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The Ranging Behaviour of *Tyto alba* in Oil Palm under Baiting with Anticoagulant Rodenticides, Warfarin and Brodifacoum and a Biorodenticide *Sarcocystis singaporensis* (Zaman & Colley, 1975)

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ABSTRACT

This study investigated the ranging behaviour of *Tyto alba* in oil palm under three different rodenticide applications. For this purpose, four treatment plots were established in the FELCRA oil palm plantation in Seberang Perak. Three plots were baited each with warfarin, brodifacoum and a protozoan based biorodenticide, *Sarcocystis singaporensis*, plus a fourth non-baited control plot. For each plot, a pair of *T. alba* was attached with radio transmitters and tracked for three nights with a radiotracking equipment. Radio locations were plotted on a 1:66 scale map. These radio locations were used to determine the home range size, the core area size, the mean distance moved from one radio location to the next and the furthest radio location from the nest box or the centre of activity. Data were analysed with the help of the software BIOTAS. The home ranges were analysed using the method of Minimum Convex Polygon (MCP), the Harmonic Mean (HM) and the Kernel estimator. The home range sizes of the chemical rodenticide areas were consistently larger than the biorodenticide and the non-treated control areas. For males, the home sizes calculated using the MCP method were 60.51 ha; 36.95 ha; 18.19 ha and 15.22 ha for the brodifacoum, warfarin, control and biorodenticide treated plots, respectively. As for the females, the corresponding home range sizes were 69.39 ha, 52.50 ha, 28.80 ha, and 49.85 ha. Meanwhile, the home range sizes of the females were significantly larger than those of the males when calculated using the MCP and HM methods. The core area size, which is conventionally treated as the defended area around the nest box, yielded male core area sizes of 16.43 ha, 9.0 ha, 4.48 ha and 1.39 ha for brodifacoum, warfarin, control and biorodenticide treated plots respectively, based on the MCP method. The corresponding core area sizes for the females were 28.55 ha, 37.17 ha, 11.21 ha and 19.02 ha. The females tend to move over a longer distance compared to that of the males; however, the mean distances travelled by the females and males were not significantly different. The data suggest that the furthest radio locations of the females from the nest box were greater than that of the males in all the treatment plots. The difference between the furthest radio locations of the females and males were significant. These data suggest that in areas treated with chemical rodenticide, *T. alba* has to engage in greater exploratory flight resulting in larger home range size, core area size and greater distance between the radio locations to secure enough prey to meet their energetic demands.

Keywords: *Tyto alba*, rat control, anticoagulant rodenticides, *Sarcocystis singaporensis*, radio-telemetry

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INTRODUCTION

Secondary poisoning to non-target animals can be primary, i.e. the exposure to poisoned baits, when non-target species consume them directly; secondary, when predators eat poisoned prey; or tertiary, when these predators were in turned consumed by a top predator (Smith *et al.*, 1990). There have been reports of secondary poisoning of predatory birds from the use of brodifacoum to control rats in many parts of the world. Eastern Screech-Owls, *Otus asio*, were found dead after exposure to brodifacoum, which had been applied in orchards (Merson *et al*., 1984; Colvin *et al.,* 1987). In New Zealand, the woodhens, *Gallirallus australis australis* and *Gallirallus australis scotti* were found dead after consuming rats that had fed on bait containing brodifacoum (Taylor, 1994). In Britain, the issue of secondary exposure and poisoning by second-generation rodenticides was highlighted in the 1980s as a part of the National Predatory Bird Monitoring Scheme via a long-term study in which residues were detected in barn owl *Tyto alba* carcasses which had been collected from throughout the country (Newton *et al.*, 1990). There have been reports of *T. alba* decimated in oil palm in Malaysia as a result of secondary poisoning from second generation rodenticide. Berny *et al*. (1997) suggested that poisoned rodents were more vulnerable and more easily captured than their unexposed counterparts because of their slower reactions, thereby increasing the chance of capture by predators such as, the barn owl. This will certainly enhance the exposure of anticoagulant rodenticides to raptors and carnivores.

The risk of secondary poisoning from chemical rodenticides prompted the search for an alternative approach that would not disrupt natural predation. In the recent years, the use of biorodenticides has found its practical application in the field for rodent control. One of the most effective biorodenticide to date is *Sarcocystis singaporensis,* a protozoan parasite. Zaman (1976) stated that *S. singaporensis* has been extensively studied for more than 25 years on its potential as a biorodenticide. It is a parasitic unicellular organism of the phylum Apicomplexa. The main hosts of the parasite include boid snake (*Phyton reticulatus)* and rodents of the genera *Rattus* and *Bandicota.* This particular parasite is not effective for or harmful to a wide range of birds, reptiles, mammals including primates, as well as other members of the rodent family, *Muridae*. Previous laboratory and field studies revealed that the infection of wild rats with high numbers of infective stages of *S. singaporensis* induced mortality of up to 100% in the laboratory and 70%-90% in the field after 10-14 days (Jakel *et al*., 1999). This parasite induces a fatal pneumonia in rodents once infection with sporocysts exceeds a certain threshold (Wood, 1985). Jakel *et al*. (2006) have shown that tactical infection of field rats with *S. singaporensis* is highly effective and economically competitive to poison baits in ricefields.

Since *S. singaporensis* has a specific host, it can be a viable option for a sustainable biological control of rodents using barn owl in oil palm. *T. alba* a vagrant species at the turn of the century is now a common resident in oil palm. Basri *et al*. (1996) reported that *T. alba* were widely established in oil palms and their population reaching some 15% of areas in Peninsular Malaysia by the early 1990s. The owls feed almost exclusively on rats, for instance, it makes up 99.4% of their diet in one study (Smal, 1990), it had gone from ‘‘rare’’ to ‘‘common’’ in Malaysia (Duckett & Karuppiah, 1990).

Warfarin has been the main rodenticide applied in most oil palm plantations in Malaysia, in combination with the natural propagation of *T. alba.* However, with reports of rats showing resistance towards warfarin, the second generation anticoagulant, particularly brodifacoum, is increasingly employed. While there has been no apparent evidence of secondary poisoning from warfarin, the detrimental effects of brodifacoum on *T. alba* have been documented (Mendenhall & Pank, 1980). Apart from the known and unknown risks from secondary poisoning, the application of rodenticides may have other effects, including the behaviour of predators. In particular, they may influence

the foraging behaviour of the owls, which can have a far reaching consequence in the long run. In this study, radiotelemetry was employed to compare the foraging behaviour of owls under the application of baiting with warfarin, brodifacoum and biorodenticide. A number of parameters, including home range size, core area size, mean distance moved and furthest distance moved away from the nest, were used to compare the effects of rodenticides to *T. alba* behaviour of these rodenticides. This study has provided some insights into the impact of rodenticide and how it may influence the sustainability of the barn owl natural propogation programme for a viable rat control in oil palm.

MATERIALS AND METHODS

The study was conducted at the FELCRA oil palm plantation in Seberang Perak, Perak, from March to May 2009 and from July to September 2009, both during the breeding seasons when rat damage to oil palm was greater than 5% at the plantation.

Baiting with Rodenticides

Four treatment plots, with six nest boxes each, were established in this study. The area for each plot is not less than 100 ha. Each plot is separated between three and five km from one another. Three plots were baited with warfarin, brodifacoum and the biorodenticide, based on *Sarcocystis singaporensis*, respectively. The fourth was left untreated and served as the rodenticide-free control plot. Since the nest boxes were not evenly distributed, the average density of the nest boxes worked out to be one box for every 25 ha. The first baiting campaign with warfarin and brodifacoum was carried out on 20-25th October 2008 and the second baiting campaign was carried out on 10-12th March 2009. Baiting with biorodenticide was carried out on 25-27th January 2009. The baits were placed at the base of each palm tree. In the first campaign, a single round of baiting was carried out, while two baiting rounds were conducted in the second baiting campaign. The baits were placed at the base of each palm tree in each of the designated plots.

Radio Telemetry

In this study, radio telemetry was used to detect the locations of owls in real time and delineate individual home range size. The radio telemetry set was comprised of a radio receiver Model CE – 12 (Custom Electronics of Urbana Inc), with a frequency range coverage of 150 – 152 MHz. The transmitters used were surface-mounted design, equipped with a 3-3.5 V cells. Signals emitted by the transmitters were detected with the help of a 3-element Yagi antenna. The frequency employed for this study was in the range of 150-151 MHz. Meanwhile, the 3-element Yagi antenna is suitable for the frequency above 140 MHz and for tracking on foot. This antenna has the advantage, based on its signal reception pattern of distinguishing between true and reverse bearing (Kenward, 2001).

A pair of *Tyto alba* nesting in one of the nest boxes in each treatment plot was captured and tagged with a radio transmitter. This would allow a comparison between the mating pairs. The occupancy rate at the time of the radio telemetry exercise was in the range of 50 to 66% (three or four boxes occupied in each plot). This would reduce the effects of different densities of barn owl on home range size. The transmitters were harnessed and mounted as backpacks on each *T. alba* and were pre-set to emit signals at unique frequencies. By tuning the radio receiver to the desired frequency and following the path of the strongest signal, the position of the owl was ascertained on the ground. Each bird was followed for three nights, i.e. from 1900 hrs to 0700 the following day. The radio locations of the owls were recorded at an hourly interval. Radio tracking commenced four to five days after the second baiting campaign. It has been established in most wildlife radio tracking studies that at least 35 fixes are required since any additional radio locations add little to the home range area (Kenward, 1987).

Home Range Analysis of Barn Owl

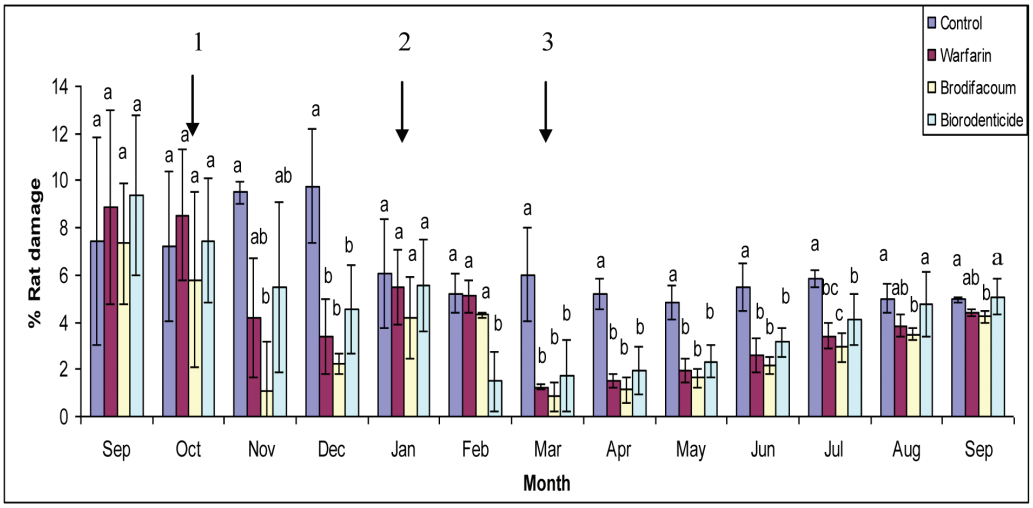
The home range and the core area size were calculated using the Minimum Convex Polygon (MCP) and the Harmonic Mean (HM) methods. The dataset was analysed with the help of BIOTAS, an ecological software solution. The MCP method, which simply calculates the area of the polygon formed around the outermost radio locations, has been the most commonly employed method to represent range size and shape (Harris *et al*., 1990). Meanwhile, the HM method allows the demarcation of the 'core area' which can be assumed as the defended perimeter, if territoriality is exhibited by the owls. By convention, 95% and 50% of the utilized areas calculated were regarded as the home range and the core area, respectively.

Harris *et al*. (1990) suggested using at least two home range estimators with any dataset; one of which should be the MCP because it would be used to compare with other home range studies. Meanwhile, Seaman *et al*. (1999) reported that out of the home range studies published from 1980 to 1997, 87% used the MCP method, the HM estimator (22%), the kernel method (7%), and the bivariate normal ellipse method (7%). In this study, the MCP and the HM methods were employed, along with a third which is the most recently developed kernel method, using the statistical technique that is increasingly used in home range studies. The results from the BIOTAS output would be multiplied with the actual distance on the ground so as to estimate the actual home range size of *T. alba.* The radio locations were first plotted on a 1cm x 1cm graph paper to determine their coordinates; the area 1cm x 1cm (1 cm^2) on the graph represents 66.67m x 66.67m (4445 m^2 = 2.25 ha) in the field.

RESULTS

Rat Damage

The percentage of rat damage is shown in *Fig. 1*. After the first baiting campaign in the biorodenticide and warfarin treated plot, rat



1. First baiting campaign – all rodenticides
2. Second baiting campaign – biorodenticide only
3. Second baiting campaign – warfarin and brodifacoum

Fig. 1: The mean Percentage of rat damage in all the treatments from September 2008 to September 2009. Arrows indicate rodenticide application. Different letters indicate significant difference

TABLE 1.1
Home range size* of males.

Treatment	Home range size (ha.)		
	MCP	HM	KERNEL
Control	18.19	27.43	33.46
Warfarin	36.95	59.14	78.19
Brodifacoum	60.51	115.09	147.37
Biorodenticides	15.22	46.63	25.50

*The home range size is based on the calculations from 95% of radio fixes (to reduce the effects of outliers). In the MCP method, the furthest fix was ignored.

TABLE 1.2
Home range size* of females

Treatment	Home range size (ha.)		
	MCP	HM	KERNEL
Control	28.80	41.84	58.22
Warfarin	52.50	91.64	143.12
Brodifacoum	69.39	160.52	167.33
Biorodenticides	49.85.	70.42	104.82

*The home range size is based on the calculations from 95% of radio fixes (to reduce the effects of outliers). In the MCP method, the furthest fix was ignored.

damage was found to decrease from 7.46% to 5.47%, and from 8.55% to 4.18%, respectively. These reductions were substantial compared to the control plot (9.49%) although they were not significantly different ($F = 4.65$; $p = 0.052$). In the brodifacoum plot, the level of damage decreased to 1.11% from 5.80%, which was significantly lower than the control plot, although not significantly different from the warfarin and biorodenticide treated plots ($F = 4.65$; $p = 0.052$). When two baiting rounds were carried out in the second campaign, rat damage was found to have substantially decreased from 5.56% to 1.48% in the biorodenticide treated plot, and this was significantly lower than the control plot (5.20%) ($F = 14.84$; $p < 0.01$). Meanwhile, the rat damage increased gradually after baiting, but it remained low (4.13%), and was still significantly lower compared to the control plot (5.86%) ($F = 15.46$; $p<0.01$) six months after baiting. Similarly, rat damage in the warfarin treated plot increased gradually after baiting. Compared to the biorodenticide plot, however, the level of damage in the warfarin plot one month after baiting was 4.41%, and this was not significantly different from the control plot (4.97%). In the brodifacoum plot, the damage was decreased to 0.84% from 4.32%; a reduction which was significantly lower than that of the control plot (6.02) ($F = 19.79$; $p < 0.01$).

Home Range Size

Signals from all the radio-tagged individuals were successfully detected by the radio receiver. Only 95% of the radio fixes were included, while the furthest point was ignored to minimize the influence of the outliers on the home range size. The estimated home range and core area size are summarized in Tables 1.1 and 1.2 for the males, and in Tables 2.1 and 2.2 for the females.

The home range sizes estimated by the three methods yielded the following results. For the males, the estimated home range size

TABLE 2.1
Core area size (50%) of males

Treatment	Core area (ha.)		
	MCP	HM	KERNEL
Control	4.48	5.91	2.99
Warfarin	9.0	15.65	5.97
Brodifacoum	16.43	22.06	36.25
Biorodenticides	1.39	3.27	3.32

Estimation of Core area is based on 50% of radio fixes (Selection of radio fixes by the software is based on different criterion for each estimator)

TABLE 2.2
Core area (50%) of females

Treatment	Core area (ha.)		
	MCP	HM	KERNEL
Control	11.21	7.46	12.91
Warfarin	37.17	20.74	35.54
Brodifacoum	28.55	24.44	31.72
Biorodenticides	19.02	24.06	26.73

Estimation of Core area is based on 50% of radio fixes (Selection of radio fixes by the software is based on different criterion for each estimator)

determined by the MCP method were 15.22 to 60.51 ha, followed by 27.43 to 115.09 ha for the HM method, and 25.50 to 147.37 ha for the fixed kernel range estimator. For the females, the home range size estimated from the three methods yielded the home range sizes of 28.80 to 69.36 ha, 41.84 to 160.42 ha, and 58.22 to 167.33 ha, respectively. The home range sizes, estimated using the MCP method, were smaller than the other two methods for both the sexes. The home ranges delineated by the MCP method are shown in *Fig. 2 – 5*.

The data from all the three methods consistently showed that the range size of the individuals in the areas treated with chemical rodenticides was larger than those of the untreated control and biorodenticides treated areas. Meanwhile, the home range sizes of the females were significantly larger than the males, as calculated using the MCP (*t*-test, P = 0.028) and the HM (*t*-test, P = 0.019) methods, but they were not significantly different when calculated by the kernel estimator (*t*-test, P = 0.071).

Core Area Size

The core area sizes of individual owls are shown in Tables 2.1 and 2.2. The percentages of the core area to the home range size are shown in Tables 3.1 and 3.2. For the males, the estimated core area, using 50% MCP ranging between 1.39 and 16.43 ha, corresponded to 9% and 27% of the home range size, respectively. The core area size determined by 50% HM ranged from 3.27 to 22.06 ha, which corresponded to 15% and 19% of the home range sizes, respectively. The kernel estimator yielded core area sizes of 2.99 to 36.25 ha, which corresponded to 8% and 24% of the home range sizes, respectively. The core areas for the males were consistently smaller in the untreated control and biorodenticide treated areas, and these corresponded to 4.48 and 1.39 ha, based on the 95% MCP method, followed by 5.91 and 3.27 ha (the 95% HM method), and 2.99 and 3.32 ha (the 95% kernel estimator). In comparison, the core area for the males in warfarin and brodifacoum treated areas were 9.0

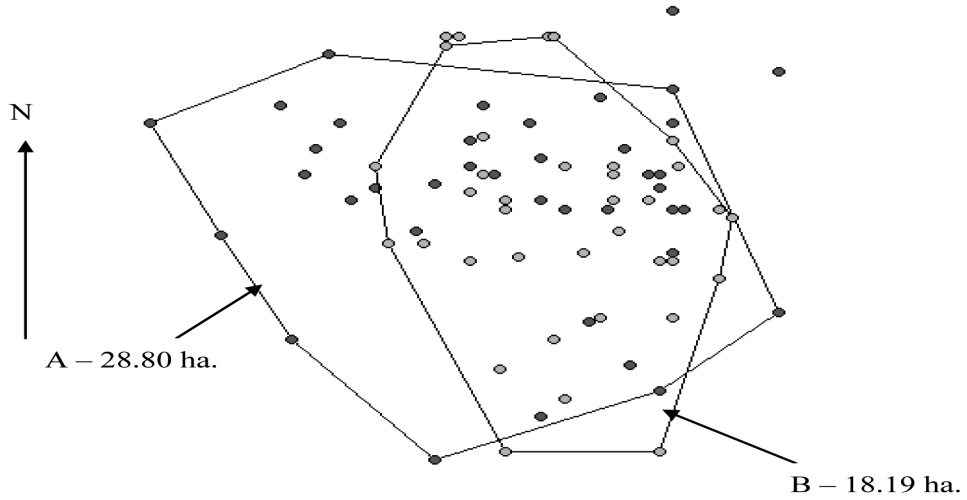


Fig. 2: Home Range of owls in the control plot using the MCP method: A – Female; B – Male (not drawn to scale)

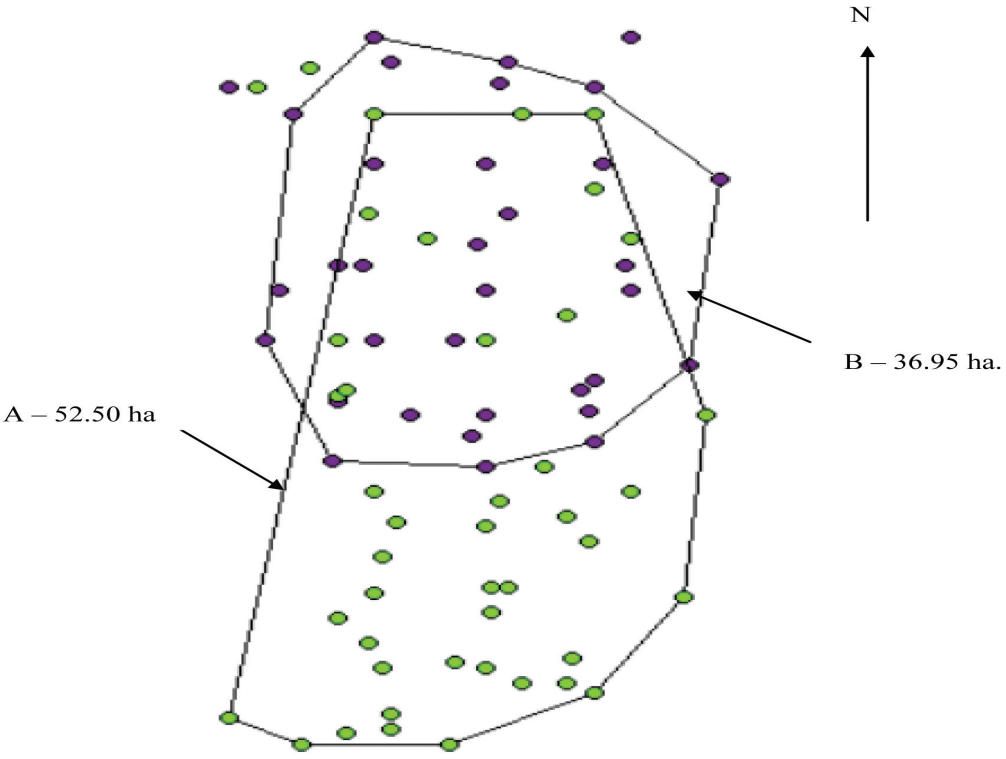


Fig. 3: Home Range of owls in warfarin Treatment plot using the MCP method: A – Female; B – Male (not drawn to scale)

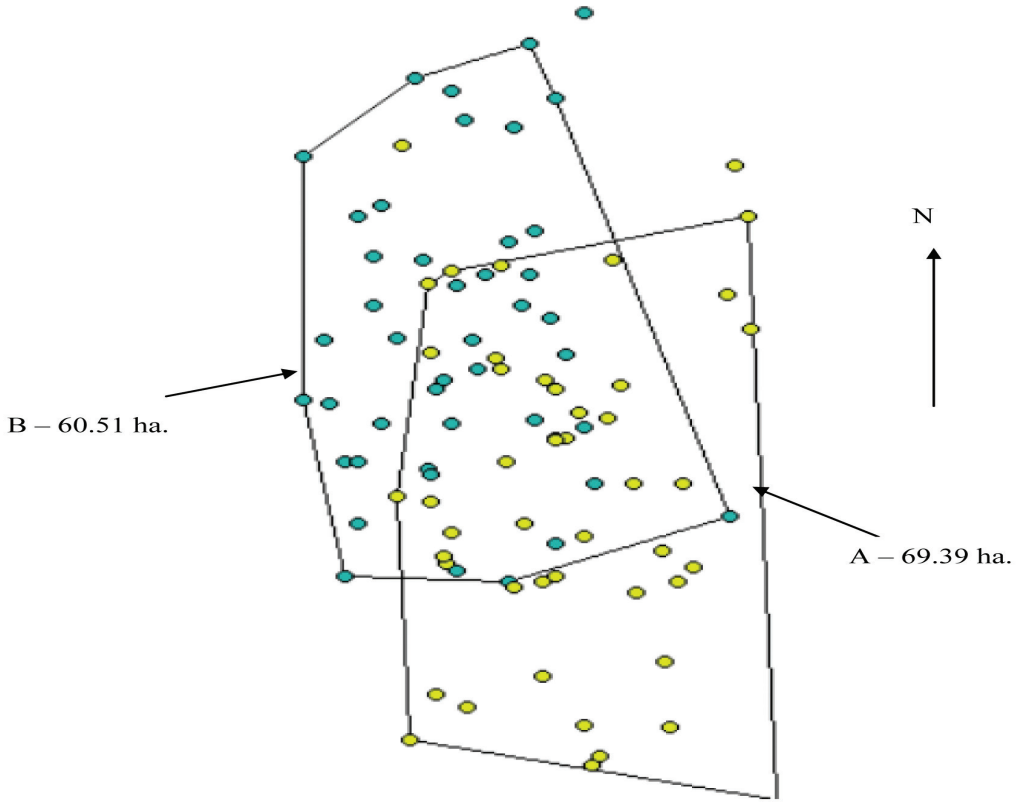


Fig. 4: Home range of owls in brodifacoum treatment plot using the MCP method: A – Female; B – Male (not drawn to scale)

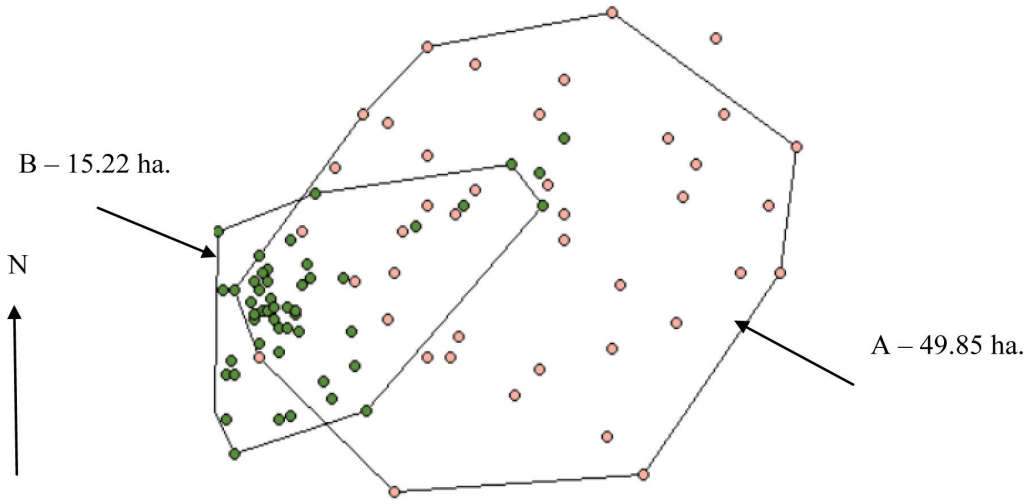


Fig. 5: Home range of owls in biorodenticide treatment plot using the MCP method: A – Female; B – Male (not drawn to scale)

TABLE 3.1
Percentage of the core area size of males

Treatment	Percentage of core area to home range size (%)		
	MCP	HM	KERNEL
Control	24.65	21.54	8.95
Warfarin	24.36	26.46	7.64
Brodifacoum	27.15	19.17	24.60
Biorodenticides	9.17	7.02	13.02

Table 3.2
Percentage of the core area size of the females

Treatment	Percentage of core area to home range size (%).		
	MCP	HM	KERNEL
Control	38.90	17.82	22.18
Warfarin	70.80	22.63	24.83
Brodifacoum	41.15	15.23	18.96
Biorodenticides	38.17	34.17	25.50

and 16.43 ha, based on the MCP method, 15.65 and 22.06 ha (the HM method), and 5.97 and 36.25 ha (the kernel estimator). The core areas for the females were consistently smaller in the untreated control plot by the MCP, the HM and the kernel estimator, with 11.21, 7.46 and 12.91 ha, respectively. However, the core area sizes of the females in the rodenticide treated areas were larger.

As for the females, the core area estimated by the 50% MCP method ranged between 11.21 and 28.55 ha, which corresponded to 38% and 41% of the home range sizes determined using the 95% MCP method. The core area calculated using the 50% HM ranged between 7.46 and 24.44 ha and this corresponded to 18% and 15% of the home range sizes calculated with the 95% HM method. The core area, calculated by the kernel estimator, ranged between 12.91 and 35.54 ha, and this corresponded to 22% and 25% of the home range size estimated with 95% kernel estimator.

A comparison between the males and females showed that the core area of the latter group were significantly larger than their male counterparts, when estimated with 50% MCP (*t*-test, P = 0.04), but not significantly different from HM (*t*-test, P = 0.06) and the kernel estimator (*t*-test, P = 0.10). Meanwhile, a comparison of the percentages of the core area to home range between the males and females showed that they were not significantly different, either using the MCP method (*t*-test, P = 0.12); the HM (*t*-test, P = 0.25) or the kernel estimator (*t*-test, P = 0.08).

Mean Distance Moved between Radio Locations and Furthest Radio Locations from Nestbox

The mean distance moved between the radio locations for the males and females are shown in Table 4.1. The females had the tendency to move over a longer distance compared to males. The mean distance moved by the females and males ranged from 281.18 m to 453.03 m, and from 184.09 m to 449.67 m, respectively. Thus, the mean distance travelled by the females and males were not significantly different (*t*-test = 0.072, P > 0.05). This could be attributed to the small sample size, being a female and a male each for

TABLE 4.1
The mean distance travelled between radio locations

Treatment	Male (m)	Female (m)
Control	228.96	281.18
Warfarin	327.62	400.33
Brodifacoum	449.67	453.03
Biorodenticides	184.09	384.39

TABLE 4.2
The furthest radio locations from the nestbox

Treatment	Male (m)	Female (m)
Control	515.36	578.67
Warfarin	700.03	920.71
Brodifacoum	1076.05	1474.74
Biorodenticides	673.37	774.71

each treatment plot. Table 4.2 summarizes the furthest radio locations from the nest box, i.e. a measure of how far a bird flew away from the nestbox. The furthest distance moved from the nest box for each treatment for the females were 578.67m for the control untreated plot, 920.71 m for the warfarin treatment plot, 1474.74 m for the brodifacoum treatment plot and 774.71m for the biorodenticide treatment plot. The data suggest that the furthest radio locations of the females from the nest box were greater than that of the males in all the plots. For comparison purposes, the furthest radio locations from the next box for the males were 515.36m, 700.03m, 1076.05 m and 673.37 m, respectively. The difference between the furthest radio locations of the females and males was found to be significant (t-test = 0.0402, $P < 0.05$).

DISCUSSION

The home range size of individual owls radio tagged in the chemical rodenticide areas was consistently larger than the biorodenticide and the non-treated control area. This is evidently obvious as rodents in the warfarin and brodifacoum treated areas could be suggestively lower in density (as reflected by the damage levels in *Fig. 1*) compared to the other treatment plots, indicating that the low rat population is associated with larger home range size of barn owl. Village (1982) showed that home range of kestrel was inversely correlated with vole abundance, i.e. low vole population size was associated with large home range size and vice versa. Depletion of rat population from direct feeding of baits could be the plausible reason why the home range sizes of owls were substantially larger. It reflects the greater exploratory flight the owls have to engage before encountering a potential prey. Meanwhile, the home range size of owls radio-tracked in biorodenticide treated area was smaller and in fact almost comparable to the control untreated plots. This could be explained by the delayed action of the onset of death. In contrast, Wood *et al.* (1989) found that the LFP_{50} for *R. tiomanicus* fed with warfarin was 3.08 days (1.38 – 9.08) for the females and 1.22 days (0.38 – 4.16) for the males. For single feeding anticoagulant like brodifacoum, death would be much quicker. Although rats exposed to biorodenticide baits did not succumb as fast as rats that had consumed single feeding chemical rodenticides, particularly the second generation

anticoagulant, they were not as active as when the parasites started to induce pneumonia, i.e. 10 – 14 days post consumption (Jakel *et al.,* 1999). This is because the parasite multiplies in the endothelial cells of blood vessels of the rat, thereby perforating the vessels once it leaves the host cells (Jakel *et al.,* 1996). Therefore, they become easy preys for the owls to spot on and this explains the substantially smaller home range, which is quite similar to the baseline home range size in normal hunting condition, i.e. the non-treated areas.

The home range sizes of females were consistently larger than those of the males in all the treatment plots as estimated by all the three methods. This could be explained by the females being more active at the onset of the breeding season. A study by Taylor (1994) showed that the females had to accumulate substantial body fat reserve to prepare for the nesting and incubation period. Sufficient fat reserve is crucial to produce a viable clutch size and to improve reproductive output. Taylor (1994) found that clutch size was related to the body weight of the female immediately before laying. The larger home range size reflects the higher rate of predation by a female compared to a male which only hunts for individual metabolic requirements.

Core area is a reflection of the area around the centre of activity within the general home range area. It could be defended or otherwise depending on the food resources. In barn owls, the core areas are typically associated with the nest box. If territorial behaviour is maintained than the core area is mutually exclusive and actively defended from encroachment by other individuals. According to Jason *et al.* (2005), barn owls usually do not actively defend their foraging territories from other owls, but they will defend the immediate area around their nests. In this study, this particular aspect could not be ascertained as a number of owls from neighbouring boxes will have to be radio-tracked simultaneously. This is an indication that the males in the rodenticide-treated areas have to maintain a larger core area size to secure sufficient prey.

The mean distance between the radio locations was also quite consistent with the home range and the core area data. The mean distances travelled between the radio locations for the females were further than those of the males for all the treatments, illustrating a higher hunting activity of the females. The same argument applies i.e. the females have to accumulate sufficient body fat for egg production and subsequent incubation. Higher energetic requirements demand higher food intake. Assuming that the males and females hunt with equal efficiency, the latter have to move over a longer distance per unit time to secure more prey than the males. The furthest radio locations from the nest box for the females were also greater than those of the males. This supports the argument that the females would venture further than the males from the centre of activity, i.e. the nest box in search of greater quantities of prey. According Newton (1979), females must also build up enough reserves for use during incubation to act as an insurance against temporary food shortage, while Perrins (1970) suggested that females started breeding as soon as they had accumulated enough reserves of energy and nutrients to produce eggs. Thus, insufficient prey will influence female barn owl's ability to accumulate adequate body reserves which consequently lead to failure to start breeding (Taylor, 1994).

The comparison between the treatment plots is also consistent with the home range and the core area data. The mean distance travelled between the radio locations were the highest in the warfarin- and the brodifacoum-treated areas for both the males and females. Meanwhile, the densities of the rats in these plots, where chemical rodenticides had been applied, were lower than the control untreated plot. Chemical rodenticides, especially brodifacoum has been proven to be effective against rat (Wood *et al.,* 1989) as it only needs a short time to inflict death to rats when baits have been ingested. In the warfarin- and brodifacoum-treated areas, rat damage was successfully suppressed to below 2% and 1% respectively from around 5% before baiting was done. The lower rat population

would result in a larger home range size of barn owl where they had to travel over a larger area to look for prey. The data for biorodenticide treated area seemed to match those of the control non-treated area. This is probably due to the rats taking longer time to succumb from the onset of pneumonia. As they grew weaker, the owls had a better chance of hunting them down. Comparing the furthest radio locations from the nest box shows that of the distance in the brodifacoum treated area was twice that of the biorodenticide area for both the males and females. Rats exposed to brodifacoum succumbed much earlier than those who were exposed to biorodenticide. Therefore, the higher and faster rate of mortality in the brodifacoum treated area resulted in a substantially lower rat density compared to the biorodenticide treated area. Consequently, the owls had to cover a much greater distance from the nest box to meet their food requirements.

Jason *et al.* (2005) estimated the individual home ranges of barn owls to be as large as 3174 ha and as small as 151 ha depending on the differences in the availability of habitat and prey. They also concluded that during the scarcity of food in a particular area, an owl might have to travel long distances to get adequate food that it needed to survive. It would hunt over a much smaller area if food abounds; the home ranges of neighbouring barn owls in food rich situation could overlap significantly (Jason *et al.,* 2005).

CONCLUSION

This study concludes that both the first and the second generation anticoagulant rodenticides led to a larger home range size of *T. alba.* The lack of adequate food source by the depletion of prey forced the owls to engage in greater exploratory flight. The implication would be the owls had to expand more energy to meet their metabolic requirements. For the females, this might have a drawback on its reproductive potential as it might offset the build-up of fat reserve for egg laying and incubation purposes. The application of biorodenticides had less impact on the ranging behaviour of the owls as the home range size was comparable to the control non-treated plot. The longer time to death, from biorodenticide bait consumption compared to anticoagulant rodenticides and the weaker infected rat, made them easier prey and thus less effort to secure sufficient prey. The host specific *S. singaporensis* has an added advantage compared to the anticoagulants since it poses no risk of secondary poisoning to the owl. Therefore, *S. singaporensis* would serve as a better choice rodenticide for a sustainable biological control of rats using *T. alba.*

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