HABITAT SELECTION OF ELONGATED TORTOISES (*INDOTESTUDO ELONGATA*) IN SAKAERAT BIOSPHERE RESERVE, NORTHEAST THAILAND

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การเลือกแหล่งที่อยู่อาศัยของเต่าเหลือง (*INDOTESTUDO ELONGATA*) ในพื้นที่สงวนชีวมณฑลสะแกราช ภาคตะวันออกเฉียงเหนือของประเทศไทย

นางสาวอิสเบลลา กอนซาเลส มอนทานโย่

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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ในพื้นที่สงวนชีวมณฑลสะแกราช ภาคตะวันออกเฉียงเหนือของประเทศไทย (HABITAT
SELECTION OF ELONGATED TORTOISES (*INDOTESTUDO ELONGATA*) IN
SAKAERAT BIOSPHERE RESERVE, NORTHEAST THAILAND)
อาจารย์ที่ปรึกษา : อาจารย์ ดร.คอลิน โทมัส สไตรน์ 65 หน้า.

การเปลี่ยนแปลงแหล่งที่อยู่อาศัยและการเกิดพื้นที่ย่อมป่า เป็นสองสาเหตุที่เกิดจากการกระทำของมนุษย์ซึ่งก่อให้เกิดการคุกคามความหลากหลายทางชีวภาพ และการเข้าใจถึงความต้องการแหล่งที่อยู่อาศัยของสิ่งมีชีวิตคือกลยุทธ์สำคัญที่จะสร้างความเหมาะสมเพื่อการอนุรักษ์ความหลากหลายทางชีวภาพ โดยข้อมูลด้านสภาพแวดล้อมจึงจำเป็นต่ออัตราการรอดและการเจริญเติบโตของสิ่งมีชีวิต โดยเฉพาะสิ่งมีชีวิตที่มีความเสี่ยงต่อการสูญพันธุ์ เต่าเหลือง (*Indotestudo elongata*) เป็นสิ่งมีชีวิตที่ใกล้จะสูญพันธุ์และยังเป็นสิ่งมีชีวิตประจำถิ่นของภูมิภาคเอเชียตะวันออกเฉียงใต้ วัตถุประสงค์ของการศึกษาเพื่อจำแนกการเลือกลักษณะแหล่งที่อยู่อาศัยของเต่าเหลือง ในสถานีวิจัยสิ่งแวดล้อมสะแกราช ระหว่างเดือนมีนาคม พ.ศ. 2559 ถึง เดือนกันยายน พ.ศ. 2561 ซึ่งได้ทำการติดวิทยุติดตาม (radio-telemetry) เต่าเหลืองจำนวน 17 ตัว โดยแต่ละตัวจะใช้วิธี Euclidean distance analysis (EDA), compositional analysis (CA) และ Manly's selection ratio (Manly's) เพื่อวิเคราะห์ลักษณะภูมิประเทศและขนาดพื้นที่หากินของเต่าเหลือง การเลือกแหล่งที่อยู่ตามฤดูกาลจะทำการประเมินเต่าเหลืองทุกตัว โดยใช้การวิเคราะห์แบบ CA และ Manly's สำหรับการวิเคราะห์แบบ EDA จะใช้ สำหรับการวิเคราะห์ลักษณะภูมิประเทศที่พบเต่าเหลืองบริเวณป่าเต็งรังและวิเคราะห์ขนาดพื้นที่หากินของเต่าเหลืองบริเวณป่าดิบแล้ง ในขณะที่การวิเคราะห์แบบ CA และ Manly's จะใช้วิเคราะห์ลักษณะภูมิประเทศที่พบเต่าเหลืองบริเวณชายขอบป่าและวิเคราะห์ขนาดพื้นที่หากินของเต่าเหลืองบริเวณป่าดิบแล้งตลอดทั้งปี ในช่วงฤดูแล้ง การวิเคราะห์แบบ CA และ Manly's จะใช้วิเคราะห์ลักษณะของภูมิประเทศที่พบเต่าเหลืองบริเวณชายขอบป่าและวิเคราะห์ขนาดพื้นที่หากินของเต่าเหลืองบริเวณป่าดิบแล้ง ช่วงฤดูฝนการวิเคราะห์แบบ CA และ Manly's จะใช้วิเคราะห์ลักษณะภูมิประเทศที่พบเต่าเหลืองบริเวณป่าเต็งรังและสำหรับขนาดพื้นที่หากินของเต่าเหลือง โดยใช้การวิเคราะห์แบบ CA พบว่าขนาดพื้นที่หากินของเต่าเหลืองเป็นแบบสุ่มในขณะเดียวกันการวิเคราะห์แบบ Manly's พบว่าขนาดพื้นที่หากินของเต่าเหลืองบริเวณป่าเต็งรังนั้นมีขนาดเล็กและในช่วงฤดูหนาวพบว่า เต่าเหลืองเลือกใช้พื้นที่เฉพาะบริเวณชายขอบป่าซึ่งได้จากการวิเคราะห์แบบ Manly's เต่าเหลืองในสถานีวิจัยสิ่งแวดล้อมสะแกราช มีการเลือกพื้นที่ที่อยู่อาศัยที่

แตกต่างกันเพื่อรับมือกับสภาพอากาศที่มีการเปลี่ยนแปลงตามฤดูกาลและทรัพยากรที่มีอยู่ โดยลักษณะของแหล่งที่อยู่อาศัยทั้ง 3 รูปแบบนั้นมีความสำคัญต่อเต่าเหลือง ซึ่งจะขึ้นอยู่กับทั้งฤดูกาลและขนาดของพื้นที่ การศึกษาครั้งนี้ชี้ให้เห็นถึงความต้องการในการจัดการพื้นที่ ซึ่งได้มีการพิจารณาและดำรงซึ่งความหลากหลายของพื้นที่ที่อยู่อาศัยและเพื่อความอยู่รอดของเต่าเหลือง จากการศึกษาพบว่าความแตกต่างของการเลือกพื้นที่ที่อยู่อาศัยของเต่าเหลืองขึ้นอยู่กับฤดูกาลและขนาดพื้นที่

สาขาวิชาชีววิทยา　　　ลายมือชื่อนักศึกษา____________________

ปีการศึกษา 2561　　　ลายมือชื่ออาจารย์ที่ปรึกษา____________________

YSABELLA G. MONTAÑO : HABITAT SELECTION OF ELONGATED TORTOISES (*INDOTESTUDO ELONGATA*) IN SAKAERAT BIOSPHERE RESERVE, NORTHEAST THAILAND.
THESIS ADVISOR : COLIN THOMAS STRINE, Ph.D. 65 PP.

ELONGATED TORTOISE / HABITAT SELECTION / COMPOSITIONAL ANALYSIS/ MANLY'S SELECTION RATIO / EUCLIDEAN DISTANCE / SEASONAL

Habitat loss and fragmentation associated with anthropogenic changes are two of the main forces that threaten biodiversity. Understanding the habitat requirements of a species is essential in establishing adequate conservation strategies. It provides information on environmental characteristics needed for a species to meet the requirements to survive and thrive, especially in threatened species. The elongated tortoise (*Indotestudo elongata*) is an endangered species native to southeast Asia. This study aims to identify the forest habitat types which *I. elongata* is selecting for inside Sakaerat Biosphere Reserve (SBR). Between March 2016 and September 2018, 17 tortoises were tracked using radio-telemetry. Each individual was analyzed using Euclidean distance analysis (EDA), compositional analysis (CA), and Manly's selection ratio (Manly's) at the landscape and home range scales. Seasonal habitat selection was assessed for all individuals within both scales using CA and Manly's. EDA detected selection for dry dipterocarp forest at the landscape scale and dry evergreen forest at the home range scale. CA and Manly's detected selection for edge habitat at the landscape scale and dry evergreen forest at the home range scale across the year. During the hot season, CA and Manly's detected selection for edge habitat at the landscape scale and dry evergreen forest at the home range scale. During the wet season, CA and Manly's detected selection for dry dipterocarp forest at the landscape scale. At the home range scale, CA detected random selection while Manly's showed weak selection for dry dipterocarp forest. During the cold season, there was only selection for edge habitat at the landscape scale with Manly's. Elongated tortoises in SBR require multiple different habitat types to cope with seasonal variation in weather and resource availability. Each of the three habitat types has importance to the species depending on season and scale. This study highlights that management needs to consider maintaining multiple habitats for species survival, as illustrated by the difference in selection within season and scale.

School of Biology Student's Signature____________________

Academic Year 2018 Advisor's Signature____________________

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Ysabella G. Montaño

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CHAPTER I

INTRODUCTION

1.1 Background and Problems

Habitat loss and fragmentation associated with anthropogenic changes are two of the main forces that threaten biodiversity (DeGregorio et al., 2011). The increase of human population and human activities have resulted in rapid and massive structural and chemical changes to the natural environment (Hoekstra et al., 2005). Leading to the direct destruction and fragmentation of habitats resulting in the formation of varied landscapes which include remnants of the original habitats and also areas of development for human populations (Rojas-Morales, 2012). Understanding the habitat requirements of a species is essential in establishing adequate conservation strategies. It provides information on environmental characteristics needed for a species to meet the requirements to survive and thrive, especially in threatened species.

Understanding habitat requirements is crucial in constructing effective conservation actions. Using radio telemetered individuals and visually observed locations of individual animals can gather key data for habitat selection analysis (Manly et al., 2002). The data collected in this manner is of location and habitat type. Categorical, temporal and spatial data which is analyzed through one (or more) of a few methods to create rankings and/or weightings of selection preference in these habitat types recorded. DeGregorio et al. (2011) and Miller et al. (2012) used both compositional analysis and Euclidean distance approach to assess habitat selection at the landscape and home range levels. Compositional analysis (CA) is a classification based approach in analyzing the proportion of habitats used relative to proportion of habitats available (Aebischer et al., 1993). Euclidean Distance Analysis (EDA) is a distance-based approach comparing distances between animal locations and the nearest representative of each habitat type (DeGregorio et al., 2011). DeGregorio et al. (2011) was able to detect that his study species were making habitat selection choices on different spatial scales. There are classically 4 spatial scales in the study of habitat selection; the geographical range of a species (geographic scale), the home range of a species within a study area (landscape scale), within the home range of a species (home range scale) and the foraging and resource sites (microhabitat scale) of a species (Johnson, 1980). DeGregorio et al. (2011) results showed that the two methods of analysis performed differently at the landscape and home range scale. CA works well at the landscape level while EDA is more advantageous on finer scales. He suggests combining the two methods when assessing habitat selection at different spatial scales (DeGregorio et al., 2011). Another habitat selection analysis option is the Manly's selection ratio, a computation of selection ratios for habitat selection (Calenge and Basille, 2017). Using program R the selection ratio (named Wides in the adehabitat HS package) measures the ratio of availability against usage in habitat or microhabitat features. Wides II measures the habitat selection at the landscape scale with Wides III measuring the habitat selection within the home range scale (Calenge and Basille, 2017). My study will be using these techniques to explore habitat selection along the landscape and home range scales of the individuals.

The Elongated tortoise (*Indotestduo elongata*), listed as endangered in the IUCN Red List of threatened species, is a medium sized tropical tortoise species found over a wide geographic range of southern and Southeast Asia (IUCN, 2016). Its population levels and ecology are little known with few studies ever conducted on the species across its large range. A quick "Science Direct" web journal search for the species lead to only 23 results. Of these articles, nine were related to phylogenetics and only briefly mention the species (if at all), six were related to trade and were generalist in Southeast Asia trade concerns, and the rest were not related at all to the species. Actual studies on the species are sparse and largely unhelpful with regard to wild ecology or conservation as they used either translocated individuals from trade seizures, captive animals (or from highly disturbed areas) or short term seasonal studies in addition to natural history notes (Van Dijk, 1998; Ihlow et al., 2014; Ihlow et al., 2016). Many of the habitats that *I. elongata* is known to utilize within its range are endemic to the region, such as the dipterocarp forests which are preferred by the species in India, Thailand and Cambodia (Sriprateep et al., 2013; Ihlow et al., 2016).

This study aims to identify the forest habitat types which *I. elongata* is actively selecting for inside the Sakaerat Biosphere Reserve (SBR). This would highlight direct requirements within regional habitats for the species and steer conservation guidelines to better protect the species extant range and future growth. The critical information around the habitat selections and requirements of *I. elongata* will develop the knowledge of the species ecology and habitat availability throughout its range (Wilson et al., 2009). My study will focus on a population of *I. elongata* in northeast Thailand within a protected biosphere reserve however the data and resulting conclusions garnered will be comparable and applicable to the species across its range which share the aforementioned habitats.

1.2 Research Objectives

1.2.1 Determine if there is non-random habitat selection by *I. elongata* at the home range and landscape scales.

1.2.2 Determine if variation in habitat selection of *I. elongata* is observed between seasons.

1.2.3 Compare results between the habitat selection analyses (Compositional analysis, Manly's selection ratio, and Euclidian distance analysis).

1.3 Research Hypotheses

1.3.1 Adult *I. elongata* will non-randomly select dry dipterocarp forest as preferred habitat type. Because of the multiple available shelter types and dense vegetative cover attributed to the bamboo grass within this habitat type.

1.3.2 There will be significant seasonal variation in the habitat types selected for by *I. elongata.*

1.3.3 Hot season will see non-random selection for dry evergreen forest (DEF) over other forest types. The temperature and humidity is more consistent within this habitat type and does not reach extremes as other habitats (Ihlow et al., 2016).

1.3.4 Wet season will see non-random selection for dry dipterocarp forest (DDF). Wet season produces milder temperatures and preferred shelter and food resources available (van Djik, 1998).

1.4 Scope and Limitations of the Study

Field research was conducted in two sample sessions from March 2016 to March 2017, and October 2017 to September 2018, within the core area of SBR. Seventeen adult female *I. elongata* were located using radio-telemetry, 10 individuals within the first sample (5 males, 5 females) and 7 further female individuals in the second sample. Females were selected in the second sample to limit variables which may have affected habitat selection and movement and maximize the sex sample size. Using females over males also allowed for the inclusion of important nesting habitat, a key habitat feature for the species which may not be apparent when studying males. This study took place in dry dipterocarp forest (DDF), dry evergreen forest (DEF), edge habitats (Edge) and stream beds during all annual seasons. Data collection focused on habitat types and the abiotic factors; rainfall, temperature (maximum and minimum), and humidity, and individual UTM GPS locations. Tracking and data collection took place 3-4 times per week, however times of heavy rain and humidity limited tracking because of the potential damage to equipment. The study focused on the landscape and home range scales of habitat selection. Using three primary analyses to measure selection; compositional analysis (CA), Euclidean distance analysis (EDA) and Manly's selection ratios (Manly's).

CHAPTER II

LITERATURE REVIEW

2.1 Habitat Selection

Habitat selection, defined as "the disproportionate use of resources or conditions by living things", is an important aspect of ecology (Mayor et al., 2009). It is often studied to provide information on environmental characteristics needed by wildlife and determine how important a habitat is for a species (Calenge, 2007). This is critical for wildlife management and species conservation. Habitat is defined by Hall et al. (1997) as the "conditions and resources present in an area that produce occupancy (including survival and reproduction) by an organism". Habitat selection requires the comparison of the environmental composition of the location where a species is present with the environmental composition of the location where a given species is absent. However, determining species absence in a site may be difficult if a species has low detection probability. Therefore, the analysis of habitat selection relies on comparing sites where the species is present with available sites where the species presence is uncertain (Calenge, 2007).

Ecologists have long studied how environmental factors and structures affect the distribution, abundance, and fitness of individuals within a species. Johnson (1980) defined four orders of habitat selection at different scales: 1) physical or geographical range of a species, 2) within that, the home range of a species (landscape level), 3) usage of habitat components within the home range (home range level), and 4) food items at foraging sites. Habitat selection can be assessed at these different spatial scales by measuring components of habitat types or by determining the usage and availability of vegetation and shelter sites (Johnson, 1980). Studies have shown that animals select habitat differently depending on the scale examined (Steen et al., 2010; DeGregorio et al., 2011; Miller et al., 2012; Falconi et al., 2015).

2.1.1 Compositional Analysis

Compositional analysis (CA) is a method of habitat selection for several animals when resources are defined as categorical vegetative types (Calenge and Basille, 2017). Barbaro et al. (2008) used CA to assess the habitat selection of Eurasian hoopoe (*Upupa epops*) at the landscape and home range scales. At the landscape scale Barbaro et al. (2008) discovered that hoopoe breeding pairs selected heterogeneous parts of the landscape. They showed preference for deciduous woodland, hedgerow and meadow with avoidance of mature pine plantations. At the home range level there was positive selection of the sand tracks and deciduous woodlands and hedgerows too (Barbaro et al., 2008). Further CA use can be seen in Greenspan et al. (2015) in a study to identify the habitat selection of the eastern box turtle (*Terrapene carolina carolina*) in the southeastern coastal plains of the USA. The proportion of mixed pine-hardwood forests was greater inside home ranges than expected according to availability. Agricultural landscapes, aquatic habitats pine plantations and scrub habitat were all used significantly less than available (Greenspan et al., 2015). John and Kostkan (2009) used CA for the study of habitat selection in the European beaver (*Castor fiber*) in the Morava River, Czech Republic. Instead of using radio telemetry for known locations of beaver, the team used signs of beaver presence along the river. Even using sign over known telemetry locations John and Kostkan (2009) found that there was selection within the landscape level. They conclude that beavers non-randomly selected home range sites along a river around riverine willow scrub and willow-poplar forests as preferred habitats.

2.1.2 Euclidean Distance Analysis

Euclidean distance analysis (EDA) is a multivariate technique comparing Euclidean distances between animal locations and habitats to the expected distances derived from random locations (Millspaugh and Marzluff, 2001). Euclidean distance analysis can also be used over multiple scales and is considered to be a suitable method when incorporating edge habitats and fragmented habitat (Menzel et al., 2005). Using radio telemetry data collection many analyses run into the problem of type 1 errors, the use of EDA can reduce this along with the use of fragmented landscapes (Bingham and Brennan, 2004; Menzel et al., 2005). Menzel et al. (2005) used EDA to identify the foraging habitat selection of the Indiana bat (*Myotis sodalist*) in central lowlands of Illinois, USA. They discovered that the bats concentrated foraging in forested areas rather than over grassland or agricultural areas. Roads were also significantly used highest as foraging/travelling locations over all other habitat types. Conner et al. (2003) also used EDA as a way to assess the habitat selection of telemetered Northern Bobwhite quail (*Colinus virginianus*). Habitat selection was measured at the home range level and using the EDA technique non-random selection was identified. Using the pairwise significance testing woody vegetation around roadways, fences and ditches were significantly selected for against other habitats, with crop fields having lowest preference (Conner et al., 2003). Within tortoise habitat selection Rozylowicz and Popescu (2012) used EDA at the landscape and home range scales for the habitat selection of the eastern Hermann's tortoise (*Testudo hermanni boettgeri*). At the landscape scale they discovered that the tortoises non-randomly selected for grassland and shrub habitats, avoiding creeks. Within the home range scale there was still selection for grassland and shrub habitat with avoidance of creeks again but also an avoidance of forests (Rozylowicz and Popescu, 2012).

2.1.3 Manly's Selection Ratio

Manly's selection ratio or the Wides series of selection functions in program R (package adehabitat HS) measures selection through used against available area. In design 2 (Wides II) measuring the landscape scale habitat selection, the selection ratios work under the assumption that all individuals have the same available habitat ratios (study area). It is the individual home ranges that create individual specific used habitat area ratios. In design 3 (Wides III) the proportion of locations within each habitat type inside the individuals' home range is compared against the proportional area of those habitat types (home range) (Manly et al., 2002). Resulting in different proportional areas of availability for each individual (Calenge, 2007). Walters et al. (2016) used Manly's selection ratio to investigate the habitat selection of Burmese pythons in Florida. They discovered that there was non-random selection for broad-leafed and coniferous forest with avoidance of open water habitats. This was revealed to be selection for habitats in a greater proportion outside of the dominant marsh habitats found in the area (Walters et al., 2016).

2.2 Applications of Radio-telemetry to Habitat Selection

Assessing the habitat selection for a number of species requires habitat-use data obtained through radio-telemetry (Rettie and McLoughlin, 1993). These studies provide insights on how animals utilize different habitats (Kneib et al., 2007). Radio-telemetry is a common tool for investigating home range size, habitat use and movement patterns in species which are hard to observe. The technique has been used previously on multiple chelonia species including the *I. elongata* (Ihlow et al., 2014). Telemetry is a suitable technique for habitat selection in particular as the method allows researchers to get detailed information about habitat their species select for (Deepak et al., 2016).

The use of radio-telemetry has been applied to several studies of habitat selection in tortoises. Deepak et al. (2016) radio tracked the Travancore tortoise (*Indotestudo travancorica*) in Western Ghats, India, to identify their habitat selection. This study however used generalized linear mixed-effect modeling to differentiate the selected habitats and micro-habitat elements within their study area. Guzman and Stevenson (2008) studied the seed dispersal, habitat selection and movement patterns of the Amazonian tortoise *Geochelone denticulate* using radio telemetry. They found strong preferences for specific habitat types, within both *terra firma* forest types and floodplain forest types. The *terra firma* forest types actively selected for included bamboo grasslands, avoiding mature forests. With floodplain individuals selecting for open canopy swamp forest and active avoidance of flooded palm forests (Guzman and Stevenson, 2008). Rozylowicz and Pobescu (2012) used radio telemetry to identify the habitat selection of the eastern Herman's tortoise (*Testudo hermanni boettgeri*) at the landscape and home range scale. Using the EDA method they discovered strong selection at the landscape scale for grassland habitat and forest edges, with avoidance of creeks. At the home range scale there was also selection for grasslands and shrub lands with road features occurring at a higher than expected frequency. This study concluded that there was a preference for grasslands within this species and an avoidance of creeks and forests, helping to steer land management activities for species conservation (Rozylowicz and Pobescu, 2012).

2.3 Tortoise and Turtle Conservation in Asia

There are 452 species and subspecies of chelonia (tortoises and turtles) occupying the temperate and tropical realms of the world today (Buhlmann, 2009; Rhodin et al., 2010). Chelonians are one of the most endangered vertebrates with 10% of chelonian species listed as critically endangered and between 40-60% of all other chelonia species threatened with extinction (Turtle Conservation Coalition, 2011). Most chelonian species face threats from anthropogenic causes including direct harvesting, legal and illegal trade, habitat degradation, and habitat loss (Asian Turtle Conservation Network, 2006). Asian chelonia are especially threatened from exploitation and habitat degradation, leading to sharp declines in populations. Without immediate direct conservation actions the chelonia diversity of Asia and the rest of the world will be severely depleted within the current century (Buhlmann et al., 2009).

The illegal and unregulated legal trade in wild species is a major concern for global biodiversity, with a large portion of wildlife trade regarding tropical species for use as exotic pets (Nijman and Shepherd, 2014). Freshwater turtles and tortoises are an increasingly seen commodity within international trade for the pet market but are also commodities within international food and traditional medicine markets (Nijman and Shepherd, 2014). The extent of trade in Asian chelonia is affecting wild populations so much it has been termed a crisis for the taxa (Nijman and Shepherd, 2014). During surveys between 2000-2003 Cheung and Dudgeon (2006) recorded one million individuals from 157 species of chelonia in 3 cities of southern China with 46%

threatened species. The largest numbers of individuals were located in food markets with Asian turtles comprising the most numerous. Nijman and Shepherd (2014) also identified 1,235 individuals of 20 globally threatened species of tropical chelonia in one pet market in Thailand over a ten year period. Some of the rarest species of turtle are regularly observed in such markets (Nijman and Shepherd, 2014). As the majority of species used within Asian food and medicine markets are of Asian origin this presents a significant conservation problem. Unregulated trade and illegal poaching are reducing populations of already threatened species, however many of these species remain unknown to science regarding their population health, ecology and life history, being found predominantly (or exclusively) in trade (Zhou and Jiang, 2008; Ly et al., 2011).

2.4 Study Species

The elongated tortoise or *Indotestudo elongata* is a medium sized tortoise reaching straight carapace lengths (SCL) between 280 mm to 360 mm (Ihlow et al., 2016). The carapace is highly domed, elongated (especially within males) and yellow, olive or brown in color with distinct black blotches in the center of each scute (Figure 2.1). Both males and females develop pink coloration to the nose, ears and eyes during breeding seasons as blood accumulates in the organs (Sriprateep et al., 2013).

Figure 2.1 Morphology and patterning of an adult male *I. elongata*.

The elongated tortoise has a wide distribution across Southeast Asia (Figure 2.2) and are predominantly in lowlands and foothills up to 1000 m above sea level but not observed at higher elevations (Hartmann et al., 2013). Elongated tortoises inhabit a range of habitats including open deciduous, dipterocarp, mountainous and hilly evergreen, mixed semi-evergreen, bamboo, pine, and secondary forests; as well as savannah grasslands and dry thorn scrub (Ihlow et al., 2016). In Thailand, the species has been found largely in monsoonal evergreen and deciduous forest (van Dijk, 1998). Within these habitats tortoises shelter in vegetation, fallen trees, boulder caves and burrows, but they appear to show a preference for utilizing dense grasses and fallen tree trunks (van Dijk, 1998; Ward et al., unpublished data). In evergreen forests in Laos, tortoises were observed sheltering under bamboo, dense bushes beneath pine trees, fallen tree trunks, and thick grasses (Som and Cottet, 2016). Some studies suggest the species is less active and appears to aestivate during the dry season, however other studies, including Ward et al. (unpublished data) have identified activity in dry seasons during occasions of rain (Ihlow et al., 2016).

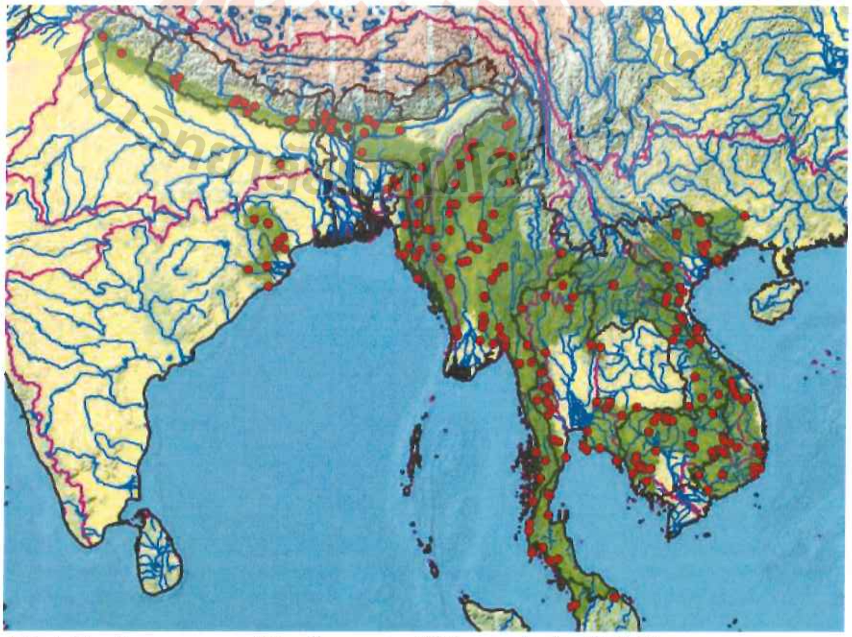

Figure 2.2 Distribution map of *I. elongata* (Ihlow et al., 2016).

Home ranges of the *I. elongata* have been recorded for animals in Cambodia, Thailand and Laos. In Cambodia home ranges were documented between 3.8 and 41.5 ha averaging 16.8 ha (Ihlow et al., 2014). Home ranges of tortoises in western Thailand varied between 8.0 and 70.0 ha with an average of 26.5 ha (Tharapoom, 1996). Tortoises in Laos maintained home ranges between 0.7 and 19.4 ha and a mean of 5.5 ha (Ihlow, 2016). All studies identified home ranges to be significantly larger during the wet season correlating with an increase in activity, movement and breeding.

Despite having a wide distribution *I. elongata* has undergone severe population declines in relation to anthropogenic factors. Thirakhupt and van Dijk (1995) documented the presence of *I. elongata* in the forests of western Thailand but reported massive declines in populations within a 10-15 year period. Vietnamese and Cambodian populations have been severely depleted through habitat degradation and harvesting since 1990 that there are expected regional extinctions and few secure populations remaining (Holloway, 2003; Ihlow et al., 2016). *Indotestudo elongata* is heavily exploited for food and medicine trade across its range with the species being collected for local use and exported internationally for wildlife trade (Holloway, 2003). In the late 1990s, *I. elongata* was suggested to be the most common chelonian in the Asian wildlife trade (Shepherd C.R. pers. comm.). Le and Broad (1995) studied the levels of wildlife trade in Vietnamese markets and estimated that over 500 kg of *I. elongata* were sold daily in Ho Chi Minh City. The species has also been observed within Chinese markets and at the height of its popularity was frequently seen across markets of China, Thailand, Cambodia and Vietnam for food, medicine and exotic pet trades (Holloway, 2003; Cheung and Dudgeon, 2006; Nijman and Shepherd, 2007).

As with many species in Southeast Asia, *I. elongata* is heavily affected by habitat degradation, fragmentation, and destruction. Southeast Asia is experiencing high rates of deforestation (Sodhi et al., 2004; Ihlow et al., 2016). The lowland habitats that are suitable for *I. elongata* are being converted for agricultural use or plantations. Biswas et al. (1978) suggested that the decline of *I. elongata* in eastern India was due to dipterocarp forest loss. *I. elongata* appear to be absent from highly disturbed areas such as the Indo-Gangetic Plain of India, the Chao Phraya region in central Thailand, and the Khorat Plateau in northeastern Thailand (Ihlow et al., 2016). Whether this is from active avoidance or extirpation through harvesting is unknown but it is unlikely to be reversed in the near future.

Indotestudo elongata was included in the "Global Action Plan for the Conservation of Tortoises and Freshwater Turtles" of the Turtle Conservation Fund after being declared endangered by the IUCN Red List in 2000 (Turtle Conservation Fund, 2002). Elongated tortoises are protected by national legislation in most countries that the species inhabit, however hunting of tortoises within protected areas and legal trade of the species continue to persist (van Dijk, 1998; Ihlow et al., 2014).

2.5 Sakaerat Biosphere Reserve

The study area covers the Sakaerat Environmental Research Station (SERS) and its surrounding landscape. SERS is situated in Nakhon Ratchasima Province, northeast Thailand at latitude 14°25'−14°33' N and longitude 100°48'−100°56' E (Figure 2.3; Ongsomwang and Sutthivanich, 2013). Sakaerat Environmental Research Station is located in a region called the Korat plateau at an altitude range of 250-762 m above sea level. This research station is part of Sakaerat Biosphere Reserve (SBR), one of four biosphere reserves in Thailand designed to promote long term ecological research, sustainable forest management and conserving biodiversity (Trisurat, 2010). Biosphere reserves are designated according to the UNESCO Man and Biosphere Programme (Ongsomwang and Sutthivanich, 2013). Biosphere reserves are separated into three distinct zones; Transition zone, Buffer zone and Core zone (Figure 2.3) delineating areas of varied activity. The Core of the SBR containing 7800 ha is the location for SERS, where strict human activity is limited to research and education. It is also listed as one of the two international long-term ecological research sites in Thailand, established in September 1967 by the applied Scientific Research Corporation of Thailand and currently operated by the Thailand Institute of Science and Technological Research (Thanee et al., 2009; Ongsomwang and Sutthivanich, 2013). The dominant forest types within the core zone surrounding SERS landscape are dry evergreen forest (60%), dry dipterocarp forest (18%), patches of bamboo forest (<3%) and plantation regrowth forest (18%) (Trisurat, 2010). The climate of SERS is similar to other areas of Thailand with the identical elevation. Northeast Thailand however has three distinct seasons of Cold season, Wet season, and Hot season. Winter or Cold seasons are typically between November to February, Hot season is from March to June with Rain or Wet season coming in June until October (Chokngamwong and Chiu, 2008). These seasonal classifications are supported by the annual changes in temperature and rainfall. Somrithipol et al. (2006) identified the highest temperatures in SERS are between March to May, with rainfall at its peak in September to October and the lowest temperatures between December and January.

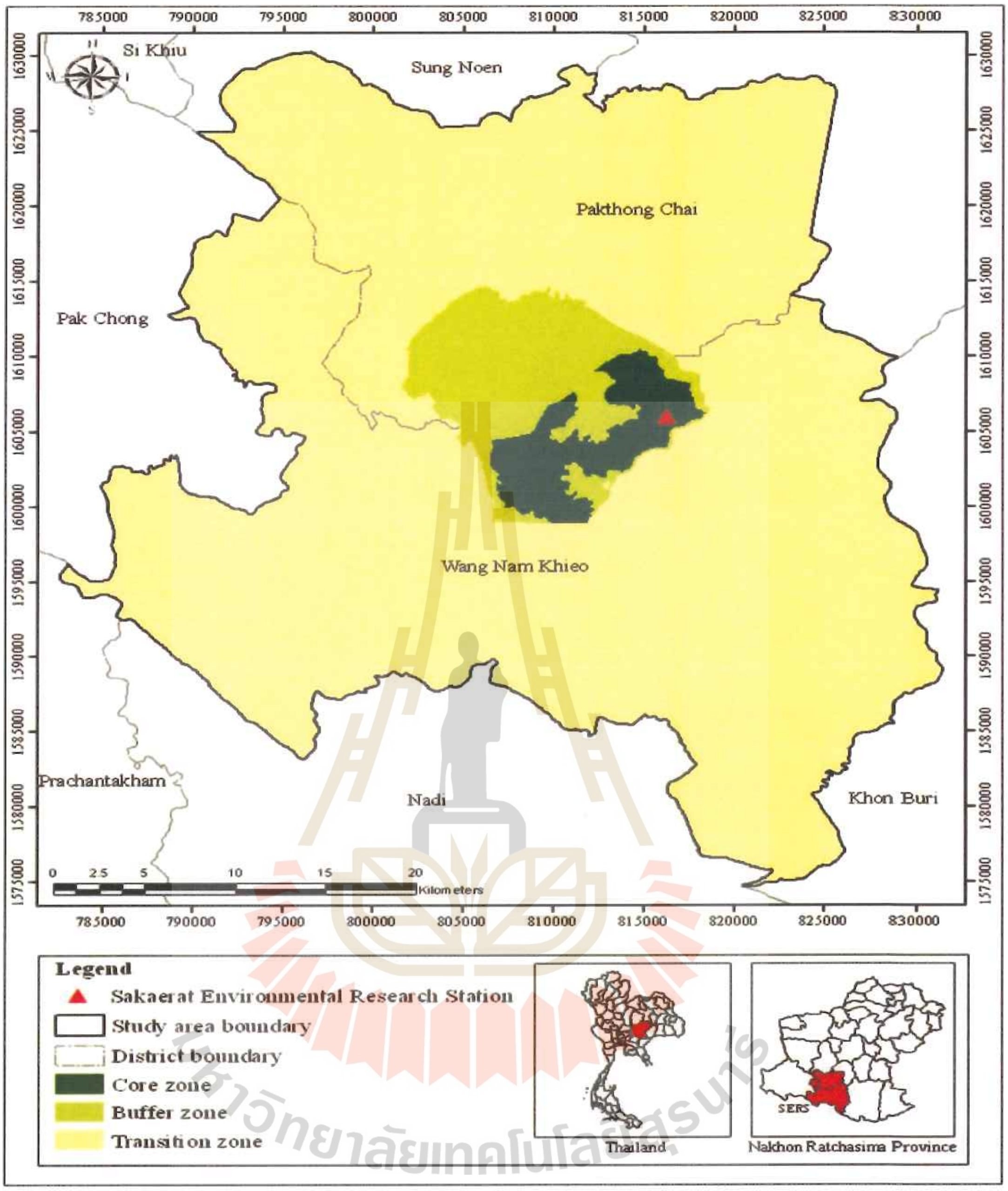

Figure 2.3 Sakaerat Biosphere Reserve and the three (Transition, Buffer and Core) zones it comprises (Omsomwang and Sutthivanich, 2013).

CHAPTER III

MATERIALS AND METHODS

3.1 Study Site

The study was conducted within Sakaerat Environmental Research Station (SERS) in the core zone of Sakaerat Biosphere Reserve (SBR) (Figure 3.1). The core area is 7,800 ha and is composed of 18% dry dipterocarp forest (DDF) and 60% dry evergreen forest (DEF) with <18% plantation regrowth forest (PRF), and fragments of bamboo forests (BBF) and grassland. The core area of SERS was selected as the study site as there were recorded sightings of the *I. elongata* from other research teams, including a simultaneous *I. elongata* study. The core area is designated for conservation, research and education purposes only. Meaning that the animals within this area are less likely to be affected by interference of poaching efforts from humans and more likely to express natural behaviors in the largely undisturbed forests of this area. The study site used here is exactly 306.19 ha of DDF, DEF, and edge habitat (Edge) within the core zone (Figure 3.2). The edge habitat is defined as the boundary point between the DEF and DDF. It is measured as 15 m both sides of the boundary according to the GIS layers of the site. At the study site there are three habitats represented with proportional area coverage of DDF 51%, DEF 42%, and Edge 7%. The study site was constructed by creating a polygon around the combined tortoise locations and adding a buffer of 40 m outside these points.

Figure 3.1 Map of Sakaerat Biosphere Reserve depicting the core, buffer, and transition zones.

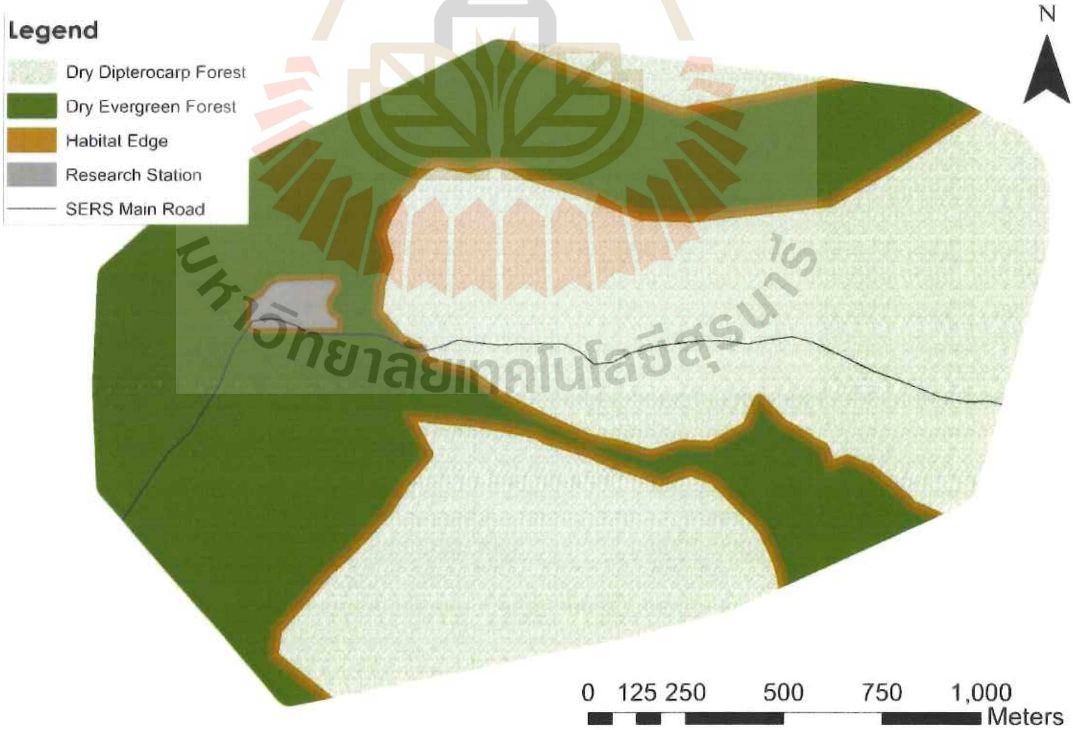

Figure 3.2 Map of study site including the three habitat types being assessed.

3.2 Study Animals

I caught seventeen adult tortoises (5 males, 12 females) for the study. All individuals were above 1 kg in weight with a mean weight of 1.84 kg for males and 1.74 kg for females and a range of 1.1 kg – 2.1 kg within each sex. One female individual was used in both sample sessions. After comparing her locations and home ranges across the samples there was no significant difference (S1: 23 ha, S2: 24 ha) in area or location. Her combined location points were used to create a combined home range and in the habitat selection analysis. Three further individuals were caught and had transmitters attached (1 male, 2 females) however they were removed from the study for multiple reasons. The one male individual (M2) was removed as he became injured and lost many of his scutes in a forest fire damage. One female (F7) had transmitter failure which required her to be removed part way through the year and the final female (F13) was lost without relocation outside of the study area (Table 3.1).

Table 3.1 Study animals with their biometric information, number of days tracked and number of relocations.

Tortoise ID	Sex	Body Length (cm)	Body Mass (kg)	No. Days Tracked	No. of Relocations
M1	Male	26.1	2.05	134	105
M2	Male	23.9	1.48	28	18
M3	Male	24.8	1.84	133	87
M4	Male	23.8	1.78	131	116
M5	Male	23.2	1.56	134	111
M6	Male	25.8	1.98	93	80

Table 3.1 Study animals with their biometric information, number of days tracked and number of relocations (Continued).

Tortoise ID	Sex	Body Length (cm)	Body Mass (kg)	No. Days Tracked	No. of Relocations
F1	Female	23.3	1.54	139	107
F2	Female	23.0	1.87	124	94
F3	Female	23.7	1.82	130	114
F4	Female	24.1	1.80	134	124
F5	Female	24.4	1.80	227	206
F6	Female	24.3	1.51	89	82
F7	Female	23.2	1.75	49	43
F8	Female	24.2	2.03	96	89
F9	Female	23.7	1.71	97	92
F10	Female	22.6	1.66	84	70
F12	Female	26.3	2.07	80	66
F13	Female	19.2	1.19	38	28
F14	Female	20.4	1.17	82	71
F15	Female	21.9	1.52	83	53

3.3 Radio-Telemetry

I adhered radio transmitters (Figure 3.3) to the anterior costal scutes of the study tortoises' carapaces using epoxy adhesive resin with this technique being preferable for tortoise telemetry studies (Ihlow et al., 2014; Deepak et al., 2016). The 9g Ri-2B radio transmitters from Holohil inc. are <5% of the tortoise's body mass and suitable for use according to the common 5% rule in minimizing external attachment weights on study animals. All tortoises were fitted with the radio transmitters, with the transmitter and antenna adhered to the anterior portion of the carapace so that it does not interfere with breeding. Tortoises were located using a portable radio telemetry receiver and a handheld collapsible antenna. Each animal was tracked approximately once every two days with each tracking session locating the animal to either its exact spot, confirmed visually, or within a 2m radius of the animal location. The tortoises' positions were recorded using a handheld Garmin 64sMap GPS unit and uploaded into the free Garmin mapping software Basecamp and ArcGIS.

Figure 3.3 Transmitter attachment to tortoise carapace using epoxy resin.

3.4 Data Collection

Data was collected on an iPad mini with the mobile data collection app epiCollect 5. The recorded data included; the day, individual tortoise, movement from last location with the new GPS coordinates, along with weather data, macro-habitat data (the main habitat type, i.e. DDF, DEF, Edge etc.) and micro-habitat (habitat features surrounding its current location such as shelter types within 5 m radius of the animal). Locations were collected using a Garmin 64map handheld GPS in datum WGS84 with UTM coordinates. GPS coordinates were used to construct home range MCPs in ArcGIS for the entire tracking period and for each season within the tracking period. Seasons were denoted monthly according to Chokngamwong and Chiu (2008) as either cold season (November-February), hot season (March-June) or wet season (July-October).

3.5 Habitat Selection

To determine whether non-random selection is occurring with the habitats, locations for the 17 telemetered tortoises were compared with available habitats. To assess differences in the scale of habitat selection, comparisons were conducted within minimum convex polygons (100% MCPs) home ranges (Croak et al., 2013; Walters et al., 2016) and between the MCP home ranges and the study area. MCPs were generated in ArcGIS in ArcMap 10.0. Each individual were analyzed using three methods of habitat selection analysis (Compositional analysis, Euclidean distance analysis, and Manly's Selection Ratio) at the landscape and home range scales (Type 2 and 3). Seasonal habitat selection was assessed for all individuals within both scales using compositional analysis and Manly's selection ratio, using seasonally specific home range MCPs and locations for this analysis.

3.6 Analyses

All analyses were conducted in program R. Compositional analysis and Manly's Selection Ratio used the package adehabitat HS. In order to identify whether habitat types were being selected for at a greater proportion than available, I used Chi-squared and Wilcox tests and analyzed the proportion of each habitat type within the tortoise's home range according to the habitats with the most locations. This was conducted for the entire study period, to identify primary habitat type preference, and further within different seasons, to identify any variation in seasonal selection.

3.6.1 Home Range Estimation

The home ranges of each individual were constructed using UTM WGS84 coordinates, area measured in hectares (ha) and graphical representation in ArcGIS software ArcMap 10.1. Home ranges were made using 100% MCPs, encompassing all locations for the individual across the study period after filtering out points for potential mistakes or unexplained outliers. These home ranges were used for the subsequent habitat selection analyses.

3.6.2 Compositional Analysis

For analysis of habitats with compositional analysis (CA) program R is used within the package adehabitat HS and function "compana". As a habitat selection method, CA assesses non-random habitat use through two steps. The significance of habitat selection is tested through a Wilks lambda before a ranking matrix is built to indicate whether each habitat type is significantly used more or less that another

(Calenge, 2017). Each habitat type used in the analysis needs to be positively present in the available habitats, however not every available habitat is required to be used. If zero values are found within a used habitats they are replaced by 0.01 values within the analysis function.

3.6.3 Euclidean Distance Analysis

Euclidean distance analysis measures habitat selection through comparing the Euclidean distances between individual locations and habitats against the distances between said habitats and random locations. Based on these Euclidean distances a vector of ratios of the distances from selected locations and random locations was created. A MANOVA was then used to determine whether these ratios differ significantly from 1. Pairwise Wilcox significance tests was used to identify which habitats were used non-randomly, to a significantly disproportionate level (Conner et al., 2003; Menzel et al., 2005). Comparing the expected random points created through simulations and the distances of these points to the categorized habitats, with the known locations of tortoises and their subsequent distance, creates a selection ratio against all available habitats. This identity of point location relating to all available habitats can be argued to better represent fine scale selection toward certain habitat types where known locations are not present because of sampling intervals or errors in habitat categorization (Conner et al., 2003).

3.6.4 Manly's Selection Ratio

The Manly's Selection Ratio identifies habitat selection through the proportional use of habitats over availability. At the landscape level, the proportional area of the different habitats within a 100% MCP home range of an individual were compared with the proportional area of the same habitats within the entire study area

(Calenge and Basille, 2017). For each individual the study area proportions are equal. At the home range level, the proportional number of locations within each habitat inside the MCP, were compared against the proportional area of each habitat inside the MCP (Calenge and Basille, 2017). Each individual here had separate proportional area available according to their home ranges with the proportions of locations being used. Within the package adehabitatHS, the function Wides type II (for landscape level) and type III (for home range level) were used to analyze Manly's Selection Ratio. The data was tabulated into two tables, one for the landscape level and one for the home range level, with these tables consisting of each individuals' proportional available area of each habitat type and used proportional area/locations (depending on the level). Within the landscape level the available areas of each habitat was identical for each individual as it represents the study area proportions. In the home range level table, the available area was the proportional area of each habitat within the individual specific home range MCP. The used columns are the proportion of location points within each habitat in the home range. Manly's Selection Ratio looks for significant deviance from the available proportions within the used proportions, to identify active selection (significantly greater proportional use) of avoidance (significantly less proportional use) of a habitat according to its availability (Manly et al., 2002; Walters et al., 2016).

CHAPTER IV

RESULTS AND DISUSSION

4.1 Results

4.1.1 Home Ranges

The home range sizes were estimated in hectares area using 100% minimum convex polygons (MCP). Home range sizes were widely variable, ranging from 3.55 ha to 70.96 ha in area. Individual M6 was only caught and added to the study after May thus he did not have sufficient location data for the hot season. The same applied to the females within sample group 2 (2017-2018). Tracking finished at the end of August thus wet season data for sample 2 was not sufficient enough for seasonal range estimation.

Table 4.1 Annual home range sizes (ha) according to 100% MCPs.

Tortoise ID	Total area	Hot season area	Wet season area	Cold season area
M1	12.41	2.86	9.89	5.68
M3	44.94	37.79	21.14	2.80
M4	29.74	8.17	20.02	18.06
M5	35.47	25.97	29.85	14.70
M6	48.73	-	31.08	10.51

Table 4.1 Annual home range sizes (ha) according to 100% MCPs (Continued).

Tortoise ID	Total area	Hot season area	Wet season area	Cold season area
F1	36.47	8.74	31.08	18.59
F2	14.71	10.46	4.17	10.67
F3	26.14	5.56	15.18	11.01
F4	17.08	10.02	13.01	8.36
F5	21.77	8.90	6.07	10.33
F6	41.69	37.43	-	6.63
F8	70.96	10.55	-	37.74
F9	12.05	5.73	-	3.86
F10	15.83	7.12	-	6.39
F12	11.39	2.83	-	2.29
F14	5.41	2.84	-	0.84
F15	3.55	2.63	-	1/40

4.1.2 Habitat Selection: All Seasons

4.1.2.1 Compositional Analysis

Compositional Analysis detected non-random habitat selection for all seasons at the landscape level ($\lambda = 0.49$, $P = 0.005$) and at the home range level ($\lambda = 0.51$, $P = 0.002$) for elongated tortoises. Habitat edge was the most preferred habitat type followed by dry dipterocarp forest then dry evergreen forest at the landscape level. While at the home range level the most preferred habitat type was dry evergreen forest followed by dry dipterocarp forest then habitat edge (Table 4.2). Within Table 4.2, the cells in the matrix consist of mean differences in the log ratios of used and available habitats. Each mean element in the matrix was replaced by a "+/-" sign. At the intersection of the row and of the column, there is a "+" sign when the habitat in the row is more used than the habitat in the column, and a "-" sign otherwise. A triple sign represents significant deviation from random at α = 0.05 (Aebischer et al., 1993).

Table 4.2 Simplified ranking matrix for elongated tortoises (*Indotestudo elongata*) based on compositional analysis of habitat selection at the landscape and home range scales for all seasons. DDF = dry dipterocarp forest and DEF = dry evergreen forest.

	DDF	DEF	Edge Habitat	Rank
Landscape Scale				
DDF	0	+	-	2
DEF	-	0	---	3
Edge Habitat	+	+++	0	1
Home Range Scale				
DDF	0	---	+	2
DEF	+++	0	+++	1
Edge Habitat	-	---	0	3

4.1.2.2 Manly's Selection Ratio

At the landscape level the Manly's selection ratio found non-random selection and avoidance of particular habitat types (Table 4.3). If selection was to occur the selection ratio intervals (Wi) would indicate positive selection for a habitat with Wi scores above 1, and avoidance of a habitat with Wi scores below 1.

Scores of 1 or not significantly different to 1 would indicate no selection. At the landscape level dry dipterocarp forest and edge habitat were selected for above random, and dry evergreen forest was avoided above random to a significant level

(Khi2L2-L1= 177.6589, df = 2, $P < 0.001$). The selection ranking being as follows; edge habitat > dry dipterocarp forest > dry evergreen forest. Edge habitat and dry evergreen forest were selected for and avoided at a significant level.

Table 4.3 Selection ratios for habitats at the landscape level across all seasons. Including the proportional availability and use of each habitat type, the selection ratio (Wi), standard error and upper and lower confidence intervals.

Habitat Type	Available	Used	Wi	SE	CI Lower	CI Upper
DDF	0.5204	0.6284	1.2075	0.1061	0.9816	1.4334
DEF	0.4103	0.2641	0.6437	0.1475	0.3297	0.9576
Edge	0.0693	0.1075	1.5512	0.2588	1.0003	2.1022

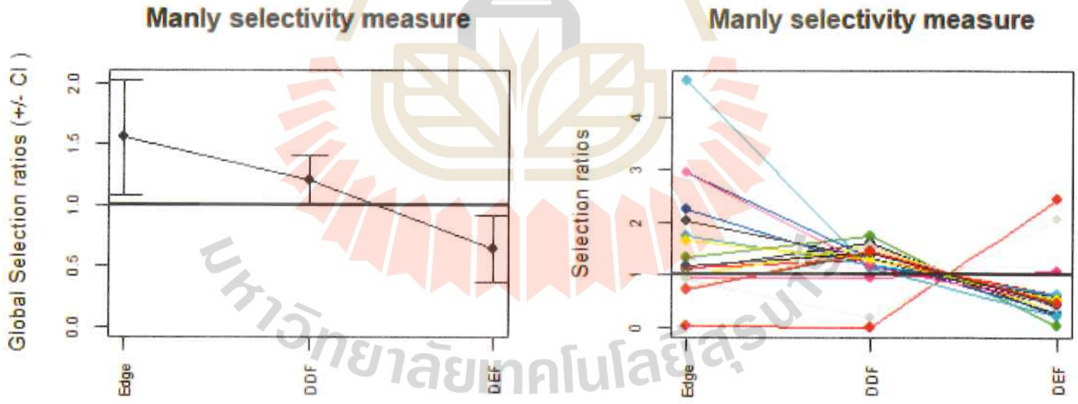

Figure 4.1 Landscape level selection ratio intervals (Wi) for habitat types within SERS with combined selection data (left) and individual selection data (right). Habitat types are shown (x-axis) with their selection ratio values (y-axis) plotted with standard error bars. Selection ratio values > 1 indicate selection; values < 1 indicate avoidance; values = 1 indicate no selection.

At the home range level there was also non-random selection observed in the following order of preference with dry evergreen forest and edge habitat selected for and dry dipterocarp forest avoided to significant levels (Khi2L = 173.0851, df = 33, $P < 0.001$) (Table 4.4). Dry evergreen forest and dry dipterocarp forest were selected for and avoided respectively at the significant level.

Table 4.4 Selection ratios for habitats at the home range level across all seasons. Including the selection ratio (Wi), standard error and confidence intervals.

Habitat Type	Wi	SE	CI Lower	CI Upper
DDF	0.8444	0.0489	0.7402	0.9486
DEF	1.3014	0.1406	1.0023	1.6005
Edge habitat	1.1691	0.1727	0.8017	1.5366

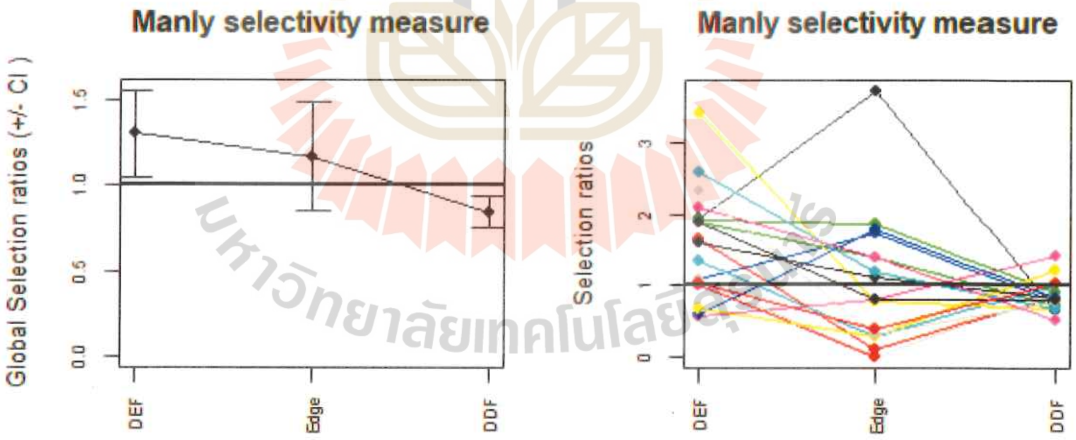

Figure 4.2 Home range level selection ratio intervals (Wi) for habitat types within SERS with combined selection data (left) and individual selection data (right). Habitat types are shown (x-axis) with their selection ratio values (y-axis) plotted with standard error bars. Selection ratio values > 1 indicate selection; values < 1 indicate avoidance; values = 1 indicate no selection.

4.1.2.3 Euclidean Distance Analysis

Euclidean distance analysis detected non-random habitat selection at the landscape level. The distances from random points within individual home ranges to the nearest habitat types were different from the distances from random locations within the study area to the nearest habitat types ($P < 0.05$). Elongated tortoises showed habitat selection ($\rho < 1$; Table 4.5) towards dry dipterocarp forest ($P = 0.00002$) while dry evergreen forest ($P = 1$) and edge habitat ($P = 0.07$) were selected at random.

At the home range level, Euclidean distance analysis indicated that tortoise locations differed from random points ($P < 0.05$). Dry evergreen forest ($P = 0.02$) was selected ($\rho < 1$; Table 15) while dry dipterocarp forest ($P = 0.0003$) was avoided ($\rho > 1$; Table 4.5). Edge habitat was selected randomly ($P = 0.23$).

Table 4.5 Use versus availability mean ratios (ρ) with associated P-values (in parentheses; values in italics denote significant selection at $\alpha = 0.05$) and standard errors for landscape and home range levels. Values for $\rho < 1$ indicate that the corresponding habitat type was used more than expected. If $\rho > 1$, the corresponding habitat was avoided more than expected (Conner and Plowman, 2001).

Habitat	**Landscape level**		**Home range level**	
	ρ	SE	ρ	SE
Dry dipterocarp forest	0.57 (*0.00002*)	0.28	1.72 (*0.0003*)	0.24
Dry evergreen forest	0.96 (1)	0.13	0.90 (*0.02*)	0.10
Edge habitat	0.73 (0.07)	0.08	0.98 (0.23)	0.08

4.1.3 Habitat Selection: Hot Season

4.1.3.1 Compositional Analysis

Compositional Analysis detected non-random habitat selection for hot season at the landscape level ($\lambda = 0.37$, $P = 0.001$) and at the home range level ($\lambda = 0.32$, $P = 0.003$). Habitat edge was the most preferred habitat type followed by dry evergreen forest then dry dipterocarp forest at the landscape level. While at the home range level the most preferred habitat type was dry evergreen forest followed by dry dipterocarp forest then habitat edge (Table 4.6).

Table 4.6 Simplified ranking matrix for elongated tortoises (*Indotestudo elongata*) based on compositional analysis of habitat selection at the landscape and home range scales for hot season. DDF = dry dipterocarp forest and DEF = dry evergreen forest.

	DDF	DEF	Edge Habitat	Rank
Landscape Scale				
DDF	0	-	---	3
DEF	+	0	-	2
Edge Habitat	+++	+	0	1
Home Range Scale				
DDF	0	---	+	2
DEF	+++	0	+++	1
Edge Habitat	-	---	0	3

4.1.3.2 Manly's Selection Ratio

During the hot season there was significant non-random selection of habitats at the landscape level (Khi2L2-L1 = 76.3185, df = 2, $P < 0.001$). Tortoises selected for edge habitat to a significant level but avoided dry evergreen forest and dry dipterocarp forest in respective order.

Table 4.7 Selection ratios for habitats at the landscape level in the hot season. Including the proportional availability and use of each habitat type, the selection ratio (Wi), standard error and upper and lower confidence intervals.

Habitat Type	Available	Used	Wi	SE	CI Lower	CI Upper
DDF	0.5204	0.4763	0.9152	0.1304	0.6377	1.1928
DEF	0.4103	0.3929	0.9577	0.1881	0.5576	1.3579
Edge	0.0693	0.1307	1.8867	0.3182	1.2094	2.5639

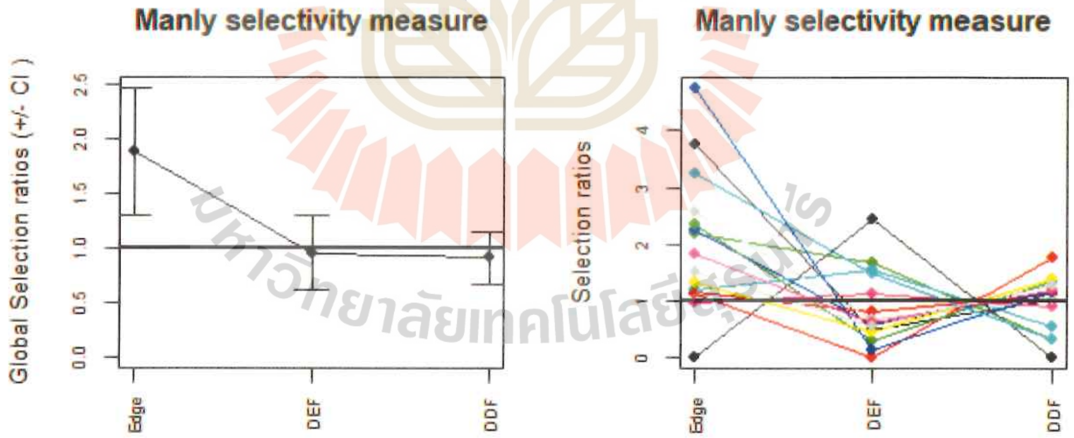

Figure 4.3 Landscape level selection ratio intervals (Wi) for habitat types within SERS in the hot season with combined selection data (left) and individual selection data (right). Habitat types are shown (x-axis) with their selection ratio values (y-axis) plotted with standard error bars. Selection ratio values > 1 indicate selection; values < 1 indicate avoidance; values = 1 indicate no selection.

Home range level selection was identified at a significant level in the hot season (Khi2L = 254.1303, df = 27, $P < 0.001$). There was selection for dry evergreen forest and avoidance of dry dipterocarp forest to significant levels however there was neither selection nor avoidance for edge habitat (Table 4.8).

Table 4.8 Selection ratios for habitats at the home range level in the hot season. Including the selection ratio (Wi), standard error and upper and lower confidence intervals.

Habitat Type	**Wi**	**SE**	**CI Lower**	**CI Upper**
DDF	0.6939	0.0639	0.5577	0.8299
DEF	1.3564	0.1494	1.0383	1.6744
Edge habitat	1.0444	0.1967	0.6259	1.4629

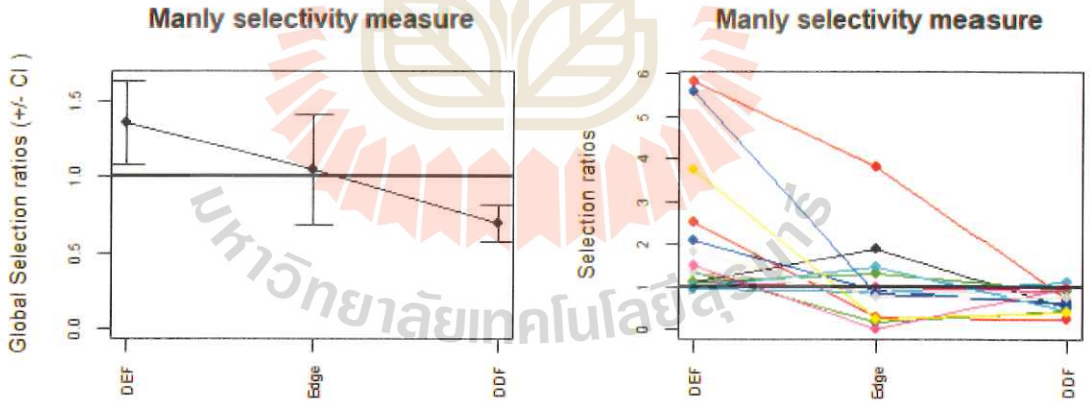

Figure 4.4 Home range level selection ratio intervals (Wi) for habitat types within SERS in the hot season with combined selection data (left) and individual selection data (right). Habitat types are shown (x-axis) with their selection ratio values (y-axis) plotted with standard error bars. Selection ratio values > 1 indicate selection; values < 1 indicate avoidance; values = 1 indicate no selection.

4.1.4 Habitat Selection: Wet Season

4.1.4.1 Compositional Analysis

Compositional Analysis detected non-random habitat selection for wet season at the landscape level ($\lambda = 0.28$, $P = 0.004$). Dry dipterocarp forest was the most preferred habitat type followed by edge habitat then dry evergreen forest (Table 4.9). There was no significant preference at the home range level ($\lambda = 0.50$, $P = 0.28$).

Table 4.9 Simplified ranking matrix for elongated tortoises (*Indotestudo elongata*) based on compositional analysis of habitat selection at the landscape and home range scales for wet season. DDF = dry dipterocarp forest and DEF = dry evergreen forest.

	DDF	DEF	Edge Habitat	Rank
Landscape Scale				
DDF	0	+++	+++	3
DEF	---	0	---	1
Edge Habitat	---	+++	0	2
Home Range Scale				
DDF	0	+	+	1
DEF	-	0	+	2
Edge Habitat	-	-	0	3

4.1.4.2 Manly's Selection Ratio

At the landscape level there was again significant selection for habitats within the wet season (Khi2L2-L1 = 612.285, df = 2, $P < 0.001$). Within the habitats there was significant selection for dry dipterocarp forest and significant avoidance of dry evergreen forest, however no selection or avoidance of edge habitat (Table 4.10).

Table 4.10 Selection ratios for habitats at the landscape level in the wet season. Including the proportional availability and use of each habitat type, the selection ratio (Wi), standard error and upper and lower confidence intervals.

Habitat Type	Available	Used	Wi	SE	CI Lower	CI Upper
DDF	0.5204	0.8593	1.6513	0.0921	1.4552	1.8474
DEF	0.4103	0.0714	0.1739	0.0640	0.0376	0.3104
Edge	0.0693	0.0693	0.9995	0.3245	0.3090	1.6901

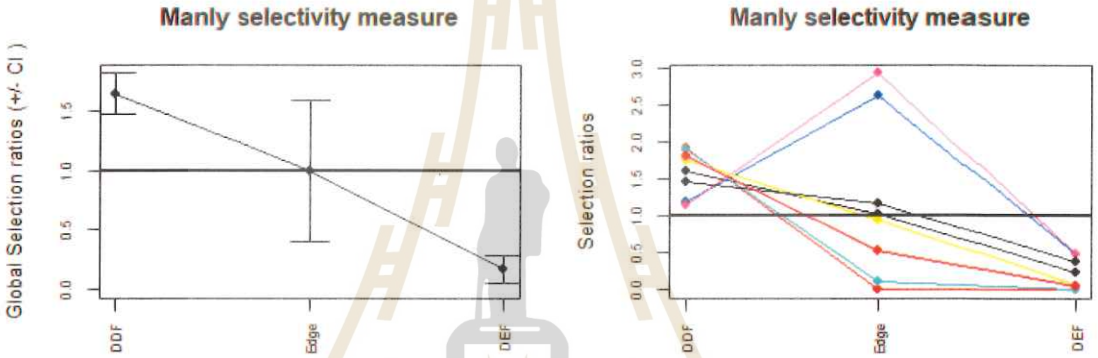

Figure 4.5 Landscape level selection ratio intervals (Wi) for habitat types within SERS in the wet season with combined selection data (left) and individual selection data (right). Habitat types are shown (x-axis) with their selection ratio values (y-axis) plotted with standard error bars. Selection ratio values > 1 indicate selection; values < 1 indicate avoidance; values = 1 indicate no selection.

At the home range level there was also significant non-random selection of habitats (Khi2L = 45.3200, df = 11, $P < 0.001$). There was no non-random selection for any habitats however there was non-random avoidance of dry evergreen forest (Table 4.11).

Table 4.11 Selection ratios for habitats at the home range level in the wet season. Including the selection ratio (Wi), standard error and upper and lower confidence intervals.

Habitat Type	Wi	SE	CI Lower	CI Upper
DDF	1.0310	0.0255	0.9769	1.0853
DEF	0.6574	0.1808	0.2726	1.0422
Edge habitat	0.9676	0.2722	0.3884	1.5469

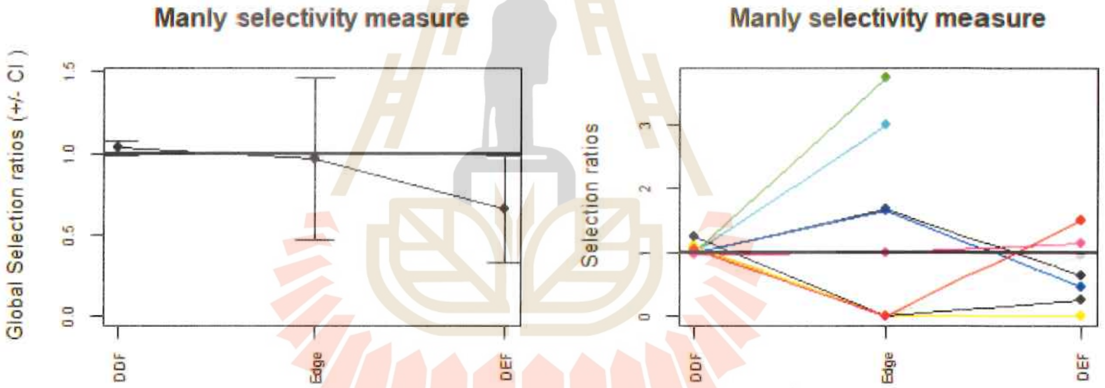

Figure 4.6 Home range level selection ratio intervals (Wi) for habitat types within SERS in the wet season with combined selection data (left) and individual selection data (right). Habitat types are shown (x-axis) with their selection ratio values (y-axis) plotted with standard error bars. Selection ratio values > 1 indicate selection; values < 1 indicate avoidance; values = 1 indicate no selection.

4.1.5 Habitat Selection: Cold Season

4.1.5.1 Compositional Analysis

Compositional Analysis detected no significant preference for cold season at both the landscape ($\lambda = 0.84$, $P = 0.26$) and home range level ($\lambda = 0.68$, $P = 0.08$). However, Table X seems to suggest significant differences between some of the habitats.

Table 4.12 Simplified ranking matrix for elongated tortoises (*Indotestudo elongata*) based on compositional analysis of habitat selection at the landscape and home range scales for cold season. DDF = dry dipterocarp forest and DEF = dry evergreen forest.

	DDF	DEF	Edge Habitat	Rank
Landscape Scale				
DDF	0	+	-	2
DEF	-	0	---	3
Edge Habitat	+	+++	0	1
Home Range Scale				
DDF	0	-	+++	2
DEF	+	0	+++	1
Edge Habitat	---	---	0	3

4.1.5.2 Manly's Selection Ratio

At the landscape level selection in the cold season there was significant selection ($Khi2L2\text{-}L1 = 247.1596$, $df = 2$, $P < 0.001$). There was significant selection for edge habitat and significant avoidance of dry evergreen forest, however no selection for or against dry dipterocarp forest (Table 4.13).

Table 4.13 Selection ratios for habitats at the landscape level in the cold season. Including the proportional availability and use of each habitat type, the selection ratio (Wi), standard error and upper and lower confidence intervals.

Habitat Type	Available	Used	Wi	SE	CI Lower	CI Upper
DDF	0.5204	0.6061	1.1646	0.1207	0.9077	1.4215
DEF	0.4103	0.2542	0.6195	0.1529	0.2940	0.9451
Edge	0.0693	0.1397	2.0165	0.4321	1.0968	2.9362

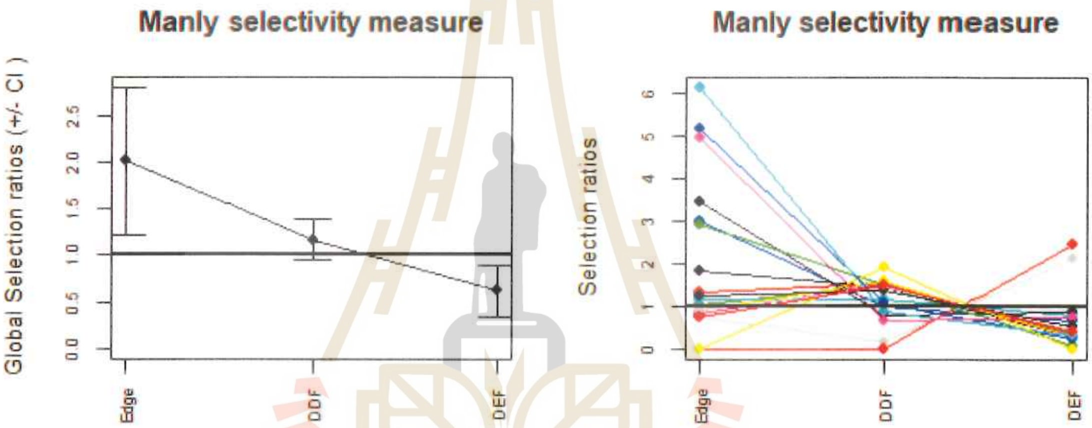

Figure 4.7 Landscape level selection ratio intervals (Wi) for habitat types within SERS in the cold season with combined selection data (left) and individual selection data (right). Habitat types are shown (x-axis) with their selection ratio values (y-axis) plotted with standard error bars. Selection ratio values > 1 indicate selection; values < 1 indicate avoidance; values = 1 indicate no selection.

At the home range level there was also significant non-random selection (Khi2L = 191.9025, df = 28, $P < 0.001$). However in the individual habitats there was limited significant selection. The dry evergreen forest was selected for with the dry dipterocarp forest avoided and the edge habitat selected randomly. Only the dry evergreen forest selection was significant.

Table 4.14 Selection ratios for habitats at the home range level in the cold season. Including the proportional availability and use of each habitat type, the selection ratio (Wi), standard error and upper and lower confidence intervals.

Habitat Type	Wi	SE	CI Lower	CI Upper
DDF	0.9049	0.0561	0.7857	1.0243
DEF	1.2761	0.1707	0.9128	1.6393
Edge habitat	0.9099	0.1414	0.6091	1.2109

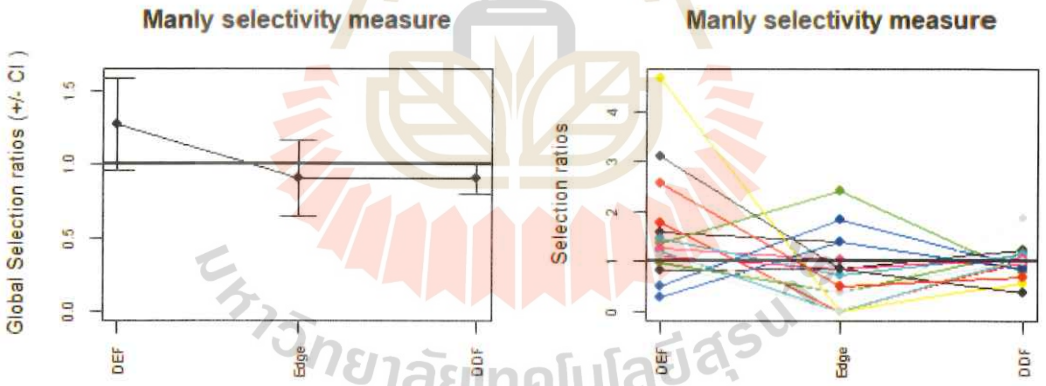

Figure 4.8 Home range level selection ratio intervals (Wi) for habitat types within SERS in the cold season with combined selection data (left) and individual selection data (right). Habitat types are shown (x-axis) with their selection ratio values (y-axis) plotted with standard error bars. Selection ratio values > 1 indicate selection; values < 1 indicate avoidance; values = 1 indicate no selection.

4.2 Discussion

4.2.1 Home Ranges

The home range sizes were estimated in hectare area using minimum convex polygons. As a method of home range estimation these can be highly inaccurate at times however they are standard use for gathering a proximate area for which to assess habitat selection. Home range sizes were widely variable, ranging from 3.55 ha to 70.96 ha in area. Seasonal variation was seen amongst all individuals with the mean ranges of each season 11.72 ha, 17.46 ha and 10.00 ha for hot, wet and cold seasons respectively. Despite these variations they were not significantly different from each other ($X^2 = 1.7523$, df = 2, $P = 0.4164$) when measured between comparable individuals.

4.2.2 Habitat Selection: All Seasons

4.2.2.1 Compositional Analysis

There was non-random selection in both the landscape and home range levels for the tortoises within SERS habitats. Across the year CA states that at the landscape level tortoise create their home ranges around proportionally more edge habitat than the other two habitat options, with dry dipterocarp being followed by dry evergreen forest in order of proportional selection. The study area is comprised predominantly of dry dipterocarp forest (52%) with large areas of dry evergreen forest (41%) and small edges between these forest types (7%).

However these small edges between habitats are significantly sought after by the tortoises. Within the home ranges of the tortoises the dry evergreen forest was significantly used more in relation to its proportional area, and edge habitat was actually preferred the least. This indicates that despite moderate area of dry evergreen forest comprising the home ranges its use was far greater. A greater use of dry evergreen forest could suggest that there are more abundant resources within this habitat not found in the other habitats, or that weather factors area affecting the habitat selection across the year.

4.2.2.2 Manly's Selection Ratio

Using the Manly's selection ratio analysis there was also a consensus of non-random selection for habitats within the tortoises at both landscape and home range levels. Selection and avoidance being decided through the selection ratio (Wi) and the significance being predicated on whether this ratio was truly past the 1.0 threshold using the standard error and confidence intervals. If the lower confidence intervals are above 1 then it is significantly selected for, or if the upper confidence interval is below 1 then it is significantly avoided. The tabulated data is also represented within the partnered figures with each figure highlighting the group selection pressure and then each individual's selection of the listed habitat types. At the landscape level there appears to be significant selection for edge habitat and dry dipterocarp forest (in that order) but significant avoidance of dry evergreen forest. At the home range level however there was also non-random selection but dry evergreen forest was most preferred with dry dipterocarp forest avoided and edge habitat non-significantly selected for. These differences could be explained someway by the methods of habitat use versus availability ratio estimation. At the landscape level the areas of each habitat are compared within the study area (same for all individuals) and inside each individuals home range. As dry dipterocarp makes up the largest portion of habitat within the study area it is not surprising that it may also comprise a large percentage of the area within an individuals' home range. Especially across the year, as we have seen that seasonal ranges change and their habitat proportions with them. Edge habitat is located at the intersection between dry dipterocarp and dry evergreen forest, and as each individual had some exposure to each of the forest types they would undoubtedly also have some edge habitat. As this habitat type is very low in total study are percentage, any inclusion in a home range can be an increase in the proportional area. In the home range level selection ratios, the areas of each habitat within a home range are compared against the number of relocations of the individual in each habitat. Across a full year the use of dry evergreen forest is much greater than its proportional area availability, and vice versa for the dry dipterocarp forest.

4.2.2.3 Euclidean Distance Analysis

The Euclidean distance selection analysis detected non-random selection at both the landscape and home range levels. At the landscape level EDA identified a selection for dry dipterocarp forest however there was no selection for dry evergreen forest or edge habitat. At the home range level there was also selection this time for dry evergreen forest with avoidance of dry dipterocarp forest and edge habitat was not selected nor avoided. The dry dipterocarp forest was the only habitat type selected for and against at a significant level within the landscape and home range levels.

4.2.3 Habitat Selection: Hot Season

4.2.3.1 Compositional Analysis

Breaking down into the hot season we see again non-random significant selection for specific habitats at the landscape and home range levels. Again the edge habitat is the most selected for habitat type at the landscape level, with dry evergreen forest and dry dipterocarp forest used less. At the home range level however the same pattern of dry evergreen forest preference is seen with significantly more proportional use than either the dry dipterocarp or edge habitats. This move toward dry evergreen forest in the hot season could be influenced by the high seasonal temperatures and vegetative differences. Dry dipterocarp forest is dominated by bamboo grasslands and sparse canopy cover, increasing the ground temperatures and reducing food and shelter resources (Tharapoom, 1996). The dry evergreen forest is cooler, has more available shelter and food resources within the hot season, leading to increased reliance on this denser multi-story forest habitat.

4.2.3.2 Manly's Selection Ratio

Manly's identified non-random selection at the landscape level for the hot season too, with edge habitat significantly selected for. Dry evergreen forest and dry dipterocarp forest were selected against but not to a significant level. At the home range level there was again significant selection for the dry evergreen forest and significant avoidance of the dry dipterocarp forest with edge habitat being neither selected for or against. Biologically this again makes sense as the resource availability and abiotic factors would push tortoises toward the more resource abundant and cooler dry evergreen forest within the hot season. The difference in landscape level and home range level selection can potentially be answered in the manner of the proportional use versus availability methods.

4.2.4 Habitat Selection: Wet Season

4.2.4.1 Compositional Analysis

Compositional analysis detected non-random habitat selection at the landscape level however there was no detectable selection at the home range level. At the landscape level there was significant use of dry dipterocarp forest against both the dry evergreen forest and edge habitat. The edge habitat was also significantly selected for over the dry evergreen forest. Unlike the hot season, the wet season has lower temperatures and increased rainfall. Creating abundant food resources such as fresh plant growth and fungi within the open canopy of the dry dipterocarp (Ihlow et al., 2016). There may also be a sense of limited availability with resources in wet season dry dipterocarp forest, as following cold and hot seasons will remove these resources. Yet in the dry evergreen forest many of these resources could remain year round (Tharapoom, 1996).

4.2.4.2 Manly's Selection Ratio

Within the wet season there is significant habitat selection at both the landscape and home range levels. At the landscape level the dry dipterocarp forest was selected for significantly higher than both other habitat types and the dry evergreen forest actually significantly avoided. At the home range level there is a similar pattern although the significant level of selection in either dry dipterocarp preference or dry evergreen avoidance is greatly reduced. In both levels the edge habitat seems to be randomly used with no selection pressure.

4.2.5 Habitat Selection: Cold Season

4.2.5.1 Compositional Analysis

According to the combined data for selection in all habitats and individuals there is not significant differences in habitat use and therefore no non-random selection for habitats in either the landscape or home range level in the cold season. Despite this non-significance there does appear to be some significant use in habitats between the edge habitat and dry evergreen forest at the landscape level. With the edge habitat being favored over the dry evergreen forest. There is also a significant avoidance of edge habitat at the home range level compared to the use of the other two habitats. The reason behind these differences in habitat selection and significance values are not known. However during the cold season movement of tortoises is greatly reduced and to avoid the low temperatures shelters are often chosen and used for long time periods with minimal travelling distances for resource use (Ward et al., unpublished data). This would reduce the number of relocations within the cold seasons and suggest that selection of specific habitats is less important than selection of shelters.

4.2.5.2 Manly's Selection Ratio

During the cold season there is significant selection in habitats at both the landscape and home range levels again. Within the landscape level having a selection for edge habitat and an avoidance of dry evergreen forest. And at the home range level a selection for dry evergreen forest (although not significantly) and no selection preference for dry dipterocarp or edge habitat. This switch in dry evergreen forest avoidance (at landscape level) and selection (at home range level) could be down to the reduced sizes of home ranges within the cold season. The cold season has the smallest average home range size with low area used by the dry evergreen forest as the animals were previously in the dry dipterocarp forest during the wet season. Because of the reduced movement the animals may have entered just into the dry evergreen forest leaving large amounts of dry dipterocarp forest available in the home range. The home range level however uses the locations and the majority of which were inside the dry evergreen forest.

4.2.3 Habitat Selection Analyses Comparison

Comparing the different analysis techniques and their selection rankings there are differences at the home range and landscape levels. Each separation of season and each analysis method identifies differences in the landscape and home range habitat selections of the tortoises. However between the methods these selections also differ. Compositional analysis identifies non-random selection of edge habitat at the landscape level with least selection of dry evergreen forest. With dry evergreen forest becoming significantly selected for at the home range level and edge least selected for (significantly less than dry evergreen forest). This pattern matches the assessment of the Manly's selection ratios which also identify a positive non-random selection of edge habitat at landscape level and avoidance of dry evergreen forest. With a selection for dry evergreen forest at home rang level but this time also selecting for edge habitat and selection against dry dipterocarp forest. While the selection for edge habitat is not significant and could be a selection against in other circumstances (CI: 0.8-1.5) it is still ranked above dry dipterocarp, which was previously ranked higher in CA. Euclidean distance analysis identifies dry dipterocarp forest as the most selected habitat type, being significantly selected for at the landscape level with dry evergreen forest and edge habitat both non-significantly and weakly selected for still. At the home range level EDA identifies a significant selection for dry evergreen forest and strongly significant avoidance of dry dipterocarp forest. Euclidean distance analysis follows CA and Manly's methods in the home range selections, exactly matching the ranking of the Manly's home range selections. However at the landscape level neither CA nor Manly's suggest strong selection for the dry dipterocarp forest with both identifying edge habitat as the primary selected for habitat. Manly's selection ratios and compositional analysis use identical data input with similar methods of area composition and proportional representation. This may be why these two methods have such similar selection preferences and observed results. It should also be noted that where selection is considered significant ($P < 0.05$) within the habitats, not within the model, there are often the same selections observed. Differences in selection between specific habitats is occurring at non-significant levels and so there is less confidence in these results anyway.

Table 4.15 Selection results of the three habitat selection methods (CA, Manly's and EDA) at the landscape and home range levels. "+/-" = selection for or against (not significant), "+++/---" = selection for or against (significant), "0" = no selection.

	CA	Manly	EDA
Landscape Scale			
DDF	0	+	+++
DEF	---	---	0
Edge Habitat	+++	+++	+
Home Range Scale			
DDF	-	---	---
DEF	+++	+++	+++
Edge Habitat	---	+	0

Table 4.16 Rankings of each habitat according to the different selection methods.

	CA	Manly	EDA
Landscape Scale			
DDF	2	2	1
DEF	3	3	3
Edge Habitat	1	1	2
Home Range Scale			
DDF	2	3	3
DEF	1	1	1
Edge Habitat	3	2	2

Comparing the Manly's selections with CA selections across the different seasons, there are some similarities and differences. At the hot season the Manly's ratios suggest a strong selection of edge habitat at landscape level and selection for dry evergreen forest at home range level with avoidance of dry dipterocarp forest. This is largely the same as the compositional analysis with matching selections of preference; however, some extra selection again suggested for the dry dipterocarp (at landscape level) and edge habitat (at home range level). Crucially it is the selection for dry evergreen and edge habitats in the two selection levels which are important and follow the biological principals of seeking habitats with the highest food, water and shelter resources available and avoiding the overheating and arid dry dipterocarp. The wet season again sees an agreement in the methods of a selection for dry dipterocarp forest at the landscape level and no significant selection for any habitat at the home range levels. The wet season providing the dipterocarp forest with the rainfall and reduced temperatures to grow fresh vegetation and fungi for tortoises to feed upon (Tharapoom, 1996; Ihlow et al., 2014).

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

5.1.1 Objectives and Hypotheses

The research objectives established for this project were; 1) Determine if there is non-random habitat selection by *I. elongata* at the home range and landscape scales, 2) Determine if variation in habitat selection of *I. elongata* is observed between seasons and 3) Compare results between the habitat selection analyses (CA, Manly and EDA). Through the use of the three above mentioned analysis methods in identifying non-random habitat selection at both home range and landscape scales the first objective has been met. Using CA and Manly's selection methods there was also habitat selection analysis of the hot, wet and cold seasons along with the full year dataset meeting the second objective. Finally a comparison between each habitat selection method was run and tabled to identify the differences in selection preferences and any discrepancies between the methods.

The first hypothesis stated that *I. elongata* will select dry dipterocarp forest non-randomly as the preferred forest type for the full year dataset at the landscape level. Looking at the preferences within the three methods we see only the Euclidean distance analysis method identifies the dry dipterocarp forest as the top selected habitat type. CA and Manly suggest that there is no strong selection for dry dipterocarp forest at landscape level. For this reason there is not enough support for this hypothesis and it is likely that the null hypothesis cannot be rejected. The second hypothesis suggested that there will be significant seasonal variation in the habitat types. Using the two methods (CA and Manly) which compared the different seasons there was indeed significant variation in the selection preferences. Both methods identified similar selections as primary preferences and avoidance in each season. The third hypothesis states that within the hot season the significantly selected habitat of preference would be dry evergreen forest. At the home range level within both CA and Manly's selection of habitats there is significant selection for dry evergreen forest during the hot season. At the landscape level however there was a selection for edge habitat with no random selection for dry evergreen forest. This means that the hypothesis is supported by the observed data. The final hypothesis stated that there would be non-random selection for dry dipterocarp forest in the wet season. Again both CA and Manly habitat selections identified that there was significant selection for dry dipterocarp forest at the landscape level and home range level. Allowing us to support the hypothesis that there is significant selection for dry dipterocarp forest in the wet season.

5.1.2 Habitat Selection Methods

There were differences between the results of the different selection methods (Table 4.15 and Table 4.16) however many of these differences could be down to the lack of significant support for these habitat preferences. When comparing the techniques according to the methods they use there are also differences that could explain some of the variation in results. Bingham et al. (2010) compared CA with EDA in simulated data for habitat selection. They also noticed significant differences in the selections made by the analyses and recommend that EDA be avoided as a method.

They suggest that the way in which EDA calculates its selection preferences, while not too dissimilar to CA, create more errors and leads to incorrect decisions. Based on the biological sense of the selection preferences made by CA. However DeGregorio et al. (2011) argue that the use of EDA should be discussed further. Comparing CA and EDA to assess habitat selection across landscape and home range scales they also found differences in the selections. At the landscape level CA was more intuitive and EDA erroneous, identifying selection for habitat unused by the animals. However at the home range level EDA was more able to identify and classify edge habitats as important habitat types (known to be used in the species tested) selected for. Similarly with Conner et al. (2003) we see that EDA can be more representative at the finer scale, allowing for a lack of known locations within each habitat to still classify the importance of the habitat. For this reason it is safer for habitat selection to be conducted using at least CA and EDA techniques with the use of Manly's selection ratios optional.

What can be concluded from this study is that the tortoises require multiple different habitat types to cope with seasonal variation in weather and resource availability. Despite a lack of certainty as to which habitat types are the most important to the species, there is certainty that each of the three habitat types displayed previously have importance to the species. Conservation actions predicated on the area and habitat protection over the species protection would be preferable in this case. Although it is noted that with large individual variations and anecdotal evidence, this species is highly adaptable and can diversify with other resources should specific habitats become less favorable or available.

5.2 Recommendations

Using the current study and results there are some recommended actions for further habitat selection study. The sample used for the current study was large enough to create significant variation in habitat selection however there is great differences in individual selection preferences. A larger sample with more representation between the sexes could help alleviate the individual differences and clarify species level selection preferences. Also allowing for identification of sex specific selection preferences.

This study was conducted within the Sakaerat Environmental Research Station (SERS) at the Sakaerat Biosphere Reserve (SBR). Within the study area there were only three habitat types (DEF, DDF and Edge) however within the reserve there are also plantation and bamboo habitats along with differences in habitat degradation stages. The use of animals within multiple sites at the reserve, along with multiple protected parks, would help elucidate which habitats are preferred when the habitats available change between sites.

As well as identifying more habitats from other sites and other areas within the SBR a correlation with the microhabitats available and used would help to identify potential drivers of habitat selection. Microhabitat features (shelter types and ground cover) along with canopy cover and microclimate changes within each habitat could highly influence the selection of locations within habitats. Further running selection studies on the microhabitats alongside macro habitat would improve the reliability and show patterns of site selection to a greater degree. Microhabitat was intended to be a large portion of the present study including recording known and random location data previously discussed. Unfortunately, there were feasibility problems which caused the microhabitat data to become non-viable and therefore macro habitat was used alone.

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