplying the encounter rate of elephants (0.188 per km^2), a population estimate of 80 Sumatran elephants could be estimated for the lowland survey area of Sikundur, and the surrounding lowland forest seen in Figure.8. Using the updated lowland forest area which incorporates recent forest loss (see Figure.8 & 9), population size was then estimated at 71 Sumatran elephants.

Table 3. The 10 established transects of Sikundur, amount of times each was walked, and total dung piles found on each.

Transect	**Times walked**	**Dung found**
1	4	6
2	4	13
3	4	6
4	3	3
5	4	2
6	4	0
7	3	5
8	3	2
9	3	5
10	2	6
Total	**34**	**48**

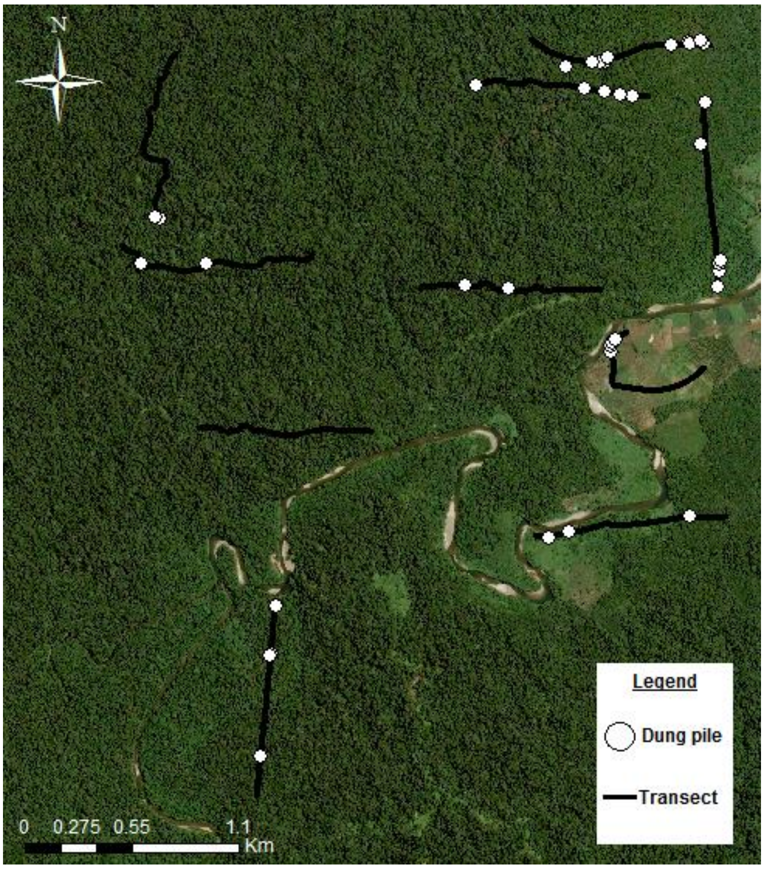

Figure 7. 10 established elephant transects and dung piles encountered in Sikundur

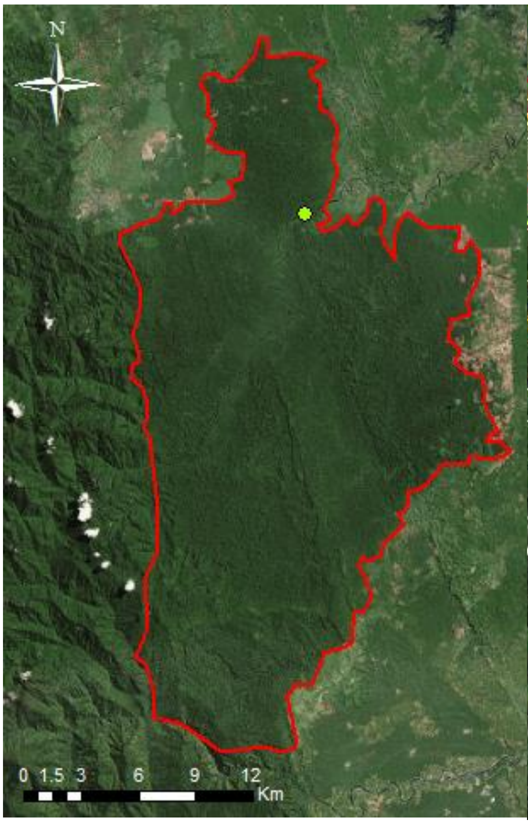

Figure 8. Lowland forest area (426km^2) surrounding the Sikundur field site derived in 2008.

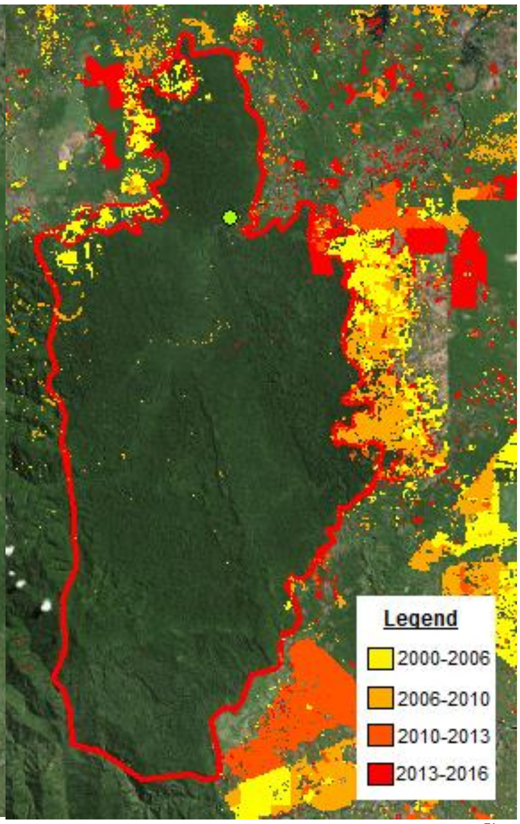

Figure 9. Lowland forest area (379km$^{2)}$ and Levels of forest cover loss from 2000-2016 (Hansen et al 2014).

3.3 Obj 3: Habitat use

3.3.1 Vegetation Structure

A total of 71 vegetation plots were measured over 9 forest transects, 36 of these consisted of non-dung plots recorded at 125m intervals and the remaining 35 plots were dung plots. The 8 vegetation plots conducted on transect 10 were removed from the analyses due to it being located within a plantation and not within the forest (Figure.7). During data collection, dung would occasionally be located within the 125m interval vegetation plots, causing an overlap of plot data. In order to attain a reliable comparison of forest structure between plots that contain dung and plots with true absence of dung, non-dung plots that occurred within a 125m radius of dung were removed from the final analyses (see appendix).

Non-dung plots (n=36), and dung plots (n=35) did not differ significantly with respect to ground percentage cover (*U*=534.500, n=71, p=0.271), understory percentage cover (U=626.500, n=71, p=.968) and canopy cover percentage (U=430, n=71, p=0.364) (Table.4, Figure.15). Tree density differed significantly between habitat vegetation plots and dung vegetation plots (*U*=239.500, n=71, p=<0.001, Table.5). A lower density of trees were seen in vegetation plots where dung was present ($\bar{x}$ =11.47) to that where it was absent ($\bar{x}$ =19.26) (Table.6, Figure.11). Due to the frequency of large emergent trees in the data, the median value was used for this data set in an attempt to reduce abnormalities in the data. The median DBH of trees were found to significantly differ among plot types, trees with a larger DBH were seen more often in areas where dung was present to plots where it was absent (Table.5, Figure.12).

Table 4. Outcome of the comparisons of ground vegetation, understory vegetation and canopy cover percentage between non-dung (n=36) and dung plots (n=35) across the 9 forest transects.

	Ground Percentage Cover (%)	Understory Percentage Cover (%)	Canopy Cover (%)
Mann-Whitney U	534.500	626.500	430.000
Wilcoxon W	1200.500	1292.500	926.000
Z	-1.101	-.040	-.907
Asymp. Sig. (2-tailed)	.271	.968	.364

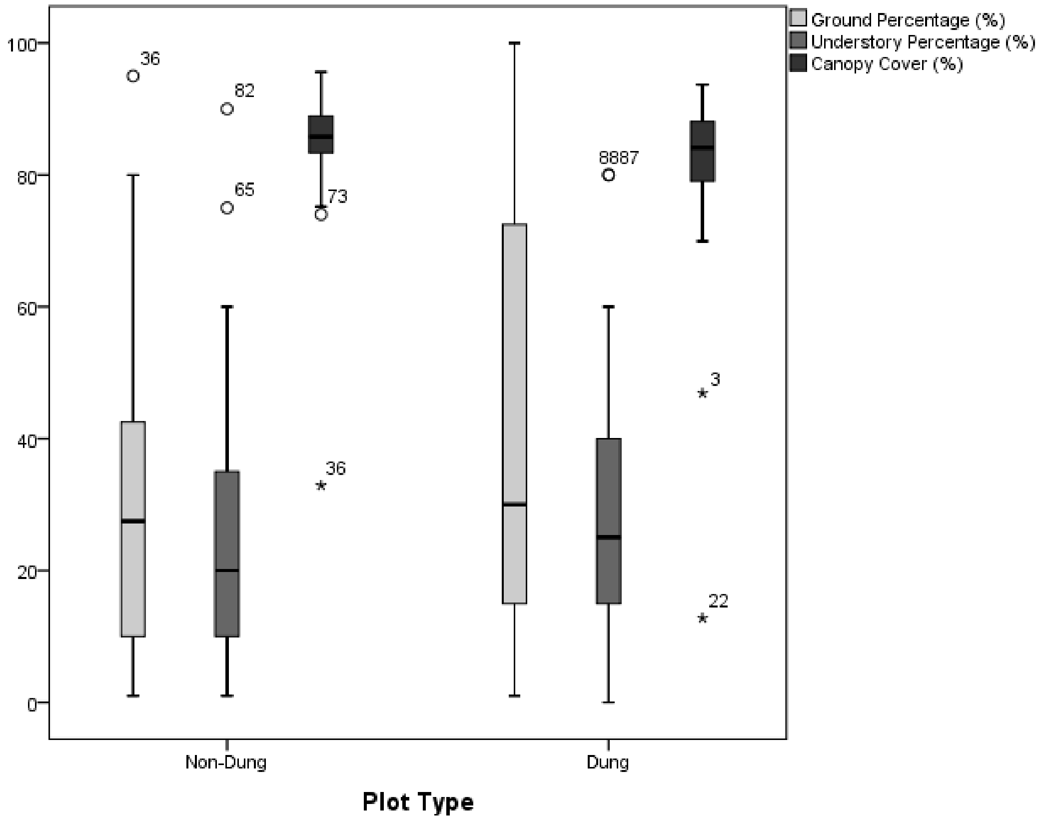

Figure 10. Boxplot showing the percentage of ground vegetation, understory vegetation and canopy cover between non-dung and dung plots of across the 9 forest transects.

Table 5. Comparisons between non-dung plots (n=36) and dung plots (n=35) of tree density, median DBH, 1st quartile, 3rd quartile, standard deviation of CBH, 95% and 5% confidence interval (CI) and maximum and minimum DBH.

	Tree Density	**Median DBH**	**DBH Quartile 1**	**DBH Quartile 3**	**DBH SD**
Mann-Whitney U	239.50	401.50	391.00	447.00	365.00
Wilcoxon W	905.50	1028.50	1019.00	1067.50	995.00
Z	-4.497	-2.517	-2.321	-1.718	-2.907
Asymp. Sig. (2-tailed)	.000	.013	.009	.052	.004

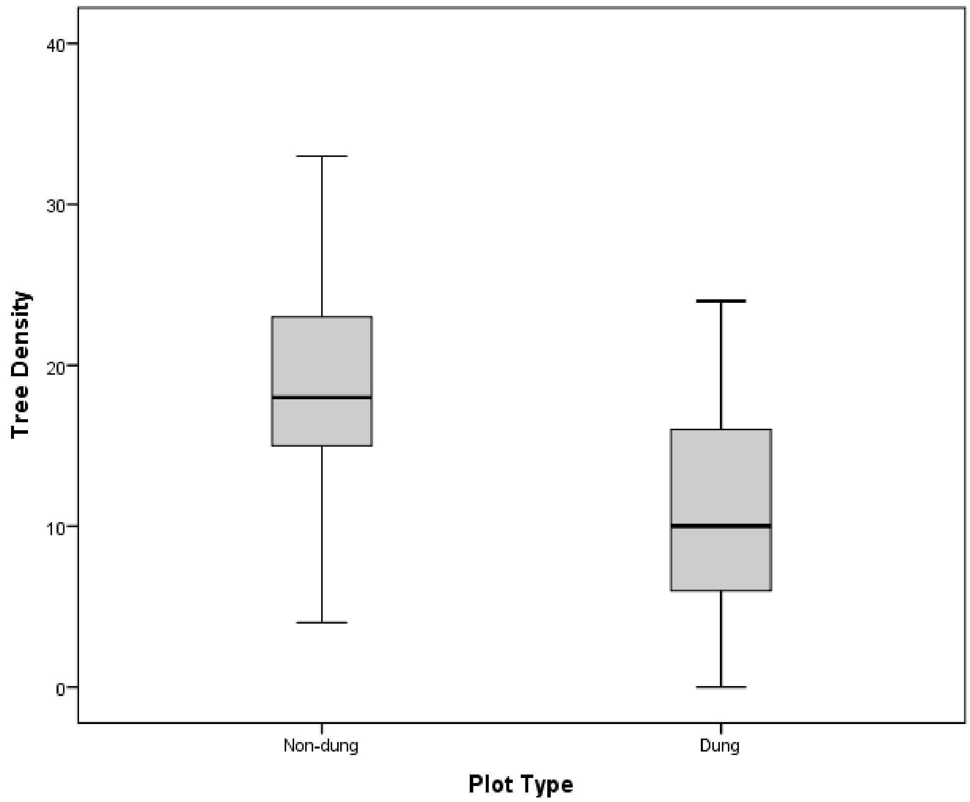

Figure 11. Box plot showing tree density between non-dung and dung

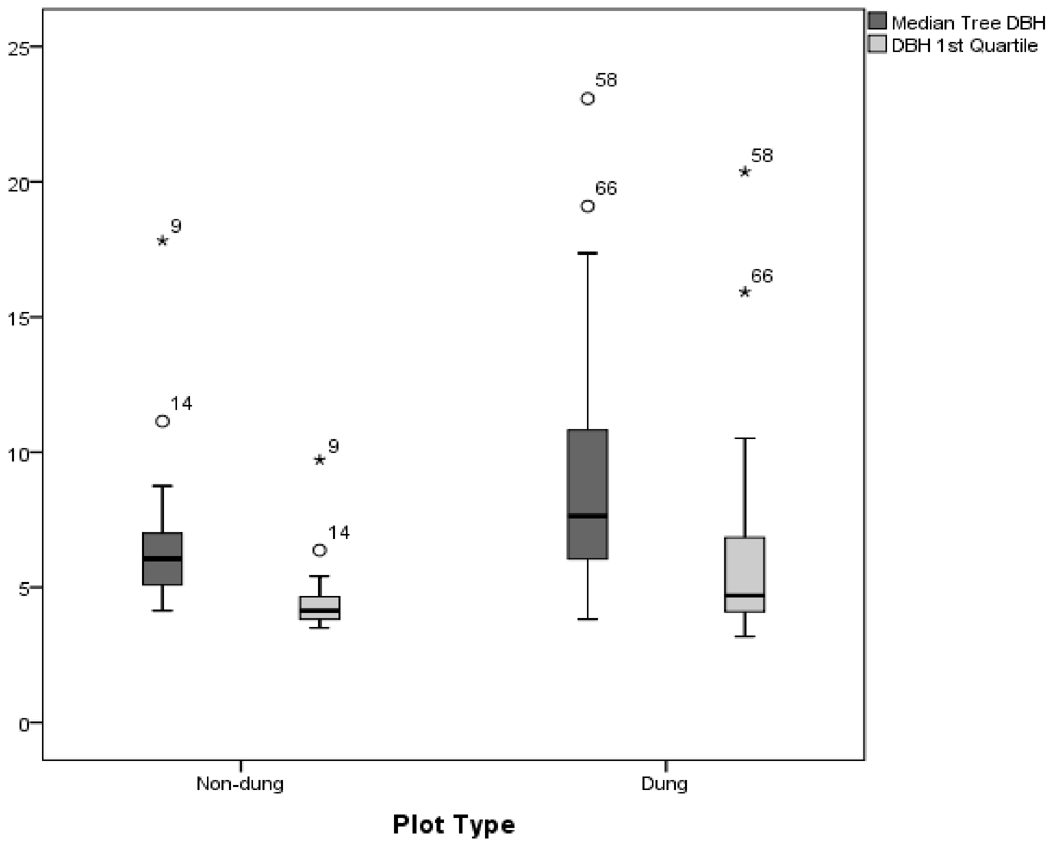

Figure 12. Box plot showing tree characteristics between non-dung and dung plots, including median tree DBH and 1st quartile DBH.

Table 6. Descriptive statistics of vegetation and forest structure between non-dung and dung plots.

Habitat Plot		N	Mean	Std. Deviation	Minimum	Maximum	Percentiles		
							25th	50th (Median)	75th
Non-dung	Ground vegetation	36	29.58	23.73	1.00	95.00	10.00	27.50	45.00
	Understory vegetation	36	26.58	20.35	1.00	90.00	11.25	20.00	35.00
	Canopy cover	32	83.82	10.40	32.90	95.60	83.13	85.80	88.90
	Tree density	35	19.26	6.22	4.00	33.00	15.00	18.00	23.00
	Tree mean DBH	35	9.76	2.61	5.74	13.85	7.20	9.93	11.53
	Tree median DBH	35	6.26	1.37	7.13	10.35	4.85	6.13	7.04
	1st quartile DBH	35	4.33	0.75	3.50	6.37	3.82	4.14	4.69
	3RD quartile DBH	35	10.86	3.37	6.69	16.23	7.15	12.21	13.49
	STD. deviation	35	9.52	3.91	3.04	15.06	5.66	10.40	12.11
	95th percentile DBH	17	39.70	17.06	12.64	60.13	22.14	42.62	54.48
	5th percentile DBH	17	3.38	0.32	3.18	4.04	3.18	3.20	3.54
Dung	Ground vegetation	35	40.63	33.22	1.00	100.00	10.00	30.00	70.00
	Understory vegetation	35	26.89	20.72	0.00	80.00	10.00	20.00	40.00
	Canopy cover	31	80.62	15.37	12.80	93.70	78.60	84.10	88.30
	Tree density	36	11.47	6.93	0.00	31.00	6.25	10.00	16.00
	Tree mean DBH	35	8.46	1.37	7.13	10.35	7.32	8.19	9.87
	Tree median DBH	35	6.69	6.21	4.77	9.55	5.09	6.21	8.76
	1st quartile DBH	33	4.91	4.46	4.06	6.68	4.08	4.46	6.20
	3RD quartile DBH	33	9.81	3.61	6.21	14.24	6.57	9.39	13.47
	STD. deviation	35	5.57	2.74	3.79	9.64	3.90	4.41	8.39
	95th percentile DBH	5	22.54	9.85	15.92	37.18	16.41	18.53	32.68
	5th percentile DBH	5	3.55	0.28	3.18	3.82	3.26	3.60	3.79

3.3.2 Elevation

3.3.2.1 GPS Data

Elevation using the handheld GPS was analysed similarly to the vegetation plot data, where all vegetation plots within 125m of a dung pile were removed from the analysis in an aim to better compare the habitat characteristics of areas with elephant activity to areas without. The elevation of habitat plots with no dung present was higher (64.04 m.a.s.l) than that of the plots with dung (44.61 m.a.s.l) (*U*=154, n=53, p=<0.001, Figure.13).

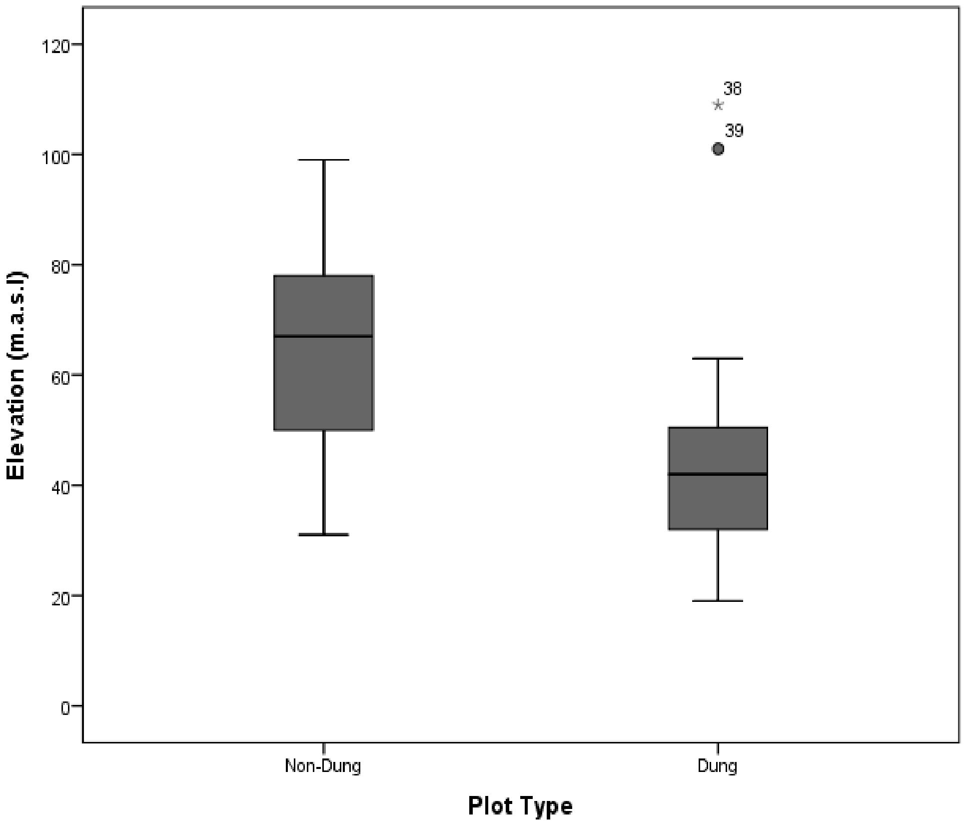

Figure 13. Elevation (m a.s.l) values for dung versus non-dung plots and dung plots.

3.3.2.2 Elevation Topography Map

The topography map was analysed by comparing the number of dung in each of the 3 elevation zones. The number of dung was compared between zone 1 (20-55m a.s.l), zone 2, (56-90 m.a.s.l) and zone 3 (>90 m.a.s.l) (Table.7, Figure.14). In total, 12.6km was walked in zone 1, 17.1km in zone 2 and 4.1km in zone 3, which was used to correct the expected values for each zone. There is a significant difference between the observed and expected values of the number of dung found in the different elevation zones of the transects (Table 7). Zone 1 (20-55 m.a.s.l), which was the lowest elevation of all 3 zones, contained the highest amount of dung (O=36), surpassing the number of dung expected (E=17). Zone 2 (56-90 m.a.s.l) contained a low number of dung compared to the expected value (O=7, E=24). Zone 3 (>90 m.a.s.l) was the highest elevation zone and contained the lowest number of observed dung piles, however the value observed largely coincides with the expected number of dung (O=4, E=5) (Figure.15).

Table 7. Table showing the observed and expected number of dung piles found in each elevation zone with the outcomes of the chi-square test (statistic X^2) and p-value. Elevation zones are: zone 1 (20-55m m.a.s.l), zone 2 (56-90m m.a.s.l) and zone 3 (>90 m.a.s.l).

Zone	**Observed**	**Expected**	**Chi-square (X^2)**	**p-value**
1	36	17.84	18.471	
2	7	24.26	12.287	
3	4	5.88	0.133	
Total	48	48	**30.892**	**<0.00**

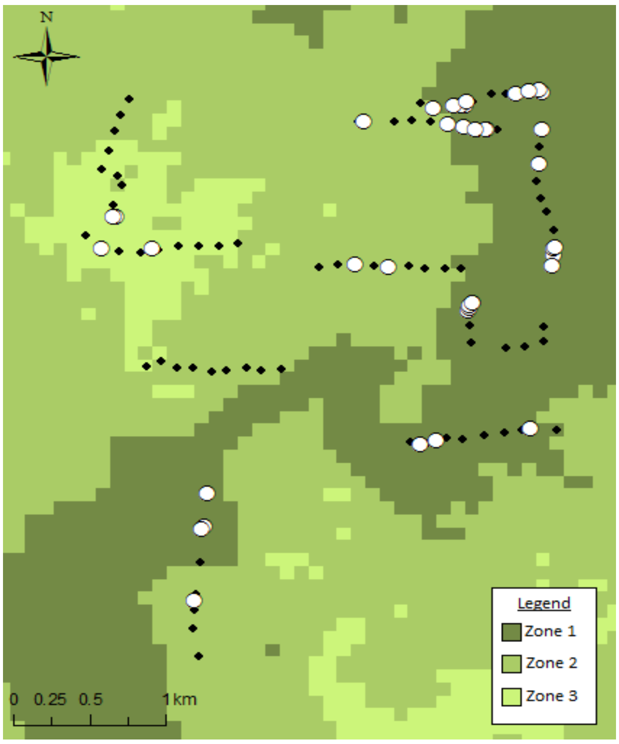

Figure 14. Map showing the 3 elevation zones of survey site, 3 elevation zones, zone 1 (20-55 m.a.s.l), zone 2 (56-90 m.a.s.l) and zone 3 (>90m m.a.s.l), transects (black circles) and encountered dung (white circles).

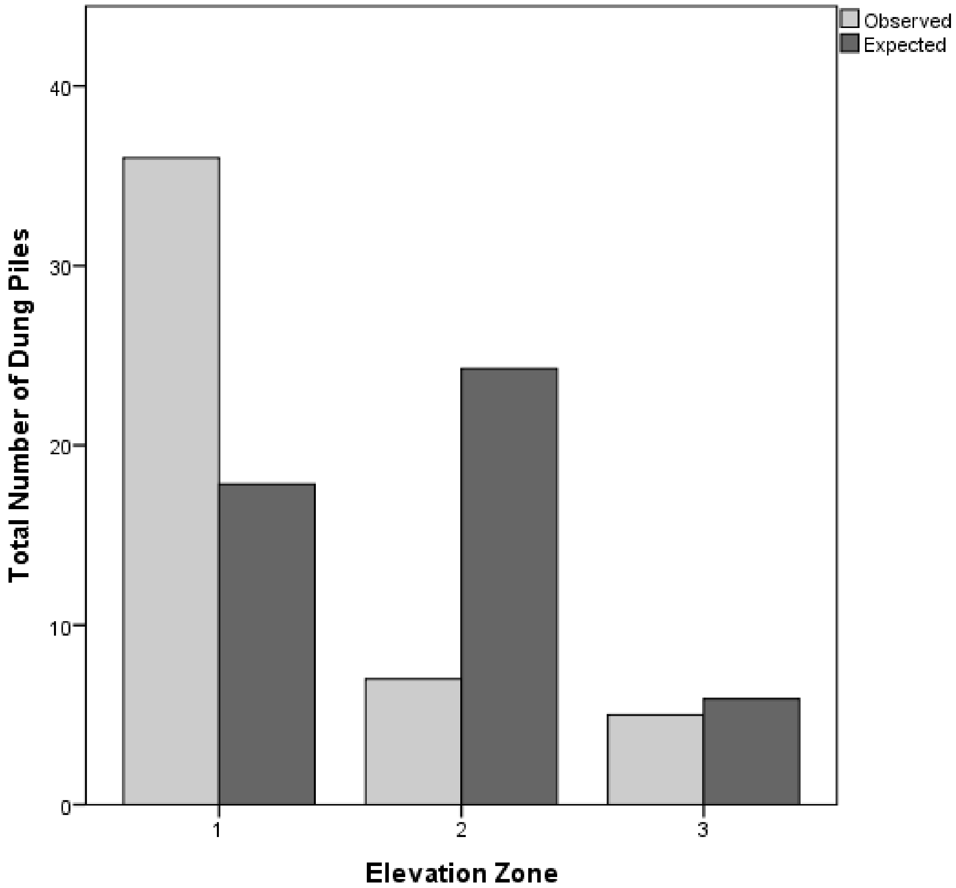

Figure 15. The total number of dung piles observed with expected values in each elevation zones of survey site, zone 1 (20-55 m.a.s.l), zone 2 (56-90 m.a.s.l) and zone 3 (>90 m.a.s.l).

3.3.3 Habitat/Forest Types

The 10 transects were divided across the 3 recognized habitat types of Sikundur, including alluvial (4km), hills (2.5km) and plains (3.5km) (Figure.16). In total, 13.9km was walked in plains, 12km in alluvial and 8.1km in hill habitats. Using the dung encounter rate found through dung count surveys (1.41 per km^2) and the distance walked in each habitat type, expected values were calculated. A total of 48 piles of dung were found in all 3 habitat types of Sikundur, alluvial (n=22), hills (n=5) and plains (n=21). The number of dung encountered in each habitat type did not significantly deviate from expected values (Table.8, Figure.17). Despite no significant result between the types, by looking at Figure.17, a distinct variance between the observed and expected values of alluvial and hill habitats can be seen, which shows more dung piles than expected in alluvial habitats and less dung piles than expected in hill habitats.

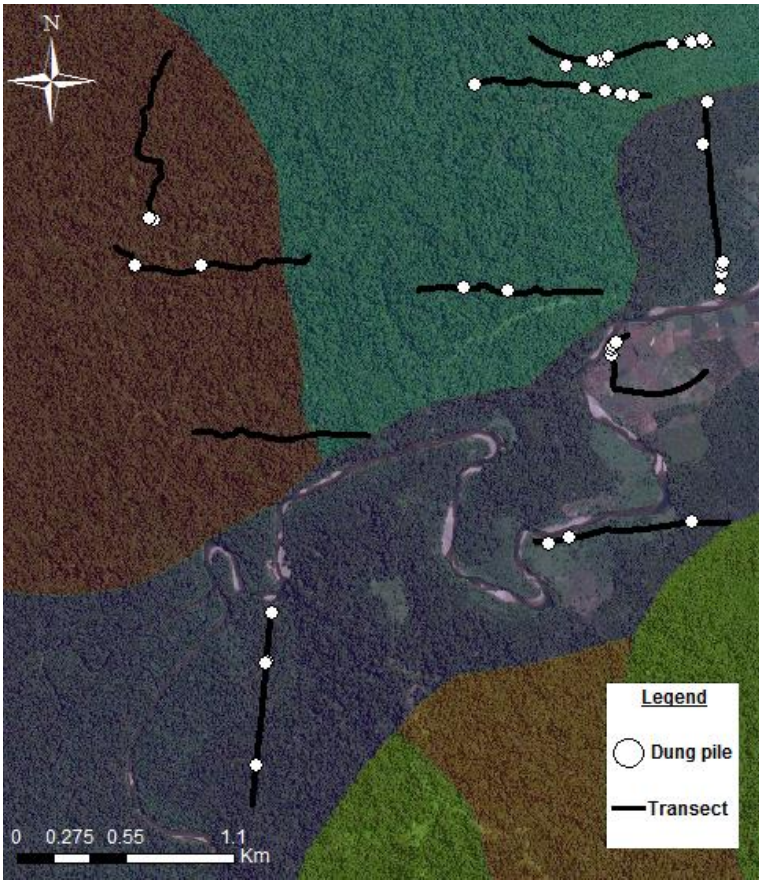

Figure 16. Map showing the 3 main habitat types of Sikundur, alluvial (middle/blue), hills (top left/red) and plains (top right/turquoise)

Table 8. The observed, expected, chi-square (X^2) and p-value of the 3 habitat types, alluvial, hills and plains

Habitat Type	Observed	Expected	Chi-square (X^2)	p value
Alluvial	22	16.941	1.510	
Hills	5	11.435	3.621	
Plains	21	19.623	0.096	
Total	**48**	**48**	**5.228**	**0.073**

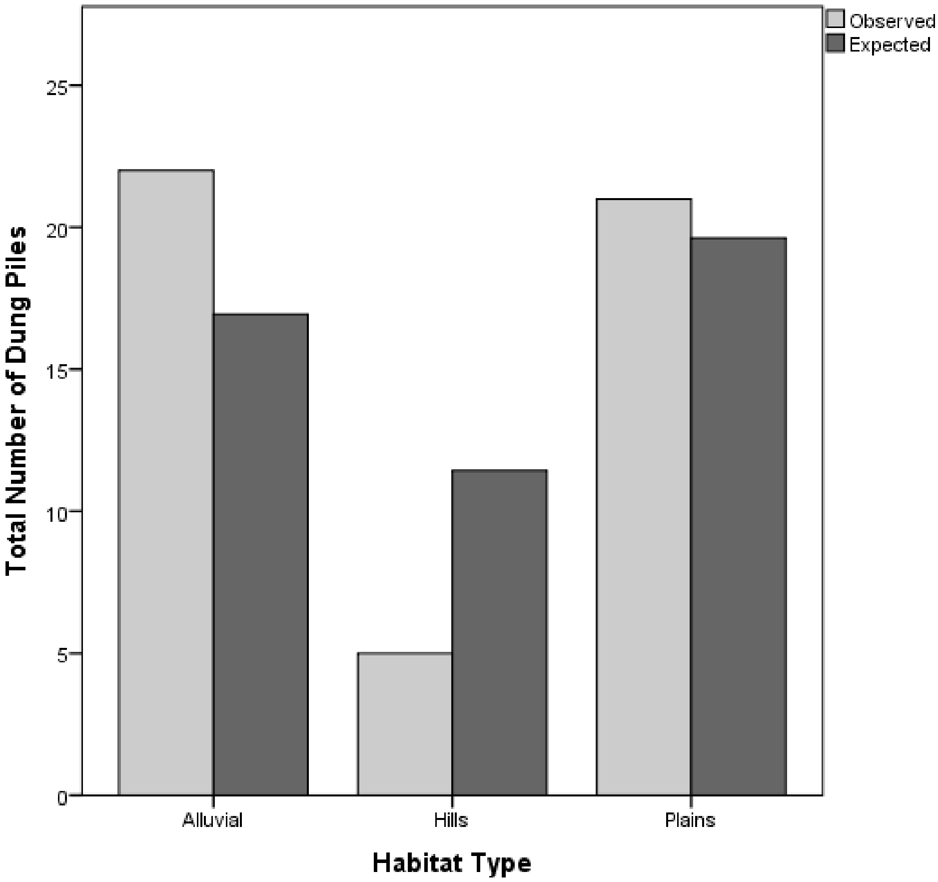

Figure 17. The total number of dung piles observed with expected values in each habitat type, alluvial, hills and plains.

3.3.4 Distance to River

Over the course of the data collection, 16.7km was walked in Zone 1, 5.6km in Zone 2 and 11.6km in Zone 3. Using the dung encounter rate found through dung count surveys (1.41 per km^2) and the distance walked in each habitat type, expected values were calculated. Comparisons of the number of dung found in the 3 river zones were undertaken using the chi-square test (X^2) (Figure.18, Table.9). No significant differences were found in the deviations from expected values of the number of dung in the 3 zones outward from the river (X^2=3.911, df= 2, p=0.418) (Table.9, Figure.19).

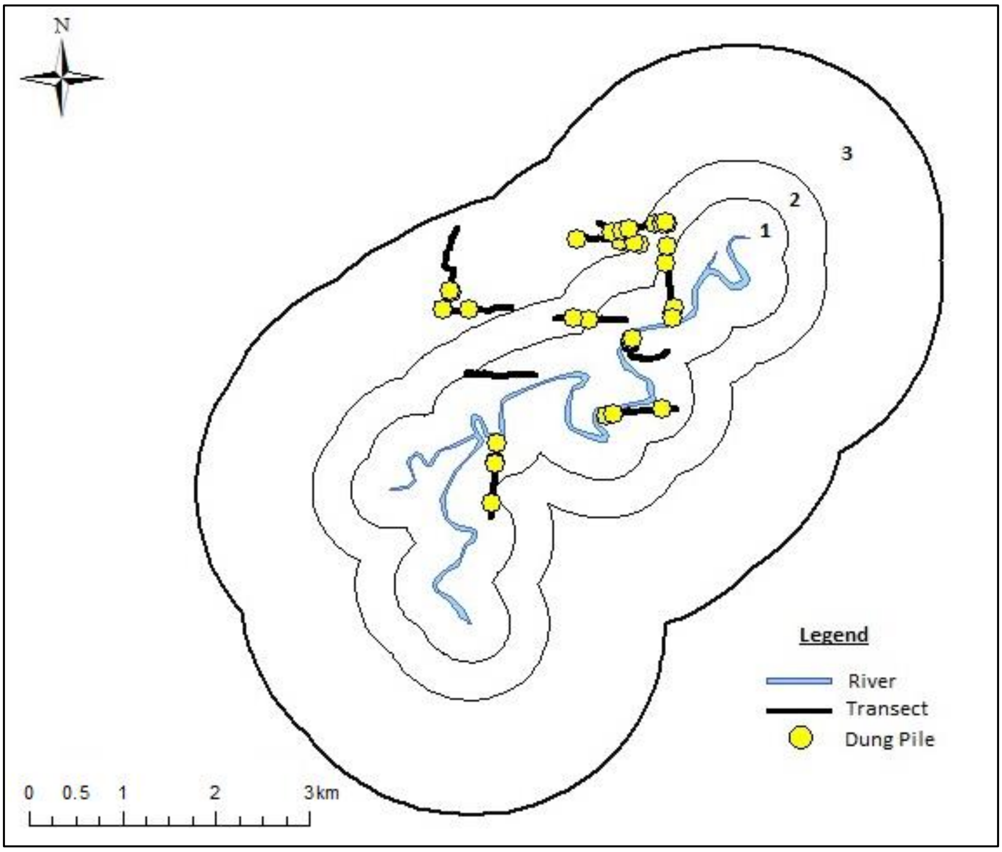

Figure 18. Transects and encountered dung piles in all 3 zones outward from the river (zone 1 & 2 (<1000m) and zone 3 (>1000m).

Table 9. The observed, expected, chi-square (X^2) and p-value of the 3 zones outward from the river, zone 1 & 2 (<1000m) and zone 3 (>1000m).

Zone	**Observed**	**Expected**	**Chi-square (X^2)**	**p value**
1	21	23.703	0.308	
2	13	7.92	3.258	
3	14	16.376	0.344	
Total	**48**	**48**	**3.911**	**0.418**

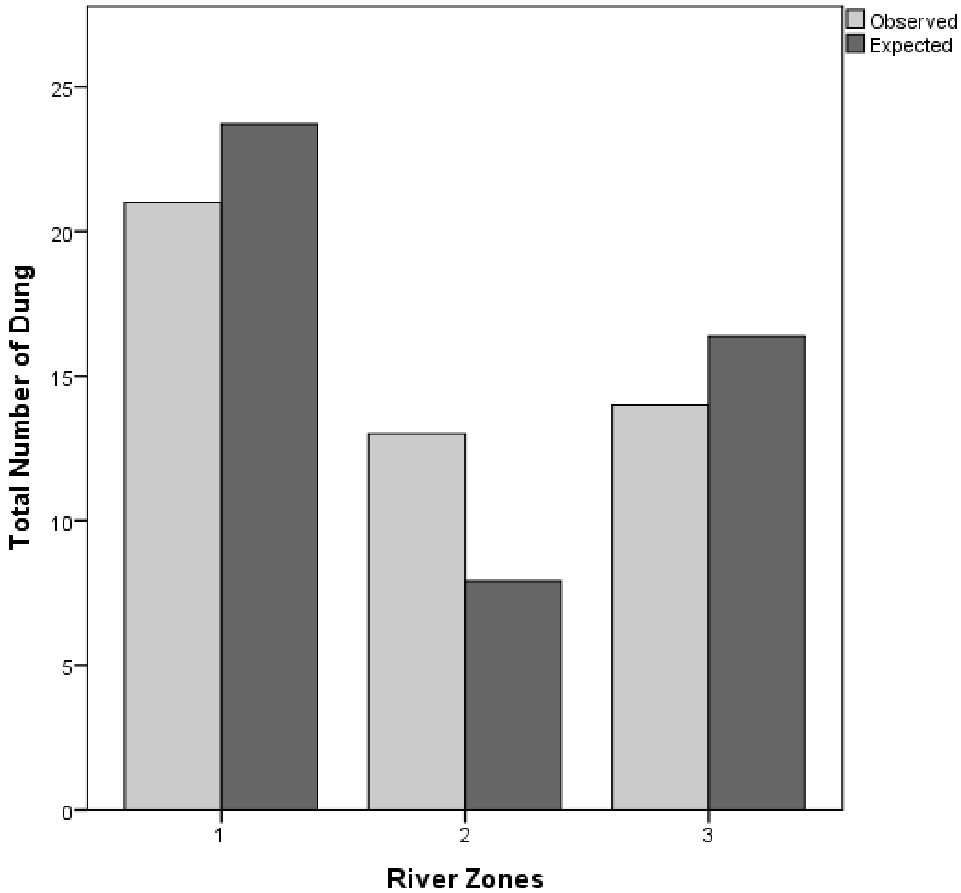

Figure 19. The total number of dung piles encountered in all 3 zones outward from the river with observed and expected values.

3.3.5 Distance to Human-Dominated Landscape

In total, 11.3km was walked in Zone 1, 7.4km in Zone 2 and 15.1km in Zone 3. Using the dung encounter rate found through dung count surveys (1.41 per km^2) and the distance walked in each habitat type, expected values were calculated (Figure.20). Comparisons between the number of dung found in from the 3 zones outward from the human-dominated landscapes were undertaken using the chi-square test (X^2) (Table.10). A significant difference was found in the deviations from expected values of the number of dung in the 3 zones ($X^{2=}$9.08, df= 2, p=0.05). A higher number of observed dung was found in zone 1 (<500m) than expected (O=22, E=15), which was also consistent with zone 2 (O=15, E=10). Zone 3 however, contained less observed dung than expected (O=11, E=21) (Figure.21). Figure.21 shows that there is significantly more dung in zones closer to human-dominated areas than in areas further away.

Table 10. The observed, expected, chi-square (X^2) and p-value of the 3 zones outward from the human dominated areas, zone 1 & 2 (<1000m) and zone 3 (>1000m).

Zone	Observed	Expected	Chi-square (X^2)	p value
1	22	15.981	2.2	
2	15	10.64	1.78	
3	11	21.37	5.04	
Total	**48**	**48**	**9.083**	**0.059**

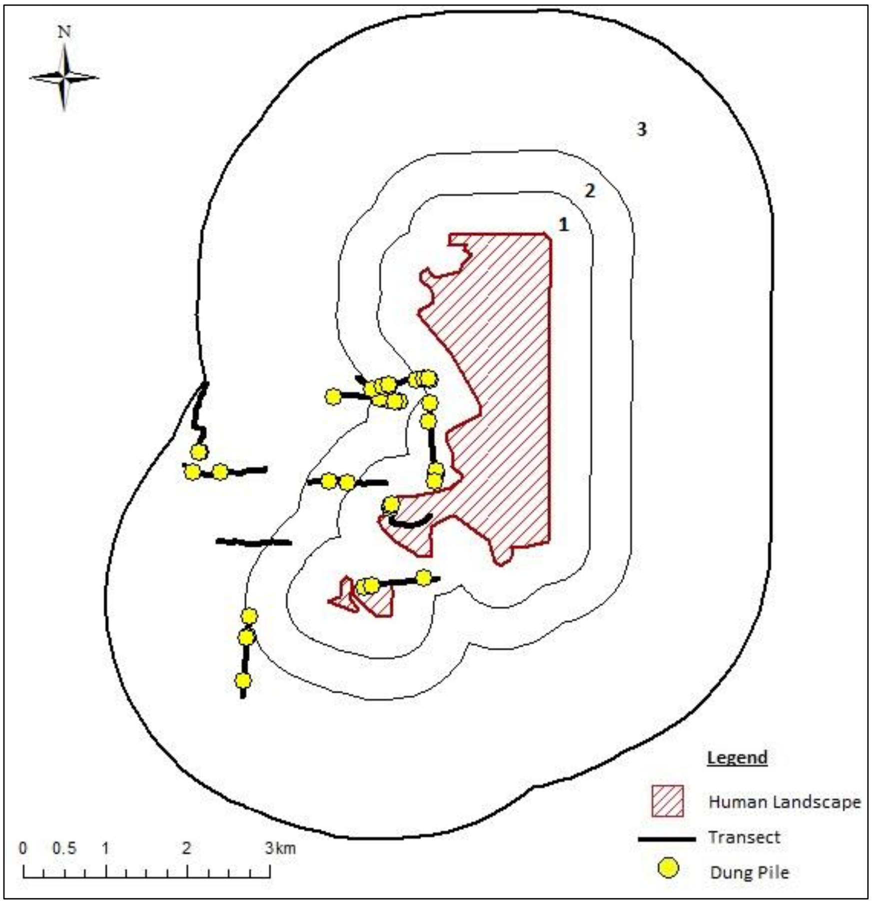

Figure 20. Transects and encountered dung piles in all 3 zones outward from the human dominated areas such as villages and plantations (zone 1 & 2 (<1000m) and zone 3 (>1000m).

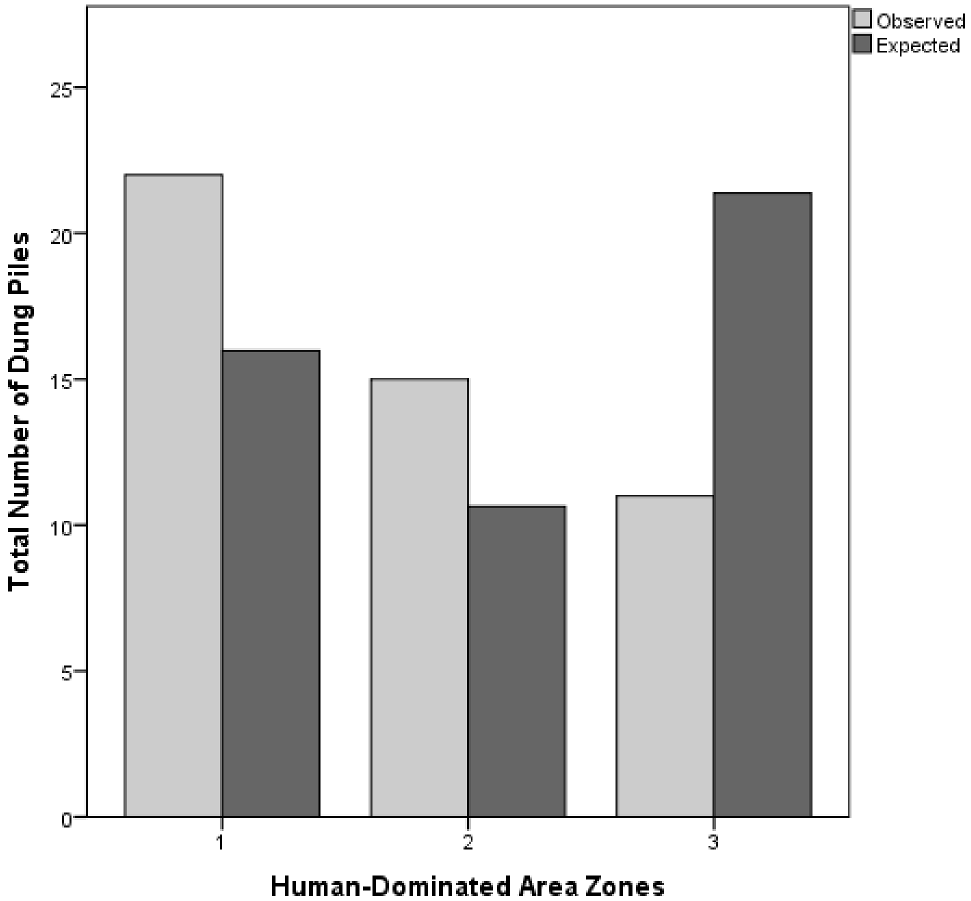

Figure 21. The total number of dung piles encountered in all 3 zones outward from human dominated zones with observed and expected values.

3.3.6 Use of Man-made Trail Systems

Over the course of the dung count surveys, a total of 10 dung piles were observed on the trail and 29 off the trail system (Figure.22). Transect 10 was excluded from the trail analysis as it passed within a plantation and so cannot be classified as on or off trail, therefore 32km was walked in total both on and off trail. Of the 32km walked, 16.9km was walked on the trail system and 15km was walked off the trail-system. The results indicate a significant difference between the number of dung piles found on and off the trail (X^2=3.566738, df=2, p=0.00) (Table.11). Fewer dung piles were observed on the trails than the indicated in the expected value (O=10, E=20), and a greater number of dung piles were observed off the trails than expected (O=29, E=18) (Figure.23). This result indicates a higher density of dung piles on non-man-made trails than on the trails.

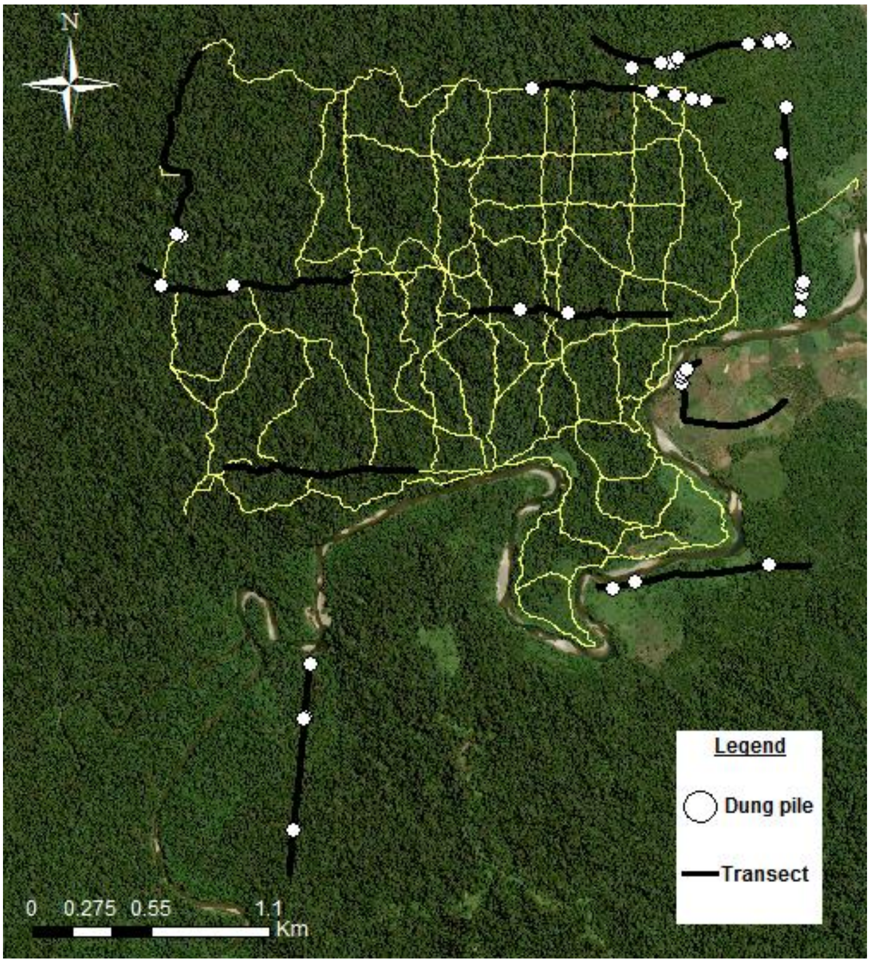

Figure 22. The trail system of Sikundur and dung piles encountered on and off the trail.

Table 11. The observed, expected, chi-square (X^2) and p-value of the 2 trail types, on and off trail.

Trail Type	Observed	Expected	Chi-square (X^2)	p value
On	10	20.70656	0.308354	
Off	29	18.29344	3.258384	
Total	**39**	**39**	**3.566738**	**0.000592**

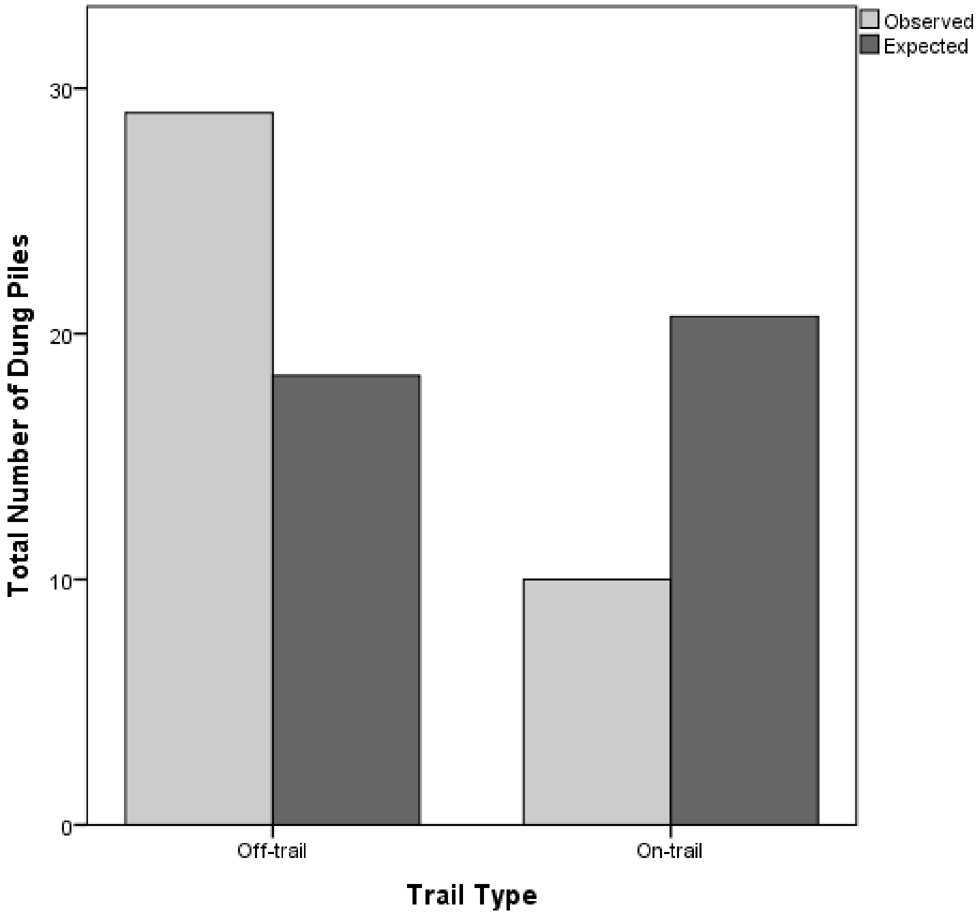

Figure 23. The total number of dung piles encountered on and off trail with observed and expected values.

3.3.7 Summary of Habitat Preference Results

Table 12. Summary table of results of habitat use, comparing hypotheses and observed results.

Habitat Characteristic	Hypotheses	Observed Results
Tree DBH & density (H_1)	Elephants will prefer areas with high tree densities with a lower DBH than trees in non-dung plots	Elephants were found in areas with lower density of trees with higher DBH than those in non-dung plots.
Canopy cover (H_1)	Canopy cover will vary and be lower in dung-plots than in non-dung plots.	Canopy cover was not found to vary between vegetation plots
Ground & understory vegetation cover (H_1)	Elephants will prefer areas of high ground and understory vegetation cover.	No difference was found between ground and understory vegetation cover between dung and non-dung plots.
Elevation (H_2)	Elephants will be found in all elevation ranges, but show an overall preference to areas of lower elevations.	Dung was found in varying elevations, but dung was found more frequently in areas that comprised a lower elevation range.
Habitat types (H_3)	A preference to alluvial habitats and an avoidance to hill habitats will be seen	No significant differences between habitat types were seen.
Distance to river (H_3)	Elephants will occur in close proximity to water sources such as rivers	Number of dung was not found to vary in distance outward from the river.
Distance and use of human-dominated landscape zones (village and man-made trail system) (H_4)	Elephants will avoid human-dominated landscapes.	Dung was found more often near human-dominated landscapes than away from them.

Chapter 4- Discussion

4.1 Sumatran Elephant Density Estimate

Elephant population density was estimated to be 0.188 elephants per km^2 in the study area. This estimate was then extrapolated to the larger area of forest around the study site to gain an overall general estimate of the possible remaining Sumatran elephants in the surrounding lowland forest. The area of lowland forest around the study site was found to be estimated at $426km^2$, and when compared to the density calculation from the dung surveys in the Sikundur site, gives an estimation of 80 Sumatran elephants in the region. However, this size calculation did not take in to consideration recent forest loss and thus the Hansen et al (2014) maps of forest cover loss per year were used to better generate a more reliable estimate. By looking at the forest loss maps, the initial boundary line roughly coincides with the areas of highest forest loss from the Landsat derived images. A distinct line of forest loss can be seen around the northern, eastern and southern areas, and can even be seen in areas previously observed to be forest cover. The boundary line of viable lowland forest is therefore likely to be smaller than previously estimated, and may continue to decrease if no action is taken. The map of forest loss suggests an overall loss of $47km^2$ with the remaining lowland forest of that area estimated at $379km^2$. This area estimation allowed for a more realistic calculation of 71 Sumatran elephants residing within the boundary area. This loss signifies a probable reduction of 9 elephants from the original estimation, occurring mostly between the years 2000-2010. This suggests that for every transpired year, 1 predicted elephant was lost as forest cover diminished. The worst time period of forest cover loss can be seen within this 10 year period, however forest cover loss over the years 2010-2016 can still be seen occurring with visible encroachment upon the forest edge.

As a population decreases in size, the risk of extinction increases. Demographic stochasticity, inbreeding, and local catastrophes then become influencing factors in the probability of population extinction, and can be even more exacerbated if the population has slow life histories, growth rates and gestation periods (Lande 1993, Purvis et al 2000). Elephants are renowned for having long lifespans and slow life histories. Asian elephants are known to live for >80 years, producing offspring every 3 to 6 years with a gestation period of 18-23 months (Lahdenperä et al 2014, Sukumar 2003). Elephants are therefore at an increased risk of extinction due to slow life histories, particularly Sumatran elephants which reside in small and fragmented population across their range (Blake & Hedges 2004, Sukumar 2006). Using population viability analysis, Sukumar (1993) states that a population of 100-200 elephants would have a high probability (>99%) of survival for the next 100 years, despite demographic stochasticity and genetic depression. This does not however take into account demography, sex ratio and environmental pressures. Sukumar (1993) also theorises that genetic inbreeding may only become problematic if the population drops to below 50 individuals. The estimation of 71 Sumatran elephants produced in this study is therefore below the minimum viable population of >100 elephants, but above the threshold where genetic depression may become irreversible. This implies that while these numbers are low, the population may have a chance of surviving extinction, assuming environmental pressures such as habitat loss do not worsen.

However, it is important to acknowledge that elephant distribution is dependent on numerous and complex factors and using a density estimate gained from the small sampling area against a much wider area may not result in a precise estimate. It is used primarily to show how many elephants could potentially be remaining in the lowland forest area as this has not been undertaken before and to achieve a more accurate estimate of how many elephants may be remaining in this forest. It is similarly worth acknowledging that this study found variation within the habitat preferences of Sumatran elephants, and therefore extrapolating the density calculation to the entirety of the surrounding North Sumatran forest without habitat, topography or elevation data may not be accurate, as elephants may occur in varied numbers depending on the habitat variables. To correct this, further studies should be undertaken on a larger scale to further asses' habitat viability for the species and achieve an accurate calculation of viable elephant habitat. As this study also only used the recce sampling method and sampling was not entirely random due to time constraints, it is important to also acknowledge that these results may not reflect true population numbers. Due to the non-random sampling methods in regards to transect start points and solely using the recce transect method (where the path of least resistance is followed), the data may in fact overestimate the population size of Sumatran elephants in the Sikundur area, and the population may be much lower than estimated here.

Furthermore, due to the small sampling size of dung monitored for decay and uncertainty in exact survival times due to the lack of fresh dung and long intervals between visits to dung, it must also be mentioned that the density estimates may also vary and may in fact be higher or lower than estimated. It is therefore vital to continue the data collection and surveys within Sikundur, and continue to improve on these methods (dung decay monitoring and survey methods), whilst also conducting new surveys further out in the forest and habitat surveys to better estimate the population that is likely already perilously low in numbers. If lowland habitat continues to decrease and no action is taken, this population could eventually become more isolated, resulting in potential extinction and an even further decrease in population numbers.

4.2 Sumatran Elephant Habitat

4.2.1 Habitat/Forest Structure

The other main aim of this study was to gather information on the distribution of Sumatran elephants within their environment. Contrary to expectation, ground and understory vegetation were not found to vary between areas with elephant presence and non-presence. A minor increase in both ground and understory vegetation in areas with dung can be seen (Figure 6); however it is not a significant difference and the variance is small. This result may be a consequence of a mosaic of environments elephants traverse, where ground vegetation and understory vegetation cover is likely to fluctuate (Rizwar 2013). Canopy cover was also not found to differ between areas with dung or without dung; this largely coincides with previous literature as canopy cover preferences are expected to differ immensely, and is dependent on elephant activity. Canopy cover preference has been found to depend on the time of day and the weather due to thermoregulation requirements, with daytime activities typically occurring under canopy cover compared to at night time, especially on days with less cloud cover (Kumar et al 2010, Sitompul et al 2013, Valeix et al 2007). The lack of significant variance between forest characteristics, such as canopy and vegetation cover, in areas containing dung compared to areas without may be a result of the data encompassing all elephant activity, as opposed to areas where the elephants will feed or rest. It is therefore difficult to make assumptions based on these factors without direct observations of elephants, and further data collection would be required.

However, other studies have found canopy and ground and understory vegetation cover play a large part in the distribution of elephants within their environment (Owen-Smith, 1988, Rizwar 2013). Nonetheless, the results of this study indicate that elephants will not solely inhabit one type of forest area, but inhabit forest types with varying levels of canopy cover and ground and understory vegetation cover types.

Tree density was found to be significantly less in areas where dung was found compared with where it was absent. Elephants favouring areas with lower densities of trees may be a direct result of movement constraints. Moving within environments with a lower density of trees may increase mobility for travel and protection from predators through increased visibility of the herd (Vanleeuwe & Gautier-Hion 1998). Lower tree density may also be a consequence of food availability, as a greater number of exposed canopies will promote higher levels of ground vegetation and young sapling growth, therefore increasing the presence of elephant food (Denslow 1987). Median DBH and 1st quartile DBH differed significantly between vegetation plots, which indicate a larger DBH of trees in areas where dung was found, these results largely coincide with previous literature which states elephants prefer areas with trees with a DBH less than 32cm. However, larger trees also tend to block out sunlight, which would typically result in less rich ground and understory in such areas. This result may also correlate with increased mobility in when elephants traverse their environment. To conclude, in relation to hypotheses 1 (H_1), forest structure was found only found to vary significantly in relation to tree density and DBH, which showed elephants prefer areas with a lower density of trees and a higher DBH than in plots that contained no dung, but no preference was seen in relation to canopy cover or ground and understory vegetation cover.

4.2.2 Elevation

Lowland forests are classified as having an approximate elevation range <500 m.a.s.l with varying elevations within this threshold, and often encompass various habitat types (Laumonier 1997). Dung was found in all elevation zones, but there was a significant difference of dung found between the 3 elevation zones, zone 1 (20-55m m.a.s.l), zone 2 (56-90 m.a.s.l) and zone 3 (>90 m.a.s.l). Zone 1, which was the area which comprised the lowest elevation range, contained the highest amount of dung and greatly exceeded that of the expected value. Zone 1 may also be compared to the alluvial habitat type (Figure.14 & Figure.16), which also contained more dung than expected. This may indicate that elephants prefer lower elevated areas, which would also coincide with depressions in the landscapes that contain alluvial habitats. Zone 2 contained a significantly low amount of dung and was much lower than the expected value; Zone 3 contained the least amount of dung, but did not majorly deviate from the expected values. Zone 3 may also be compared to the result from the hill habitat type seen in Figure.14 & 16, and may suggest elephants prefer lower elevation zones as it has been stated previously that steep slopes may limit elephant mobility (Feng et al 2008). The data shows dung was present in all zones and habitat types of elevations >90 m.a.s.l and in areas of 16-25% steep slopes, therefore supporting the hypotheses (H^2) that elephant movement is not constrained by elevation and hill areas, but elephants may favour areas with fewer steep slopes and a lower elevation range of 20-56 m.a.s.l, which also appears to coincide with alluvial areas and depressions in the landscape such as rivers. Further research investigating the impact of elevation on Sumatran elephant distribution would be beneficial in further understanding elephant habitat preferences. As Sumatran elephants have previously been observed occurring at high altitudes and occurring in areas with steep slopes, there may be corresponding factors that influence their distribution at different elevations, such as thermoregulation and temperature.

4.2.3 Habitat Types & Distance to River

No significant difference between dung found in each habitat type were identified from the analyses, however slight deviations from the observed and expected values of alluvial and hill habitats can be seen. More dung piles than expected were found within alluvial habitat types (floodplain of meandering river with flat to undulating slopes <8%), but less dung piles than expected were found within hill habitat types (parallel elongated ridges, 16-25% steep slopes). This would support the hypotheses that elephants prefer areas with fewer slopes and lower elevations (H^2).This result may indicate that while elephants may utilise all habitat types, there is a slight preference to alluvial habitat types which would support the hypotheses (H^3). A preference to alluvial habitats would also coincide with previous literature that elephants favour being close to water sources to drink and to bathe (Owen-Smith 1988, Kumar et al 2010, Santiapillai 1984, Sukumar 1989 & Chong 2005, Rizwar et al 2014). When comparing these results to the elevation analyses, the area of alluvial habitat seems to directly coincide with the Zone 1 category of elevation (20-55m m.a.s.l), which was the lowest elevation zone. Zone 1 contained significantly more dung than other zones, which may further support this preference to alluvial areas. Despite this, no significant results were found when looking at the proximity of elephant presence 2500m outward from the river, which rejects the hypotheses (H^3). A lack of significant difference when looking at the river zones may be a consequence of elephants being spread out evenly within the 2500m zone or the proximity analysis not taking in to account terrain, elevation or slopes. To further explore patterns of elephant distribution in proximity to rivers, this would need to be attempted at a greater scale. Despite this, by looking at both the elevation and habitat type analysis and previous literature, Sumatran elephants likely do show an overall preference to alluvial habitats.

4.2.4 Distance to Human-Dominated Landscapes

The human-dominated landscape used in this analysis was Sikundur village and adjacent plantations, residing on the edge of Gunung Leuser National Park. This area is one of the few that contains Sumatran elephants, but human-wildlife conflict is occurring less drastically than other areas of Sumatra (personal communication, Hankinson, E., 2018, Nyhus & Tilson 2000). The villagers typically use noise methods to deter the elephants from entering areas of human occupation and crop fields. Evidence of elephant encroachment was observed whilst undertaking transects through plantations (transect 10), and while some destruction to crops was evident, the local people did not seem to be overwhelmed by elephant presence. The local people are also provided with deterrent equipment such as head torches and fire crackers by local conservation organizations (personal communication, Hankinson, E., 2018). There may be multiple reasons why there is minimised conflict between the local people of Sikundur and the elephants residing in the adjacent forest compared to other areas of Sumatra, including crop types used, effective conflict mitigation strategies or sufficient habitat and food for elephants in the area.

In this study a significant difference was found in the deviations from expected values of the number of dung in the three zones around the human-dominated landscapes. The greatest number of observed dung was found in Zone 1, which was greater than the expected values. This zone was closest to the human-dominated landscape and within a 500m buffer radius from the village and plantations. This was comparable to Zone 2 where more dung was observed than expected. Zone 2 was above the buffer radius of 500m from the human-dominated landscapes, but below 1000m of it. Zone 3 was >1000m away from the human-dominated landscape and also contained dung, but less observed dung than was expected. These results suggest that although elephants were found in all zones around human-dominated landscapes, they occur in significant densities at the closest to the core area of human occupation. This allows a rejection of the hypotheses (H^4), which states that elephants will strictly avoid human-dominated landscapes.

The reasons for the frequent occurrence around human-dominated landscapes may be due to various influencing factors. One factor may be that Sumatran elephants, like their African counterparts, possess spatial memory that allows them to remember the spatial locations of important areas, such as water sources or areas of forage (Dale 2008, Polanksy et al 2015). Sumatran elephants are often seen occupying areas near rivers and alluvial habitats which is also seen in this study and may also be linked to low elevations.

These areas often coincide with human habituation, due to access to food, river transport and water sources and it is possible that there is a preference from both humans and elephants to reside within these areas (Kummu et al 2011). A large proportion of these areas have now become human-dominated landscapes and it may be spatial memory driving elephants to return to these parts of the forest, despite human occupation. Another factor that may drive Sumatran elephant’s preference to these landscapes is the presence of forest edges (Sitompul et al 2013, Rood et al 2010). Forest edges often contain an abundance of new growth of ground flora and therefore provide elephants with an abundance of food (Sukumar, 1989, 1990; Zhang & Wang, 2003). Forest edges may well contain larger quantities of available food for Sumatran elephants, and by also residing in these areas they can also gain more food opportunities by entering crop fields. Whether elephants reside in these areas due to spatial memory, forage opportunities or a combination of both, this study shows that elephants will undoubtedly inhabit areas in spite of human habitation, but the reason for this needs to be investigated.

4.2.5 Use of Man-made Trail Systems

Human traffic and an insurgence of human activity are known to negatively alter species' behaviour and the overall ecology of an area (Ciuti et al 2012, Griffiths and Schaik 1993, Zhou et al 2012). The negative impacts of human traffic are determined by the overall intensity and type of human presence in an area (Blake et al 2017). However, when human traffic is taking place in low quantities, such as at field research stations, fewer disturbances are expected particularly in comparison to eco-tourism hotspot areas or human settlements. However, impacts on the surrounding ecosystem still inadvertently take place, and often arise in the form of man-made trail systems used by guides and researchers (Blake et al 2017). Man-made trail systems are often created by local people or researchers to navigate forest areas more easily, and although these can have negative impacts, a selection of forest mammals have been found to show a tendency towards using these trails (Harmsen 2006, Harmsen et al 2010). Little is known in regards to elephant usage of man-made trails, this may be as they themselves are known to create natural trails through the forest (Blake 2002, Haynes 2012).The Sikundur field site and surrounding forest consists of defined to semi-defined man-made trail systems that are used daily by primate researchers. The trail system is based around trails that have been cut more recently by researchers and the old logging roads used previously when the forest was selectively logged from the 1960s until the 1980s (SOCP 2015). It is important to add that although the Sikundur trail system is the most intensely used area today, small remnants of unused trails and roads may remain further out from the trail system, however as these remain largely unused they are likely indistinguishable from the surrounding forest. Therefore, the comparison between plots on trails and those off trails is primarily done to determine whether elephants use the well-defined and intensely used Sikundur trail system, compared to other surrounding areas that do not get walked as frequently.

The results showed that elephants were present on the man-made trails and logging roads located within the trail system of Sikundur. There was however a significant difference between the amounts of dung found on and off the man-made trail system. More dung than expected was found off the trail system with a total of 29 in total, and less dung then expected was found on the trail system which was 10 in total. These results indicate that elephants did in fact utilise the man-made trail systems, despite high activity by humans, but in lesser quantities than they did non-man-made trails. This result may support the hypotheses (H^4), but it remains unclear whether elephants are actively avoiding the trail system. These results suggest that elephants are not impartial to the use of man-made trail systems and use them on an opportunistic basis alongside the creation of their own natural trails, but the presence of human traffic may have an impact on this usage. Man-made trails may however provide movement opportunities and a greater perceptibility of predators as elephants traverse their environment. Despite this, as elephants were found more frequently off the trail system than upon it, it is unlikely that it adds additional benefit from their own created trails, and the presence of humans may even cause them to avoid it entirely.

4.3 Implications for Forest & Sumatran Elephant Conservation

Deforestation and habitat loss are at present the biggest threat to the Sumatran elephant and Indonesian wildlife alike (Kinnaird et al 2003, Margono et al 2014, Mariati et al 2014). Deforestation and forest cover loss is occurring predominantly through human encroachment and concessions, such as logging or monoculture plantations. Encroachment and deforestation of tropical forests are causing highly bio-diverse areas to become reduced and surrounded by a matrix of human-dominated landscapes (Cincotta et al 2000, Janzen 1983, Nyhus & Tilson 2004). Despite this, moderate levels of disturbance in a forest such as selective logging have shown regeneration potential if left to recover (Edwards et al 2014, Knop et al 2004). This study shows Sumatran elephants inhabiting a previously logged secondary forest that was logged in the 1970s to the 1980s, but has been left to recover since the 1990s. This also coincides with the literature, because Sumatran elephants are known to inhabit secondary forests more than primary forests (Sitompul et al 2013). Secondary forests should therefore be regarded as important habitats for the Sumatran elephant, despite previous disturbance, and should be thoroughly protected akin to primary forests. However, when large patches of forest are removed, such as for the creation of urban areas or for cropland such as palm oil, regeneration is problematic and almost impossible (Grubb et al 1994, Sodhi et al 2010a). The on-going encroachment by humans and forest loss is the biggest threat to the lowland forest in North Sumatra and the population of Sumatran elephants that reside within it. If encroachment and forest loss continue, the reduction of optimal elephant habitat will likely cause interactions between humans and elephants to intensify, and conflict may occur. This occurrence would not only accelerate population decline through potential mortality of Sumatran elephants, but make the overall conservation of the species much more challenging. Human-elephant conflict has the capability to cause an upsurge in negative perceptions of elephants by the local people, and as a consequence local people will be less content with living alongside areas with elephant habituation, or cooperating with their conservation (Dickman 2010, Thomas 2017).

If elephants and humans are to co-exist without conflict, sufficient habitat for elephants and corridors to traverse between must be left available (Kinnaird et al 2003). Necessary action must be taken to ensure the long-term survival of Sumatran elephant habitat, and reduce the on-going encroachment to these last remaining lowland forests. Fortunately, our knowledge of Sumatran elephant habitat selection and distribution within forests is now growing. This study supports the notion that Sumatran elephants inhabit lowland forests with varying levels of canopy cover, ground and understory vegetation. Conservation of elephant habitat should therefore aim to promote habitat mosaics, which incorporate a diversity of habitat types, including primary forests, secondary forests and forest edges. It should also be taken into account that although elephants can traverse areas with the presence of steep slopes and inhabit hill habitats as found in this study and the study by Rood et al (2010), areas with a lower elevation range are frequently used (Kumar et al 2010). These are the areas that likewise tend to coincide with areas of human habitation, which this study found elephants not averse to inhabiting in high numbers. If sufficient habitat remains available to elephants, human-elephant interactions may not get worse, however if this habitat continues to decline, then it may well intensify with disastrous consequences for small populations such as the ones located around Sikundur forest. Therefore, to ensure the long-term persistence of the species, action must be taken to protect the remaining lowland forest, both in the area of Sikundur, North Sumatra and other sites in Sumatra. To better ensure longevity of these forests and their endemic species, the Indonesian government and governmental organizations must strictly monitor and aim to decrease the levels of on-going encroachment and illegal activities, which continue to occur in the national park and at the national park boundaries.

4.4 Recommendations for Future Research

Despite their large size and critically endangered status, Sumatran elephants remain one of the least understood large mammals in regards to their ecology, distribution and population numbers. This study attempted to gain a first density estimate for the North Sumatran population residing within a lowland forest in the Gunung Leuser National Park in the Leuser Ecosystem. However, as this research was comprised of only 5 months of field work and was focused within a small study area there was a limit on the quantity and quality of dung decay monitoring, dung count surveys and behavioural observations that could be conducted. Nonetheless, this study provides preliminary data on the population of Sumatran elephants residing within the study site located in North Sumatra, which before now were unstudied. The data collected can hopefully be used to continue elephant monitoring and research in both Sikundur and North Sumatra. Continuation of research would subsequently allow for a better evaluation of the present population in North Sumatra, through the monitoring of population, and provide insight into the overall health of the population.

To better improve population density estimates, further studies on the decay rate of dung in Sikundur and within tropical forests are needed. Within this study, problems were encountered in truly defining a dung pile as ‘gone’, particularly within the interior of the forest. It was often found that roots from the soil will grow in and around the dung, prolonging the structure of the dung for long periods of time, encasing mud and plant fibres, despite no faecal material remaining. This made the process of defining the dung as S5 (gone) difficult, as a pseudo structure would often reside for months. Having a better grasp on dung decay stages, primarily on the later stages such as S4 and S5 (and when to class a dung as gone) would be valuable when undertaking dung related survey methods in tropical forests, and would allow for a more accurate estimation of population density when undertaking dung survey methods.

To improve density estimates of the population of Sumatran elephants in Sikundur and the surrounding area, further sampling should be undertaken on further out from the original survey site using additional methods such as line transects. As this study used only a small study site to determine elephant density on a larger scale and shows elephants will occur in higher numbers dependent on habitat variables, undertaking further dung and habitat surveys in various locations within the lowland forest would allow for a more accurate density estimate of the remaining elephants. Recce transect methods have become increasingly popular due low effort needed for sampling, however it is important to acknowledge that it may also cause overestimation of density estimates due to the non-random sampling methods. By only undertaking the recce sampling method within this study, an overestimation of density estimates due to non-random sampling may have occurred. To improve the accuracy of density estimates, survey methods should including pairing line transects with recce transect methods (Walsh & White 2008). This would not only be beneficial in helping us understand the accuracy of the recce transect method overall, but improve the accuracy of density estimates for the area and allow a better understanding of the population in North Sumatra. In addition, undertaking surveys along the established transects and the creation of entirely new transects further out from the original survey site using random survey methods would allow us a more detailed and accurate insight into how many elephants are residing in Sikundur and North Sumatra as a whole.

In order to achieve a better understanding on the habitat preferences and distributions within the forest, further habitat surveys in areas of elephant presence would be beneficial. As this study was focused on a relatively small area of forest, which was in close proximity to the forest edge and human-dominated landscapes, surveys further afield from the original survey area would be required to better improve our understanding of their distribution. Data collected further out from the research station would also provide a greater scope of information and would improve our understanding of elephant movements deeper in the forest and whether elephants occur there in greater numbers to what was seen in this study. It would also be beneficial to further understand why elephants are seen occurring in high densities around human-dominated landscapes and if there is a relationship between elephants presence around human landscapes, elevation and presence of rivers. Further studies investigating this would be crucial in improving or preventing interactions between humans and elephants.

Additional studies looking more in depth on how terrain ruggedness and presence of steep slopes influence elephant distribution would also be beneficial, particularly in areas where elephants are at risk of being isolated. Undertaking additional methods, such as DNA dung testing or radio tagging, would dramatically increase our knowledge of the elephants residing in this lowland forest of North Sumatra. The use of alternate methods would not only enhance our current knowledge of species range and movement, but help identify whether the population in this study is in fact isolated within the lowland forest boundary, and if any possible corridors are available for them. If this population of Sumatran elephants are indeed isolated within this lowland forest, it is imperative that they do not get overlooked or disregarded, particularly with the already low species population numbers and the on-going threat of forest loss occurring around lowland forest boundaries and on a country-wide scale.

Chapter 5- Conclusion

The Sumatran elephant is growing increasingly vulnerable to extinction through wide-scale deforestation and habitat loss. This study gathered a first density estimate of a Sumatran elephant population residing in a lowland forest area of 379km^2, which at present is at continued risk of encroachment and deforestation, despite its protected status. To improve the conservation efforts of the species, it is imperative we increase our existing knowledge of the last remaining populations, such as the one within the study, and better understand their habitat use and preferences. This study found variation in forest characteristics between areas of elephant presence to absence, and a preference to lower elevation zones within a range of 20-55 m.a.s.l. which coincided with alluvial habitats. This indicates that although elephants can traverse areas with high elevations, they will show a preference to lower elevations. The results also found that elephants were found in close proximity to human-dominated landscapes (villages and plantations), more often than in areas further away. Elephants were similarly found using the man-made trail system of the Sikundur field site, which is exposed daily to human traffic by researchers; however they did not use it more than other areas of the forest. If optimal elephant habitat is found in close proximity to these landscapes (such as forest edges), this could cause major problems in the future, such as an increase in human-elephant conflict, as encroachment is occurring most predominately around the forest edge. In summary, although the population density estimate in this study of 71 elephants falls below the minimum viable population threshold, there may still be a chance of improving the outlook for the Sumatran elephant and increasing their numbers, assuming environmental pressures such as habitat loss do not worsen. However, if lowland habitat continues to decrease and no action is taken, this population, alike others could eventually become isolated, resulting in the loss of the sub-species as a whole. By improving our overall knowledge on all remaining populations of Sumatran elephants and their habitat preferences, we will have a better chance of protecting this species from further declines and possible extinctions in the future.

Chapter 6- Bibliography

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