PROPAGATION OF BARN OWLS, *Tyto alba javanica* FOR CONTROLLING OF RAT POPULATIONS IN URBAN AREA OF MINDEN, PENANG.

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by

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SE	Standard Error
USM	Universiti Sains Malaysia
km	Kilometer
m	Meter
cm	Centimeter
mm	Millimeter
ha	hectare
g	gram
SPSS	Statistical Package for Social Science
DNA	Deoxyribonucleic acid
EDTA	Ethylenediaminetetraacetic acid
PCR	Polymerase chain reaction
bp	Base pair
CCTV	Closed-circuit television

LIST OF APPENDICES

PENGGUNAAN BURUNG PUNGGUK JELAPANG, TYTO ALBA JAVANICA UNTUK MENGAWAL POPULASI TIKUS DI KAWASAN BANDAR MINDEN, PULAU PINANG.

ABSTRAK

Dalam kajian ini, 25 ekor burung Pungguk Jelapang telah dipindahkan dari habitat asal dan telah diperkenalkan di kawasan bandar di Minden sejak tahun 2016 untuk memastikan kesinambungan populasi mereka di kawasan baru dan bertindak sebagai musuh utama perosak tikus. Sebelum dilepaskan di kawasan bandar, eksperimen pemilihan makanan dan kelakuan pemakanan *T. alba javanica* telah dikaji. Analisis Mann-Whitney telah menunjukkan tiada perbezaan bererti ($p>0.05$) terhadap 2 spesis tikus sebagai pilihan yang lebih diingini. Burung pungguk menunjukkan pemilihan terhadap mangsa bersaiz kecil dan aktif, mangsa kecil dan tidak aktif (<50g), mangsa bersaiz sederhana dan aktif sementara diikuti mangsa bersaiz sederhana tidak aktif (80-120g) manakala mangsa bersaiz besar tidak digemari (180-220g). Kemudian, kaedah molekular dalam penentuan jantina burung pungguk telah dilakukan untuk membandingkan 10 ciri morfologi iaitu: berat badan, corak bintik badan dan warna bulu,panjang tarsus, kuku, panjang sayap, ekor, bentuk muka, sayap utama dan sekunder, kewujudan tempat pengeraman dan panjang paruh. Kajian penentuan jantina burung menggunakan ciri morfologi menunjukkan 83.3% dan 78.57 % ketepatan untuk betina dan jantan. Tambahan pula, keputusan menunjukkan kewujudan tempat pengeraman merupakan kaedah kedua paling tepat dalam penentuan jantina burung (ketepatan 100 % dan 75 % untuk jantan dan betina masing-masing). Parameter lain adalah tidak jelas dan tidak tepat dalam menentukan jantina burung pungguk. Dalam kajian ini, burung pungguk telah dilepaskan di kawasan bandar dengan 5 kaedah berbeza; burung dewasa, burung pungguk muda liar, burung pungguk yang dibela, burung pungguk muda yang telah menyesuaikan diri, dan burung pungguk dewasa yang telah mengalami proses penyesuaian di aviari. Kaedah penjejakan menggunakan radio telemetri menunjukkan burung pungguk dewasa liar *(n*=4) telah terbang jauh dari kawasan kampus setelah dilepaskan. Pelepasan burung pungguk muda liar (*n*=4) dan burung pungguk yang dibela sejak kecil (*n*=3) juga tidak berjaya. Namun, pungguk jelapang dewasa yang telah disesuaikan dalam aviari telah berjaya dilepaskan (*n*=9) dengan 3 ekor daripadanya telah menetap dan dapat dijejaki lebih dari 1 bulan di kawasan bandar. Purata julat rumah dan kawasan teras burung pungguk dewasa ini adalah 8.32 hektar dan 6.39 hektar (95 % dan 50% purata pengiraan harmonic). Impak burung pungguk jelapang yang diperkenalkan di kawasan bandar telah dikaji melalui analisis pellet burung pungguk. Analisa diet menunjukkan tikus Norway, *Rattus norvegicus*, adalah peratusan mangsa tertinggi di dalam diet burung pungguk (65.90 % biomas mangsa) manakala tikus cencurut, *Suncus murinus*, mencatat peratusan mangsa kedua tertinggi (27.18% biomas mangsa) diikuti dengan tikus rumah, *Rattus rattus* (2.72%). Tupai, *Callosciurus notatus*, mencatat 3.78 % dalam diet burung pungguk dan peratusan paling rendah dalam diet burung adalah serangga (0.046 % biomas mangsa). Burung pungguk menunjukkan keutamaan terhadap mangsa bersaiz sederhana antara 40 g hingga 120 g (52.96 % biomas dan 38.71 % keseluruhan individu). Secara konklusi, burung pungguk boleh diperkenalkan di kawasan bandar melalui kaedah perlepasan yang sesuai. Keputusan kajian ini menunjukkan kesesuaian menggunakan pungguk jelapang sebagai ejen kawalan biologi untuk makhluk perosak mammalia kecil di kawasan bandar.

PROPAGATION OF BARN OWLS, TYTO ALBA JAVANICA FOR CONTROLLING OF RAT POPULATIONS IN URBAN AREA OF MINDEN, PENANG.

ABSTRACT

In this study, 25 barn owls, *Tyto alba javanica* were translocated from their original habitat and were introduced in urban area of Minden, Penang Island since 2016 in order to establish their population and to serve as a natural enemy against rat pests. Prior to release the barn owls into urban area, food preferences and feeding behaviour of *T. alba javanica* in captivity were investigated. The Mann-Whitney analysis test showed that there was no significant difference ($p>0.05$) between different 2 species of rats (*Rattus tiomanicus* and *Rattus norvegicus*) as the barn owls preferable diets. However, the barn owls showed their preference towards small active, small inactive (<50g) medium active followed by medium inactive (80-120g) meanwhile larger preys were less preferable (180-220g). Next, molecular sexing method of *T. alba javanica* was carried out to compare ten morphological traits to determine the barn owls sexes; body mass, spotting patterns and plumage colour, tarsus length, talons, wingspan, tail, facial disc, primary and secondary remiges, presence of brood patches and culment length. This study showed that sex identification using morphological trait had 83.3% and 78.57% accuracy for both female and male respectively. Furthermore, the results indicated that the presence of brooding patch were the most second most accurate and reliable to determine the barn owls sexes (accuracy of 100% and 75% for male and female respectively). Other parameters recorded unambiguous sexing methods and were not reliable in determining the barn owls sexes. In this study, barn owl were released into urban area with five different methods; wild adults ,wild fledglings, hand-reared owls, acclimatized fledglings, and acclimatized adults and the most suitable method to introduce this species into a new area was acquired. The radio telemetry tracking recorded that the introduced wild adult barn owls (*n*=4) dispersed away from the campus soon after they were released. Similarly, wild fledglings (*n*=4) and hand-reared (*n*=3) were unsuccessful. However, the acclimatized adults (*n*=5) releases were successful with 3 of the owls established their inhabitant and traceable more than a month in the urban area. The average of home range sizes and core area of these owls were 8.32 ha and 6.39 ha, respectively according to 95% mean harmonic calculation. One acclimatized fledgling (*n*=9) were also traceable in urban area up to two weeks and the average home range and core area were 22.43 ha and 9.78 ha, respectively. However, this particular fledgling was untraceable afterwards.

The impact of introduced barn owls in urban area were studied using dietary analysis of regurgitated pellets as it is an established method to analyse owl prey content and preferences. The results showed that commensal Norway rats, *R. norvegicus* constitute highest proportion of the owls diet (65.90 % prey biomass), meanwhile common house shrews were the second highest consumed prey (27.18 % prey biomass) followed by *R. rattus* accounted for 2.72% of small rodent’s prey. Common plantain squirrel, *Callosciurus notatus* recorded 3.78 % of the diet and the smallest proportion of the prey was insects (0.046% prey biomass). As the conclusion, barn owls could be introduce into urban area and sustain their population with an appropriate methods of release. The results indicate the suitability of utilizing barn owls as a biological control agent for commensal rodent pests in urban area.

CHAPTER 1

INTRODUCTION

1.1 Overview of study

Barn owls, *Tyto alba*, which are locally known as "Pungguk Jelapang" are the most widely distributed owl species in the world (D. S. Bunn, Warburton, & Wilson, 2010; Smal, Halim, & Din, 1990). In Peninsular Malaysia, barn owls were considered as a vagrant species with only several records being made and were believed to have originated from Java or Sumatra (G. Lenton, 1985) and migrated to Peninsular Malaysia in the late 1800s (J. Duckett, 1991). The first discovery of a pair of barn owls was made in 1968 in southern Johor (Wells, 1972) and in the following years, reports of barn owls sighting and nesting increased scattered throughout Peninsular Malaysia (G. M. Lenton, 1984). The rapid spread of the Southeast Asian barn owl subspecies, *Tyto alba javanica* in Peninsular Malaysia is associated with the extensive spread of oil palm cultivation (Wood & Fee, 2003) as these plantations harbour an abundant supply of rats. Numerous studies worldwide have shown that barn owls prey exclusively on small mammals, particularly rodents (Hindmarch & Elliott, 2015; C Marti, 2010; Milchev, 2015; Paspali et al., 2013).

Barn owls have been widely used in agricultural areas to serve as biological control agents of rodent pests (Labuschagne, Swanepoel, Taylor, Belmain, & Keith, 2016; C Marti, 2010). Biological control involves the utilization and conservation of beneficial organisms to regulate pest population densities, which in most cases comprise of the natural enemy of a pest animal (Orr, 2009; Weeden, 2002). Various barn owl programmes have been conducted around the world and involve the manipulation of owl populations by supplementing artificial nest boxes to induce propagation of barn owls as biological control agent against rodent pests at targeted areas (J. E. Duckett & Karuppiah, 1990; Meek, Burman, Nowakowski, Sparks, & Burman, 2003). In natural settings, barn owls nest in tree cavities, fissures and rock crevices (Charter et al., 2010). When natural sites are limited, owls readily occupy provided artificial nest boxes (Wendt & Johnson, 2017). Therefore, providing artificial nest boxes is a common practice to increase nesting habitat and thus sustain barn owl populations. Once established, the owls have the potential to remove a significant number of rats and increase the level of predation pressure towards rodent populations. Puan (2013) stated that the success of biological control programs is based on the successful establishment of predator populations rather than a drastic evidence of their effectiveness in regulating rodent populations.

In Malaysia, barn owls commonly inhabit rice fields and oil palm plantations where they are used intensively to serve as biological agents to control rat populations (Hafidzi & Naim, 2003b; G. M. Lenton, 1984). Following their established role as an effective rat hunter, barn owls has been translocated and introduced in various landscapes such as oil palm plantations (Heru, Siburian, Wanasuria, Chong, & Thiagarajan, 2000; Rizuan, Hafidzi, Hisyam, & Salim, 2017), semi-urban areas (Meyer, 2008) and islands (Au & Swedberg, 1966; Emmerson & Ascani, 1985) for the purpose of controlling rodent pest populations. However, the potential of barn owls as a natural enemy of rats in urban areas remains largely unexplored.

Translocation of wild and captive-bred or captive-raised animals are often carried out as conservation management tool to introduce or reintroduce new populations into a new habitat or to augment existing population for genetic or demographic benefits (IUCN, 2013). This approach has been practiced over decades, and there is a well-documented history of wildlife releases to established new food resources, for biological pest control and for aesthetic reasons (R. Green, 1997; Griffith, Scott, Carpenter, & Reed, 1989). Generally, success is measured in terms of the species survival and establishment of viable populations (Seddon, 1999). Translocation of a species is not deemed successful if the particular animal fails to augment, breed or regulate a target population (van Heezik, Maloney, & Seddon, 2009).

Hypothesis of study

The two common methods and important hypotheses underlying the translocation of animals are the 'soft release' (animals acclimatized to a novel site before release) and 'hard release' (non-acclimatized animals) (Bright & Morris, 1994; Clarke, Boulton, & Clarke, 2002). The theoretical basis regarding this approach is that early experience in life may affect future habitat preferences, individual performance and behaviour. Despite many translocation programmes of animals over the years, these two hypotheses remain largely untested. Although translocation and introduction monitoring programmes have improved in recent years (Seddon, Armstrong, & Maloney, 2007), systematic studies and experimental designs of introduced and reintroduced animals are still lacking. Thus, to further understand the outcome of translocations, there is a need for thorough documentation and evaluation of the factors considered to have influence over translocations.

1.2 Objectives of study and rationale of the studies.

The main objective of this research was to translocate and introduce barn owls by employing suitable and reliable release methods in order to establish their population in an urban area. A prerequisite for an introduction attempt would be to familiarize owls towards a new diet, as well as allowing the owls to acclimatize to their new environment and landscape. Hence, experiments of the diet preference of owls were carried out and the feeding behaviour of barn owls were also studied. Sexing owls is important for sex confirmation in conservation and introduction programs, thus morphological and molecular sexing of barn owls were carried out prior to releases.

In Malaysia, barn owls have been implemented as a bio-control agent of rat populations in oil palm plantations and rice fields since 1969 (Lenton 1984; Duckett, 1991). Following their established role as an effective rat hunter, barn owls have been introduced in various landscapes such as oil palm plantations (Heru et al., 2000; Rizuan et al., 2017), semi-urban areas (Meyer, 2008) and islands (Au & Swedberg, 1966; Emmerson & Ascani, 1985) for the purpose of controlling rodent pest populations. However, there are few quantitative studies regarding the appropriate release method to translocate and introduce barn owls. The absence of such information is particularly apparent when introduction of barn owls as a biological agent are attempted in a new habitat. The right method of release is crucial especially when translocating barn owls to a new area, such as an urban environment, that contrasts to an agricultural landscape habitat.

Establishing an appropriate release method is crucial to establish a barn owl population in a new area and to ensure the sustainability of introduced owls. In this study, two common method of releases, i.e. hard release and soft release of different background of barn owls (wild adult, wild fledgling, acclimatized fledgling, acclimatized adult and hand-reared) were introduced in an effort to establish a barn owl population in an urban area. Herein, this thesis provide a comprehensive study of release methods for translocation and introduction of barn owls from their native habitat to urban area of Minden, Penang.

The specific objectives of this research are as follows:

i. To investigate the diet preferences and feeding behaviour of barn owls, *T. alba javanica* in captivity.
ii. To determine the sex of barn owls, *T. alba javanica* using morphological features and molecular-based methods.
iii. To test which method is suitable to release barn owls in an urban area.
iv. To explore the diet composition of introduced barn owls in an urban area.

CHAPTER 2

LITERATURE REVIEW

2.1 Translocation of animals

The definition of translocation by IUCN (2013) is the movement of captured animals and/or transfer of free ranging animals from one part of their historic geographic range to another. Translocation can utilize the local population or recolonize formerly occupied habitats (Meek et al., 2003). Translocations are useful when habitat demolition in one area tends to jeopardize that particular species, but a captive breeding program would not contribute to the species survival (Griffith et al., 1989). This definition of translocation also encompasses introductions, reintroductions and restocking. An introduction is the release of either captive-born or free ranging, wild born animals into an area outside their original range.

Reintroduction in a broad sense is the translocation of animals held in captivity, both wild and captive born, into an area within their original geographic range, usually when populations have significantly diminished due to natural disaster or human intervention. The term restocking is often used when animals, regardless of origin, are released into an area which already contains interspecies individuals; with the purpose to elevate the number of individuals of a species (IUCN, 2013; Kleiman, 1989).

Many species have been translocated and released to an area where populations have declined, disappeared or are naturally absent. However, Long (1981) and Cade (1986) described that most translocations, introductions and reintroductions of animals have been unsuccessful and approximately more than half of a 1000 attempts have failed. For example, the introduction of grey squirrels, *Scuirus carolinensis,* into Regent Park, London has resulted in reduction of the native red squirrel, *Sciurus* *vulgaris*, population due to interspecific conflict (Bertram & Moltu, 1986). In Kwazulu-Natal, South Africa, captive-bred antelopes (*Ourebia ourebi*) were introduced in agricultural farms and these reintroductions failed due to high mortality (Grey-Ross, Downs, & Kirkman, 2009). A study by Harrington, Põdra, Macdonald, and Maran (2014) reported a 88% failure rate of introduction of captive-born European minks, *Mustela lutreola*, due to mortality and individuals being untraceable post-release (collar or signal loss). A dramatic example is the extinction of Guam's forest birds, Guam rails (*Gallirallus owstoni*) and Micronesian kingfisher (*Todiramphus cinnamominus*), in the tropical western Pacific Ocean due to predation by introduced brown snakes, *Boiga irregularis* (Wiles, Bart, Beck Jr, & Aguon, 2003).

There are several major factors associated with translocation success. Griffith et al. (1989) described that quarry species were more likely to translocate successfully than endangered, threatened or sensitive species. Translocation into the species historical ranges are more likely to be successful than introductions outside original geographical ranges. Herbivores are more likely to survive and successfully translocate compared to carnivores or omnivores. Translocation into an area with potential competitors with similar congeneric were less successful than translocations into areas with less or absent competitors. Species with large clutches and early breeders were slightly more successful than species that bred late and had small clutches. An overall increased habitat quality is also associated with greater translocation success (Griffith et al., 1989; Seddon et al., 2007).

An important consequence of the introduction of individuals into a new area is that the animals will often spread into surrounding areas via extensive post-release movements. Hence, identifying the factors that influence the rate and spatial scale of movements should be considered when evaluating the ecological significance of introducing individuals into an area (Puth & Post, 2005). When released into a new area, animals often make excessive movements in terms of dispersal and time spent actively moving (E. Biggins et al., 1998; Robertson & Harris, 1995). Unrestrained activity in an open area may take animals to unsuitable habitats (van Heezik et al., 2009) and/or have higher chances of conflict with humans (McLellan & Rabon Jr, 2006). In addition, animals that are unable to reside and establish a home range and core area are considered unsuccessful attempts of introduction and may not contribute to the restoration of the species. Thus, erratic dispersal behaviour and excessive post-release movements may undermine the translocation objectives if surviving animals end up in unsuitable areas where they are unable to benefit their population (Skjelseth, Ringsby, Tufto, Jensen, & Sæther, 2007).

The two common methods in the translocation of animals are the 'soft release' method (animals acclimatized to a novel site before release) and the 'hard release' method (non-acclimatized animals) (Bright & Morris, 1994). Theoretically, the 'soft release' method approach concerns early experiences in life that could affect future habitat preferences, individual performance and behaviour. Practically, this simply means providing the animals with a naturalistic enclosure that resembles the habitat that the animals will encounter in the wild after release (Beck, 1991; Harrington et al., 2014). In other words, it is a method to prepare animals for 'life in the wild' and 'pre-condition' them to their natural environment prior to release while still in captivity (Roe, Frank, Gibson, Attum, & Kingsbury, 2010; Stoinski & Beck, 2004). The aim of pre-conditioning includes to induce development of particular behaviours such as foraging and hunting, or simply to induce familiarity with the new habitat and environment and to encourage natural behaviour (Maxwell & Jamieson, 1997; Soderquist & Serena, 1994).

One expected outcome from the ‘soft release’ method is that animals that acclimatize are more likely to explore appropriately in the new environment and less likely to make an excessive post-release dispersal and there is a low possibility individual would reside in unwanted areas. For instance, pre-conditioned dormice, *Muscardinus avellanarius,* in naturalistic enclosures displayed shorter post-release movements compared to non-acclimatized dormice (Bright & Morris, 1994) and acclimatized black footed ferrets, *Mustela nigripes,* showed shorter post-release movements than non-acclimatized individuals (D. E. Biggins, Godbey, Horton, & Livieri, 2011). However, some researchers report there is no difference between the two different release methods, for example translocated and introduced Palila birds, an endangered Hawaiian honeycreeper *Loxioides bailleui,* into Kanakaleonui forests showed no significant difference between soft and hard releases as the populations thrived in the release sites (Fancy, Snetsinger, & Jacob, 1997).

Despite increased translocation activities over the years, these two hypotheses remains largely untested and might have profound consequences for introduction and reintroduction purposes. Thus, it is crucial to determine and understand post-release movements and settlement patterns of released animals, as well as the factors that influence effective monitoring of post-release individuals and for assessing the probability of population establishment (van Heezik et al., 2009). Evaluating the influence of biological factors towards movement patterns are also crucial to allow selection of a suitable method for the release of animals and to assess the effects of pre-conditioning, which allows the refinement of strategies in managing translocation process in order to increase the success of future translocation programmes.

Although translocation and introduction monitoring programmes have improved in recent years (Seddon et al., 2007), systematic studies and experimental designs of introduced and reintroduced animals are still lacking in review. Equivalently, although pre-conditioning approaches are relatively common in introductions, only few scientific papers have included experimental case studies of the effectiveness of these methods (Harrington et al., 2013). In a review of 199 publications of translocation and reintroduction projects, Harrington et al. (2013) reported that less than 20% of studies reported on the post-release movements of animals, i.e. monitoring home range establishment and settlement of released animals. Among these, only 11 % of studies reported the experimental design of the effectiveness of the supportive measures adopted for comparison of alternative methods.

2.2 Translocation of barn owls

Translocation of wild and captive-bred or captive-reared birds and introductions of avian species into the wild or new areas have been used in an attempt to increase declining populations or where the population has disappeared or is absent. Scott and Carpenter (1987) described that introduction programs have provided several benefits including augmenting the target population, increasing genetic diversity, reducing inbreeding depression and establishing viable populations. However, introduction programs also have several negative impacts such as translocated birds carrying unwanted diseases and parasites, and can cause potential genetic changes (Long, 1981). Despite these potential impacts, introduction and reintroduction programs have been successful for various species including Palila, the Hawaiian honeycreeper *(L. bailleui*), Peregrine Falcons (*Falco peregrinus*), Takahe birds (*Porphyrio mantelli*) and Puerto Rican parrots (*Amazona Pittata*) (Scott & Carpenter, 1987).

Wild and captive-bred barn owls have been released at several locations and the results of those translocations have varied. Fajardo, Babiloni, and Miranda (2000) studied patterns of dispersal, survival and mortality in translocated *T. alba* in Spain, including both wild and captive owls released individually. They discovered that the two most reported mortality for rehabilitated barn owls were road traffic collisions and starvation (51.2% and 26.8%). Among the cases of starved birds, 90% of cases occurred within 4 weeks of release. After this crucial period of 4 weeks, the birds followed natural mortality and dispersal patterns. It was also observed that *T. alba* released after live prey training had more chances of survival than rehabilitated owls without this training, similarly reported by (Heru et al., 2000; Meek et al., 2003). Collectively, they monitored trained, untrained fledglings and wild fledglings in their native habitats in Spain, England and Riau, Sumatera and reported that the survival rates of the trained fledglings and wild barn owls were not significantly different.

A study by Karapan (2012) on the survival and foraging of barn owls fledglings in an oil palm plantation in Thailand showed that both trained and untrained fledglings had high mortality rates in the first month. However, the trained fledglings had a higher survival rate (66%) than untrained fledglings (33%). He suggested that mortality of the untrained fledglings may be due to foraging inexperience despite the relative abundance of rodents in oil palm plantations.

Heru et al. (2000) successfully implemented a barn owl programme for biological control of rats in mature oil palm plantations in Riau, Indonesia; where they translocated six pairs of adult barn owls from Medan, Indonesia. The direct adaptation method was used where all the translocated owls were acclimatized inside captivity for over 2 months before release. However, 24 months observation after release showed that none of the owls resided at the release area and installed artificial nest boxes were left unoccupied. The team then switched to another method; they provided an 'enticement box' and released 25 pairs of young barn owls that had just started to fledge and were translocated from other sites. The project was deemed successful when the nest boxes were occupied 4 months later, and the average percent fresh damage of palm fruits were significantly lower after the introduction of barn owls.

In Malaysia, Rizuan et al. (2017) translocated five non-paired wild *T. alba javanica* from Jerantut, Pahang. The owls were obtained from plantations in Felda Sungai Tekam, Jerantut, Pahang and were translocated to Felda Sahabat 06, Lahad Datu. Upon arrival, the barn owls were placed in an aviary for inspection, health status monitoring and acclimatization for about six to ten months before being released into the oil palm plantation. Studies are still undergoing for a complete assessment on the establishment of a barn owl population in the plantation in Lahad Datu through natural breeding, as well as the effectiveness of barn owls bio-control program of rats.

2.3 Urbanization of barn owls

In Sebokeng, Johannesburg, South Africa, Meyer (2008) carried out a project to release barn owls in semi-urban areas after resident complaints of increasing rat activity within the area. This project investigated the efficacy of using barn owls as biological control agents of rats at three schools in Sebokeng and provided environmental education towards biological control programs. Artificial nest boxes were set up at the study sites and juvenile barn owls were kept inside nest boxes and were fed daily until all individual ready to fledge and were self-sufficient. The efficiency of the biological control program was assessed by live trapping of rats when owls were absent and after the release of owls at respective study sites.

Analysis of trapping data indicated that owls removed a significant number of rats as fewer rats were trapped where owls were present compared to study sites where owls were absent. However, Meyer noted the possibility that the rats simply developed trap shyness over time. Over the period of study, more rats were trapped at the site where no owls were introduced compared to the sites where barn owls were present. It was suggested that a long-term presence of owls at the study site would have a significant impact towards the small rodent population.

Meyer's translocation of barn owls was deemed successful as she reported a 100% survival rate of the owl's post-release. In addition, the majority of the owls were observed in close proximity up to six months prior to release. Meyer stated that part of the success of the program was due to the environmental education and awareness campaigns that were carried out to ensure the local residents were aware and participated in the barn owl release programme. Meyer proposed that without the campaign, there was little doubt that residents would have killed or gotten rid of the owls due to beliefs and superstitions associated with barn owls.

2.4 Ranging behavior and radio telemetry studies

The advent of radio telemetry has facilitated the study of secretive animals, allowing the researchers to observe the animal behaviour and the area traversed (Craighead & Craighead, 1966). Comprehensive telemetry locations provide an insight into what is known as home range and allowed the researchers to estimate spatial distribution of an animals. The concept of home range and core area have been well described by several authors (Burt, 1943; Calhoun & Casby, 1958; Powell & Mitchell, 2012).

‘Home range’ is defined as the area habitually used by an individual or a pair in the course of their normal activity. The term hunting range is used as a synonym of home range when applied to studies of birds of prey. The term ‘core area’ is defined as part of the home range which forms the focus of the individual’s activities, for example, roosting and breeding. Measuring the animal’s home range size, distribution and patterns of utilization is crucial for ecological studies, particularly those related to foraging behaviour, population density, habitat selection, spatial distribution and their interactions (Harris et al., 1990).

Several analytical techniques exist to estimate the ranging behaviour and to study the patterns of home range size and utilization. Radio tracking is a conventional method that is used frequently by researchers to provide data on location, movement and behaviour of animals, from which home range sizes and patterns of utilization can be determined (Harris et al., 1990). This technique was introduced in early 1960’s (Cochran & Lord Jr, 1963) and since then various studies regarding radio-tracking data have been published, such as Kenward (1987). Radio-tracking has been used as a supplement to other techniques such as visual observations (Porter & Labisky, 1986), habitat use estimation through pellet counts (Loft, Menke, & Burton, 1984), and to improve estimates of relative abundance and home range sizes by less accurate methods such as track-counts (Servin, Rau, & Delibes, 1987) and grid trapping (Trevor-Deutsch & Hackett, 1980).

There are two types of radio tracking in radio-tracking studies; continuous and discontinuous (Harris et al., 1990). Continuous study involves tracking an animal in shorter time intervals, for instance between 10 to 30 minutes. This technique produces a series of fixes which displays a rough estimation of an animal's travel route. Usually this technique is deployed when the chances of losing the tracked animals are high due to sudden movements and significant unsuitable terrain. Continuous radio-tracking is also useful to predict the utilization of home range size of an animal, to study the dispersal, movements and activity patterns of the animal or to study the effects of other parameters such as weather condition towards animal behaviour (Harris et al., 1990; Powell & Mitchell, 2012). In addition, it is useful for comprehensive study on habitat selection when animals are introduced into a new area, especially when the habitat patches are small.

Discontinuous radio-tracking involves tracking an animal at random time intervals or at distinct time intervals over the study period. This technique allows for simultaneous study of larger group of animals, particularly herds or social groups, and discrete populations of sympatric species (Forde, 1989). It is important to organize these tracking programs to ensure that the collected data are true samples of tracked animals. For example, comparing sympatric Roe deer (*Capreolus capreolus*) and Muntjac deer (*Muntiacus reevesi*) where these species have distinct diurnal and nocturnal shifts. For home range size calculations, it is important to collect a 24-hour period of data for Roe deers, whereas such tracking period it less crucial for Muntjac deers. In some studies, animals were radio-tracked once daily at 24 hours interval, and the subsequent fixes were denoted as total daily movement of an individual. However, Laundré, Reynolds, Knick, and Ball (1987) found that this technique was inadequate to validly determine the actual distance travelled from 24 hour relocations.

2.5 The barn owl

Tyto alba, which literally derives from Latin meaning 'white owl', is referred to as the common barn owl to distinguish them from the other species in its Family: Tytonidae. To date, owls are divided into two families: Tytonidae and Strigidae. The family Tytonidae includes the barn owls from subfamily Tytoninae and the bay owls (subfamily Phodilinae). The Strigidae family includes all other owl species. Compared to members of the Strigidae family that have round facial discs, barn owls have heart-shaped facial discs, other distinguishable traits are the stiff feathers along the beak of barn owls, giving it a nose-like structure and their calls are screeches instead of typical owl hoots (Taylor, 1994).

A total of 36 *T. alba* subspecies have been identified across habitable continents and islands; with every subspecies having their own morphological variation and behavioural and ecological adaptation that allow them to survive in their respective habitats. *Tyto alba javanica* is a subspecies that resides in the Southeast Asian region, ranging from Peninsular Malaysia to the Greater Sunda (G. M. Lenton, 1984). Across the world, barn owls can be found inhabiting low elevation open habitats such as grasslands, farmlands, deserts, marshes and agricultural fields. In Malaysia, *T. alba javanica* are well adapted predatory bird species that can be found foraging throughout rice fields and oil palm plantations. These nearly worldwide birds are closely associated with man through their use of traditional barn lofts, abandoned buildings, farm buildings as well as tree trunks and fissures in cliffs for their nesting sites where they usually live for the rest of their lives (D. S. Bunn et al., 2010).

Barn owls are cavity nesters that depend on tree holes, cracks and fissures in cliffs, abandoned nests of other species and man-made artificial nest boxes. Barn owls do not construct a nest and do not carry nest materials. Once a nesting site is chosen, they make a slight depression and during the course of incubation the female barn owls will pull out fur from the pellets cast around them, leading to eggs being assembled on a pad of matted, small mammal hair (C. Shawyer, 2011; D. Smith & Marti, 1976). They breed in the first year of life between 10 and 11 month of age, although sometimes males do not mate until their second year of life (D. S. Bunn et al., 2010). In captivity, aviary bred-barn owls exhibit courtship behaviour and copulate as early as 26 to 34 weeks of age (C. Shawyer, 2011).

Breeding season of barn owls usually commence when food availability and weather conditions are favourable so that the females can lay eggs and rear their offspring (Taylor, 1994). In tropical grasslands, barn owls commonly lay eggs during the dry season. As the prey populations reach a peak level earlier at the end of the wet season, the annual die-back of vegetation affects the prey availability to thrive. In temperate regions, breeding season occurs mainly from March to June; which coincide with the onset of higher temperatures. In arid tropical areas, for example in Australia, where vegetation changes are less important, breeding may start during wet periods; corresponding with rodent breeding activity (Taylor, 1994). Barn owls in Southeast Asia, particularly in Malaysia, have two major breeding seasons: from the months of July to September, and from December to February (G. M. Lenton, 1984). The dual breeding seasons are related to the bimodal season of crop yield in plantations and the dual monsoon pattern of Peninsular Malaysia (Lam, 1988).

Female barn owls typically lay 4 to 7 eggs at 2 to 3 days interval, resulting in a considerable age and size hierarchy among the owlets. Duration between the first and the last egg hatch varies between broods, ranging from 29 to 34 days (D. S. Bunn et al., 2010; G. M. Lenton, 1984). The eggs hatch at staggered intervals and usually about every 48 hours. Among the factors that affect the clutch size are the food supply, ability of males to provide food for their mates, condition of breeding adult owls following winter in temperate regions and the date of egg laying (C. D. Marti, 1994). The average hatching success differs among populations and range between 69% to 83% (G. M. Lenton, 1984; Wilson, Wilson, & Durkin, 1986).

2.6 Distribution and variation

To date, barn owls have achieved a global distribution and is found almost everywhere except in the most inhospitable desert regions, closed primary rainforests, mountains areas with extreme winters and some remote islands (D. S. Bunn et al., 2010; Taylor, 1994). The earliest fossil records of barn owls discovered date back 25 to 12 million years ago back in the Miocene period. Generally, barn owls are medium to small-sized owls and most subspecies have long wings and legs that facilitate them to hunt by slowly quartering suitable open habitats and dive into long vegetation to catch their small rodent prey. Some are adapted to more wooded habitats by having shorter wings which enable agile manoeuvring.

Barn owls have a pale heart-shaped facial disc along its round black eyes; a trait that distinguishes this species from other families. Their general coloration varies according to subspecies; from deep grey and rich buff to soft golden washes and immaculate white. In all subspecies, females are generally darker than males, with deep buff on both underparts and upper parts. Females also tend to have darker and more scattered black spots in the wings and tails feathers compared to males. (D. S. Bunn et al., 2010; Taylor, 1994). With any pair of owls, it is easy to distinguish between males and females on the basis of coloration even at some distance. Taylor

(1994) reported that the most reliable characteristic to differentiate between captured males and females was the amount of black flecking on the underparts. Most females (98%, *n*=182) had heavily marked flecks on the underparts of their contour feathers and underwing coverts. In contrast, 95% (*n*=149) of males had less markings on the underpart of their wings (Taylor, 1994).

As previously mentioned, barn owl subspecies vary among one another depending on continents and their habitats. Island subspecies tend to be smaller than mainland owls and among the latter, the South-east Asian subspecies is by far the largest barn owls. Subspecies inhabiting more forested areas tend to have shorter wings and darker plumage whereas those that live in more open habitats such as grasslands and savannahs have longer wings and lighter plumage coloration (Taylor, 1994).

2.7 Barn owls as biological control

Biological control involves the suppression of one organism by another and is a process used for the eradication and/or control of invasive alien species (Cook & Baker, 1983). Agents of biological control most commonly utilized are pathogens, parasites and insects. The biological control agent should preferably be an indigenous species or dependent on the target species for survival, as this will minimize the risk that the control agent may over time become an invasive alien species (Weeden, 2002). As one of the important components in integrated pest management, biological control should be a control that is long-lasting, sustainable, environmental-friendly, efficient and cost efficient (Singleton, Leirs, Hinds, & Zhang, 1999).

Barn owls as a biological control agent is amongst the simplest approach to integrated pest management. It typically involves the manipulation of owl population by supplementing artificial nest boxes (Wendt & Johnson, 2017). Once established, the owls will hugely increase the predation levels of rodent populations and potentially remove significant numbers of these pest species by hunting and consuming a substantial amounts of rats and mice (C. D. Marti, 1988). Barn owls are tied to the cyclical nature of their prey population and the increase and decrease in numbers is associated with prey abundance (Taylor, 1994). Additionally, barn owls are a sedentary species and are less likely to migrate to a new location once they have settled down within a nesting site (Paz et al., 2013). Despite a wide range of diet, barn owls are specialists of small rodents such as rats, mice, voles, and others.

Various barn owl bio-control programs have been implemented around the world. To name a few examples, Meek et al. (2003) carried out a 21 year carefully documented *T. alba* study and release in lowland southern England as part of a reintroduction program of the declining local barn owl population and as a bio-control agent against field voles and wood mice. M. Green and Ramsden (1986) released 223 captive-bred barn owls at Devon, and studied their distribution, release methods, the distance after release, duration and site fidelity across Britain as part of their reintroduction and conservation program. A study by Martin (2009) in an Everglades agricultural area in South Florida, USA, installed artificial nest boxes and reported an increased regional abundance of barn owls. However, the owls were not capable of reducing rodent numbers as the reproductive capacity of rodents simply outpaced removal of rodents via predation. Nevertheless, he suggested that more long term data was required as his data consisted of rodent numbers after only a year from the program initiation.

2.8 Diet of barn owls

Numerous feeding ecology and diet composition studies of barn owls have been carried out over its worldwide distribution owing to the ease of identifying prey remains found inside regurgitated pellets. Pellets are regularly collected at nesting sites during breeding seasons and can be collected at roosting or perching sites. Inside pellets, skulls, skeletal parts and mandibles of small mammals, birds, insects, amphibians and reptiles are found intact and can be easily identified. The proportion of prey remains found inside the pellets are relatively similar with the proportion of prey consumed as barn owls swallow their prey whole (Raczyński & Ruprecht, 1974; Terry, 2004).

2.8.1 Diversity of prey in the diet

Numerous studies regarding diet composition of barn owls worldwide have shown that small mammals are their main prey. In most parts of the world, three major group of mammals, i.e. rats and mice (Muridae), shrews (Soricidae), and voles (Microtidae), contribute to 74% to 99% of barn owl prey (Kross, Bourbour, & Martinico, 2016). Other prey items recorded were amphibians, small birds, lizards, insects and in remote cases, bats (Vargas, Carlos Landaeta, & Simonetti, 2002). However, these alternate preys are uncommon and usually occur when the preferred small mammal prey is scarce, and these alternative preys are abundant. For example, barn owls on Cape Verde Island feed on geckos and a variety of small birds such as plovers, godwit, weavers, pratincoles and turnstones when the rodent population fluctuates (Rabaça & Mendes, 1997). Insects are commonly taken in relatively smaller amounts and in most studies, insects feature in the diet of barn owls in significantly hotter, drier and temperate environments (Goyer, Barr, & Journet, 1981; Shehab, 2005).

2.8.2 Diet in relation to habitat

The nature of the habitat has significant influence towards the relative proportion of different species in the local small mammal community. Throughout Europe, field voles (*Microtus agrestis*) and common voles (*Microtus arvalis*) are the most important prey of barn owls, contributing from 50% to 65% in both prey numbers and biomass (D. Glue, 1967; Kitowski, 2013; Love, Webon, Glue, Harris, & Harris, 2000). These two vole species can be found in different landscapes as the field voles prefer moist long grasslands and common voles mostly inhabit drier, shorter grasslands such as pastures and cereal crops (D. S. Bunn et al., 2010). To the south of Europe, Mediterranean climates where the conditions are unfavourable towards growth of grasslands, these *Microtidae* are absent and the diet of barn owls mainly depend upon various species of mice, particularly the house mouse (*Mus musculus*), African house mouse (*M. spretus*) wood mouse (*Apodemus sylvaticus*) and yellow-necked mouse (*A. flavicollis*) (Bontzorlos, Peris, Vlachos, & Bakaloudis, 2005; Love et al., 2000; Scheibler & Christoff, 2004). In general, rats and mice of the family *Muridae* are the main prey of barn owls in most Mediterranean habitats and over much of the tropics and subtropics, in Australia and many islands (Taylor, 1994).

In most parts of the world, shrews are usually significant secondary prey species that are frequently taken by owls as these species can be found living almost everywhere from North America to North-western America, Africa, Eurasia, Asia and Australia. This species has adapted to life in a wide variety of environments; inhabiting tropical forest, tundra, coniferous, savannah, humid and arid grasslands and deserts (D. S. Bunn et al., 2010; Taylor, 1994).

Most studies of barn owls in South-east Asia are concentrated in Malaysia, Thailand and Indonesia. This raptor species thrives in rice field areas and oil palm plantations and throughout both agricultural fields, barn owls feed mainly on indigenous rat species such as the Malayan wood rat (*Rattus tiomanicus*) and rice field rat *(Rattus argentiventer*). In more suburban to urban areas, a substantial amount of commensal pest Norway rats (*Rattus norvegicus*) have been reported as a principal prey species in the diet composition of barn owls as this rodent dominates and thrives in this habitat (Hindmarch & Elliott, 2015).

2.9 Barn owl pellets

The stomach acid of barn owls is weaker than other predatory birds, as the prey consumed are partially digested, leaving the bones and other undigested prey remains such as fur, hair, teeth and claws are intact. (Andrews & Cook, 1990; Hoffman, 1988). These undigested food contents will be regurgitated in the form of a pellet and the proportion of prey recovered from pellets usually coincide with the proportion of prey consumed (Dodson & Wexlar, 1979; Raczyński & Ruprecht, 1974). Generally, these pellet provide information on the ecological role of predators via the natural predation of small mammals and predator-prey relationship in different habitats, different seasons as well as different years (D. E. Glue, 1970; Teta, Hercolini, & Cueto, 2012). In addition, it provides the details of food spectrum of the owls and the food selection of avian predators. A number of avian predators are considered as effective samplers of local small mammal abundance, producing vertebrate assemblages in quantities that would take a longer period of trappings session to accumulate (D. E. Glue, 1970).

2.10 Prey selection and foraging habitats

Throughout most of its range, barn owls are entirely nocturnal based on the absence of day-time hunting that has been noted from personal observation and through the use of radio-telemetry studies in North America (B. A. Colvin & McLean, 1986; Jaksić, 1982; Rosenburg, 1986), Southeast Asia (J. Duckett, 1991; Hafidzi, Zulkifli, & Kamarudin, 1999; Heru et al., 2000) , Africa (Meyer, 2008) and Australia (Dickman, Predavec, & Lynam, 1991). In northern parts of Europe, barn owls were seen hunting during the daytime as well as night during summer and winter due to shorter periods of night time and little darkness during mid-summers (Meek et al., 2003). Barn owls generally start hunting between 1900 hours to 2000 hours (Taylor, 1994).

Barn owls often search for prey and hunt from their perching sites, where they frequently perch motionless and observe for any prey movement in the landscape. Barn owls also spend a certain amount of time airborne foraging for targeted prey by slowly quartering suitable habitats (Taylor, 2009). Unlike other bird species, this raptor has a relatively long wingspan which give them a high wing surface area to body mass ratio, enabling them to glide slowly and make sudden turns without stalling. Low wing loading also enables them to carry and lift heavy prey such as large-sized rats at slow flight speeds, thereby reducing the force required and minimising energy expenditure when transporting prey to their nest or perching site (D. S. Bunn et al., 2010).

Barn owl flights are completely silent and this advantage reduces the chances of being detected acoustically by prey, particularly small mammals (Sarradj, Fritzsche, & Geyer, 2011). The noise suppression developed by owls during their evolutionary period million years ago has been described by these three structural adaptations; (i)