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Range Measurement and a Habitat Suitability Map for the Norway Rat in a Highly Developed Urban Environment

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Abstrak: Kajian kesesuaian habitat (KS) sangat diperlukan apabila habitat haiwan telah diubahsuai atau haiwan berhijrah ke habitat yang sangat berbeza daripada habitat asli mereka. Kajian ini dijalankan untuk menaksir KS dan mengabungkan sistem maklumat geografi untuk *Rattus norvegicus* di kawasan perbandaran yang sangat membangun. Menggunakan data daripada pasar Campbell dan kuarters polis di George Town, Malaysia, kawasan rayau (kaedah 100% *Minimum Convex Polygon* [MCP], 95% MCP dan 95% *Harmonic Mean* [HM]) dianggarkan. Kawasan rayau tikus jantan di pasar Campbell mencapai asimptot pada 96 isyarat radio dengan sedikit peningkatan (kawasan rayau = 133.52 m^2; titik pusat = 29.39 m^2). Tikus betina mencapai asimptot pada 62 isyarat radio (kawasan rayau = 13.38 m^2; titik pusat = 9.17 m^2). Di pasar Campbell, tikus jantan muncul pada jam 1900 setiap hari manakala betina muncul pada jam 2000 tetapi di kuarters polis, masa kebiasaan kemunculan untuk jantan adalah pada jam 2000 dan betina pada jam 2200. Carta raster *R. norvegicus* menunjukkan titik tumpuan tikus boleh dikategorikan kepada 4 zon (pasar, rumah kedai, kediaman dan kawasan tumpuan awam). Carta raster yang diseragamkan memisahkan kawasan utama titik tumpuan tikus ialah di pasar dengan frekuensi tikus tertinggi iaitu 225. Semua analisis kesesuaian habitat termasuk kawasan dibangunkan, kawasan tong sampah, sumber air dan tapak semulajadi dalam kajian ini mempamerkan corak berstruktur (peningkatan atau penurunan monotonik) kesesuaian habitat.

Kata kunci: Asimptot, Algoritma, Isyarat, Raster, Monotonik, Perangkap

Abstract: Studies of habitat suitability (HS) are essential when animals' habitats have been altered or when animals migrate to a habitat different from their natural habitat. This study assessed HS and used an integrated geographic information system in the assessment of *Rattus norvegicus* in a highly developed urban environment. Using data from the Campbell market and the police quarters of George Town, Malaysia, home range (through the use of 100% Minimum Convex Polygon [MCP], 95% MCP and 95% Harmonic Mean [HM]) was estimated. Home range for male rats at Campbell market reached an asymptote, with a slight increase, at 96 radio fixes (home range = 133.52 m^2; core area = 29.39 m^2). Female rats reached an asymptote at 62 radio fixes (home range = 13.38 m^2; core area = 9.17 m^2). At Campbell market, male rats emerged at 1900 hours every day, whereas females emerged at 2000 hours; at police quarters, the most common time of emergence for males was 2000 hours and for females was 2200. Raster charts of *R. norvegicus* showed that rat hot spots can be grouped into 4 zones (market, shop houses, settlement and general places). The standardised raster chart isolated the market as the

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major rallying points of the rats (hot spots) by producing the highest rats frequencies of 255. All of the habitat suitability thresholds, including the built-up points, skip bins, water source and nature of the site explored in this study, produced a structural pattern (monotonic increase or decrease) of habitat suitability.

Keywords: Asymptote, Algorithm, Fixes, Raster, Monotonic, Trap

INTRODUCTION

Rodent control has become necessary because increasing populations of rodents have consequently led to vast increases in the economic importance of these animals (Traweger & Slotta-Backmayr 2005). Rats have, however, proven useful as laboratory models for physiological and genetic studies (Wang *et al.* 2011). Globally, the current and prominent strategies used in rodent control and management are the use of traps and rodenticides (Trawerger *et al.* 2006; Van Adrichem *et al.* 2013). These strategies have been used for decades (Bell *et al.* 2011; Belmain *et al.* 2013; Van Adrichem *et al.* 2013); hence, they are gradually becoming ineffective because rodents are developing ways to evade these strategies (Roomaney *et al.* 2012). There is therefore a growing need for an all-encompassing or integrated rodent control strategy such as has been advocated round the globe (Frantz 1988; Frantz & Davis 1991; Spragins 2002). A preliminary survey of the rat population in an urban centre clearly established a stable rat population in distinctive colonies that do not mingle with other colonies, similar to results obtained in cities worldwide (Yasuma & Andau 1999; Wood 2006; Patergnani *et al.* 2010). Normally, home range and movements of city rats are smaller than for rats living in natural habitat but can provide useful information for the all-encompassing approach to a rodent control strategy. The city can provide suitable habitat conditions, where the rats can obtain all the resources needed without being required to linger far from their nest/source. Modifications in the urban landscape also restrict the rats' movements to different places (Dickman & Doncaster 1987). Few or none of these studies, however, have integrated the application of Geographical Information System (GIS) into home range studies of the rat. Knowledge regarding the home range of this commensal rat in urban areas is necessary, as it enhances our expertise in the control and management of the population and provides the basis for integrative pest management.

The aim of using GIS was to gain information concerning the potential distribution of *Rattus norvegicus* within this zone (developed urban environment) relative to the spatial positions of the rats. In addition, GIS will help to ease the researcher's effort in searching, analysing and presenting the data map. Thus, GIS provides powerful automated tools for an integrated rodent control strategy and can enhance an ecological understanding of this animal in a developed urban environment. The objective of this study was therefore to measure the movement and the home range size of *R. norvegicus* in the Campbell market and in areas of human settlement in the developed urban environment and to establish a GIS distribution map of *R. norvegicus* in relation to the different habitats. This study also aimed to develop an integrated habitat suitability map using GIS.

MATERIALS AND METHODS

This study was conducted in George Town, Malaysia, using both Campbell market (Site 1) and the police quarters (Site 2). Campbell market, built in 1947, is a wet market for chicken, duck, pork, and fish, as well as others aquatic species, and it covers an area of 5000 m^2. The market usually commences as early as 6:00 to 7:00 a.m., when the market becomes busy with human activities. The police quarters, on the other hand, was built in 1986 and covers an area of 20,000 m^2. The police quarters are composed of four blocks in the housing area with facilities including a 'surau' (small mosque), kindergarten and a badminton court. Using the Kenward (2001) method, home range measurements for the rats and rat activities (time of leaving and returning to the nest) were recorded for two months (March to April 2008) including six days of intensive radio-tracking during which the mean movements of the rats were recorded every hour (2–4 rats/tracking). These two months were found (in a preliminary study) to be the most suitable periods (peak activity) for study of the animals. For accuracy of the transmitter in the study area, a TR-4 transmitter radio (Sirtrack Limited, New Zealand) was used to ensure frequency and range accuracy, which was boosted with a Yagi antenna (Sirtrack Limited, New Zealand) to a distance of 150 m (Fig. 1). All tagged rats were in good health before and after the experiment (with respect to body and agility), and their body weights ranged from 267 g to 350 g. The mean distances and patterns of 2–4 rats/sex were monitored using radio-tracking as previously described.

(a)

Figure 1: (a) red rectangle shows one of the study site, the police quarters; (b) detection process going on with the Yagi-antenna being directed towards the ground on one of the sites (*continued on next page*).

(b)

Figure 1: *(continued)*

Data analysis for this home range study of *R. norvegicus* was divided into two parts: home range determination and active movement mapping. Movement is one of the main activities of rats and provides the basis for the fractal activity of rats (Hsieh *et al.* 2014). Therefore, movement was the variable of interest in our study and was compared between genders as well as locations (using the mean of the sex of the rats followed). The GIS coordinates of the 2 locations (Campbell market and police quarters) were obtained using GPS (GARMIN - 60CSX, Kansas, USA), and the cumulative area curve was plotted using the Ecological Solution Software (Biotas Version 2.0, Florida, USA). Additionally, 100% Minimum Convex Polygon (MCP), 95% MCP and 95% Harmonic Mean (HM) were used to estimate the home range in this study. Meanwhile, to estimate the core area, two of these methods – the 50% HM and 50% MCP – were employed. The total distance of a rat's movements that was detected each day was measured based on the linear distance of the radio fixes at every alternate hour using Ecological Software Solutions (Biotas Version 2.0). The daily movement rate for each individual was obtained by the division of the daily distance moved each day by the total active period for that individual rat. Differences between sexes and the site for total active period were statistically compared using Mann-Whitney *U* tests. The development of the suitability map of *R. norvegicus* was achieved using data from the questionnaire and secondary data from the Mapping and Survey Department (JUPEM) of the Ministry of Natural Resources and Environment Malaysia and the Pulau Pinang Municipal Council, George Town, Malaysia. The secondary data were derived by superimposing the rat home range and suitability onto an original map of Pulau Pinang. The data gathered were used to update the existing database and were digitised into computer-compatible format using Arc-GIS 9.3 software (Apriso Corporation, California, USA) for GIS. An algorithm for suitability map development was written (Fig. 2).

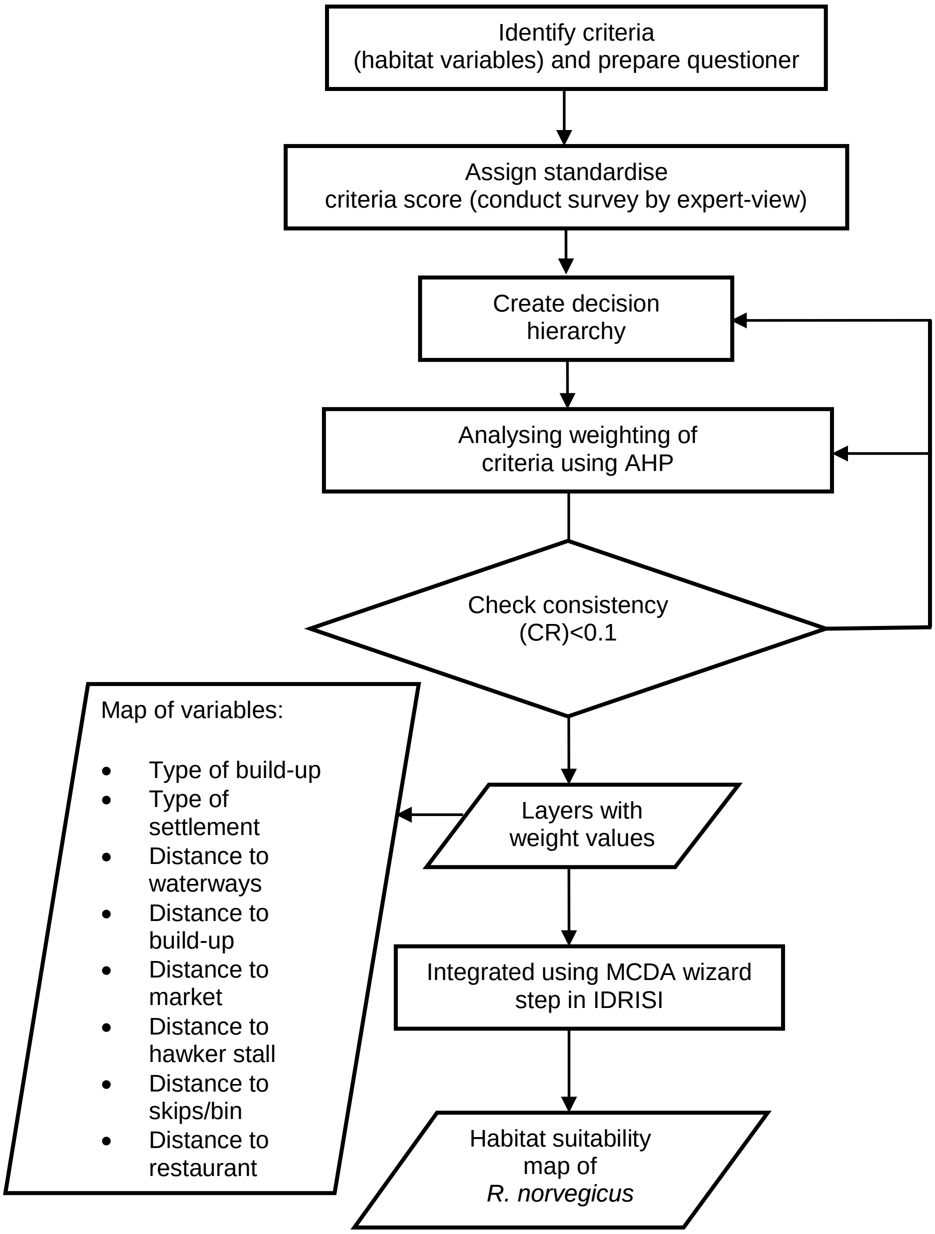


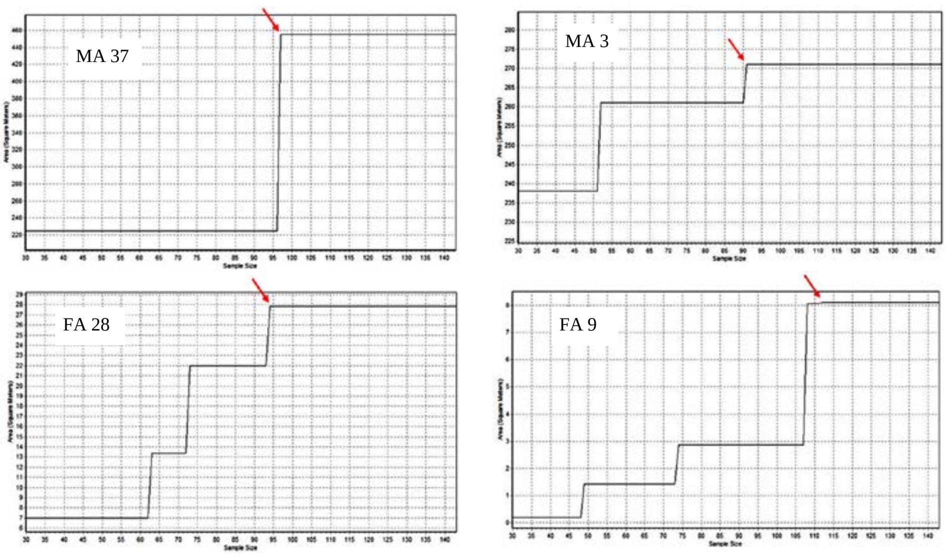
Figure 2: Habitat suitability map algorithm.

RESULTS

Radio-tracking of *R. norvegicus* and the Cumulative Area Curve

Generally, the mean body weight of the male rats was 305 g, whereas that of females was 315 g, and a total of 786 rats were encountered during the study. The home range curves of one adult male (MA 37) at Campbell market reached an asymptote, with a frail increase, of 96 radio fixes, while for one adult female (FA 28), the asymptote was reached, with a slight increase, after a minimum of 62 radio fixes (Fig. 3 [a] and [b]). These curves generally reached a visible asymptotic limit after 90 radio fixes (approximately 98 radio fixes for MA 37 and 94 radio fixes for FA 28; Fig. 3). At the police quarters and for one adult male (MA 3), the curve appears to reach an asymptote after a minimum number of 51 radio fixes, whereas for adult females, the minimum number of radio fixes was 47 (Fig. 3[c] and [d]). Both curves progressively increased, and a clear asymptotic limit was reached at 92 radio fixes for MA 3 and at 112 radio fixes for FA 9.

The implication of the closeness of the minimum number of radio fixes (47 and 51 radio fixes) was that the movements of the rats were usually from the same starting points. The rats usually departed, however, at a different distance from the source until reaching a point where their further movement could not yield a meeting/intersection point. Additionally, differences existed in the home range distances covered at each of the sites; the existence of these differences was established based on the differences in the number of radio pixels covered at each site.



(a) (b)

Figure 3: Number of fixes required to reach an asymptote for (a) male (MA 37) and female (FA 28) rats at Site 1, as well as (b) male (MA 3) and female (FA 9) at Site 2.

Note: The home range size was calculated using the 100% MCP. Arrows indicate the point of reaching asymptote.

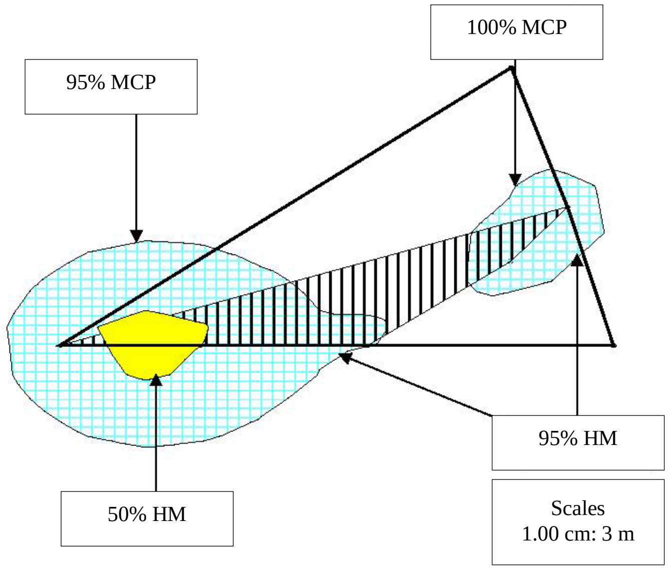
Home Ranges and Home Range Pattern

The analysis of the movements detected in rats at both locations showed that the rats did move far from the nests and only came out in search of food. The rodents headed in similar directions and did not change their route much in the days in which they were followed, and thus, the use of 100% MCP was a suitable approach for estimating the width of the home range. At Campbell market, the adult males (MA 37, MA 38 and MA 39) had an average home range size of 133.52 m^2 and an estimated mean core area size of 29.39 m^2, whereas an adult female (FA 28) had a mean home range of 13.38 m^2 and an estimated mean core area size of 9.17 m^2 (Table 1). The graphical distribution of the home range and core area for MA 37 and FA 28 showed that no home range overlap was obtained between MA37 and FA28 at site 1 (Fig. 3 [a] and [b]). At the police quarters, the adult male (MA 3) had an estimated home range size of 271.11 m^2 and an estimated mean core area size of 16.6 m^2. The adult female (FA 9) had an estimated mean home range size of 11.9 m^2 and a very small estimated core area (0.10 m^2). The graphical distribution of home range and core area for MA 3 and FA 9 are presented in Figure 4. Additionally, there was no overlap of the home range between MA3 and FA9 in Site 2 (Fig. 3[a] and [b]). Male rats at both sites had a larger home range and core area than their female counterparts (Table 1).

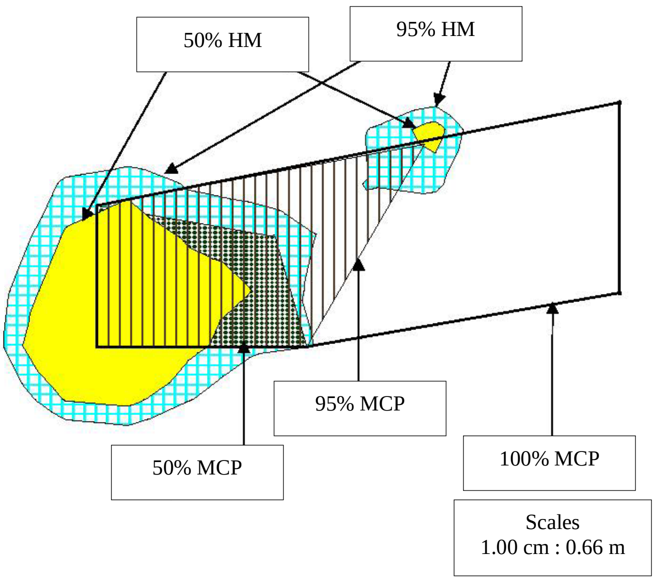
Table 1: Home range and estimates of core area for individual rats from both sites.

Site	Animal ID	100% MCP	95% MCP	95% HM	50% HM	50% MCP
1	MA 37	455.35	133.52	374.35	29.39	
	FA 28	27.84	13.38	19.77	9.17	7.28
	MA 38	452.10	134.87	370.10	29.24	
	FA 27	29.59	12.03	21.02	9.42	7.03
	MA 39	458.60	132.17	378.60	29.54	
	FA 29	26.09	14.73	18.52	8.92	7.53
	Mean	241.60	73.45	197.06	19.28	7.28
2	MA 3	271.11	271.11	107.68	16.60	0.73
	FA 9	11.90	11.90	18.30	0.10	0.07
	MA 4	271.00	272.02	107.47	18.71	0.69
	FA 10	12.05	11.55	16.95	0.05	0.07
	MA 5	271.22	270.20	107.89	14.49	0.77
	FA 11	11.75	12.25	19.65	0.15	0.08
	Mean	141.51	141.51	62.99	8.35	0.40

Note: Site 1 is Campbell market and Site 2 is police quarters.



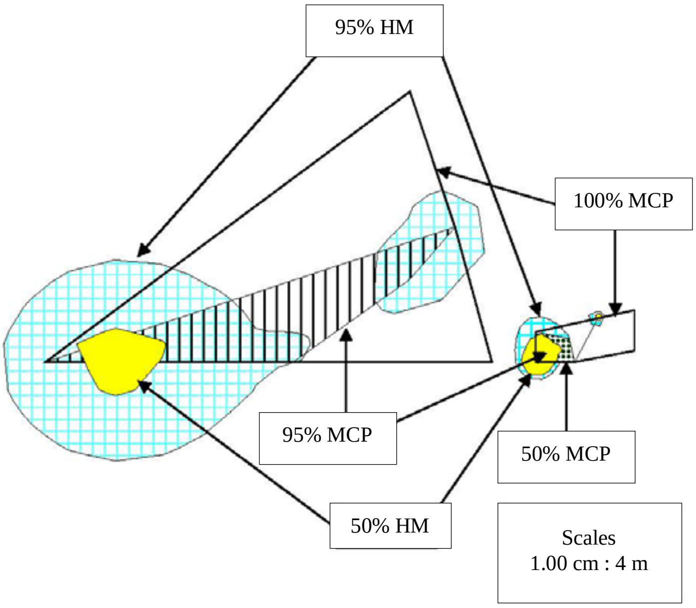
(a)



(b)

Figure 4: Distribution map of the home range and core area for an adult male MA 3 at Site 1 (a and b) and Site 2 (c and d) (*continued on next page*).

Notes: The outer lines encompass an area that represents home range area using estimates of 100% MCP, the inner shaded area represents 95% MCP and 95% HM and the core area represents 50% HM and 50% MCP.



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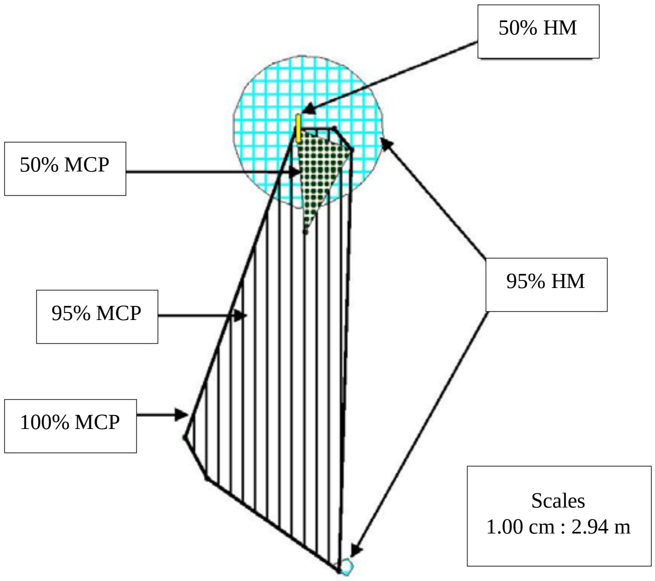


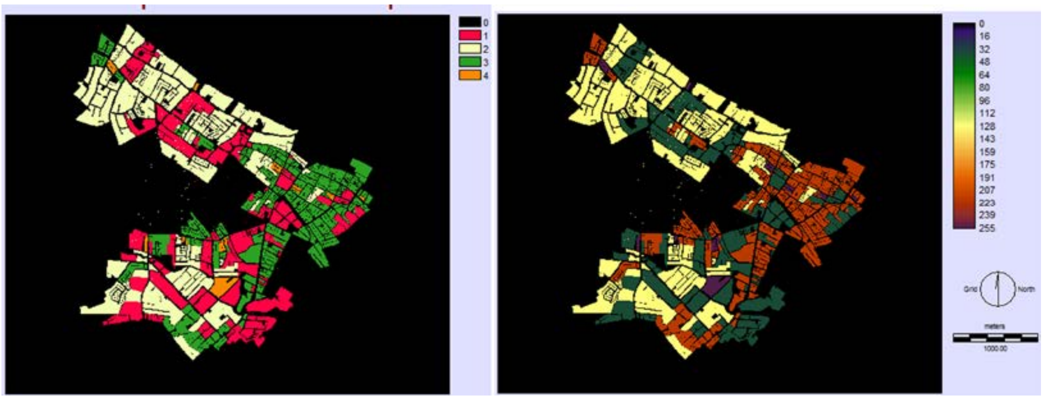
(d)

Figure 4: (*continued*)

Generally, the mean home range size of rats at Site 1 (range = 12.03–134.87m^2) was 47.4% larger than that of rats at Site 2 (range = 11.90–271.11 m^2). In contrast to the core area size, the home range for rats at the Campbell market was 56.69% larger than the home range for any individual adult at police quarters, which was 19.28 m^2 (range 9.17–29.39 m^2 , Table 1). The home range pattern followed by male rats in Campbell market differs markedly from that of female rats in the same markets and even from the male rats from the police quarters (Fig. 4). The home range map shows that the male rats movement pattern was of a shape with four unequal sides (Fig. 4a), whereas the movement pattern of the female followed the shape of a rhombus (Fig. 4b). However, a similarity in home range pattern was observed in both male and female rats at the police quarters. The home range pattern (Fig. 4[c] and [d]) followed the shape of a triangle. These results suggest that home range pattern may or may not follow the same pattern depending on the site.

Raster Layers of Habitat Variables for Habitat Suitability

Raster charts of the rat showed that rat hot spots can be grouped into 4 zones: market, shops, settlement and general places; however, the standardised raster chart identified the major rallying points of the rats (hot spots) as the market because the highest frequency of rats (255) was obtained in the area marked in pink on Figure 5(a) and (b). Meanwhile, the non-standardised raster charts (Fig. 5[a] and [b]) showed that built-up points at the market place were the least likely places for the rats to frequent. These results suggest that the higher the number of built-up points, the smaller the rat population, indicating a monotonic decrease in the quality of rat habitat. Additionally, the raster charts delineated the habitat quality of rat of the study area into 3 types: inner city area, mixed settlement area and commercial area. The inner city area was smaller in comparison to the mixed settlement and commercial areas. However, the standardised raster chart showed that the settlement smallest in size was inhabited by the highest number of rats (Fig. 5[c] and [d]). This chart also indicated monotonic decrease, as was obtained in the built-up areas. The raster charts of the distance of the rats from the waterways showed that the greater the distance from the waterways, the higher the habitat quality, thus showing a relation that was both monotonically increasing and positive. The purple coloration in Figure 6(a) and (b) shows habitat that is more suitable for rats (Fig. 6[a] and [b]). From these results, it is essential to note that habitat quality could depend on factors such as waterways, built-up points and the type of settlement. In additions, these factors affect the suitability either directly or inversely (that is positively or negatively).



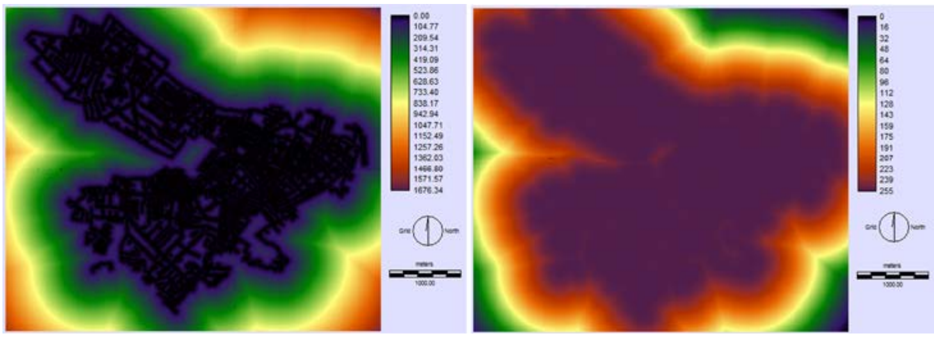
(a)

(b)

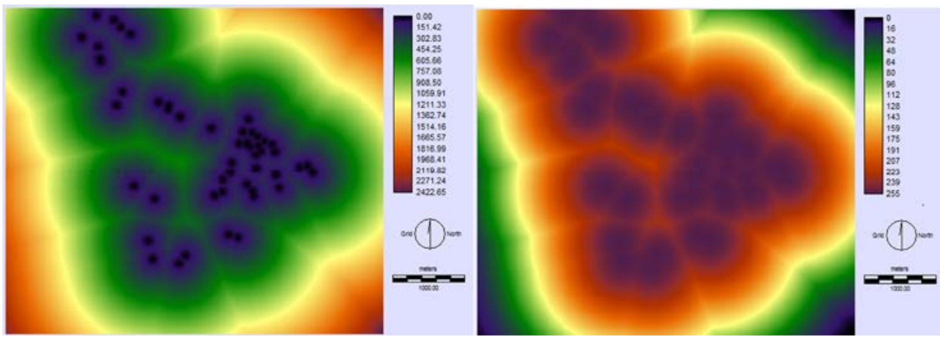
Figure 5: (a) raster chart of build-up type (V1) as well as settlement type (V2) before standardised with fuzzy (ranking type: 4 - market, 3 - shop houses, 2 - settlement, 1 - general); (b) map layer of build-up type (V1) after standardised with fuzzy.

Activity/movement Parameters and a Habitat Suitability Map for *R. norvegicus*

The emergence of *R. norvegicus* from their nests (marking the beginning of activity) generally occurred between 1900 hours and 2200 hours. At Campbell market, the most common time of emergence for male rats was 1900 hours, while for female rats, it was 2000 hours (Table 2). At the police quarters, however, the most common time of emergence for males was 2000 hours and for the females was 2200. This result implied a marked difference in the time of emergence of *R. norvegicus* from the nest between sexes as well as between sites. The animals at the police quarters seem to enter the nest (as the end of activities) earlier than the rats at Campbell market. At the police quarters, the most common time of entry/withdrawal for male and female rats proved to be the same (0400 hours), unlike in Campbell market, where the females returned/withdrew to the nest earlier than the males. The females returned to the nest at 0600 hours, whereas the males returned to the nest at 0700 hours (Table 2). The mean total daily distance of movement observed in adult rats at Site 2 was 8.16% more than that for rats from Site 1 (Table 2). There was no significant difference in the total daily distance travelled for Campbell market and the police quarters rats (U = 65, p>0.05, Mann-Whitney U-Test).



(a)



(b)

Figure 6: (a) raster layer of distance to waterways (V4) before standardised with fuzzy; (b) raster layer of distance to skips/bin (V7) before standardised with fuzzy (distance in metres).

Table 2: Time of emergence from and withdrawal into the nest of *R. norvegicus* according to sex at Site 1 and Site 2.

Site	Sex/animal ID	Number of days	Time of exit from nest (hours)	Time of entry into nest (hours)
1	Male (MA 37)	6	1900	0700
	Female (FA 28)	6	2000	0600
2	Male (MA 3)	6	2000	0400
	Female (FA 9)	6	2200	0400
Site	**Sex**	**Number of days**	**Mean total active period (h)**	**SD**
1	Male and female	14	8.25	3.12
	Male	7	6.83	3.66
	Female	7	9.66	2.58
2	Male and female	14	11.80	2.92
	Male	7	7.00	3.66
	Female	7	4.80	2.17

Note: Site 1 is Campbell market and Site 2 is police quarters.

The mean total length of the daily active period for rats at the police quarters was 3.55 hours longer than in Campbell market (Table 3). Statistical analysis shows that when the total length of daily active period for adult individuals were compared between both sites, the difference was not significant. However, the total length of the daily active period of the female rats from Campbell market was significantly longer compared to female rats at police quarters (U = 2.5, p<0.05). In males, there were no significant differences when comparing Campbell market rats to police quarters rats (U = 14, p>0.05). The total length of daily active periods within both sexes (male and female) at each site were not significantly different at either Site 1 (U = 6, p>0.05) or at Site 2 (U = 5.5, p>0.05). Apparent differences existed within sex and site for the length of the active period of the rats, and male rats had a larger home range than their female counterparts.

According to the suitability map, the distribution of *R. norvegicus* shows a patchy pattern (Fig. 7), and the map can be delineated (with a cut-off method) into three categories of habitat quality: high (0.75–1), medium (0.35–0.74) and low (0.06–0.34). The habitat suitability map showed that most of the habitats (>2/3) are suitable for rats because these habitats fall within the highly suitable region (Fig. 7).

Table 3: Total active period and total distance travelled for males and females at Site 1 and 2 for six consecutive days.

Sites	Animal ID	MA 37		FA 28	
	Days	$\sum x_i$	$\sum y_i$	$\sum x_i$	yi $\sum y_i$
Site 1	1	4.00	49.49	6.00	12.09
	2	4.00	93.69	7.00	16.00
	3	5.00	37.39	12.00	21.35
	4	5.00	54.78	10.00	20.56
	5	12.00	79.58	12.00	17.24
	6	11.00	93.25	11.00	14.15
	Mean	6.83	68.03	9.66	16.89
	(SD)	–3.66	–24.02	–2.58	–3.60
Sites	Animal ID	MA 3		FA 9	
Site 2	1	6.00	149.94	–	–
	2	8.00	78.62	3.00	12.90
	3	9.00	67.35	6.00	19.81
	4	9.00	71.76	6.00	7.36
	5	–	3.00	2.00	20.90
	6	3.00	67.14	7.00	37.54
	Mean	7.00	72.97	4.80	19.70
	(S.D)	–3.66	–46.73	–2.17	–11.38

Note: x and y are total active period in hours and total distance travelled in metres, respectively.

DISCUSSION

The results of this study showed that the home range patterns of the rats differed according to sex, as well as by site and may depend on the differences in the activities or roles of each of the sexes. These home range patterns may also be related to differences in the availability of key resources such as food, burrows and vegetation at each of the sites (Dickmann & Doncaster 1987; Davies *et al.* 2013). The lack of home range overlap as established in this study may be because the burrows of *Rattus* do not normally overlap. This finding conforms with observations of non-overlapping ranges in *Microtus breweri,* which were reported by Zwicker (1989). Similarly, home range patterns may or may not be different according to this study because the similarity or otherwise would be based on the landscape connectivity. Landscape connectivity (Wang *et al.* 2008) has been found to affect the dispersal of brown rats around houses in Amsterdam. Landscape connectivity for the 2 locations (Campbell market and police quarters) differs. At Campbell market, burrowing might be easy for the rats, whereas at the police quarters, burrowing is limited because the entire area has been tarred. This situation is in agreement with the findings of Van Adrichem *et al.* (2013) and Yabe (1979) who established that the availability of green area and food were some of the factors that govern rat population density in and around houses in Amsterdam.

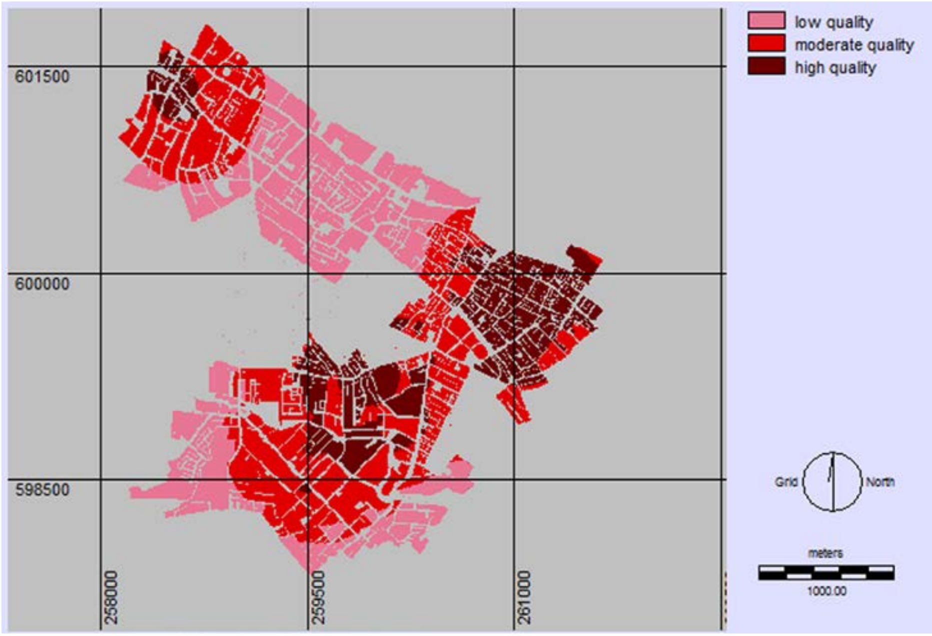


Figure 7: Habitat suitability map of *R. norvegicus* in the city of George Town, divided into three classifications of spaces.

All the habitat suitability thresholds, including built-up points, skip bins, water sources and the nature of the site explored in this study, produced a structural pattern of habitat suitability for the raster chart. These habitat thresholds are similar to the habitat factors identified for rodents in urban habitat (Spragins 2002). However, notably, while some of these thresholds produce monotonic increases, others produced monotonic decreases in habitat suitability. This increase or decrease occurs because while some of the threshold factors enhance rat habitats, others inhibit the habitat. In addition, others have found that areas with sewage serve as suitable habitat for *Rattus* (Channon *et al.* 2000), contrary to the findings in this study. This contradiction might be dependent on differences in the sewage systems. Sewage that is always or partially free to provide habitat for rodents can be suitable for rodents, but sewage that always contains large quantities of water and other waste (such as in the study area) would definitely be avoided by rats (Harper *et al.* 2005; Kolawole *et al.* 2009). Meanwhile, in a study by Trawegger *et al.* (2006), fewer rats were trapped in the sewage. Similarly, the differences observed in the active period of the rats in terms of sex and site, as found in this study, may be linked to differences in the social roles of the 2 sexes, as well as to differences in the habitat factors at each of the sites. Food availability, weather condition and predators are some of the factors that can influence the movements and activities of rats (Carlini *et al*. 1972). Additionally, activities at the 2 sites are markedly different because the sites are located in 2 dissimilar settlements.

CONCLUSION

A habitat suitability map of a highly urbanised area was produced for *R. norvegicus* in this study. This map can be used in the rodent control programme because the use of habitat structure provides a pragmatic and integrative approach to rodent control that can be used to supplement previous rat control methods. The map is adaptable to any urbanised area with characteristics similar to the study area; otherwise, the algorithm established in the study can be used to establish a new habitat suitability map for a different type of urban area. Therefore, this study provides a basic foundation for further study of rat management and control. Furthermore, the patterns of the rat movements (4-sided and triangular structure pattern) established in this study can be used in the control of rodents in similarly structured areas. This habitat suitability map is therefore recommended for use along with other rodent control measures as part of an integrated pest management strategy for better efficiency.

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