Asian elephant movement ecology within Human-Elephant Conflict landscape in Johor, Peninsular Malaysia

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ABSTRACT

As the largest terrestrial animal on earth, elephants perform important and irreplaceable ecological roles within their natural ecosystems. However, elephants are regarded as pests owing to significant damages they can cause to farms. Farmers find elephants extremely difficult to manage due to elephants' vast appetite, high degree of intelligence to circumvent mitigating efforts, and potential for causing harm. In Malaysia, movement ecology of wildlife is challenging to be incorporated into conservation actions due to lack of direct sightings in the rainforest and difficulty to deploy tracking devices on endangered species. However, the growing database of Asian elephant (*Elephas maximus*) GPS movement in Malaysia provides opportunities for researchers to elucidate the movement ecology and spatial needs of Asian elephant that can benefit both conservation and management in a variety of ways (e.g., mitigation measures). This study aims to help the agriculture community to manage Human-Elephant Conflict in Johor, Malaysia and promote coexistence with elephants. The objectives of this study are to estimate the home range sizes of collared elephants in Johor using dynamic Brownian Bridge Movement Models and, to determine the impact of land use changes on elephant movement pattern using spatial and pathway analysis. We analysed GPS telemetry data from eight elephant individuals in Johor between 2020 – 2022, and found the elephants to have large area requirements, with mean home ranges (95% utilization) of 245 km^2 (min-max range 142 km^2 – 326 km^2). The home range sizes were smaller when the proportion of agricultural land used within its home range was higher ($R^2 = 0.56$, p-value = 0.033, $F_{1,6} = 7.58$) and when the proportion of forest within its home range was smaller ($R^2 = 0.59$, p-value = 0.027, $F_{1,6} = 8.52$). Least-cost path and Circuitscape analyses of possible corridors connecting the core area (50% utilization home range) were used to visualized landscape connectivity and help informed potential sites for the development of corridors in future. This thesis contributes to a better understanding of Asian elephant movements and space use within agricultural and forested landscapes, and help support conservation management of Asian elephants and their habitat.

Keywords: GPS telemetry, *Elephas maximus*, movement ecology, home range, movement patterns, Peninsular Malaysia

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INTRODUCTION

1.1 General background

Elephant is the biggest representative of terrestrial megafauna today. Elephants belong to the family Elephantidae, which consists of two genera represented by two species in Africa and one species in Asia, namely the African bush elephant (*Loxodonta africana*), African forest elephant (*Loxodonta cyclotis*), and Asian elephant (*Elephas maximus*). The Asian elephant can be divided into three extant subspecies: The Sri Lankan elephant (*Elephas maximus maximus*), the Indian elephant (*Elephas maximus indicus*) from mainland Asia, and the Sumatran elephant (*Elephas maximus sumatranus*) from the island of Sumatra (Sukumar, 2006; Shoshani & Eisenberg, 1982). However, DNA test suggested that the Bornean elephant (*Elephas maximus borneensis*) is genetically distinct from other Asian elephant populations (Fernando et al., 2003).

As the largest terrestrial mammal, elephants contribute to the maintenance of entire ecosystem by dispersing seeds, particularly from megafauna-syndrome plants (Campos-Arceiz et al., 2013), making paths for smaller animals, and influencing the structure and composition of vegetation (Terborgh et al., 2018). No other animals can take over the role of Asian elephant with their seed dispersal capability for certain plant species (Campos-Arceiz et al., 2013; Terborgh et al., 2018; Ong et al., 2019). The International Union for Conservation of Nature (IUCN) Red List for Threatened Species has classified Asian elephants as Endangered, with a worldwide population size of 41,410 to 52,345 individuals (Choudhury et al., 2008). Global population of Asian elephants continue to decline due to various threats such as habitat loss, poaching and ivory trade, as well as human-elephant conflicts (Choudhury et al., 2008).

1.2 Deforestation

Generally, forests are utilised to support national economy, agricultural growth, commercial logging and mining (Jomo et al., 2004). The rainforests of Southeast Asia are some of the oldest in the world and home to the world's largest number of threatened megafauna (Ripple et al., 2016; Ripple et al., 2017), and it is particularly vulnerable to biodiversity loss and deforestation (Sodhi et al., 2004), with land being transformed to accommodate growing populations, subsequent urban sprawl, and agricultural conversion (Laurance et al., 2014; Schneider et al., 2015). Due to fast economic growth, road construction, and forest loss, it is also a location where vulnerable megafauna suffers some of the highest levels of human pressure (Allan et al., 2017; Dulac, 2013; Miettinen et al., 2011). Human action is thought to have resulted in the loss of around 6 million km² (35%) of tropical forest (Wright 2010). Between 2000 and 2010, Miettinen et al. (2011) predicted a 1% annual reduction in forest cover in insular South-East Asia and in 2013, recorded the highest rate of primary forest loss in the world (Hansen et al., 2013).

Malaysia, a country rich in biodiversity and with a fast-rising economy in Southeast Asia, exhibits the tensions that many tropical countries face between conservation and economic growth. Malaysia is part of the Sundaland Biodiversity Hotspot (Myers et al., 2000) and has a National Biodiversity Index of 12th in the world (CBD Secretariat, 2015). However, Malaysia faces trade-offs in its aim to maintain forest complexes and biodiversity while continuing to grow and generate profit from natural resources (Jomo et al., 2004; Nagulendran et al., 2016). Peninsular Malaysia remains a refuge for megafauna (Ripple et al., 2016), including Asian elephants (Saaban et al., 2011), however the region's megafauna, particularly Asian elephants are increasingly threatened by human pressure, deforestation and urbanisation (Wadey et al., 2018; de la Torre et al., 2019; de la Torre et al., 2020). At the same time, other megafauna in Peninsular Malaysia also experienced a serious decline, for instance the loss of Sumatran rhinos (*Dicerorhinus sumatrensis*) and a steady decline of Malayan tigers (e.g. Clements et al., 2010; Havmøller et al., 2015; Hance, 2014). Peninsular Malaysia is home to approximately 1500 wild elephants (Saaban et al. 2011). Given the drastic change of forest cover in Peninsular Malaysia from 80% in 1940 to 44% in 2014 (Aiken & State, 1994; Forestry Department of Peninsular Malaysia (FDPM), 2016), elephants' range and population numbers have unavoidably decreased as a result of habitat degradation and the consequently led to an increase in human-elephant conflicts. Furthermore, large portions of lowland forest which was ideal elephant habitat were transformed into oil palm and rubber plantations. Additionally, the introduction of government agriculture land schemes such as FELDA (Federal Land Development Authority, 1956), RISDA (Rubber Industry Smallholding Development Authority, 1973) and FELCRA (Federal Land Conversion and Rehabilitation Authority, 1966) aimed at developing and improving poverty in rural area had led to the expansion of low-land areas for agricultural propose and the development of infrastructures and settlements, further fragmenting elephant habitat.

Current, Asian Elephant populations are very scattered, with populations found in seven of the eleven states, and concentrated in areas within the states of Perak, Kelantan, Terengganu, Pahang, and Johor. Kedah has a small population and Negeri Sembilan has only one individual (Saaban et al., 2011). Although elephants do not only occur in forested area, the shrinking of forested area might lead to a significant reduction of elephant range in Peninsular Malaysia, creating fragmented elephant populations and increase human-elephant conflicts, hence seriously threatening the survival of elephant (Clements et al., 2010; Saaban et al., 2011; Thaufeek et al., 2014; Tan, 2016). Infrastructure construction, such as roads along forest reserves, acts as an ecological sink since elephants are drawn to the abundance of food but they suffer from negative effects on movement and safety as a result of poaching and collision (Clements et al., 2010; Wadey 2018; Patah et al., 2018).

1.3 Human-Elephant Conflict

Human-elephant conflict (HEC) is a long-standing issue that arises when elephants and human agricultural societies clash (Sukumar, 2003). Elephants crop raids on farms, people injury or death caused by elephants and human retaliation against elephants are common examples of human-elephant conflict (Sukumar, 1990; Fernando et al., 2005). HEC in Peninsular Malaysia was first documented in the early 1900s (Maxwell 1907) where elephants have been observed destroying banana and coconut crops. Human-elephant conflict existed in Peninsular Malaysia prior to the extensive conversion of forests (Zafir and Magintan, 2016), but it was discovered to have increased following forest conversion in the 1800s when elephants were drawn to durian crops (Kathirithamby-Wells, 2006) and is now regarded as serious human-wildlife conflict when rubber plantations were converted to oil palm and there were opening of new peat and forest land for oil palm plantation (Saaban et al., 2011; Zafir and Magintan, 2016). The main wildlife species involved in wildlife conflicts with humans are the long-tailed macaques (*Macaca fascicularis*) followed by the Asian elephants (*Elephas maximus*) and the wild boars (*Sus scrofa*) (Saaban et al., 2011). However, elephants often become the focus of the discussion due to their large size, proclivity for raiding crops, potential for aggression and their high degree of intelligence to circumvent mitigation measures such as electrified fences and trenches (Fernando et al., 2008; Mumby & Plotnik, 2018). In many elephant range countries, due to intense human-elephant conflict, farmers became increasingly frustrated and resorted to illegal tactics such as poisoning and shooting of elephants (Doyle et al., 2010; Santiapillai et al., 2010; Saaban et al., 2011). In Sri Lanka, it shows a big number of elephants being killed by farmers due to HEC. Approximately 183 elephants died in 2007 alone due to gunshot wounds, electrocuted, falling into wells, poisoned, landmines, accidents and other causes (Santiapillai et al., 2010). Although illegal, 10 retaliatory killings of elephants by poisoning were reported in Peninsular Malaysia between 1974 to 2002 (Saaban et al., 2011). However, when combined with the number of unreported cases and the amount cases after 2002 where the incident of HEC shows an incline, it is expected that the number of cases should be high. If the cases are high, it may gradually skew the sex ratio in numerous Asian elephant populations, since male elephant are more aggressive and involve more in HEC. This has an influence on genetic variety in such groups and may result in interbreeding, further affecting population size.

The Department of Wildlife and National Parks Peninsular Malaysia (DWNP) received 10,759 HEC complaints between 1998 and 2010, and calculated approximately RM 18.8 million in economic losses between 2005 and 2010 in Peninsular Malaysia. The number of HEC cases showed an increase trend with 549 cases in 2020 and an estimated loss of crop damage of RM 30 million (Saaban et al., 2021). Furthermore, the entire projected economic loss from crop damage in the state of Johor during 2001 and 2002 was roughly RM 760,000, with oil palm damage accounting for nearly 94.3% of the total (Salman & Nasharuddin, 2003) and estimated loss is predicted to increase over the year as the number of HEC in Johor increases steadily from 2015 to 2020 (Salman et al., 2021). In addition to direct economic losses, human-elephant conflict also results in indirect economic losses due to the resources and time required to resolve the conflict (Fernando et al., 2008). There have been cases where elephant attacks have resulted in human fatalities. The exact number of cases are unclear, however there is at least one case for the year 2022 (New Straits Times, July 9, 2022). Eventually, people who live in elephant range areas become increasingly fearful of HEC and affected local populations develop negative attitudes toward conservation policies (Woodroffe & Frank, 2005). Conflict-prone Asian megafauna, such as Asian elephants, rely on people's ability to coexist with them in the Anthropocene. The continuation of this conflict without a viable mitigation plan or strategies to develop capacity for coexistence would only result in a reduction of the population of Asian elephants.

1.4 Mitigation in Peninsular Malaysia

Measures of mitigation (fences, barriers, insurance and etc.) are usually used to minimize Human-Wildlife Conflict. However, due to regional differences in the species of animals involved, and the prevalent attitudes of the local people towards wildlife, methods and techniques that help resolve conflict need to be adapted carefully to local scenarios. There is no “one-size-fits-all” solution. There is a need of ongoing monitoring and research to develop, create and innovate new suitable approaches.

In Peninsular Malaysia, the DWNP is in charge of elephant conservation and management, as well as mitigating the effects of HEC. Before 1974, conflict elephants were considered as pest and there was pressure to kill the elephants. However, after the Elephant Management Unit (EMU) was formed in 1974, killing was banned and translocation of conflict elephant individuals to conservation areas like Taman Negara National Park, Belum-Temengor, and Endau Rompin became part of the new mitigation measure alongside chasing and guarding (Saaban et al., 2011). The translocation of elephants from conflict areas to forest reserves is one of the most common mitigation measures taken in resolving this conflict (Fernando et al., 2008) and considered a humane strategy also (Massei et al., 2010).

The Department of Wildlife National Parks (DWNP) captured and relocated over 600 elephants from all over Peninsular Malaysia between 1974 and 2010 (Saaban et al., 2011). However, studies on the elephant translocation process revealed that owing to demographic, environmental, and genetic instability, when elephants are captured and removed from a group, the smaller population left in the original habitat faces a greater risk of extinction (Sukumar, 1989). Furthermore, translocation process may cause abnormal behaviour in some elephants and may affect the stress response of the elephants (Wong, 2017). Additionally, there are other reasons such as the high cost of translocation (RM40,000) (Saaban et al., 2011) and translocated elephants returning back to the captured site (conflict area) (Fernando et al., 2012; Wadey., 2019) suggesting that it might not be a long-term solution (Saaban et al., 2020).

In 2009, DWNP adopted the use of electric fencing to overcome HEC for village areas (Saaban et al., 2011). Private land owners have been actively using elephant trenches together with electric fence. However not all can afford the cost of electric fence as it can reach up to RM 36,000 to RM 53,00 per km depending on the location, and this amount does not include the cost to maintain and repair damaged fences (Saaban et al., 2011). Capacity issues like lack of skills or limited availability of workers, may affect the maintenance and operation of electric fence systems, leading to intrusion by elephants (Saaban et al., 2021). Additionally, the effectiveness of electric fences is determined by their position (i.e., geographical features), the size of the enclosed area, closeness to elephant concentration regions, elephants' previous experiences with fences and willingness of the villagers to cooperate (Fernando et al., 2011; Ponnusamy et al., 2016). Although large plantation companies can afford electric fencing for mitigation but small land owners, on the other hand might find it difficult to afford such mitigation measures (Sinha, 2022). Electric fences have some success in mitigating HEC however can be challenging to implement for large areas or over a long period of time. In retrospect, the fences are just psychological barriers and elephants can break through electric fences if they have experience or are driven to cross it (Fernando et al., 2011; Mutinda et al., 2014). Additionally, soil erosion in trenches can weaken the pole base for electric fences over time, it also causes soil at the trench walls to fall to the bottom of the trenches, making the trenches less shallow and allowing elephants to cross the trenches (own observation, more elephant foot prints were found at the eroded site of the trench).

Integrated mitigation measures like the combination of guarding and fences were shown to be more successful than standalone strategies in avoiding crop raiding by elephants, as there is no single mitigation strategy was found to be completely effective against elephant raids (Sinha, 2022). Therefore, we believe that with considering elephant behaviours in the development of mitigation strategy and synergising already established mitigation measures, a long-term solution in the form of coexistence can be achieved.

1.5 Spatial Analysis

1.5.1 Movement Ecology

The most critical task for Asian elephant conservation is transforming human-elephant conflict into human-elephant coexistence, which would involve a thorough understanding of the conflict's behavioural and ecological drivers (Campos-Arceiz, 2013). Behavioural study such as movement ecology provide better understanding on how animals navigate and move through space and time continuum. Knowledge of movement corridors, conflict hotspots and landscape connectivity for the wildlife, can help wildlife managers in their conservation efforts on the ground and in planning for future work (NECAP, National Elephant Conservation

Action Plan). The integration of elephant movement ecology with conflict management strategies, alongside the local understanding of human dimension, can help provide a more holistic assessment of the situation on the ground and can help guide the development of mitigation strategies (Sinha, 2022).

Movements are important for living organism as it contributes to longer-term fitness considerations such as inbreeding avoidance and increasing population viability, and short-term goals that include reproduction, eating, survival and avoiding threats (Holyoak et al., 2008; Doherty & Driscoll, 2018). Meanwhile dispersal, wandering, ranging, and nomadism are terms that have been used to describe distinct long distance movement modes (Nathan et al., 2008). Animal mobility is also important considerations for network function studies including seed dispersion, predation, and disease dynamics (Nathan et al., 2008; Allen, & Singh, 2016).

In the recent decade, the study of movement ecology has evolved fast, with the help of analytical and technological advances in tracking animal movement (Tomkiewicz et al., 2010). This expansion has brought a variety of advantages to wildlife conservation and management, including a better knowledge of vital wildlife habitats, regions crossed by wide-ranging or migratory species, and information essential for species management plans in order to integrate movement and migration considerations (Hebblewhite & Haydon, 2010; Allen, & Singh, 2016). As stated by Fraser et al. (2018), increased knowledge of habitat associations, the size and usage of geographical ranges, phenology, and migratory paths, as well as interactions between animals and their environment was a result from improvements in the accuracy and precision of animal tracking. Movement ecology help provides the evidence to influence management and policy decisions, by vividly visualising movements and spatial models with colourful maps alongside statistical results, which then can be used to inform species conservation status and for dynamic or adaptive management purpose by decision-makers (Allen and Singh, 2016; Coristine et al., 2018).

In response to habitat patchiness, predation pressure, and other conditions, animals acquire unique movement characteristics through natural selection that support their survival and reproduction fitness over many generations (Fahrig, 2007). However, habitat loss, fragmentation, and degradation can disrupt the balance of these stressors, preventing animals from expressing their behaviour correctly, for example, inability to disperse and find new territories or mating partners (Doherty & Driscoll, 2018). Many megafaunal carnivores (equal or weighing more than 15 kgs) and megafaunal herbivores (equal or weighing more than 100 kgs) are facing the threat of extinction (Ripple et al., 2016). Many megafaunas have comparatively large environmental impacts encompassing of plant-animal interactions, ecosystem functions and services (Dirzo et al., 2014), and without overlap or redundancy in their ecological niches with other species, their extinction could result in trophic cascades (Terborgh, 2015). Asian elephant is the largest land mammal in Asia, and in some regions where rhinos have gone extinct like in Malaysia, elephants now play the important role of dispersing seeds for megafaunal syndrome plants and other fruit trees (Ong, McConkey & Campos-Arceiz, 2022). Elephants are more robust and are able to tolerate some anthropogenic activities such as logging (Sodhi et al., 2010), and is able to utilise a variety of habitat including forest, secondary growth and new agriculture areas (de la Torre et al., 2021).

In an era of rapid, human-induced global change, understanding the links between animal movement and habitat selection together with fundamental data on species distributions and migratory behaviour is important in assisting conservation-based measures as people continue to damage available ecosystems. There are only few places on Earth where animals may move without coming into contact with human activities in a human-dominated environment (Allan et al., 2017). Human population growth and infrastructure expansion has resulted in a global limitation on megafauna mobility, increased species extinctions and caused rapid population declines (Altizer, Bartel, & Han, 2011; Dirzo et al., 2014; Tucker et al., 2018; Ripple et al., 2016). To allow long-term coexistence of people and megafauna together with the continuation of ecological services and functions, we need to identify species home ranges and habitat areas for protection and restoration, while working with stakeholders on the ground to manage identified conflict hotspots.

1.4.2 Home Range

The size of an individual home range is a key characteristic of animal space utilisation that has significant consequences for ecological and evolutionary processes, population management, and ecosystem conservation. The widespread use of telemetry and home-range estimators based on telemetry data has resulted in a massive body of research on animal "home ranges." The region that an animal, or a group of social animals, traverses in the course of their typical activities of acquiring food, mating, and rearing young is referred to as their home range (Burt, 1943), generally means area that is inhabited while engaging in daily activities.

Meanwhile, territory of an individual or group is the region within their home range that they actively defend (Burt 1943), it might be the full home range or only a section of it (Powell 2000). Researchers were able to estimate the entire utilisation of area by an animal, which is widely thought to reflect an animal's home range, using aggregated telemetry locations, which revealed insights about what animal’s call home (Powell & Mitchell, 2012). Additionally, telemetry and sign surveys can help elucidate the species’ presences and space utilisation in association with the type of spatial topography and land use, clarify the knowledge of an animal's spatial niche, and infer the decision-making processes that the species use for traversing a road or utilise resources available in the landscape (Mitchell & Powell, 2004, 2012; Powell & Mitchell, 2012; Fieberg & Kochanny, 2005; Xirouchakis et al., 2021).

Home range size of an animal provide researchers the fundamental understanding of what environmental resources or factors are important for an animal’s fitness (Powell & Mitchell, 2012). Knowledge on target species home ranges can help support land use and protected area management (Linnell et al., 2001; Viggers & Hearn, 2005; Houser, Somers & Boast, 2009). For example, a study on Indigo snakes (*Drymarchon couperi*) home ranges by Breininger et al., (2011) shows that to avoid significant causes of road mortality, Indigo snakes required extensive land tracts with broad corridors between locations. If the underlying data is effectively processed and the result is evaluated in a biological context relevant to the wildlife species, these technologies can help support recommendations for land use planning and management together with development of wildlife corridors.

Many factors, including behavioural and foraging ecology, body size, group size, and habitat quality, can influence the size of home range (Gregory, 2016). Lower quality or fragmented habitat may also necessitate larger home ranges. Home range metrics are essential for understanding a species’ behavioural ecology and can provide crucial information for biological conservation (Woodroffe & Ginsberg, 2000; Lin & Shiraishi, 1992). Infrastructure development, land-use change, and human population density can all negatively influence animal movements and home range (Kareiva, Watts, McDonald, & Boucher, 2007; Venter et al., 2016). Male jaguars in Brazil and Argentina, for example, have expanded their home ranges as human density has grown (Morato et al., 2016) due to locating mates and obtaining resources in fragmented areas, but wild boar home ranges have shrunk and its daily movements (traveling speed) have increased in Poland (Podgórski et al., 2013) due to increased human activities. Additionally, route tortuosity and home range overlap of wolves and coyotes increase near roads where prey species are known to concentrate (Riley et al., 2006; Whittington, St Clair, & Mercer, 2004). Home range models can be used to track changes in human–wildlife interaction over time, including crop raiding, in the absence of direct observation or survey data (Scull et al., 2012). The migration of animals and the utilisation of resources are inextricably intertwined. In places affected by habitat fragmentation and agricultural conversion, investigating these relationships to understand how animals use space and choose habitats is extremely important.

The increase in size and weight of a species, and in turn their metabolic demands, is expected to be reflected by a larger home range (Dahle & Swenson, 2003; Harestad & Bunnell, 1979). Greater-bodied creatures and animals that live in larger groups have a tendency to inhabit larger regions, although this is not always the case. Therefore, as the largest terrestrial animal, elephants are expected to have large home ranges; and as a sexually dimorphic species, males too are expected to have even larger home range sizes than females. Elephants have home ranges of hundreds of km and can travel long distances, sometimes seasonally (Baskaran & Desai, 1996; Fernando et al., 2008; Alfred et al., 2012). For example, Magintan et al, (2016), research on home range size for a single individual of male and female Asian elephant shows that home range size of each individual was estimated at 96.53 km² for female elephant and 367.99 km² for male elephant, meanwhile the estimated home range of Bornean elephants was between 250 to 400 km² (Alfred et al. 2012), both using minimal convey polygon method (MCP) and addition it was also found that elephants occupying fragmented landscapes had larger home ranges (600 km²) (Alfred et al. 2012). The elephants' movement rate and home range sizes increase as the environment becomes more fragmented, most likely due to their inability to locate enough of their daily resource requirements in a changed environment. In Indonesia, elephants preferred inland marsh grasses over mixed swamp forests and secondary forests due to the abundance of food plants (Rizwar et al., 2014). Elephant home range size is inversely related to food availability and productivity. Food and water are the two most important elements that influence elephant range sizes, with elephants requiring roughly 150 kg of fresh vegetation per day and up to 190 litres of water every few days (Vancuylenberg, 1977). As a result, elephants travel great distances, up to 64.7 kilometres and spend a significant amount of time up to 17 hours per day just for feeding (Sukumar, 1990; Rowell, 2014; Wall, Wittemyer, Klinkenberg, LeMay, & Douglas-Hamilton, 2013).

Within an animal's home range, movement patterns might disclose finer-scale decisions. Elephants' home range overlap, for example, can indicate crucial social and reproductive tactics that males and females use (Wittemyer, Getz, Vollrath, & Douglas Hamilton, 2007). Because elephants are a non-territorial species, they have home ranges that overlap (Fernando et al., 2008; Wittemyer et al., 2007). Home range crossing time is a statistic that measures how long it takes an animal to cross its home range (Morato et al., 2016). Understanding how elephants migrate across their home range on a temporal scale might reveal information about resource utilisation across a home range. At a finer scale, resource distribution is known to influence how animals move throughout their home range, areas with high resource density result in higher tortuosity (high turning angle), whereas low resource density can result in lower tortuosity (less turning angle) between resource patches (Bartumeus, 2009; Bartumeus, da Luz, Viswanathan, & Catalan, 2005). Straight-line travel in elephants has been related to strong spatial recall of resources, allowing for more effective use of time between limited supplies (Polansky et al., 2015; Wato et al., 2018).

Methods such as kernel density estimator (KDE) (Worton 1989), low convex hull (LoCoH) (Getz et al. 2007), minimal convex polygon (MCP) (Krausman et al. 1989), grid cell method (Haugen 19420 and Brownian Bridge Movement Models (BBMM) have traditionally been used to estimate home range size (Kie et al. 2010; Wilckens 2014; Parr 2015). Even though there are a variety of approaches, but there is no one standardised method for estimating an animal's or a group of animals' home range (Powell 2000), as the way an animal or a group utilises an area, or how the utility distribution is weighted, determines the best methods (Gregory, 2016). For example, research on Uganda mountain gorillas by Scull et al, (2012) suggested that low convex hull (LoCoH) provide a more accurate home range estimation compared to minimal convex polygon (MCP). Since, the mountain gorilla prefers to roam in less irregular area of the study site, LoCoH, take into account the abrupt landscape but it is not influenced by them.

1.5.3 Studies in Peninsular Malaysia

Previous studies on Asian elephant movement in this region were few due to the cost and limitations to the technologies available at the time and the dense canopy of rainforest in Malaysia (Stüwe et al., 1998). However, with technical advancements, GPS collars are now more affordable (± RM 30,000), less weight (17kg, less than 1% of total body weight of the elephant) and with life span up to 2 -5 years (depending on the setting to obtain GPS coordinates) (Africa Wildlife Tracking, South Africa). In recent years, with a combination of animal GPS telemetry, geospatial tools, and mathematical modelling, Management and Ecology of Malaysian Elephants (MEME) has been able to access and map Asian elephants' movements in Peninsular Malaysia, providing more insight into elephant home ranges, elephant behaviour towards transportation infrastructure (e.g., road), and even behaviour of males and females in this region (Wadey et al., 2018; Wong et al., 2018; de la Torre et al., 2019; de la Torre et al., 2021). MEME is a collaboration between University of Nottingham Malaysia and Department of Wildlife and National Parks of Peninsular Malaysia (PERHILITAN). It was founded in year 2011 by Prof Ahimsa Campos-Arceiz who has been researching Asian megafauna, particularly elephants, for more than 15 years now. MEME's general aim is to use science to develop an evidence-based approach to the conservation of Asian elephants in Peninsular Malaysia.

MEME's studies have used movement ecology to identify critical forest patches for connectivity and determine landscape connectivity for elephant movement in the focus areas for Central Forest Spine Masterplan (de la Torre et al., 2019). The combination of these findings provides us hints for long-term mitigation strategy. The majority of research in Peninsular Malaysia, on the other hand, is based on the effects of anthropogenic development like roads (Wadey, 2018), but only few on plantation areas (de la Torre et al., 2020). There are some but limited data to identify environmental parameters that are influencing the movement of Asian elephants at local level in Peninsular Malaysia. To gain a better understanding of the effects of anthropogenic development on Asian elephants at localised areas, movement analysis can help shed light on behaviour of elephants in conflict landscapes.

By understanding the patterns and movement of Asian elephant within HEC landscape, this study can help to identify home range size, habitat variables influencing home ranges and available movement corridors to support the co-existence initiatives, and contribute towards helping the agriculture community to manage HEC in Johor, Malaysia and promote coexistence with elephants.

1.6 Aim & Objectives

The aim of this study is to understand how anthropogenic development like agriculture can influence the movement and space utilization of Asian elephants in Human-Elephant Conflict areas in Johor, Malaysia. This study will produce analysis on (elephant home range sizes, preferred land use type and movement corridors) which will support recommendations to assist the agricultural community in Johor in managing HEC and shift towards coexistence with elephants. Therefore, the following objectives are established:

1. To estimate the home range size of collared elephants in Johor using dynamic Brownian Bridge Movement Model.

2. To examine the relationship between land use type (e.g., agriculture) and elephant movement pattern using spatial and pathway analysis. In turn mapping out potential movement path for elephants in Johor state.

METHODOLOGY

2.1 Study area

The study area was selected based on frequent incident of human-elephant conflict reported by Department of Wildlife and National Parks, mainly on four districts: Kluang, Kota Tinggi, Mersing and Segamat. Indeed, nearly half of Johor's districts, including its largest, have HEC incident (Figure 2-1). Therefore, Johor was selected as the study area. It is also an effort to support Achieving Coexistence with Elephants (ACE) Project in Johor.

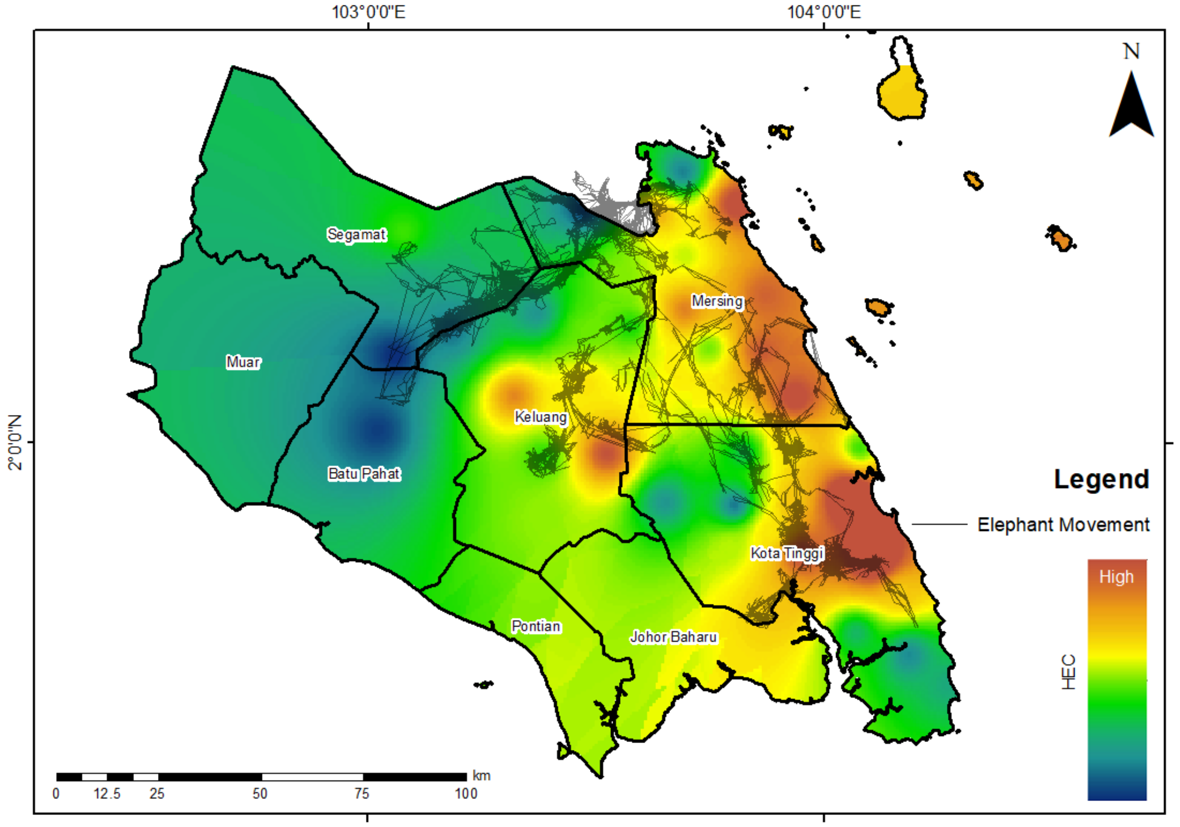


Figure 2-1. Hotspot map of Human-Elephant Conflict in Johor (Data from DWNP). Red colour indicates high HEC cases and blue colour indicated low HEC cases. Grey line are elephant movement data in Johor from 2020 to 2022.

Johor is the second largest state in Peninsular Malaysia after Pahang, covering an area of 19,166 km^2 (Department of Statistics, Malaysia, 2018). Around 83% of Johor's topography is lowlands, while the remaining 17% is high and steep terrain (Johor State Forestry Department, 2018). The total number of permanent forest reserve in Johor in 2019 is 334,650.04 hectares, consisting of terrestrial forest (312,162.47 ha), peat swamp forest (289.36 ha) and sea swamp forest (18,198.20 ha) (Johor State Forestry Department, 2019).

Johor state is also a part of Central Forest Spine (CFS) landscapes designated by National Physical Plan (NPP) in 2005 (Regional Planning Division Department of Town and Country Planning Peninsular Malaysia, 2009). The ecological corridor area in the State of Johor falls under the category CFS2 and consists of four corridors namely two main corridors: Primary linkages PL1 and Primary linkages PL3, as well as two secondary corridors which are Secondary linkages SL4 and Secondary linkages SL5. PL1 consist of Labis Timur, Lenggor, Mersing Forest reserves with a total of 13,066.6 ha, PL3 consists of Ulu Sedili and Panti Forest reserves with a total of 6,838.6 ha. Meanwhile, SL4 and SL5 consists of Mersing, Jemaluang, Panti and Kuala Sedili Forest reserves with a total of 9,750.3 ha (Figure 2-2) (Johor State Forestry Department, 2019).

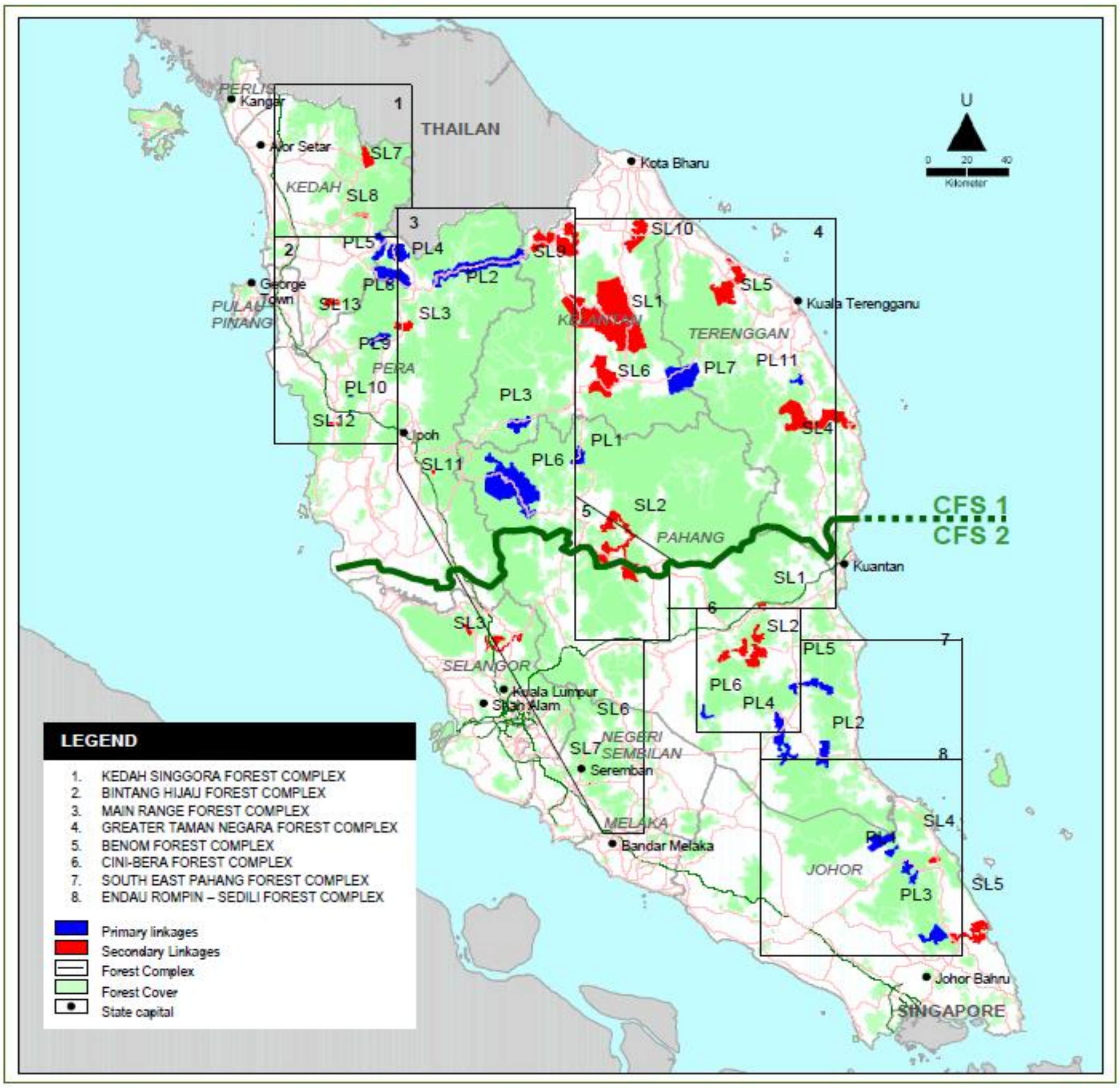


Figure 2-2. Location of CFS corridors in Peninsular Malaysia. (Source, CFS 1: Master Plan for Ecological Linkage)

2.2 Telemetry data

The collaring process were carried out by Department of Wildlife and National Parks (DWNP). The elephants were collared using Iridium and OGI GPS collars made especially for elephants (by Africa Wildlife Tracking, Pretoria, South Africa). GPS collars were programmed to record a location every one or three hours. However, data recording may not be consistent as it was influenced by external elements such as canopy cover, weather, position of collar etc.

The collared elephants consist of both "local" and "translocated" wild elephants. Elephants that are collared and released at the same location after a brief interval are referred as local elephants, whereas translocated ones were elephants translocated by the Department of Wildlife and National Parks from human-elephant conflict areas to protected areas (Saaban et al., 2011). GPS data were collected up until the end of fieldwork for this study, or until the collar battery was exhausted or the collar has fallen off the elephants.

All the GPS dataset was collected in Africa Wildlife Tracking and downloaded for this study. The GPS dataset included in this study includes two local and six translocated elephants, that represents seven males and one female (Table 2-1). The translocated elephants in this study were all relocated within the state of Johor (Endau-Rompin National Park). The GPS data were processed to remove duplication and since some of this dataset includes translocated individuals, first 15 days of localization was removed to reduced potential effects of the capture and release (capture effect) (de la Torre et al., 2019).

Table 2-1. Date of collaring and location of the collared individuals captured and translocated.

Id	Sex	Age class	Treatment	Captured Location	Release Location	Collared Date
Aramijaya	Sex	Adult	Local	Ladang Aramijaya	Ladang Aramijaya	9/9/2021
Kathy	Male	Adult	Translocated	Bt. 6, Kota Tinggi, Johor	Endau-Rompin National Park	21/2/2020

Mat Cool	Female	Adult	Translocated	Kg. Tenang	Lenggor Forest Reserve	16/6/2021
Mat Easter	Male	Adult	Translocated	Felda Bukit Easter	Endau-Rompin National Park	3/10/2020
Mat Jagoh	Male	Adult	Local	Ladang Gunung Mas, Johor	Ladang Gunung Mas, Johor	6/2/2021
Mat Pasak	Male	Adult	Translocated	Felda Pasak, Johor	Endau-Rompin National Park	15/8/2020
Mat Pinggir	Male	Adult	Translocated	Kg. Pinggir, Johor	Endau-Rompin National Park	3/6/2021
Si Rabik	Male	Adult	Translocated	Felda Nitar, Johor	Endau-Rompin National Park	18/7/2020

2.3 Ground tracking

On-the-ground radio tracking of collared elephants was carried out for three months (January 2022 to March 2022). Each collared elephant's GPS collar contains built-in very high frequency (VHF) transmitters and were tracked using a telemetry receiver (Telonics R1000). On-ground data such as social behaviour of collared elephants (in herd, bachelor group or lone bull), time the collared elephant was observed during tracking, type of vegetation and area (plantation, forest and etc) the collared individual were observed. On-the-ground tracking provides a better visualization of land use type utilised by elephants as some data are not updated to the current study year. Meanwhile, knowledge on the social behaviour of elephant provides some information on other elephant groups within the collared elephant’s home range.

2.4 Home range

The dynamic Brownian Bridge Movement Models (dBBMMs) method was used to calculate the home range size for all collared elephants. The calculations were made using statistical software R Studio, version 4.1.2 (Rstudio Team 2020) using the “move, version 4.1.6” (Kranstauber et al., 2018) and “adehabitatHR”, version 0.4.19” (Calenge 2006) packages. Dynamic Brownian Bridge Movement Models on the other hand considers the sequence of relocations as well as length of time an animal spends at each location and works on the assumption that the animal's previous and future locations are connected, whereas traditional methods handle locations independently of each other (Kranstauber et al., 2012). The method, dBBMMs may provide a more accurate representation of the animal movement and how it occurs in both space and time, and was yet use for home range calculations for collared elephants in this study. Recent animal movement studies particularly in Asian have adapted the use dBBMM. (Othman, N. 2017; Silva et al., 2018; Silva et al., 2020 & Wilson et al., 2020) compared to the more traditional methos such as Kernel density estimator (KDE) (Worton 1989) and minimal convex polygon (MCP) (Krausman et al. 1989). The studies have shown that the most effective method for representing elephant home range estimates was found to be dBBMM. (Othman, N. 2017 & Wilson et al., 2020).

Two extra inputs are required for dBBMMs, namely margin size and window size. Margin size refers to the minimum amount of data points required to ensure a behavioural state change, while window size is the minimal amount of data points required to render the behaviour relevant (Wilson et al., 2020). Thus, the window and margin sizes are used to evaluate an animal's movement capability and identify variations in movement (motion variance) depending on behavioural states (Smith et al., 2021). Motion variance is a measurement of changes or variation in movement intensity that can be utilized to detect behavioural changes. In dBBMMs, the window and margin size should be ecologically relevant to the study species and sampling regime (Kranstauber et al., 2012). This study uses 13 data points for window size and 5 data points for margin sizes as per recommendations from Wilson et al. (2020), for the home range study of Sumatran elephants and both values for these parameters must be odd numbers (Kranstauber et al., 2019).

The home range sizes were extracted at 50%, 90%, 95%, and 99% utilization. Extracted home range sizes can be classified into two components; the core area (50%) as area with greater intensity use, the activity zone (usually 90, 95 and 99%) which considered as an ecologically significant area that removes outlying GPS points and can be used to reveal movement pathways (Silva et al., 2018). All the home range sizes at different utilization were exported from Rstudio as vector files for further analysis.

2.5 Proportion of land use

Land use vector file of Johor with varied land use categories for the year 2020 were obtained from PLANMalaysia (PLANMalaysia, 2020). The vector file consists of 12 categories, with an extra 500m forest buffer category (Figure 2-3) using the QGIS buffer tool. Distance for the forest buffer was determined based on results in Ram et al. (2021), who found that elephant attacks on human were more common near forest edges (less than 500 metres away from forest), due to more frequent use of the area by elephants.

In total five major land use categories were examined in this study as follows: 1) Forest, which includes only forested areas; 2) Agriculture, which includes all agriculture crops; 3) Forest buffer, a constructed 500m buffer of forest nearest to forest boundary; 4) non-Forest Buffer, forest away from 500m from forest boundary; 5) Others, which consist of other land use variables other than that mentioned above.

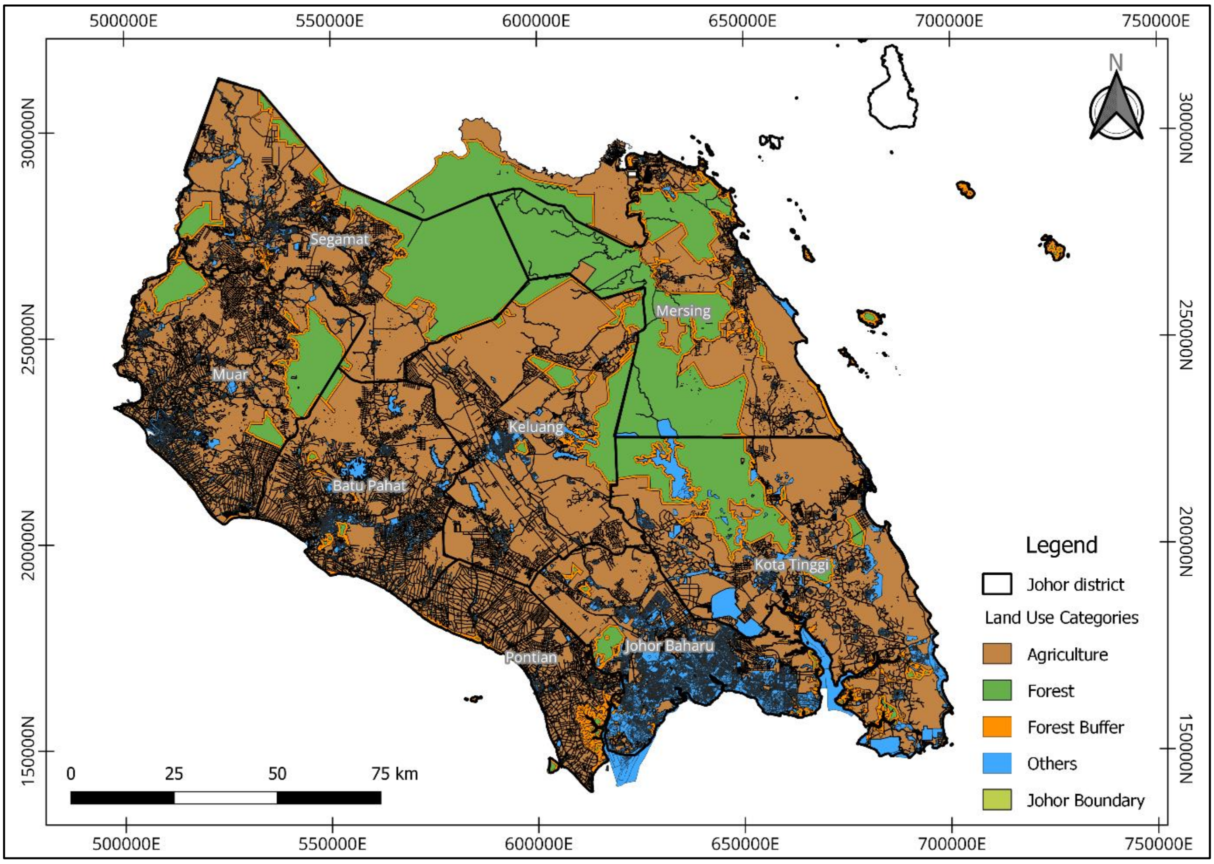


Figure 2-3. Types of land use categorised by PLANMalaysia in study area in Johor with a portion of Pahang site included. Black lines represent the boundary of each district in Johor.

According to Wilson et al. (2020), 95% is sufficient to represent major space-use. The individual elephant's habitat selection preferences within 95% home range utilization were calculated with the following steps. First, the vector shape file representing 95% home range utilisation generated from Rstudio (home range analysis) was overlaid on the land use map. Then, using the clip function, the land use for individual elephants (within the vector home range shape) was extracted and the proportion of land use in percentages and km^2 were calculated using the field calculator function. To assess how frequent the land type is used by the elephant in comparison to available land type within its home range, the number of GPS points within each land use proportion were compared with calculated land use proportion.

2.6 Pathway analysis

Past research done by MEME (de la Torre et al., 2019) used Step Selection Functions to create a resistance map for elephant movement based on GPS movement data from 53 Asian elephants. This study is one of the most comprehensive elephant movement analyses to date for Peninsular Malaysia. In this study, I used the standardized coefficient from the movement analysis done by de la Torre et al. (2019), to generate a resistance map for elephant movement in Johor for the year 2022 using updated land use map. The movement variables and coefficients from de la Torre et al. (2019) study is presumed to represent the general habitat preferences of Asian elephants in Peninsular Malaysia, since the study has a bigger sample size and the elephant individuals are from different parts of Peninsular Malaysia. Please see Appendix, Table S1 for detailed explanation on the types of variables used and how each variable used in this analysis is obtained.

The probability of movement layer represents landscape which is permeable to elephant movement and movement resistance layer is the vice versa. To generate the layer representing elephants' probability of movement, 1) The covariates were downloaded from Google Earth Engine and some were generated from QGIS, 2) Clipped with the boundary for the state of Johor, 3) Aligned the layers, in order to sync the coordinates, 4) The calculation and assignment of coefficients to land use covariates were done using raster calculator in QGIS. The result is a probability of movement layer generated with 250m resolution throughout the study site, with each cell having a continuous value between 0 (low probability of movement) and 1 (high probability of movement). When the probability of movement map is inverted, a resistance map is generated, with each cell having a continuous value between 0 (low resistance) and 1 (high resistance).

Least-cost path (LCP) and Circuit theory methods was used to model potential connectivity between individual's core area (50% utilization). LCP chooses the least costly route as well as the shortest distance between two core area by taking movement resistance into account (Adriaensen et al., 2003). A minimum patch size of 10 hectare and maximum distance of 13km was chosen as parameters for the LCP analysis. Maximum distance was based on the calculated mean maximum distance throughout the study period of eight GPS collared elephant per month.

Current density (current map) values generated by Circuit theory shows the likelihood that a random walker will pass through a certain cell while travelling from one patch to another (McRae et al., 2008). Higher current densities represent cells that have a higher net passage probability for random walkers moving from one patch to the other and high current through a node or branch indicates that removing or converting it will have a high impact on connectivity

(McRae et al., 2008). Analysis for Least-cost path and Circuit theory was performed using Graphab software 2.6 (Foltête et al., 2012) and Circuitsscape software (McRae et al., 2008) respectively. Both LCP and Current map generated were overlaid to visualize whether the collared elephants are using the predicted pathway, meanwhile patch capacity provides information and visualization of important area (50% utilization home range) that should be considered for future planning of movement corridors.

RESULT

3.1 Telemetry data & Ground tracking

GPS dataset used in this analysis includes the movements of eight Asian elephants monitored between 2020 to 2022. There were two local (all males) and six translocated (one female and five males) individuals (Table 4-1). Translocated and local elephants were tracked for an average of 441 ± 189 (range = 218-779) days with 26,153 localizations (GPS point) (Figure 4-1). Five collared elephants have monitoring duration of more than a year, with one individual reaching up to two years. The time lag, or the interval between two consecutive GPS data points for an individual, was between one to three hours. The average tracking lag was 3.12 ± 0.03 hours. See Appendix, Table S2 for detailed explanation.

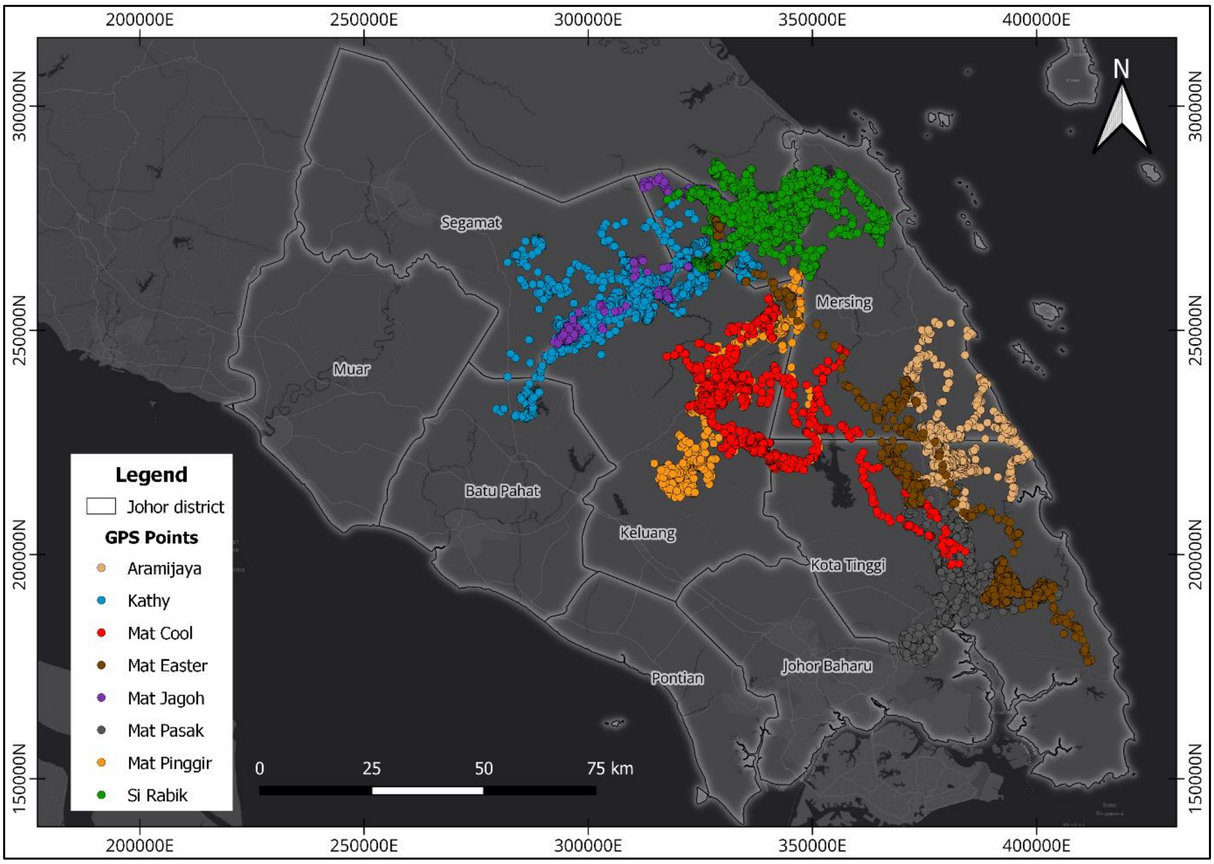


Figure (3-1). GPS points of collared Asian elephants in Johor after filtering the data set for duplications and errors.

Table 3-1. Collared Asian elephant individuals tracked in this study and number of days tracked (GPS Data) per individual. The first 15 days of GPS points was removed to reduced potential effects of the capture and release.

No.	Id	Sex	Age class	Treatment	Duration after captured effect removed (Days)	No. of GPS points after captured effect removed
1	Aramijaya	Male	Adult	Local	279	2245
2	Kathy	Female	Adult	Translocated	779	5574
3	Mat Cool	Male	Adult	Translocated	363	2779
4	Mat Easter	Male	Adult	Translocated	218	1755
5	Mat Jagoh	Male	Adult	Local	311	665
6	Mat Pasak	Male	Adult	Translocated	509	4610
7	Mat Pinggir	Male	Adult	Translocated	375	2965
8	Si Rabik	Male	Adult	Translocated	696	5560

Only six individuals were tracked on the ground; while the other two collared individual's GPS collars fell off before the tracking process could begin. Throughout the three months of tracking, we have direct sightings of only four of the six monitored individuals. The elephant, Aramijaya, was an adult male moving in a herd consisting of other males, females and young numbering up to 20 individuals or more. While Mat Pasak is a lone bull in an area with presences of female groups but been mostly sighted alone on two separate occasions before his collar dropped. The two male elephants (Mat Pinggir & Mat Cool) were seen in the same bachelor group that consist of three to four individuals (all males), but exhibited fission-fusion behaviour. They split into smaller groups (two individuals) or was alone foraging on several occasions, and regroup after a few weeks (Table 4-2). When they rejoin in a bigger group, a female herd was observed to be nearby. The other two individuals we did not encounter while tracking were one male (Si Rabik) and one female (Kathy). Kathy's foot print and dung size during tracking indicated that it may be in a herd or following close to a herd, however Si Rabik's foot print indicated it was a lone bull. A photograph sent by a villager from Kampung Peta in the monitoring area showed Si Rabik was roaming around alone. The collared elephants were encountered in a variety of habitats, including plantations, secondary forests, open scrub or grassland, abundant agriculture site and fragmented area. Additionally, direct sightings often occur more frequently in the evening (6pm-9pm) and nearly always on the edges of a forest or plantation. Elephant encounters in the daytime were often further inside the forest or away from the plantations.

Table 3-2. Summary of ground tracked elephant individual's social structure.

ID	Social structure	Structure size (Individuals)
Aramijaya	Herd	± 20
Kathy	Herd	NA
Mat Cool	Bachelor group	± 4
Mat Easter	NA	NA
Mat Jagoh	NA	NA
Mat Pasak	Lone bull	1
Mat Pinggir	Bachelor group	± 4
Si Rabik	Lone bull	1

3.2 Home range size

Collared elephants in this study had a mean core home range (50% utilization) of 20.6 ± 8.8 km² and a home range (95% utilization) of 247.3 ± 70.5 km². Male elephants had a mean core home range (50% utilization) of 20.5 ± 9.4 km² and home range of (95% utilization) of 238.3 ± 70.9 km² (Table 3-3). Unfortunately, as there is only one female elephant in this study, no sex-based comparisons can be done. The collared elephant with the largest 95% utilization home range of 374.2 km² was Mat Jagoh and the smallest 151.4 km² was Aramijaya.

Table 3-3. Home range size (km²) for 50% ,90% ,95% and 99% utilization.

Id	Sex	Home Range (km²)			
		50%	90%	95%	99%
Aramijaya	Male	17.7	103.2	151.4	268.8
Kathy	Female	21.4	209.5	310.8	648.9
Mat Cool	Male	9.8	140.1	243.3	477.8
Mat Easter	Male	7.5	104.5	182.8	441.9
Mat Jagoh	Male	30.4	260.6	374.2	620.7
Mat Pasak	Male	26.9	166.7	243.5	463.2

Mat Pinggir	Male	17.7	120.1	181.3	340.4
Si Rabik	Male	33.7	208.6	291.5	457.3

The visualization of the contours (50%, 90%, 95% and 99% confidential area) generated by the dynamic Brownian Bridge Movement Models (Figure 4-3). shows that the home range of collared elephants extends from north to south-east of Johor. Covering all of Johor's largest districts, including Segamat, Mersing, Kluang, and Kota Tinggi. Additionally, it was observed that a small portion of Kathy's home range falls in the Batu Pahat area, closer to the boundary between Kluang and Segamat, where Kathy was seen roaming around Batu Pahat's Bekok Dam, a man-made structure. While, Mat Pasak has a small portion of its home range in Ulu Tiram, Johore Baharu.

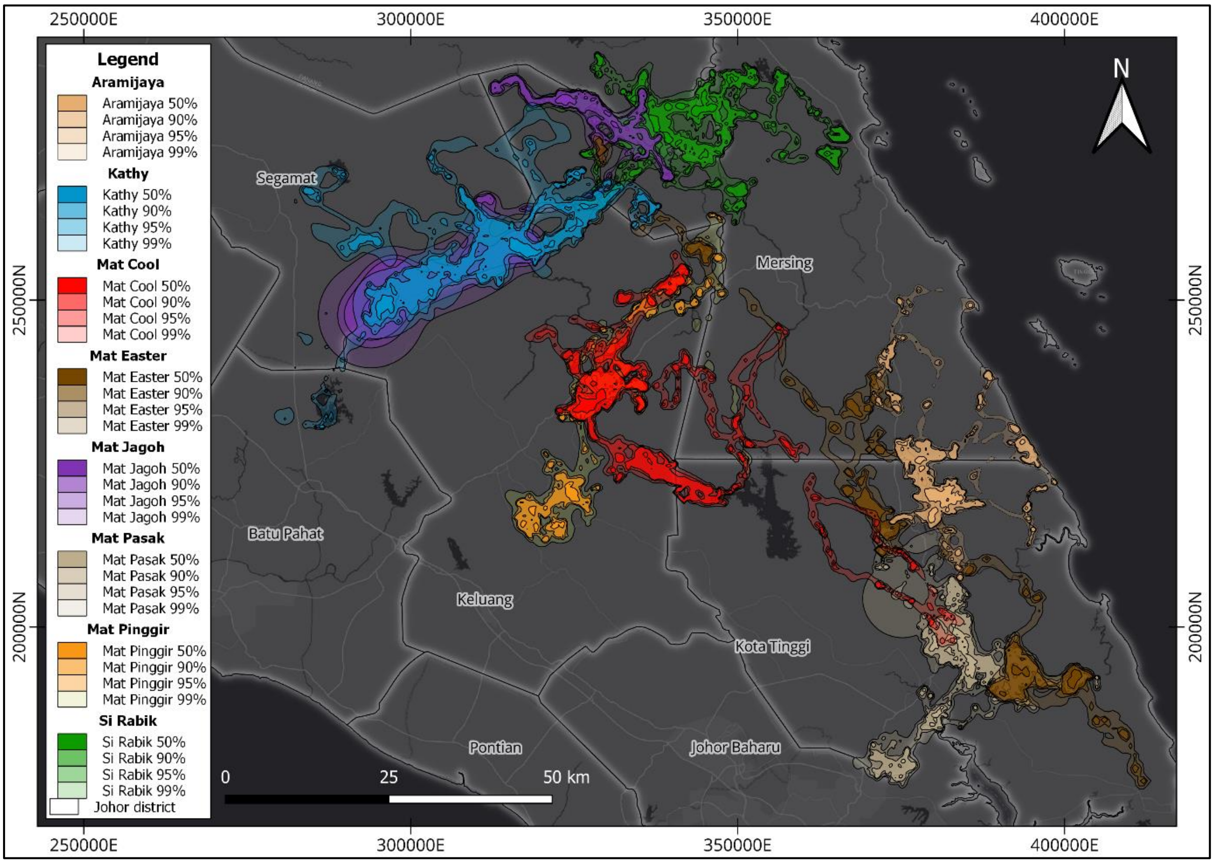
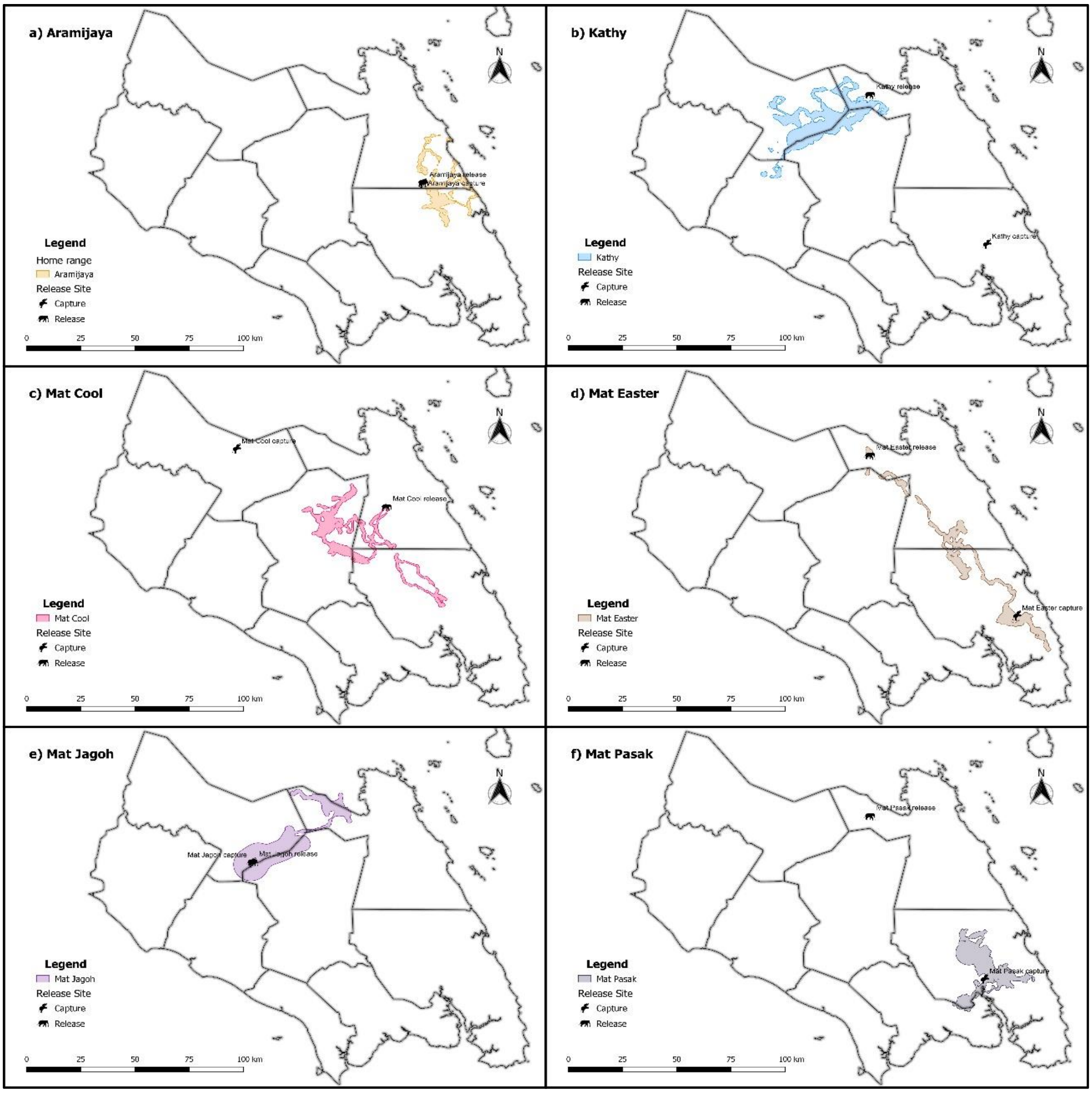


Figure (3-2). Contours generated from dynamic Brownian Bridge Movement Models for 50%, 90%, 95% and 99% home ranges for eight GPS collared Asian elephants in Johor. Border of district and state is represented by black line.

Kathy, Mat Pinggir, Mat Easter, Mat Pasak, and Si Rabik were all released at the same location, however only Kathy and Si Rabik did not return to captured site. Mat Pasak and Mat Easter clearly returned to the captured location, while Mat Pinggir left the released site but did not return to the captured site (Figure 4-3). Mat Easter showed more linear movements compared with other collared individuals, moving from the released site to captured site (almost 6 months) while Mat Cool did not go back to the captured site (Segamat) and have been observed to roam around Mersing and Keluang.



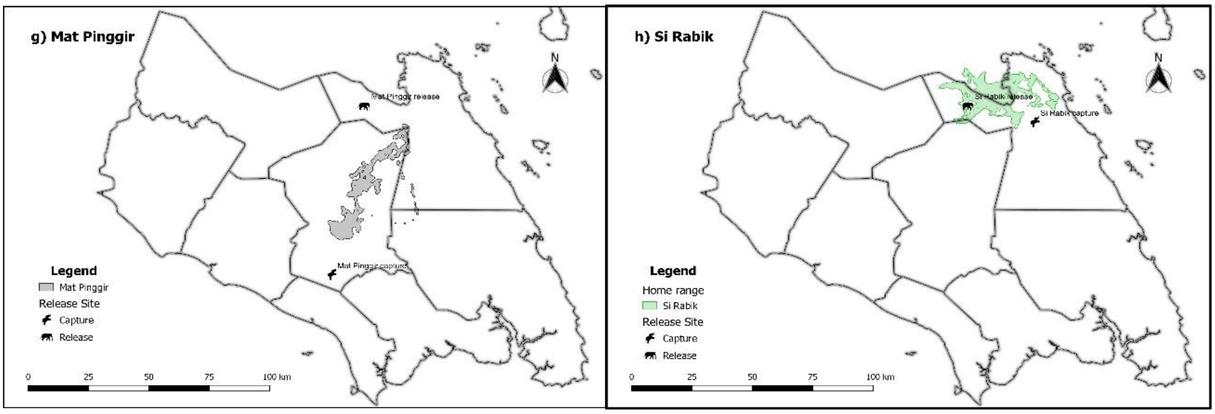


Figure (3-3). Capture and release site of collared Asian elephant together with 99% utilization home range. Kathy, Mat Cool, Mat Easter, Mat Pasak, Mat Pinggir and Si Rabik were translocated elephants, only Aramijaya and Mat Jagoh were non translocated elephants. Border of district and state is represented by black line

Based on the Figure (3-2) most of the collared Asian elephants have overlap in home range area. Kathy, Si Rabik, and Mat Jagoh have overlaps in home range area, while Mat Pinggir and Mat Cool had overlapping home ranges. Only one individual (Mat Easter) showed overlap with all the other collared elephants. The overlap between Mat Pinggir and Mat Cool seems to be more than 50% as they were seen in the same bachelor group. Mat Cool was capture at Segamat and collared 13 days after Mat Pinggir, who has been captured and collared at Kluang, both individuals were released at different sites, center of Mersing (Mat Cool) and Endau Rompin (Mat Pinggir). Both individuals eventually formed a small bachelor group with other adult male elephants.

3.3 Proportion of land use

Analysis of land use proportion within each collared elephant’s 95% utilization home range found that elephants that preferred agricultural sites have smaller home range sizes as there is a moderate negative relationship between proportion of agriculture land and the elephant’s home range ($R^2 = 0.56$, p-value = 0.033, $F_{1,6} = 7.58$, Figure 3-4). While there is a moderate positive relationship between home range sizes to the proportion of forest within the elephants’ home range ($R^2 = 0.59$, p-value = 0.027, $F_{1,6} = 8.52$, Figure 3-5) and elephants that preferred forest have bigger home range sizes.

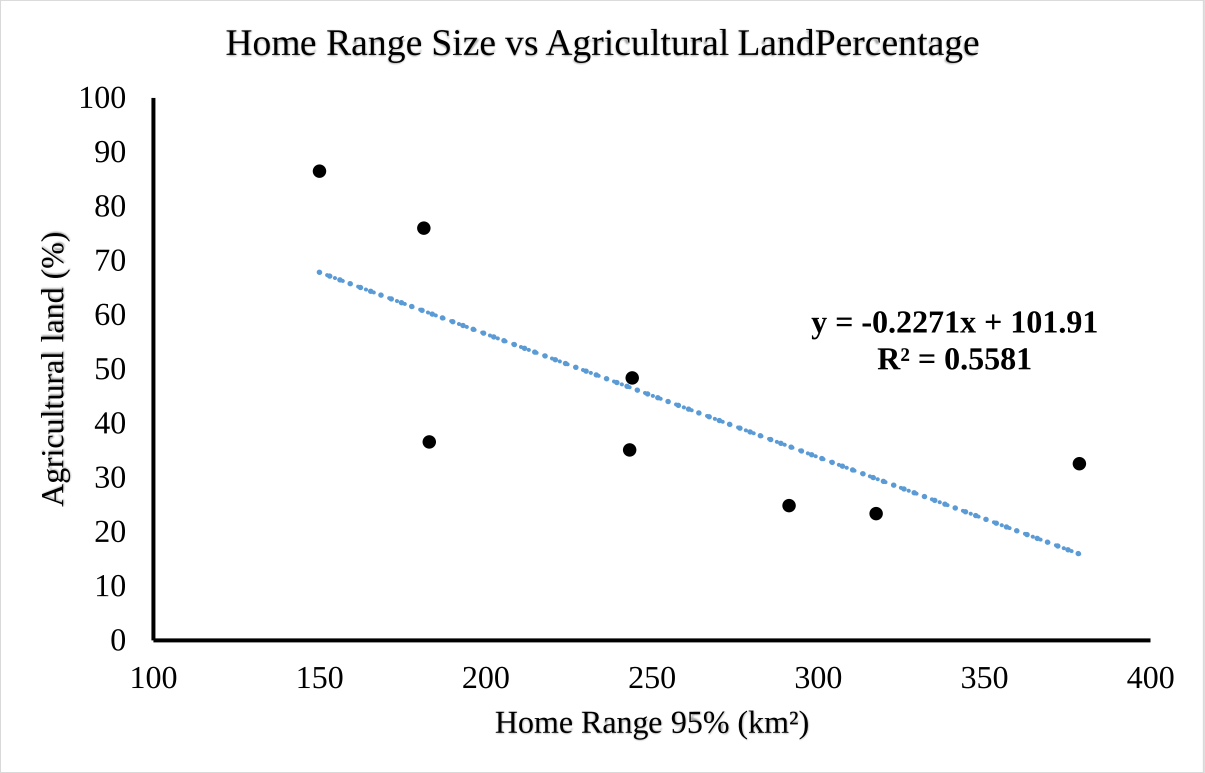


Figure 3-4. Graph comparing home range size and proportion of agricultural land within home range.

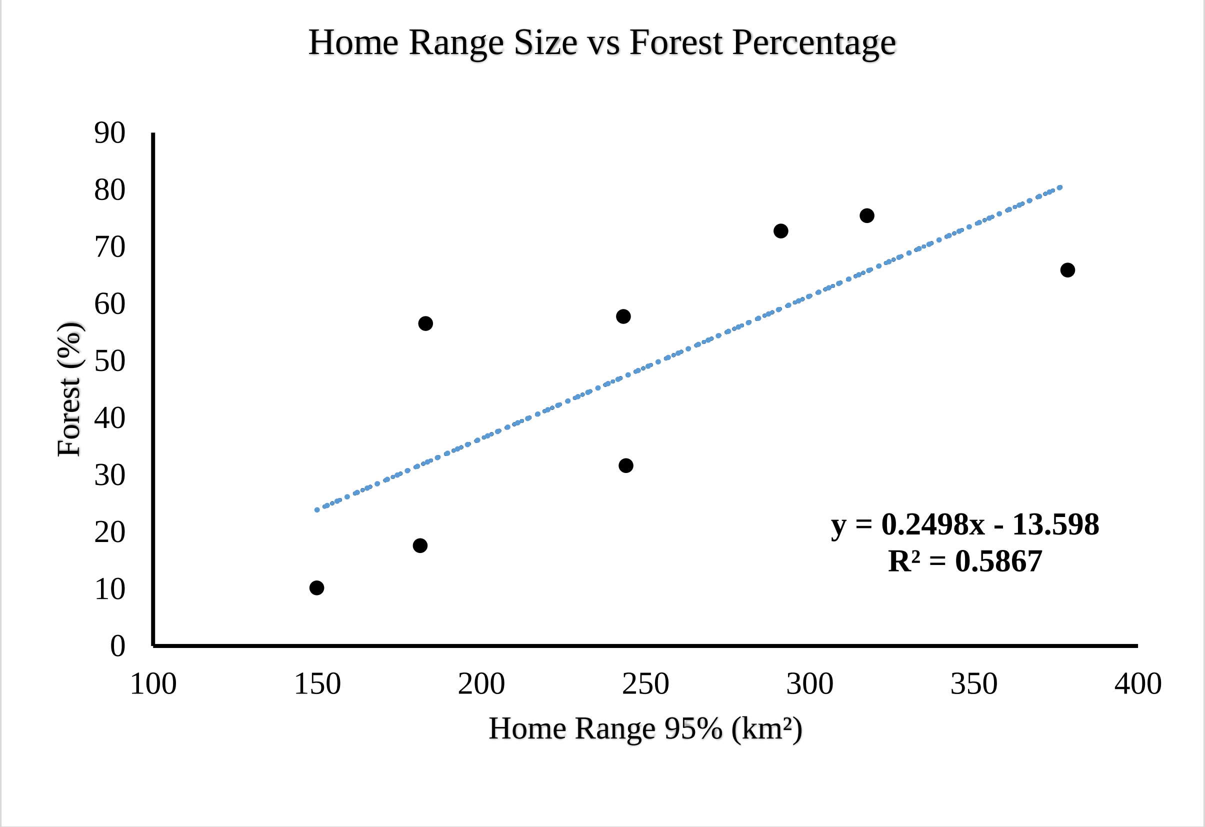


Figure 3-5. Graph comparing home range size and proportion of forest within home range.

The elephant with the largest home range roamed an area 2.5 times bigger than the elephant with the smallest home range, which also has 6.6 times more proportion of forest comparatively. Three out of eight collared elephants seemed to favour agricultural areas over forested areas (Table 3-4, Figure 3-6).

Table 3-4. Proportion of land use within each collared Asian elephant's home range (95% utilization).

Land use (%) / Elephants	Aramijaya	Kathy	Mat Cool	Mat Ester	Mat Jagoh	Mat Pasak	Mat Pinggir	Si Rabik
Forest	10	75	58	57	66	32	18	73
Agriculture	87	23	35	37	33	48	76	25
Others	3	1	7	7	2	20	6	2

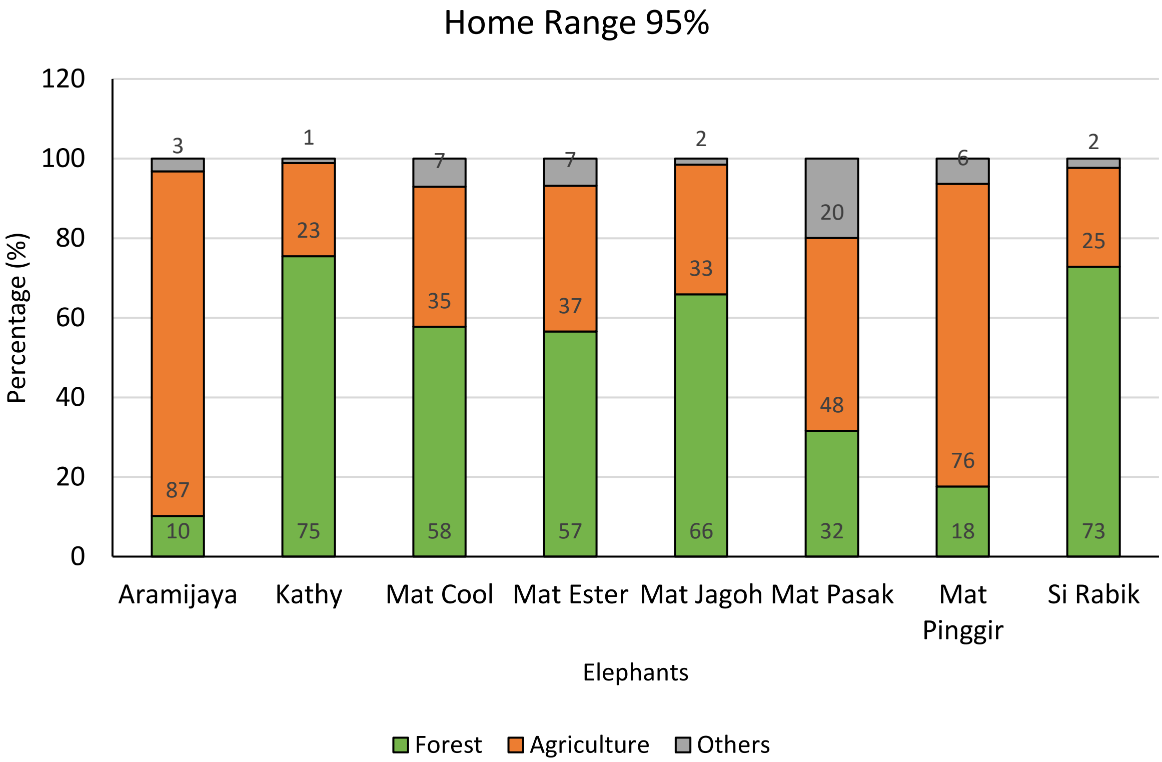


Figure 3-6. Proportion of land use preferred by collared Asian elephants within home range (95% utilization).

Table 3-5. Proportion of forest is split into non-forest edge and forest edge within each collared Asian elephant's home range (95% utilization). Forest buffer is the forested area 500m from forest edges.

Land use (%) / Elephants	Aramijaya	Kathy	Mat Cool	Mat Ester	Mat Jagoh	Mat Pasak	Mat Pinggir	Si Rabik
Forest edge	8	11	18	10	8	11	9	12
Non forest edge	3	64	40	47	58	21	9	61

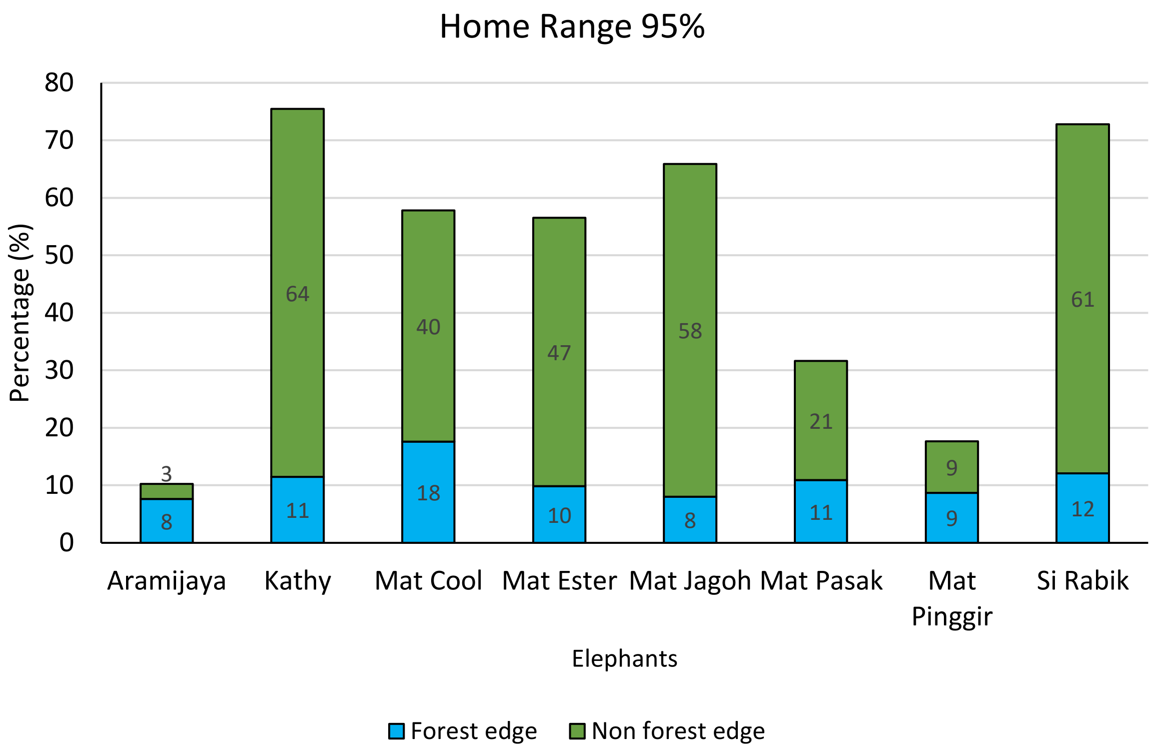


Figure 3-7. Proportion of land use (Forest edge and non-forest edge) preferred by collared Asian elephants within home range (95% utilization).

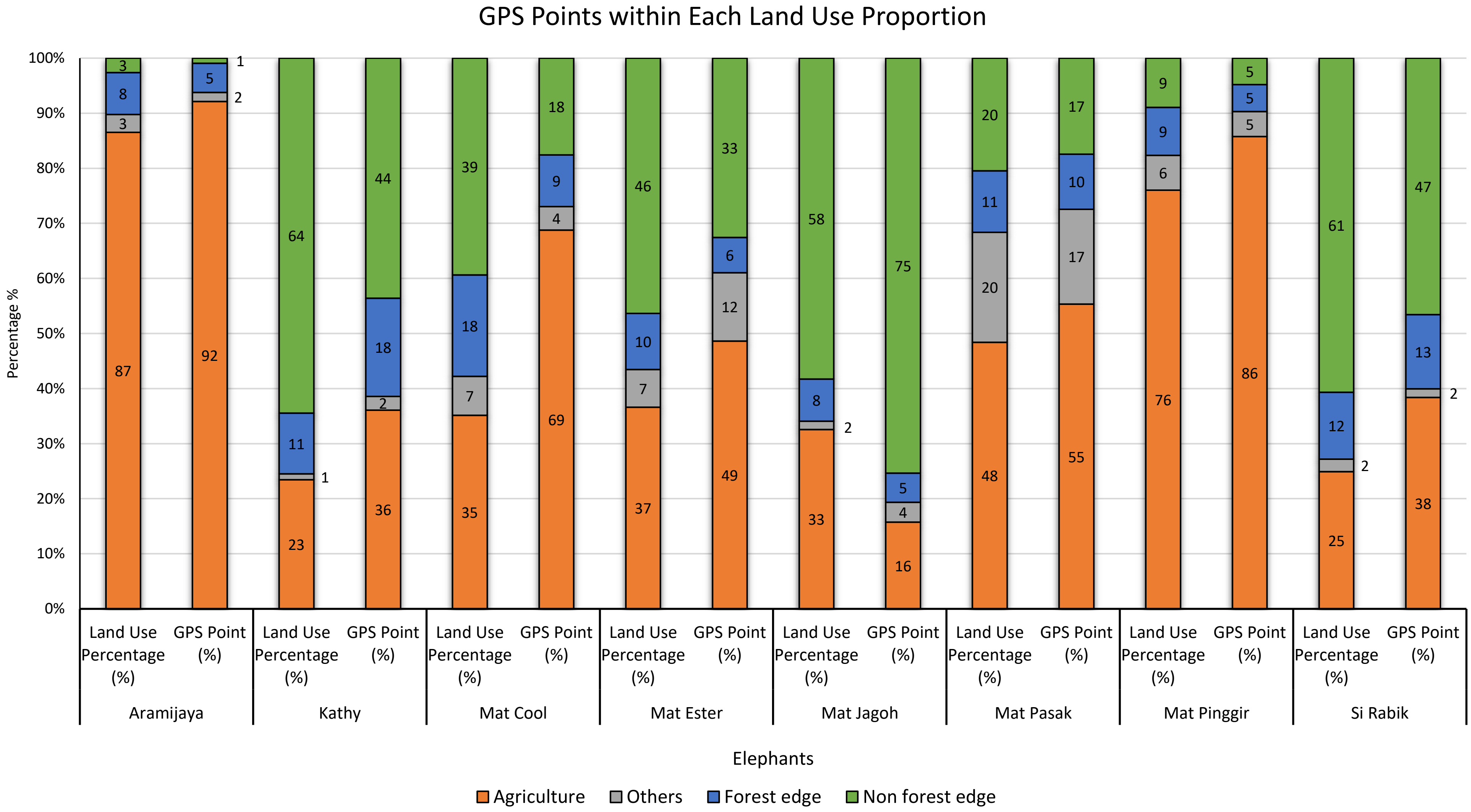


Figure 3-8. Proportion of land use and number of GPS points within each land use for collared Asian elephants within home range (95% utilization.

When comparing the proportion of GPS points (Figure 3-8) to the available proportion of land use within the 95% utilization home range, it seems the elephants spend more time in the agriculture. For example, home ranges for Mat Cool and Mat Easter have a large proportion of forest (58% and 66%, respectively), however the number of GPS points that fall under forest (27% and 39%) are lower than those in agriculture (69% and 49%). This suggests that, even though the proportion of that particular land use is high within the home range, but the collared individual does not necessarily spend more time or utilize that specific region more frequently. But this does not negate the previous finding that forest percentage influence the home range size of elephants. Elephants who favoured forested areas spend a smaller amount of time at forest edge (500m from forest edge) compared to non-forest edge or the interior of the forest (Table 3-5). The elephant, Aramijaya, is the only individual who preferred agriculture area and spend a high proportion of time at forest edge, but Aramijaya is also roaming in a large group of elephants consisting of females and young. Another elephant, Mat Pasak who spent more time in urban area compared to other elephants (20% Other landuse) and a high proportion of time in agriculture, have more points at non-forest edge than forest edge. Meanwhile, there is no notable differences in elephants' preference for forest and non-forest edges when compared using proportion of GPS points than proportion of land use (Table 3-5), except for Mat Jagoh and Si Rabik which had a very reduced percentage of non-forest edge use.

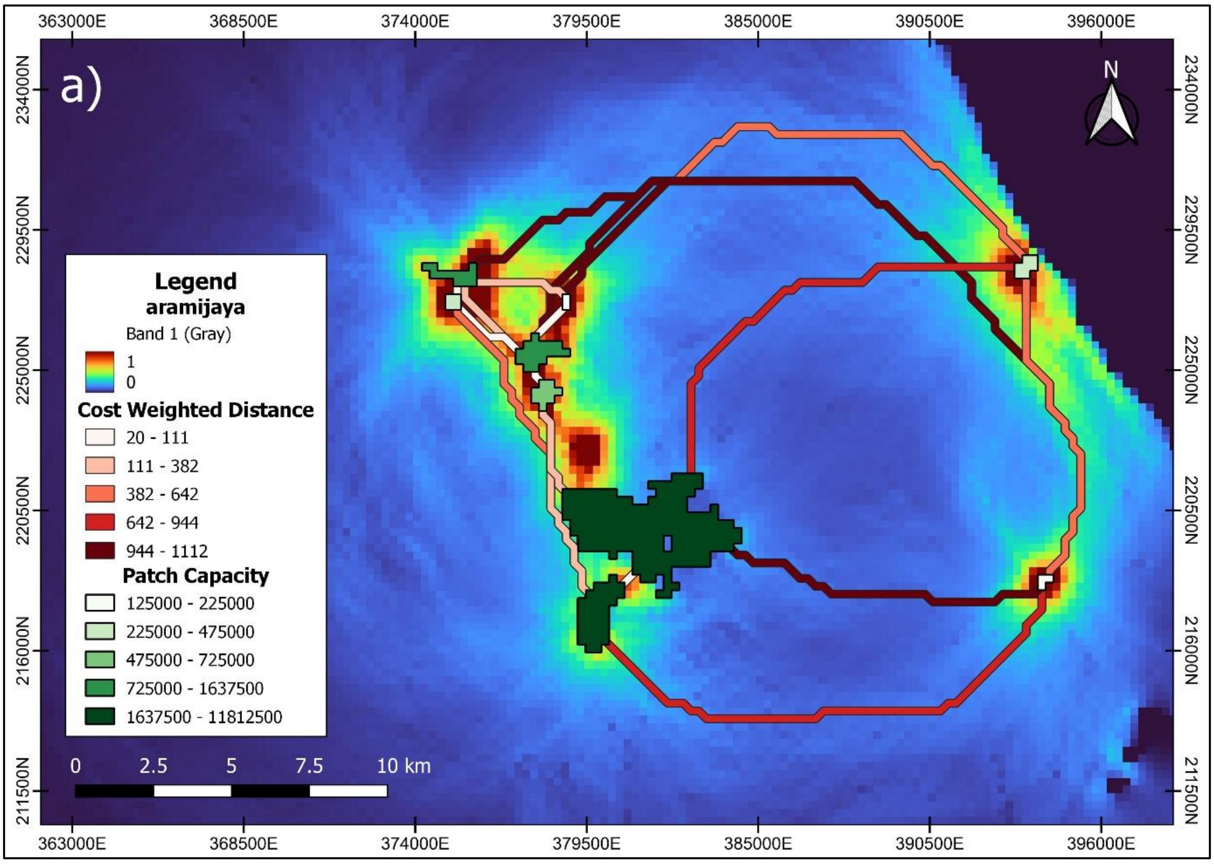
3.4 Pathway analysis

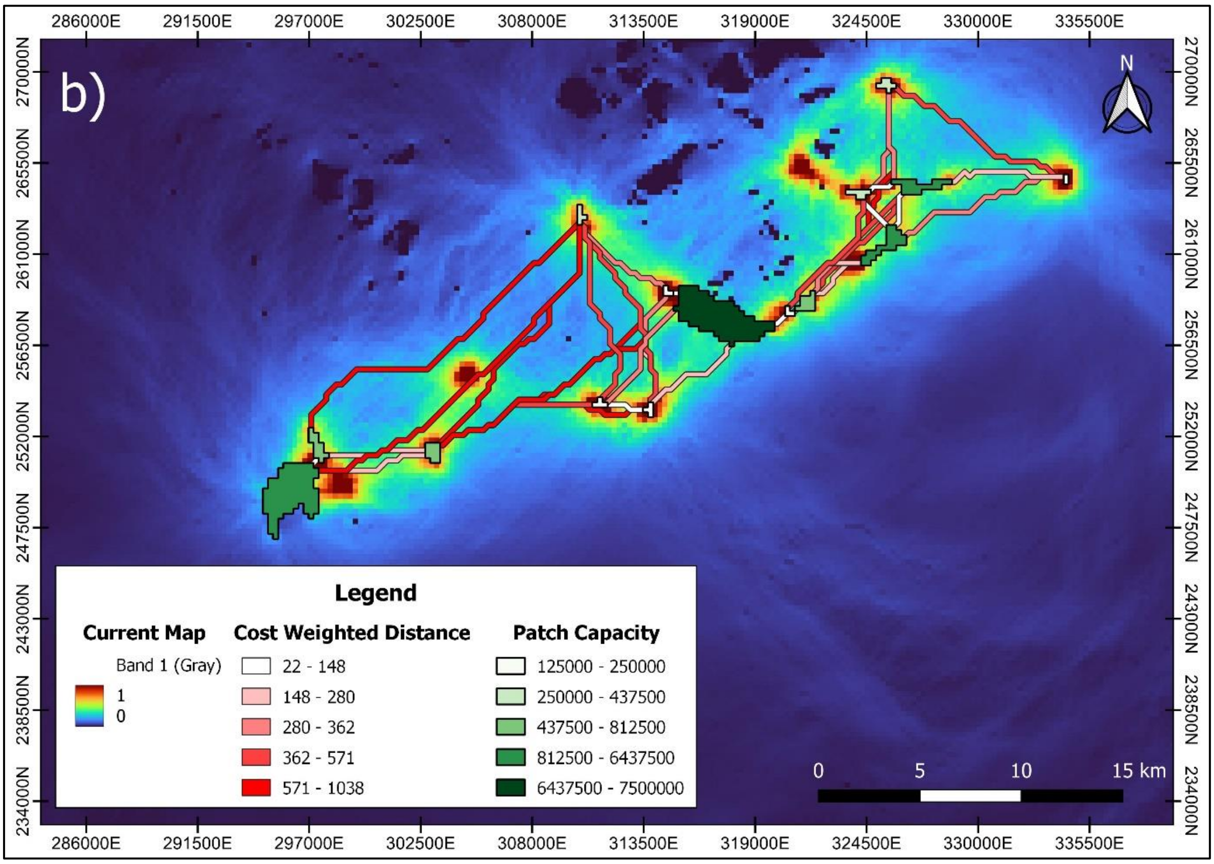
Both the Least-cost path and Circuit theory analysis have identified a total of 308 cost-weighted corridors between 101 patches (50% utilization) (Figure 3-9) for all collared individuals. The mean and standard deviation cost-weighted distance of 493.3±70.3 (in cost unit) and mean of distance of all corridors is 9.9±2.8km. Mat Easter had the least number of identified corridors, with only four patch and five corridors and a mean cost-weighted distance of 460.3±310.8 (in cost unit) and mean distance for all corridors of 7.3±4.9 km. The biggest count of corridors belongs to Mat Pasak with a total of 26 patches (mean cost-weighted distance 432, in cost unit) and 89 corridors (mean distance of 6.9 km). Mat Cool and Si Rabik have one of the longest estimated corridor distances (mean distance of 13.1 km and 13.5 km) respectively meanwhile, Mat Easter has the shortest (mean distance of 6.8 km).

Table 3-6. No. of estimated corridors based on LCP, together with cost-weighted distance (in cost unit) mean distance (km) of corridors for each individual. No. of patches (core area) used for estimating the corridors.

Elephants	No. of patches	No. of corridors	Mean and standard deviation cost-weighted distance	Mean and standard deviation distance (km)
Aramijaya	9	21	509.6±394.2	11.6±10
Kathy	15	37	366.9±260.8	7.3±4.9
Mat Cool	6	9	572.2±451.2	13.1±11.5
Mat Easter	4	5	460.3±310.8	6.8±6.2
Mat Jagoh	7	31	555.0±571.0	11.1±12.3
Mat Pasak	26	89	432.0±366.1	6.9±6.2
Mat Pinggir	17	42	499.2±395.2	8.6±0.4
Si Rabik	17	74	551.7±391.5	13.5±10.9

Circuit theory analysis provides visual inspection of the current density map and together with predicted path by LCP, suggests suitable corridors connecting all the core patches (Figure 3-9). Based on visualization of both LCP and Current density map (Figure 3-10), some of the estimated corridors fell in both agricultural and forested area. For Kathy, Mat Jagoh and Si Rabik most of the estimated corridors are within the forested area and only few in agricultural area, however, they are near to forest edges. Meanwhile for Mat Cool, Mat Easter, Mat Pasak and Mat Pinggir, most of the estimated corridors are within the agricultural area and forest edges and only a few are near forested area. Visualization of LCP overlaid with estimated home range (Figure 3-11), shows that most of the predicted LCP corridors with less resistance (low cost-weighted distance) fell within the elephant’s home range. The predicted LCP corridors which are not within the estimated home range are those with high resistance (high cost-weighted distance). Only Kathy have shown to have all the predicted LCP corridors within its home range. A model of all the estimated corridors using LCP for Johor State using all eight collared elephant GPS data (Figure 3-12). Based on the predicted corridor, Keluang, Mersing and Segamat have less cost-weighted distance connected them, meanwhile the corridors connecting these three to Kota Tinggi have high cost-weighted distance.


a)
N
Legend
aramijaya
Band 1 (Gray)
1
0
Cost Weighted Distance
20 - 111
111 - 382
382 - 642
642 - 944
944 - 1112
Patch Capacity
125000 - 225000
225000 - 475000
475000 - 725000
725000 - 1637500
1637500 - 11812500
0
2.5
5
7.5
10 km
363000E
368500E
374000E
379500E
385000E
390500E
396000E
234000N
229500N
225000N
220500N
216000N
211500N


b)
N
Legend
Current Map
Band 1 (Gray)
1
0
Cost Weighted Distance
22 - 148
148 - 280
280 - 362
362 - 571
571 - 1038
Patch Capacity
125000 - 250000
250000 - 437500
437500 - 812500
812500 - 6437500
6437500 - 7500000
0
5
10
15 km
286000E
291500E
297000E
302500E
308000E
313500E
319000E
324500E
330000E
335500E
270000N
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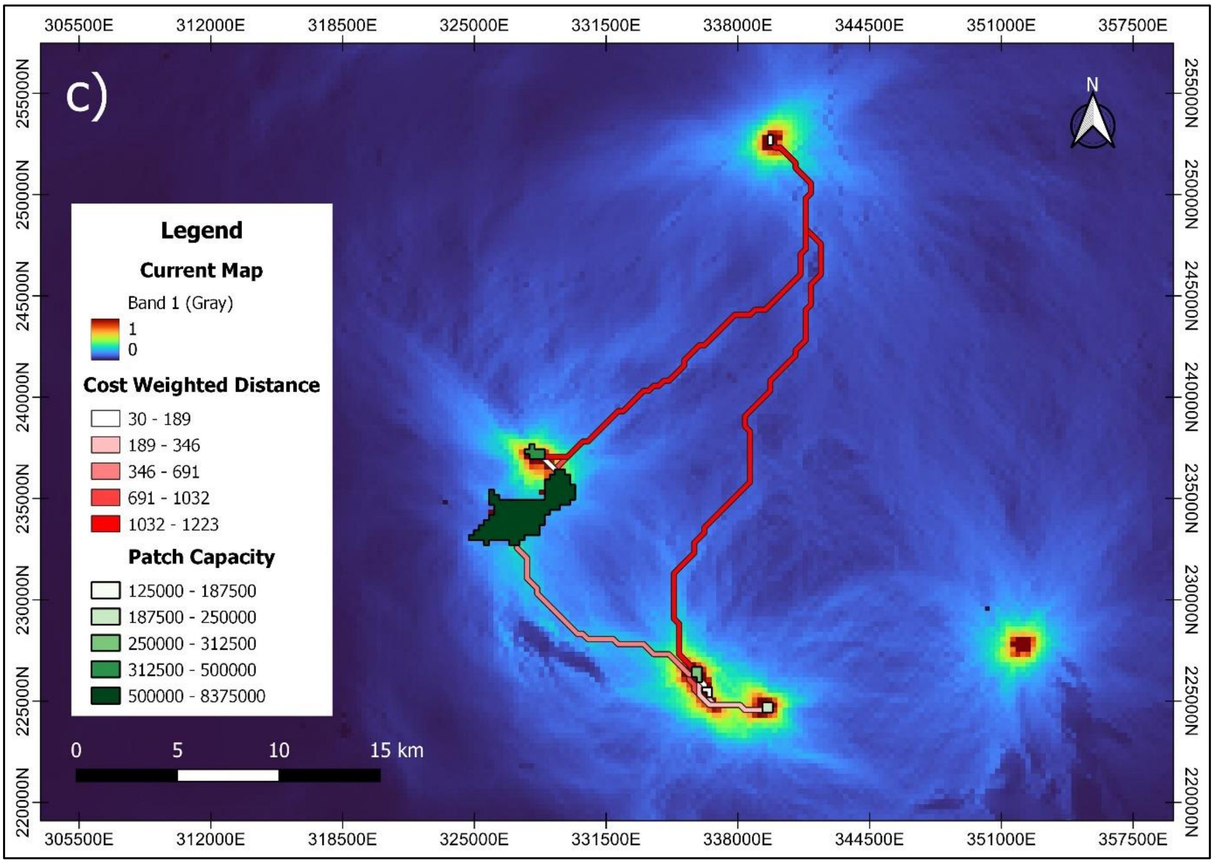
243000N
238500N
234000N


c)
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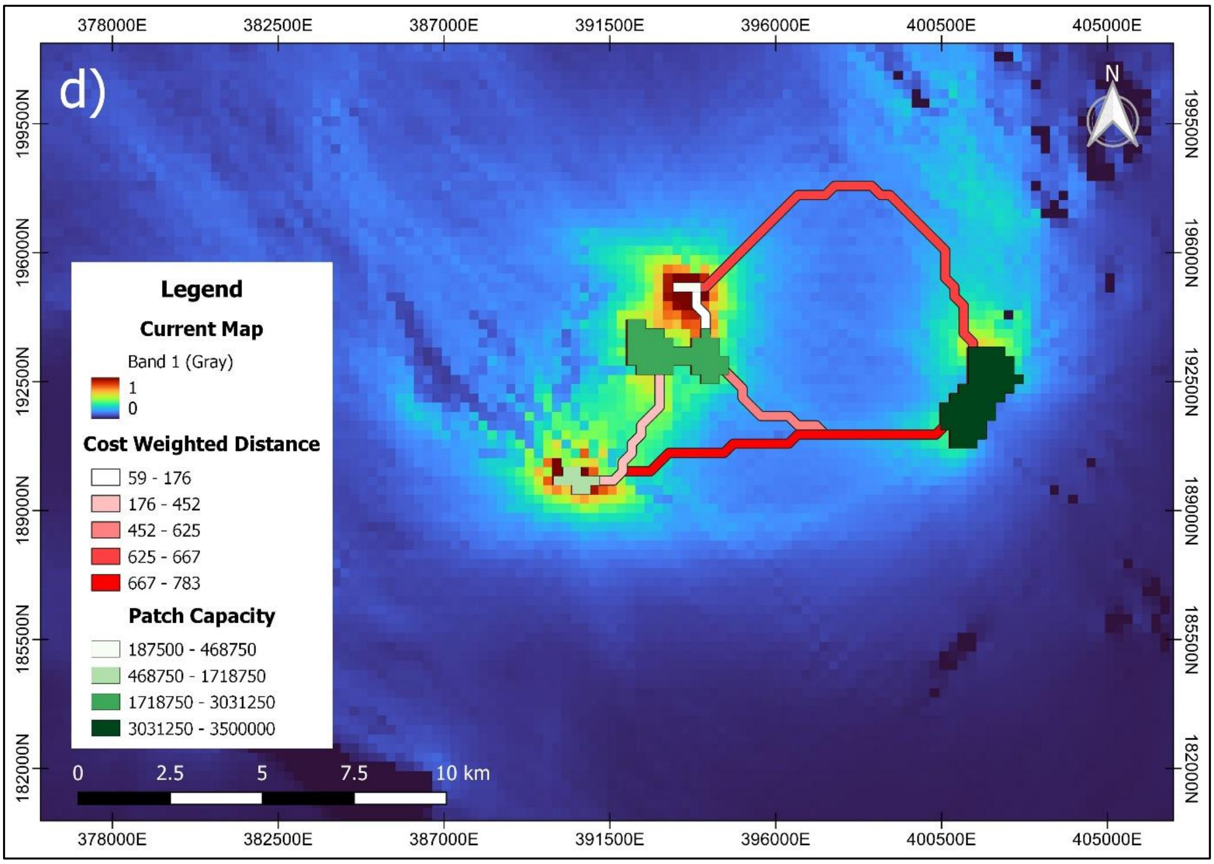
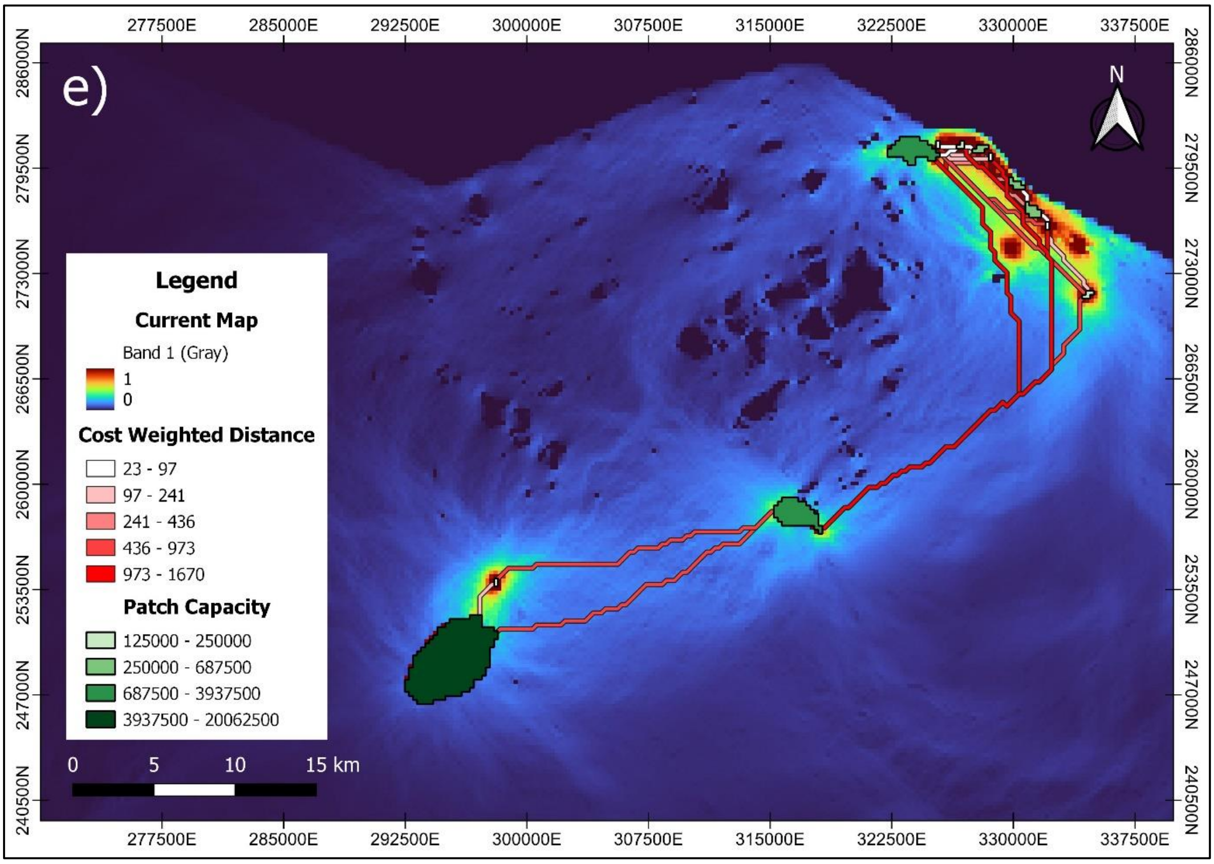
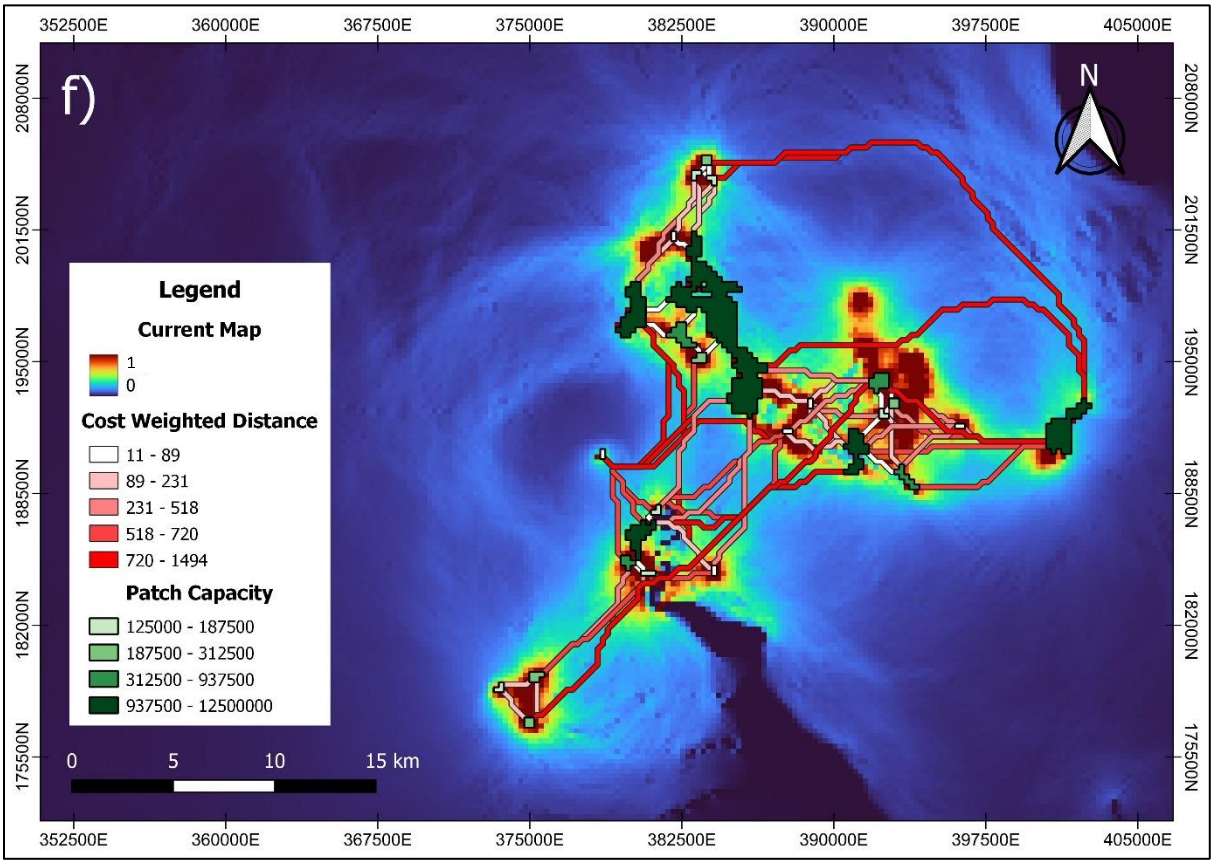
312000E
318500E
325000E
331500E
338000E
344500E
351000E
357500E
255000N
250000N
245000N
240000N
235000N
230000N
225000N
220000N
N
Legend
Current Map
Band 1 (Gray)
1
0
Cost Weighted Distance
30 - 189
189 - 346
346 - 691
691 - 1032
1032 - 1223
Patch Capacity
125000 - 187500
187500 - 250000
250000 - 312500
312500 - 500000
500000 - 8375000
0
5
10
15 km


d)
378000E
382500E
387000E
391500E
396000E
400500E
405000E
199500N
196000N
192500N
189000N
185500N
182000N
N
Legend
Current Map
Band 1 (Gray)
1
0
Cost Weighted Distance
59 - 176
176 - 452
452 - 625
625 - 667
667 - 783
Patch Capacity
187500 - 468750
468750 - 1718750
1718750 - 3031250
3031250 - 3500000
0
2.5
5
7.5
10 km


e)
N
277500E
285000E
292500E
300000E
307500E
315000E
322500E
330000E
337500E
286000N
279500N
273000N
266500N
260000N
253500N
247000N
240500N
Legend
Current Map
Band 1 (Gray)
1
0
Cost Weighted Distance
23 - 97
97 - 241
241 - 436
436 - 973
973 - 1670
Patch Capacity
125000 - 250000
250000 - 687500
687500 - 3937500
3937500 - 20062500
0
5
10
15 km


f)
N
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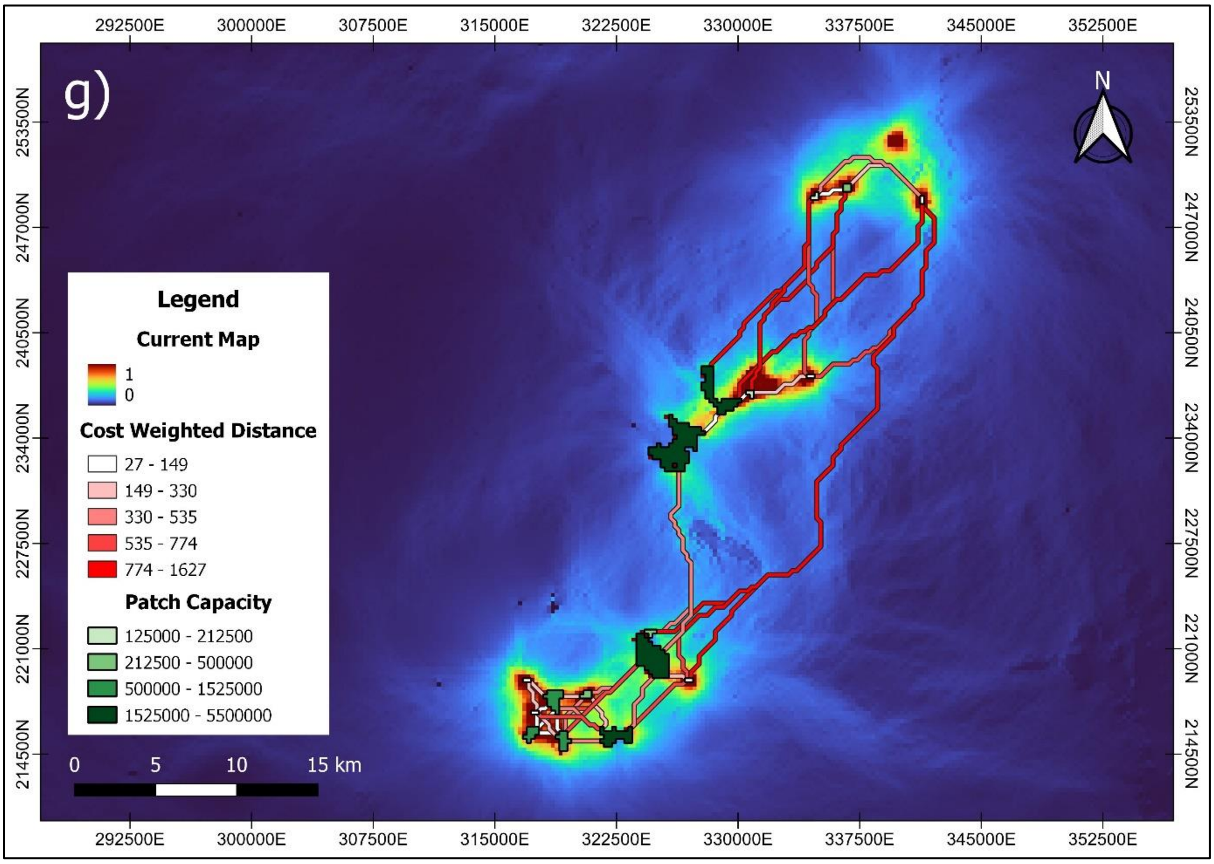
360000E
367500E
375000E
382500E
390000E
397500E
405000E
208000N
201500N
195000N
188500N
182000N
175500N
Legend
Current Map
1
0
Cost Weighted Distance
11 - 89
89 - 231
231 - 518
518 - 720
720 - 1494
Patch Capacity
125000 - 187500
187500 - 312500
312500 - 937500
937500 - 12500000
0
5
10
15 km


g)
N
Legend
Current Map
1
0
Cost Weighted Distance
27 - 149
149 - 330
330 - 535
535 - 774
774 - 1627
Patch Capacity
125000 - 212500
212500 - 500000
500000 - 1525000
1525000 - 5500000
0
5
10
15 km
292500E
300000E
307500E
315000E
322500E
330000E
337500E
345000E
352500E
253500N
247000N
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227500N
221000N
214500N

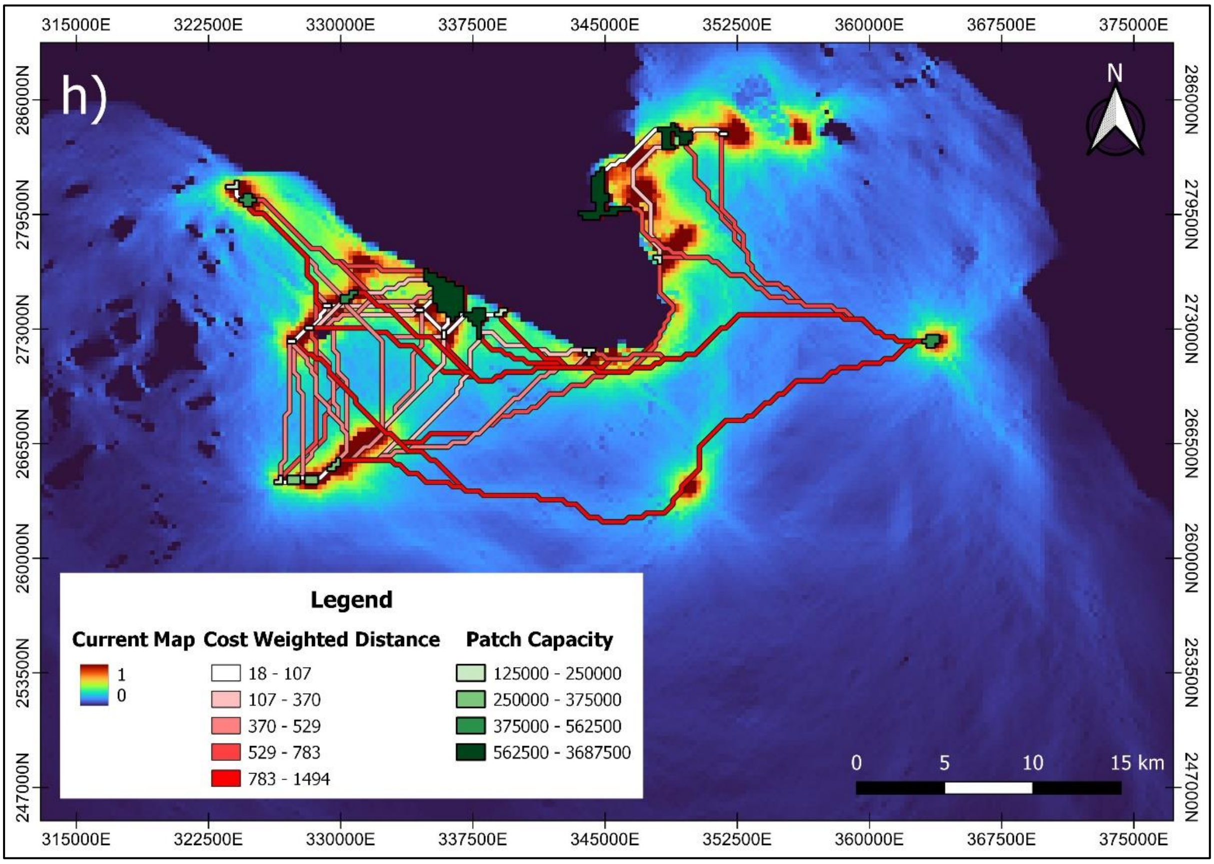
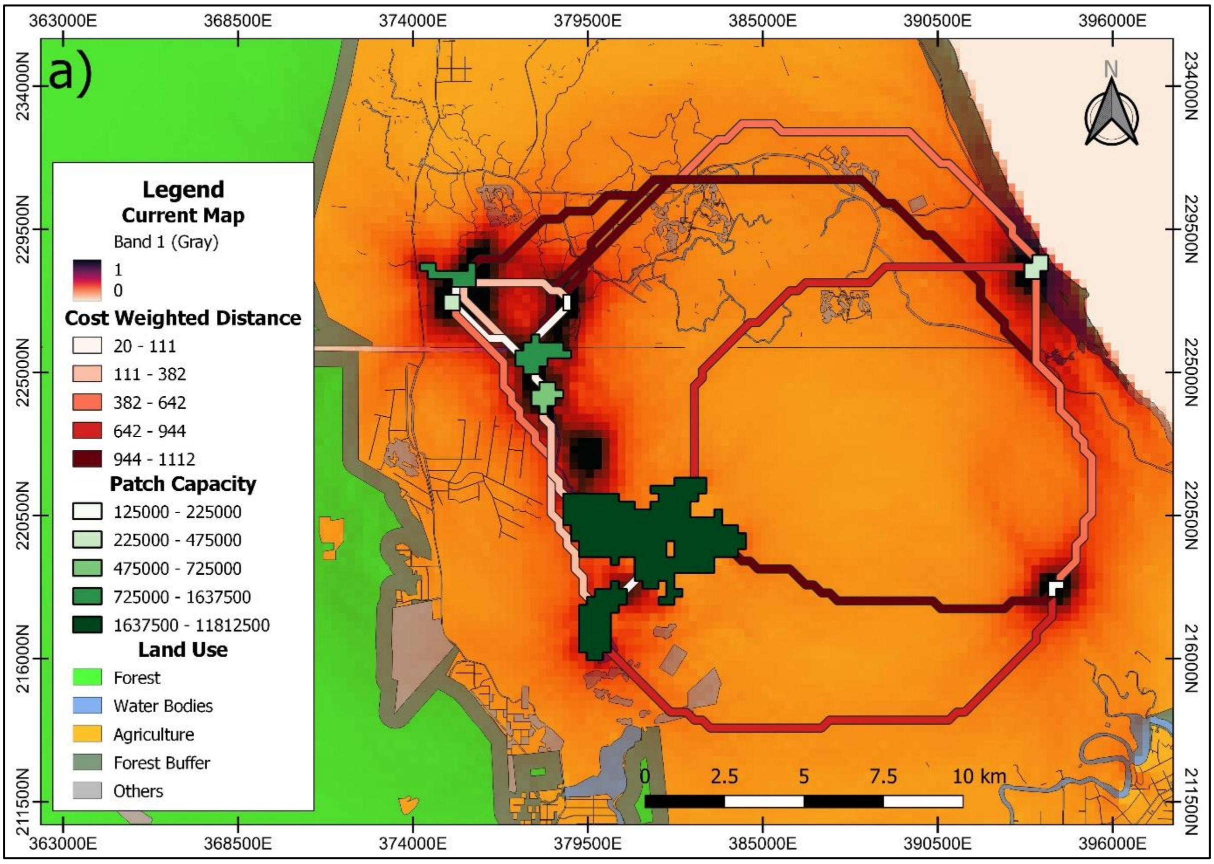
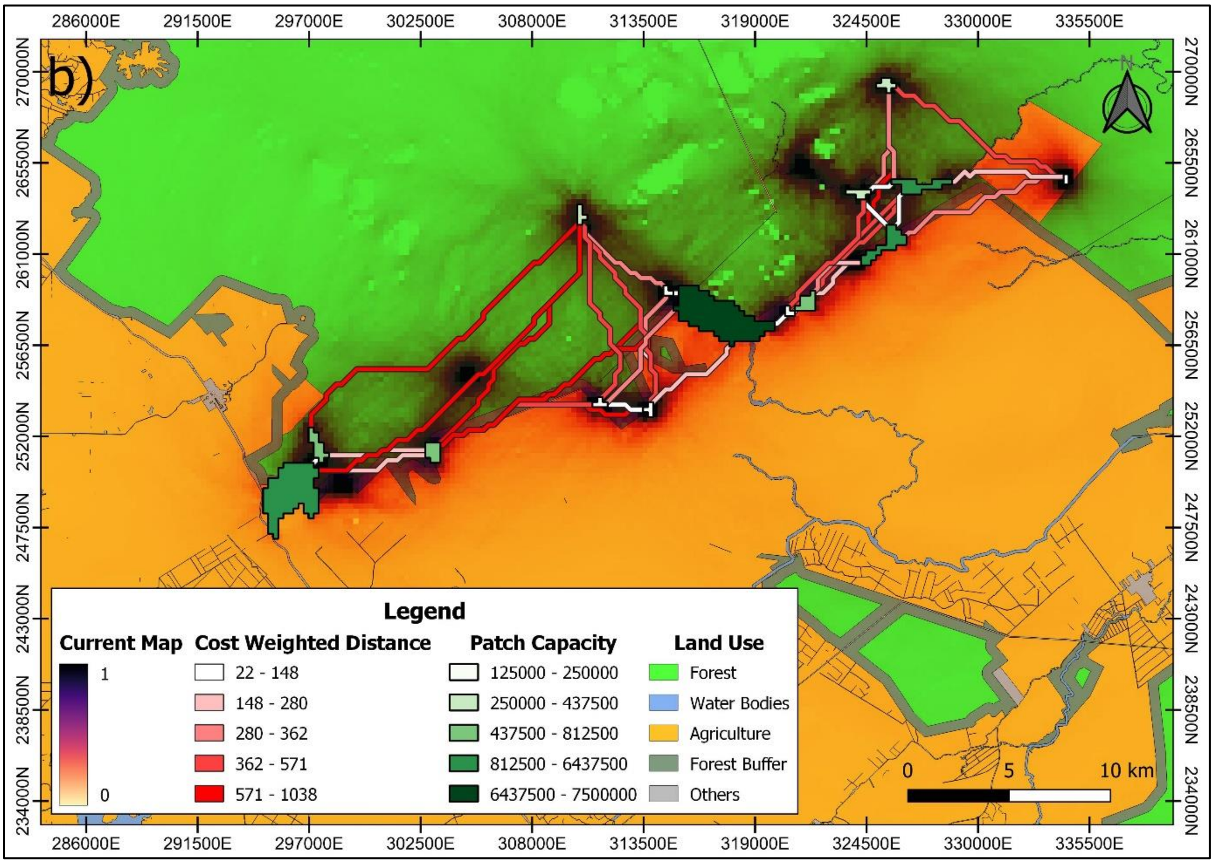
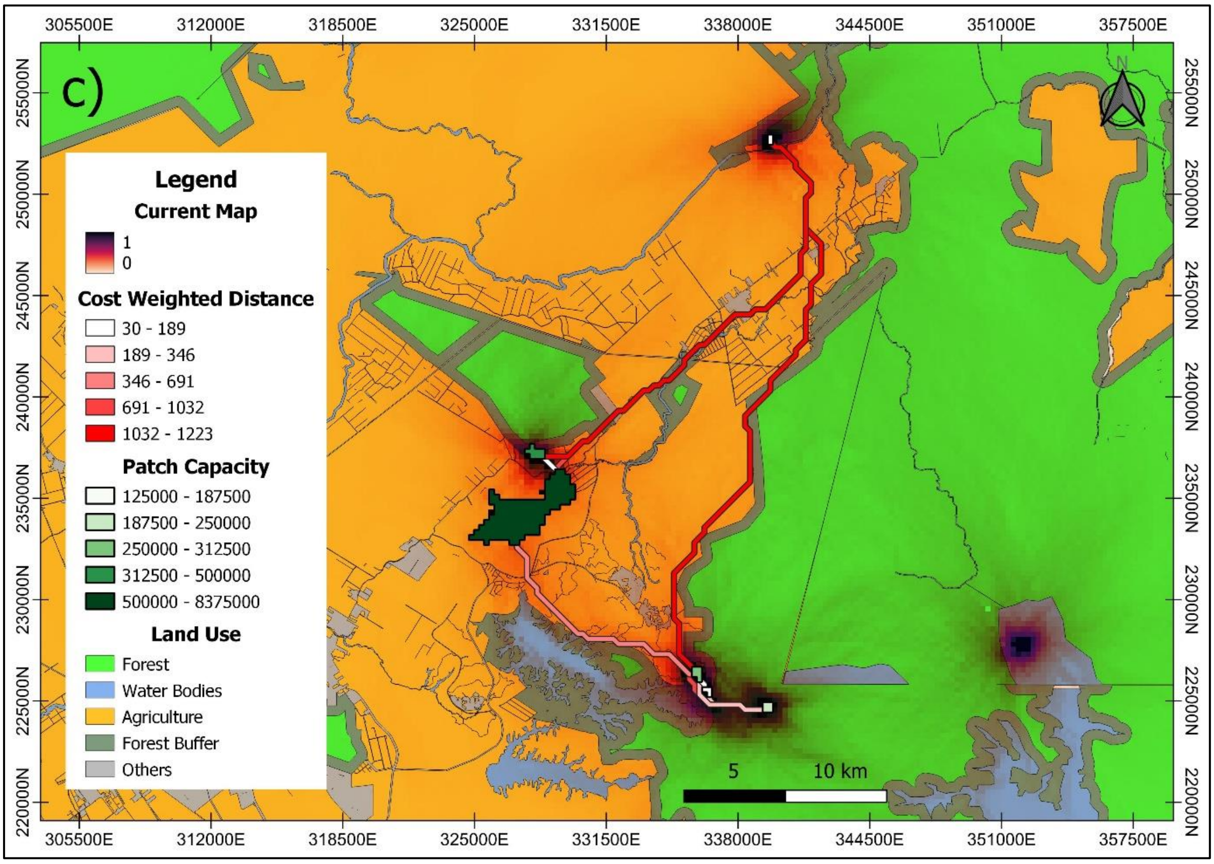
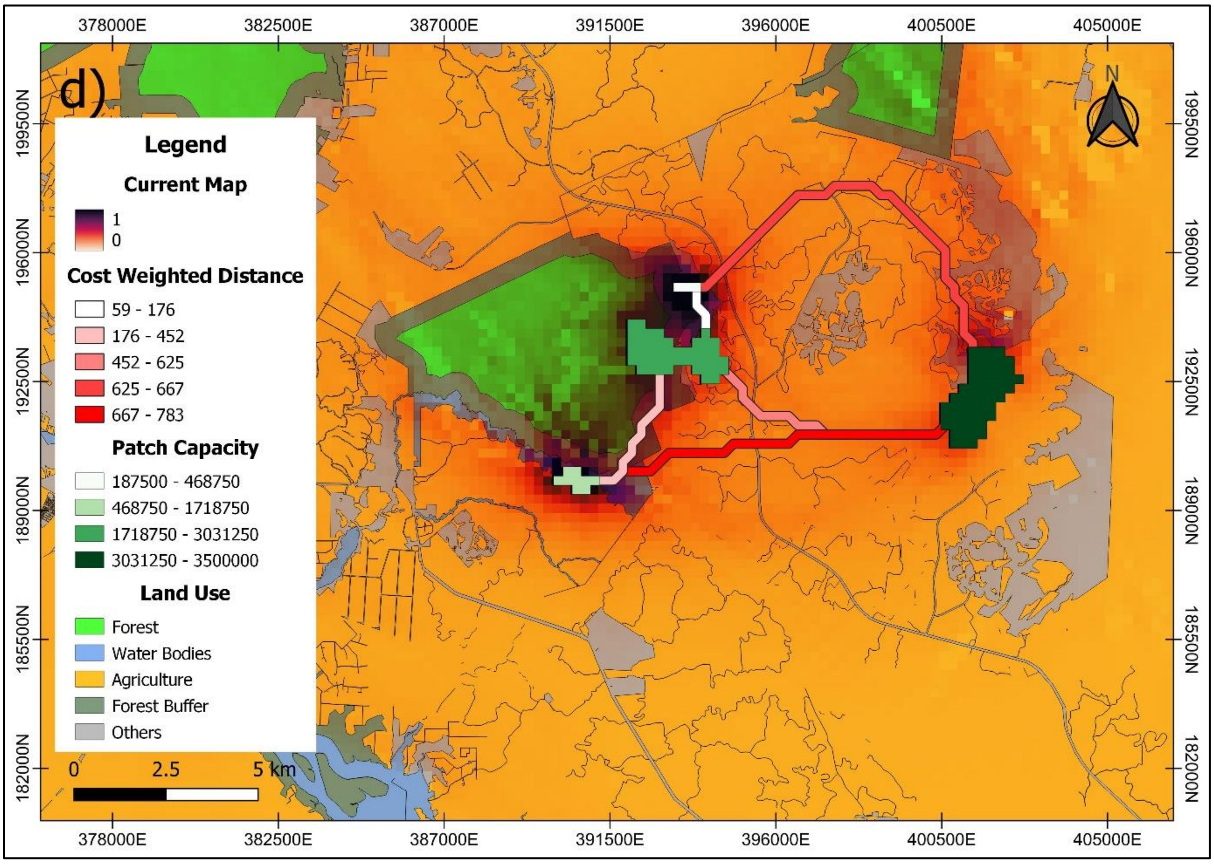

h)
N
Legend
Current Map
1
0
Cost Weighted Distance
18 - 107
107 - 370
370 - 529
529 - 783
783 - 1494
Patch Capacity
125000 - 250000
250000 - 375000
375000 - 562500
562500 - 3687500
0
5
10
15 km
315000E
322500E
330000E
337500E
345000E
352500E
360000E
367500E
375000E
286000N
279500N
273000N
266500N
260000N
253500N
247000N

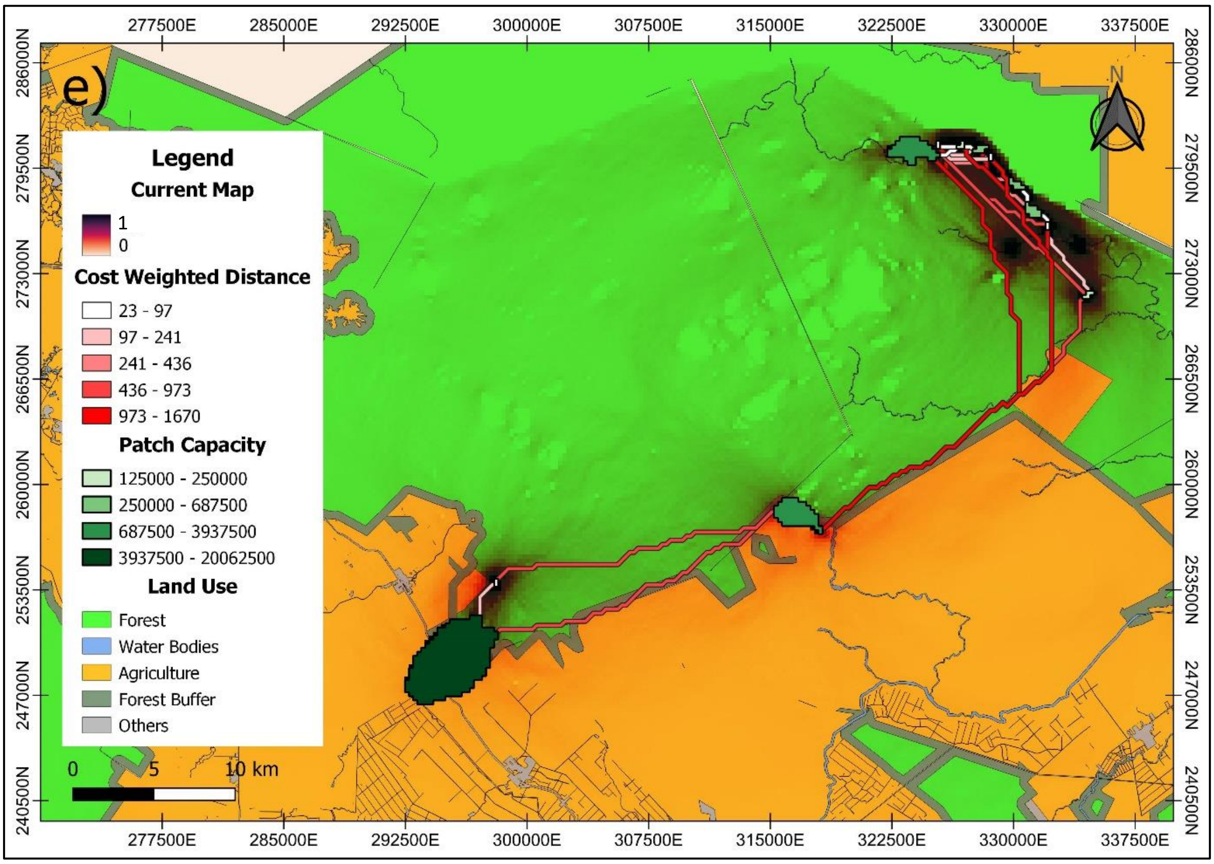
Figure 3-9. Predicted corridors using Least Cost Path and current density map from Circuit Theory for (a) Aramijaya; (b) Kathy; (c) Mat Cool; (d) Mat Easter; (e) Mat Jagoh; (f) Mat Pasak; (g) Mat Pinggir; (h) Si Rabik. Patch capacity (patches with high capacity in dark green, lower in bright green), Cost-weighted Distance (lines with high cost in dark red, lower in bright red and white), Current density map (higher current densities in red, lower in blue).




b)
286000E
291500E
297000E
302500E
308000E
313500E
319000E
324500E
330000E
335500E
270000N
265500N
261000N
256500N
252000N
247500N
243000N
238500N
234000N
Legend
Current Map
1
0
Cost Weighted Distance
22 - 148
148 - 280
280 - 362
362 - 571
571 - 1038
Patch Capacity
125000 - 250000
250000 - 437500
437500 - 812500
812500 - 6437500
6437500 - 7500000
Land Use
Forest
Water Bodies
Agriculture
Forest Buffer
Others
0
5
10 km
N


c)
305500E
312000E
318500E
325000E
331500E
338000E
344500E
351000E
357500E
255000N
250000N
245000N
240000N
235000N
230000N
225000N
220000N
Legend
Current Map
1
0
Cost Weighted Distance
30 - 189
189 - 346
346 - 691
691 - 1032
1032 - 1223
Patch Capacity
125000 - 187500
187500 - 250000
250000 - 312500
312500 - 500000
500000 - 8375000
Land Use
Forest
Water Bodies
Agriculture
Forest Buffer
Others
5
10 km
N


d)
Legend
Current Map
1
0
Cost Weighted Distance
59 - 176
176 - 452
452 - 625
625 - 667
667 - 783
Patch Capacity
187500 - 468750
468750 - 1718750
1718750 - 3031250
3031250 - 3500000
Land Use
Forest
Water Bodies
Agriculture
Forest Buffer
Others
0
2.5
5 km
N
378000E
382500E
387000E
391500E
396000E
400500E
405000E
199500N
196000N
192500N
189000N
185500N
182000N


e)
Legend
Current Map
1
0
Cost Weighted Distance
23 - 97
97 - 241
241 - 436
436 - 973
973 - 1670
Patch Capacity
125000 - 250000
250000 - 687500
687500 - 3937500
3937500 - 20062500
Land Use
Forest
Water Bodies
Agriculture
Forest Buffer
Others
0
5
10 km
N
277500E
285000E
292500E
300000E
307500E
315000E
322500E
330000E
337500E
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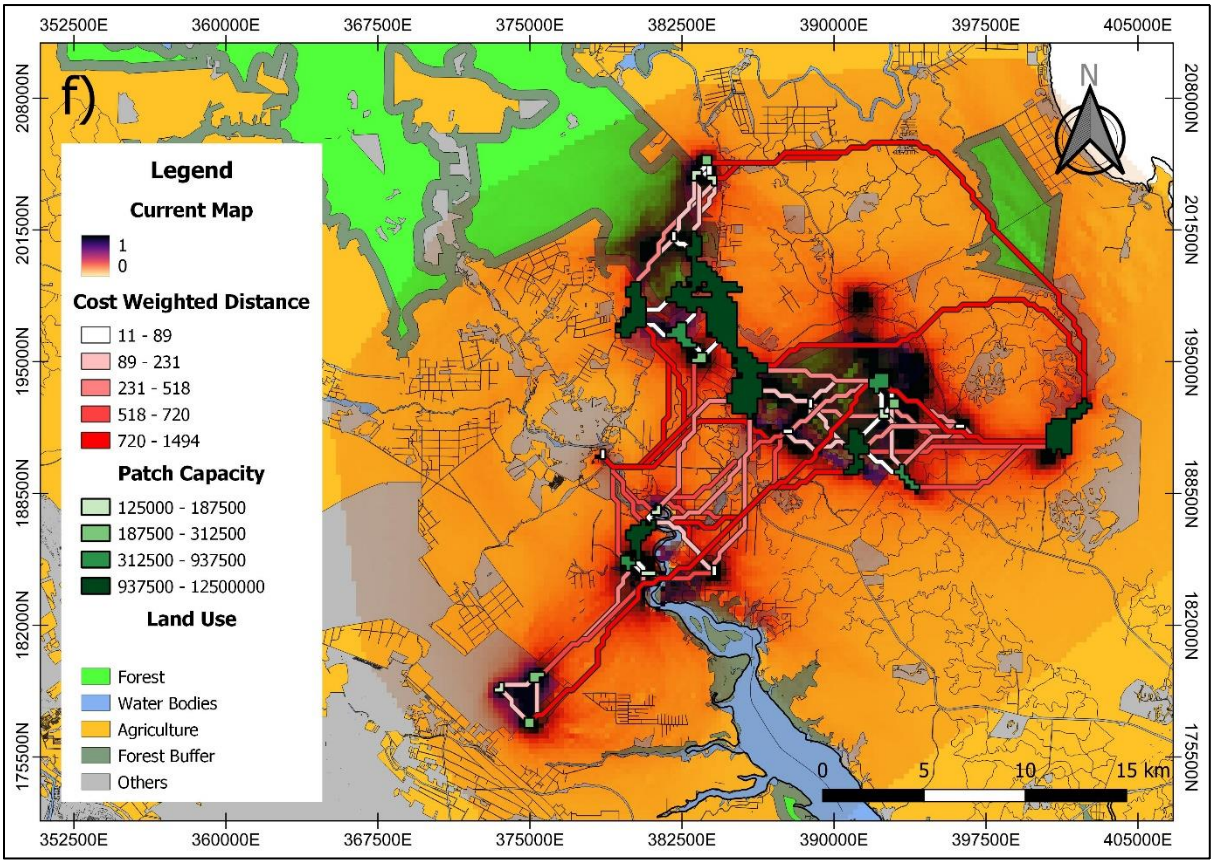
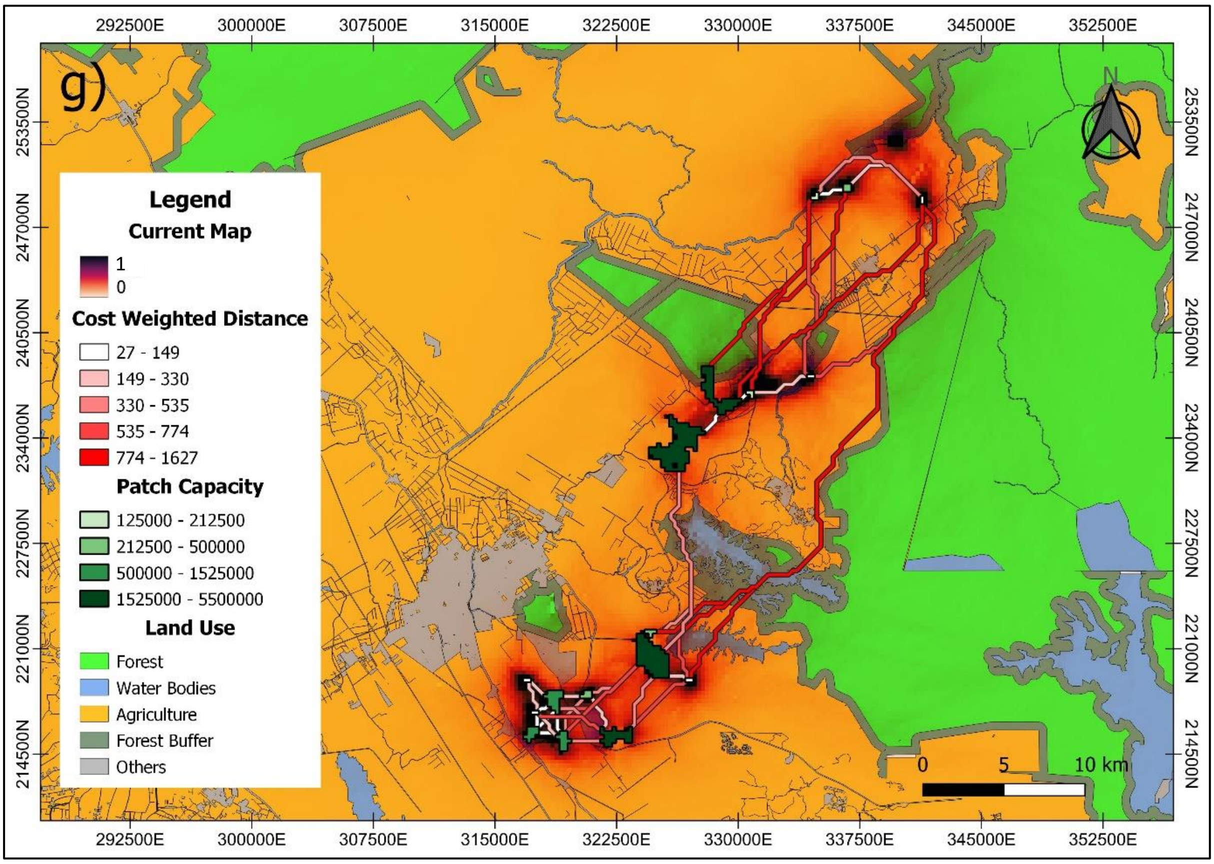
253500N
247000N
240500N


f)
Legend
Current Map
1
0
Cost Weighted Distance
11 - 89
89 - 231
231 - 518
518 - 720
720 - 1494
Patch Capacity
125000 - 187500
187500 - 312500
312500 - 937500
937500 - 12500000
Land Use
Forest
Water Bodies
Agriculture
Forest Buffer
Others
N
0
5
10
15 km
352500E
360000E
367500E
375000E
382500E
390000E
397500E
405000E
208000N
201500N
195000N
188500N
182000N
175500N


g)
Legend
Current Map
1
0
Cost Weighted Distance
27 - 149
149 - 330
330 - 535
535 - 774
774 - 1627
Patch Capacity
125000 - 212500
212500 - 500000
500000 - 1525000
1525000 - 5500000
Land Use
Forest
Water Bodies
Agriculture
Forest Buffer
Others
N
0
5
10 km
292500E
300000E
307500E
315000E
322500E
330000E
337500E
345000E
352500E
253500N
247000N
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227500N
221000N
214500N

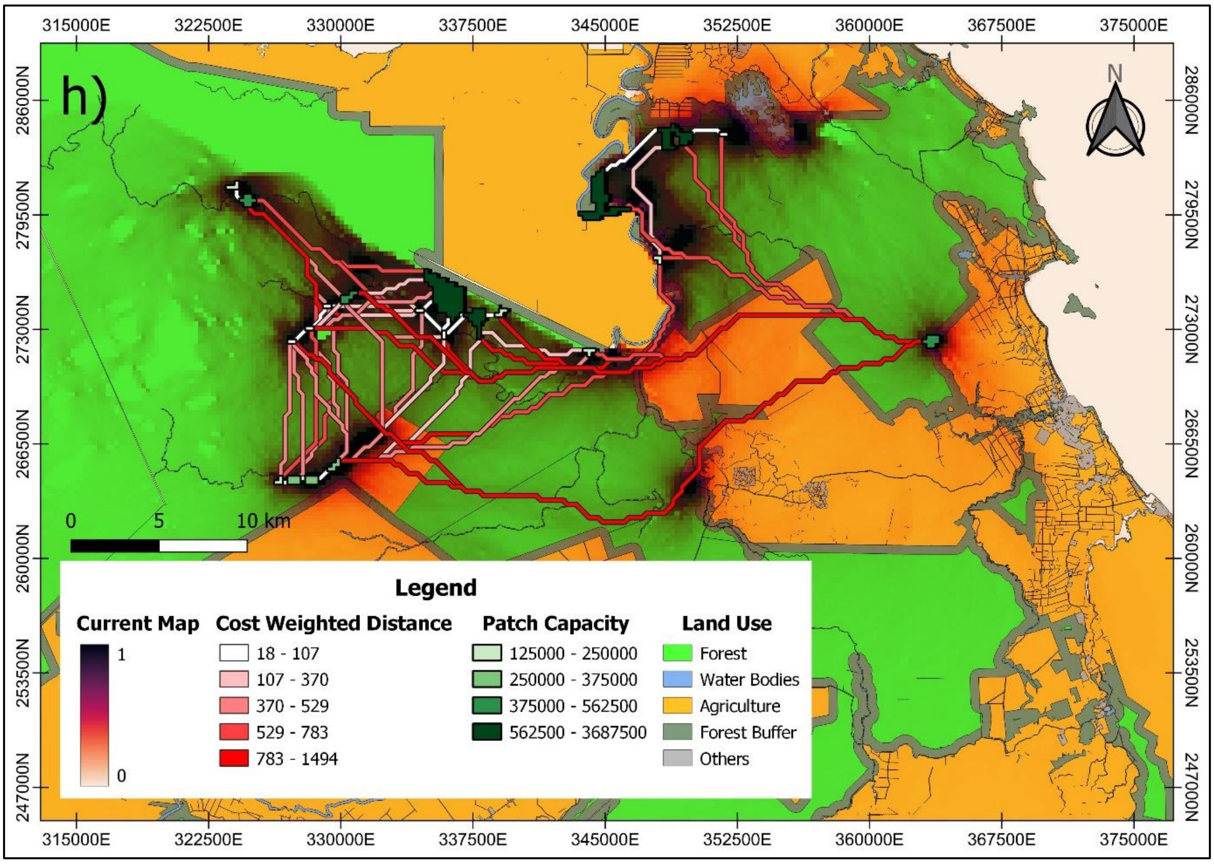
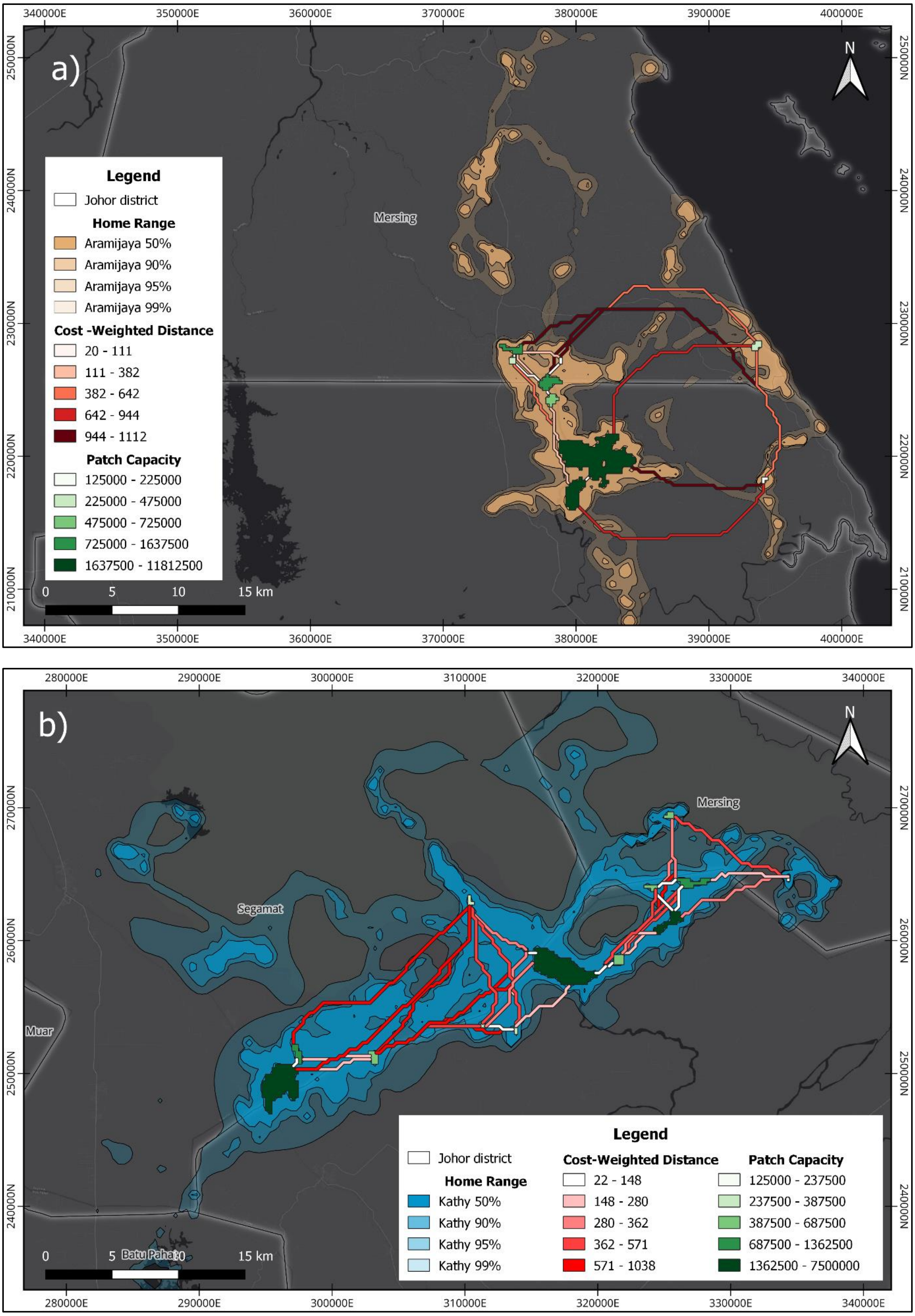
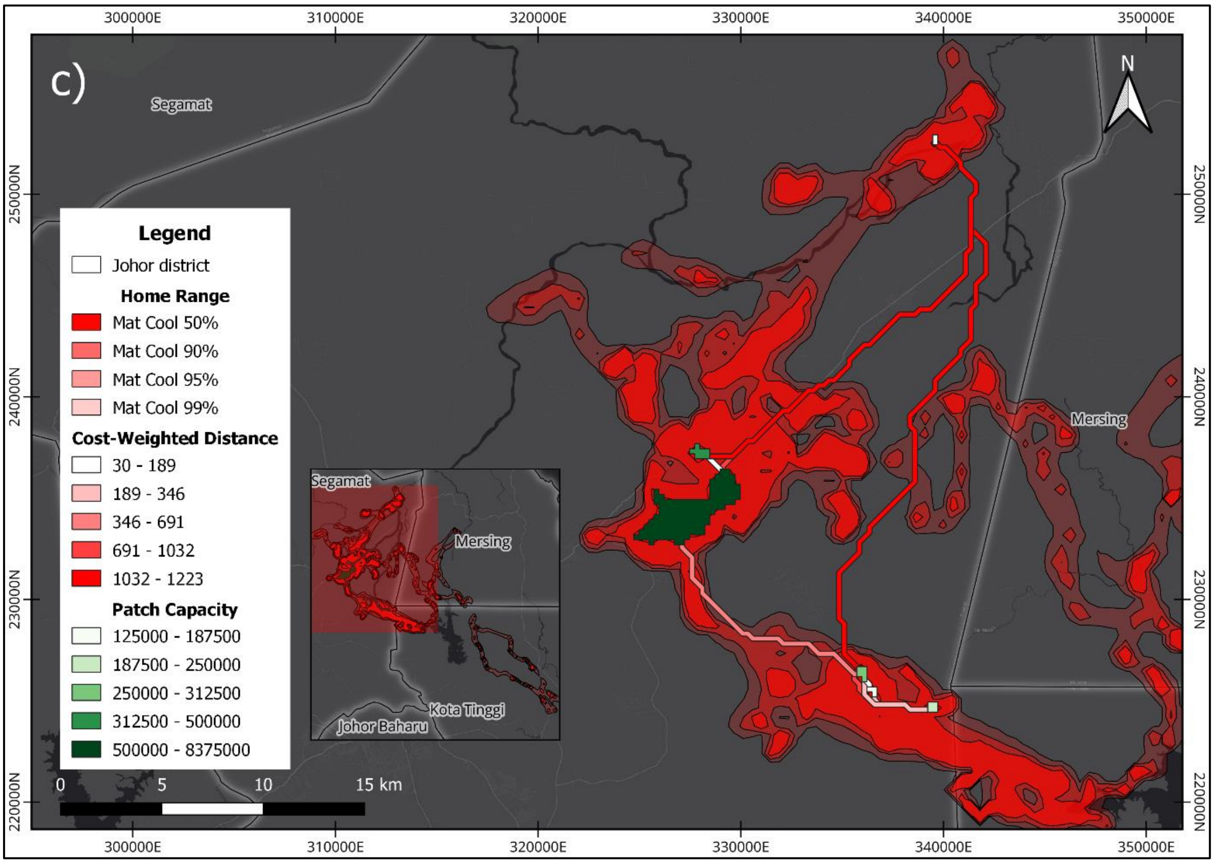
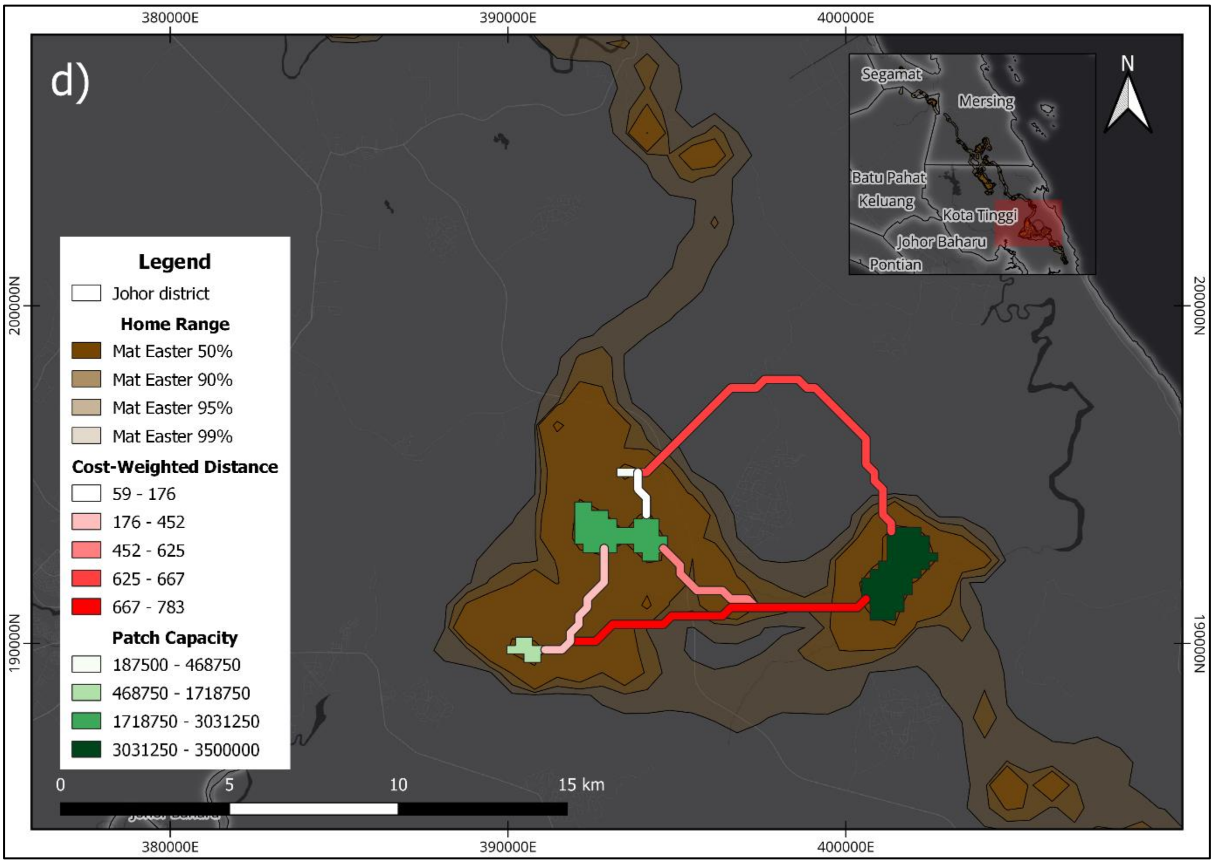
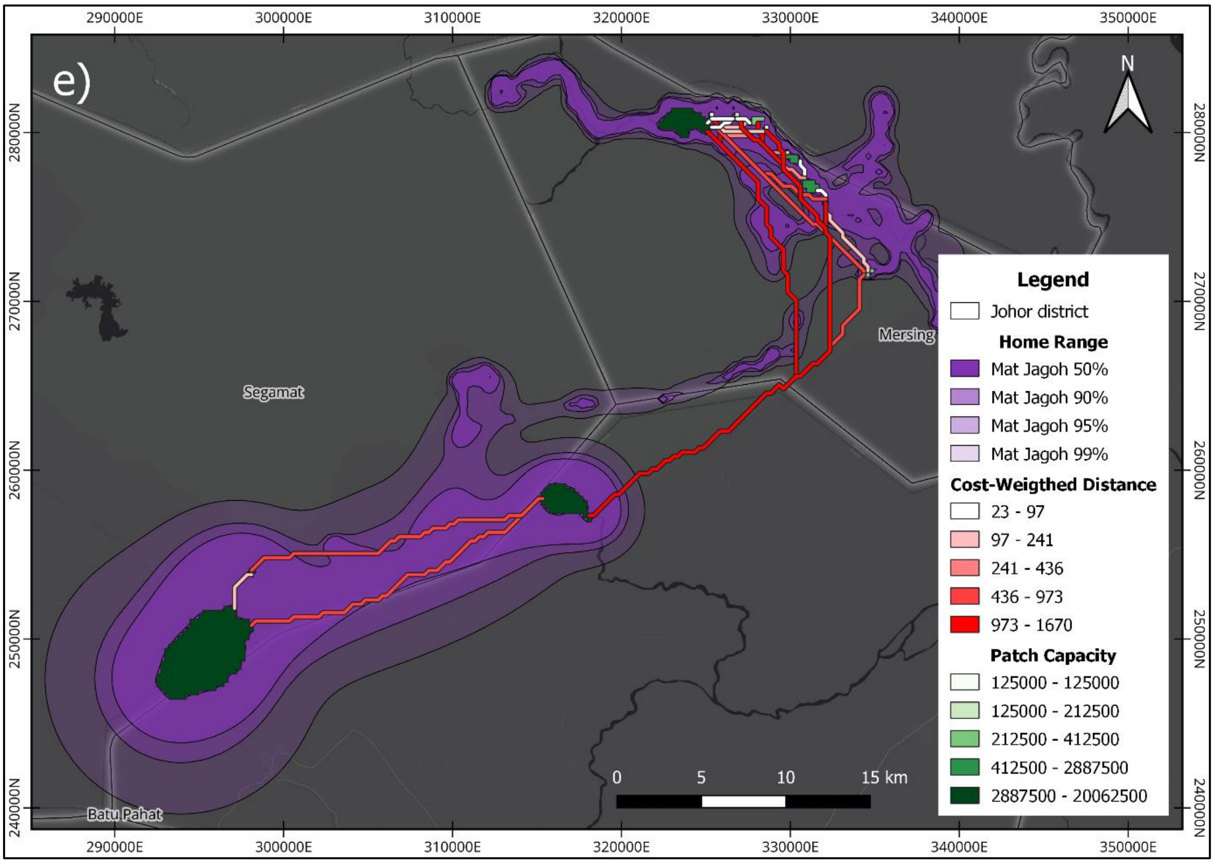


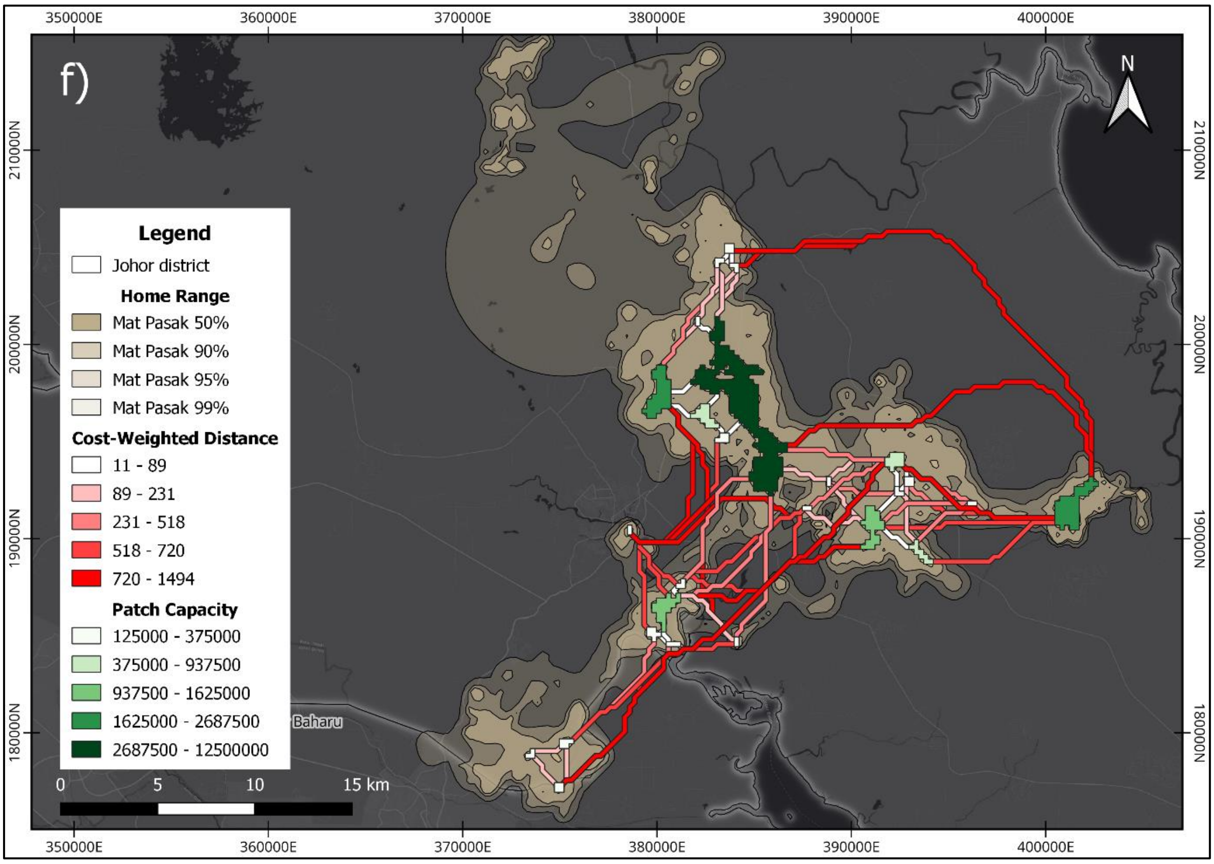
Figure 3-10. Estimated corridors using Least Cost Path and current density map from Circuit theory overlaid with land use map (a) Aramijaya; (b) Kathy; (c) Mat Cool; (d) Mat Easter; (e) Mat Jagoh; (f) Mat Pasak; (g) Mat Pinggir; (h) Si rabik. Patch capacity (patches) (high capacity in dark grey, lower in bright grey), Cost-weighted Distance (lines with high cost in dark red, lower in bright red and bright red), Current density map (higher current densities in dark violet, lower in white).


a)
340000E
350000E
360000E
370000E
380000E
390000E
400000E
250000N
240000N
230000N
220000N
210000N
N
Mersing
Legend
Johor district
Home Range
Aramijaya 50%
Aramijaya 90%
Aramijaya 95%
Aramijaya 99%
Cost -Weighted Distance
20 - 111
111 - 382
382 - 642
642 - 944
944 - 1112
Patch Capacity
125000 - 225000
225000 - 475000
475000 - 725000
725000 - 1637500
1637500 - 11812500
0
5
10
15 km
b)
280000E
290000E
300000E
310000E
320000E
330000E
340000E
270000N
260000N
250000N
240000N
N
Mersing
Segamat
Muar
Batu Pahat
Legend
Johor district
Home Range
Kathy 50%
Kathy 90%
Kathy 95%
Kathy 99%
Cost-Weighted Distance
22 - 148
148 - 280
280 - 362
362 - 571
571 - 1038
Patch Capacity
125000 - 237500
237500 - 387500
387500 - 687500
687500 - 1362500
1362500 - 7500000
0
5
10
15 km


c)
300000E
310000E
320000E
330000E
340000E
350000E
250000N
240000N
230000N
220000N
N
Segamat
Mersing
Kota Tinggi
Johor Baharu
Legend
Johor district
Home Range
Mat Cool 50%
Mat Cool 90%
Mat Cool 95%
Mat Cool 99%
Cost-Weighted Distance
30 - 189
189 - 346
346 - 691
691 - 1032
1032 - 1223
Patch Capacity
125000 - 187500
187500 - 250000
250000 - 312500
312500 - 500000
500000 - 8375000
0
5
10
15 km


d)
380000E
390000E
400000E
200000N
190000N
N
Segamat
Mersing
Batu Pahat
Keluang
Kota Tinggi
Johor Baharu
Pontian
Legend
Johor district
Home Range
Mat Easter 50%
Mat Easter 90%
Mat Easter 95%
Mat Easter 99%
Cost-Weighted Distance
59 - 176
176 - 452
452 - 625
625 - 667
667 - 783
Patch Capacity
187500 - 468750
468750 - 1718750
1718750 - 3031250
3031250 - 3500000
0
5
10
15 km


e)
N
Segamat
Mersing
Batu Pahat
290000E
300000E
310000E
320000E
330000E
340000E
350000E
280000N
270000N
260000N
250000N
240000N
0
5
10
15 km
Legend
Johor district
Home Range
Mat Jagoh 50%
Mat Jagoh 90%
Mat Jagoh 95%
Mat Jagoh 99%
Cost-Weigthed Distance
23 - 97
97 - 241
241 - 436
436 - 973
973 - 1670
Patch Capacity
125000 - 125000
125000 - 212500
212500 - 412500
412500 - 2887500
2887500 - 20062500


f)
N
Baharu
350000E
360000E
370000E
380000E
390000E
400000E
210000N
200000N
190000N
180000N
0
5
10
15 km
Legend
Johor district
Home Range
Mat Pasak 50%
Mat Pasak 90%
Mat Pasak 95%
Mat Pasak 99%
Cost-Weighted Distance
11 - 89
89 - 231
231 - 518
518 - 720
720 - 1494
Patch Capacity
125000 - 375000
375000 - 937500
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1625000 - 2687500
2687500 - 12500000

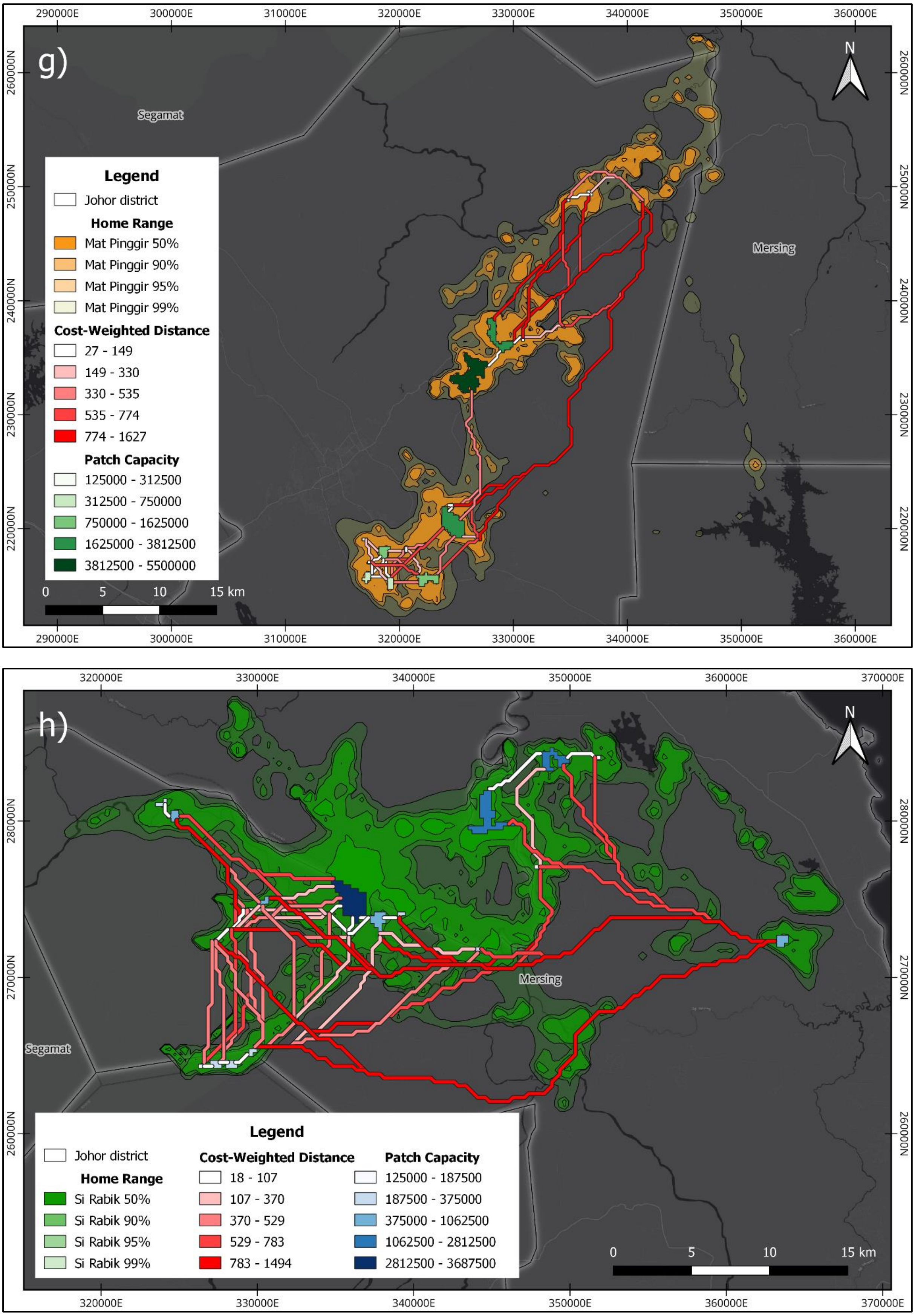

Figure 3-11. Estimated corridors using LCP overlaid with estimated home range map of (a) Aramijaya; (b) Kathy; (c) Mat Cool; (d) Mat Easter; (e) Mat Jagoh; (f) Mat Pasak; (g) Mat

Pinggir; (h) Si Rabik. Patch capacity (patches with high capacity in dark green, lower in bright green), Cost-weighted Distance (lines with high cost in dark red, lower in bright red and white).

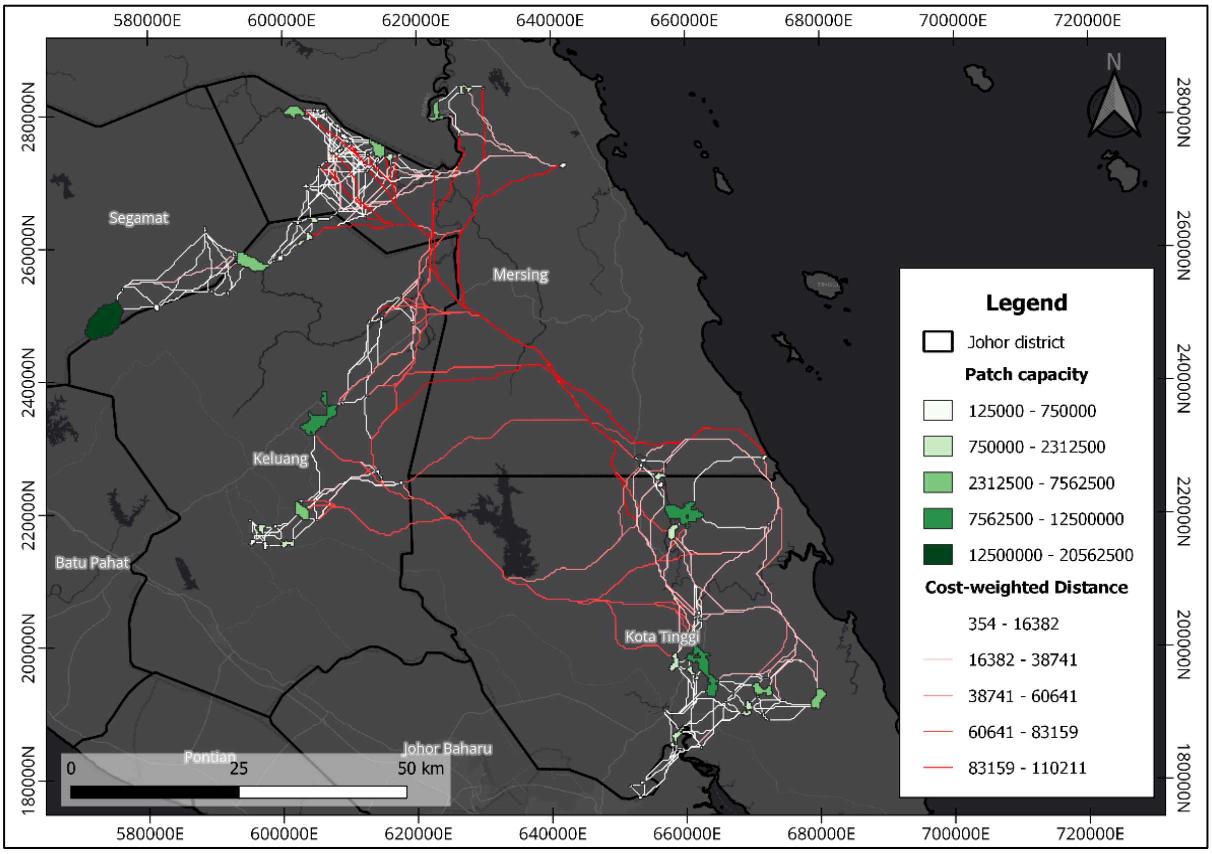

Figure 3-12. Estimated corridors using LCP for Johor State using all eight collared elephant GPS data (patches with high capacity in dark green, lower in bright green), Cost-weighted Distance (lines with high cost in dark red, lower in bright red and white).

DISCUSSION

The long-term monitoring of eight GPS collared Asian elephants between 2020 and 2022 in the State of Johor, Peninsular Malaysia served as the foundation for this study. This study has produced useful knowledge and increased understanding of elephant movements in Johor in particular, the estimation of home range sizes, proportion of land use preferred by the collared elephants and the prediction of potential movement corridors.

4.1 Home range

This study's group of elephants was by far the largest for the State of Johor (eight Asian elephants) for elephant home range estimation. Furthermore, this is the first study in Peninsular Malaysia to utilize dynamic Brownian Bridge Movement Models (dBBMM) home range estimator to estimate Asian elephant home ranges. Previous Asian elephant home range research was conducted in the states of Perak, Kelantan, Pahang, and Terengganu and used traditional home range estimator like Minimum Convey Polygon and Kernel Density Estimator (Magintan et al., 2016; Wadey, 2020). When compared to other analysis methods, the dBBMM method used in this study provides a better representation of space use by elephants because it considers the speed of movement and behavioural changes along animal tracks (Horne et al. 2007; Kranstauber et al. 2012). Since elephants are non-territorial animals (Fernando et al., 2008), the overlap of home ranges between collared elephants is expected. This species' lack of territoriality may be related in part to its dependence on widely dispersed resources (water, wild fruits, shade etc) which is difficult to protect from others (Wittemyer & Getz, 2007) and elephants devote a large part of their day to feeding and traveling (Sukumar, 2003).

Telemetry study of elephants may take about eight to twelve months before achieving a stable calculation of home range (Fernando et al., 2008; Wadey, 2018). When visualizing GPS coordinates throughout the study period for each individual elephant using temporal control function in QGIS, most of the elephants tend to move in a loop (pers. obs). The individuals revisit the site after few months and continued to another location which was visited previously. It is suggested that the time taken to revisit each site by the elephant could be an indicator of how much time is needed for food resources to recover at that particular area (English et al., 2014; Wadey, 2018). Site fidelity is considered as an animal's tendency to return to a previously occupied place. This is reflected in the home range analysis, where the core home range is displaying the highest frequency of detection. Future studies could examine the type of resource and regrowth rate or recovery rate of the resources and how it might be related to time interval between the visits.

The estimated mean home range size for this study was 247.3 km² (151.4 km² – 374.2 km²) (95% utilization). Previous studies in Malaysia by Alfred et al., 2012 (250 km2 - 400 km2), Magintan et al., 2016 (96.53 km2 - 367.99 km2) and Wadey, J. 2020 (mean 228 ± 203 km2, range 12 km2 - 701 km2) using Minimum Convex Polygon and Auto correlated kernel density estimator. Home range studies using dBBMM estimator in Borneo and Sumatra, Indonesia shows mean home range size of 150.01 km² and 149.27 km² respectively for 95% utilization (Evans et al., 2020; Wilson et al., 2020). The mean home range is this study is similar to the previous studies done in Malaysia, even though the methods are different. This is because the theses studies do include translocated individual into their home range analysis. However, when compared with similar method but different location (Borneo and Sumatra) Evans et al. (2020) and Wilson et al. (2020), the estimated mean home range size is slightly bigger. This may due to translocated individuals travelling form translocated site back to captured site as observed in Figure (3-4), which applies to, Mat Pinggir, Mat Easter and Mat Pasak. Evans et al. (2020) mentioned that all the collared individuals in his study were relocated to the nearest protected forests (<10 km) meanwhile, Wilson et al. (2020) focused on three local adult female elephants from different clans within two different protected areas in Sumatra which did not involve translocation process. Since the translocated elephants for this study were relocated to Endau Rompin Forest reserve, which is ±130km from Kota Tinggi where Mat Pasak and Mat Easter were captured, the estimated home range size for this study could be bigger as the elephants were trying to get back to its original range.

The estimation of the home range may be influenced by the change in location. The studies in Malaysia were conducted in human-impacted areas like Royal Belum and Temenggor which are split by the Gerik-Jeli highway and logging activities (Wadey, J. 2020), Magintan et al. (2016) conducted their study at Hulu Terengganu during the construction of a hydroelectric dam. Alfred et al. (2012) also mentioned the estimated home range size to be 250 to 400 km2 in a non-fragmented forest and 600 km2 in a fragmented forest. The forested area in this study was secondary forest (HSK Panti, HSK Sedili, Endau-Rompin and etc.) and predominantly human-impacted. This may help to explain why, despite the methodology being different, the home range size projected in this study fits within the range of other studies in Malaysia.

Additionally, the time interval between two GPS coordinates may influence the home range size. Mat Pasak has data missing continuously for two weeks (± 80 GPS points) in the middle of the monitoring duration (2020- 2022) which produce a slightly bigger estimated home range area around the missing gaps similar to Mat Jagoh (Figure 3-9). Since the missing data occurred in the middle of the monitoring period, eliminating the data before or after that missing gap (only using the data before or after the incident) was not an option as it may result in the loss of a large amount of relevant information. In this case, I have changed the margin from 5 to 7 and window size of 13 to 21 for dBBMM estimator as recommended from a previous study for Asian elephant home range estimation (Wilson et al., 2020).

This study found evidence that agriculture had an impact on elephants' home range sizes. As the proportion of agriculture land inside the estimated home range increases, the size of the home range for the elephant decreases ($R^2 = 0.56$, p-value = 0.033, Figure 3-4). In other words, elephants who prefer agricultural to forested areas have smaller home ranges. For example, elephants which prefer agriculture have home range size as small as 151.1 km^2 - 243.5km^2, (95% utilization, N=3), while for those prefer forested area have home range from 182.8 km^2 - 374.2 km^2 (95% utilization, N=5). Since elephants require large amounts of food (up to 150kg) daily (Vancuylenberg, 1977; Sukumar, 2003) as suggested by (Wadey, 2018) the reduction in home range sizes suggest that elephants can satisfy the same energy requirements at smaller ranges due to abundance in food supply. Furthermore, when food and water are plentiful all year, elephant home ranges are generally smaller and more stable, for example, 115 ± 64 km^2 (100% MCP & 95% fixed kernel method) in Sri Lanka (Fernando et al., 2008). It is speculated that due to presence of grasses and early successional plants in disturbed habitat and crop depredation that occur in some of the plantations, the home range of Aramijaya (151.1km^2) (95% utilization) is the smallest of all eight collared individuals.

To meet the need of daily energy use, elephants have been observed to select food items which are rich in sugar, protein and high glutamate sources, plus minimize fibrous elements to reduce energy spend for digestion (Suba et al., 2020). Elephants have been observed consuming palm shoots, leaves, and shoots of newly planted oil palms (Guharajan et al., 2019; Othman et al., 2019). Crops or plantations, such as oil palm, provide elephants with nutritionally dense and concentrated resources (Foguekem et al. 2011; Rode et al. 2006; Sukumar 1990). Hence elephants are attracted to such areas. Additionally, based on elephant encounters during on ground telemetry tracking, most elephants have been seen to consume secondary vegetation at the plantation edges and oil palm trees. Secondary vegetation is very common in agriculture sites as the opening of land for planting crops provides opportunities for secondary vegetation to grow.

The availability of grasses and other early succession plant means the elephants do not need to travel far between food source, plus available food source being easily digested by elephant's digestive system explain why Aramijaya, Mat Pasak and Mat Pinggir may prefer disturbed area more that forested area (Yamamoto-Ebina et al., 2016; Fernando et al., 2016; Koirala et al., 2016; Suba et al., 2018; Wadey, 2018). Additionally, cultivated crops are selectively bred by people to improve their quality (Foguekem et al. 2011), hence the taste for palatability and nutritional food source may be key for site selection despite the pressure that the elephants received there from anthropogenic activities (Neupane et al., 2019; Suba et al., 2020; Liyanage et al., 2021). The smallest home range size (151.4 km^2, Aramijaya) does not belong to the individual who has been monitored for the shortest amount of time (Mat Easter) plus, Aramijaya was found roaming in a herd. Even strengthening the finding of home range size is influenced by agriculture, because elephant herds tend to prioritize safety for their young. Based on Aramijaya's herd behaviour, there might be two reasons; 1) availability of food source around the neighbouring forest patches is not meeting the demand of daily food supply for Asian elephant (approximately 100 – 500 kg which is 10% of their body weight) (Sukumar, 2006; Fernando, 2015); 2) or that the location chosen by Aramijaya's herd may be safer for their young (Vidya & Sukumar, 2005; de Silva et al., 2011). During on ground telemetry tracking Aramijaya have been observed in both agriculture and abandon agricultural land. The abandon agricultural land does not pose any threat to elephants' safety, as no human activities were being conducted there and some of these areas are swampy (occasionally flooded during monsoon) and provides opportunities for secondary vegetation to grow.

4.2 Proportion of land use

The preference for nutrition and abundance of food source explained why some elephants in this study have higher proportion of agriculture within their estimated home range. The high preference for agriculture site may be due to fewer opportunities for feeding in natural sites or decreased landscape permeability (Abram et al., 2022). Meanwhile for elephants with higher proportion of forested area in their home range, risk avoidance may explain this preference. Elephants are exposed to injuries or even mortality when encountering humans which is a result of human-elephant conflict issues. Research by Abram et al. (2022), showed that forest patches are important for elephants, mainly females, in Such scenario has been observed from the sole female elephant in this study, Kathy, whose usage of forested land use is the highest proportion among all the collared individuals. Adult female elephants influence and direct their herd’s movement patterns and habitat consumption, by selecting habitats and movement routes that are ideal for their young, such as natural forest habitat, a strategy likely used to increase the survival of their offspring, (Vidya & Sukumar, 2005; de Silva et al., 2011).

Elephants were found to be attracted to disturbed habitat and chose not to venture far from roads or forest (Wadey, 2018), which explains why the proportion of Aramijaya and Mat Pinggir in forest buffer is equal or higher in proportion compared to that of non-forest buffer (internal forest). Evidence from home range visualization and proportion of GPS Points within each calculated 95% land use proportion of the form home range, suggest there are elephants who use forest patches as corridor for movements. There are differences between individual elephants and their preferences for agriculture areas and forest land. For example, Mat Easter and Mat Cool have high proportion of forest in its home range, however the percentage of GPS points within each forest proportion area is smaller compared to percentage of GPS points in agriculture. Since the GPS location interval is set to every 1 to 5, fewer GPS points in large land use proportion may indicate that, less time is spent at that particular area, however the delay between each GPS point due to external factor may influence the results. I conclude that Mat Cool and Mat Easter use available forest patches within their home range for movements rather than foraging. Meanwhile, a high percentage of GPS points within proportion of agriculture land use, indicates that more time was spent at agriculture area, reinforcing our conclusion. However, some elephants (Kathy and Aramijaya) have been observed to spend the day in closed canopy land and most of the daytime is spent at the forest edge (Rood et al., 2013). Similar results were also recorded by numerous studies, where elephants spend time in forested areas during the day and roam in agricultural sites at night (Kumar et al., 2010; Sitompul et al., 2013; Krishnan et al., 2019). This behaviour may explain how elephants avoid risky areas like agricultural sites by modifying their roaming pattern.

Since elephants prefer human-dominated landscapes (Collins, 2018; Krishnan et al., 2019; de la Torre et al., 2021), forest patches might be used as main routes of movement during the daytime and agricultural sites might be used as foraging sites at night time. This behaviour could be the reason why some elephants in this study showed more proportion of forest within their home range, as the home range for this individual is bigger compared to individual preferring agricultural area. In order to have a larger home range, the elephants must be moving more or covering a longer distance. Future studies could include categories of time spent (day and night) in land use proportion, as this would reflect the proportion of land use by elephants during day versus night. The result might increase our knowledge of how the available land is being utilized for daily activities and the importance of remaining forest patches for elephant movement.

Si Rabik has shown a higher proportion of forested area within home range and the home range does overlap (8%) with Kathy's home range. Based on ground telemetry tracking, Kathy and Si Rabik have been observed to be closed to each other (± 10 km) and Si Rabik spend most of the time nearby the tracked area (Endau Rompin State Park) for more than 2 months. This situation may reflect that Si Rabik's preference for forested area may be influenced by mating opportunities. Male elephants have been observed to follow female herds during mating season (Rajaram, 2006; Fernando et al., 2008). However, since there was no direct sighting of Kathy and Si Rabik together at that location, this condition may be coincident.

Land use by herds and lone bulls varies and is influenced by the social structure of elephants (Baskaran et al., 2018). Therefore, home range size and land use proportion are not only influenced by availability of food and water source, but by different types of social structure of elephants as well. Female herd have shown to choose route that are safer for their young, while males have shown to use varies types of movement pattern. Mat Cool and Mat Pinggir, formed a small bachelor group (3 individuals) when roaming in agricultural sites which is confirmed during on ground tracking. After few months the bachelor group split into even smaller group (Mat Cool being alone and Mat Pinggir with another lone bull). Same observation was made by Srinivasaiah et al. (2019), whereby Asian elephants exhibit spectacular emergent behaviour by creating a long-lasting, all-male groups, usually in places that are not covered in trees. This may be true for sub-adult males, which have been shown to efficiently enhance their bodily condition when in all-male groups by exploiting anthropogenic resources such as via crop raiding. These behaviours are most likely an adaptive strategy for male Asian elephants who may have learned to tolerate increasingly anthropogenic disturbed environments.

This study has several limitations worth discussing. First of all, majority (six out of eight individuals) of the GPS collared Asian elephants in this study were translocated and mostly male elephants. Future home range analysis should focus on collaring non translocated male and female elephants to compare home range estimates. As translocated elephants have the tendency to travel back to capture site, the home ranges tend to be larger and more linear. Secondly, only four months of on-ground telemetry tracking was conducted due to the limitation of time. Hence only selected habitat was ground truth compare to the overall studied area. Although shape files were updated with current info, but there could be other areas that requires ground truthing to capture changes in landscape. On-ground telemetry tracking provides information that may not be captured by satellite imagery. These include, barriers such as electric fences and elephant trenches which are not recorded by the officials or reported by the stakeholder. This barriers and fences can be recorded in the future studies which in cooperate elephant movement studies. Thirdly, for this study, only the elephant social behaviour, social structure and visual observation of types of land use were recorded. It is recommended for future studies to monitor and record types of vegetation when tracking elephants to examine if the rate of elephant returning to the site is because of the regrowth of plants. The rapid growth of the human population, leads to the expansion of agriculture area to sustain the human population, understanding the barrier to movements might be the key to reveal how Asian elephant adapt to the changing landscapes and resources.

4.3 Pathway analysis

Since isolated habitats restrict movement, gene flow, and access to essential ecological resources, functional connectivity is crucial for the survival of widely dispersed animals. Least cost patches and Circuit theory have provided information about key patches (core area) that are important in maintaining the connectivity for movement and possible routes that facilitate elephant movements. Based on visualization of the LCP result (Figure 3-9), elephants have been observed to use the suggested cost-weighted distance with least resistance (low resistance, white and brighter red lines) to move from one place to another within the estimated home range. Low cost-weighted distances provide routes for elephants to move with the least resistance as possible based on all the resistance values and barriers assigned to the resistance map.

Elephants in this study are using landscape which are less resistant to their movement while still having little movements above the comfort zone (area more resistance to movements, darker red lines). Elephants are edge species (Campos-Arceiz, 2013), and likely to roam in areas with secondary vegetation and avoid areas with high anthropogenic disturbances (de la Torre et al., 2021). In a different site north to Peninsular Malaysia, elephants were attracted to forage on grasses beside road sides near to forest (Wadey, 2018). As observed by Kathy's predicted LCP (Figure 3-8), this behaviour may reflect more of female herds as safety of their young is a priority or an individual elephant who choose safe pathways to move. Meanwhile for male elephants, optimal-foraging behavioural patterns and high-risk foraging strategy thrive their movement to riskier areas and eating nutritious foods to increase their fitness for reproduction (Sukumar & Gadgil, 1988; Srinivasaiah et al., 2019; Suba et al., 2020). As observed by Aramijaya, Mat Pasak and Mat Pinggir's predicted LCP (Figure 3-8).

Together with LCP and current land use map, a corridor with preferred size based on the study subjects can be identified. These corridors are recommended to be placed at the LCP for the respected home ranges of each individual with a width of 6km (Ford et al., 2020). LCP gives a single line which reflects the less cost path connecting two areas (Foltête et al., 2012), meanwhile current map provides a range of values from high movements (high current densities) to low movements (low current densities) between two consecutive patches (McRae et al., 2008). When the results of both are overlaid, it is possible to visualize the extent of the width of the suggested corridors. Therefore, utilizing these two tools together, it provides better visualization of possible movement corridors.

This study has several limitations worth discussing. First, the current map has included patches which are not included in LCP. The minimum patch size for LCP analysis was set to 10 hectares (100000 m^2), therefore 50% utilization core area patches which areas are smaller than the minimum size was not taken in count during LCP analysis. Those patches have shown to have significantly high connection between the surrounding patches. Technically, the minimum patch size can be lowered but this means LCP results needs to interpret with caution. Future analysis can consider using the output patch layer from LCP (which the minimum patches are not included) for analysis in circuit theory, so that the minimum patches (< 10 hectare) that are not taken in count by LCP are not included in circuit theory analyses. Second, The LCP results display patches passing across settlement area, as settlements were not included as a covariate in the original modelling of step-selection function (de la Torre et al., 2021) across the forested Central Forest Spine. Hence it was not a part of covariates used for resistance calculation. Based on recent news reports, elephants have been observed to roam in housing areas near forest or agricultural sites (Worldofbuzz, September 26, 2022), and settlement proximity to forest are prone to elephant attacks (Ram et al., 2021), therefore it is suggested that future studies to include distance to settlement and percentage of settlement in the making of resistance map. Large and more compact settlement may be more resistance to movement, while small and scattered settlement may be less resistance. Settlements which are further or at the edges of large and compacted human residencies were prone to elephant disturbance (personal communication, January 18, 2022). Further understanding on the barriers and the preference of elephants might provide information for better corridor planning, especially in a rapidly changing environment where available refuges for elephants are shrinking. In future, inclusion of localized barriers like electric fences and elephant trenches should be considered when analysing movement patches. These barriers can result in a loss of connectivity and an increased likelihood of Human-Elephant Conflict in new locations (Osipova et al., 2018).

Based on the findings of this study, few recommendations are suggested: (1) consider the home range size and land use type preferred by Asian elephant for management and planning of protected area and connectivity with surrounding forests. Elephants require an immense area (648.9km2) for foraging and movement, based on the size of their projected home range. As shown in Kathy, Mat Jagoh, Si Rabik, Mat Pasak, and Mat Cool's home range, forests like Endau Rompin, HSK Panti, and HSK Sedili do play a significant part in supplying food and shelter. These forests serve as a corridor for elephants to move from one forest to another, in addition to providing food and shelter.; 2) Identifying and enrich abandoned agricultural area for foraging and roaming of Asian elephants. Only one location was found to be abandoned and utilized by elephant for foraging and movement. Therefore, more on ground tracking should be conducted to identify these abandoned areas and whether the elephants are using this area to foraging and movement. There may or may not be an issue with land ownership if we encourage foraging in these areas. So, engaging with the stakeholder and encouraging them to adapt corridors as a mitigation for HEC is a way forward; 3) Involve agricultural area in corridor planning for wildlife movements. The corridor is recommended to place at the LCP of each individual and should be implemented by stages. First, conducted pilot study in few of the proposed corridor and look at the effectiveness of the corridor for elephant movement. Second, incorporate multiple mitigations such as electric fences and elephant tranches together with the corridor for more efficiency. Third, expending the corridors to other locations. It is possible that adding agricultural land to the corridor may raise HEC.

CONCLUSION

In conclusion, by studying how Asian elephants utilize space and land use type, this thesis provided insights that are useful for the conservation and management of an endangered species. It fills in research gaps on elephant home range and movement which can be utilized to advocate for and plan conservation activities in Peninsular Malaysia. This study has revealed that: 1) elephants in Johor have a mean home range size of 245 km^2 (range 142 km^2 – 326 km^2) (95% utilization). 2) elephants with larger proportion of agricultural land use within home range have smaller home ranges, while elephants with higher forested areas within home range have bigger home ranges. 3) and Asian elephants choose least resistance route to travel from one location to another. Additionally, this study identified important patches (core area) within the collared elephant home ranges and alternative corridors for daily movement or roaming.

Overall, our findings emphasize the need of evaluating the impact of anthropogenic development on megafauna and other animals, particularly in Southeast Asia, which has the largest number of vulnerable megafauna and plans for large-scale infrastructure development in the future decades. Conservation of these endangered megafauna would require, consideration of and a synthesis of animal habitat use, landscape connectivity, animal movement and anthropogenic development activities.

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APPENDICES

7.1 Supplementary Table

Table S1. List of environmental variables evaluated to modelling the resistance map of Asian elephant and land use types map from PLANMalaysia 2020 for Johor, Peninsular Malaysia.

Type	Variable name	Initial Data resolution	Source
Raster format			
Natural	Distance to forest	250 m	PLANMalaysia, 2020
	Elevation	250 m	SRTM (Google earth engine)
	Slope	250 m	PLANMalaysia, 2020
	Percentage of water	250 m	PLANMalaysia, 2020
	Wetness	250 m	Landsat 8 (Google earth engine)
Anthropogenic	Mean of nightlight	500 m	VIIRS (Google earth engine)
	Percentage of plantations	250 m	PLANMalaysia, 2020
	Distance to plantations	250 m	PLANMalaysia, 2020
	Percentage of regrowth and new plantations	500 m	MODIS (Google earth engine)
	Distance to roads	250 m	PLANMalaysia, 2020
Vector Format			
Natural	Forest	-	PLANMalaysia, 2020
	Water bodies	-	PLANMalaysia, 2020
	Forest buffer	-	Generated form Buffer tool, QGIS using PLANMalaysia, 2020 forest shapefile
Anthropogenic	Agriculture	-	PLANMalaysia, 2020 &

			information from MEME workshop
	Others	-	PLANMalaysia, 2020

7.2 On-ground telemetry tracked collared Asian elephant

Figure S1. Aramijaya

Figure S2. Mat Pasak

Figure S3. Mat Cool

Figure S4. Mat Pinggir

Figure S5. Variety size of dung was encountered when tracking Kathy