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SPATIAL ORGANISATION AND FEEDING ECOLOGY

OF THE AMERICAN MINK (*Mustela vison*)

IN A COASTAL HABITAT

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Department of Biological Sciences
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ABSTRACT

The American mink (*Mustela vison* Schreber) is the only introduced carnivore that has successfully colonised the British Isles. In the present study, the important problem of understanding which are the factors that limit or enhance their number has been addressed. A mink population (*Mustela vison*) inhabiting a coastal area of SW Scotland, was studied. The main purpose was to relate the spatial organisation of mink with spatial and temporal variations in the abundance and distribution of its prey, through the study of foraging strategies and habitat selection. Different scales of spatial organisation were considered.

Foraging strategies (activity levels, habitat use, foraging behaviour) were found to vary over time and in areas with different habitat characteristics. The distribution and abundance of terrestrial prey was found to be important in determining such strategies, ultimately influencing mink densities. This observation supports the hypothesis of Clode and Macdonald (1995) on the influence of terrestrial prey on mink ability to disperse.

Habitat selection of mink in the intertidal zone was studied here for the first time. Resident animals, which were foraging at low or mid tide, and within core areas were found to behave selectively, preferring areas with high prey abundance. In the intertidal zone, prey was most abundant in the lower shore, in areas without fresh water, and in areas with abundant and large rockpools. Mink showed preference for all these habitat characteristics. The nature of the substratum was also important in determining the abundance of prey out of rockpools.

The results of this study are discussed in relation to limiting resources and competition with native carnivores.

Finally a new home range estimator - the Density Circles method - was developed. This estimator is particularly suitable for describing home ranges presenting anomalous shapes, such as those found in mink.

ACKNOWLEDGEMENTS

mimetic...', 'I always have problems with roundabouts, in Italy we don't have them...'). Moreover, I wish to thank Dr. Mike Stacy and all the technical staff, in particular Erick, Jack and Margaret, for their support and for being very nice people.

I don't know what I would have done without all my lab mates, Julian, Panos, Steven, Yih-Yia, and Dawn, who kept bringing me back to life with several welcomed distractions, such as chatting, food, and terrible coffee, and have been such good friends.

Somehow I managed to steal some time also from the busy lives of Rurik List-Sanchez, Paul Stewart and Paul Johnson, that helped me for various bits and pieces of this thesis. I am grateful to them as well.

Finally there are two people I would like to thank in particular: Alex, whose friendship was the most beautiful result of all this adventure, and Michele (Puzko) for so many reasons that I don't know where to start...

(Sasha in one of her dens)

P.S: I am very grateful to all the mink, Sasha, Alex, Ivan, Olga, and Nelly, for having put up with those radio-collars without saying a word.

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DECLARATION

I declare that this thesis is original. Any material which is not my own work has been identified as such. The analysis and interpretation of the results are entirely my own unless otherwise stated. No part of it has been submitted previously for a degree at any other university.

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Laura Bonesi

Durham

1996

CHAPTER 1

GENERAL INTRODUCTION

The American mink (*Mustela vison* Schreber) is the only introduced carnivore that has successfully colonised the British Isles. This species was imported from the United States in the 1920s' for the fur industry and, following incidental escapes and deliberate releases, a feral population was established at least since the 1950s' (Dunstone 1993).

Mink are semi-aquatic mustelids living in freshwater or marine habitats. They have a great ability to adapt to different ecological conditions, due to their generalist and opportunistic feeding habits (Dunstone 1993), and in Britain they have occupied a niche not fully exploited by indigenous carnivores (Day and Linn 1972, Dayan and Simberloff 1994).

The presence of mink has generated concern on the possible effects of this semi-aquatic predator on native fauna and domestic stock (Lever 1978, Linn and Chanin 1978, Chanin 1981). The impact of the mink on domestic stock has been shown to be negligible (Dunstone and Ireland 1989, Harrison and Symes 1989), while the negative effects of mink on British wildlife are still a matter of concern. Such negative effects could be exerted either through competition with native carnivores occupying a similar food niche (Day and Linn 1972) or through excessive pressure on the native prey species.

The feeding niche occupied by the mink partly overlaps that of native carnivores such as the otter (*Lutra lutra*) (Clode and Macdonald 1995), the polecat (*Mustela putorius*) (Lodé 1993), and the stoat (*Mustela erminea*) (Dunstone 1993). Competition is therefore expected.

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The native prey species most affected by mink are water voles (*Arvicola terrestris*) (Woodroffe *et al.* 1990, Halliwell and Macdonald 1996) and ground-nesting birds (Dunstone 1993, Craik 1995). The distribution of water voles has been reduced in the past years due to a loss of habitat (Lawton and Woodroffe 1991) and mink appear to be one of the contributing factors that are negatively influencing an already threatened population (Halliwell and Macdonald 1996). Ground-nesting birds such as waterfowl and some sea-bird species, such as the common tern (*Sterna hirundo*), are particularly at risk during the nesting season (Gerell 1968). However, none of these prey types appears to be a major component of the mink diet (Gerell 1967, Chanin and Linn 1980, Dunstone and Birks 1987, Clode and Macdonald 1995).

Very little is known about the effects of mink on the intertidal fauna in spite of the fact that, especially in winter, fish appear to be the major food item in the diet of both male and female mink in coastal areas (Dunstone and Birks 1987). Clode and Macdonald (1995) have studied food competition between mink and otters. They concluded that fish must be a limiting resource able to restrict the dispersion of mink in areas where otter competition is intense and where terrestrial prey, such as rabbits (*Oryctolagus cuniculus*), are scarce.

The main purpose of the present study was to investigate how prey abundance and distribution determine the foraging strategies of mink in a coastal area, and how these, in turn, determine the spatial organisation and ultimately, mink densities.

Chapter 2 describes the study area and the methods that are common to every chapter. The spatial organisation and densities of mink inhabiting the Ross peninsula and the Little Ross island during the period December 1994 to March 1995, are described in Chapter 3. Home ranges, observed mobility patterns and denning behaviour are discussed and compared with those found in previous studies.

In Chapter 4, mink foraging strategies in two different areas, the Ross peninsula and Little Ross island, are compared and related to the relative abundance of prey in each area. In this chapter, the foraging strategies of mink in 1994-95 will also be compared with those characteristic of the 1980s' in the same area. Particular attention was given to how the mink exploits the aquatic resources in the intertidal zone, such as fish and crabs, since these are the most important part of the mink's diet in winter (Dunstone and Birks 1985). This will be the subject of chapter 5, where habitat selection within the intertidal zone is investigated and a description of the criteria according to which the selection occurs is sought.

Studies of habitat selection within the home range usually require a detailed assessment of home range size and shape. Mink home ranges, in most of the aquatic habitats, present anomalous shapes. A new home range estimator - the Density Circles method - was developed to describe accurately mink home ranges. This method is presented and tested in Chapter 6. Finally in chapter 7 the general conclusions are drawn, and the impact of mink on prey species and competition with native carnivores are discussed.

CHAPTER 2

GENERAL METHODS

2.1 Study area

The study area was located in the Dumfries and Galloway Region of south-west Scotland, near Kirkudbright (O.S. grid reference NX6543). It comprised the Ross peninsula (210ha), and a small island (17ha), known as Little Ross (Figure 2.1). The peninsula comprised mainly rough pasture fields, separated by dry stone walls, where cattle and sheep grazed.
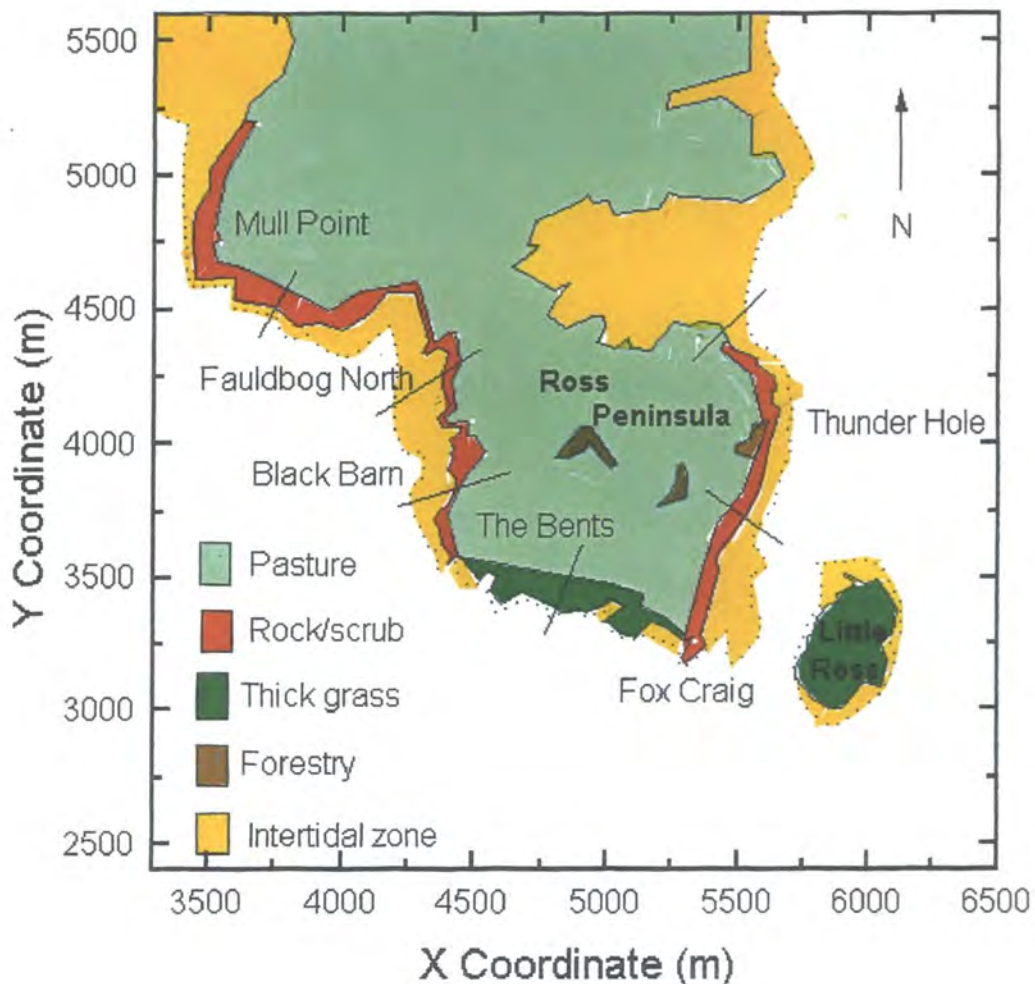
Figure 2.1: Map of different habitats found in the studied area. The lines perpendicular to the shore delimit the different areas, from Mull Point to Thunder Hole.

Three coniferous plantations were interspersed amongst the fields. The shore around the peninsula was a very heterogeneous habitat in terms of exposure, substratum, rockpools and presence of flowing fresh water. The rock substrate was of Silurian Grey Wacke, which by its nature lays down strata in which numerous rockpools can form. In general the substratum of the shore was rocky (Plate 2.1), except for two sandy bays. Just above the shore an area of rocks and scrub was found. This area provided good den sites for the mink. Part of the coast comprised high cliffs that hosted nesting sea-birds colonies of herring gulls (*Larus argentatus*).

Plate 2.1: Rocky shore located in the west side of the Ross peninsula.

Other carnivores were present on the peninsula including the red fox (*Vulpes vulpes*), the European otter (*Lutra lutra*), the stoat (*Mustela erminea*), and domestic dogs. Stoats were sometime trapped in the mink traps. Otters were seen on three occasions and spraints were frequently found.

The Little Ross island presented a rather different habitat from the mainland. This island has not been grazed for about 30 years and was covered by a thick layer of the grass *Festuca rubra* (Plate 2.2). No trees were found on the

island. The shore was rocky and in the south part it was steep and hosted a colony of sea birds, mainly herring gulls (*Larus argentatus*).

Plate 2.2: Thick grass habitat on the island of Little Ross. A herring gull carrion, probably killed by a mink, is also shown.

No other carnivores were found on the island, except for the sporadic presence of otters, as reported by the local people (no sprainting sites were found), and domestic dogs.

2.2 Trapping

The mink were trapped with cage traps set at fixed points and disguised with stones, hay, grass and algae. Dry hay was left inside the trap for the mink to make a nest. The traps were baited with a dead day-old chick and set in the rock/scrub area well above the shore to prevent risk of inundation. Where

possible, traps were set near mink dens or along mink paths. The traps were set the previous evening and checked as early as possible in the morning.

Seven minks, four males and three females, were captured during the course of the study (Table 2.1). Five of these minks were resident (trapped or observed at least for two weeks) in the area. Two of the trapped mink, Mikail and Dimitri, were transient males (trapped or observed for less than two weeks) which appeared only at the time of mating. Thirty-nine captures were achieved in 294 trapping nights (13% success).

Table 2.1: Results from the trapping study. ('n.k.'= not known)

MINK	SEX	TIMES TRAPPED	FIRST CAPTURE	LAST CAPTURE	AVERAGE WEIGHT (g)
IVAN	M	9	December	March	1218
ALEX	M	7	January	February	1153
MIKAIL	M	1	March	/	1050
DIMITRI	M	1	February	/	n.k.
SASHA	F	13	December	March	617
NELLY	F	3	December	December	650
OLGA	F	5	December	March	625

The most evident dimorphism between male and female mink was in their body size. From Table 2.1 it can be seen that males (1140g ± 84.71, n = 3, range: 1050 to 1218g) weigh on average 1.80 times more than females (631g ± 17.21, n = 3, range 617 to 650g). This ratio is very similar to that found in adult mink by other authors (for example 1.86 - Chanin 1983, 1.75 - Ireland 1990).

2.3 Handling procedures

The mink were handled only when it was necessary to fit or to check a radio-collar. The animal was transferred from the trap into a perspex-sided wooden box where it was sedated with an inhalation anaesthetic (Halothane). If it was

necessary to handle the mink for more than a couple of minutes, the animal was weighed and anaesthetised with a dose of ketamine hydrochloride proportional to its weight (concentration of 11mg/kg). While under anaesthesia a series of biometric measures, such as body condition, tooth wears, body length, etc. were taken. Age was assessed by measuring the width of the baculum in males (Elder 1951) and by the presence of white hairs in the back of the neck in females, deriving from mating bite wounds (Ireland 1990). Finally the radio-collar was fitted and the animal released in the same point of capture when fully recovered from the anaesthesia.

2.4 Radio-tracking

2.4.1 Equipment

The radio-collars were manufactured by Biotrack (Biotrack, Wareham, Dorset) and consisted of a transmitter circuit potted in epoxy-resin and fitted on a plastic cable tie that was secured around the neck of the mink. The antenna made a loop within the plastic tube and ended with a whip antenna sticking out from the tube. The whip antenna was usually lost after few days, reducing the power of transmission of the radio-collar from 1000m to about 500m. Each collar weighted 20 g, which is 3% of the weight of a female mink and 2% of the weight of a male mink.

These collars were designed to last at least six months. However, out of six collars, only one functioned for this period. The others all had problems at various stages, mainly due to water infiltrating at the attachment between the collar and the epoxy-resin body.

Mariner Radar M57 and AVM LA12 receivers, operating in the 173Mhz waveband, were used. A three-element Yagi antenna allowed directional location.

2.4.2 Location technique and accuracy of radio fixes

Mink were easily located when in den, because the signal could be traced to the exact position of the animal. When the animal was active the location technique used was 'homing-in' and involved following the transmitted signal's increasing strength until the mink was very close (< 20 m). It is very likely that with this method the mink were disturbed at least in the initial phase of location. It was attempted to reduce this disturbance by keeping a distance of at least 30 m while following them during their active period. Sometimes it was also possible to observe them.

Due to the linear nature of the habitat, the movements of the animal once located, were easily followed, because it was almost always found between the observer and the sea. Sometimes, when its position was not obvious and it was not possible to home in because of the nature of the terrain, triangulation was used.

The error associated with the 'homing-in' method was tested with 6 trials involving the location of a hidden radio-collar, and an average error of 9.67 m (9.67 m ± 7.17, n = 6, range:0 to 20) was estimated. When the receiver was located at a higher position than the transmitter a better estimate was obtained. However, these estimates were made on a non-moving collar, and a greater error is possibly expected when locating a moving animal.

2.4.3 Data collection

Radio fixes were taken at five minutes intervals. Each tracking period was of six hours and occurred within one of four fixed observation periods: 04.00-10.00, 10.00-16.00, 16.00-22.00, and 22.00-04.00. However it was not always possible to maintain this schedule. On six occasions the animals were tracked for 12 consecutive hours.

Four different behaviours were recorded on the basis of the location of the animal and the frequency and strength of the signal:

a) **Inactive in den**: the mink was in den and the signal was constant.

b) **Active in den**: the mink was in den and the signal strength fluctuated.

c) **Foraging**: The mink was out of the den and was moving slowly enough to be searching for food. The signal fluctuated.

d) **Travelling**: The mink was out of the den and was moving too fast to be searching for food. The signal fluctuated.

Meteorological variables, and habitat variables were recorded during the period of radio-tracking.

2.4.4 Sample size

There is a considerable disparity in the amount of radio-tracking data collected for the different mink (Table 2.2). This is due to various reasons, for example Nelly disappeared in January; Olga and Alex were residents on Little Ross island and came on the mainland very seldom; Ivan had problems of neck irritation caused by the collar and therefore the collar was often removed to avoid abrasion; and finally the collars had problems of malfunction caused by water infiltration.

Table 2.2: Sample size from radio-tracking.

Mink	Sex	Months	Days	Minutes
Ivan	M	3	9	2880
Alex	M	2	5	1210
Sasha	F	4	40	13205
Nelly	F	1	4	510
Olga	F	2	9	2150

2.5 Data Base

On 65 out of 109 (60%) sessions of radio tracking the animals spent the entire observation period in den. When this was the case, in order to reduce the weight of the fixes obtained from the animal whilst in den, only the first fix from the radio-tracking session was considered in the analysis. When a foraging bout or part of a foraging bout was sampled, all the active fixes plus the last fix in den before emerging and the first fix of re-entering a den were considered. Therefore in the home range analysis both active and inactive fixes were analysed, although the influence of inactive fixes was greatly reduced by applying the selection rules described above. On average only 15% (15 ± 7.04, n = 5, range:5 to 25) of fixes were retained in the final data base (Table 2.3).

Table 2.3: Number of fixes collected (initial fixes) and analysed (final fixes).

Mink	Initial fixes	Final fixes	Final/Initial x100
Ivan	576	26	5%
Alex	242	27	11%
Sasha	2641	660	25%
Nelly	102	15	15%
Olga	430	73	17%
	Total: 3991	Total: 801	Average: 15%

2.6 Use of other data bases

For Chapter 5 and 6, the analysis required a larger sample size than could be collected in the field season 1994-95. Only one of the mink I studied provided sufficient data to be analysed in these chapters. In order to increase the sample size, data concerning two mink were used from those collected by Mark Ireland in 1982-85 on this study site. The methods of trapping and radio-tracking used in the present study were the same as those used by Ireland (see Ireland 1990), except that in the present study fixes were taken

every five minutes, while Ireland took them every ten minutes. Data collection and classification were overseen by Ireland in the present study to maintain similarity.

The two mink added were males (Fred and Ted). Fred was radio-tracked from November 1983 to January 1984, while Ted was followed from November 1984 to February 1985. The radio-tracking data for these mink is shown in Table 2.4. The same rules for the construction of the data base adopted for the mink tracked in 1994-95, were applied to these mink. For both mink 32% of their fixes were retained in the data base.

Table 2.4: Sample size of radio-tracking data for Fred and Ted.

Mink	Sex	Months	Days	Minutes	Initial fixes (I)	Final fixes (F)	F/I x100
Fred	M	3	26	7470	747	239	32%
Ted	M	4	49	9060	906	294	32%
					Tot.: 1653	Tot.: 533	

2.7 Statistical analysis

Univariate and multivariate stepwise linear regression, Pearson correlation coefficient, t-test and Chi-square goodness-of-fit tests were used as statistical tools for the analysis. The t-test was always a two-tails test, unless otherwise specified. The mean is always expressed with its standard deviation. The calculations and statistical analysis were performed either with EXCEL 5.0c, or with SPSS for Windows 6.1.1. The use of additional statistical tools is discussed in particular chapters, where they are of interest.

CHAPTER 3

SPATIAL ORGANISATION OF THE MINK POPULATION ON THE ROSS PENINSULA AND LITTLE ROSS ISLAND

3.1 Introduction

The study of the spatial organisation of mink is important in order to understand what influences the population densities of this species. Mink spatial organisation has been studied mainly by focusing on the home range and on the use of its internal areas (core areas) (eg. Gerell 1970, Birks and Linn 1982). The results of these studies suggest that three major factors affect the size and shape of mink home ranges: the type of habitat, the abundance and distribution of food sources, and the abundance and distribution of dens (Gerell 1970, Hatler 1976, Birks and Linn 1982, Dunstone and Birks 1985). Mink are expected to be relatively abundant in most productive habitats, such as the coastal habitat or eutrophic lakes (Dunstone and Birks 1985), and where there is plenty of vegetation cover to provide protection and denning sites (Allen 1983, Halliwell and Macdonald 1996).

Dens are also known to be a limiting resource of great importance in determining the use of different areas within the home range, especially along rivers (Gerell 1970). However, where den-sites are abundant, mink are likely to choose their dens in areas with best prey availability (Birks and Linn 1982).

The mink population inhabiting the Ross peninsula has been studied for several years since the 1980's (see Dunstone 1993 for a review). In this chapter the home ranges, movements and denning behaviour of the mink population inhabiting the Ross peninsula and Little Ross island in the winter 1994-95, will be discussed and compared with those of the 1980s'. I will use here an extended concept of home range: for home range I include not only the area where the animal normally lives (Burt 1943), but also the areas which have been visited by the animal for short periods of time. I will do so for reasons of comparison with previous studies.

3.2 Methods

To assess their home ranges, 3 female and 2 male mink were radio-tracked from 4 to 40 days from December 1994 to March 1995. A detailed description of radio-tracking methods and of the study area is given in chapter 2. In order to calculate home ranges, trapping data were included to increase the sample size. The home range is expressed as length of coastline occupied.

Inter-den movements of mink were also determined from radio-tracking data. An inter-den movement was considered to occur when the mink moved between dens which were at least 100m distant from each other.

3.3 Results

3.3.1. Home range estimates

All mink movements were associated with the coast line and no fixes were recorded more than 100m from MHWS (Mean High Water Springs). The home ranges of males (2250m ± 212.13, n = 2, range:2100 to 2400) were bigger than those of females (1430m ± 450.93, n = 3, range:1000 to 1900) (t = 2.31, df = 3, p < 0.05) (Table 3.1).

Table 3.1: Home range size calculated as length of coastline occupied. Radio-tracking and trapping data were used. For Alex and Olga the home range includes the Little Ross island.

MINK	SEX	HR LENGTH (m)	Number of Fixes	Times trapped
ALEX	M	2400	27	7
IVAN	M	2100	26	9
SASHA	F	1900	660	13
NELLY	F	1400	15	3
OLGA	F	1000	73	5

The density of mink on the Ross Peninsula was on average 0.56 mink/km of coastline in the winter 1994-95. On Little Ross island the density was 1.3 mink/km of coastline. However, for mink inhabiting Little Ross island, the calculation of the home range as length of coast occupied was not a particularly valid measure, since the animals did not make much use of the coastal strip.

Asymptotes for home range size of each mink were reached within few days of radio-tracking and trapping (Figure 3.1). Only Sasha and Ivan were followed for a sufficient time to affirm with confidence that the ranges observed did actually reach their full extent.
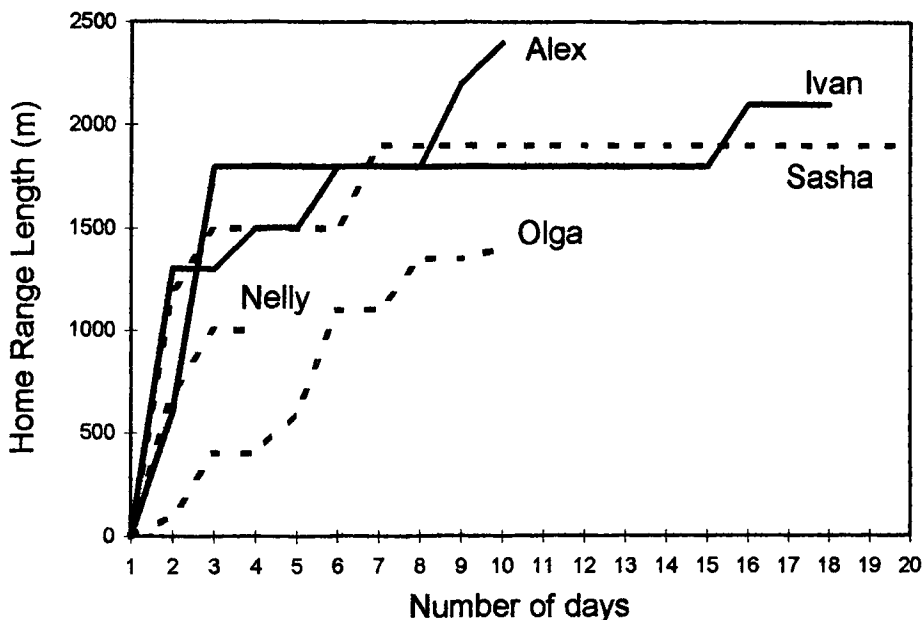
Figure 3.1: Graph showing the increase of home range size, calculated as length of coastline, with increasing days of radio-tracking and trapping. Females are represented with a broken line, males with a continuous line.

3.3.2 Comparison with other home range studies

Home ranges of male and female mink, as well as those of other carnivores, are expected to be related to food abundance (Sinclair 1989). Sandell (1989) suggests a formula to estimate the home rage size of males of a given

species in relation to that of females. This estimate is based on energy requirements.

$$\text{male range size} = \frac{\text{female range size} \times (\text{male weight})^{0.75}}{(\text{female weight})^{0.75}}$$

This formula was applied to the results of the studies conducted in the Ross peninsula (Table 3.2). In the winter months, the size of male home ranges was well predicted by their energy requirements, the difference between observed and predicted home range size being relatively small in these months. However, when the mating season was included in the sample, a greater difference was found between observed and predicted size of the home range. This result suggests that, in some parts of the year, the home range of male mink might be determined by factors other than food requirements.

Table 3.2: Predicted male home range size with the formula proposed by Sandell (1989). The sample sizes are n = 2 males, n = 3 females in this study, n = 4 males, n = 4 females in Dunstone and Birks (1985), n = 26 males, n = 22 females in Ireland (1990). Home ranges are expressed in meters, weights are expressed in grams. In the last column, observed male ranges are subtracted from predicted, and the absolute value of the difference is given.

Source	Season	Home Range		Weights		Predicted male range	|O- P|
		M	F	M	F		
This study	Winter	2250	1430	1140	631	2228	22
D+B 1985	Winter	1500	1090	1144[a]	644[a]	1677	177
Ireland 1990	All year	2650	1240	1148	656	1887	763

[a] = no data were available on the mink weights in Dunstone and Birks 1985. Given the low variation in male and female body weight ratio in this species (see chapter 2), male and female body weights of the present study were averaged with those obtained by Ireland (1990).

3.3.3 Intra and Intersexual home range overlap

Both females and males occupied intrasexually exclusive territories, while male territories were found to overlap those of females extensively (Figure 3.2 and Figure 3.3). In two cases (Nelly/Olga and Alex/Ivan) there is an apparent intrasexual territorial overlap. This is due to the fact that data from different months were pooled together. In neither case were individuals of the same sex found simultaneously in the same area, i.e. there was no overlap in the temporal domain. Nelly was present in the study area only in December, and then disappeared. In January, both Olga and Alex, a female and a male which normally lived on Little Ross island, came to the mainland and stayed there for a few days before swimming back to the island. Alex travelled much further than Olga when on the mainland. His range extended to the Black Barn area on the west side of the peninsula (Figure 3.2). His movements were within the home ranges of both Sasha, a female, and Ivan, a male. However, while Alex was at Black Barn, both Sasha and Ivan where located at Mull Point, more than a kilometre away.
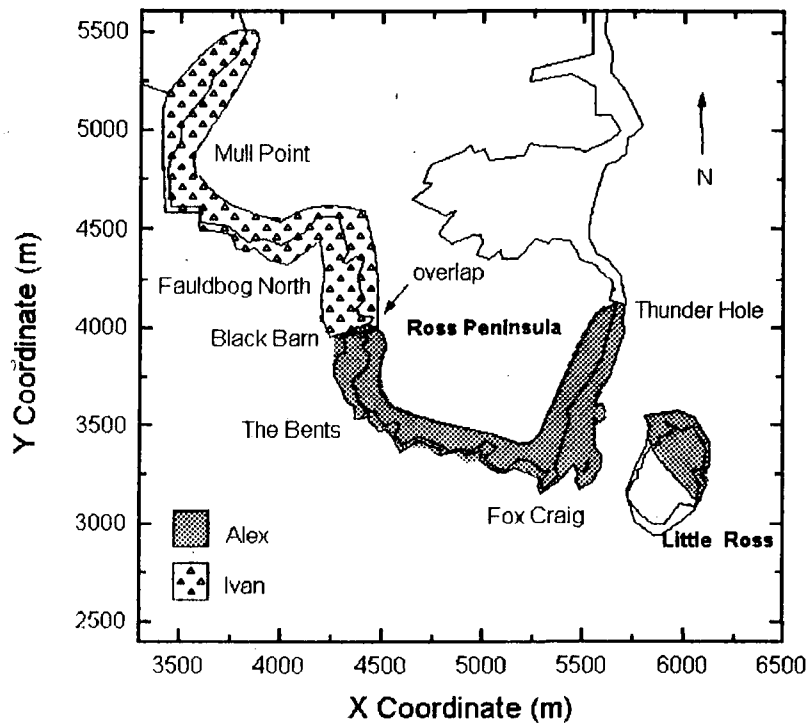
Figure 3.2: Linear home ranges of MALES from December 1994 to March 1995. The limits of each area from Mull Point to Thunder Hole are shown in Figure 2.1.
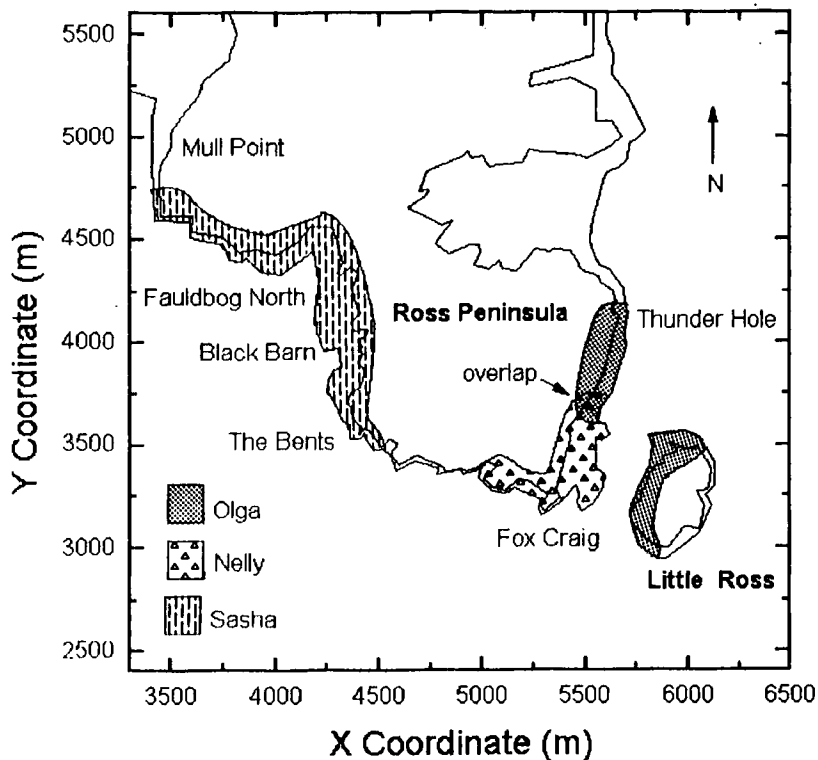
Figure 3.3: Linear home ranges of FEMALES from December 1994 to March 1995. The limits of each area from Mull Point to Thunder Hole are shown in Figure 2.1.

3.3.4 Movements within the home range

For both Alex and Olga, the movements to and from the mainland resulted in a fragmentation of their home range, areas of their home range were separated by areas of unsuitable habitat such as the sea in this case. On one occasion Olga was observed leaving the mainland to swim back to the island. She had been tracked from 20.00 on 10 January 95 until 07.00 of the following day. During that night she was observed foraging on the shore on four occasions and usually returned to the same den. On the last occasion she stayed in a temporary den on the shore from 03.20 until 06.50, when she swam back to the island. It is interesting to note that when she left, the weather conditions were very favourable and the sea was particularly calm. She left 30 minutes before low tide, thereby minimising swimming distance and possibly exploiting the outgoing current. Between the mainland and the

island there is an isolated rock, known as Richardson's rock, which emerges only during low tides and it is possible that this is used as a resting point during travel to the island (Figure 3.4).
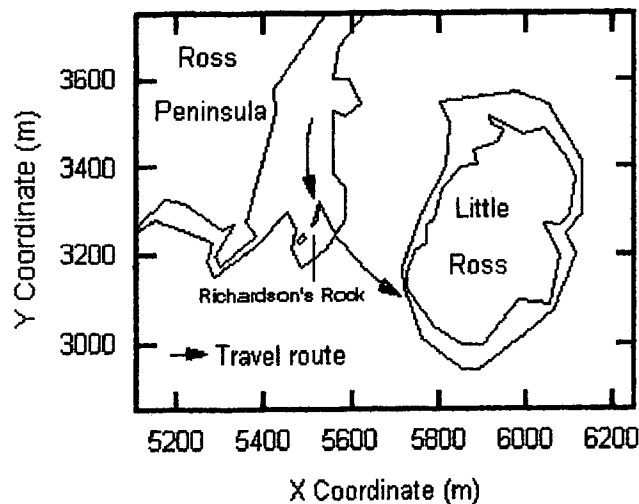
Figure 3.4: Probable swimming route of Olga on 11 January 1995, from the Ross peninsula to Little Ross island.

On the mainland the movement patterns observed were similar to those found by Gerell (1970) and by Birks and Linn (1982) in riverine habitats. Extensive travel within the home range can be represented as oscillatory movements between dens or group of neighbouring dens (Gerell 1970). These inter-den movements usually occurred along linear features of the home range, such as the rocky area above the shore, stone walls or the upper tidal area. The regression analysis showed that for Sasha, the mink for which most data were available, these inter-den movements decreased significantly (F = 4.60, p = 0.07) in frequency as the season progressed (Figure 3.5 and Table 3.3).

Table 3.3: Analysis of variance of Inter Den Movements, with time as the independent variable.

	df	Sum of Squares	Mean Square	F-value	P-value
Regression	1	0.68	0.68	4.60	0.07
Residual	7	1.04	0.15		
Total	8	1.72			
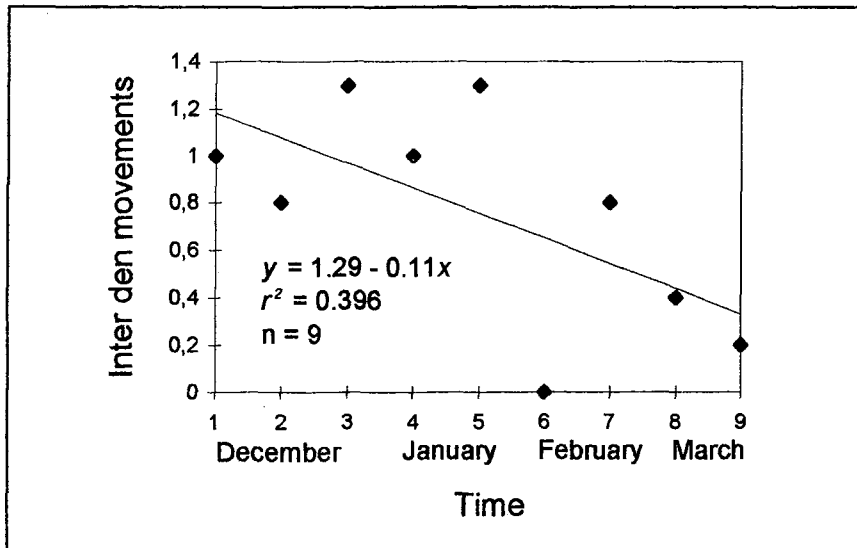
Figure 3.5: Regression analysis of inter-den movements. Time is the independent variable. Each increment of one unit on the x axis represents a five day period. The inter-den movements are expressed as movements per day.

3.3.5 Denning behaviour

The mean number of dens used by mink between December and March, was 5.6 (5.6 ± 4.82, n = 5, range:2 to 14). A total of 31 dens was recorded in use on the Ross peninsula during the course of the study (Figure 3.6). The highest proportion of these dens (75%) was found in the rock/scrub area up to 50m above MHWS. Dens in this habitat were either under scrub, mainly gorse (*Ulex europaeus*) and hawthorn (*Crategus monogyna*), or in rock cavities. Other dens were found in human artefacts such as stone walls, a shed and a barn. A rabbit burrow was found to be used as a den by mink on only one occasion. This den was the farthest one from the shore, being located 80m above MHWS. Temporary dens were sometime found on the shore.
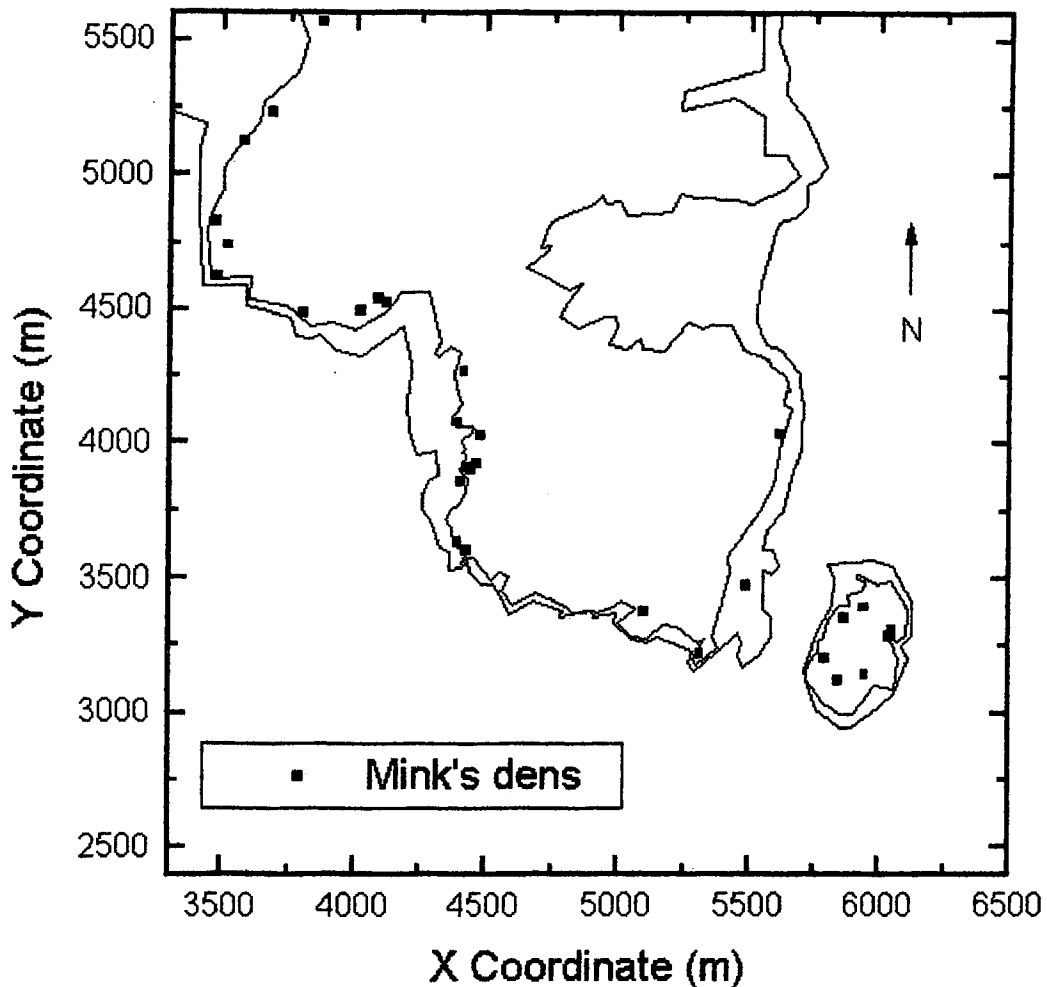
Figure 3.6: Location of the dens on the Ross peninsula.

On the island of Little Ross five dens out of eight were made of tunnels 'excavated' in the thick grass *Festuca rubra* (Plate 3.1). Some of these dens were quite extensive when compared with the ones found on the mainland, and conspicuous mink trails were observed to connect them (Figure 3.7). It was assumed that these trails were made by mink, since there was no other species on the island, except for the sporadic presence of the otter, that could have made trails of about 10 cm wide. Moreover, five out of eight dens were found along these trails.

Plate 3.1: Den located in the thick grass on Little Ross Island.
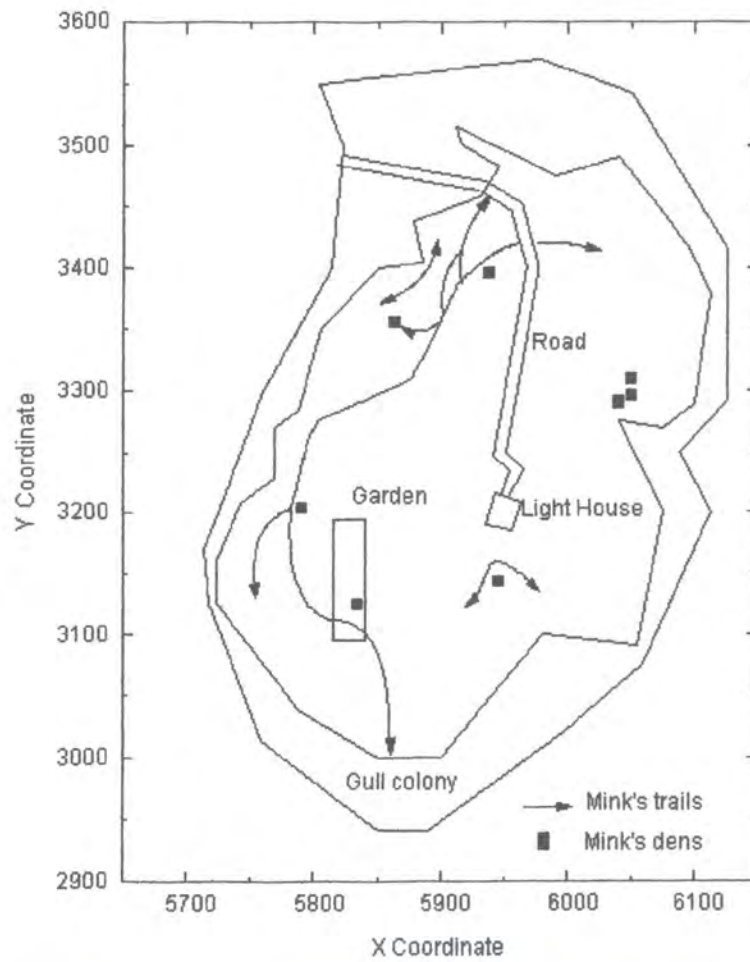
Figure 3.7: Map of dens on Little Ross Island and trails connecting them.

Mink were observed to stay at the same den for a maximum of five consecutive days, however the majority of den-stays was less than one day duration (Figure 3.8), confirming the observed high mobility of mink (Gerell 1970, Birks and Linn 1982, Ireland 1990). The longest den-stay was recorded in March for a female.
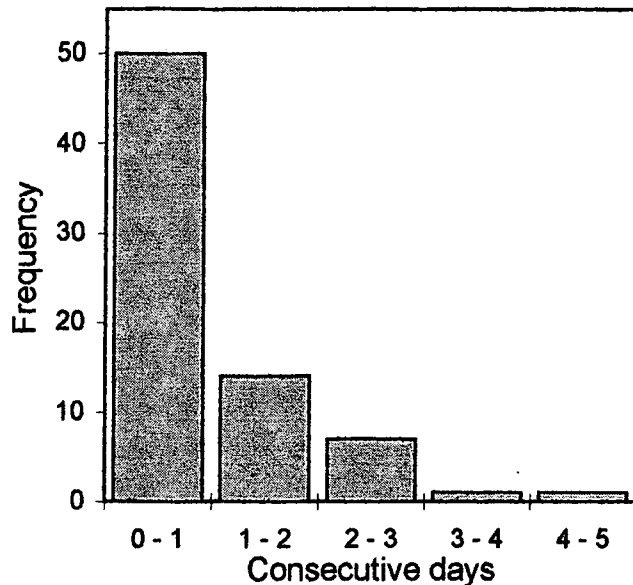
Figure 3.8: Frequency of occurrence of den-stays of different duration. A den-stay is defined as the period of time spent by a mink at a den. n = 63 days, data for five mink have been pooled.

Simultaneous use of a den by two mink was never observed. Male and female mink were recorded to use the same den at different times on several occasions. However, only in one case were two males observed to use the same den, which was located outside the territory of both males, within one of the female's core areas. On two occasions, a male (Ivan) and a female (Sasha) were found inactive in neighbouring dens (20 - 50m apart) on the same day.

3.4 Discussion

The results of this study confirmed the spacing patterns characteristic of mink, where intrasexual exclusion and a certain degree of intersexual overlap of territories is the norm (Gerell 1970, Chanin 1976, Dunstone and Birks 1983, Ireland 1990). Intrasexual exclusion and intersexual overlap are common spacing patterns amongst Mustelidae (Powell 1979). The intersexual tolerance in mink is expressed also in the use of dens. Male and female were observed to share the same den at different times and were found in neighbouring dens at the same time, while two mink of the same sex were very rarely observed to use the same or neighbouring dens. Food niche differentiation is known to be a factor that allows coexistence of different species (Begon et al. 1990). It is possible that one of the reasons that allow intersexual territorial overlap in mink, is the marked difference of feeding habits between males and females (Birks and Dunstone 1985).

Males had longer home ranges than females, confirming the observation by other authors (eg. Dunstone and Birks 1985, Ireland 1990). In general, the size and distribution of female territories are thought to be determined by the dispersion of food or other vital resources. Male home ranges are sized and spaced so as to encompass the territories of one or more females, which are considered by males to be the fundamental resource (Clutton Brock and Harvey 1978, Sandell 1989). This explanation seems to hold for mink during the mating period, February-March, when males move greater distances for mating purposes and possibly for territory defence against transient males (Ireland 1990). Outside the mating season male home ranges appeared to be well predicted by their energy requirements (see Table 3.2). It must be pointed out that, although the formula proposed by Sandell (1989) well predicted the home ranges of males from an energy standpoint, it does not consider that there could be marked intersexual differences in the diet, and therefore in the feeding strategies, ultimately leading to differences in home range size. In mink a marked intersexual difference in the diet has been

observed by Dunstone and Birks (1985), however, such difference doesn't seem to affect the size of male home ranges relative to that of females.

The increase in males' mobility in February and March corresponds to a decrease of mobility by females. The oscillatory movements of one of the studied mink, Sasha, decreased from December to March. Such trends for female mink were also found by Ireland (1990). In March parturition has not yet occurred and it is unlikely that females restrict their movements because of a superabundance of food, the levels of which are expected to increase from May onwards (Ireland 1990). It is possible, however, that they restrict their movements because of the presence of transient males, which have been observed to be dominant over females (Gerell 1970, Birks 1981). Later on, in May and June, females are known to restrict their home range due to the presence of suckling kits in the den (Ireland 1990).

Mink were observed to change den almost every day. Gerell (1970) attributed this high frequency of long distance movements within the home range to the need for patrolling the territory. Another explanation could be that such movements are due to the depletion of prey in exploited feeding areas, forcing the mink to switch frequently between feeding areas in search for new food patches. However, on the shore, depleted food patches are expected to be replenished regularly by the tide (Kruuk *et al.* 1988). Moreover, if the mink's movements were determined by the need to reach non-exploited patches, these movements should occur more often in the winter than in the summer, and especially in late winter, when lower prey availability is expected. Instead it was observed, in this and other studies (Ireland 1990), that such movements decrease from December to March, and that they occur more often in the summer than in winter (Birks and Linn 1982). These observations do not support the hypothesis that frequent movements within the home range serve the need of switching between feeding areas due to a depletion of food sources.

Occasionally the home ranges of mink appear fragmented. In his study, Ireland (1990) observed mink to exploit forestry areas distant from the shore which are separated by low productivity pasture fields. In the present study a fragmentation of the home range was observed for Olga and Alex, two mink that had their core areas on Little Ross island. In general, the fragmentation of the home range can be explained by considering that the food sources are patchly distributed and the mink has to travel through unsuitable habitat, such as pasture fields, to reach other food patches. It is not clear however, why these mink were undertaking difficult travel from the island to the mainland when the prey abundance on the island seemed to be sufficient to support them (Chapter 4).

Resident mink were found to live at higher density on Little Ross island (1.30 mink/km) than on the Ross peninsula (0.56 mink/km). Since no difference in den sites abundance was observed between the island and the peninsula, the difference in density was more likely to be determined by a difference in prey abundance (Chapter 4).

When the density of mink on the Ross peninsula in 1994-1995 (0.56 mink/km) was compared with that found by Dunstone and Birks (1983, 1985) in the winters of 1981 and 1982 in the same area (1.24 mink/Km and 2 mink/Km), a remarkable decrease in mink density was noted. No major changes in the habitat of the Ross peninsula have occurred since the 1980s'. This means that a decrease in the abundance of den sites was not likely to have caused the decrease in mink density. Here again the reason for such decrease is to be sought in a modification of the abundance of prey, which will be the subject of next chapter.

CHAPTER 4

COMPARING FORAGING STRATEGIES
IN DIFFERENT AREAS

4.1 Introduction

Mink adopt an opportunistic strategy while feeding (Dunstone 1993), therefore they are expected to take the prey species available locally in proportion to their abundance. Studies on the feeding ecology of coast living mink (Dunstone and Birks 1987, Ireland 1990) have shown that the shore provides several prey species of small and medium size, and female mink regularly exploit this resource (Birks and Dunstone 1985). Male mink are known to partition their foraging effort almost equally between the shore and the rocky/scrub area just above the shore, where they feed on rabbits (Ireland 1990). Such intersexual differences in habitat selection reflect major differences in the diet, with males relying more on lagomorphs and females foraging mostly on fish and Crustacea (Birks and Dunstone 1985, Ireland 1990). However, both sexes were observed to rely more on shore-living prey during the winter months, when lagomorphs were scarce (Dunstone and Birks 1987, Ireland 1990).

A variation in the abundance and availability of prey species is likely to force the mink to switch to other prey sources. If the variation is consistent and no alternative food sources are available the densities of mink might be affected as well.

In the present chapter, the foraging strategies of mink in two different coastal areas, the Ross peninsula and Little Ross island, will be compared and related to spatial differences in prey abundance. Temporal differences in prey abundance will also be discussed and related to foraging strategies and variations in mink densities. In optimal foraging theory, foraging strategies

are assumed to enhance an animal's fitness, through maximisation of its net rate of energy intake (Begon *et al.* 1990). Foraging strategies are measured here in terms of the animal's activity levels, use of the habitat, and foraging behaviour, for example hunting and searching.

4.2 Methods

The data on the Ross peninsula were collected during a 56 day duration study, in the first two weeks of every month from December 1994 to March 1995. The data relative to Little Ross island were collected on six occasions, four days in February and two in March.

4.2.1 Prey abundance

Prey abundance was estimated using different methods. The rodents were live trapped using Longworth traps. The traps were set along 15 transects and spaced at 5 m intervals (Figure 4.1). The transects were set in different habitats and in different areas of the peninsula and of the island. For each transect the trapping was repeated on three consecutive days and rodents were individually marked by fur clipping, to reveal re-captures.

Changes in the abundance of rabbits and hares were assessed once a month by counting individuals along a standardised 2 km walk (Figure 4.1), starting 30 min before sunset.

Littoral prey was sampled by means of 20 transects, one meter width, carried out on the shore at low tide (Figure 4.1). Only shore crabs (*Carcinus maenas*) greater than 3.0 cm and fish species known to occur in the mink's diet (Dunstone and Birks 1985), were considered in the analysis. Further details of the sampling technique are given in Chapter 5.

Carrion was counted as encountered, mainly during radio tracking. If the carrion was abundant, as on the island, specific carrion counting was carried out.

The position of sea-bird colonies was recorded. Birds were counted if the colony was located within the home range of one of the radio-tracked mink.
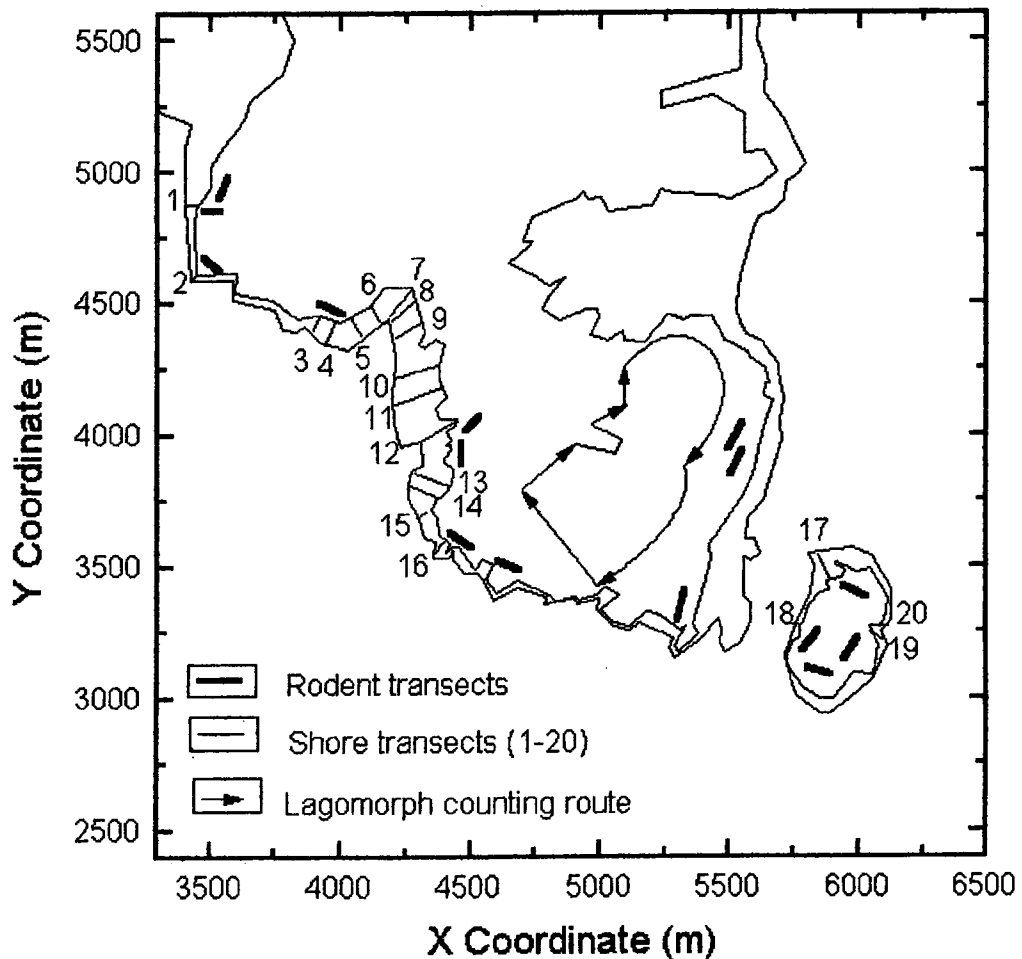
Figure 4.1: Lagomorph counting route and location of transects in the study area.

Relative assessment of prey abundance on the Ross peninsula and on Little Ross island were computed with an index that took into account the total number of specimens counted or trapped during the course of the study relative to the total area of the peninsula (210ha excluding sandy bays) and of the island (17ha). For rodents, the prey index also took into account the

sampling effort. The number of specimens trapped was divided by the total number of trapping nights and then by the total area of the study site. The prey indices only serve as a comparative measure of prey abundance between the island and the peninsula. They are not comparable between different prey types and are not an indication of absolute prey abundance.

4.2.2 Foraging strategies

The data on foraging strategies of mink were derived from the radio tracking study (Chapter 2) and from direct observation. When analysing habitat use, a time of five minutes between fixes was considered to be sufficient for a mink to change from one type habitat to another, therefore the fixes were considered independent (Chapter 5). Habitat availability was calculated with the G.I.S. program Arc/Info (Version 7.0.3, Environmental Systems Research Institute, Inc. Redlands, USA).

4.3 Results

4.3.1 PREY ABUNDANCE

4.3.1.1 Rodents

On the Ross peninsula, the most productive habitats for rodents were the forestry areas and the ungrazed fields covered with thick grass (Table 4.1). The scrub and rock/grass habitats above MHWS showed a significantly lower density of rodents (χ^2= 10.9, p < 0.05, df = 3) compared to forestry and ungrazed fields.

Table 4.1: Relative percentage rodent captures in different habitats on the Ross peninsula. n = 80. The percentages are obtained by dividing the number of rodents trapped per habitat by the number of trapping nights in each habitat.

HABITAT	Trap nights	Captures
Thick grass	18	32%
Forestry	21	31%
Scrub	126	19%
Rock/grass	87	18%
TOTAL	252	100%

The rock/grass and scrub habitats on the east side of the peninsula had a significantly higher abundance of rodents (38% of trapping success, n = 63 trapping nights) when compared with the same habitats on the west side of the peninsula (24% of trapping success, n = 150 trapping nights)(χ^2= 5.92, df = 1, p < 0.05).

Five different species of rodents were trapped on the Ross peninsula: woodmouse (*Apodemus sylvaticus*), field vole (*Microtus agrestis*), bank vole (*Clethrionomys glareolus*), common shrew (*Sorex araneus*) and pygmy shrew (*Sorex minutus*). All these species are known to be part of the mink's diet in this area (Dunstone and Birks 1987, Ireland 1990). Table 4.2 shows the trapping success for each species in each habitat. *Apodemus sylvaticus* was abundant in all habitats except for thick grass. Some degree of habitat preference for the thick grass was found in *Microtus agrestis*. Three out of the four captures of *Clethrionomys glareolus* occurred in the forestry habitat, while the shrews (*S. araneus* and *S. minutus*) were only found in the thick grass habitat.

Table 4.2: Results of Longworth trapping of small mammals in different habitats on the Ross peninsula. Numbers in parenthesis in the first row represent the total number of specimens captured for each species. The percentages are obtained by dividing the number of specimens trapped per habitat by the number of trapping nights in each habitat. Number of trapping nights per habitat are shown in table 4.1.

HABITAT	Apodemus (n =60)	Microtus (n =13)	Clethrion. (n =4)	Sorex (n =3)
Thick grass	12%	59%	0	100%
Forestry	32%	25%	86%	0
Scrub	26%	13%	14%	0
Rock/grass	30%	3%	0	0
Total	100%	100%	100%	100%

Indirect evidence suggested that the island of Little Ross hosted a very abundant population of rodents, although rodent trapping on the island was unsuccessful. Out of 84 trapping nights only two specimens of *Microtus agrestis* were trapped. This is a very low rate of success (2%) when compared to the 30% trapping success (n = 252 trapping nights) on the mainland. A large number of rodent galleries and paths were found in the thick grass, and rodents were frequently observed compared to mainland. Further evidence, supporting the hypothesis of a numerous rodent population inhabiting the island, came from the presence of birds that predate predominantly on rodents. Two barn owls (*Tyto alba*), two tawny owls (*Strix aluco*), and two kestrels (*Falcus tinnunculus*) were permanently resident on the island of Little Ross. Moreover, on the Ross peninsula, the thick grass habitat was shown to be the one that hosted the greatest abundance of rodents, when compared to the other habitats (Forestry, Rock/grass, Scrub).

4.3.1.2 Lagomorphs

Very few rabbits (*Oryctolagus cuniculus*) and Brown hares (*Lepus capensis*) were observed on the peninsula (Table 4.3) and no lagomorphs were found on Little Ross island.

Table 4.3: Number of hares and rabbits counted each month on the Ross peninsula.

MONTH	HARES	RABBITS
December	1	1
January	0	0
February	0	3
March	0	4

4.3.1.3 Marine birds and carrion

The cliffs on the south-west coast of the Ross peninsula hosted colonies of seabirds that were not easily accessible to mink due to the steepness of the coast. The most common species was the herring gull (*Larus argentatus*). During the course of the four months, six bird carcasses were found along the coast of the peninsula: two cormorants (*Phalacrocorax carbo*), two oystercatchers (*Haematopus ostralegus*) and two herring gulls. A rabbit and a kestrel (*Falcus tinnunculus*) carrion were found near a forestry on the mainland.

A large colony of herring gulls, easily accessible to the mink, was located on the south side of the Little Ross island. 170 Herring gulls were counted in February 1995. A total of 27 adult herring gulls carcasses were found in four days, compared with the eight carcasses found during a 56 days sampling period on the mainland.

4.3.1.4 Intertidal fauna

The number of fish and crabs found per meter of transect on the Ross peninsula (0.04 specimens/m, n = 16 transects) was very similar to that found on Little Ross island (0.03 specimens/m, n = 4 transects). The number of prey specimens per meter is not a particularly good indicator of littoral-prey abundance, since it depends highly on the characteristics of the shore

(Chapter 5). Although a detailed micro-habitats assessment of the intertidal zone was carried out in the Ross peninsula, no accurate data were obtained for Little Ross island, due to the restricted time available. Therefore an overall comparison between the island and the peninsula was not possible. However, the shore on Little Ross island seemed less favourable to the mink than that of the peninsula, due to a rather steep and exposed coast.

In summary, if a comparison of the abundance of prey species available to the mink is made between the island of Little Ross and the Ross peninsula (Table 4.4), it can be seen that Little Ross was particularly rich in rodents and sea-birds, while the Ross peninsula, with its extensive variety of intertidal habitats, offered possibly a greater abundance of aquatic prey, such as small fishes and crabs.

Table 4.4: Assessment of prey abundance on Little Ross island relative to that of the Ross peninsula. The prey index gives the total number of specimens trapped or observed per unit area (10 ha). 'n.c.' means that it was not possible to calculate the prey index, in which case the assessment of prey abundance was qualitative and therefore given in parentheses.

	Peninsula		Island	
PREY	**Prey index**	**Assessment**	**Prey index**	**Assessment**
RODENTS	0.19	(scarce)	n.c.	(abundant)
CLIFF BIRDS	n.c.	(scarce)	100.00	(abundant)
LAGOMORPHS	0.43	scarce	0	absent
CARRION	0.38	scarce	15.88	abundant
SHORE	n.c.	(abundant)	n.c.	(scarce)

4.3.2 FORAGING STRATEGIES

4.3.2.1 Levels of activity

On the Ross peninsula, female mink were, on average, significantly more active than males, when the number of active fixes was considered out of the total number of recorded fixes ($t = 2.55$, df $= 3$, $P<0.05$) (Table 4.5). This means that females spent more time out of den foraging or travelling.

Table 4.5: Percentage of fixes when the mink were found active out of den on the Ross peninsula.

Mink ID	SEX	% Time active	Total number fixes
Sasha	F	21%	2641
Nelly	F	14%	102
Olga	F	12%	355
Ivan	M	3%	576
Alex	M	8%	164

On the mainland mink were active out of den on average 11.6% of the total observation time (11.6% time ±6.7, n = 5, range:3-21). On the island the levels of activity were much lower. Olga and Alex were never observed to leave the den for foraging when on the island. They were sometime found active inside the den or in its immediate surroundings (7% of total observation time, n = 153 fixes).

4.3.2.2 Habitat use

On the Ross peninsula the mink were observed to forage on average more often on the shore (61% of all foraging fixes ± 39.7, n = 5, range:0 -100) than in any other habitat (Table 4.6b). All the rest of their activity was spent foraging in the rock and scrub area just above MHWS (39% of all foraging fixes ± 39.9, n = 5, range:0- 100). Virtually no foraging was observed in the pasture habitat in spite of the fact that this was the most abundant habitat in the study area (Table 4.6a). Mink were never observed foraging in forestry areas. However, a great individual variability was observed in the use of the habitats. Much of this variability is almost certainly due to the small sample size: only two mink (Sasha and Olga) yielded a sufficient number of fixes to reasonably assess their habitat use. For this reason habitat selection was not tested statistically.

Table 4.6: Percentage of habitat available (a) and time spent foraging in different habitats on the Ross peninsula (b). The side of the peninsula where the foraging was observed is reported in the second column. The use of pasture fields as a foraging area for males is likely to be underestimated and therefore is expressed with a question mark.

(a)

	HABITAT AVAILABLE			
	ROCKY SHORE	ROCK/ SCRUB	PASTURE	FORESTRY
	18%	13%	68%	1%

(b)

MINK	Side	HABITAT USED				SAMPLE SIZE	
		ROCKY SHORE	ROCK/ SCRUB	PASTURE	FORESTRY	Fixes	Foraging Bouts
SASHA	west	88%	11%	1%	0	456	50
OLGA	east	45%	55%	0	0	38	5
NELLY	east	0	100%	0	0	4	1
IVAN	west	70%	30%	?	0	10	2
ALEX	west	100%	0	?	0	13	1

For males the use of pasture fields as a foraging area was probably underestimated. In this habitat male mink are known to hunt rabbits in their burrows (Ireland 1990). Once a rabbit is captured the mink is likely to spend up to three days in the rabbit burrow, consuming the carcass (Ireland 1990). In the present study when a mink was found in a rabbit burrow it was not considered to be 'foraging', even if it was active, and therefore the relative fixes have been excluded from the analysis (Chapter 2).

Due to the low level of activity observed in mink on the Little Ross island, it was not possible to calculate their habitat use. However, the presence of conspicuous mink trails on Little Ross island (Chapter 3, Figure 3.7) indicates that mink use to travel, and possibly forage, in the area just above MHWS. Out of the 27 Herring gulls carrion found on Little Ross, 15 (56%) were located in an overgrown garden, about 100m from to the bird colony (Plate 2.2). Olga had a den in this garden and a trail connected her den to the gull colony (Figure 3.7). This suggests that the cliffs, where the gull colony was located, were a much used area.

4.3.2.3 Foraging behaviour

On some occasions it was possible to observe the mink while foraging on the shore. The mink were observed to use all the three foraging behaviours described by Hatler (1976): bird-dogging, poking and diving in rockpools. Bird-dogging implies moving along with the nose close to the ground in order to pick up the scents, while poking occurs when the mink sticks its head into cervices and under boulders to obtain fish and small invertebrates. On the Ross peninsula, prey items captured on the shore or in the rocky area above MHWS were sometime dragged back to the den for consumption. A female was observed, on two separate occasions, to drag a cormorant back to its den, despite the fact that the cormorant weighs at least twice as much the mink (Lindsay Maclean 1993). Sometimes, the remains of fish or a crab exoskeleton, were found at the entrance or close to a den. On one occasion a mink on the mainland restricted its foraging activities for two days whilst eating a fish head hidden in the proximity of the den.

On the Little Ross island a similar restriction of the foraging activities to the vicinities of the den was common. Several gull carcasses were located in the vicinity of dens. These carcasses were probably dragged by the mink from the bird colony to the den to be consumed in relative safety.

4.4 Discussion

Remarkable differences in foraging strategies were observed between the mink inhabiting the mainland and those inhabiting Little Ross island. The island has not been grazed in the last 30 years, therefore allowing the development of the grass *Festuca rubra,* which creates optimal conditions for field voles (Corbet and Southern, 1977, Elton 1942). This is the most favoured of all small rodent species by mink (Day and Linn 1972, Dunstone and Birks 1987, but see Chanin and Linn 1980). Moreover, the island hosts a large colony of herring gulls (*Larus argentatus*). These two food sources

allowed the mink living on the island to spend little time hunting. Overall, prey abundance on the island seemed to be greater than on the mainland. This observation is also supported by the fact that two mink, Alex and Olga, had the core of their home range in a relatively small island (17ha), while on the Ross peninsula, which covers an area of about 210 ha, a maximum of three mink were permanently resident (Chapter 3).

On the Ross peninsula mink were found to forage more often on the shore, the most productive habitat. Large portions of the peninsula were grazed and rough pasture fields were very poor in terms of prey availability for mink, unless they hosted a population of rabbits.

Differences in habitat use can be found also between the two different sides of the peninsula. It is interesting to note, that two out of three mink that were observed foraging on the east side of the Ross peninsula, showed a high use of the rock and scrub area compared to mink foraging on the west side (Table 4.6). This tendency might be due to the higher abundance of rodents in the east side relative to that of the west side.

When the results of prey abundance and foraging habits are compared with previous studies carried out in the same area (Dunstone and Birks 1983, Birks and Dunstone 1984, Ireland 1990) some interesting changes are found. The scarcity of lagomorphs on the peninsula suggest that in the winter season 1994-95 this prey type must have played only a minor role in the mink's diet. This contrasts with the previous studies where lagomorphs constituted a much greater proportion of the diet at this time of the year (average of 34% of bulk from December to March, from Ireland 1990). The abundance of lagomorphs on the peninsula has dropped dramatically in the past ten years from an average of about 35 lagomorphs per count in winters 1982 to 1985 (Ireland 1990), to an average of 1 lagomorph per count in 1994-95. In their study in the same area, Birks and Dunstone (1984) found lagomorph remains in many mink dens, confirming their importance to the mink at that time. This trend is reflected also in their den use. In this study

only one den out of the 31 recorded was found in a rabbit burrow, while Ireland (1990) found in his study that 57% of the dens were located in rabbit burrows.

The decrease in the population of rabbits and hares has probably affected males more than females, since males, due to their bigger size, are the main exploiters of this resource (Birks and Dunstone 1985). This could have had two effects on the male population: it either forced males to switch to other food sources, such as littoral or small terrestrial prey, and/or it reduced the number of male mink, restricting them to areas where rabbits were still found. Inadequate data were collected to prove the former case, however the latter case was directly observed. Only one mink was permanently living on the Ross peninsula in 1994-95, compared with at least two males (ranging from 2 to 4) resident in the 1980s' (Dunstone and Birks 1983, 1985, Ireland 199).

Other evidence supporting the idea of male mink still being dependent on lagomorphs as a food source, were the observed lower levels of activity in males compared to females . This was probably due to the fact that males still foraged on larger prey, eg. hares and rabbits, in spite of their scarcity. The females forage on smaller prey items, typically found in the intertidal zone as has been previously demonstrated (Birks and Dunstone 1985, Ireland 1990). Therefore they need to forage more often in order to gain enough energy to fulfil their daily energetic requirements.

In summary, from this study it appears that terrestrial prey are very important in determining both spatial and temporal variations in the foraging habits and spatial organisation of mink. The importance of terrestrial prey in limiting the dispersal of mink has been stressed by Clode and Macdonald (1995). The present study supports their hypothesis and shows that prey might ultimately affect spatial and temporal variations of mink densities.

CHAPTER 5

HABITAT SELECTION ON THE SHORE

5.1 Introduction

In the winter months, the prey items found on the shore are a resource of primary importance for both male and female mink (Dunstone and Birks 1987). Unlike the otter, that favours foraging in the open sea (Kruuk 1995), the mink prefers to forage in the intertidal zone. This observation is supported by laboratory investigation of mink hunting strategies, where the mink was shown to lack the underwater endurance necessary to pursue prey in open water (Dunstone and O'Connor 1979a,b). Several fish species, crabs and other Crustacea are available to the mink in the intertidal zone. Mink have been observed to hunt in rockpools or to search for their prey under boulders or in crevices (Hatler 1976). In spite of the importance of this habitat to the mink little is known about how they exploit this resource. Two main questions will be addressed in the present chapter:

- Do mink forage selectively on the shore ?
- If so, what are the criteria used in habitat selection ?

Several factors are likely to affect the habitat selection of mink on the shore, for example, the presence of dominant competitors (eg. the otter) or physical characteristics of the shore (eg. the steepness of the coast). However, the main factor that is likely to influence habitat selection of mink on the shore is the distribution and abundance of prey, which ultimately depends on the characteristics of the environment.

In this chapter the abundance of prey was modelled in relation to environmental characteristics. The model was then used to predict prey abundance in different areas of the shore to investigate whether mink were choosing areas with higher prey abundance under all conditions. The preference of mink for certain habitat characteristics of the shore was also

studied, and related to the factors that are likely to influence selection, such as prey and competitors.

The term 'habitat selection' is used here to indicate the selection for both biotic (prey) and abiotic (nature of the substratum, exposure, etc.) characteristics of the environment. 'Micro-habitat' is used to indicate a relatively small part of the intertidal area such as a rockpool for example, while 'habitat' is used to indicate an area of the shore of homogenous characteristics.

5.2 Methods

5.2.1 PREY ABUNDANCE

5.2.1.1 Prey abundance index

A prey abundance index was obtained by sampling prey that occur in the mink's diet (Dunstone and Birks 1987). Potential prey were sampled by means of 20 transects carried out at low tide. The locations of the transects were chosen to cover all habitats available, both within and between observed feeding areas (Figure 4.1, Chapter 4). Each transect was divided into four tidal zones according to the distribution of the algae (Table 5.1). An area of 50 cm either side of the transect was surveyed.

Table 5.1: Classification of intertidal zones according to the distribution of algae (from Lewis 1964).

TIDAL ZONE	AVAILABILITY	ALGAE/LICHENS	FAUNA
LOW	available only at low neap tides or at low spring tides	*Laminaria spp., Fucus serratus, Rodphyceae*	*Patella aspera*
MID 1	covered and uncovered every day	*Ascophyllum nodosum, Fucus vesciculosus*	*Littorina littorea,* Barnacles
MID 2	available always except at neap tide	*Fucus spralis, Pelvetia caniculata*	*Littorina neritoides, Littorina saxatils*
HIGH	covered only at very high spring tides	*Verrucaria spp.*	

The following prey species were considered:

Eel (*Anguilla anguilla*)
Blenny (*Blennius pholis*)
Butterfish (*Pholis gunnelus*)
5-Bearded Rockling (*Ciliata mustela*)
Seascorpion (*Taurulus bulbalis*)
Goby (*Gobius* spp.)
Shore crab (*Carcinus maenas*)

The common shrimp (*Crangon vulgaris*) and various Isopods were also surveyed. However, these were excluded from the calculation of the prey abundance index because they were not a major part of the mink's diet (13% bulk, Dunstone and Birks 1987) and were probably taken incidentally as prey of fish eaten.

Size parameters of prey were measured. Only crabs with a carapace wider than 3.0 cm were examined in the analysis, as the smaller crabs were considered to be not a rewarding prey, providing a low ratio of energy content to handling time (Dunstone unpublished data).

For each transect a set of habitat variables was recorded (Table 5.2). The exposure of the shore was assessed by considering the distribution of the algae as a biological indicator of the strength of wave-action (Ballantine 1961). 90% of the shore in the study area was either semi-exposed or sheltered. Rockpool abundance and rockpool size were summarised into a rockpool index.

Table 5.2: Description of the habitat variables considered in the analysis.

HABITAT VARIABLE	MODIFIERS	SCALE OF MEASUREMENT
Substratum	Rock Rock and boulder Boulder and shingle	Ordinal
Relative Exposure	Extremely exposed Semi-Exposed Sheltered	Ordinal
Relative Rockpool abundance	High Medium Low None	Ordinal
Rockpool size	Big (> 2mx2m) Medium (1mx1m - 2mx2m) Small (<1mx1m)	Ordinal
fresh water	Present Absent	Ordinal

Each habitat was defined by the above habitat characteristics (modifiers). Stepwise multiple linear regression was used to model the abundance of prey in habitats with different characteristics. The habitat variables were used as independent variables for the model. Two dependent variables were considered: a distinction was made between prey found in rockpools and elsewhere, eg. under rocks or in crevices. This separation allowed a better prediction. If all the prey, those found in rockpools and those found under rocks, were pooled the results were confused because the occurrence of prey in these two micro-habitats depends on different environmental factors. For example the presence of fresh water might negatively influence the presence of prey living under boulders, but it might not affect the presence of prey in a rockpool unless the fresh water is flowing through the rockpool.

It is important to note that the species belonging to the two considered groups, rockpool and non-rockpool, were the same. A crab (*Carcinus maenas*) could be found either in a rockpool or under a rock, the same can be said for all the fish species considered in the analysis.

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It is important to note that the species belonging to the two considered groups, rockpool and non-rockpool, were the same. A crab (*Carcinus maenas*) could be found either in a rockpool or under a rock, the same can be said for all the fish species considered in the analysis.

The prey abundance index describes the total amount of potential prey in a certain habitat. Pooling the data concerning fish and crabs is justified by the fact that the mink is an opportunistic feeder (Dunstone 1993) and therefore eats what it encounters if it is appropriate, regardless of the species. However, a correction was made to take into account the energy content and the handling time of fishes compared to crabs. The correction for the energy contents was based on the results obtained by Watt (1991 cited by Kruuk 1995, pg. 136) in a coastal habitat on similar fish species. This author found that fishes were about 20% more rewarding than crabs in terms of energy content. Moreover, crabs require a greater handling time compared to fish. A live crab of about 5 cm carapace width, requires a handling time of little less than 5 minutes (Dunstone unpublished data). No data are available for fish. However, it is reasonable to assume the handling time to be shorter in their case. Taking into account all the above considerations, in the equation the fish was given a weighting of 2/3 and the crabs a weighting of 1/3.

Two equations were obtained from the regression analysis, one for prey in rockpools and one for prey available elsewhere. The prey abundance index was given by the sum of these two equations.

The prey that were likely to be found on the shore during the surveys were detectable and accessible to a mink as well, since the sampling methods did not imply the lifting of heavy rocks and boulders. Therefore it can be said that prey abundance in this case is a good estimate of prey availability.

5.2.1.2 Prey abundance in different habitats on the shore

The shore was surveyed and the same habitat variables recorded for each transect (Table 5.2) were quantified for shore areas. Tidal zones were discriminated on the basis of the distribution of the algae (Table 5.1). The shore was divided into polygons, each one encompassing a homogeneous

habitat in terms of the five habitat variables considered, and belonging to a particular tidal zone.

In order to evaluate the prey abundance in each polygon, the significant habitat variables from the stepwise multiple regression, were used in the equation for the calculation of the prey abundance index. Each polygon was therefore characterised by a certain prey abundance depending on its habitat characteristics. The prey abundance was assumed to be constant from November to March.

5.2.2 HABITAT SELECTION

Habitat selection was studied by means of radio-tracking (Chapter 2). Three mink, two males and one female, were followed between November and March. For one of the mink (Sasha) the data were collected in 1994-1995. The data on the other two mink (Fred and Ted) were collected by Mark Ireland in the same area between 1983 and 1985. Sasha was sampled every five minutes, while Fred and Ted were sampled every ten minutes. A total of 311 foraging fixes were analysed for Sasha, 118 fixes for Fred and 56 fixes for Ted, corresponding to 45, 20 and 12 foraging bouts.

All three mink were using the same area of the shore in the west side of the Ross peninsula, between Fauldbog North and The Bents (Figure 2.1, Chapter 2), although in different years. It is possible that the absolute abundance of prey on the shore varies in different years, however it was assumed that the relative abundance of prey between different habitats did not vary from year to year.

5.2.2.1 Foraging areas

Under the assumption that the animal has available different amounts of the various habitats according to the foraging area it is visiting, it was important

to group the foraging bouts in order to identify the foraging areas within which the selection occurred. Foraging bouts were grouped according to the exit from and returning to the den. Dens which were found within a given core area, as identified by the Density Circles method (Chapter 6, Figure 6.8 and Appendix 1, Figures A.9 and A.10), were assumed to be close enough to be considered as equivalent by the mink, i.e. the mink was likely to return to any of the dens within a given core area after a foraging bout. Therefore the foraging bouts relative to each single core area, were grouped together. The foraging bouts when the animal was moving between core areas formed a separate group.

Once the foraging bouts were grouped, the foraging area was identified as the portion of the shore situated between MHWS (Mean High Water Springs), MLWS (Mean Low Water Springs), and line perpendicular to the main direction of the shore passing through the two fixes at the extreme ends of the foraging area. In order to estimate this area, all active fixes were included (foraging and travelling), under the assumption that if the animal had visited a certain place the habitat in that area was potentially available.

The term 'foraging area' is used separately from 'core area'. The former was identified with the method described above, while the latter was determined with the Density Circles method, and does not necessarily cover all the locations in which the mink was observed to forage.

Depending on the state of the tide, different sections of the shore were available to the mink. To take this into account, the foraging bouts were divided into three groups according to when they occurred: low, mid or high tide. A fix was considered to be at low tide or high tide when it occurred respectively within one hour and a half before or after the estimated low or high tide (Admiralty Tide Tables 1994, 1995). All the other fixes were considered to be at mid tide. At low tide all the shore, comprised between MHWS and MLWS, was considered to be available to the animal. At mid tide the low tidal zone was considered to be not available. At high tide the low

tidal zone and the mid 1 tidal zone (Table 5.1) were considered to be not available. The term 'tide group' is used separately from 'tidal zone'. Tide group is defined as the time with respect to the position of the tide at which the mink is foraging (low, mid and high tide). Tidal zone refers to a particular area on the shore as defined by the position of the algae (low, mid 1, mid 2, high tidal zone).

5.2.2.2 Selection for prey abundance

Habitat selection was tested for areas with different prey abundance using the method suggested by Neu et al. (1974). The null hypothesis, that the use of the habitat occurs in proportion to its availability when all habitats are considered simultaneously, was tested with a Chi-square goodness-of-fit analysis. In the analysis, the Chi-square was applied if the average expected observation over all categories was six or more (Roscoe and Bayars 1971 cited by Neu et al. 1974).

The Chi-square goodness-of-fit analysis requires the fixes to be independent. The data were considered to be independent if the animal was able to move out of any polygon between one sampling unit and the next (five or ten minutes according to the mink considered). In order to assess independence, the maximum distance covered between two fixes was calculated for each animal and compared with the maximum distance between two points in a polygon. The maximum distance between two points in a polygon was 238m and the maximum distance moved between two fixes was for Sasha, Ted and Fred respectively 256m, 323m, and 456m. The fixes were therefore considered independent.

If the mink did not move out of the polygon and kept on foraging, this was considered as a 'choice' for that particular habitat, indicating that the animal was preferring it, by choosing to search there instead of elsewhere. This assumes that the mink had a previous knowledge of the area, which is

reasonable in this case since all the studied mink were residents. The amount of time that the animal spent 'searching' in different habitats, rather than the total amount of time including handling and eating time, was considered. Hence, when the animal was foraging but not moving, only the first fix of the series of consecutive fixes was included in the analysis.

For the cases where significant results were obtained, each habitat was considered separately and tested with a Bonferroni z-statistic to see whether its use diverged significantly from availability (Neu *et al.* 1974). In order to ensure that the statistics' distribution is well approximated np and $n(1-p) \geq 5$, where n is the sample size and p is the proportion of fixes.

Data from different mink were pooled only if habitat availability for each animal was the same, as required by the Neu *et al.* (1974) method.

5.2.2.3 Selection for different habitat characteristics

Each habitat variable (Table 5.2) was tested separately to investigate if mink preferred or avoided some of the habitat features. The observed frequencies of habitat use were compared with the expected frequencies, as calculated from the habitat availability. This comparison was carried out for each mink in each foraging area (n = 5). For each habitat variable, a table reporting the sign of the difference of observed minus expected frequencies was produced. If the trends, resulting from the signs, were consistent across all foraging areas for a given habitat characteristic, then the Neu *et al.* (1974) procedure for analysing habitat selection was applied. The selection was considered to occur only if the Chi-square goodness-of-fit results were significant for all foraging areas. This procedure was adopted to reduce the probability of incurring into type I or type II errors.

Pearson correlation coefficient was used to investigate the relation between the five different habitat variables considered in the analysis.

5.3 Results

5.3.1 PREY ABUNDANCE

5.3.1.1 Prey abundance index

From the stepwise multiple linear regression the abundance of prey within rockpools was predicted by the abundance and size of rockpools and by the position within the tidal zone (F = 14.78, p < 0.001) (Table 5.3 and 5.4). Rockpools in the lower shore were much richer in prey suitable for mink than those in the upper shore.

The presence of fresh water and the nature of substrata determined the abundance of prey outside rockpools (F = 10.48, p < 0.001) (Table 5.3 and 5.5). The presence of fresh water had a negative effect on the presence of prey. This is possibly due to physiological constraints, since marine organism are not adapted to fresh water conditions. The regression also indicated that prey living out of rockpools favour areas with small boulders rather than areas with bare rock or large boulders, probably because there were crevices in which to hide.

The high tidal zone was relatively poor in potentially available prey. However, this did not result when modelling the abundance of prey out of rockpools. Slightly less prey were counted in the lower tidal zone than in the mid one, and no prey were found in the high tidal zone. The linear regression could not describe this distribution of prey abundance, and therefore the abundance of prey out of rockpools was not predicted by the position within tidal zones.

Table 5.3: Regression equations that predict the amount of prey within and out of rockpools. In the last column the amount of variance explained by each regression (R^2) is stated.

PREY LOCATION	REGRESSION EQUATION	R^2
Within rockpools	E1= 2.25 + 2.39 (Rockpools) - 0.85 (Tidal zone)	33%
Out of rockpools	E2= -1.57 - 4.92 (Fresh water) + 2.21 (Substratum)	26%

Table 5.4: Analysis of variance of abundance of prey within rockpools. Independent variables are rockpool and tidal zone.

	df	Sum of Squares	Mean Square	F-value	P-value
Regression	2	378	189	14.78	p < 0.001
Residual	61	779	13		
Total	63				

Table 5.5: Analysis of variance of abundance of prey out of rockpools. Independent variables are substrata and fresh water.

	df	Sum of Squares	Mean Square	F-value	P-value
Regression	2	6473	3237	10.48	p < 0.001
Residual	60	18522	309		
Total	62	24995			

The prey abundance index (PAI) was given by the sum of the two regression equations:

$$PAI = [-1.57 - 4.92 (Fresh water) + 2.21 (Substratum)] + [2.25 + 2.39 (Rockpools) - 0.85 (Tidal zone)]$$

5.3.1.2 Relative abundance of prey species

Table 5.6 shows the number of specimens of each species trapped within and out of rockpools. It is not possible to compare number of prey items within and out of rockpools, since the sampling was done along transects and therefore the density of prey per unit area is not known.

Amongst the fish, the blenny (*Blennius pholis*) was by far the most common (67% and 75% of fish captures respectively in and out of rockpools, n = 15, n = 28). This species was found by Dunstone and Birks (1987) to be the most frequently taken fish by mink on the Ross peninsula (37% bulk amongst the

recognised fish species). Crabs were also relatively common in this season (29% and 43% of total captures in and out of rockpools, n = 21, n = 49) compared to all fish species, except for the blenny.

Table 5.6: Number of specimens of each species counted within and out of rockpools. The percentage of total captures (%Tot.) and the percentage of total fish captures (% Fish) are given.

Prey species	Numbers in Rockpools	% Tot.	% Fish	Numbers out of Rockpools	% Tot.	% Fish
Blenny	10	48	67	21	43	75
Butterfish	0	0	0	3	6	11
5-Bearded Rockling	0	0	0	3	6	11
Seascorpion	3	14	20	0	0	0
Goby (*Gobius* spp.)	0	0	0	1	2	4
Eel	2	10	13	0	0	0
Shore crab	6	29	–	21	43	–
Totals	21	101	100	49	100	101

5.3.1.3 Prey abundance in different habitats on the shore

Each polygon on the shore was assigned a prey abundance score (Figure 5.1) which depended on the habitat characteristics identified by the regression equations. The shore from Fauldbog North to the Bents, had prey abundance scores ranging from -1.01 to 15.17. In order to render all the scores positive, a constant 'c' (c = 1.11) was summed to each value. After the transformation the scores were ranging from 0.10 to 16.28 (mean 8.03 ± 5.15, n = 63). Lower scores indicate poor foraging areas, while the higher scores indicate rich foraging areas.
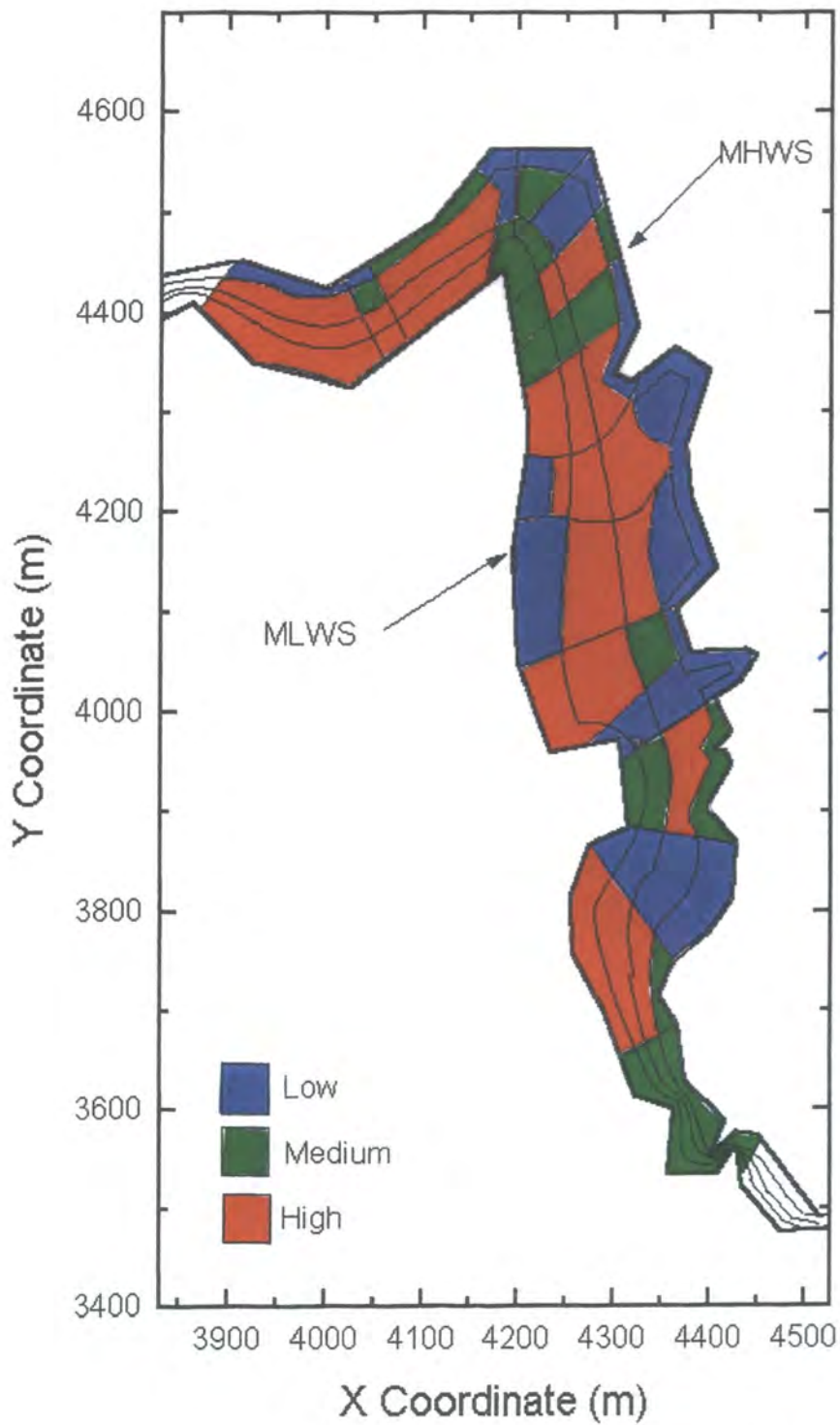
Figure 5.1: Prey abundance score for each of the considered polygons in the intertidal zone. Low = 0-5.42; Medium = 5.43-10.84; High = 10.85-16.28.

5.3.2 HABITAT SELECTION

5.3.2.1 Foraging areas

Three foraging areas were identified for Sasha (Table 5.7), one at Fauldbog North (Figure 3a), one comprising the area from Black Barn to Fauldbog North (Figure 3.b), and one comprising the area from Black Barn to the Bents (Figure 3.a). One foraging area, centred on Black Barn, but extending also into the Fauldbog North and the Bents areas, was identified for both Fred and Ted (Figure 5.2c and Table 5.7).

The Bents did not fall within the Black Barn core area for any of the mink (Figure 6.8, Figure A.9, Figure A.10). For Sasha and Fred a separate smaller core area was located at the Bents (Figure 6.8 and A.9). However, mink were observed to use that portion of the shore, between Black Barn and the Bents, as a discrete foraging area. For example during a foraging bout a mink often started at Black Barn, travelled to the Bents and returned to Black Barn. Therefore it was decided to consider the whole area (Black Barn to the Bents) as a single foraging area.

Table 5.7: Foraging areas considered in the analysis.

MINK	Foraging Area	Type	Number of Foraging area
Fred	Black Barn	At a core area	1
Ted	Black Barn	At a core area	2
Sasha	Black Barn	At a core area	3
Sasha	Fauldbog North	At a core area	4
Sasha	F.North-B.Barn	Between core areas	5
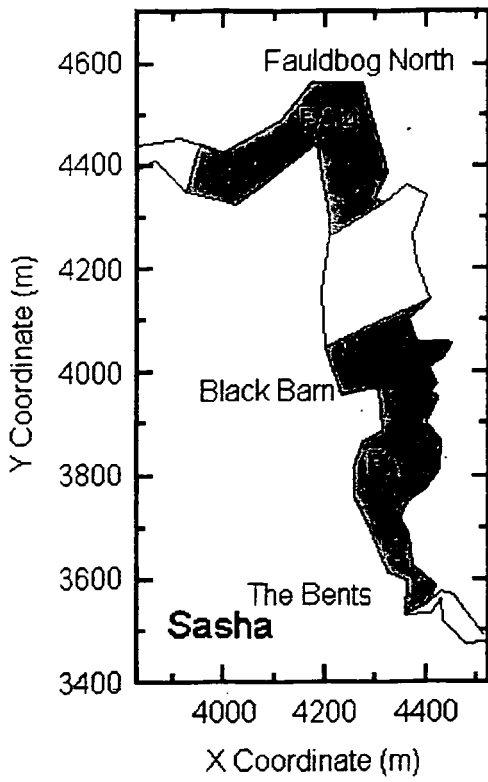
Figure 5.2a: Foraging areas of Sasha at Fauldbog North (FA 4) and at Black Barn-The Bents (FA 3).
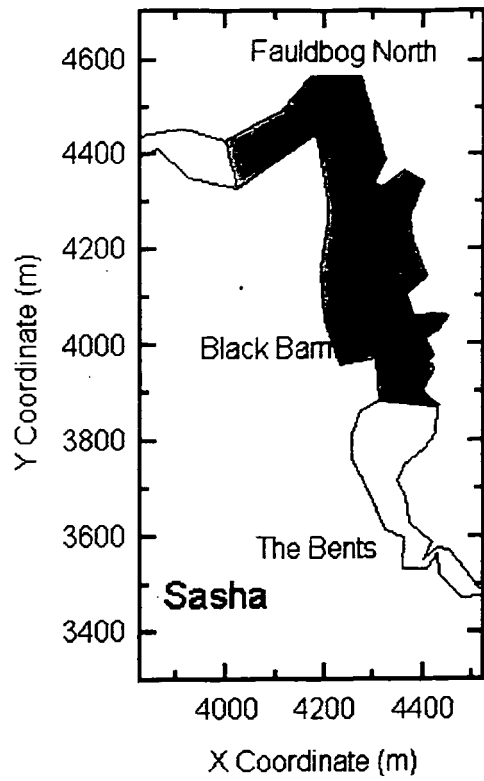
Figure 5.2b: Foraging area of Sasha between Fauldbog North and Black Barn (FA 5).
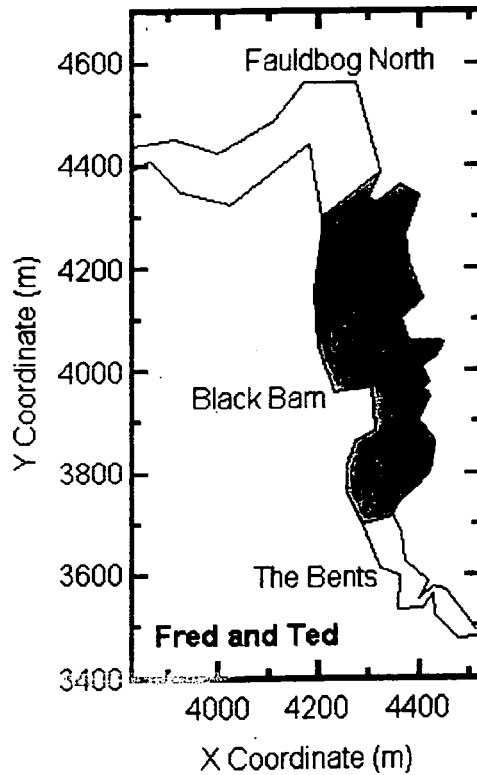
Figure 5.2c: Foraging area of Fred and Ted at Black Barn (FA 1 and FA 2).

From Table 5.8 it can be seen that the average speed of Sasha was significantly higher when foraging between core areas (Foraging area 5) than when foraging within a core area (Foraging areas 3 and 4) (t = 2.00, df = 27, p < 0.05, one-tail). The two males were also observed to be faster than the female when foraging within core areas.

Table 5.8: Distance moved between consecutive fixes (m/5min) within each foraging area.

MINK	Foraging area	Speed (m/5min)
Fred	1	38
Ted	2	43
Sasha	3	37
Sasha	4	35
Sasha	5	44

5.3.2.2 Selection for prey abundance

Habitat selection was first tested by separating polygons according to their prey abundance score, into three classes of equal size (0 - 5.42, 5.43 - 10.84, 10.85 - 16.28). Habitat selection was tested separately on the various animals for each of the foraging areas listed in Table 5.7, a part from Fred and Ted which were pooled, since the habitat available to them was the same.

Each tide group was tested separately and the results of the goodness-of-fit analysis are given in Tables 5.9a, 5.9b and 5.9c. In most cases, when foraging at low (Table 5.9a) and mid tide (Table 5.9b), the mink were selective in their habitat use. The exception was for foraging area 5, where no selection apparently occurred. This is the only foraging area located between two core areas, and therefore a different behaviour is expected than that found when foraging within a core area.

Table 5.9a: Chi-square goodness-of-fit test for selection of polygons with different prey abundance scores at LOW TIDE. Habitat availability is calculated within each foraging area and is expressed in hectars (ha). PA class = prey abundance class.

Foraging Area	PA class	Habitat availability	Proportion of available habitat	Observed fixes	Expected fixes	Chi-square results
1 and 2	0.1-5.4	3.13	0.300	8	18.60	$\chi^2 = 10.35$
	5.4-10.9	1.21	0.116	6	7.44	$p < 0.01$
	10.9-16.3	6.06	0.583	48	35.96	
		Totals:10.40 ha	1.001	62	62.00	
3	0.1-5.4	1.79	0.247	2	7.00	$\chi^2 = 7.06$
	5.4-10.9	2.17	0.299	7	8.4	$p < 0.05$
	10.9-16.3	3.29	0.454	19	12.6	
		Totals: 7.25 ha	1.000	28	28.00	
4	0.1-5.4	0.81	0.152	1	10.49	$\chi^2 = 10.23$
	5.4-10.9	1.35	0.253	19	17.46	$p < 0.01$
	10.9-16.3	3.18	0.596	49	41.12	
		Totals: 5.34 ha	1.001	69	69.07	
5	0.1-5.4	2.76	0.237	21	15.89	$\chi^2 = 2.368$
	5.4-10.9	2.43	0.209	14	14.00	$p = 0.306$ NS
	10.9-16.3	6.46	0.555	32	37.19	
		Totals:11.65 ha	1.001	67	67.08	

Table 5.9b: Chi-square goodness-of-fit test for selection of polygons with different prey abundance scores at MID TIDE. Habitat availability is calculated within each foraging area and is expressed in hectares (ha). PA class= prey abundance class; n.c. = not calculated because too few fixes.

Foraging Area	PA class	Habitat availability	Proportion of available habitat	Observed fixes	Expected fixes	Chi-square results
1 and 2	0.1-5.4	2.51	0.295	5	26.10	$\chi^2 = 38.90$
	5.4-10.9	0.90	0.106	2	9.90	**p < 0.001**
	10.9-16.3	5.11	0.600	83	54.00	
		Totals: 8.52 ha	1.001	90	90.00	
3	0.1-5.4	1.63	0.318	6	13.12	$\chi^2 = 8.23$
	5.4-10.9	0.98	0.191	6	7.79	**p < 0.05**
	10.9-16.3	2.51	0.490	29	20.09	
		Totals: 5.12 ha	0.999	41	41.00	
4	0.1-5.4	0.81	0.191	0	8.02	$\chi^2 = 11.58$
	5.4-10.9	1.03	0.242	16	10.16	**p < 0.01**
	10.9-16.3	2.41	0.567	26	23.81	
		Totals: 4.25 ha	1.000	42	41.99	
5	0.1-5.4	2.21	0.232	2	3.71	n.c.
	5.4-10.9	1.80	0.189	2	3.02	
	10.9-16.3	5.52	0.579	12	9.26	
		Totals: 9.53 ha	1.000	16	15.99	

Table 5.9c: Chi-square goodness-of-fit test for selection of polygons with different prey abundance scores at HIGH TIDE. Habitat availability is calculated within each foraging area and is expressed in hectares (ha). PA class = prey abundance class. n.c. = not calculated because too few fixes.

Foraging Area	PAI class	Habitat availability	Proportion of available habitat	Observed fixes	Expected fixes	Chi-square results
1 and 2	0.1-5.4	2.20	0.416	10	10.5	$\chi^2 = 0.835$
	5.4-10.9	0.60	0.113	2	2.75	$p = 0.361$ **NS**
	10.9-16.3	2.49	0.471	13	11.75	
		Totals: 5.29 ha	1.000	25	25.00	
3	0.1-5.4	1.32	0.423	12	13.86	$\chi^2 = 0.787$
	5.4-10.9	0.61	0.196	6	6.60	$p = 0.648$ **NS**
	10.9-16.3	1.19	0.381	15	12.54	
		Totals: 3.12 ha	1.000	33	33.00	
4	0.1-5.4	0.81	0.276	2	4.97	$\chi^2 = 9.888$
	5.4-10.9	0.71	0.242	10	4.36	**P < 0.01**
	10.9-16.3	1.41	0.481	6	8.66	
		Totals: 2.93 ha	0.999	18	17.89	
5	0.1-5.4	2.08	0.343	5	n.c.	n.c.
	5.4-10.9	1.18	0.194	0	n.c.	
	10.9-16.3	2.81	0.463	0	n.c.	
		Totals: 6.07 ha	1.000	5		

At high tide (Table 5.9c), in two out of three cases the mink were not selective. The only significant result obtained with the Chi-square goodness-of-fit test was not confirmed when preference/avoidance of each prey abundance class was tested with the Bonferroni z-statistic analysis (Table 5.10). This suggests that overall the animals did not forage selectively when foraging at high tide.

For foraging area 4 at mid and high tide, the number of fixes was not sufficient to proceed with the Chi-square goodness-of-fit test. However, at mid tide a comparison of observed and expected fixes (Table 5.9b), showed that foraging occurs roughly according to availability.

In the foraging areas where mink were found to forage selectively, each prey abundance class was tested separately to see whether it was preferred, avoided or used according to its availability. The results showed that areas with low prey abundance were always avoided (Table 5.11a and 5.11b). At low tide (Table 5.11a) areas with an intermediate prey abundance were used according to their availability, while areas with high prey abundance were preferred in two out of three cases, and used according to availability in one case. At mid tide (Table 5.11b) areas with intermediate prey abundance were used according to their availability in two out of three cases, and avoided in one case. Areas with high prey abundance were preferred in two cases out of three, and used according to availability in one case.

Table 5.10: Results of the Bonferroni z-statistic for testing avoidance/preference of each Prey Abundance class (PA class) at HIGH TIDE. In the last column the signs indicate whether the class has been preferred (+), avoided (-), or used in proportion to its availability (=). The level of significance is $\alpha = 0.1$, for which z-score = 2.128. The observed number of fixes and the habitat availability in ha can be found in table 5.9c.

Foraging Area	PA class	Proportion of fixes per class (p)	Proportion of available habitat	Confidence interval	Sign
4	0.1-5.4	0.111	0.276	$-0.047 \leq p \leq 0.269$	=
	5.4-10.9	0.556	0.242	$0.307 \leq p \leq 0.805$	=
	10.9-16.3	0.333	0.481	$0.097 \leq p \leq 0.569$	=
		1.000	0.999		

Table 5.11a: Results of the Bonferroni z-statistic for testing avoidance/preference of each Prey Abundance class (PA class) at LOW TIDE. In the last column the signs indicate whether the class has been preferred (+), avoided (-), or used in proportion to its availability (=). The level of significance is $\propto$ = 0.1, for which z-score = 2.128. The observed number of fixes and the habitat availability in ha can be found in table 5.9a.

Foraging Area	PA class	Proportion of fixes per class (p)	Proportion of available habitat	Confidence interval	Sign
1 and 2	0.1-5.4	0.129	0.300	$0.038 \leq p \leq 0.220$	-
	5.4-10.9	0.097	0.116	$0.017 \leq p \leq 0.177$	=
	10.9-16.3	0.774	0.583	$0.661 \leq p \leq 0.887$	+
		1.000	1.001		
3	0.1-5.4	0.071*	0.247	$-0.032 \leq p \leq 0.174$	-
	5.4-10.9	0.250	0.299	$0.076 \leq p \leq 0.424$	=
	10.9-16.3	0.679	0.454	$0.491 \leq p \leq 0.867$	+
		1.000	1.000		
4	0.1-5.4	0.014*	0.152	$-0.016 \leq p \leq 0.044$	-
	5.4-10.9	0.275	0.253	$0.161 \leq p \leq 0.389$	=
	10.9-16.3	0.710	0.596	$0.594 \leq p \leq 0.826$	=
		0.999	1.001		

* The asterisk indicates that np (where n is total number of fixes and p is the proportion of fixes per class) is ≤ 5.

Table 5.11b: Results of the Bonferroni z-statistic for testing avoidance/preference of each Prey Abundance class (PA class) at MID TIDE. In the last column the signs indicate whether the class has been preferred (+), avoided (-), or used in proportion to its availability (=).The level of significance is $\propto$ = 0.1, for which z-score = 2.128. The observed number of fixes and the habitat availability in ha can be found in table 5.9b.

Foraging Area	PA class	Proportion of fixes per class (p)	Proportion of available habitat	Confidence interval	Sign
1 and 2	0.1-5.4	0.056	0.295	$0.004 \leq p \leq 0.108$	-
	5.4-10.9	0.022	0.106	$-0.011 \leq p \leq 0.055$	-
	10.9-16.3	0.992	0.600	$0.862 \leq p \leq 0.982$	+
		1.000	1.001		
3	0.1-5.4	0.146	0.318	$0.029 \leq p \leq 0.263$	-
	5.4-10.9	0.146	0.191	$0.029 \leq p \leq 0.263$	=
	10.9-16.3	0.707	0.490	$0.556 \leq p \leq 0.858$	+
		0.999	0.999		
4	0.1-5.4	0.000*	0.191	–	-
	5.4-10.9	0.381	0.242	$0.222 \leq p \leq 0.540$	=
	10.9-16.3	0.619	0.567	$0.460 \leq p \leq 0.778$	=
		1.000	1.000		

* The asterisk indicates that np (where n is total number of fixes and p is the proportion of fixes per class) is ≤ 5.

To investigate why there was a lack of selectivity at high tide, the amount of time the mink spent foraging on the shore and in the area above the shore were compared. Table 5.12 shows that when the tide was low, mink tended to spend most of their foraging time on the shore, while at high tide the mink spent an increasing amount of time foraging in the area above MHWS. Most of this time was spent in the rock-scrub area (84%), and the rest was spent in rough pasture.

Table 5.12: Percentage of fixes recorded in areas above MHWS while foraging at different states of the tide. (n = total number of fixes).

MINK	n	LOW TIDE	MID TIDE	HIGH TIDE
SASHA	415	3%	12%	13%
FRED	136	9%	8%	18%
TED	125	2%	51%	83%

5.3.2.3 Selection for different habitat characteristics

Each one of the five habitat characteristics (substrata, rockpools, fresh water, exposure, tidal zone) was then considered separately to investigate whether mink showed preference or avoidance. The expected and the observed frequencies of fixes were compared. A summary of these differences is given in Table 5.13. For each habitat characteristic, if the sign of the difference between observed minus expected was the same for all mink across at least one class, then that habitat characteristic was tested for selection with the Neu et al. (1974) method. The results of the Chi-square goodness-of-fit tests were further tested with the Bonferroni z-statistics only if the Chi-square values were significant across all the foraging areas. The previous analysis on the prey abundance indicated that the mink behaves differently while moving from one core area to the next, therefore in considering such trends foraging area 5 was excluded.

Table 5.13: Summary of the differences between observed and expected frequencies of radio-tracking fixes for each habitat characteristic. '+' habitat characteristic is preferred in all foraging areas; '-' habitat characteristic is avoided in all foraging areas; '=' habitat characteristic is preferred in some and avoided in other foraging areas. n.p. that particular habitat is not present in the considered foraging group.

A: SUBSTRATA	Foraging at		
	Low Tide	Mid Tide	High tide
Rocks	=	=	=
Rocks + boulders	=	=	=
Boulders + shingle	=	=	-

B: ROCKPOOLS	Foraging at		
	Low Tide	Mid Tide	High tide
Few and small	-	=	=
Medium	=	=	=
Lots and big	=	+	=

C: FRESH WATER	Foraging at		
	Low Tide	Mid Tide	High tide
Absent	+	+	+
Present	-	-	-

D: EXPOSURE	Foraging at		
	Low Tide	Mid Tide	High tide
Low	=	=	=
Medium	=	=	=
High	=	=	=

E: TIDAL ZONE	Foraging at		
	Low Tide	Mid Tide	High tide
Low	-	n.p.	n.p.
Medium 1	+	=	n.p.
Medium 2	=	=	=
High	-	-	=

The results show that areas with fresh water tended to be avoided (Table 5.13C). At high tide this trend was not particularly strong, since none of the Chi-square tests were significant (Table 5.14). At mid tide, the Chi-square tests were significant for all the three considered groups (Table 5.14). When tested with the Bonferroni z-statistic the animals were found to significantly

avoid areas with fresh water and to prefer areas without fresh water (Table 5.15a).

Mink showed a preference for the mid 1 tidal zone and avoided the low and high tidal zone when foraging at low tide (Table 5.13E), however, only two out of three of the Chi-square tests showed a significant result (Table 5.14). At mid tide, all the three Chi-square tests were significant (Table 5.14). In this case, when tested with the Bonferroni z-statistic (Table 5.15b), the high tidal zone was found to be significantly avoided in all three cases.

No consistent trend was found for the use of the substrata at low or mid tide. At high tide, all the mink showed a tendency to avoid foraging in areas of boulders and shingle (Table 5.13A). However, this trend was not supported by the results of the Chi-square test, only one test out of three being significant (Table 5.14).

Areas with no rockpools were under-used at low tide, while areas with abundant rockpools were used more than expected at mid tide (Table 5.13B). Also here the trends were not particularly strong, only three out of a total of six Chi-square tests being significant (Table 5.14)

Table 5.14: Results of the Chi-square goodness-of-fit test on the habitat variables that showed the same sign across foraging areas 1 to 4. The significance is expressed as: ns not significant; * significant at $p < 0.05$; ** significant at $p < 0.01$; *** significant at $p < 0.001$.

Habitat variable	Tide group	Foraging areas		
		1 and 2	3	4
Substrata	High tide	ns	ns	*
Rockpools	Low tide	*	*	ns
Rockpools	Mid tide	***	ns	ns
Fresh water	Low tide	*	*	ns
Fresh water	Mid tide	***	*	*
Fresh water	High tide	ns	ns	ns
Tidal zone	Low tide	***	ns	***
Tidal zone	Mid tide	*	*	***

Table 5.15a: Results of the Bonferroni z-statistic for testing avoidance/preference of habitat with or without FRESH WATER at MID TIDE. In the last column the signs indicate whether the class has been preferred (+), avoided (-), or used in proportion to its availability (=). The level of significance is $\propto$ = 0.1, for which z-score = 2.128. The observed number of fixes can be found in table 5.9a.

Foraging Area	Fresh water	Proportion of fixes per class (p)	Proportion of available habitat	Confidence interval	Sign
1 and 2	Absent	0.887	0.775	$0.801 \leq p \leq 0.973$	+
	Present	0.113	0.245	$0.027 \leq p \leq 0.199$	-
		1.000	1.001		
3	Absent	0.854	0.689	$0.737 \leq p \leq 0.971$	+
	Present	0.146	0.311	$0.029 \leq p \leq 0.263$	-
		1.000	1.000		
4	Absent	1.000 *	0.873	$1.000 \leq p \leq 1.000$	+
	Present	0.000 *	0.127	$0.000 \leq p \leq 0.000$	-
		1.000	1.000		

* The asterisk indicates that np or $n(1 - p)$ (where n is total number of fixes and p is the proportion of fixes per class) is ≤ 5.

Table 5.15b: Results of the Bonferroni z-statistic for testing avoidance/preference of each TIDAL ZONE at MID TIDE. In the last column the sign indicates whether the class has been preferred (+), avoided (-), or used in proportion to its availability (=). The level of significance is $\alpha = 0.1$, for which z-score = 2.128. The observed number of fixes can be found in table 5.9b.

Foraging Area	Tidal zone	Proportion of fixes per class (p)	Proportion of available habitat	Confidence interval	Sign
1 and 2	Mid 1	0.489	0.379	$0.377 \leq p \leq 0.601$	=
	Mid 2	0.467	0.478	$0.355 \leq p \leq 0.579$	=
	High	0.044 *	0.143	$-0.002 \leq p \leq 0.090$	-
		1.000	1.000		
3	Mid 1	0.585	0.391	$0.421 \leq p \leq 0.749$	+
	Mid 2	0.293	0.357	$0.142 \leq p \leq 0.444$	=
	High	0.122	0.252	$0.013 \leq p \leq 0.231$	-
		1.000	1.000		
4	Mid 1	0.619	0.311	$0.468 \leq p \leq 0.778$	+
	Mid 2	0.310	0.429	$0.158 \leq p \leq 0.462$	-
	High	0.071 *	0.198	$0.013 \leq p \leq 0.155$	-
		1.000	1.001		

* The asterisk indicates that np (where n is total number of fixes and p is the proportion of fixes per class) is ≤ 5.

5.3.2.4 Relationships between habitat variables

The relationships between habitat variables were investigated using correlation analysis (Table 5.16). The nature of the substratum was positively correlated with the presence of fresh water, indicating that fresh water is more likely to be found on substrata made of small boulders and shingle, rather than on bare rock. The presence of rockpools increased going from small grain substratum to bare rocks. Rockpools were also less likely to be found where fresh water was present, possibly due to the fact that where there is fresh water the substratum is made of shingle and small boulders, a condition that doesn't well suit the formation of rockpools. Areas which were more exposed were usually characterised by bare rocks, while areas less exposed were usually characterised by wide shores composed of small to medium size boulders. Finally, there was a positive correlation between the presence of fresh water and the tidal level. This indicates that fresh water was more likely to be found in the upper shore rather than in the lower shore.

Table 5.16: Pearson correlation coefficient for habitat characteristics. n = 72. The asterisks indicate the level of significance: * = significant at $p < 0.05$; ** = significant at $p < 0.01$; *** = significant at $p < 0.001$.

	Substrata	Rockpools	Fresh water	Exposure	Tidal zone
Substrata	1				
Rockpools	- 0.457 ***	1			
Fresh water	0.500 ***	- 0.453 ***	1		
Exposure	- 0.651 ***	0.131	- 0.294	1	
Tidal Zone	- 0.078	- 0.152	0.201 *	0.019	1

5.4 Discussion

The present study has shown that the mink is behaving selectively when foraging on the shore, favouring areas with high prey abundance and avoiding areas with low prey abundance. However, its selectivity appears to vary according to at least three different factors, as shown in schematic form in Figure 5.3.

A prerequisite for the mink to behave selectively might be the degree of knowledge that it has of the area (Valone 1991). A resident mink is expected to know the area better than a transient one. This hypothesis is supported in this study by an anedoctal observation. The three mink considered in the analysis were all residents and used the shore selectively. However, in a single foraging bout of an individual mink not familiar with the area, the individual spent 60% of its 65 minute foraging bout in a sub-optimal habitat of small boulders with fresh water, even if it was foraging at mid tide and therefore was expected to be selective. This single observation is not conclusive, but suggests that a link between actual knowledge of the area and selectivity should be investigated in future research.

If the mink is resident, then selectivity will depend on the state of the tide. When foraging at low or mid tide, mink chose the best areas in terms of prey abundance and avoided areas with scarce prey. When foraging at high tide, however, it was not foraging selectively. The reason for this non-selectivity is probably explained by considering that at high tide the only area available was the least productive zone of the shore. At high tide the mink were observed to spend a greater time in the rock/scrub area while also foraging on the shore (Table 5.12). It is therefore possible that the use of the shore was conditioned by what was available above MHWS.

Figure 5.3: Flow diagram representing the factors determining whether the mink behaves selectively or not, when foraging in the intertidal zone.
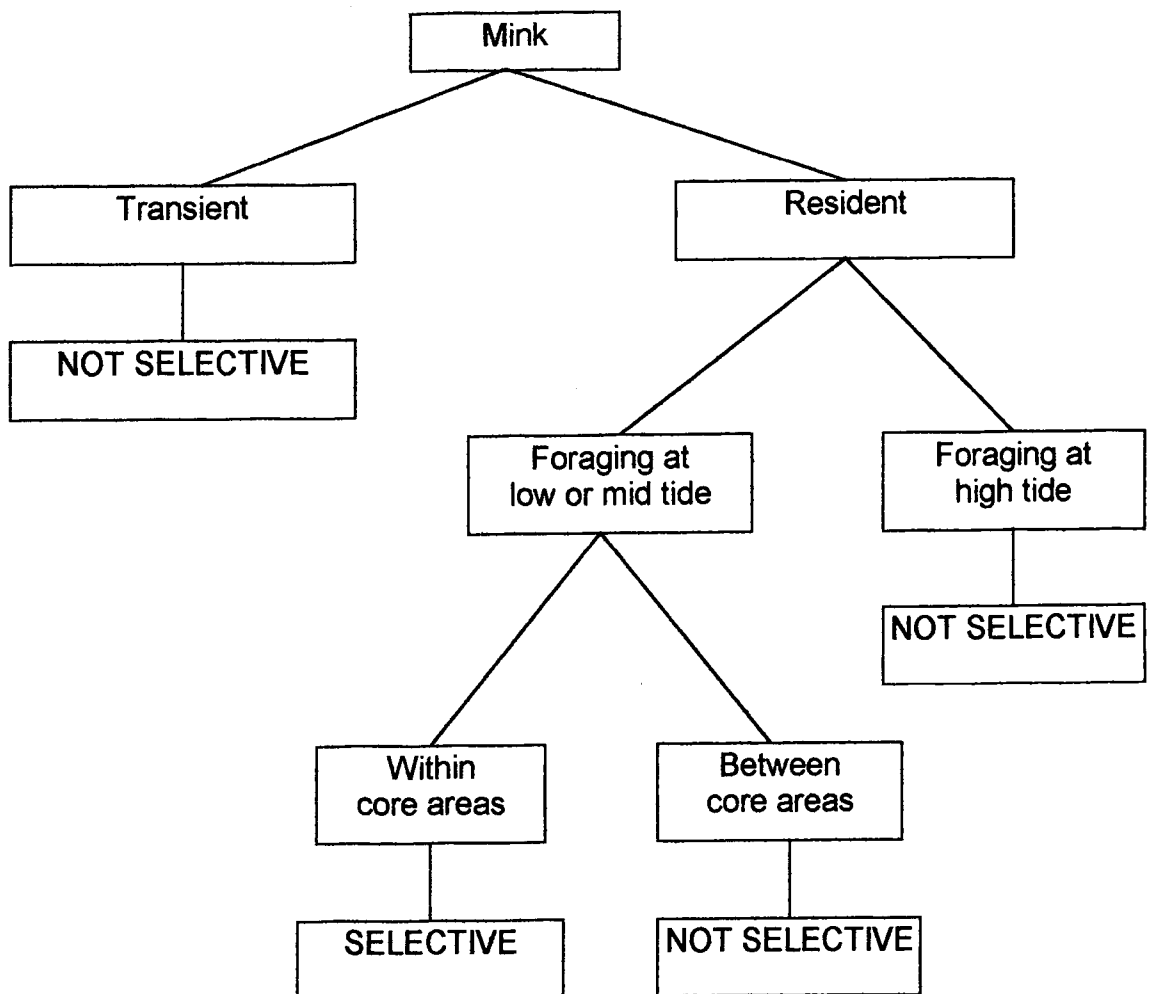
Another factor that possibly determined a selective behaviour was the motivation for the activity out of den. There were at least two kinds of motivation: one for which the mink was moving about with the primary intention of foraging, and one for which it was moving with the additional intention of reaching a specific place within its home range. In the first case the activity took place within the same core area, while in the second case the activity lead the mink from one core area to the next. These different types of movements within the home range have been observed also by Gerell (1970) and Birks and Linn (1982) in riverine habitats. When the mink had to move between two core areas it travelled longer distances, through

.areas of the shore that it was not usually visiting, and behaved non-selectively. In this case, it might be that the actual foraging was not the main motivation, and the mink was mainly driven by the necessity to reach its destination safely and as quickly as possible.

The second purpose of this study was to identify the criteria according to which the selection occurs. Prey abundance was found to be an important factor in determining the preference for areas of the shore, with mink choosing areas where prey, eg. fish and crabs, were abundant and avoiding areas where they were scarce.

Four factors appeared to be important in predicting prey abundance: the tidal zone, the abundance of rockpools, the nature of the substratum and the presence/absence of fresh water. The way in which these factors influence prey abundance, and how this might in turn influence the selection of mink, is represented in Figure 5.4.

It is interesting to notice, that the variables highlighted by the model as responsible for a greater abundance of prey, are the same as those which turned out to be most strongly selected, with the exception of substrata. Therefore even if the model explains only about 1/3 of the variance its ability to predict the abundance of prey it is supported by the fact that the mink actually selects for the variables identified by the model. It is possible that by increasing the number of habitat characteristics considered the predictive power of the model would be improved. The choice of these variables is not easy, since it implies a very broad knowledge of the behaviour and ecology of all the prey species considered, and for most of these very little is known (see Kruuk et al. 1988).

Figure 5.4: Flow diagram showing how the habitat characteristics might influence habitat selection of mink in the intertidal zone, through determining prey abundance
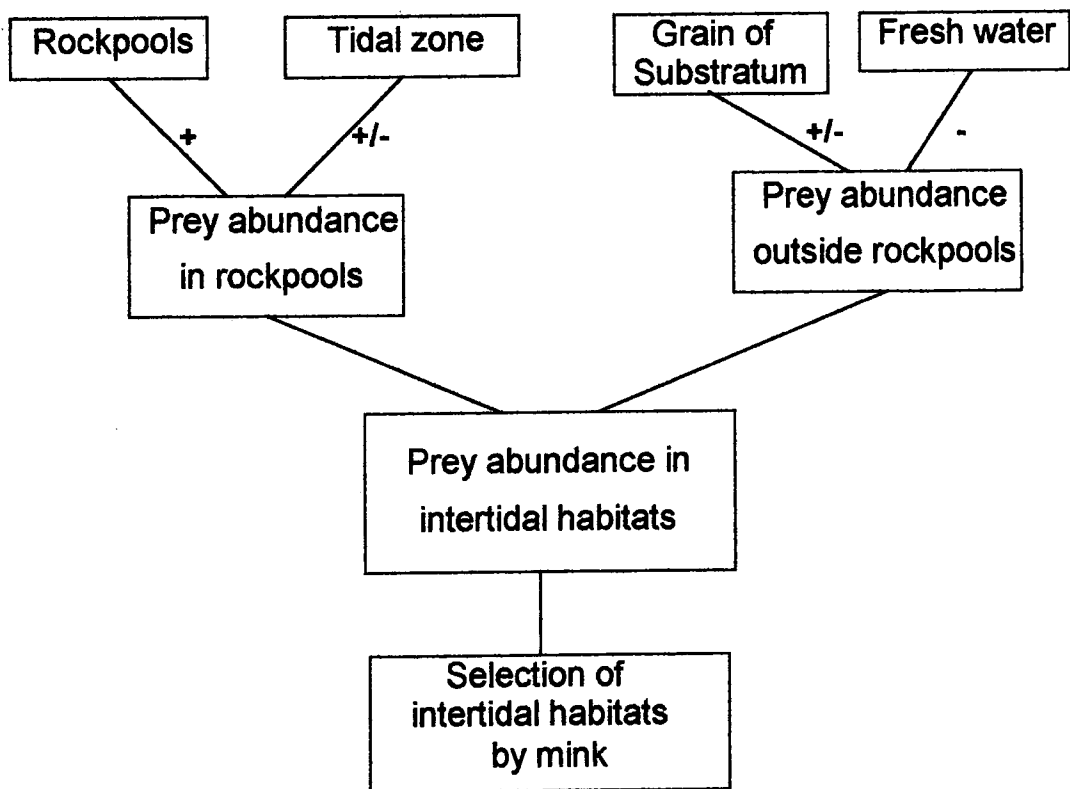
When different habitat characteristics were tested, mink appeared to prefer areas of the middle shore and to avoid the low tidal zone. This could be due either to this area being seldom available (being completely uncovered only at low neap or spring tides) or it might be due to the fact that the very low shore is the favourite hunting area of the otter (Kruuk 1995), and mink might want to avoid direct competition.

Mink were observed to forage both in rocky areas with rockpools and in boulder fields, and no preference for either habitat characteristic was detected. One of the most common fish prey that was likely to be found on the shore, the blenny, is also the most important fish in the mink's diet in this area (Birks and Dunstone 1987), confirming the hypothesis of mink adopting an opportunistic foraging strategy. During a survey of 45 rockpools, Dunstone and Birks (1987) found that the blenny represented only 14% of

the total fish found. In the present study the blenny was found to be the most abundant fish prey in boulder fields (Table 5.6). This evidence suggests that boulder fields might be an important feeding resource as well as rockpools, which importance has been more stressed in previous studies (Dunstone and Birks 1987). The mink's poor ability to hunt underwater also supports this hypothesis. Dunstone and O'Connor (1979a,b) found that mink are not efficient swimmers, furthermore their vision underwater is poor, especially in conditions of reduced light (Dunstone and Sinclair 1978). Hunting in rockpools is also expensive from an energetic point of view, since there is a greater heat loss due to the contact with a wet and cold medium, as shown for the otter (Kruuk et al. 1994).

There is an obvious link between optimal foraging theory and the study of small scale habitat selection, i.e. selection within foraging areas. Both deal with foraging strategies and are based on the fundamental assumption that high fitness is achieved by maximising energy intake. A theoretical frame encompassing both approaches has not been fully developed at present, however the links between these two approaches are widely recognised (Rosenzweig 1985).

In the present study, a habitat selection approach was adopted to investigate mink foraging strategies. Most of the studies of habitat selection have been carried out on birds (for example, Cody 1985). Birds fly, and therefore they reach suitable patches of food (or habitats) without having to actually move through unsuitable ones. Selectivity in birds can be studied by counting the number of times an individual selects a given food patch (or habitat) and ignoring the amount of time it spends within that patch. In studying selectivity in mammals, one has to take into account that, in order to reach a suitable food patch, the animal might have to travel through patches containing few or no suitable food items. Due to this foraging pattern, in mammals the amount of time the individual spends in each patch, is most appropriate as a measure of preference, than the number of times it visits a given patch. Time was therefore chosen in this study as a measure of habitat preference. This

choice is supported also by the marginal value theorem (Charnov 1976, Parker and Stuart 1976), which predicts that the optimal stay-time in a patch should be greater in more productive than in less productive ones.

In this study, the distance of each area from the den was not taken into account. It can be argued that the mink would preferentially stay in the areas closer to the den, and if these areas happen to be rich in prey then of course the mink would be shown to be selective. However, this was not the case in the present study. The shore was relatively heterogeneous and a variety of habitat, rich and poor in terms of prey, could be easily reached from each den.

In summary, the scale at which the selection was studied yielded some interesting results, which showed that the mink is actually selective and indicated which criteria are used in selection. However, the above considerations show that when studying mink habitat selection at a very detailed scale, as in the present study, one cannot ignore the implications of both optimal foraging theory and habitat selection. By integrating the two approaches it will be possible to reach a better understanding of the foraging behaviour and strategies adopted by mink.

CHAPTER 6

A NEW HOME RANGE ESTIMATOR: THE DENSITY CIRCLES METHOD

6.1 Introduction

Mink home ranges usually develop along a water body and therefore have a strong linear component. Accordingly, in most previous studies, the home range of mink has been expressed as the total length of waterway (river, lake or coast) occupied by an individual (eg. Gerell 1970; Birks and Linn 1982; Dunstone and Birks 1985). However, in studies of habitat selection within the home range, knowing the length of water way occupied by an individual might be not sufficient for understanding its degree of selection. In this kind of studies a measure of the 'area' occupied by the animal is more appropriate. This is true especially in coastal areas where the width of the shore, a much exploited habitat by the mink, may vary.

Most home range estimators (eg. Minimum Convex Polygons, Mohr 1947, Southwood 1966; Bivariate Normal Ellipse, Jennrich and Turner 1969; Harmonic Means, Dixon and Chapman 1980) have been designed for species which show a tendency for a circular or elliptic home range and are not suitable for describing home ranges with a strong linear component. Moreover, for mink, it is particularly difficult to collect a sufficent amount of independent data to be used in a probabilistic estimator, due to its low and unpredictable pattern of activity (Dunstone and Birks 1987, pers.obs.).

The elaboration of a new method for home range estimation arose from the need for a simple estimator that could analyse home ranges presenting anomalous shapes with a strong linear component, and that could exploit data sets made of continuous data. Another desirable feature of the new home range estimator is to describe the intensity of use of different areas within the home range.

6.2 A new estimator: the Density Circles Method

6.2.1 Theory and construction of the estimator

The Density Circles Method aims to describe the spatial pattern of locations in terms of their relative positions. The method is based on the assumption that, where the fixes are denser, the animal has spent a greater amount of time and therefore has preferred that local area. To estimate the home range, an area proportional to the local density of fixes is attributed to each location. By associating such area to each fix, we also take into account that there is a variable degree of inaccuracy in the location of the animal within that area, that is, the area around position x,y, due to unreliability of the fix co-ordinates originating from errors in locating the animal and in reporting the fix on a map. Moreover, we also take into account that there is a time bias due to slightly discontinuous sampling (the animal has been found at a specific location because the sampling has taken place at that specific point in time; had the sampling been either sooner or later the animal might not have been in precisely the same location). The area attributed to each location was chosen to be a circle since all the points of its perimeter are equidistant from the centre. This is a desirable property that allows to take into account sampling error and time bias, since there are no reasons to assume that the location should be positioned in any preferable direction due to these factors.

As a measure of the density of locations the covariance of each fix in relation to its n nearest neighbours was calculated. Where the fixes are dense the covariance is relatively low, and conversely where fixes are sparse it is relatively high. To obtain a measure of density that generates higher values when the fixes are denser and lower values when the fixes are sparse, the inverse of the covariance was considered.

In practice the calculation proceeds as follows. For any particular co-ordinate (x,y) the n nearest fixes are considered. The mean $m(x,y)$ and the covariance $\text{Cov}(x,y)$ of these $n + 1$ points are then calculated.

The means along the X and Y axis are calculated respectively:

$$m(x) = \sum_{h=1}^{n+1} x_h / n + 1 \qquad\qquad (6.1)$$

$$m(y) = \sum_{h=1}^{n+1} y_h / n + 1 \qquad\qquad (6.2)$$

The variances along the X and Y axis are calculated respectively:

$$s(x) = \left[\sum_{h=1}^{n+1} (x_h - m(x))^2 / n+1 \right] \qquad\qquad (6.3)$$

$$s(y) = \left[\sum_{h=1}^{n+1} (y_h - m(y))^2 / n+1 \right] \qquad\qquad (6.4)$$

where $m(x)$ and $m(y)$ are the mean of the points along X and along Y, and n is the number of neighbouring fixes considered. In the following computations eight fixes were considered ($n = 8$), as this was a suitable number of fixes necessary to describe the density of locations in a given area.

The covariance relative to the considered point is:

$$Cov(x,y) = [s(x) + s(y)] / 2 \qquad\qquad (6.5)$$

The function $(f(x,y))$, that allows calculation of the density area at each fix, is given by:

$$f(x,y) = b\{1/[Cov(x,y)]^a\} \qquad\qquad (6.6)$$

where a and b are two constants. The constant 'a' determines the range of the radius values. It must be chosen so that there is an adequate difference

between the smallest and largest circle area. When the constant value is set to -0.1 there is a 2 or 3 fold difference between the smallest and largest radius. In the calculations, such values provided a good visual estimate of the home range, therefore a = -0.1 was used in all computations. The constant 'b' determines the length of the radius. This value was chosen by taking into account the mean distance moved between fixes (velocity of the animal) and the error associated with each location. The constant b was then set so that the minimum radius was not less than the error and not greater than the average distance moved between fixes. In the following computations, the minimum radius was set as the half value of the mean distance covered between fixes.

When the nine (n + 1 = 9) fixes considered are coincident the covariance $Cov(x,y)$ is zero. In this case the radius was set equal to the maximum radius found.

6.2.2 Calculation of home range size

To calculate home range size, Equation 6.6 must be computed for every fix and the home range area is assessed by considering for each fix a circle centred on (x,y) and with radius $f(x,y)$. I refer to such circles as "density circles" because they represent the density of fixes in the area where the considered fix is located. An example of the circles can be seen in Figure 6.2a on page 88.

To calculate the area, a grid was overlaid on top of the circles and the grid cells whose central point coincided with a point belonging to one of the circles were counted. The sum of the areas of the selected cells gave a numerical estimate of the area of the home range. The finer the grid, the more precise the area estimate. It is important to emphasise that the introduction of a grid at this point was functional only to the calculation of the area.

6.2.3 Home range graphical representation

To visualise the home range a graphical software, which plots for every location the circle centred in x,y and with radius $f(x,y)$, can be used. Alternatively the shape of the home range can be represented by means of the grid that considers cells whose central point coincides with a point belonging to one or more of the above circles.

6.2.4 Core areas

The Density Circles method provides a description of the internal structure of the home range. The exclusion of circles with smaller radius reveals the most used areas within the home range, i.e. the areas with the highest density of fixes. A criterion can be set to determine core areas.

6.2.5 Dispersion of locations

With the Density Circles method the degree of dispersion of locations can be evaluated by using the variance of the radii of the density circles as a measure of dispersion. A Chi-square test for random distribution, where the ratio of the variance to the mean is considered, was used to test the dispersion of locations. This test is based on the principle that if the animal locations are clumped, with very intensely used areas and little used areas, the variance is relatively high when compared to the mean. If the fixes are randomly or regularly spaced then the variance has a relatively low value when compared to the mean. For samples larger than 30 sampling units the Chi-square value must be converted to a z-score (Sokal and Rohlf 1995).

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6.3 Applying and testing the Density Circles Method

The new home range estimator was tested on field data collected on mink in the present study in 1994-95, and the results were compared with those obtained on the same data from other three home range estimators: the Minimum Convex Polygon (Mohr 1947, Southwood 1966), the Grid Cell Method (Siniff and Tester 1965, Voigt and Tinline 1980) and the Kernel estimator (Worton 1989). The Density Circles method was also applied to data from two other mink, collected by Mark Ireland from 1982 to 1985. The results for these two mink are given in Appendix 1.

6.3.1 Methodology

6.3.1.1 Data Base

The data were collected from December 1994 to March 1996 on five mink inhabiting a coastal area. However, only one of the sampled animals provided sufficient data to proceed with a comparison of the home range estimators, i.e. only for one animal the home range size reached an asymptote with all four methods. In the home range analysis, both active and inactive fixes were considered, although the influence of inactive fixes was greatly reduced by applying the selection rules described in Chapter 2.

6.3.1.2 Independence of Data

The Kernel method requires data to be spatially and temporally independent. Schoener's ratio t^2/r^2 (Swihart and Slade 1985) was employed to calculate time to independence. t^2 is the mean squared distance between successive

observations, while r^2 is the squared distance from the centre of activity. Schoener's ratio was compared with the $\alpha_{0.250}$ critical value calculated empirically by Swihar and Slade (1985). Time to independence was identified when a non-significant t^2/r^2 ratio, followed by a further two non significant intervals, was found. This method for calculating time to independence was chosen for reasons of comparison, since it is one of the most common methods.

6.3.1.3 Home range asymptotes

In home range estimation the sample size is considered to be sufficient when the home-range size reaches an asymptote when plotted against number of locations (Harris *et al.* 1990). In the present study, in order to calculate the home range asymptote the data were removed sequentially (Harris *et al.* 1990). When calculating the asymptote for the Density Circles Method the minimum radius was recalculated at each level of inclusion by considering only the data incorporated. As a consequence the constant b varied at different percentages of inclusion (range:47-64).

6.3.1.4 Home range parameters estimate

The following home range parameters were estimated: size, shape, core areas and dispersion of locations. To estimate the home range with the Density Circles Method a program written in FORTRAN 77 was implemented by Dr. Michele Vendruscolo and myself, to carry out the computations (Appendix 2). The plots were obtained with the graphic software Smongo (An Interactive Plotting Package, Edition 2.4.0, 1996).

Kernel and Minimum Convex Polygons estimates were obtained by applying the RANGESV software (Kenward, Institute of Terrestrial Ecology, Wareham, UK, 1996), specifically written for home range analysis. The smoothing

parameter in the Kernel estimator was chosen by a visual assessment of the fit of isopleths to the data. The best results were given with a value of h = 0.7. The Adaptive Kernel Method (Worton 1987, 1989) was applied.

Grid Cell estimates of home range were obtained by hand calculations. In order to make the results comparable with those obtained by Ireland (1990), who had previously studied mink home ranges in the same study area, a grid cell of 25m side was considered and consecutive fixes were joined by lines. Cells containing fixes and/or lines have been considered as part of the home range.

Core areas were determined by comparing home range areas at different levels of fix inclusion. The percentage of the total home range area was plotted against the different levels of inclusion, and a core area was considered to "resolve" where there was a maximal increase in area between two levels of inclusion (Wray *et al.* 1992a), which corresponds to a change in the gradient of the slope of the plotted curve. When the point of inflexion lay between two values, the lower one was used to define the core area (Harris *et al.* 1990). To identify core areas with the Minimum Convex Polygons method, the polygons were 'peeled' from the arithmetic mean of locations. In the case of the Grid Cell method, core areas were identified where a relatively high number of fixes per grid cell was found.

6.3.2 Results

6.3.2.1 Independence of Data

Data for Sasha were made independent in order to apply the Kernel estimator. The Swihart and Slade (1985) estimator gave a time to independence of 9 hours (Table 6.1). From the complete data set of 660 fixes

only those nine or more hours distant from each other were retained. This sub-sample was composed of 46 fixes.

A time of nine hours to independence is very high when compared with other studies (eg. Swihart and Slade 1985; Cresswell and Smith 1992). Such a high value was due to the linear shape of the home range, which implies that many fixes were far away from the centre of activity. This gives a high value for r^2 and therefore a resulting low Schoener's ratio (t^2/r^2).

Table 6.1: Calculation of the time to independence on Sasha's data using the method proposed by Swihart and Slade (1985). Time to independence is reached when t^2/r^2 is greater than the $\alpha_{0.25}$ critical value calculated as suggested by Swihart and Slade (1985).

Interval (hrs)	t2/r2	$\alpha_{0.25}$	N. fixes
1	1.2275	1.8755	660
2	1.6057	1.8566	75
4	1.6972	1.8427	61
8	1.7759	1.8250	48
9	**1.8341**	**1.8221**	**46**
10	1.8670	1.8190	44
11	1.9305	1.8130	41

6.3.2.2 Calculation of home range size

In Table 6.2, the estimates of the home range at different levels of fix inclusion, obtained using the four different methods, are shown. Smaller levels of inclusions were not calculated for the Grid Cell method. With this method the criteria for establishing most used areas, is to count the number of fixes per cell, rather than by elimination of fixes. In Table 6.3, the difference between the estimates obtained with the Density Circles method and the other three methods are shown. These differences are expressed as a percentage obtained by dividing the value for a given method by the value

obtained for the Density Circles Method and then multiplying the result by 100.

The estimate of Sasha's home range at 100% inclusion (all the fixes considered) using the Density Circle Method gave an area of 25.6 ha (Table 6.2). The Kernel method estimated an area of 36.0 ha, which is 141% larger than the estimate obtained with the Density Circles method (Table 6.3). The Grid Cell method gave an estimate of 20.3 ha, which is 80% of the area estimated with the Density circles method (Table 6.3). The Minimum Convex Polygons method gave the highest estimate of the home range, indicating an area of 77.9 ha. There is a three fold difference between the estimate obtained with the Minimum Convex Polygons method and that of the Density Circles method.

From Table 6.2 we can see that the Grid Cell Method was the most restrictive of the four methods in estimating the 100% area. The Density Circles Method gives the second lowest value at 100% inclusion. This is due to the fact that with these two methods a very strict fit to the data was obtained: areas that have not been used by the animal are not included

Table 6.2: Home range estimates (ha) using different methods. The Kernel method has been applied on independent data. n.c. = not calculated (see text).

Method	100%	80%	60%	40%	20%	Parameters	n
	Levels of inclusion						
DCM	25.6	17.0	12.2	9.1	6.7	a = -0.1, b = 47	660
MCP	77.9	24.8	18.6	14.9	6.9	none	660
Grid Cell	20.3	n.c.	n.c.	n.c.	n.c.	grid cell = 25 m	660
Kernel	36.0	11.9	2.8	2.8	2.1	h = 0.7	46

Table 6.3: Difference of the estimates between the Density Circles Method (DCM) and the other home range estimators.

| Method	100%	80%	60%	40%	20%	Parameters	N
	Levels of inclusion						
DCM	100	100	100	100	100	a = -0.1, b = 47	660
MCP	304	146	152	164	103	none	660
Grid Cell	80	n.c.	n.c.	n.c.	n.c.	grid cell = 25 m	660
Kernel	141	70	23	31	31	h = 0.7	46

At high levels of inclusion (100%, 80%) the results of the Density Circles method were similar to those obtained with the Kernel method and differed consistently from those obtained with the Minimum Convex Polygons. At low levels of inclusion (60%, 40%, 20%) the Density Circles Method gave results more similar to the Minimum Convex Polygons than to the Kernel estimator. This is due to the fact that to obtain the area at lower levels of inclusion the circles with smaller radius, corresponding to less used areas, were first eliminated. Only circles with larger radius, corresponding to areas with high fix density, remained. These circles contributed to a greater portion of the estimate of the home range also at higher inclusion levels. Therefore, the elimination of the circles with smaller radius did not influence the estimate of the home range to any great extent.

In the Density Circles Method, the radius of the smallest circle must be equal to half of the mean distance travelled between fixes and greater than the error associated with each location (Paragraph 6.2.1). For Sasha this value was reached when the constant 'b' was equal to 47 (b = 47, mean distance travelled = 19.4m, minimum radius = 19.4m). This value was also greater than the error associated with each location (error = 9.67m ± 7.17, n = 6) therefore satisfying the second requirement. For the same value of 'b' the maximum radius of the circles was equal to 63.5 m. There is a 3.3 fold difference between the maximum and the minimum radius. This difference is an expression of the homogeneity of data. When there is a great difference

between the maximum and minimum radius the data are irregularly spaced. When there is a small difference between the maximum and minimum radius the data are more evenly spaced.

6.3.2.3 Home range asymptotes

The home range asymptotes were calculated for all the four estimators (Figure 6.1). With the Minimum Convex Polygon method the home range area reached stability at 70% of fixes included. With the Kernel estimator the stability was reached at 60% inclusion. The Density Circles Method required a bigger sample size in order to reach stability, which was obtained at 80% inclusion. With the Grid Cell method home range size reached an asymptote at almost 100% inclusion, therefore requiring even more fixes than the Density Circles Method.
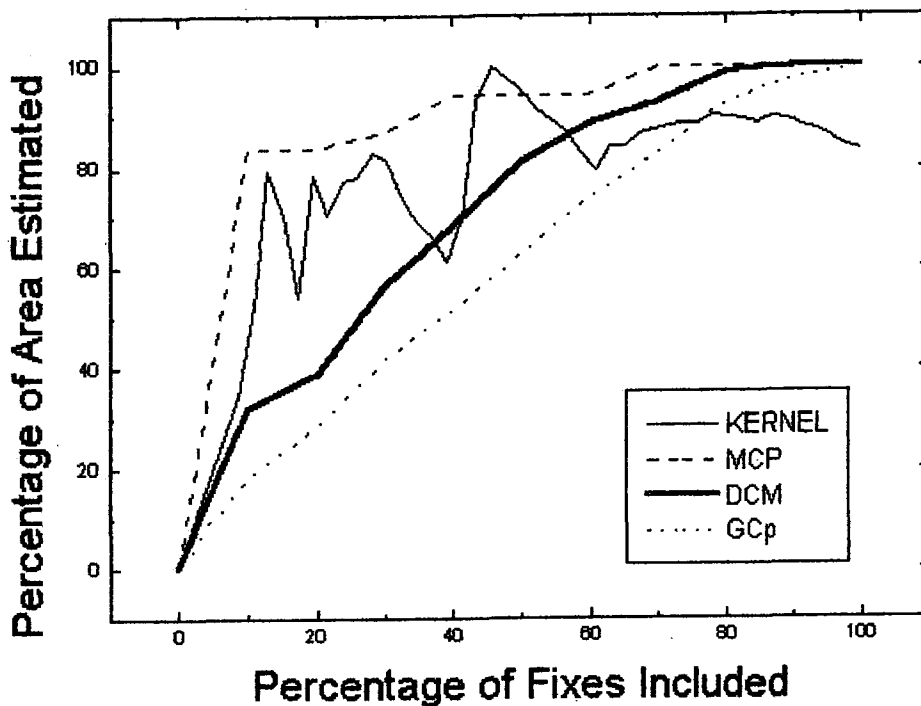

Figure 6.1: Home range asymptotes calculated using the four methods. For the Minimum Convex Polygons (MCP), Grid Cell (GCp) and Density Circles (DCM) methods all fixes have been used, while for the Kernel method only independent fixes have been used.

6.3.2.4 Habitat use and representation of the home range

In Figure 6.2 the location of fixes is shown for comparison with Figures 6.3 to 6.6, where the home range of Sasha, obtained using the four different methods, is plotted. The Density Circles Method represents the home range as a series of overlapping circles (Figure 6.3a). With this method, areas used most intensively, are identified by circles of relatively large radius. Such areas are highlighted by eliminating the circles with smaller radius (Figures 6.3b and 6.3c). The Kernel method represents areas of different intensity of use with isopleths corresponding to a given probability density, that indicate the animal's probability of occurrence at given points in space (Figure 6.4). The Minimum Convex Polygons method highlights areas used intensively by 'peeling' the polygons from a given point. In this case the polygons were peeled from the arithmetic centre of locations. Three different areas, encompassing different percentages of the total fixes, are shown in Figure 6.5. For the grid cell method, habitat use within the home range is represented with squares of different density of shading, corresponding to the frequency of fixes per grid cell (Figure 6.6).

The actual habitat use was compared with the habitat use as estimated using the four different home range estimators. Actual habitat use (Table 6.4a) was calculated by considering the percentage of total fixes falling within each habitat (Shore, Above Shore, Sea). Estimated habitat use (Table 6.4b) was calculated by overlying the home range on a map, and then computing the percentage of area within the home range falling into the different habitats. The calculation of actual habitat use showed that most of the active fixes (84%) were located on the shore, few in the area above the shore (16%) and none in the sea. The Grid Cell and the Density Circles methods gave the best fit to this pattern of habitat use, by excluding, almost entirely, non-used areas. These methods located most of the home range area on the shore (respectively 84% and 85%). With the Grid Cell method the remaining area was located above MHWS (15%). The Density Circles method located 14% of the remaining area above MHWS and 1% on the sea.
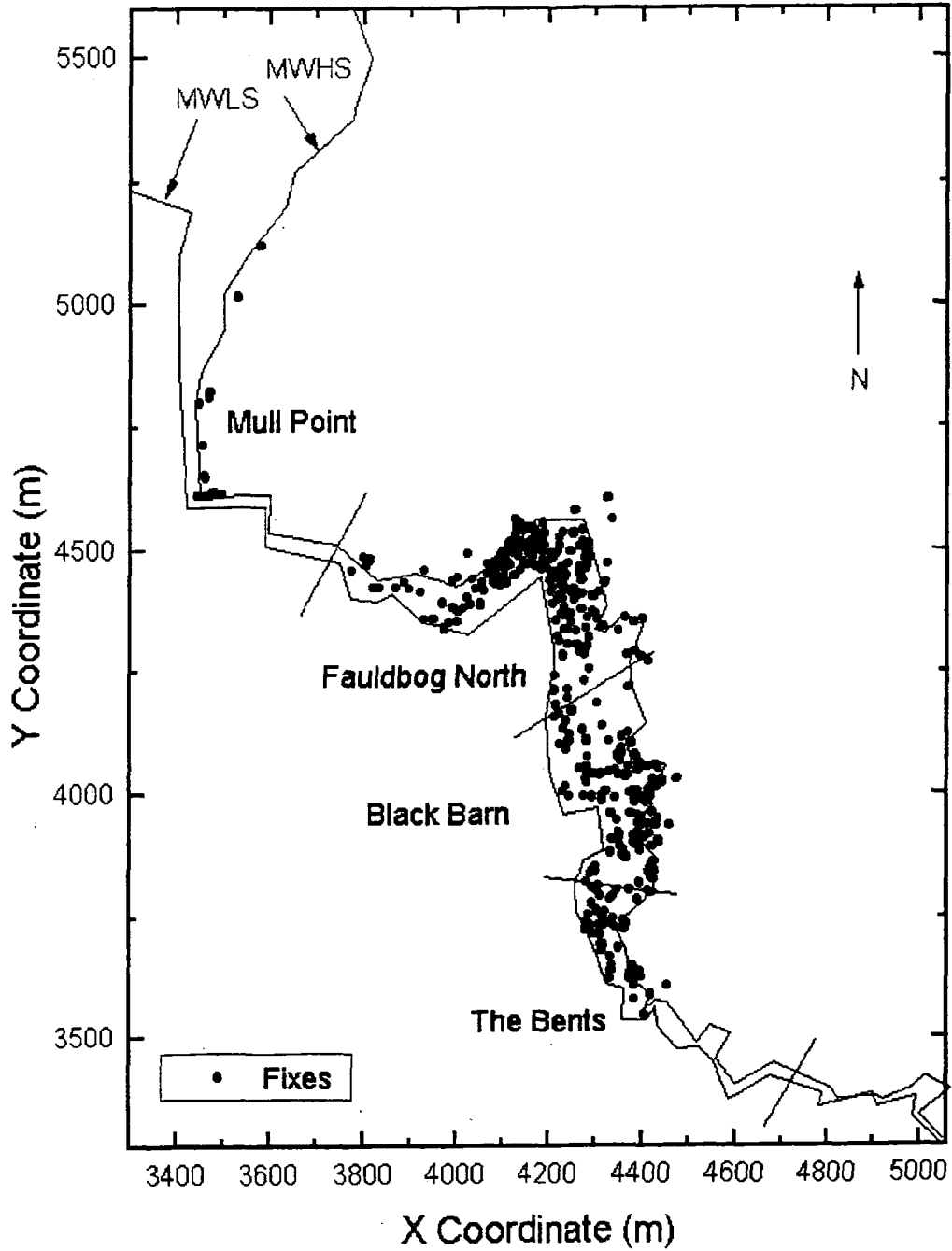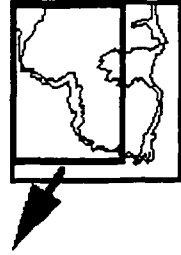
Figure 6.2: Position of fixes recorded for Sasha from December 1994 to March 1995. The lines perpendicular to the shore indicate the limits of the different areas from Mull Point to the Bents.
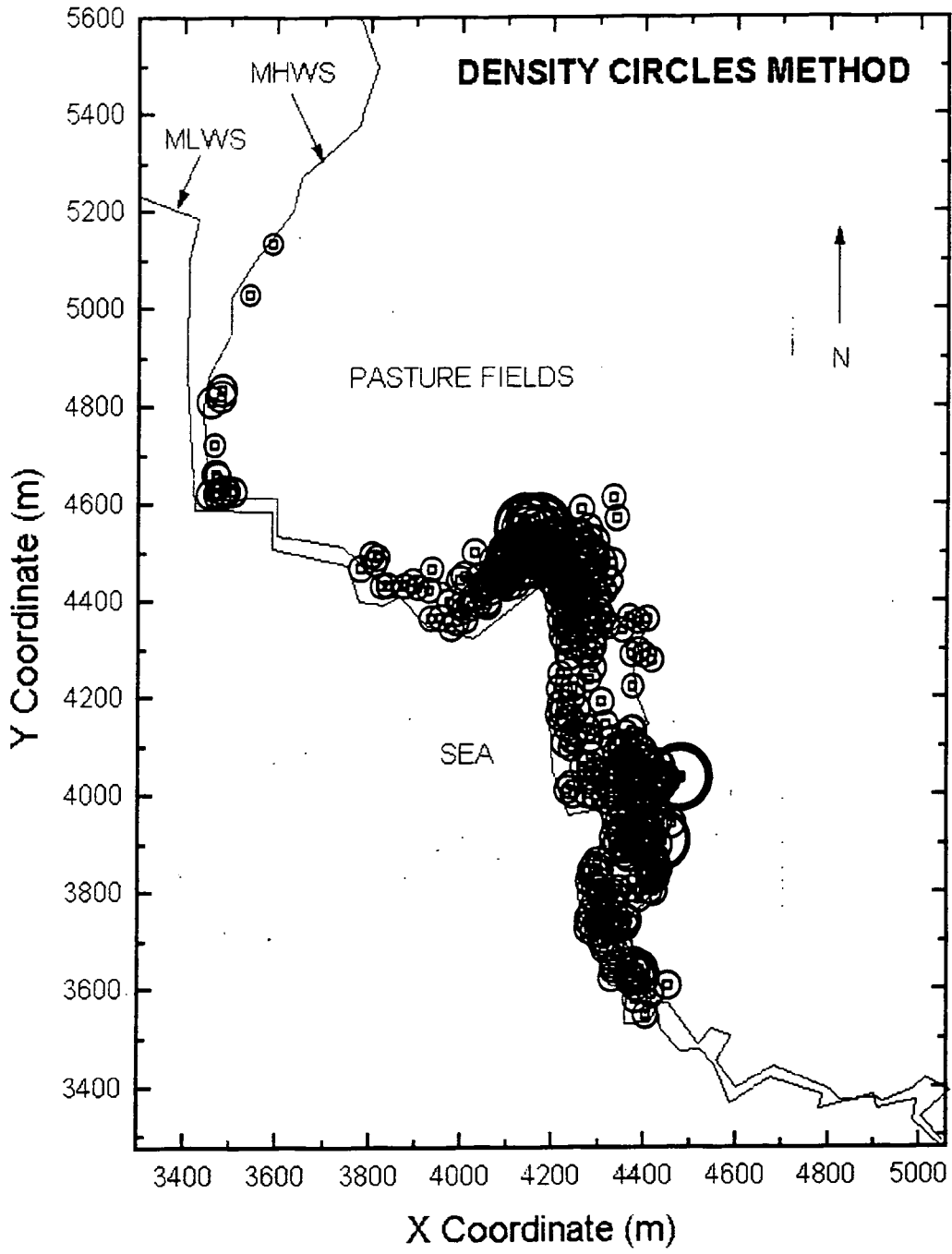
Figure 6.3a: Home range of Sasha as identified by the DENSITY CIRCLES method, at 100% level of inclusion.
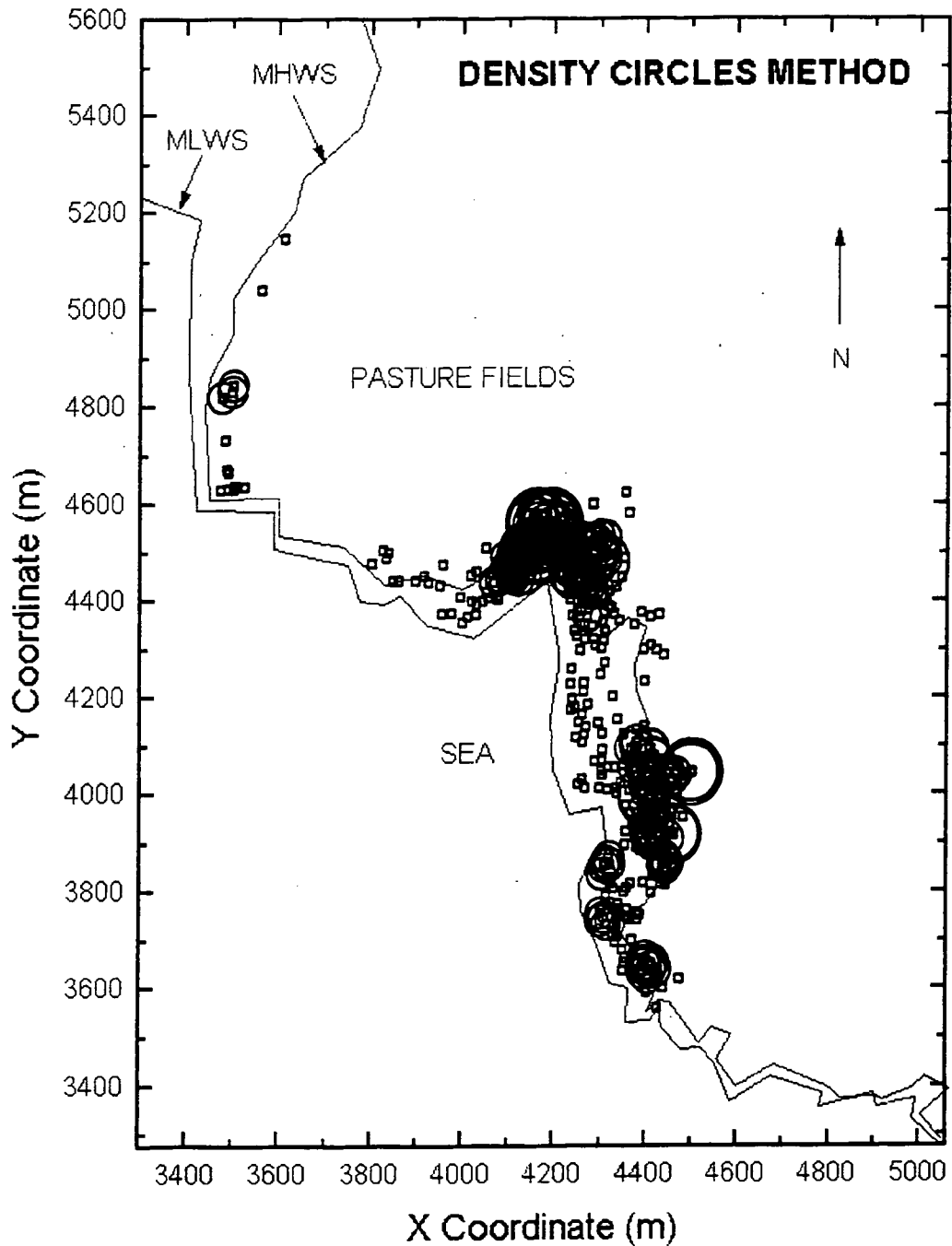
Figure 6.3b: Home range of Sasha as identified by the DENSITY CIRCLES method, at 60% level of inclusion. The little squares represent the location of the fixes.
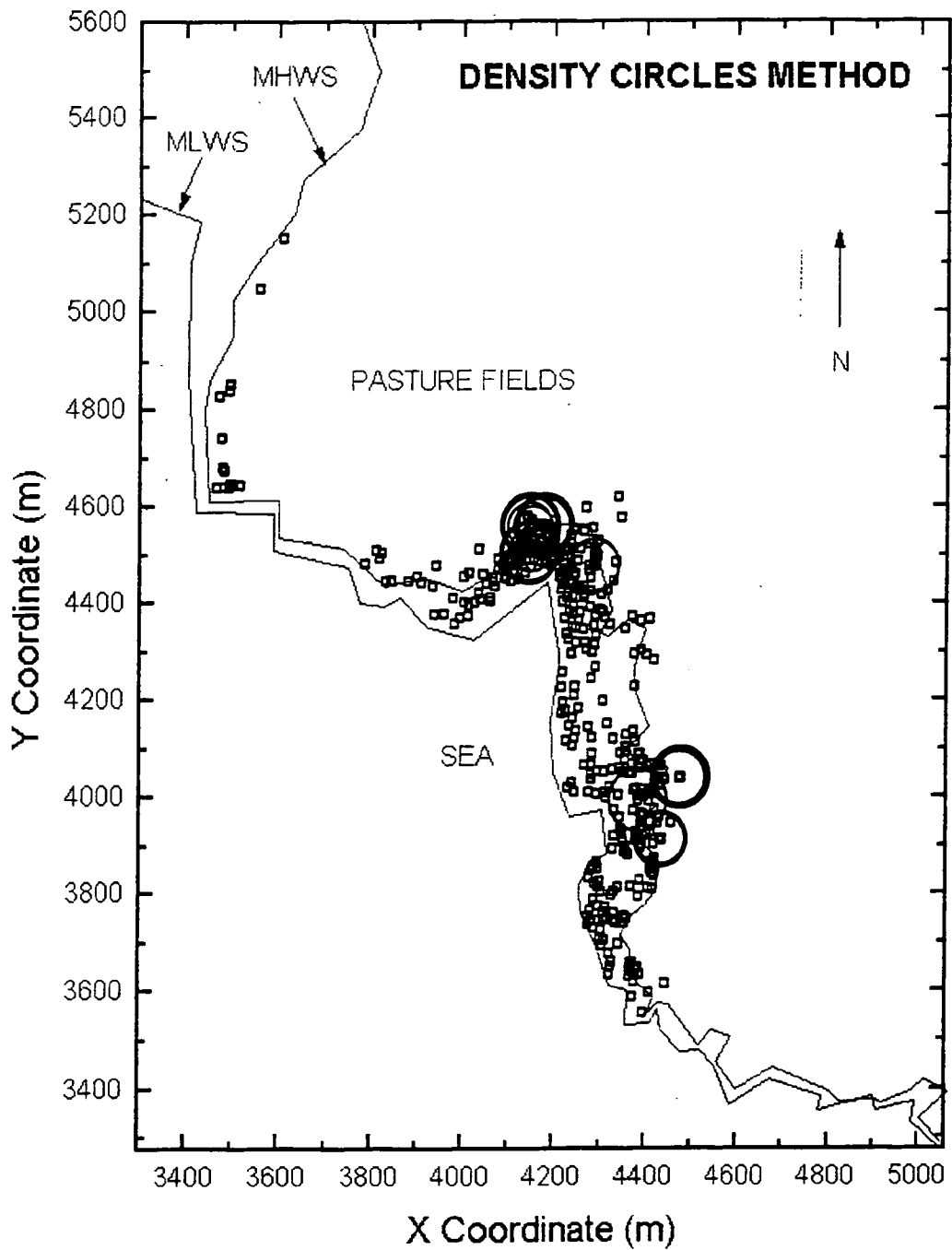
Figure 6.3c: Home range of Sasha as identified by the DENSITY CIRCLES method, at 20% level of inclusion. The little squares represent the location of the fixes.
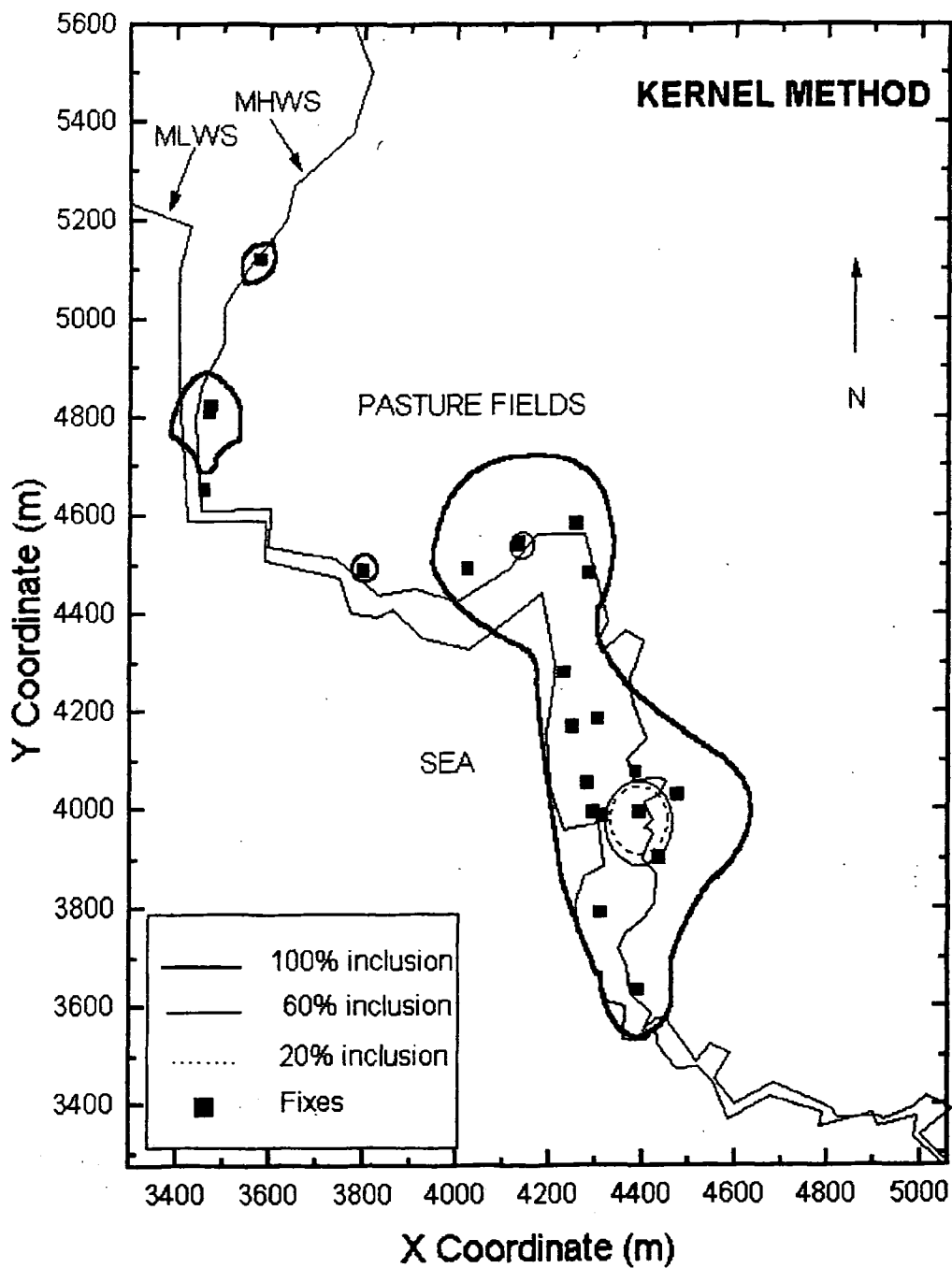
Figure 6.4: Home range as identified by the KERNEL method. Three different levels of inclusion of fixes are shown (100%, 60%, 20%). Fixes distant nine or more hours form each other (independent fixes) are also shown.
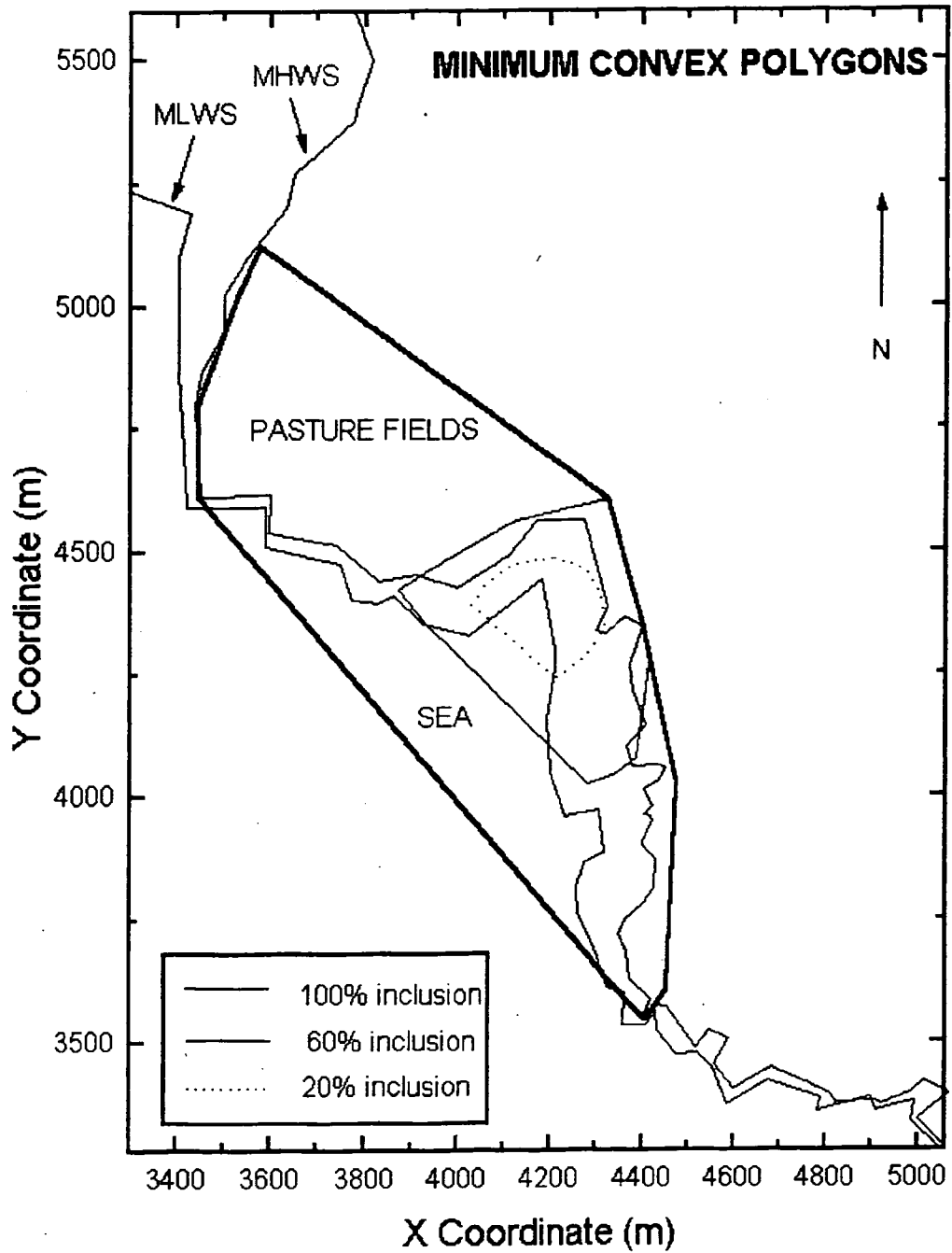
Figure 6.5: Home range as identified by the MINIMUM CONVEX POLYGON method. Three different levels of inclusion are shown (100%, 60%, and 20%).
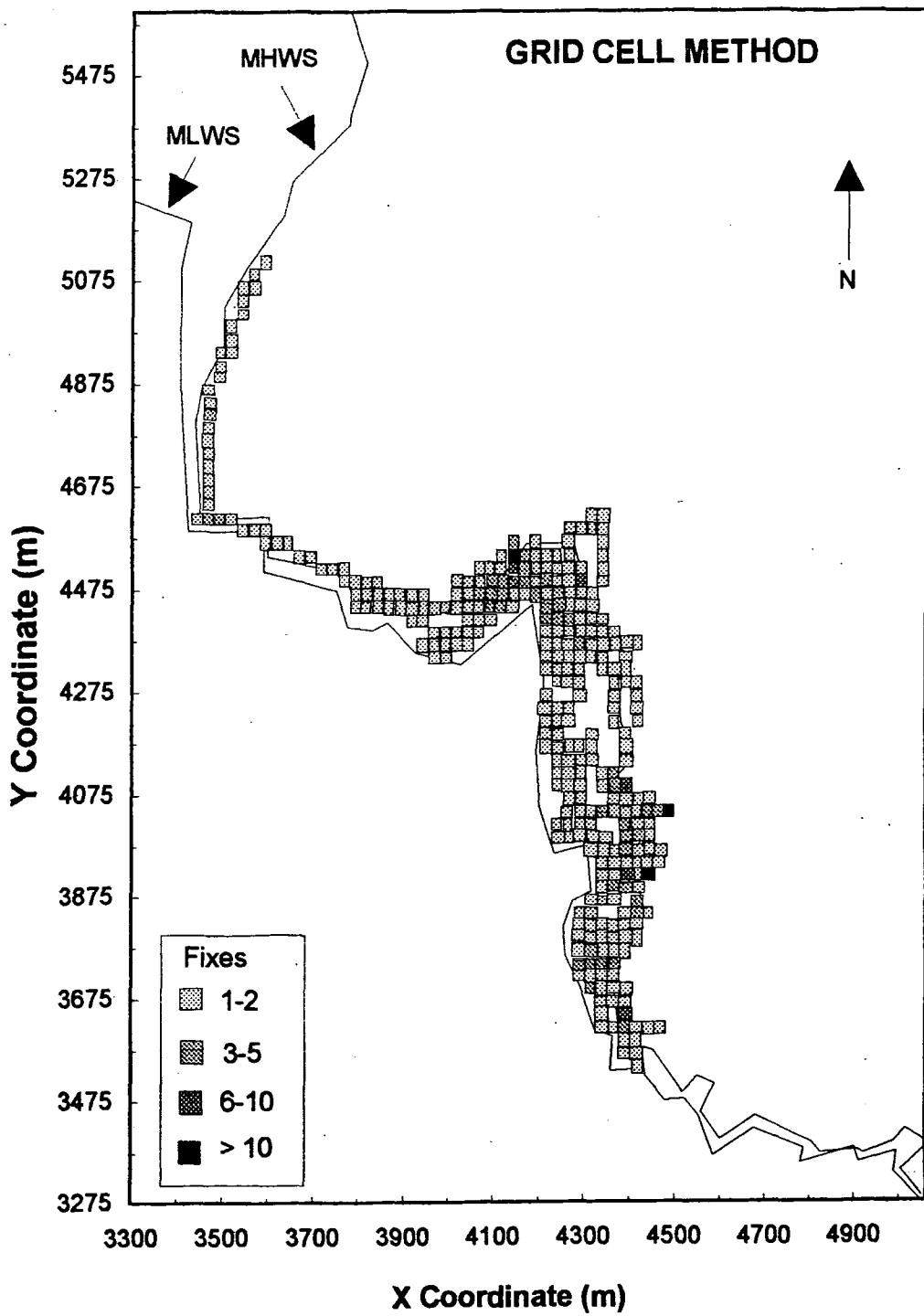
Figure 6.6: Home range as identified by the Grid Cell method. Density of shading represents the number of times the mink was recorded to have passed through a particular 25m square.

By comparison with the Density Circles and Grid Cell methods, the 100% Minimum Convex Polygons included large amounts of non-used habitat. This method located 41% of the home range on the area above the shore and 2 5% on the sea. However, at lower levels of inclusion, this method fits the data much better by reducing the inclusion of the sea and of the area above the shore (Figure 6.5). The Kernel estimate gave a better fit to the data than the Minimum Convex Polygons, however, a small percentage (7%) of the estimated home range area was located over the sea. Moreover, with the Kernel method a rather consistent percentage (41%) of the home range lay on the area above the shore, which was not used much.

Table 6.4: Comparison between actual habitat use and estimated habitat use. DCM = Density Circles method, MCP = Minimum Convex Polygons method.

(a)	ACTUAL HABITAT USE		
Animal	**Shore**	**Above shore**	**Sea**
Sasha	84%	16%	0%

(b)	ESTIMATED HABITAT USE		
Method	**Shore**	**Above shore**	**Sea**
DCM	84%	15%	1%
MCP	34%	41%	25%
Grid Cell	85%	15%	0%
Kernel	52%	41%	7%

6.3.2.5 Core areas

From Figure 6.7 the core areas were identified at 60% level of fix inclusion for the Kernel method and at 70% for the Minimum Convex Polygons method. Actually for the Minimum Convex Polygons there was an evident change in the gradient of the slope between 100% and 90%, but this was due to the influence of outliers rather than to the presence of a core area at 90% inclusion. For the Density Circles Method there was a slight change in the

slope of the curve between 30% and 20% level of fix inclusions. However, such a difference was not as marked as for the other two methods. This was due to the fact that the circles with smaller radius are progressively excluded and therefore the home range decreases smoothly.
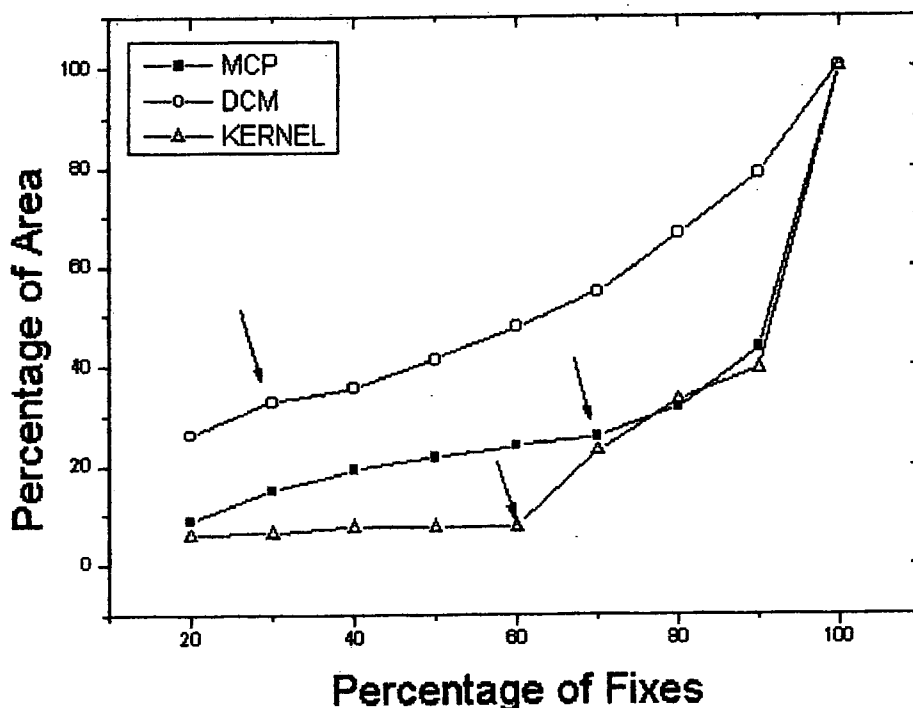
Figure 6.7: Percentage of fixes plotted against percentage of area estimated for Sasha. Minimum Convex Polygons (MCP) Density Circles Method (DCM) are calculated on all fixes, while the Kernel is calculated only on independent fixes according to Swihart and Slade (1985).

Using the Grid Cell method, core areas were identified by grid cells holding a relatively high number of fixes. Grid cells containing three or more fixes were considered part of a core area. The four plots representing the core areas are shown from figure 6.8 to figure 6.11. The Density Circles, Kernel and Grid Cell methods (Figure 6.8, 6.9, and 6.10), identified two main core areas, one around the Black Barn area, and one around Fauldborg North (the limits of the areas along the coastline from Fauldbog North to the Bents are shown in Figure 2.1, page 4). The Grid Cell and the Density Circles method identified also a smaller core area located at the Bents. The Minimum Convex Polygon (Figure 6.11) identified a single core area that has not a biological meaning, since it includes little used areas between Black Barn and Fauldbog North.
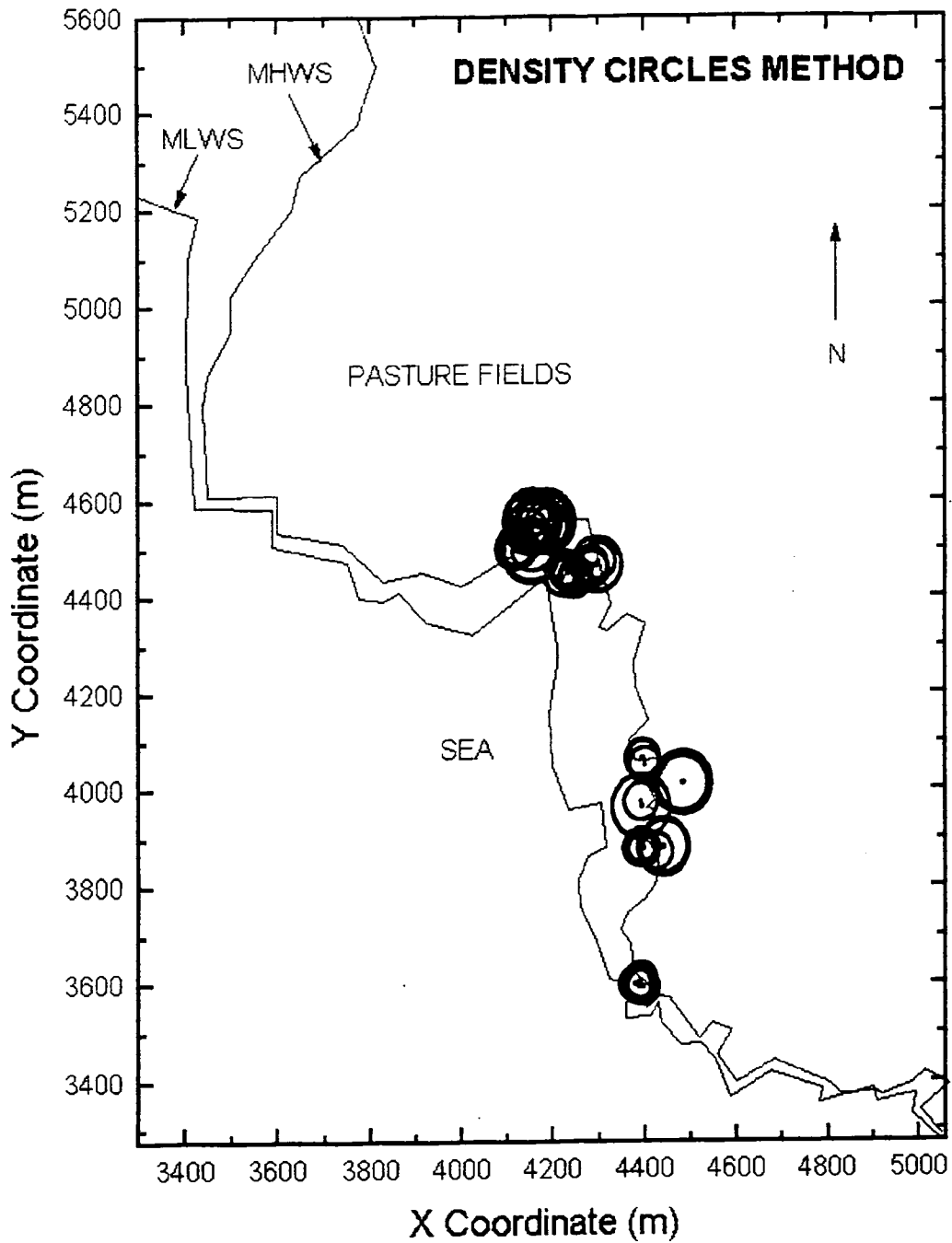
Figure 6.8: Core areas of Sasha at 30% of fix inclusion using the DENSITY CIRCLES method.
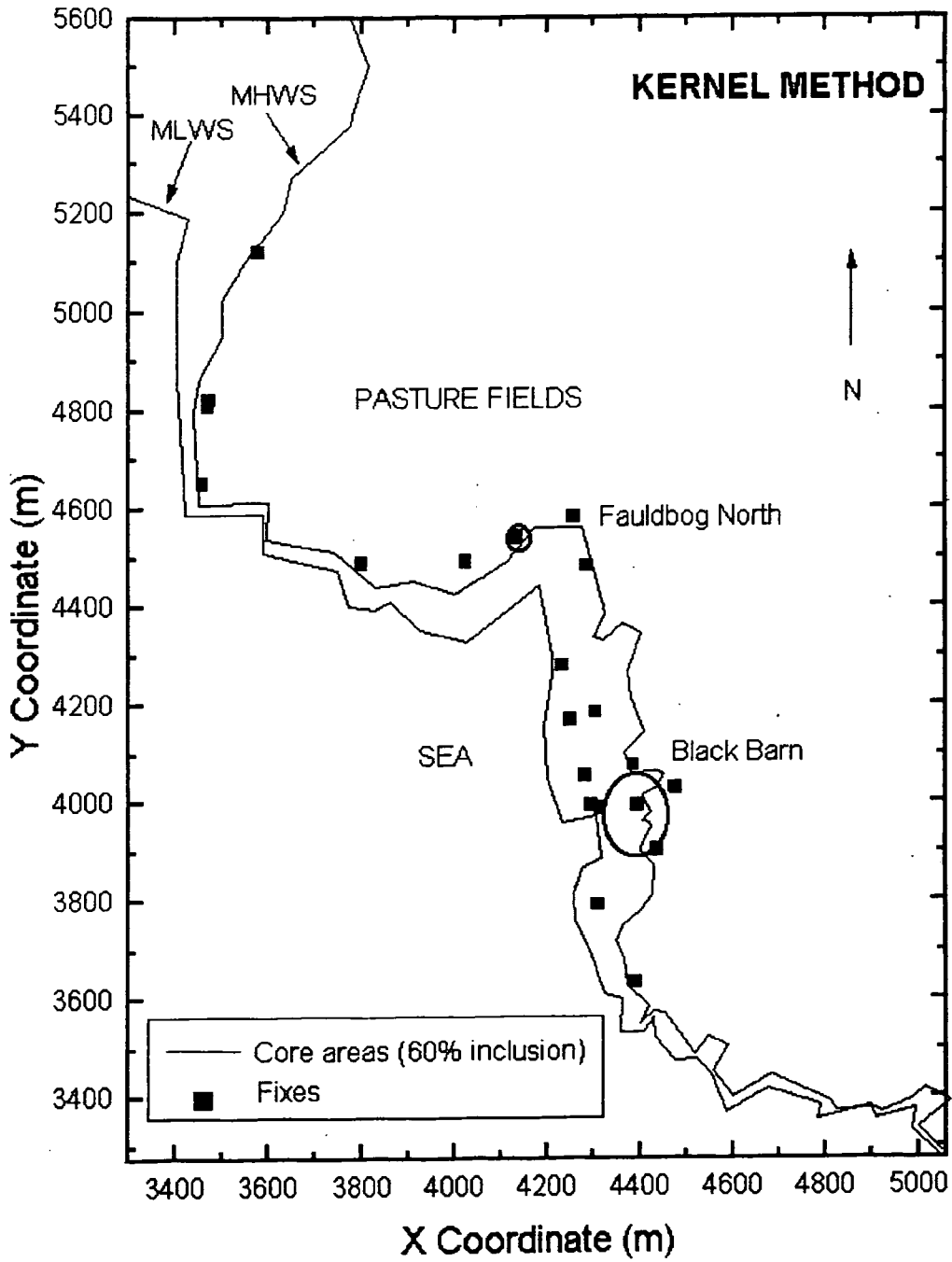
Figure 6.9: Core areas identified at 60% of fix inclusion using the KERNEL method.
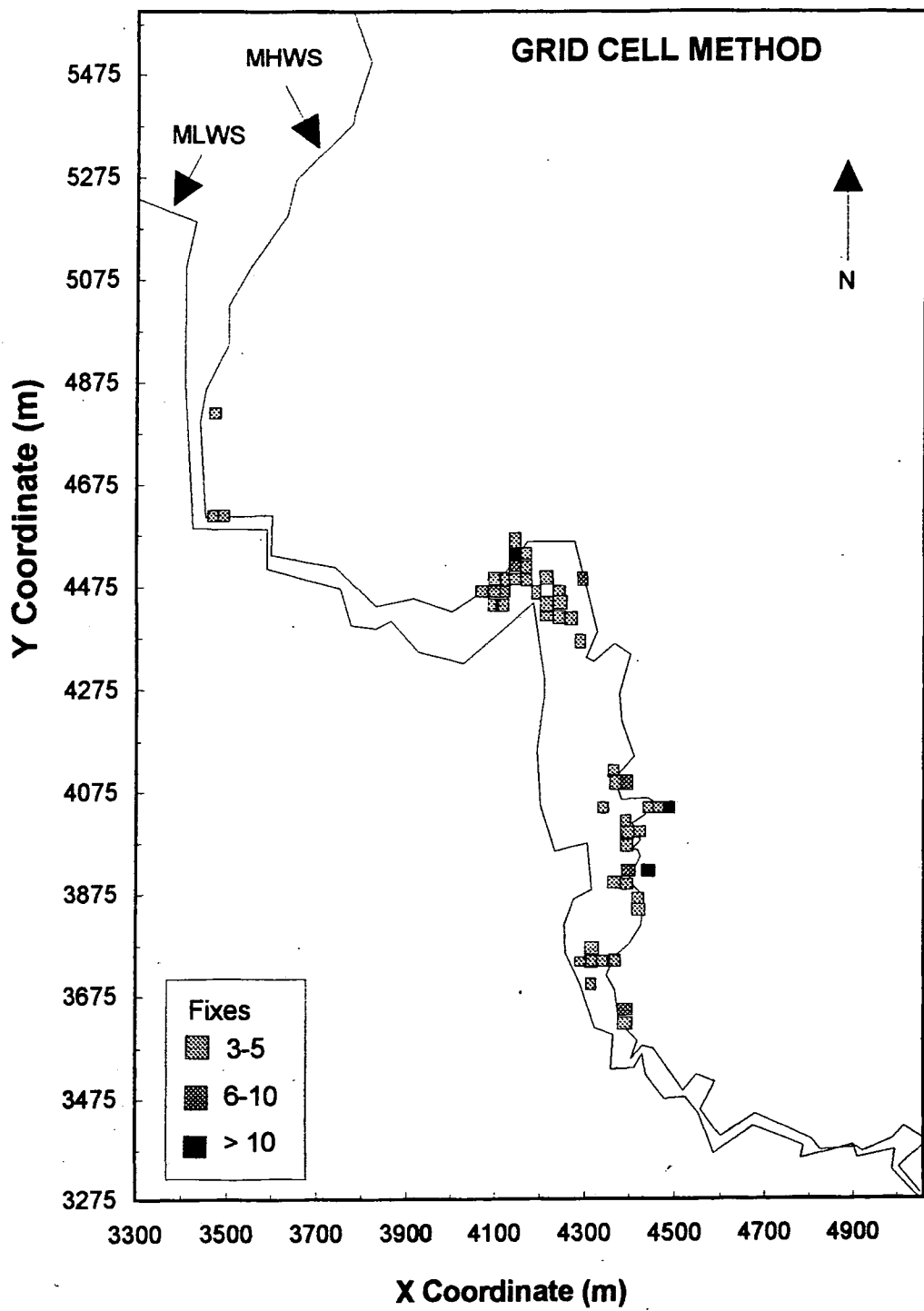
Figure 6.10: Core areas identified by cells containing more than 3 fixes using the GRID CELL method.
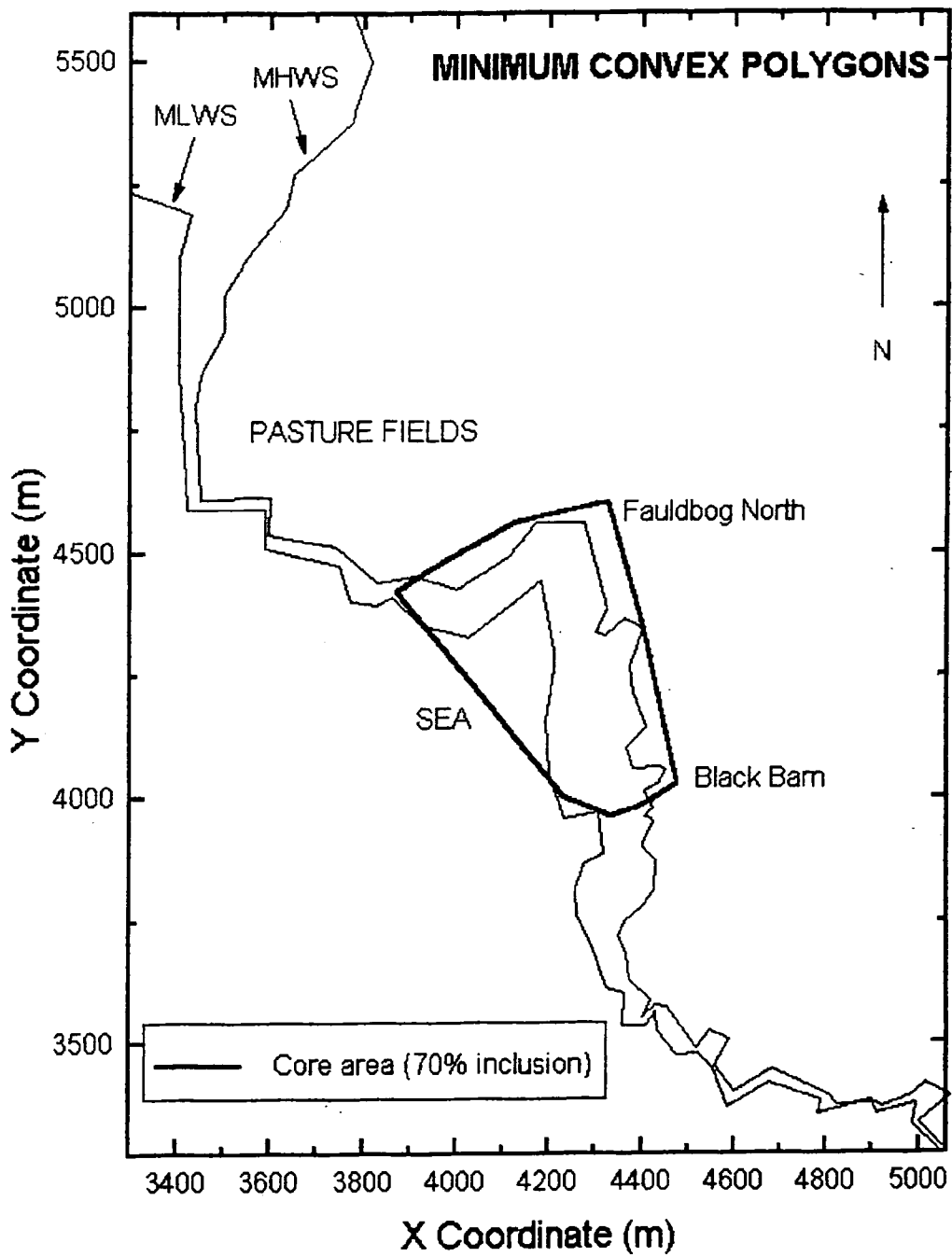
Figure 6.11: Core area identified at 70% fix inclusion with the MINIMUM CONVEX POLYGON method. The polygons have been peeled from the aritmethic centre of locations.

6.3.2.6 Dispersion of Locations

To measure the dispersion of locations with the Density Circles method the variance (156.4m) and the mean (35.4m) of the radii were calculated. The variance was significantly greater than the mean (z-score = 40.02, z-critical value = 2.58, p < 0.01) indicating that the distribution of fixes was clumped, meaning that some areas were used very intensively while others were exploited very little. The biological interpretation of this result is that the animal was selective in its use of space. However the z-score value is especially useful when it can be compared with values derived from other mink or other mustelid species to see whether there is any difference in space use.

6.4 Discussion

The single mink studied inhabits a home range whose shape is highly conditioned by the shape of the coast. The range is compressed between two areas of unsuitable habitat, the sea to the west and pasture fields to the east. This result concords with those found for other mink, where linear home ranges strongly conditioned by the shape of the water bodies are found (eg. Gerell 1970, Birks and Linn 1982, Dunstone and Birks 1985).

The only estimate of mink home range areas available for comparison is that obtained by Ireland (1990) in the same study area. Ireland (1990) has estimated the area of the home range with the Grid Cell method and he obtained much lower values (average for females was 4.9ha ± 1.0) than that here found (Sasha hr = 20.3ha). This difference can be partially explained by considering that Ireland calculated this value using data collected over the annual cycle, while the observations of the present study cover only the winter months. Due to the presence of suckling kits in the den, in May and June the females greatly restrict their movements, therefore reducing the size

of their home range. However, if the length of Sasha's home range is calculated (excluding unusual erratic movements) a length of 1.44km is obtained which is comparable with those of 1.2km and 1.09km, found for female mink in other studies in the same coastal area (Dunstone and Birks 1985, Ireland 1990).

These findings suggest that measuring the home range length alone does not provide sufficient information for a detailed understanding of the spatial organisation of this species. This is true especially in coastal areas, where the width of the shore varies greatly, as on the Ross Peninsula. Where the shore is wider the animal has a greater amount of habitat available for foraging, especially at low tide, and this aspect is not taken into account when home range length alone is measured.

The results of the Density Circles method portray clearly the main characteristics of the studied home range, namely its linear shape and its concentration around the shore. The new method describes these characteristics better than the Minimum Convex Polygons and the Kernel method. When the Minimum Convex Polygons method was used to estimate the home range, a high proportion of non-used areas was included in the home range (Table 6.4). This result is due to the importance given to outlier fixes by this method. The Kernel, amongst the non parametric methods, calculated the home range more accurately, but this method requires the fixes to be independent because strong probabilistic assumptions are made. With mink it is very difficult to collect an adequate amount of independent data. This species has a very unpredictable pattern of activity and spends most of the day in the den and comes out only for short periods (Dunstone and Birks 1987). As a consequence, the main technique of study by most authors has been to exploit all occasions when an animal was found active by collecting continuous data. Other non-parametric methods such as the Dirichlet Tesselation (Wray et al. 1992b) and the Harmonic means are not really suitable for describing linear home ranges, but are rather designed for circular or elliptic home ranges. The Grid Cell method also gave a good fit of

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the data by locating most of the used habitat on the shore. For continuous tracking data, the Grid Cell method has so far been the only non-probabilistic estimator available for calculation of home range size in mink, since alternatives are not suitable for calculating home ranges presenting linear or curved shapes. However Harris *et al.* (1990) suggest that the grid cell method should not normally be used as an estimator of home range size, where an 'outline' technique is more suitable. They argue that this method finds its application in describing the use of different areas of the home range rather than in the calculation of home range size.

To a certain extent the results of the Density Circles estimator were similar to those of the Kernel estimator (Worton 1989). Both methods rely on a weighed sum of distances of recorded fixes from x,y. The difference is that, while the Kernel estimator aims at describing the home range of an animal in terms of a probabilistic model, the Density Circles estimator does not. It can be argued that the Density Circles estimator makes a probabilistic assumption by considering that where the fixes are denser the animal has preferred that local area. However, the method does not attempt to build a probability distribution of fixes (the utilisation distribution) but just to express in terms of an area the local density of fixes.

In some respect the Density Circles method is rather similar to the Dirichelet Tesselation method (Wray *et al.* 1992b), in that the spatial pattern of locations is described in terms of their relative positions. One of the disadvantage of the Dirichelet Tesselation is that at a very high percentage of inclusion the tiles are incomplete. To obtain a realistic estimate of the home range the authors suggest discarding the outer fixes. With the Density Circles Method this problem does not occur, since the more peripheral fixes, found in low use areas, are represented by very small circles that contribute little to the final estimate of the home range. This is also an advantage with respect to the Minimum Convex Polygons method, where the peripheral fixes have a great influence on the estimate of the home range often leading to overestimates.

The disadvantages of the Density Circles method are due mainly to the fact that its estimation depends heavily on the values of the constants a and b, which are set arbitrarily. As suggested in the paragraph 6.2.1 the constant b should be set so that the smallest radius is equal to half of the mean distance covered between fixes, and should be no less than the error associated with each location. The circle should therefore be representative of the movements of the animal and of the accuracy of data collection. If the animal is sampled for example every five minutes, there is no point in setting a circle of 20 meters when the animal takes on average more than five minutes to cover such a distance. Moreover, it makes no sense to consider circles that are smaller than the estimated error since we would attribute to the fix an accuracy that is not true. It is more difficult to find a justification for the constant a. Why should the biggest radius be two or three times greater than the smallest one? There is no biological justification for this choice. In the analysis the choice of the parameter 'a' has been made upon a visual fit of the circles to the distribution of data, and possibly this method could be improved by setting a more objective criterion of selection required for cross study comparison.

Another disadvantage of the Density Circles method is that the areas of the home range can be disjointed. The animal must have been using the area between two disjointed areas, but this is not taken into consideration by the Circles estimator. However, this is a minor drawback, because if the animal has not been observed moving from one disjointed area to the next it could be more correct to avoid making assumptions on its route.

The Density Circles Method is very sensitive to the time interval between successive fixes. If this method is applied on discontinuous data, i.e. data that are highly spaced in time, the minimum radius required is relatively big and the circles cover areas that the animal has never visited. For example, in the case of Sasha, if only fixes spaced one hour apart are considered, the minimum radius is 230m and the calculation of the home range gives an area

of 308.3ha. Such value is clearly a gross overestimate of the home range. However, this result is comparable with the result obtained with the Harmonic Mean method (Dixon and Chapman 1980) at 100% inclusion (255.4ha). The Kernel method gives a much more conservative estimate when applied on the same data (32.5ha). Such a high value of the Density Circles method is due to the fact that by eliminating data much information is lost and therefore it is more difficult to determine with precision the home range area. In order to overcome this problem the criteria for determining the minimum radius could be changed. However this would not be a good solution but rather a way to artificially adjust the output. I suggest to apply this method only on continuous data and to use other methods, less sensitive to the loss of information, such as the Kernel for example, to analyse discontinuous data.

Table 6.5: Summary of the properties of the Density Circles Method

Assumptions	• Where the fixes are denser the animal has spent a higher amount of time and therefore has preferred that local area
Advantages	• Assumes no prior knowledge of the shape of the home range (no parametric assumptions)
	• Does not depend on a grid
	• This method takes into account that there could be non used areas within the home range
	• It does not increase indefinitely with increasing number of data
	• Outliers do not influence home range area
	• Provides a measure for intensity of use
Disadvantages	• Areas of the home range can be disjointed
	• The size of the density circles depend heavily on the value of the constants a and b

The general properties of the Density Circles method are summarised in Table 6.5. In conclusion, this method is very useful to describe the shape of the home range and to point out the most utilised areas and dens, when the data set is based upon continuous data. However, to describe properly the home range this method needs a greater amount of data compared to other estimators considered (i.e. it takes longer to reach an asymptote). As a consequence the Density Circles Method finds its best application in studies aimed at investigating detailed habitat selection within the home range and/or within foraging areas.

CHAPTER 7

GENERAL DISCUSSION

7.1 Introduction

There are important conservation, ecological, and economic issues involved in the management of introduced species, such as the mink. One of the most important issues concerning the mink, involves the understanding of its impact on the native wildlife. In order to quantify such impact, it is important to study what limit and regulate mink populations. There are two approaches to the study of what limits and regulates the number of individuals of a species in a given area: the spatial organisation can be studied in relation to limiting factors, such as food and habitat, or the study can pursue a population dynamics approach, by looking at age structure, dispersion, recruitment, mortality and reproduction.

Most studies of mink have adopted the first approach, where spatial organisation has been related to the factors that might be limiting mink numbers. The second approach requires long term studies and large sample sizes. As a result of these constraints very little is known about the population dynamics of this species (see for example Gerell 1971).

In the present study, the first approach was adopted and the spatial organisation of mink was considered at three different scales. The first-order spatial scale involved the study of mink home ranges. Within these, the location of foraging areas was assessed (second-order spatial scale), and within foraging areas the selection for different habitats was investigated (third-order spatial scale). A study structured in this way leads to the understanding of what affects mink densities and, ultimately, to what limits and regulates mink numbers.

In Britain, mink densities in coastal areas tend to be relatively high (Dunstone and Birks 1983, 1985) compared with densities in freshwater areas (Birks and Linn 1983, Dunstone and Birks 1985, Halliwell and Macdonald 1996). In the present study, however, mink densities in a coastal area were found to approximate those of freshwater areas; the densities of mink on the Ross peninsula having dropped by more than 50% in the last ten years (Chapter 3).

Figure 7.1: Flow diagram showing how limiting food resources and competitors could determine mink densities, through affecting mink spatial organisation at different scales. The double arrow indicates that there is a two way relationship.
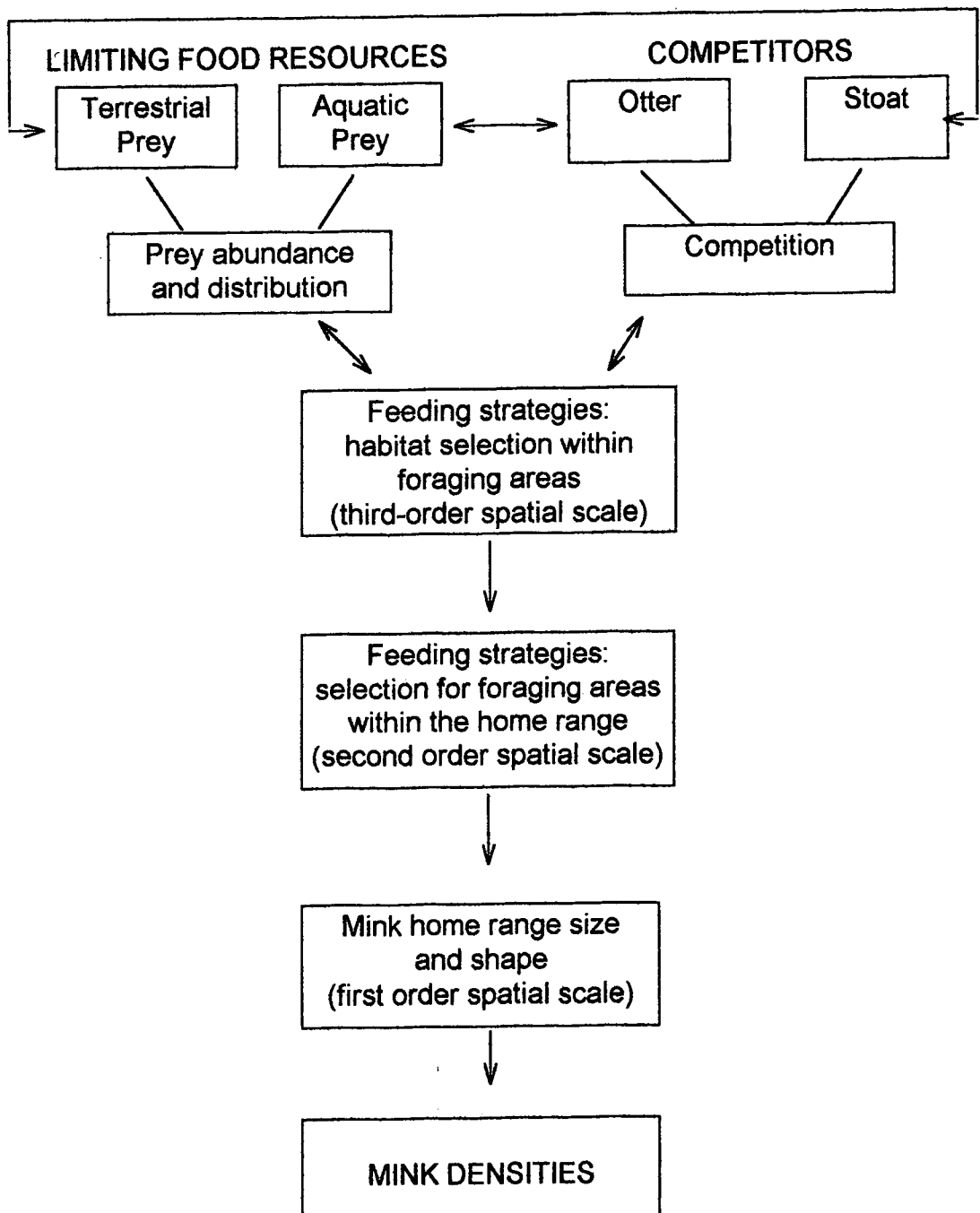
The major extrinsic factors likely to affect mink spatial organisation at all scales are limiting resources and competition with other carnivores. Figure 7.1 shows how limiting food resources and competitors could affect the densities of the mink population of the Ross peninsula, through directly affecting mink spatial organisation at a small scale. In figure 7.1 it is also shown that there is not only a relationship between mink and food resources or mink and competitors, but also between competitors and food resources. In this relationship, the otter is more likely to affect the aquatic prey source, while the stoat affects terrestrial prey sources, mainly small mammals and lagomorphs.

It is in resource availability and competition that an explanation for the changing population of the Ross peninsula must be sought.

7.2 Limiting Resources

For terrestrial mammals, the overwhelming cause of population regulation is food supply (Sinclair 1989), and the mink is no exception. The characteristics of the home range (first-order spatial scale) and the location of feeding areas (second-order spatial scale) of mink in relation to environmental variables, have been extensively studied both in freshwater and in marine habitats. Prey abundance and distribution were found to be the major limiting factors in determining the densities of mink (Gerell 1970, Hatler 1976, Birks and Linn 1982). Food was also shown to be the decisive factor in limiting the numbers of other small mustelids, such as weasels (Erlinge 1974, 1975) and stoats (King 1981, 1983). Where dens were limited, den availability was also shown to be an important factor in determining mink densities (Gerell 1970, Melquist et al. 1981, Mason and Macdonald 1983, Allen 1983, Halliwell and Macdonald 1996).

Male and female mink are likely to be affected by the availability of different prey, due to marked intersexual differences in their diet (Birks and Dunstone 1987). Males are approximately twice the size of females and this allows them to hunt for bigger, more rewarding prey, such as rabbits and hares. Therefore, a change in the abundance of bigger prey items is more likely to affect males than females. In Chapter 4 it was shown that the rabbit population of the Ross peninsula dropped dramatically from the 1980's to the 1990's. This change was probably due to the heavy control operations carried out by the local farmers, together with the incidence of myxomatosis. The scarcity of rabbits and hares was probably a major cause of the observed lower density of mink, especially males, in 1994 when compared with those of the 1980's.

In the present study, it was possible to compare mink densities not only at different moments in time (1980's-1990's) but also at the same time in two different areas: the Ross peninsula and the Little Ross island. Mink densities on Little Ross island were higher than those of the mainland. On the island, there were no rabbits, but rodents and sea-birds were very abundant (Chapter 4). This observation supports the hypothesis that the scarcity of terrestrial prey is a strong limiting factor in determining mink densities, especially in areas where densities of otters are also high, and therefore mink cannot exploit the aquatic food source at its maximum (Clode and Macdonald 1995).

The selection within feeding areas (third-order spatial scale) was investigated for the first time in the present study (Chapter 5). It is very important to know how the mink forages at a very detailed scale, because this is the first step of the process that leads to the regulation of mink populations. Within the intertidal zone, mink were observed to forage selectively by choosing areas that scored the highest prey abundance. This is perhaps not surprising, since at this scale the selection is predominantly determined by the abundance and distribution of food sources. The habitat characteristics of the shore were shown to determine the abundance of prey

and therefore the selective behaviour of mink (Chapter 5). For example, mink were shown to avoid foraging in areas of the shore with fresh water and to prefer areas with abundant rockpools. These preferences suggest that mink might live at higher densities in coastal areas with shores presenting certain characteristics favourable to this species (no fresh water, abundance of rockpools and boulder fields). It was not possible to assess the importance of the den location in the selection process, but due to the heterogeneous nature of the shore it is possible that the location of the den played only a minor role.

When habitat selection is studied in the intertidal zone, the limits of the foraging areas, i.e. of the habitat available, are relatively easy to define since they have a natural boundary determined by MHWS and MLWS. However, when habitat selection is studied at a larger scale or at a fine scale in other habitats not so well defined, it is important to assess accurately the area available to the animal. The Density Circles method, proposed in this study, proved to be very suitable for this purpose. This method described accurately the characteristics of mink home ranges, which usually present linear shapes conditioned to the shape of the water body along which they develop.

7.3 Competition

During the habitat selection process mink are affected, not only by the distribution and abundance of resources, such as prey and dens, but also by the spatial and temporal distribution of their competitors. Competition in mustelids has been extensively studied in terms of spatial, temporal and dietary overlap (for example, Erlinge 1972, Moors 1984, Melquist et al. 1981, Clode and Macdonald 1995). Body size is an important factor in determining the outcome of the competition when interference competition is involved. This kind of competition was observed between stoats and weasels, with stoats being dominant over weasels and occasionally predating upon them (Erlinge and Sandell 1988). Coexistence of different species of mustelids is

however possible because the different body size allows exploitation of different prey (Rosenzweig 1966, King and Moors 1979, Melquist *et al.* 1981).

In the study area, there were two mustelid species that were likely to compete with the mink: the otter and the stoat. Indirect evidence, such as an increase in the number of otter sprainting sites and reports by the local people, suggest that the population of otters on the Ross peninsula has increased since the 1980s'. Otters rely mostly on aquatic prey (eg. Jenkins and Harper 1980, Chanin 1981). If we assume that the otter population has increased then we would expect greater competition with mink to occur, especially in winter when terrestrial prey are more scarce and the mink is known to exploit the intertidal zone more heavily. The otter is expected to dominate the mink due to its larger size (otter:mink weight ratio 7:1). Interference competition between otter and mink was observed for the first time in the present study, when an otter was seen to steal a fish captured by one of the radio-collared mink. In a linear habitat, such as the coast or a river, where otter and mink home ranges develop in one dimension, the chances of encounters between the two species are increased. In a riverine habitat, it was observed that mink and otters were using different habitats, therefore minimising the probability of encounters (Erlinge 1972, Melquist *et al.* 1981). The otter was exploiting more the aquatic resource, while the mink was concentrating more on terrestrial prey. In the present study, it was observed that spatial segregation is likely to occur not only between different habitats, but also within a given habitat, as demonstrated in Chapter 5. In the intertidal zone, mink were observed using the mid-tidal area, while the otter was expected to use the lower tidal area or to hunt in open water (Kruuk *et al.* 1990).

Spatial segregation of different species is favoured in heterogeneous environments (Begon *et al.* 1990). Melquist *et al.* (1981) have argued that environmental heterogeneity is the major factor in promoting the coexistence of mink and otter in riverine habitats. If we consider the shore at a scale at which a mink or an otter would consider it, we can say that the shore is

actually a very heterogeneous habitat. In coastal areas, the shore is probably one of the most important habitats that enhances the coexistence of these two species.

Where rabbit numbers are low and the number of otters is high, we would expect the mink to switch to other kinds of terrestrial prey, such as sea-birds and small rodents. However, terrestrial prey were not very abundant on the Ross peninsula (Chapter 4), and mink had to compete for these prey with other carnivores, such as the fox and the stoat (Chapter 2). Stoats are much smaller than mink, and therefore we might expect the mink to exclude them form the best habitats by means of direct aggression and by scent communication. This form of competition has been observed between stoats and weasel (Erlinge and Sandell 1988). Conversely, stoats are expected to exploit populations of small rodents more efficiently than mink, due to their smaller size which allows them to access smaller tunnels when hunting for rodents.

In the past, much attention has been focused on the interaction between otter and mink (eg. Erlinge 1972, Jenkins and Harper 1980, Chanin 1981, Melquist et al. 1981). However, the influence of the mink on stoat populations has never previously been studied. If mink exert a negative effect on a native carnivore it is more likely to affect carnivores of similar or smaller size, such as the polecat and stoat, rather than larger size competitors, such as the otter. A study of the dietary overlap and spatial and temporal interactions between stoats and polecats with mink, is needed to assess the likelihood of mink to exert negative effects on these species.

In conclusion, this study has provided a unique insight into the subject of habitat selection of mink, and additionally it has assessed the impact of the distribution and abundance of prey species on mink. These sort of studies provide useful information on which future conservation strategies for native fauna can be based.

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APPENDIX 1

DENSITY CIRCLES METHOD
APPLIED ON ADDITIONAL DATA

The density circles method was applied to data collected by Mark Ireland in 1983-1985 on the Ross peninsula (Chapter 2). The method was applied on two mink, Fred and Ted, in order to investigate their core areas. This allowed the identification of the area in which these mink were foraging, for subsequent analysis in Chapter 5. The methods used to calculate their home ranges and core areas are the same as those adopted for Sasha in Chapter 6.

Fred was living mainly on the west side of the peninsula, in the area comprised between Fauldbog North and the Bents (Figure A.1). This mink foraged mostly on the shore, but was also recorded near inland forestry areas.
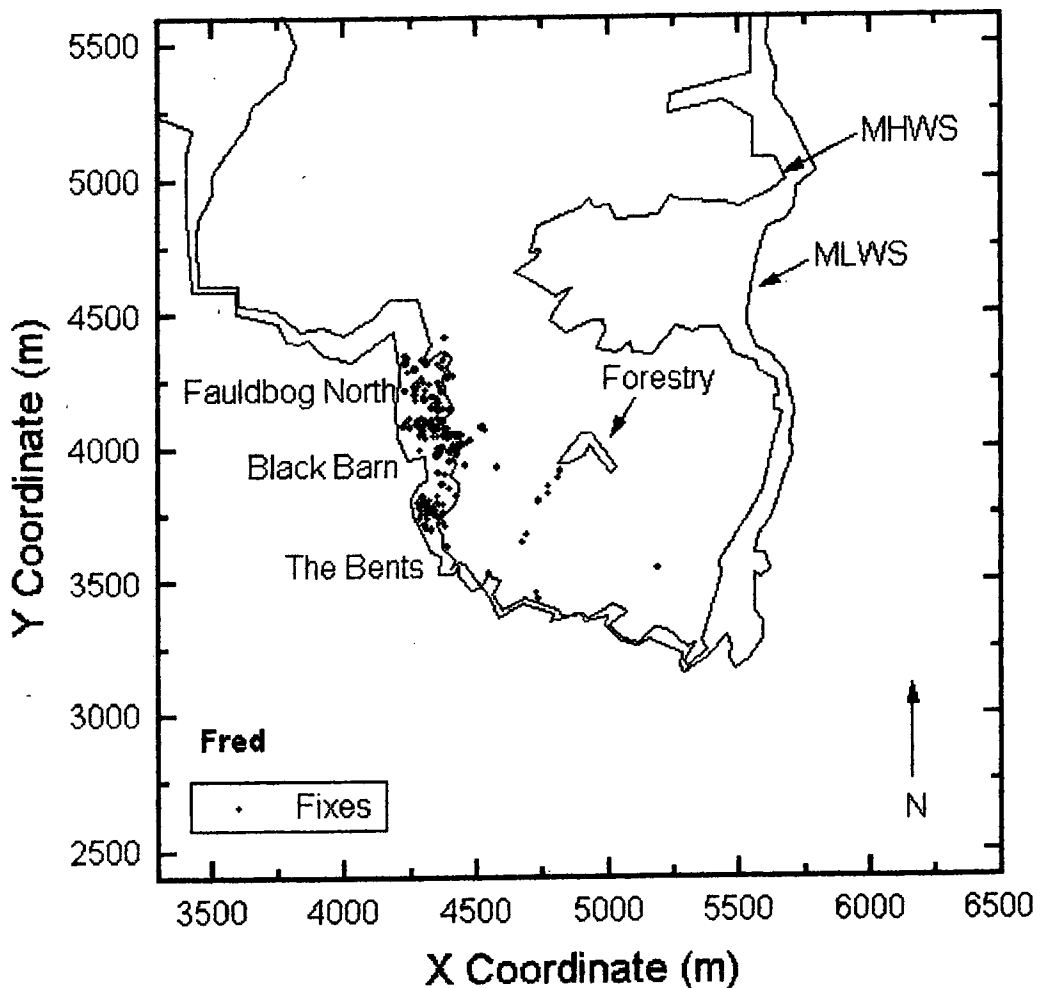
Figure A.1: Location of fixes of Fred.

Ted was considerably more mobile than Fred, and his movements covered almost the entire peninsula, from Mull Point to Thunder Hole (Figure A.2). This mink also visited two of the forestry areas on the peninsula.
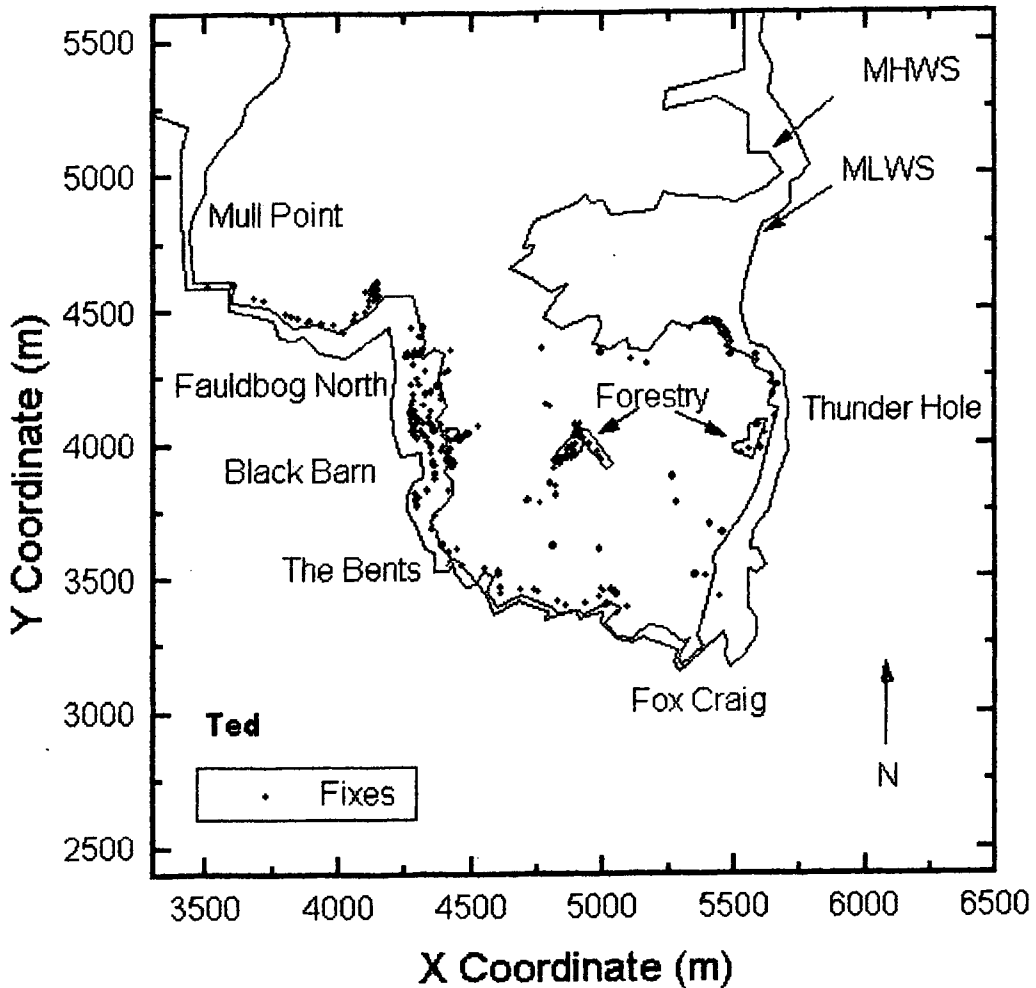

Figure A.2: Location of fixes of Ted.

The estimated home range area for Ted was much greater at any particular level of inclusion than that estimated for Fred (Table A.1), reflecting his greater mobility.

Table A.1: Estimated home range area (ha) with the Density Circles method at different levels of inclusion.

Mink	100%	80%	60%	40%	20%	Parameters	n
	Levels of inclusion						
Fred	28.5	18.6	15.36	12.7	8.9	a =-0.1, b = 108	239
Ted	72.4	45.7	29.3	23.0	16.35	a =-0.1, b = 122	294

The constant 'b' was set so that the average radius of the smallest circle was equal to half of the mean distance travelled between fixes and greater than the error associated with each location (Chapter 6). The minimum radius for Fred was r = 38m (b = 108), and for Ted r = 43m (b = 122). The error associated with each location was not known. However, it is reasonable to assume that it was not much different from the one obtained in the present study (error = 9.67m ± 7.17, n = 6), since the equipment and the radio-tracking methods employed to study Fred and Ted in 1982-1985 were similar as those used in 1994-1995.

The total home ranges of Fred and Ted (100% fixes included), as obtained with the Density Circles Method, are represented respectively, in Figure A.3 and A.4.
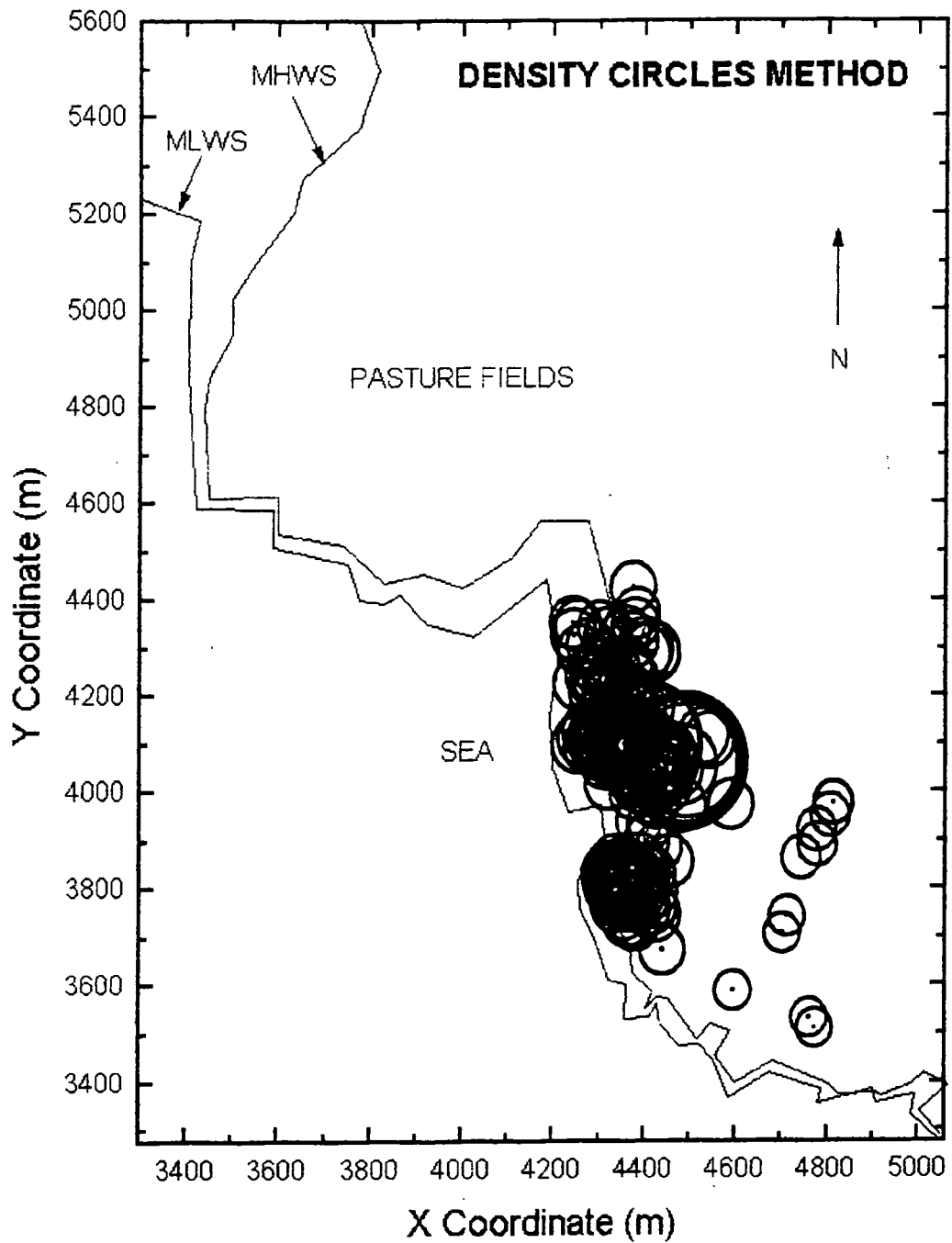
Figure A.3: Home range of Fred as obtained using the DENSITY CIRCLES method, at 100% level of inclusion.
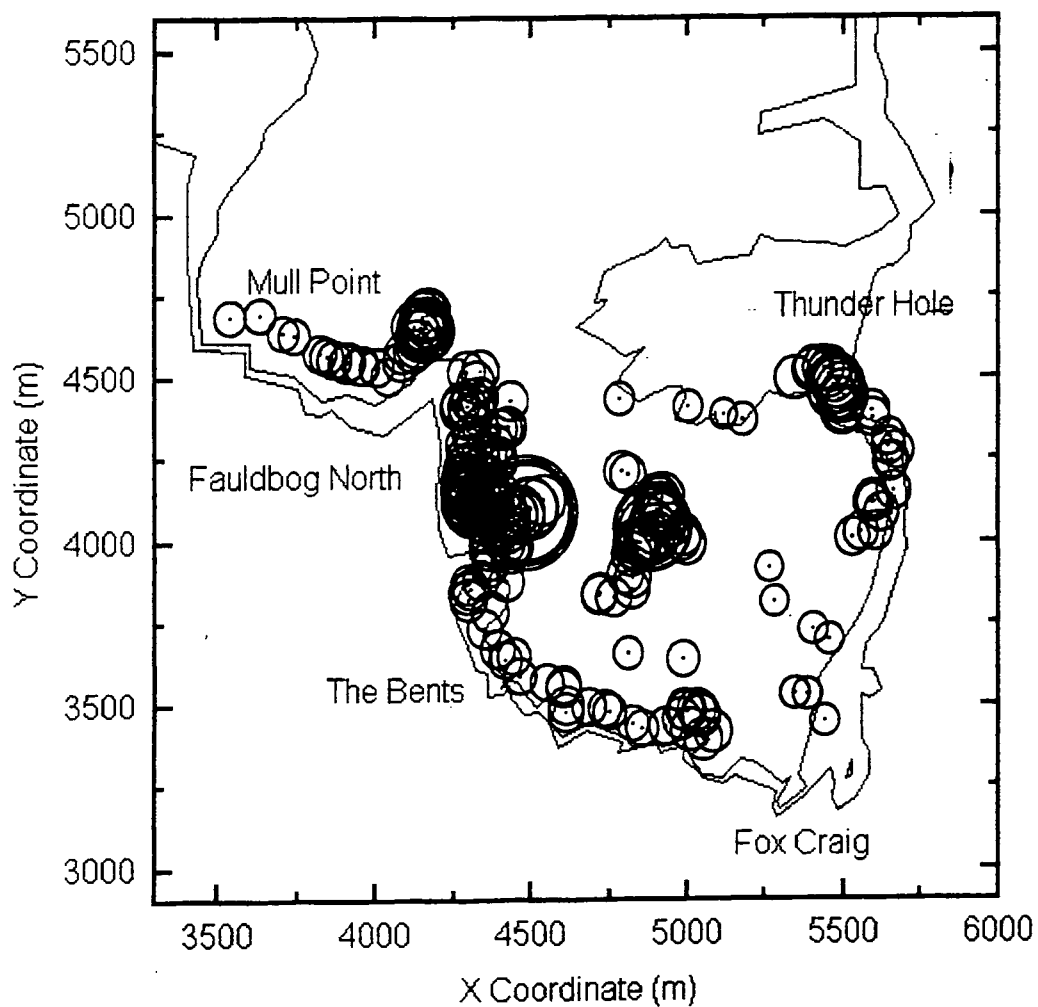
Figure A.4: Home range of Ted as obtained using the DENSITY CIRCLES method, at 100% level of inclusion

The home ranges of neither Fred nor Ted reached an asymptote (Figure A.5 and A.6). Ted's home range increased constantly from November to February. The home range of Fred reached an asymptote in December and January, and increased sharply from mid January onward (80% of fixes).
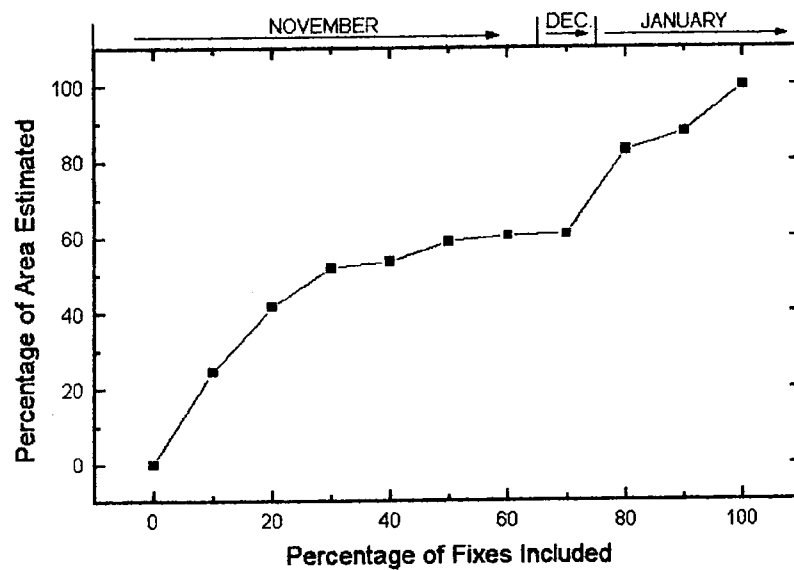
Figure A.5: Graph showing the increase of the home range size of FRED from November to January, with increasing number of fixes.
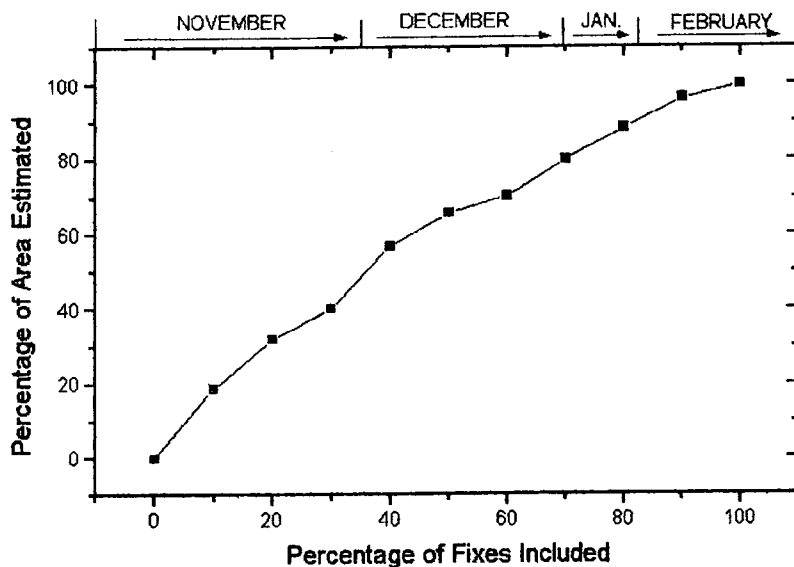
Figure A.6: Graph showing the increase of the home range size of TED from November to February, with increasing number of fixes.

The fact that neither home range reached an asymptote was probably due to the approach of the mating season, when males are known to become more mobile (Ireland 1990).

Core areas were estimated using the method of Wray *et al.* (1992). This method considers the core areas to "resolve" between two levels of inclusion (percentage of fixes) where there is a maximum increase in area. This corresponds to a change in the gradient of the slope of the broken line representing the increase of home range size as smaller circles are added. From Figure A.7 it can be seen that Fred's core area resolved at 30% inclusion, while, in Figure A.8, Ted's resolved at 50% inclusion.
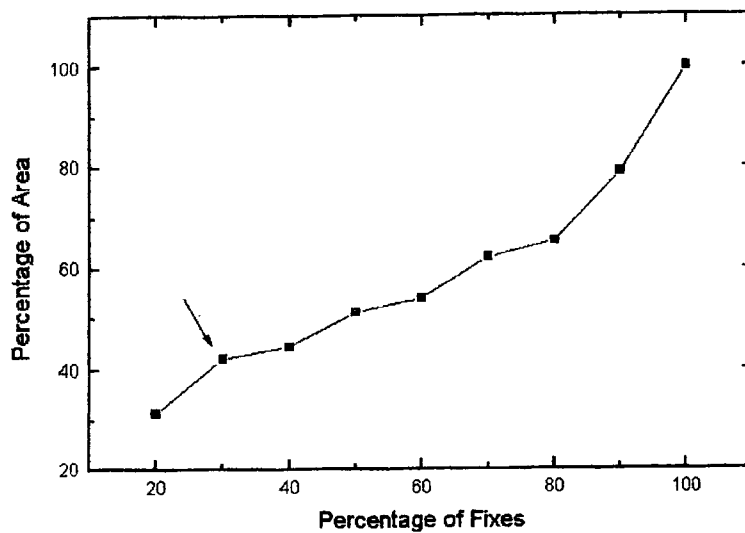
Figure A.7: Percentage of fixes of Fred plotted against the increase in the percentage of total area. The arrow indicates where the gradient of the slope changes.
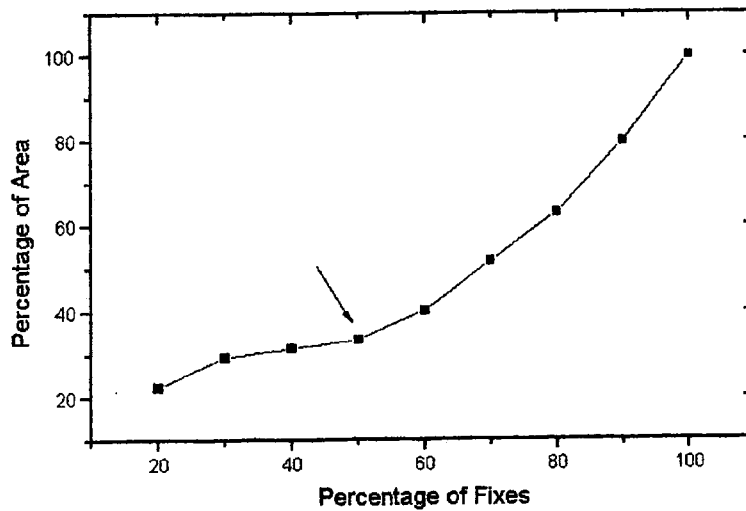
Figure A.8: Percentage of fixes of Ted plotted against the increase in the percentage of total area. The arrow indicates where the gradient of the slope changes.

The locations of the core areas on the Ross peninsula for Fred and Ted are shown, respectively, in Figures A.9 and A.10. Two core areas were identified for Fred (Figure A.9). A bigger one centred around Black Barn, where one of its most used dens was located, and a smaller one nearby, centred on a less used den. Four core areas were identified for Ted (Figure A.10), three were on the coast and one was centred on a forestry area visited often by this mink. Amongst the core areas on the coast, the most important was the one at Black Barn.
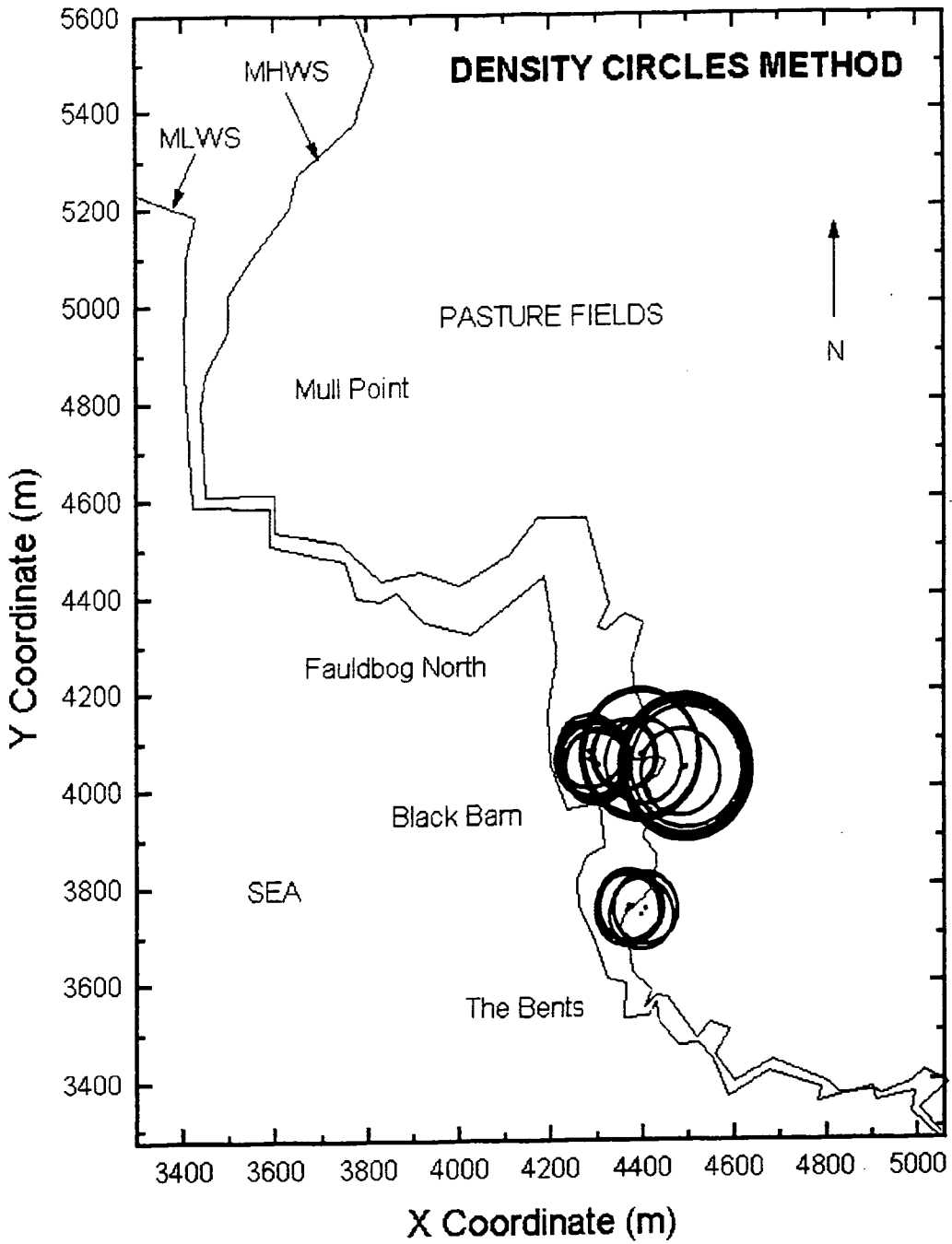
Figure A.9: Core areas of Fred identified at 30% fixes inclusion using the DENSITY CIRCLES method.
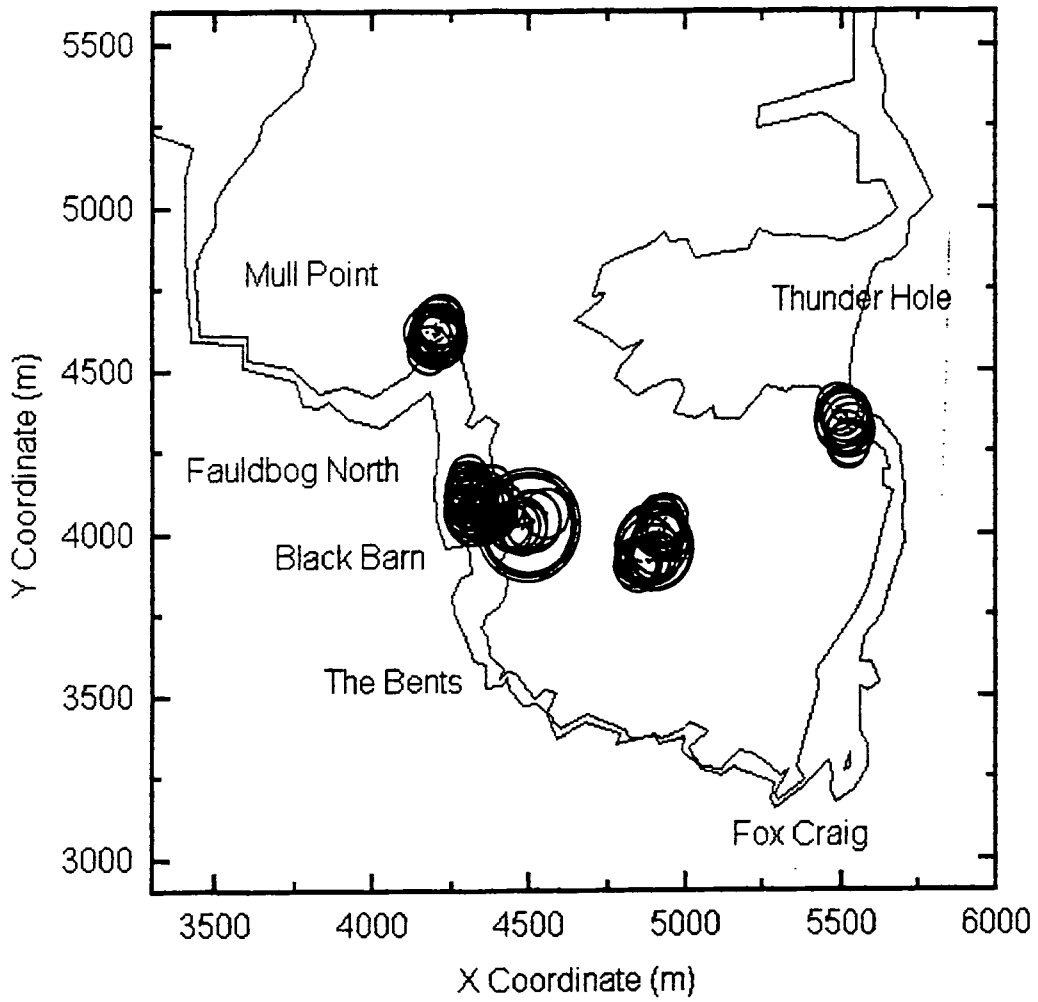
Figure A.10: Core areas of Ted identified at 30% fixes inclusion using the DENSITY CIRCLES method

APPENDIX 2

PROGRAM FOR THE ESTIMATION OF HOME RANGES WITH THE DENSITY CIRCLES METHOD

```fortran
program home_range

      implicit none
      integer i,j,jmin1,jmin2,jmin3,jmin4,jmin5,jmin6
     .       ,jmin7,jmin8,ndat,ii
     .       ,ix,iy,nx,ny,nhr,mask(700),count
*     .       ,ind
      real*8  x(700),y(700),d(700)
     .       ,xa(700),ya(700),sigma(700)
     .       ,dd,dx,dy,xm,ym,dmin1,dmin2,dmin3,dmin4,dmin5,dmin6
     .       ,dmin7,dmin8,xinf,xsup,yinf,ysup,deltax,deltay,delta
     .       ,sigmaa,sigmab,sigmamin
     .       ,sigmamax,frac,frac0,area,xtest,ytest,grid,h
*     .       ,pnorm,p(700), sigmami,sigmame,

      character filein*20,chara*1
      read(5,'(a20)') filein
      read(5,*) frac     ! <--- fraction of points considered (0-1)
      read(5,*) delta    ! <--- extension of the gird
      read(5,*) grid     ! <--- size of grid cell in meters
      read(5,*) h        ! <--- constant b

      open(10,file=filein,status='old')
      open(11,file='prob.d',status='new')
*     open(12,file='covar.d',status='new')
*     open(13,file='area.d',status='new')
      open(14,file='res.d',status='new')

* Writes in file the input values

      write(14,*)'INPUT DATA- 8 points considered'
      write(14,*)
      write(14,*)'Fraction of points considered ',frac
      write(14,*),'Grid increment',delta
      write(14,*) 'Grid cell dimension',grid
      write(14,*) 'Constant b',h
      write(14,*)

* Set the confrontation values

      xinf=10.0d10
      xsup=0.0d0
```

```fortran
         yinf=10.0d10
         ysup=0.0d0
         sigmamax=0.0d0
         sigmamin=1.0d10

* Find the max and min range of data in x and y

         read(10,'(a1)') chara
         i=0
100   i=i+1
         read(10,*,end=101) ii,ii,x(i),y(i)
         if (x(i).lt.xinf) xinf=x(i)
         if (x(i).gt.xsup) xsup=x(i)
         if (y(i).lt.yinf) yinf=y(i)
         if (y(i).gt.ysup) ysup=y(i)
         goto 100

* Define the amplitude of the grid, bigger than min and max of a delta

101   ndat=i-1
         write(14,*) 'Total # data',ndat
         write(14,*)
         xinf=xinf-delta
         xsup=xsup+delta
         yinf=yinf-delta
         ysup=ysup+delta
         nx=nint((xsup-xinf)/grid)
         ny=nint((ysup-yinf)/grid)

         write(14,*)'OUTPUT DATA'
         write(14,*)
         write(14,*) 'Max x value considered', xsup
         write(14,*) 'Max y value considered', ysup
         write(14,*) 'Min x value considered', xinf
         write(14,*) 'Min y value considered', yinf
         write(14,*)
         write(14,*) 'number grid cells on x axis ', nx
         write(14,*) 'number grid cells on y axis ', ny
         write(14,*)

do i=1,ndat
         dmin1=10000.0d0
         dmin2=10000.0d0
         dmin3=10000.0d0
         dmin4=10000.0d0
         dmin5=10000.0d0
         dmin6=10000.0d0
         dmin7=10000.0d0
```

```
      dmin8=10000.0d0
      jmin1=1
      jmin2=1
      jmin3=1
      jmin4=1
      jmin5=1
      jmin6=1
      jmin7=1
      jmin8=1

* Calculate the distance of all points

      do j=1,ndat
        dx=x(i)-x(j)
        dy=y(i)-y(j)
        d(j)=dsqrt(dx*dx+dy*dy)
      enddo

* Choose the nearest point by comparing with the initial value of
* dminx=10000

      do j=1,ndat
        if (j.ne.i) then
          if (d(j).lt.dmin1) then
            jmin1=j
            dmin1=d(j)
          endif
        endif
      enddo

* Choose the IInd nearest point by comparing with the initial value of
* dminx=10000

      do j=1,ndat
        if (j.ne.i.and.j.ne.jmin1) then
          if (d(j).lt.dmin2) then
            jmin2=j
            dmin2=d(j)
          endif
        endif
      enddo

* Choose the IIInd nearest point by comparing with the initial value of
* dminx=10000

      do j=1,ndat
        if (j.ne.i.and.j.ne.jmin1.and.j.ne.jmin2) then
          if (d(j).lt.dmin3) then
```

```
            jmin3=j
            dmin3=d(j)
          endif
        endif
      enddo

* Choose the IVth nearest point by comparing with the initial value of
* dminx=10000

      do j=1,ndat
        if(j.ne.i.and.j.ne.jmin1.and.j.ne.jmin2.and.j.ne.jmin3)then
          if (d(j).lt.dmin4) then
            jmin4=j
            dmin4=d(j)
          endif
        endif
      enddo

* Choose the Vth nearest point by comparing with the initial value of
* dminx=10000

      do j=1,ndat
        if(j.ne.i.and.j.ne.jmin1.and.j.ne.jmin2.and.j.ne.jmin3.
     .      and.j.ne.jmin4)then
          if (d(j).lt.dmin5) then
            jmin5=j
            dmin5=d(j)
          endif
        endif
      enddo

* Choose the VIth nearest point by comparing with the initial value of
* dminx=10000

      do j=1,ndat
        if(j.ne.i.and.j.ne.jmin1.and.j.ne.jmin2.and.j.ne.jmin3.
     .      and.j.ne.jmin4.and.j.ne.jmin5)then
          if (d(j).lt.dmin6) then
            jmin6=j
            dmin6=d(j)
          endif
        endif
      enddo

* Choose the VIIth nearest point by comparing with the initial value of
* dminx=10000

      do j=1,ndat
```

```fortran
      if(j.ne.i.and.j.ne.jmin1.and.j.ne.jmin2.and.j.ne.jmin3.
     .    and.j.ne.jmin4.and.j.ne.jmin5.and.j.ne.jmin6)then
        if (d(j).lt.dmin7) then
          jmin7=j
          dmin7=d(j)
        endif
      endif
      enddo
```

* Choose the VIIIth nearest point by comparing with the initial value of
* dminx=10000

```fortran
      do j=1,ndat
      if(j.ne.i.and.j.ne.jmin1.and.j.ne.jmin2.and.j.ne.jmin3.
     .    and.j.ne.jmin4.and.j.ne.jmin5.and.j.ne.jmin6.
     .    and.j.ne.jmin7)then
        if (d(j).lt.dmin8) then
          jmin8=j
          dmin8=d(j)
        endif
      endif
      enddo
```

* Calculates the mean distance (xm,ym) of the 9 points

```fortran
      xm=0.0d0
      ym=0.0d0
      xm=x(jmin1)+x(jmin2)+x(jmin3)+x(jmin4)+x(jmin5)+x(jmin6)
     .    +x(jmin7)+x(jmin8)+x(i)
      ym=y(jmin1)+y(jmin2)+y(jmin3)+y(jmin4)+y(jmin5)+y(jmin6)
     .    +y(jmin7)+y(jmin8)+y(i)
      xm=xm/9.0d0
      ym=ym/9.0d0
```

* Decide where to centre the circle

```fortran
      xa(i)=x(i) ! centred on the point
      ya(i)=y(i)
```

* Calculates the variance (sigma(i)) of these points

```fortran
      sigma(i)=(((xm-x(jmin1))**2+
     .          (xm-x(jmin2))**2+
     .          (xm-x(jmin3))**2+
     .          (xm-x(jmin4))**2+
     .          (xm-x(jmin5))**2+
     .          (xm-x(jmin6))**2+
```

```
   .            (xm-x(jmin7))**2+
   .            (xm-x(jmin8))**2+
   .            (xm-x(i))**2)/9.0d0)
   .          +(((ym-y(jmin1))**2+
   .            (ym-y(jmin2))**2+
   .            (ym-y(jmin3))**2+
   .            (ym-y(jmin4))**2+
   .            (ym-y(jmin5))**2+
   .            (ym-y(jmin6))**2+
   .            (ym-y(jmin7))**2+
   .            (ym-y(jmin8))**2+
   .            (ym-y(i))**2)/9.0d0)


* Identifies the max and min radius

      if(sigma(i).ne.0.0) then
        if(sigma(i).gt.sigmamax) sigmamax=sigma(i)
        if(sigma(i).lt.sigmamin) sigmamin=sigma(i)
      endif

* Ends the do stared with choice of closest points

      enddo

      do i=1,ndat
        if(sigma(i).eq.0.0) sigma(i)=sigmamax
      enddo


* Decision rule for selecting the circles that will be used to
* estimate the home range

      frac0=-0.001
12    frac0=frac0+0.001
      count=0
      do i=1,ndat
        mask(i)=1
        if(sigma(i).ge.sigmamin+frac0) then
          count=count+1
          mask(i)=0
        endif
      enddo
      if (count.gt.frac*ndat) goto 12

      do i=1,ndat
        if(mask(i).eq.0) then
          write(11,'(i4,1x,2(f7.0,1x),f10.4)') i,x(i),y(i),sigma(i)
```

```
        endif
      enddo

      write(14,*)'% of points to be considered', frac*100.
      write(14,*)'% of points considered    ',100.*count/dfloat(ndat)
      write(14,*) 'number of points considered ', count
      write(14,*) 'total number of data      ', ndat
      write(14,*)

      sigmaa=0.0d0
      sigmab=0.0d0
      do i=1,ndat
        if(mask(i).eq.0) then
          sigmaa=sigmaa+sigma(i)
        else
          sigmab=sigmab+sigma(i)
        endif
      enddo
      if(count.ne.0)sigmaa=sigmaa/(count)
      if(count.ne.ndat)sigmab=sigmab/(ndat-count)

* Writes the output

      write(14,*) 'min radius      ',sigmamin
      write(14,*) 'max radius      ',sigmamax
      write(14,*) 'average radius included',sigmaa
      write(14,*) 'average radius excluded',sigmab

*.....home range calculation

      deltax=nint((xsup-xinf)/dfloat(nx))
      deltay=nint((ysup-yinf)/dfloat(ny))
      nhr=0

* Finds the central point of each grid cell

      do ix=1,nx
        xtest=xinf+(ix-0.5)*deltax !grid
        do iy=1,ny
          ytest=yinf+(iy-0.5)*deltay !grid
          do i=1,ndat
            dd=dsqrt((xtest-xa(i))**2+(ytest-ya(i))**2)
            if (dd.lt.sigma(i)) then
              if(mask(i).eq.0) then
*                write(13,*) xtest,ytest
                nhr=nhr+1
                goto 9
              endif
```

```fortran
            endif
          enddo
9         continue
        enddo
      enddo

      area=deltax*deltay*nhr     !grid**2*nhr

      write(14,*)
      write(14,*) 'number of test points',nx*ny
      write(14,*) 'number of hr points  ',nhr
      write(14,*) '% of hr points'     ,100.*nhr/dfloat(nx*ny)
      write(14,*) 'home range area      ',area
      write(14,*) 'total area considered',grid**2*nx*ny !deltax*deltay*nx*ny
      write(14,*) '========================================='

      stop
      end
```

SUMMARY

- The foraging strategies and spatial organisation of a mink population (*Mustela vison*) inhabiting a coastal area of SW Scotland, were studied at different scales, and related to prey abundance and distribution.

- The home ranges, observed mobility patterns, and denning behaviour of five mink were investigated. The results confirmed those found in previous studies, with mink showing intrasexual territorial exclusion and intersexual territorial overlap. Male home ranges were found to be bigger than those of females, as predicted from their greater energy requirements.

- The foraging strategies (activity levels, habitat use, foraging behaviour) of mink in two areas, the Ross peninsula and Little Ross island, were compared and related to food abundance and distribution. Lower levels of activity were found on the Little Ross island, due to the great abundance of terrestrial prey, such as rodents and sea-birds. On the mainland, where terrestrial prey was less abundant, mink were more active out of den and made greater use of the shore. The greater abundance of terrestrial prey on the island of Little Ross determined also higher mink densities (1.30 mink/km), compared to the mainland (0.56 mink/km).

- Mink densities on the Ross peninsula were higher in the 1980's than those found in the present study in winter 1994-1995. This difference was attributed to the dramatic decrease of the lagomorph population, i.e. rabbits and hares. This decrease affected more males than females, since the former relayed more heavily on this prey source.

- Habitat selection was studied in the intertidal zone. Three factors were found to determine whether the mink behaved selectively or not: residency, state of the tide and the motivation for the displacement. If the mink was resident, foraging at low or mid tide, and was not moving

between core areas then it behaved selectively, preferring areas with high prey abundance and avoiding those with low prey abundance.

- Prey abundance in the intertidal zone was found to be determined by four habitat characteristics: the nature of the substratum, the presence/absence of fresh water, the abundance and size of rockpools, and the position within the tidal zone. When foraging in the intertidal zone mink was found to prefer the following habitat characteristics: absence of fresh water, abundance of rockpools, and the mid tidal zone.

- The preference for the mid tidal zone was argued to be the result of mink trying to avoid interference competition with the otter, which was directly observed in the present study. The intertidal zone is a very heterogeneous environment therefore promoting spatial segregation.

- During the course of the study a new home range estimator - the Density Circles method - was developed for studies of habitat selection, where the home ranges must be measured accurately. The new estimator is particularly suitable for describing home ranges presenting anomalous shapes, such as those found in mink.

(Alex peering from behind a rock)