GEOLOGY AND OTTER DISTRIBUTION ON THE ISLE OF SKYE

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Chapter 1

Introduction

CONTENTS

SETTING THE SCENE

This thesis deals with ecological research carried out on the Eurasian otter (*Lutra lutra*) on the Isle of Skye, on the north western seaboard of Scotland. It is aimed primarily at obtaining data on distribution and population density, to look at what factors influence the distribution of the otter population around the coastline, and to investigate if the geology of the coastal zone has an influence on this population. The results will help to formulate an effective strategy for their conservation not only in this region but in northern Scotland and possibly elsewhere.

The question could be asked: "why waste time and money studying otters, especially as the earth is losing its biodiversity at an alarming rate?" However, single species conservation is still important, especially with a species like the otter, which stands at the top of the food chain and lives both on land and in water; anything which affects the otter affects all other species linked to it in the food web. As Dr George Rabb, Chairman of the World Conservation Union (IUCN) Species Survival Commission, says "otters are environmental ambassadors of first class rank" (Foster-Turley et al, 1990).

The decline of the otter in Britain has been well documented. In 1566 the otter was officially designated as a "pest" in the Act of Preservation and every otter killed was worth a bounty (Chanin, 1985). Just under 400 years later, "Where are the Otters" by Ivester Lloyd (1962) was the first public statement about the decline of the Eurasian otter in Britain and this was published in "Gamekeeper and Countryside". When the Nature Conservancy Council's Joint Otter Group published a report of the status of the otter in the UK no further information was available and they listed ten pressures affecting the otter which might have caused its rather rapid decline: these were disturbance, hunting, riparian clearance, pollution, disease, road mortality, killing for pelts, severe winters, increasing mink populations and the impact of fisheries.

The Eurasian otter is considered by IUCN to be "vulnerable" due to the threatened or declining status of many of its populations throughout its range. It is indeed one of the sad casualties of the 20th century with European populations declining overall since the 1950's. Today it is on Appendix I of CITES and also protected under European law, being listed in Annexes IIa and IVa of the EC Habitats Directorate (92/43) and Conservation (Natural Habitats) Regulations (1994).

This decline is attributed to a variety of factors including pollution (of both agricultural and industrial origin), together with widespread habitat destruction (Mason and Macdonald in Foster-Turley et al, 1990). This decline, however, went relatively undetected until populations reached a critical level and therefore no detailed work has been undertaken on what actually did cause it. Attention today is focused on theoretical risks like habitat destruction or PCB levels but it is not at all adequate to rest the case at this. We need to know which resources in the habitat have changed, for example food, shelter, holts.

To date, a lot of research on otter distribution has taken place in areas where otter populations are already under threat. At the final stage when numbers are low and the population may die out because of various demographical or environmental problems there are additional problems with sampling (Caughley and Gunn, 1996).

If we are concerned about the conservation of a species like the otter, then research must be undertaken a long time before such a crisis occurs. It is trends in numbers and not absolute population size that cause worry. If we wait until an otter population becomes small, as in parts of England, we change conservation management into crisis management, with all the panic and shortcuts and wasted money that this brings with it.

Otters can only be conserved by broad-based conservation strategies, and it has been suggested that the long term survival of the species in the western Palaearctic should be primarily aimed at preserving healthy populations that still remain (Mason and Macdonald in Foster-Turley, et al 1990). In order to achieve this, research should be aimed at identifying viable populations and establishing a sound scientific base to maintain such a population. The general message for the conservation management of otters is that in order to maintain the population, animals will have to be protected in their context, as part of the ecosystem, as part of the food web (Kruuk, 1995).

Most ecological theory has developed from studies conducted on a small scale within patches of a single habitat and there is a tendency to ignore possible complicating factors operating over the larger scale. Populations of animals are patchy and the distribution of a species can vary from patch to patch (Begon et al 1999; Murray, 1989), and this would seem to be the case with the otters on Skye (Yoxon, pers. obs). This patchiness may be a part of the physical environment, or the availability of food around the coastline. The limiting factors of any animal population are complicated and there are two schools of thought which have been debated over many years. The first idea is that the population size is determined from forces acting on the population from outside. Andrewartha and Birch (1954 and 1984), stated that the number of animals in a natural population can be limited in three ways:

i) Shortage of material resources, ie food, shelter
ii) Inaccessibility of these material resources relative to the animal's capacity for dispersal and searching.
iii) Shortage of time when the rate of reproduction is positive.

The second idea is that the population abundance is regulated by the effects of crowding. The abundance of the population is determined by all factors acting on it and the population will decrease when its size is above a particular level and increase when the size is below that level. Nicholson (1957 and 1958) argues that these density dependent, biopic interactions play the main role in determining a population size. It would seem for large terrestrial mammals that they are regulated by the availability of food, and smaller mammals the single most important regulatory factor is the exclusion of juveniles from breeding (Begon et al 1999, Sinclair, 1989). These generalisations however must have bias and for the regulatory factors effecting the otter population on Skye I will look at both external and internal factors.

CONSERVATION AND OTTERS IN THE ISLE OF SKYE AND PREVIOUS OTTER RESEARCH

The Isle of Skye is situated on the north west seaboard of Scotland lying between Latitude 57^{0}44'N and 57^{0}03'N. Its most westerly point is Longitude 6^{0}46'W and its most easterly 5^{0}38'W. The island is 130km long and its breadth varies considerably due to the 15 major sea lochs that dissect the land mass. The geology of the island is varied and complex with rocks covering eight major geological periods, giving rise to a complex coastal scenery.

The island's otter population has never been studied in any great detail; people have known otters existed but as to population numbers and habitat preferences this was not really known. I have been studying otters on Skye for many years it would seem the otter population on Skye is stable and probably doing very well (Yoxon. G.M and Yoxon, P. 1990). Caughley and Sinclair (1994) stated that conservation biology had two threads: the small population paradigm and the declining population paradigm. When looking at the problems of otters on Skye, my work had to be based on the small population paradigm essentially because the Skye population was not declining. However, the theories of the declining population paradigm are still useful and should not be ignored.

The otter population on Skye may vary slightly year by year as a result of variation in weather or other environmental conditions. If the population gets too small, it may be forced to extinction because the dynamics of low numbers are governed by the fortunes of individuals. Genetic drift and inbreeding can lower numbers even further, but Caughley and Sinclair (1994) identified the commonest cause of extinction as habitat modification and the introduction (usually by humans) of a new element into the environment.

On Skye, the research also necessitates looking at potential agents of decline as well as understanding the basic requirements of the population. Eurasian otters have only been studied in detail since the 1960's by Erlinge (1967, 1968 and 1972) working in freshwater systems in Sweden, but before that time we were largely ignorant about the animal, despite an interest for many years from naturalists all over Europe.

Many books published on the subject, such as Chanin (1985) and Mason and Macdonald (1986), deal in detail with conservation and natural history but a lot of this knowledge comes from captive animals or the occasional glimpse of an animal in the wild in a river system.

Eurasian otters in coastal areas were not studied until 1978 when Watson researched the coastal otters of Shetland. With the advent of the oil terminal at Sullom Voe much concern was expressed with regard to spills and the possible effect on otters, (Baker et al, 1981; Conroy and French, 1985) and resources were put into Shetland to fund research into the ecology and behaviour of coastal otters on Shetland.

Since then a string of published material has come out of Shetland, which makes the Shetland coastal otters some of the best researched in Britain: Herfst (1984), Kruuk et al (1989), Kruuk and Moorhouse (1991) and Kruuk's recent book based on many years of observing wild otters in Shetland (1995).

On the north western seaboard of Scotland, however, recent work has come from Watt (1991) and Mason and Macdonald (1980) with early work being undertaken by Green and Green (1980 and 1997) and Yoxon and Yoxon (1990).

I was also concerned that most of the surveys undertaken in Britain had been done with no direct observations whatsoever and used only the anal deposits (spraints) to look at distribution. This is shown in the Otter Survey of Scotland (Green and Green, 1980 and 1997), Otters of Exmoor (Jarman, 1981), and Otters on the Somerset Levels (Jarman, 1979).

The standard survey method for the Eurasian otter was devised in the 1970's and in summary is as follows: (Green and Green, 1980)

1. It is based on 10 X 10km grid squares.

2. Within these squares wetland sites are visited at 8-10km intervals along rivers, lakes and sea coasts.

3. At each site a maximum of 600m is searched for otter signs. If signs are found the search is terminated and the site is recorded as positive; if no signs are found it is marked as negative.

This type of survey can provide initial distribution data, identify possible problems for otters and form a base-line for further studies. For example, if searches are made at 50 sites on a river catchment and 75% prove positive with many signs found at each site it may be assumed that the animals are at a higher density than on an adjacent catchment with only 15% of sites proving positive and with few signs found at each site.

However, the concept of using spraints to estimate actual otter numbers has been under great debate over the years (Kruuk and Conroy et al, 1986, Jefferies, 1985, Conroy and French, 1987).

It was generally concluded that caution should be used in interpreting the results of spraint surveys until such time as the existence of a relationship between otter numbers and spraint numbers has been established, and that more data should be gathered with regard to correlations between otters and spraints, (Kruuk and Conroy, 1987).

Preliminary observations of otters on Skye have suggested a link between otter distribution on Skye and the coastal geology. Living on Skye all year I am fortunate in that I am able to study the otter on a frequent basis and have done so for many years. Given that the coastal Eurasian otter is largely diurnal, it offers a unique opportunity to study the distribution of otters around the Skye coastline by direct observation as well as by secondary signs.

This thesis has the following objectives:

1. To determine the influence of geology on the distribution of otters around the Isle of Skye coastline, including the coastal type (ie Muddy, Sandy), inland vegetation, and the number of holts and freshwater pools.

2. To describe the diet of otters living along this coastline, including prey species and the variation in diet in space and time (yearly and seasonal) and along the different geological coastal zones.

3. To describe the spatial patterns of prey available to otters and investigate what factors influence these.

4. To study other factors influencing otter distribution and whether secondary signs like spraint numbers, sprainting points or holt numbers can be used to calculate otter numbers.

5. Develop a predictive model to estimate the occurrence of otters along the Skye coastline.

6. To estimate the number of otters around the Skye coastline and to explore the implications of my results on otter conservation on Skye.

OUTLINE OF THESIS

The thesis consists of eight chapters. Firstly, I describe the coastal geology of the Isle of Skye (Chapter 2), which forms the foundation for the conclusions I make throughout the rest of the chapters. Since the early part of the nineteenth century the island has been studied by professional and amateur geologists who have been inspired by the spectacular landforms, the stunning coastal and mountain scenery and the great variety of rock and fossils. It is important for the reader to fully understand the different geology of the coastal zones laid out in this chapter as the geological coastal zones are referred to frequently in Chapters 3 to 8.

Chapters 3 and 4 analyse the diet and prey availability and compare these to the seven geological coastal zones. Chapter 3 is about the diet as analysed by the faeces of the otter (spraint) and it also looks at some of the problems associated with spraint analysis. Chapter 4 looks at the availability of prey around the Skye coastline in the seven geological coastal zones and compares this with the diet as analysed by spraint analysis. It builds on some of the findings in Chapter 3 and identifies the main prey available to the otter.

Chapter 5 brings in all the environmental variables and looks at otter activity in the seven geological coastal zones. It incorporates data from both my intensive study and an extensive study undertaken by trained volunteers in 1994. It also identifies what makes good otter habitat on Skye and looks at the variables on the coastline to see if a correlation can be made between geology and activity.

Chapter 6 follows on from Chapter 5 in producing a model to predict the presence or absence of otters around the coastline and shows how particular combinations of factors can be used accurately to predict the presence and absence of otters. Besides its theoretical importance this method could be a useful tool for conservation purposes.

The final main Chapter 7 puts forward population figures for the otters on Skye. Wildlife conservation plans can only be implemented if actual trends in populations can be followed. Estimating populations of otters is difficult; although they are diurnal on Skye and can be observed and identified over large stretches of the coastline, obtaining numbers over all the coastline would be time consuming and virtually impossible. For this reason, an indirect method of census using the numbers of otter holts to estimate the numbers of otters was used in this Chapter.

In the last Chapter 8, I have woven all the results of the previous chapters together to look at the long term implications for the conservation of otters on the Isle of Skye, and by using research undertaken in other areas consider the measures needed to protect the otter in the future. In order to effectively conserve the otter, we have to have detailed knowledge of their habitat and ecological requirements and it is only by effective research that this can be achieved.

Plates 1.1, 1.2 and 1.3 show some of the otters on the Isle of Skye.

STATISTICAL METHODS

Most of the statistical analysis was done using SPSS Version 6 for Windows, a statistical and graphics package designed for use on personal computers. The package was on loan from the Open University Computer Department.

The probability threshold for rejecting a null hypothesis was 5%, ($p=0.05$). Increasing significant differences were indicated by $p<0.05$(*), $p<0.01$(**) and $p<0.001$(***). Parametric tests were used when the data were normally distributed and non-parametric tests for data that were not (or not known to be) normally distributed. Non-parametric statistics for behavioural sciences (Siegel and Castellan, 1988), SPSS for Windows (Foster, 1993) and SPSS advanced statistics 6.1 (Norusis, 1994) were used as the standard references. The following notations were used:

n = number of units in a sample
SD = standard deviation of the sample
SE = standard error of the sample
P = probability
r_s = Spearman Rank Correlation Coefficient
W = Kendall's Coefficient of Concordance
F = test statistic for F test
ns = not significant
χ^2 = Chi-squared

Plate 1.1, 1.2 and 1.3. The Eurasian otter on the Isle of Skye
Plate 1.1, Female Otter at Loch na Dal, Sleat Peninsula, Isle of Skye
Plate 1.2, Male Otter at Ardnish, Isle of Skye, showing distinctive pink nose patch
Plate 1.3, Female Otter eating Saithe, Drumfearn, Sleat peninsula, Isle of Skye

Chapter 2

Geology, Physiogeography and Climate of the Isle of Skye

Synopsis

Skye is unique among the Hebridean islands for its variety of geology and landscape which has resulted in a diverse range of coastal types. The coastline was divided into seven geological zones and various physical parameters were examined in relation to these geological coastal zones. A total of 55% of the coastline of Skye was assessed for intertidal type, width of intertidal zone, slope of the shoreline and the inland vegetation, using trained volunteers to supplement my four year intensive study on 29 x 500m sections of coastline.

Geology did play an important role in determining the intertidal make up, width of intertidal zone, height 25m from High Water Mark and inland vegetation. Tidal widths between 20-60m dominated all zones except the Cambrian where widths of 100-200m dominated and the Cambrian had no tidal widths over 200m. The Torridonian and Cambrian had the highest percentage of gently sloping shorelines (11^o-21^o). The Torridonian also had a lack of coasts with slopes over 63^o, and the Tertiary Lavas had a dominance of slopes ranging from 21^o-63^o.

The intertidal make up is also related to geology: the Torridonian, Cambrian, Mesozoic, Intrusive and Landslip have a dominance of boulder coastlines whereas for the Tertiary Lavas rock outcrop dominates.

Grassland occurred in large percentages in all coastal zones ranging from 75% of coastlines in the Tertiary Lavas to 33% for the Torridonian. The percentage of cover adjacent to the High Water Mark was greater in the Torridonian zone (24% native wood, 23% scrubland), and was lowest on the Tertiary Lava zone (7% native wood, 11% scrubland).

Rainfall varied considerably between the years and on a monthly basis, with 25% more rain falling in the central coastal areas than in the north. During the months of May and June evaporation exceeds rainfall by as much as 80% and this will play an important part in limiting the availability of freshwater pools that are utilised by otters.

CONTENTS

INTRODUCTION

This chapter provides a description of the geology, physiogeography and climate of the Isle of Skye, and is based on intensive field surveys by myself and an extensive study by teams of Earthwatch volunteers. The work was also based on extensive literature searches and unpublished data from geological mapping projects. Climatic data was obtained from the Meteorological Office.

The coast of the island was divided into seven geological zones, based on currently available maps from the British Geological Survey (BGS) and these were used for the basis of the thesis. These are described in detail later in this chapter and various physical parameters associated with these geological coastal zones are examined, namely width of tidal zone, slope, intertidal type, boulder size and inland vegetation.

The island's geological history spans over 3,000 million years of the earth's history (Stephenson and Merritt, 1996) and the seven geological coastal zones consist of major time divisions based on the standard geological time scale. This is outlined in Table 2.1 and the outcrop areas are shown in the geological map of Figure 2.1.

The oldest rocks, the Pre-Cambrian, consist of the Lewisian, Moine and Torridonian groups. Lewisian and Moine rocks were heavily metamorphosed (altered by heat and pressure) to form gneiss and schists, which outcrop in the Sleat peninsula in the south of Skye. The Torridonian group are the only unmetamorphosed Pre-Cambrian rocks in Britain and consist of a sequence of sandstones, shales and conglomerates. They outcrop in the Sleat peninsula, around the Broadford area and around Sconser.

The Cambrian rocks overlie the Torridonian and consist of a series of quartzites, shales and limestones. In places the limestones have been metamorphosed and altered to marble. Cambrian rocks outcrop in a narrow band running south west from Broadford, and also around Ord in the Sleat peninsula.

The island's geological history misses some 275 million years of earth's history covering the Silurian, Devonian and Carboniferous periods. This is due to a period of uplift and erosion after the Cambrian period resulting in no deposition of sediments. The next group of rocks belong to the Mesozoic Era and these represent the Triassic, Jurassic and Cretaceous periods. They are essentially a series of sedimentary rocks, outcropping in the Strathaird peninsula, around Broadford Bay and north of Portree.

The next major geological period to affect Skye was the Tertiary period, which was largely a period of intense igneous activity. This was responsible for the formation of the Black Cuillin and Red Hills in the centre of the island, the vast areas of plateau basalt lavas in the north west and the minor intrusions which occur throughout the island.

Following the violent volcanic outburst of the Tertiary period, the landscape was subject to great erosion. During the Pleistocene period, ice sheets covered the area. An ice sheet moved westwards from the Scottish Highlands to the Hebridean region, leaving boulders and scratch marks. In the mountain areas ice caps developed locally and moved down the mountains, scouring the rocks and carving out corries. Eventually when the ice melted and retreated, it left behind vast boulders and stone blocks. On Skye the great majority of boulders and stone consist of basalt, with a lesser number of boulders of granite and gabbro. The material carried at the margins of the ice was mostly sand and gravel and a less compacted deposit known as moraine was deposited.

After the Ice Age, the sea level had many fluctuations resulting in the development of raised beach deposits at different levels, forming the 7m, 14m and 35m raised beaches seen around the coastline (Boyd, 1983). In north Skye, where Tertiary lavas lie on older Mesozoic rocks, landslipping is common. The spectacular scenery of the Quirang on the Trotternish peninsula is formed by a landslip extending 31km from Beinn a'Chearcaill in the south to Meall na Suiramach in the north. The start of this slipping was probably associated with faulting in Tertiary times, but evidence was removed during the glaciation (Anderson and Dunham, 1966). After the glaciation the slipping continued and it still continues at the present day.

Thus the island's complex geology has had a profound effect on the landforms and coastal geomorphology. The Tertiary igneous centres are mountains with sharp high ridges or rounded hills and the Tertiary lava fields in north west Skye have a terraced appearance. In contrast, Lewisian and Torridonian rocks give rise to gently undulating scenery of low hills and uneven low cliffs.

Coastal exposure varies around the Skye coastline. The eastern side to the north of Portree (the Trotternish peninsula) is continually being eroded causing the landslip there to be unstable. However, the eastern coast of Skye to the south of Portree is more protected by the neighbouring islands, and wave action is limited. The same is true for the Torridonian and Lewisian coastlines along Loch Alsh, Kylerhea and the Sound of Sleat where there is little severe wave action.

Table 2.1 Geological Time Scale. The seven zones used for the thesis are shown in the column marked coastal zones. Ages for the geological periods are shown in millions of years and represent when the corresponding geological period begins. Data based on Eager and Dunning (1992).

YEARS (Millions of years)	**PERIOD**	**EPOCH**	**COASTAL ZONES** (Zone numbers)
1.64	Quaternary	CAINOZOIC	7. Landslip
			6. Tertiary Intrusives
65	Tertiary		5. Tertiary Lavas
146	Cretaceous	MESOZOIC	4. Mesozoic
205	Jurassic		
251	Triassic		
290	Permian	UPPER PALAEOZOIC	
353	Carboniferous		
395	Devonian		
439	Silurian	LOWER PALAEOZOIC	
510	Ordovician		
550	Cambrian		3. Cambrian
		PRE-CAMBRIAN	2. Torridonian
4,000			1. Lewisian/Moine

Figure 2.1. Geological map of the Isle of Skye, showing the seven geological coastal zones.

METHODOLOGY

For the purposes of my research the Skye coastline was divided into 1139 sections of 500m in length measured at the high water mark. Personal experience had shown that such sections are easily manageable for field work and are long enough to observe otter activity from a set vantage point without losing a part of the section around a corner or blocked off by a hill. For each section a data sheet was printed (Appendix 1). The data sheet was designed to be used in the field and was tested on volunteers. After the trial small changes were made before its use in the study. The island was divided into seven zones based on the geology maps produced by the British Geological Survey 1:50,000 series -BGS Sheets, 71W (1976), 80E and Part 81 (1975), 80W (1975), 90 and Part 91 (1975), 61 (1971), 70 (1964), 71E (1976). The research was undertaken in two parts an intensive study undertaken over 3 years by myself and an extensive study from August to October 1994 by trained Earthwatch volunteers. A total of 622 coastal sections were examined, accounting for 55% of the total Skye coastline, and these were chosen to be representative of the seven geological coastal zones.

The training consisted of a two hour lecture on the various parameters on the data sheet and a day of demonstration in the field. The errors associated with using volunteers are discussed later.

Those volunteers who displayed a greater competence during the training were made group leaders and put in charge of a team of three other people. These four people made up one group and each group was given 8km of coastline to survey in a day; the amount done in a day varied in relation to the difficulty of the terrain. For each 500m section they had to spend a minimum of 30 minutes observing for otter's in this coastal zone. If an otter was seen information on what it was doing was recorded. It was standard practice that two of the group would scan the coastline while the other two would complete the data sheet for all other variables. To test the accuracy of each group a test section of 4km of coastline was used and each group had to spend one day on this; if the team could not accurately define the intertidal make up, the inland vegetation, width of tidal zone, slope of shoreline and boulder size all within 80% of my findings, their data was not used in the survey.

In this chapter six factors are examined, namely:

a) Geology
b) Width of tidal zone
c) Height of point 25m from High Water Mark
d) Coastal type
e) Inland vegetation
f) Climate

Geology

A geological map of the seven geological coastal zones is shown in Figure 2.1 and individual outcrop maps are shown in the descriptions of each geological coastal zone. The seven geological coastal zones are also shown in Table 2.2.

***Table 2.2 The seven geological coastal zones used for the survey. The sections surveyed by the volunteers are shown with the total sections in each geological group for all the coastline shown on the right*.**

ZONE	SECTIONS SURVEYED	TOTAL SECTIONS
1. Lewisian/Moine	71	91
2. Torridonian	84	131
3. Cambrian	17	17
4. Mesozoic	99	119
5. Tertiary Lavas	206	538
6. Tertiary Intrusives	104	113
7. Landslip	41	130
TOTAL	622	1139

Width of Tidal Zone

The width of the tidal zone was measured using the maximum width over the 500m section. It was measured using the Ordnance Survey 1:25,000 map. Since the maximum width is used in all sections it will give a standard benchmark for the width of the intertidal zone.

For the purpose of analysis the results were recorded on a scale from 1-5 according to width:

1 = <20m
2 = 20-60m
3 = 60-100m
4 = 100-200m
5 = >200m

Height of point 25m from High Water Mark

The height of the point 25m from the High Water Mark was used as an indicator of the general slope of the shoreline and measured from the 1:25,000 map. The reading was taken from the centre of the 500m section at the relevant contour line nearest this 25m mark.

For statistical analysis heights were recorded on a scale from 1-5:

1 = <5m
2 = 5-10m

3 = 10-50m
4 = 50-100m
5 = >100m

Intertidal Make up

The intertidal coastal zone was divided into six shore types shown below. Excluding the rock outcrop all are related to grain size as shown in Table 2.3. Examples of different shoretypes are shown in Plate 2.1. The shore type was estimated with the eye and by looking at samples on the shore. The shore type chosen for the 500m section was that which occupied the largest part of it (usually >50%). The maximum diameter of the boulder was measured using a pocket tape measure.

Table 2.3 Grain sizes of different intertidal coastlines used in the study. These are standard definitions based on Gore (1997), Read(1972), and Blatt et al (1972).

CATEGORY	GRAIN SIZE (Minimum)	GRAIN SIZE (Maximum)
Muddy	None	0.0625 mm
Sandy	0.0625 mm	2mm
Shingle	2 mm	64mm
Boulder <20cm	64mm	200mm
Boulder >20cm	200mm	None

Muddy:
I used the definition of mud given by Gore (1997), which describes it as a mix of silt and clay and defines "mud" as a substrate containing 15% sand, 45% silt and 40% clay. Clay particles are defined as any particle less than 0.0625mm in diameter.

Muddy shores require sheltered conditions to form, and in places vegetation is dominated by the red algae *Phyllophora crispa*, and in the sublittoral zone by *Laminaria saccharina* and *Chorda filum.*

Sandy:
Sand grains are by definition between 0.0625mm and 2mm in diameter (Read, 1972). The definition of sand usually means quartz sand, but other sands are present on Skye following the breakdown of basalt lavas. Feldspars, olivine, pyroxene, mica and shell fragments can also be mixed with quartz to form a sand.

Sandy coasts have poor vegetation communities and are too mobile to support algae. Isolated patches of *Laminaria saccharina* were present with beds of *Zostera marina* in the littoral zone.

Shingle:
Pebble, gravel or shingle deposits range in grain size from 2-64 mm (Blatt et al, 1972). Shingle

is a mixture of material accumulated on beaches or offshore bars. The shingle shores make up one of the poorest maritime habitats. Thick beds of *Phymatolithon calcareum* and *Lithothamnium corallioides* occurred on some shores and in places *Laminaria saccharina* was present in the sublittoral zone.

Boulder:

Boulder shorelines were classified as those with individual particle sizes ranging from 64 mm upwards and consisted of eroded country rocks and glacial material.

They were divided into two size groups as follows:

i. > 20 cm
ii. < 20 cm

The littoral region was dominated by *Ascophyllum nodosum* and *Fucus serratus* on the sheltered coasts and *Fucus vesiculosus* on the more exposed areas. In the sublittoral zone the encrusting algae *Lithothamnium corallioides* became common.

Rock Outcrop:

When the dominant coastal type was bare rock, this category was used to define the intertidal zone. Rock outcrop could be steep eroded country rocks, as with the gabbro intrusion of the Cuillin, or gently-sloping wave-cut platform as shown by many of the Mesozoic sedimentary rocks.

The communities on the rocky coastlines consisted of *Ascophyllum nodosum* and *Fucus serratus* in the littoral region with the sublittoral region dominated by *Laminaria saccharina* and *Laminaria digitata* on more sheltered coasts replaced by *Laminaria hyperborea* and *Fucus vesiculosus* on exposed coasts.

One of the above categories was allocated for each 500m coastal section. When more than one category was present in the zone, the dominant category in that 500m coastal zone was allocated. The "boulder" category was further divided into boulders greater or less than 20cm. A random sample of boulders were measured and again the dominant boulder size was recorded.

Inland Vegetation

Inland vegetation was recorded 20m from High Water Mark and the categories used are shown below. Examples are shown in Plate 2.1.

Heather:

The heather moors are dominated by Ling (*Calluna vulgaris*) although this is not the only heather species present: Bell Heather (*Erica cinerea*) and Cross-Leaved Heath (*Erica tetralix*) occur frequently with Ling. Heather grows on well drained soils, but hollows occur with grasses, sedges and rushes in these waterlogged areas.

Scrub:
Scrub habitat consisted of a mixture of plants including Willow (*Salix sp*), stunted Birch (*Betula pendula*), Bramble (*Rubus sp*) and Bracken (*Pteridium aquilinum*).

Grassland:
These are areas that are extensively grazed by sheep and cattle. The pastures have been modified by cultivation and draining and the grasslands have communities of tall herbs associated with the production of hay.

Native Wood:
Native woods are scarce on Skye (Ball, 1983), and are restricted to gorges and small coastal areas out of the reach of grazing animals and fire. The woods are dominated by Birch (*Betula pubescens*), and Hazel (*Corylus avellana),* with some Rowan (*Sorbus aucuparia*), Holly (*Ilex aquifolium*) and Oak (*Quercus petraea*). Many of the Skye woodlands have a remarkable bryophyte and fern flora which is of international importance.

Plantation:
Plantations of conifer species to produce timber are found around the coastline. The commonest species are Sitka Spruce (*Picea sitchensis*), Norway Spruce (*Picea abies*) and Pine species (*Pinus sp*).

Plate 2.1. Intertidal make up and vegetation.
Birch scrub woodland on a Torridonian coastal zone
Mother and cub on a Mesozoic rocky coastline

Climatic methods

Climatic data for 1990 to 1994 were obtained from the Meteorological Office in London in order to cover the main period of field work from 1991 to 1994. Since freshwater pools are important for Eurasian otters utilising the marine environment (Kruuk and Balharry, 1990) I wanted to compare the rainfall and evaporation data to look at water replenishment of these pools.

Since 1986 there has been no full meteorological recording station on Skye, and the nearest full station was at Plockton, 15km from Kyle of Lochalsh, the main entry point for the island. Rainfall data were obtained from a 3-hour rain monitoring station at Cnocan, Knock, Isle of Skye.

Evaporation data, which are calculated using computer modelling from rainfall, temperature and humidity were purchased from the Meteorological Office. The data are computed for the

Sleat peninsula, at Knock, National Grid Reference (NG 671:091). Variations in rainfall and temperature between localities on Skye were obtained from Scottish Environmental Statistics (Central Statistics Unit, 1996).

Analysis of Data

Most of the statistical analysis was done with SPSS for Windows Version 6.1. This is a statistical and graphics package designed for personal computers.

The Chi-squared Test

The Chi-squared test for association was used to test the association between the different physical make up of the coastline and its associated geology. Contingency tables were set up for each variable and the null hypothesis (Ho) was that there was no association between the geological coastal zones and the environmental variables.

Spearman Rank Correlation Coefficients were used to describe the relationships between the Torridonian and all other geological coastal zones.

GEOLOGICAL DESCRIPTIONS

ZONE 1: LEWISIAN/MOINE

The oldest rocks on Skye are the Lewisian gneiss which are also some of the oldest rocks in Europe, at about 2,800 million years old. These formed from a variety of other rocks which have undergone intense metamorphism. Some 1,100 million years ago these Lewisian rocks were raised to the Earth's surface since when they have been worn away by the action of wind and water to form the present day topography.

These rocks are exposed in the Sleat peninsula, and outcrop on the coast from Duisdale in the north to Armadale pier in the south. They account for some 8.6% of the Skye coastline.

Lewisian rocks are hard-wearing and give rise to a distinct scenery of undulating plateaux with small hills and lochans, and acidic soils. The Lewisian has little drainage and there are many hollows either filled with water or generally boggy with large accumulations of peat. Most of the land is between 90m and 240m in altitude with relief values of 15-90m (Baird, 1993; Price, 1976).

The Moine schist outcrops on the west side of the Sleat peninsula, in a band from Armadale pier to Tarskavaig Bay. These rocks are thought to be in part equivalent in age to the Torridonian (Benison and Wright, 1975) and are generally very uniform over great vertical thicknesses. This suggests that the sediments were deposited in shallow water of a slowly subsiding basin and were later metamorphosed. They consist largely of schists and granulites and obtain a maximum thickness of some 6,000m. The Moine schists form moderately high, heather-covered hills with a predominance of terraced slopes, giving rise to steep clifflines.

The effects of the Quaternary Ice Age on the Lewisian and Moine rocks have been well described by Peacock (1983). The resulting landscape comprises smooth eastern-facing slopes and rougher western-facing crags, and generally boggy land with accumulations of peat. Only in local coastal areas on the raised beach deposits is the land suitable for agriculture. Photographs of Lewisian/Moine coastal scenery are shown in Plate 2.2.

Plate 2.2. Lewisian/Moine coastal scenery
Knock Bay- Lewisian gneiss
Tarscavaig Bay - Moine schists

ZONE 2: TORRIDONIAN

The contrast between the Lewisian, Moine and the Torridonian sandstone is quite remarkable. Torridonian rocks form one of the largest as well as one of the most ancient masses of sedimentary rocks in the British Isles, and in essence they consist of a series of arkosic sandstones, shales and conglomerates reaching up to 7000m in thickness.

They outcrop on the Sleat peninsula forming the backbone of the peninsula and rise to form the mountains of Sgurr na Coinnich and Beinn na Caillich, although the hills become lower towards the south west. In coastal outcrops they occur from Lusa to Loch na Dal and around Loch Eishort. A small outcrop also occurs in Loch Scavaig.

The following groupings have been recognised by Peach et al (1910).

	Thickness (m)
Applecross Group	+1500
Diabaig Group	
Kinloch Formation	1100
Beinn na Seamraig Formation	750
Loch na Dal Formation	800
Epidote Grit Formation	100

The Epidote Grits consist of eroded Lewisian basement rocks and these pass up into a sequence of sandy and gritty shales and sandstones. In places they have been altered and consist of pebbles and clastic grains with traces of chlorite. They were deposited in an intertidal environment and are overlain by various thicknesses of sandy shales and coarse sandstones which have been subdivided into three further formations according to lithology.

Most of the Torridonian on Skye is arkosic, which means that the rocks contain noticeable amounts of feldspar grains - here it is nearly as abundant as the quartz.

Generally the Torridonian is cemented by a microcrystalline mixture of silica and chlorite. These arkoses are particularly interesting in that there is an apparent lack of weathering of the feldspar crystals; feldspar decays very quickly on exposure and these rocks must therefore have been deposited rapidly so that diagenetic alteration was kept to a minimum. The high silica composition of the Torridonian and the way this rock erodes has resulted in low porosity, which is important in the creation of freshwater pools for use by otters.

Photographs of Torridonian landscape are shown in Plate 2.3.
Plate 2.3. Torridonian coastal scenery
Ob-Allt an Daraich, near Kyleakin
Drumfearn, Sleat peninsula

ZONE 3: CAMBRIAN

Rocks of Cambrian age crop out in two main areas: firstly, around Ord on the Sleat peninsula and, secondly, in a broad tract running south from Broadford towards Torrin. They are seen on the coast around Ord on the Sleat peninsula and the north eastern side of Loch Slapin.

The division of the Cambrian rocks are shown in Bell and Harris (1986) based on Peach et al (1910) as follows:

	Thickness (m)
Durness Limestone	265
Fucoid Shale/Salterella Grit	32
Quartzite	180

The history of the Cambrian is one of a marine transgression in which the sea level encroached onto the Lewisian/Moine/Torridonian landscape. The basal beach deposits are represented by quartzites and as the sea became deeper limestones were laid down. In lithology the basal quartzites are pure white or pale pink and above these lie the Fucoid Shales which weather to a rusty brown colour and contain bands of calcareous siltstones. These are in turn overlain by limestones.

The bulk of the Cambrian rocks consists of the Durness Limestones which are a varied series of carbonates named after their type location at Durness. In essence all these limestones have been dolomitised to some degree and have been subjected to tectonic deformation.

Dolomitisation is the process whereby the original calcium carbonate rock has been changed into a calcium magnesium carbonate rock, and this can take place any time after the deposition of the original material. The replacement of calcite by dolomite involves a contraction of between 12-13% on a molecule to molecule basis and this has extensive effects on the porosity; it can mean an increase in porosity of 10% and water is easily absorbed through the rock.

Carbonate rocks are very soluble in weak acid and they can be dissolved by rainwater which finds fissures and makes underground water courses; this results in generally smooth, well-drained areas.

Near some of the Tertiary granite intrusions the limestones have been contact metamorphosed to form brucite-forsterite rich marbles.

Photographs of Cambrian coastal scenery are shown in Plate 2.4.
Plate 2.4. Cambrian Coastal Scenery
Torrin beach, Strathaird peninsula
Sgianadin

ZONE 4: MESOZOIC

The Mesozoic rocks on Skye are sedimentary and are extremely fossiliferous. They have only been slightly deformed and contribute considerably to the present scenery. They outcrop chiefly along the eastern and southern coastlines of the island, from Camas na Sgianadin to Lusa, Camas Malag to Boreraig and around Loch Slapin to Loch Scavaig.

The Mesozoic Era is divided into the following periods, although on Skye Jurassic rocks form by far the greater part:

Cretaceous
Jurassic
Triassic

Rocks of Triassic age are sparse in outcrop and occur chiefly in two thin beds from Broadford to Heaste and Broadford to Glen Boreraig. They consist of conglomerates and red and green sandstones. The Cretaceous rocks are also sparse in outcrop being only about 4.5m in thickness, and outcropping inland around the Strathaird peninsula. Both the Triassic and Cretaceous rocks are present in small outcrops but are not present in any significant lengths along the coastal zone. They will therefore not be considered further here.

The Jurassic rocks form a 1000m sequence of lithologically varied sediments that are very fossiliferous. In general, silty shales, sandstones and limestones predominate in the sequence and they are divided as follows:

Lower Jurassic

The Lower Jurassic rocks were deposited in shallow seas and consist of limestones and calcareous sandstones succeeded by sandy shales - these are the Lower Lias and they are followed by sandstones of the Middle Lias and shales of the Upper Lias. Within this sequence there are certain beds that are very fossiliferous with ammonites, corals and oysters.

The Lower Jurassic rocks outcrop mainly in the Strath area of Skye around Broadford.

Middle Jurassic

The Middle Jurassic started in marine conditions with a series of limestones, sandstones and shales with abundant ammonite and belemnite fossils. These Inferior Oolite rocks were followed by the Great Estuarine Series which were deposited mainly in lagoons rather than in actual estuaries. They consist of a series of sandstones and shales with abundant fossils such as bivalves, ostracods, fish and reptile remains.

Middle Jurassic rocks outcrop in the areas around Strollamus, Strathaird and Loch Sligachan, and from Camustianavaig northwards to Upper Tote. In north west Skye they reach a thickness of 115m and contribute largely to the rugged cliff scenery. The sandstones are dominantly cemented by calcium carbonate and weather to form fascinating features, an example of which is the honeycombing seen on the cliffs at Elgol.

Upper Jurassic

Upper Jurassic sediments rest on the Middle Jurassic with no apparent break and they comprise a series of fossiliferous sandstones, shales and limestones, giving a total thickness of 180m.

The Jurassic rocks of the eastern cliffs of Trotternish are capped for most of their length by a dolerite sill. However, another type of Jurassic scenery occurs in the Strathaird peninsula, where Tertiary dykes are numerous and the sandstones are locally metamorphosed and hardened. This has resulted in a deeply dissected coastline with steep gullies and caves where the dykes have been eroded.

The shallow dip of the Jurassics and high calcium and silica content is of local importance as it gives rise to fertile soils and rich vegetation along the coastal zone. The Jurassic rocks are well exposed in cliff and shore sections and form excellent gently dipping wave cut platforms which provide a wide feeding area for otters at high tide.

Photographs of Mesozoic coastal landscape are shown in Plate 2.5.
Plate 2.5. Mesozoic Coastal Scenery
Broadford Bay
Dunan shoreline

TERTIARY PERIOD

The Tertiary period started about 65 million years ago and it is thought to be associated with the opening of the Atlantic Ocean. This thinning of the earth's crust created major structural breaks that both encouraged and permitted the emplacement of large volumes of molten magma. The nature of the rock types produced varies widely according to the chemistry of the magma and the level at which it cooled and solidified. In northern and western Skye the landscape is dominated by a stepped landscape created by lava flows form these volcanoes. The flows are horizontal or gently sloping and form flat topped hills with steep sides, and these are discussed in more detail below:

ZONE 5: TERTIARY LAVAS

This zone extends over most of north west Skye from Rubh an Dunain to Uig and consists dominantly of basalt lavas. The outburst of igneous activity occurred some 65 million years ago and resulted in the eruption of extensive plateau basalts. Individual flows can be as much as 10-15m in thickness, and at the top and bottom they are usually broken and slaggy. Anderson and Dunham (1966) estimated the total thickness before erosion during late Tertiary times of some 1200m. Most of these flows were erupted rapidly with little explosive activity, pouring out of long cracks in the Earth's crust running north west to south east. Volcanic ash, which would indicate explosive activity, is rare on Skye except at the very base of the lava pile and this would indicate a more explosive initiation of the Skye volcanic activity.

There is a marked tendency for basalt to cool to form six-sided columns at right angles to the cooling surface and this is well illustrated in north west Skye. As a result of these vertical joints the edges of the lava plateaux stand out as cliffs, as can be seen in much of the coastal scenery in the north west of the island. Almost all of the scenery in north and north west Skye is dominated by "trap" or stepped landscape.

The lavas of north Skye dip at a shallow angle to the west and can be divided into five groups (Bell and Harris, 1986) However, for the purposes of this study the basalt groups will be considered together as their overall effect on the landscape is similar. All the lavas were erupted sub-aerially and have weathered tops, giving rise to flat topped hills with terraced slopes. Many examples of these features can be seen in north west Skye, and are shown in photographs in Plate 2.6.

Plate 2.6. Photographs of Tertiary Lava coastlines
Caroy, north west Skye
Eabost, north west Skye

ZONE 6: TERTIARY INTRUSIONS

Towards the later part of the extrusion of the basalt lavas, the basic Cuillin centre was intruded, and the date of this is believed to be about 59 million years.

The scenic mountains of the Isle of Skye were eroded out of these plutonic intrusions, which represent the deeply eroded roots of the ancient volcanoes.

They comprise two main component parts: the jagged Cuillin ridge with its serrated peaks, many of which reach nearly 1000m, is made of the basic rock gabbro; to the east lie a group of smoothly contoured mountains, the Red Hills, which are composed of granophyre and granite.

Four intrusive centres have been recognised within the Cuillin complex, which are dominantly basic to ultrabasic in composition. Geographically the gabbro complex has two very distinct parts: the most spectacular is the main Cuillin ridge running from Sgurr nan Gillean to Gars-Bheinn and the other part consists of the Blaven ridge. This is well seen from Torrin and is essentially an offshoot from the main ridge.

In coastal outcrop major intrusive rocks can be seen from Loch Sligachan around Loch Ainort and at the northern end of Loch Scavaig. The rock types of the complex were examined in detail by Harker (1904), Bell and Harris (1986) and Hutchinson and Bevan (1977) and it was concluded that they formed in response to several injections of magma. The layering in the complex was formed due to gravity separation and crystal settling (Carr, 1952, 1954).

A stratigraphical column can be made up as shown below (Wadsworth, 1982):

	Thickness (m)
j) Inner Layered Gabbro Series	750
i) Inner Layered Eucrite Series	450
h) Inner Layered Allivalite Series	500
g) Druim nan Ramh Eucrite	?
f) Outer Layered Gabbro Series	?
e) Outer Layered Eucrite Series	1600
d) Outer Layered Allivalite Series	1800
c) Layered Peridotite Series	500
b) Border Group	?
a) Outer Marginal Gabbros & Eucrites	?

However, as only groups (a) and (e) outcrop along the coastal zone, only they will be considered here:

a. The Outer Marginal Gabbros and Eucrites

These rocks are thought to form the earliest part of the Cuillin complex and are in part in contact with the basalt lavas. The gabbro is typically coarse-grained and is composed of plagioclase feldspar, augite and olivine. Eucrite contains no olivine and outcrops along the Loch Scavaig area with steeply dipping contacts.

e. Outer Layered Eucrite Series

This series is exposed in a large section of the complex, essentially around the Bad Step-Loch Coruisk area. The outer boundary of this series dips inwards at 70^{o} with layering more prominent towards the top of this series. Carr (1952) makes mention of the presence of xenoliths of dunite and peridotite. The presence of these points to erosion of the main intrusion before the intrusion of this part of the series.

As the gabbro magma rose it had enough heat to completely melt the Torridonian country rocks, which were essentially sandstones and shales with a composition of quartz, feldspar and mica. This is typically the composition of a granite and this granitic magma rose to produce the Red Hills. The granitic mass forming the Red Hills is the result of a number of injections of magma and it occurred over many millions of years. The granites can be divided into a western centre and an eastern centre and these great granite masses have been smoothed by ice action.

The Western Red Hills Centre

Richey (1932) defined this as a separate centre of activity which covers an area of 35km dominated by intrusions of granite, granophyre and felsite. The granitic mass forming the Western Red Hills has been described as a laccolith intrusion, a dome-like mass of igneous rock which arches the overlying sediment and has a flat base to the intrusion. Although, some of the roof of the intrusion is seen in places no floor is exposed.

The Eastern Red Hills Centre

The granites in this centre are concentrated around Beinn na Caillich near Broadford. This is a boss-type intrusion, having a circular plan and steep sides to the south and west. To the north the regularity of this outcrop is broken by a faulted mass of mainly basalt lavas. The Beinn an Dubhaich granite is intruded into the centre of a curving anticline of Cambrian limestone and dolomite and its contacts are quite intricate (Tuttle and Keith, 1954). The granite has in parts metamorphosed this limestone to produce marble.

Minor Intrusions

Cracks in the Skye countryside which fed the volcanic eruptions continued to act as pathways for molten magma long after the surface volcanic activity had ceased (Stephenson and Merritt, 1996). Magma hardened in these cracks as vertical sheets of rock called dykes and many examples are seen around the coastline where they cut through the country rocks; often they stand proud after erosion, looking like man-made walls, although in places they can be eroded to form gullies.

In places the magma forced its way between individual beds of rock to form sills. These can be as much as 90m thick displaying well-developed columns, as at Kilt Rock. Other outcrops occur at Rubh an Hunish and around the Staffin area.

The dykes and sills are well developed around the coastal zone and when they cut through the Jurassic sediments they weather at a slower rate giving rise to unusual coastal features. They can produce a series of wall structures and when the tide retreats water can be trapped in ponds which are used for foraging by otters.

The intrusive rocks weather relatively slowly producing bare rock topography, with steeply sloping shorelines as shown in the photographs in Plate 2.7.

Plate 2.7. Tertiary Intrusive Coastal Scenery
Loch Ainort - Granite coastal exposure
Rubha Ban, Strathaird Peninsula - Gabbro coastal exposure

ZONE 7: LANDSLIP

The landslips of northern Skye have not only given rise to a unique landscape but are slips unrivalled in Britain. This is an area of destabilisation formed by the break-up of weaker

Jurassic rocks underlying the basalt lavas, and this has caused massive landslips, tearing and twisting the rocks into strange shapes. Details of the mechanisms of the slip are given by Anderson and Dunham (1966) and Bell and Harris (1986).

These rotational slips are most spectacularly developed on the Trotternish peninsula, but smaller slips are evident south of Portree, at Inveralivaig to Camastianavaig, and also in the north west of the island at Dunvegan Head, Gillen and Neist Point.

The term 'landslip' has been used by many people to mean many things and so it is necessary to give a definition for use here. Anderson and Dunham (1966) gave the following definition for the landslip on Skye and only those movements which exhibit the following characteristics are regarded as being in the landslip zone for the purposes of this study:

a) In vertical section the glide plan is a curved surface on which the overlying material moves downwards and outwards. A rotational element in this movement is an essential feature.

b) In horizontal section the glide plane is a curved surface so that the inner margin of the slipped mass is always a curve.

A diagrammatic representation of the Storr Landslip is shown in Figure 2.2 (Yoxon and Yoxon, 1987)

Other associated phenomena with this area include: rock falls, in which fragments of rock have broken away and fallen in a haphazard arrangement to a lower level; rock slides, in which masses of rock have slid along an inclined bedding plane; and creep, in which consolidated material moves by gravitational pull.

Figure 2.2. The Storr Landslip

<u>Landslip History on Skye</u>

In late Tertiary times the lava plateau was tilted slightly towards the west and extensively broken by faulting. This resulted in an unstable situation, with a cliff reaching the height of over 600m in places (Bell and Harris, 1986).

The lower part of this cliff is made up of Jurassic sedimentary rocks cut by a major dolerite sill, on top of which is a massive pile of Tertiary basalt lavas. This arrangement became unstable and the sediments moved under the weight of the lava overburden.

On Skye the following landslips are recognised:

<u>The Storr Landslip</u>
This stretches from the Storr (719m) across a glaciated trough to the coast stretching some 1.5

km. This slip is now mature with an angle of rest of 15^o. The coastal section consists of a wave-cut platform and rock debris backed by a 100m cliff.

The Quiraing Landslip

This is the largest landslip in the British Isles extending some 2.1 km, from Meall nan Suiramach to the coast at Staffin Bay, with its angle of rest being 15^o. Between the Storr and Quiraing the slip is semi-stable and mature, but further north around Flodigarry the toe of the landslip is continually being eroded and there are spasmodic small movements.

Ben Tianavaig Landslip

This is located on the south side of Portree Bay and is both an immature and unstable landslip with a slope of some 21^o, where landslipping occurs on a continual basis. Here there are some 300m of sediments separated by a thick dolerite sill from the base of the lavas.

Other Slips

There are other smaller slips in northern Skye: the north side of Loch Losait in Vaternish and on the west side of Dunvegan Head, are typical but no sediments are exposed. The slip at Moonen Bay does have fragments of Jurassic sediments covered by debris and scree.

Present day geomorphology of this zone consists of an immature landscape with waterfalls coming off the back cliff, which averages 100m in height.

The coastal scenery is shown in the photographs in Plate 2.8.

Plate 2.8. Landslip coastal scenery
Bearreraig Bay
Rubha Sughar

THE LAST GLACIATION (26,000 to 13,000 years ago)

Evidence from striations and glacial erratics points to Skye being influenced by three ice sheets (Anderson and Dunham, 1966, Stephenson and Merritt, 1996): as well as the main Scottish ice caps and the ones from Scandinavia, the island developed its own ice sheets. Some of the most exciting scenery is the result of the final short glaciation some 13,000 years ago: terminal moraines at the mouth of Coir 'a' Ghrunnda and other corries, needle-sharp aretes like Sgurr nan Gillean and roches moutonnees. Glaciers reached the sea at lochs Scavaig, Slapin, Sligachan and Ainort and as they retreated they left hummocky moraines.

RESULTS

Width of Tidal Zone

Widths of tidal zones in relation to the geological coastal zones are shown in the bar charts in Figure 2.3.

A Chi-squared test showed significant differences in the tidal width between the different geological coastal zones (χ^2=79.4, df=24, p<0.001). Widths lying between 20-60m occurred more frequently in the Tertiary Lavas, Intrusives and the Landslip zones and widths 100-200m occurred more frequently in the Cambrian zone. Tidal widths greater than 200m are absent from the Cambrian and Landslip zones and are found in greater numbers (18%) on the Lewisian/Moine coastline.

Figure 2.3 Relationship between the width of the tidal zone and the geology

Height of Land 25m from High Water Mark (Height Marker)

The slope of the shoreline may be an important factor in the utilisation of the coastal zone by otters. Kruuk et al (1984) point out that 64% of dives are in water less than 3m deep and generally otters forage little in water over 5m in depth. A shallow sloping shore will therefore give more area to feed per coastal length than a steeply sloping shore.

Height markers in relation to the geology zones are shown in Figure 2.4. There were significant differences between the height marker and the different geological coastal zones (χ^2=157, df=24, p<0.001). Both the Torridonian and Cambrian coastal zones had no height markers over 50m. The dominant height markers for the Torridonian coastal zone lay between 5-10m (37%). The Tertiary Intrusives had 43% of the height markers between 50-100m and 8% over 100m. This is due to the steep-sided nature of the intrusions, which dip steeply in the coastal zone. Using the height marker, an estimate of the coastal slopes could be made using:

$$\text{Tan } \alpha = \frac{Height\ 25m\ from\ High\ Water\ Mark}{25}$$

The Torridonian coastlines had no slopes over 63^0 and had 37% of the coastal slopes between 11^0 and 21^0. The Tertiary Intrusives and Landslip had the dominant amount of coastal slopes in the range 21^0 to 63^0 and the Tertiary Intrusives had 43% of coastal slopes ranging from 63^0 to 76^0 with 8% over 76^0.

Spearman Rank Correlation Coefficients were calculated between the height marker and the tidal width and shows a negative correlation between the width of the intertidal zone and the height 25m from High Water Mark (r_s=-0.42, df=621, z=10.5, p=0). If the height or slope of the shoreline increases the tidal width decreases.

Figure 2.4. Relationship between the height 25m from High Water Mark (height marker) and the geology

Intertidal make up

The physical make up of the intertidal zone may be important for the utilisation of these areas by otters and in turn may be related to geology. Figure 2.5 shows the relationship between geological coastal zones and the intertidal make up.

An association was found between geology and intertidal make up (χ^2=54.6, df=24, p<=0.01). Boulder coastlines dominate the intertidal zone in all geological zones and the dominant boulder size is greater than 20cm. When examining individual geological zones, the Lewisian/Moine zone has a dominance of rock outcrop (48%) and an absence of sandy shoreline. The Torridonian zone has a dominance of boulder (49%) and rock outcrop (36%). The Cambrian and Tertiary Intrusive zones lack muddy and sandy shorelines and have a dominance of boulder and rock outcrop.

A comparison of the Torridonian and Tertiary Lava coastal zones shows that the Torridonian is dominated by boulder (49%) with the greater majority of the boulders greater than 20cm (69%), whereas the Tertiary Lava coastlines are dominated by rock outcrop (53%), with boulder shorelines accounting for 35%.

Figure 2.5. Relationship between intertidal make up and the geological coastal zones

Inland Vegetation

Inland vegetation in relation to geology is shown in Figure 2.6. A Chi-squared test showed significant differences between the inland vegetation and the geology of the coastal zone (χ^2=122.8, df=24, p<0.001). This would be expected as geology does affect soil type and, ultimately, vegetation. The inland vegetation had an abundance of grassland but the amount varied considerably in the coastal zones with 78% of coastal sections in the Tertiary Intrusive zone, 63% for the Tertiary Lavas and only 33% of the coastlines in the Torridonian. Native woodland occurred most frequently (33%) in the Cambrian coastal sections and the Torridonian coastlines (23%).

Given the correlation between bankside vegetation and otter activity in rivers, I looked at the amount of cover available to the otter adjacent to the High Water Mark by combining the scrub, native wood and plantation. The results are shown in Table 2.4.

The Tertiary Lava and Intrusive zones show poor amounts of cover above the High Water Mark, while the Cambrian, Torridonian, Lewisian and Landslip all have cover of 50% and over. The Torridonian coastal zone had 59% cover, the highest of all the geological coastal zones.

Table 2.4. Percentage cover adjacent to the High Water Mark (Percentage cover is found by combining scrub, native wood and plantation)

Geological Zone	Percentage Cover
Lewisian/Moine	45%
Cambrian	50%
Torridonian	59%
Mesozoic	27%
Tertiary Lavas	19%
Tertiary Intrusive	16%

Landslip	44%

Figure 2.6. Relationship between the inland vegetation and the geology

CLIMATE

Rainfall

The island has a wet and windy oceanic climate. Mean annual rainfall for the period was 1636mm (±135), although there was considerable variation between the years and the months (Figure 2.7). The differences in rainfall between the months was examined from 1990-1994 and are shown in Figure 2.8. There was considerable variation as would be expected. On average the driest months are May, June, July and August.

Rainfall also varied between different localities on Skye and these are shown in Figure 2.9. The northern part of the island had considerably less rain than the central mountain areas, and in the winter months there was as much as 150mm difference. In the coastal zone the variation in rainfall in July was not very apparent and occurred mostly in the coastal zone around Broadford. The variation in January occurred most strikingly around the Cuillin and Red Hills coastal areas and accounted for a 100mm maximum monthly rainfall variation.

Temperature

Mean daily temperatures between the years are shown in Figure 2.10. 1990 was the warmest year with a mean temperature of 9.3^{o}C and 1993 the coldest year with a mean temperature of 8.7^{o}C. July was the warmest month and January the coldest and monthly variations are shown in Figure 2.11. Temperature variations between different localities on Skye are shown in the map of Figure 2.12 and are only available up to 1994. In January the northern part of the island is up to 1^{o}C warmer than the southern end but this trend is reversed in the summer, with the southern part of the island up to 1^{o}C warmer than the northern part in July.

Figure 2.7. Annual rainfall data (mm) from Sleat peninsula, Isle of Skye from 1990-1994
Figure 2.8. Total rainfall (mean showing SE) for each month from the Sleat peninsula, Isle of Skye from 1990-1994.
Figure 2.9. Average rainfall (mm) for the Isle of Skye from 1951-1994. Maps show rainfall for the summer (July) and winter (January)
January July
Figure 2.10. Annual temperature variation (celsius) from north west Scotland (Plockton) from 1990-1994
Figure 2.11. Daily temperature variation (mean showing SE), for each month from north west Scotland (Plockton) from 1990-1994
Figure 2.12. Mean daily temperatures for the Isle of Skye from 1951-1994. Maps show temperature for summer (July) and winter (January)

Evaporation

Evaporation data for 1992 and 1993 are shown in Tables 2.5 and 2.6 below.

Table 2.5. Rainfall and Evaporation Data (Based on Station Knock, Skye)

Rainfall and Evaporation data for 1992. (Rainfall data obtained from the Meteorological

Office was only available in whole numbers)

MONTH	RAINFALL (mm)	EVAPORATION (mm)	DIFFERENCE (mm)
JANUARY	152	18.5	133.5
FEBRUARY	235	31.5	203.5
MARCH	195	38.6	156.4
APRIL	157	55.6	101.4
MAY	91	108.2	-17.2
JUNE	24	59.4	-35.4
JULY	95	80.0	15.0
AUGUST	205	78.1	126.9
SEPTEMBER	158	50.1	107.9
OCTOBER	142	27.9	114.1
NOVEMBER	236	26.3	209.7
DECEMBER	204	16.5	187.5

Table 2.6. Rainfall and Evaporation Data (Based on Station Knock, Skye)
Rainfall and Evaporation data 1993

MONTH	RAINFALL (mm)	EVAPORATION (mm)	DIFFERENCE (mm)
JANUARY	327	37.2	289.8
FEBRUARY	103	20.5	82.5
MARCH	123	44.3	78.7
APRIL	163	60.2	102.8
MAY	49	88.0	-39.0
JUNE	62	77.9	-15.9
JULY	133	74.6	58.4
AUGUST	58	62.9	-4.9
SEPTEMBER	33	49.3	-16.3
OCTOBER	48	26.8	21.2
NOVEMBER	77	26.9	50.1
DECEMBER	226	16.2	209.8

Spearman Rank Correlation Coefficients for rainfall between the months for 1992 and 1993 showed that there was no correlation (r_s=0.12, df=12, p=0.69). Rainfall varied between the years with 235mm in February 1992 and only 103mm in February 1993; the rainfall in August was 205mm in 1992 but only 58mm in 1993. A strong correlation did exist for the evaporation data (r_s=0.9, df=12, p=0) comparing the months for the different years. During the months of May, June, July and August evaporation exceeded rainfall and in May 1993 this difference was as high as 80% corresponding to only five wet days for that month.

DISCUSSION

Limitations and Assumptions

To provide sufficient data for a comprehensive study of the Skye coastline, volunteer helpers were required, and the results were checked for consistency; volunteer data was rejected if the team did not achieve at least 80% accuracy in a standardised test (Consisting of identifying coastal type, boulder size, inland vegetation etc correctly). This could have resulted in a 20% error in classifying the variables but this error would have been expected to occur on all the seven geological coastal zones and not affected the overall conclusion of the results.

In their work in Shetland, Conroy and Jenkins (1985) found that a single search of a coastal strip does give an accurate index of the variables used in my survey. They also found that different observers of similar initial efficiencies are expected on average to continue to work with similar efficiencies, if given enough break time. Observer efficiency was seen to wane after two hours if a break was not given. My groups were expected to work from 10am to 5pm but had adequate lunch and afternoon breaks therefore fulfilling the above criterion.

General Points

It has been shown that the Isle of Skye has seven distinct geological coastal types, each with a different physical make up, which influences the slope, tidal width, intertidal make up and inland vegetation. Tidal widths between 20-60m dominated all zones except the Cambrian where widths of 100-200m dominated and the Cambrian and Landslip zones had no tidal widths over 200m. All the other zones had widths over 200m with the Lewisian/Moine zone having a greater percentage of these large tidal widths (20%)

The height marker is used as an approximation to the slope of the shoreline, and the angles of the slope could be calculated. The Torridonian and Cambrian had the highest percentage of gently sloping shorelines lying between 11^0 and 21^0, compared with a dominance of slopes lying between 21^0 to 63^0 for the Tertiary Lava zone. The Torridonian and Cambrian zones also had a lack of coasts with slopes over 63^o.

The intertidal make up is also related to geology: the Torridonian, Cambrian, Mesozoic, Intrusive and Landslip have a dominance of boulder coastlines whereas for the Tertiary Lavas rock outcrop dominated the coastal sections. Looking at the boulder size, boulders with a mean size greater than 20cm dominate the Lewisian/Moine (96%), Torridonian (69%), and the Cambrian (86%). For the Mesozoic this figure is 54%, for the Lavas 56%, and for the Tertiary Intrusive 50%.

The inland vegetation had a predominance of grassland in all zones ranging from 75% of coastlines in the Tertiary Lavas to 33% for the Torridonian. The percentage of cover adjacent to the High Water Mark was greater in the Torridonian zone (24% native wood, 23% scrubland), and was lowest on the Tertiary Lava zone (7% native wood, 11% scrubland).

Rainfall and evaporation determine the amount of water available to otters in freshwater pools. The rainfall was very variable when comparing monthly figures between the years; for example, there was a large rainfall in August in 1992 (205mm) and little in 1993 (58mm). Evaporation predominates during the months of May and June and pools have the potential to decrease by as much as 80% in the Sleat peninsula (from the Knock Station data). This has the potential to limit the ability of the otter to wash and drink in freshwater. However, these months have an average maximum temperature of 15.8^{o}C and minimum temperatures of 6.7^{o}C (Meteorological Office data) and therefore any lack of adequate facilities for washing may be counteracted by adequate temperatures to keep the otter warm enough even if the coat was not in perfect condition. During these conditions the otter would have to use small burns to drink.

In conclusion, the geology of the coastal zone had the greatest effect on the slope of the shoreline, the make up of the intertidal zone and the inland vegetation, although the correlation between geology and these parameters does not appear to have been noted in the literature. Kruuk et al (1989) in Shetland divided the coastal zone into groups with a number of parameters including sea cliffs, agriculture, peat and built-up areas, and used these to correlate holt numbers. He found that larger numbers of holts (13.3 holts per 5km coastal section) existed on gently sloping coastlines of approximately 5^{o} slope. The present study shows that dominant heights below 5m (giving rise to a slope of 2^{o}-11^{o}) are found on the Torridonian zone (34%) compared with 22% for the Tertiary Lavas.

In the present study, the dominant coastal type for the Torridonian was boulder coastline with rock outcrop coastline dominating the Tertiary Lava coastal zone. I looked at the amount of cover available to the otter adjacent to the High Water Mark, as in previous studies; Lunnon and Reynolds (1991) found significant correlations in Ireland between bankside vegetation and otter activity, and Mason and Macdonald (1986) also found this correlation on river systems in England. I therefore combined the scrub, native wood and plantation which would all give adequate cover for the otter, and found that the Tertiary Lavas (19%) and Intrusive (16%) show poor amounts of cover above the High Water Mark, while the Cambrian (50%), Torridonian (59%), Lewisian (45%) and Landslip (44%) all have good cover. While no conclusions can be drawn as yet as to what effect the geology and these variables have on otter activity it has been shown clearly that geology does influence the physical make up of the coastal zone and may have a limiting effect on otter utilisation. Before examining this in any detail I want to look at the diet and availability of prey along the Skye coastline to see if this limits the Skye otter population and I will come back to otter utilisation on these coastal zones in Chapter 5.

Chapter 3

The diet of marine-foraging Eurasian otters (*Lutra lutra*) on the Isle of Skye

Synopsis

The diet of marine-foraging Eurasian otters (*Lutra lutra*) was assessed along the Isle of Skye coastline using spraint analysis. Over the four-year study period, a total of 1,480 spraints were analysed, yielding 4,588 individual vertebrae or identifiable remains of 19 prey types. Annual, seasonal and geologically related differences were examined.

Throughout the year the diet was dominated by small benthic fish, with the exception of the free-swimming Saithe. Spraint analyses showed that five key prey species (namely Viviparous Blenny *(Zoarces viviparus)*, Five-Bearded Rockling (*Ciliata mustela)*, Butterfish *(Pholis gunnellus)*, Saithe (*Pollachius virens)* and Sea Scorpion (*Taurulus bubalis*) accounted for over 75% of the diet.

The variation in diet between the years was not statistically significant for the five key prey species ($p<0.001$) although Five-Bearded Rocklings were taken in greater numbers in 1993 compared with the years 1991 and 1992. Seasonal variations were apparent with Viparous Blenny found in higher numbers in the spring and summer, Five-Bearded Rockling occurring in higher numbers in the autumn and winter, Sea Scorpion and Saithe found in higher numbers in the autumn and winter and Flatfish found in higher numbers in the spring and low numbers in the autumn. No significant seasonal difference occurred in Butterfish and Conger Eel ($p>0.05$).

The variation along the seven geological coastal zones was significant for all species except Viviparous Blenny which dominated the diet in all zones. Very highly significant differences occurred between Butterfish, 5-Bearded Rockling, Saithe, Sea Scorpion, Flatfish, Common Eel, Sand Eel and highly statistical significant differences occurred between Shore Crab and Butterfish and the geological coastal zones. However the 5 Key prey species dominated the diet in all zones and are an important factor which limits the otter population on the Isle of Skye coastline.

CONTENTS

INTRODUCTION

Various factors can limit an animal population from density dependant forces within a population to external forces like food and shelter acting on the population from the outside (Begon, M et al 1999). Food is one of these factors that limits a population (Elton 1927), and whole communities may be dependent on food supply. It has been suggested by Sinclair (1989) that larger mammal populations are totally regulated by food and small mammal population limited by the exclusion of juveniles for breeding. The diet of the Eurasian otter may depend on food distribution and density and on preferences for different types of food, and there is evidence to suggest that the nature and abundance of food is the most powerful factor deciding the existence and abundance of an otter population (Dowdeswell, 1984). Natural mortality is highest in times of food shortage (Kruuk and Conroy 1991; Kruuk et al, 1993).

It has also been suggested that limited availability of food may have contributed to the rapid decline in otter numbers in the Western World (Kruuk et al, 1993), in addition to causes such as pollution, disturbance and habitat loss (Chanin and Jefferies, 1978, Mason and Macdonald, 1984).

This chapter considers the overall diet of the Eurasian otter (*Lutra lutra*) around the coastline of the Isle of Skye, compares this with results from other areas, and then analyses annual and seasonal variation. The variation in the diet over the seven geological coastal zones is then considered.

The method of spraint analysis has been used for well over 30 years. Before this Elmhirst (1938) observed coastal feeding otters and Stephens (1957) studied the stomach contents from corpses from all over Britain. Although much work has been undertaken on the diet of the otter in freshwater habitats, (Erlinge 1967, 1969; Jenkins, 1979; Watson and Hewson, 1973; Veen, 1975; Webb, 1975; Wise et al, 1980), few studies existed on the diet of coastal otters before Watson (1978) studied the diet of otters on rocky shores in Shetland, and Mason and Macdonald (1980) in Loch Broom, north west Scotland. Subsequently, a wealth of recent information came from Herfst (1984), Kruuk and Moorhouse (1990), Kruuk (1989 and 1996) on Shetland and more recently Watt (1991 and 1995) on the Isle of Mull.

Both Kruuk and Watt presented detailed accounts of the diet of the Eurasian otter in relation to prey abundance. The diet on Shetland and Mull has been shown to be both seasonal and area related (Herfst, 1984; Kruuk et al, 1987; and Kruuk and Moorhouse, 1990). Watt (1991 and 1995) showed that Butterfish predominated in all spraint samples in all seasons, while Kruuk and Moorhouse (1990) showed that otters on the Shetland coastline preferred Viviparous Blenny, Five-Bearded Rockling, and Sea Scorpion to Butterfish.

Otters, being semi-aquatic predators, catch their prey primarily in the water (Mason and Macdonald, 1986), and spend much of their time on land, compared to truly aquatic mammals such as seals. Unlike otters, seals have a good form of thermal insulation in the form of blubber (Estes, 1989; Kruuk and Balharry, 19895). To forage in water is extremely expensive in terms of energy costs for thermoregulation and therefore otters adapt their feeding strategies to minimise the loss of body heat. They prefer to forage in shallow water (Kruuk et al, 1984), as here the thermal insulation provided by the two layers of fur is more effective (Nolet et al, 1993).

Knowledge of the availability of prey may make an important contribution to understanding the distribution of a population of otters and information obtained on this is a first step in understanding possible habitat preferences in relation to the geology of the coastal zone.

The most commonly used method of diet analysis is by studying faeces (spraints) but problems do exist with this method. Limitations are apparent when looking at the diet over different coastal zones due to the fact that otters can travel large distances (Kruuk et al, 1986) and faeces may contain remains of food eaten some distance away. There also appears to be no consistent method for interpretation of the faeces analysis but the method does provide an approximation of prey composition. A critical review had to be undertaken to see if the results I obtained were valid in the light of recent discussions on the methodology of faecal sampling for accurate determination of the diet of wild otters (Carss, 1995 and 1996). (See Discussion)

The main questions investigated were:

1. What was the species composition of the diet of the Eurasian otter on the Isle of Skye?
2. Does the diet vary over different years and different seasons and if so why?
3. Does the diet vary in the different geological zones and if so how?
4. How do the results compare with similar studies in other areas?

METHODS

Study areas

Initially observations were carried out in an intensive study area consisting of 7km of Mesozoic coastline from Camas Malag to Boreraig, and 2.5km of Mesozoic coastline on the Ardnish Peninsula, both in the south of the island. As the research progressed the area of study was increased to represent the whole of the island of Skye using spraint samples from all seven geological coastal zones which are described in Chapter 2. Ten 500m areas within the coastal zones were chosen randomly from a geological map; a pointer was placed on the map and the nearest section easily accessible by road and walking was used as the sample section. These sections were then added to the original study areas as shown on the map in Figure 3.1 and they are listed opposite.

Figure 3.1. The sections of coastline used for spraint analysis on the Isle of Skye

Table 3.1 The geology of the spraint collecting areas and the number of spraints collected.

Area	**Geology**	**Number of spraints**
Duisdale	Lewisian	92
Knock	Lewisian	92
Ob-Allt	Torridonian	108
Loch na Dal	Torridonian	108
Sgianadin	Cambrian	108
Ardnish	Mesozoic	240
Camas Malag-Boreraig	Mesozoic	240
Loch Harport	Tertiary Lava	108
Eabost	Tertiary Lava	92
Ard Dorch	Tertiary Intrusive	108
MacCoitir's Cave	Landslip	92
Bearreraig Bay	Landslip	92

Collection of spraints

Firstly, it was important to identify the key sprainting sites in order to provide long term data on diet using spraints, and also to enable spraints to be counted for further research. Sprainting on land is seasonal (Conroy and French, 1987), and it was more difficult to find spraints in the summer than in the winter. Therefore, having identified the key collecting sites made it easier to find spraints during the low summer season.

In the coastal environment, spraints are found most frequently on rocky coasts, on well-marked sites at the mouths of rivers, on otter runs or, at certain times of the year, at the entrance to holts (Conroy and French, 1985, 1987). The droppings add nitrogen to the surrounding area making sprainting points very obvious: grassy areas tend to be very green with a prominent growth of nitrophylous grasses. Rocks may be covered by green algae, and some sprainting areas on the coast are without vegetation exposing soil as a result of the continuous addition of urine (Conroy et al, 1993).

Examples of sprainting points on Skye are shown in Plate 3.1.

Droppings which could be mistaken for those of the otter come from the American mink, (*Mustela vison*) although the smell, size and shape are different. However, mink are absent from Skye; animals were released from a failed mink farm in the late 1950's and initially they were frequently seen in the Varigill river (Yoxon and Yoxon, 1990). However, they did not become established and there have been no sightings since 1950. Therefore, there is little danger that mink droppings will be found on the Isle of Skye.

Plate 3.1. Examples of sprainting points on the Isle of Skye.
Typical green sprainting point by freshwater pool, Boreraig.
Sprainting point near a holt, Strathaird peninsula.

Spraints were collected from December 1990 to February 1994. From December 1990 to November 1992, 20 spraints per month were taken from each of the Camas Malag-Boreraig and Ardnish coastlines. The spraints were collected from five sprainting points along the 2.5km Ardnish coastline and nine sprainting points along the 7km Camas Malag to Boreraig coastline. From March 1992 to February 1994, a minimum of four spraints each month were taken from the ten coastal sites mentioned above; more spraints were collected from the geological zones only sampled once and the exact numbers of spraints collected in each zone are shown in Table 3.1. Spraints were collected from different sprainting points along the 500m coastal section. A total of 1,480 spraints were examined in the total survey.

Carss (1996) used captive otters whose diets were known, and showed that sampling spraints fortnightly and monthly ranked the prey in approximately the correct order, and few inaccuracies occurred in using monthly sampling intervals. Mason and Macdonald (1986) found that 90% of the spraints had disappeared in three weeks; therefore, collecting spraints on a monthly basis increases the chance of collecting new spraints without prejudicing the analysis.

Analysis of spraints

Only fresh spraints were collected for analysis and stored in labelled plastic canisters. In the laboratory, mucus was removed using Co-op false teeth cleansing solution (Composition greatest first: sodium chloride, sodium percarbonate, trisodium phosphate, magnesium carbonate, methol, peppermint oil and sodium lauryl sulphate). The samples were soaked in the solution for 48 hours then washed and sieved using a 0.5mm sieve. This method has been used by many workers including Erlinge (1967, 1968); Watson, (1978) and Beja, 1995.

The bulk of the prey remains consisted of fish bones with occasional bird feathers and small mammal bones. The prey was identified by comparing the fish vertebrae, bird feathers and small mammal bones with a reference collection and also compared with the published keys of Watson (1978) and Conroy et al (1993).

No method of expressing the results of spraint analysis describes the diet of otters accurately

(Wise et al, 1981; Kyne et al, 1989; Rowe-Rowe, 1977; Jenkins et al, 1980; Heggberget, 1993; Carss, 1996); however, the two most commonly used methods are described by Conroy et al (1993).

a) Percentage Frequency of Occurrence, where all the remains of each species in a spraint are taken to represent only one specimen and its frequency is calculated as the number of times it appears in all spraints in the sample.

It is calculated as:

$$\frac{\textit{Number of spraints containing a particular prey item}}{\textit{Total number of spraints in sample}} \text{ x } 100$$

b) Relative Frequency of Occurrence, where all the bones are identified in every spraint, and the frequency of each species in that spraint determined.
It is calculated as:

$$\frac{\textit{Number of occurrences of a prey in each spraint}}{\textit{Total number of all prey items identified in the spraint}} \text{ x } 100$$

These methods, however, have important limitations which will be considered in the Discussion.

I have presented the results of spraint analysis in two ways: 1) Percentage Frequency of Occurrence; 2). I have also introduced a Random Sampling method which is a variant of the Percentage Frequency of Occurrence to see if it would provide a quicker way of testing large numbers of spraints over a long time period. It was suggested by Kruuk (personal communication) that it may give a reasonable result.

1. Percentage Frequency of Occurrence

As described above

2. Random Sampling

A disc of paper with a cross was placed in the sampling dish; the dried spraint was placed in the dish and spread evenly around; the vertebra closest to the cross was identified. Each prey was defined as one observation and the percentage observations were calculated as the number of observations of that prey relative to the total number of observations of all categories.

STATISTICAL TREATMENT

The Chi-squared test was used to compare results between the seasons and the geological coastal zones. Spearman Rank Correlation Coefficients (r_S) were used to describe the relationships between the two methods of spraint analysis. Kendall's Coefficient of

Concordance (W) (Siegel and Castellan, 1988), was used to test for agreement between years.

RESULTS

Total spraint composition

Over the study period 1,480 spraints were analysed, yielding 4,588 individually identifiable remains of 19 prey types.

The results are shown in Table 3.2 and Figure 3.2, comparing Percentage Frequency Analysis and Random Sampling. The two methods were in nearly perfect agreement (r_s=0.99; $p<0.001$). Thus in large scale spraint analysis surveys it may be worth using the Random Sampling method to save time and effort.

The Percentage Frequency of Occurrence of prey remains shows that marine fish dominated the diet (97.3%), with the most common prey species being Viviparous Blenny (30.5%), Five-Bearded Rockling (19.1%), Butterfish (10.8%), Saithe (9.3%), and Sea Scorpion (5.9%). It is worth noting the importance of Saithe which constitutes 9.3% of the prey remains and is the only free-swimming species as the other four are small benthic fish. Seabirds played a small part (1.2%); otters were seen taking guillemots (*Uria aalge*) and shags (*Phalacrocorax aristotelis*) but such sightings were very infrequent. The only freshwater component was the common trout (*Salmo trutta*) (0.5%) and frog (*Rana temporaria*) (1.1%).

Mammal bones also occurred but accounted for only 0.6% of the prey remains. On three occasions out of 15 spraints with small mammal bones it was possible to identify Vole (*Clethrionomys sp*.) remains. Otters do eat Rabbits (*Oryctolagus cuniculus*) extensively (direct observation on the Isle of Pabay, off Skye), but rabbit remains were not identified in the spraint analysed from the Skye coastline.

Five species make up over 75% of the total faecal contents and these will be called the KEY PREY SPECIES (ie Viviparous Blenny, Five-Bearded Rockling, Butterfish, Saithe, and Sea Scorpion).

Table 3.2. Occurrence of prey items in otter spraints collected from December 1990 to February 1994 expressed as percentage by Random Sampling and Percentage Frequency of Occurrence. Number of spraints analysed = 1,480

PREY ITEMS	SCIENTIFIC NAME	% BY RANDOM SAMPLING	% FREQUENCY OF OCCURRENCE
Blenny-Viviparous	*Zoarces viviparus*	29.2	30.5
5-Bearded Rockling	*Ciliata mustela*	18.1	19.1
Butterfish	*Pholis gunnellus*	10.0	10.8
Saithe	*Pollachius virens*	10.8	9.3
Sea Scorpion	*Taurulus bubalis*	5.5	5.9
Flatfish	*Pleuronectida sp*	5.0	4.4
Common Eel	*Anguilla anguilla*	3.6	3.5

Shore Crab	*Carcinus maenas*	3.6	3.4
Conger Eel	*Conger conger*	3.3	3.3
Sand Eel	*Ammodytidae sp*	2.7	2.9
Sea Snail	*Liparis liparis*	1.3	1.2
Frog	*Rana temporaria*	1.3	1.1
Birds	*(Mostly seabirds)*	1.1	1.0
Sea Stickleback	*Spinachia spinachia*	1.1	0.8
Angler	*Lophius piscatorius*	0.8	0.8
Gobies	*Gobius sp*	0.5	0.7
Small Mammals		0.9	0.6
Sea Trout	*Salmo trutta*	0.7	0.5
Lumpsucker	*Cyclopterus lumpus*	0.5	0.2

Data are from 4,588 occurrences.

Figure 3.2. Prey remains of the Eurasian otter as analysed from spraints. Results expressed as Percentage Frequency of Occurrence. (1,480 spraints sampled with 4,588 occurrences)

Annual variation in spraint composition

The yearly variation in prey remains is shown in Figure 3.3 which covers the period from 1991-1993 (Data for 1990 and 1994 were not for the full year). Comparisons were made using Percentage Frequency of Occurrence.

Kendall's Coefficient of Concordance (W), for agreement between years in the relative importance of prey items was calculated and showed a strong concordance between years (W=0.94, χ^2=51.3, df=3, p<0.001), for the five key prey species (Viviparous Blenny, Five Bearded Rockling, Butterfish, Sea Scorpion and Saithe). However, Five-Bearded Rockling was taken in slightly greater numbers in 1993 compared with the other years, and shore crabs were taken in greater numbers in 1992. Remains of Viviparous Blenny represented 30-31% of the faeces content over the three year period.

Small variations in prey species taken did occur between the years: Lumpsucker was only present in the diet in 1992, while Angler was absent in 1992 and small mammals in 1993, but all those species combined in the "Other" category only comprise some 4-9% of the total diet.

Figure 3.3. Interannual variation in prey items in otter spraints. Results are expressed as Percentage Frequency of Occurrence.
1991 = 480 spraints (1488 occurrences), 1992 = 440 spraints (1037 occurrences), 1993 = 240 spraints (816 occurrences)
Other = Frog, bird, mammals, angler, gobies, sea snail and sea stickleback

Seasonal variation in spraint composition

The seasonal trends in the consumption of the food categories were assessed by combining the data from December 1990 to February 1994 using all geological coastal zones as discussed above. The seasons are divided as follows: Winter = December to February; Spring = March to May; Summer = June to August; Autumn = September to November.

The results are shown in Figure 3.4, which shows the occurrence of the individual species by seasons, and Figure 3.5, which shows the composition of the spraint contents for each season. Results shown are as Percentage Frequency of Occurrence. Chi-squared tests for the seasonal variation of the prey species are shown in Table 3.3.

Chi-squared tests were performed on the number of occurrences of each taxon in each sample. There were no significant seasonal differences in the occurrence of Butterfish and Conger Eel. Significant seasonal differences ($p<0.001$) did occur in all other species. Viviparous Blenny occurred more in the spring (34%) and summer (35%) than the autumn (25%) and winter (31%). Five-Bearded Rocklings occurred most frequently in the winter months accounting for 26% of the diet. Saithe was taken more often in the autumn (13%) and winter (11%) with low numbers in the spring (4%). Sea Scorpion dominated the diet in the autumn (10%) with low numbers taken in the spring (4%). Common Eel was absent in the winter but was taken most frequently in the spring (6%) and summer (5%). Flatfish was more common in the spring (6%) and summer (5%) with low numbers in the autumn (2%) and winter (2.5%) and shore crab was found in the spraints more in the summer (6%) with low numbers in the spring (2%) and winter (2%). There were also significant seasonal differences in what is classed as "Other", which accounts for 15% of the diet in the spring. This was due to frogs (5%), birds (5%), Angler (2%), Trout (2%) and small mammals (1%). The lowest percentage of all the five key prey species occurred in the spring (68%) compared with a high in the winter months (83%).

Figure 3.4. Seasonal variation in prey species in spraints from 1990 to 1994. Since different numbers of spraints were sampled in each month the results are expressed as Percentage Frequency of Occurrence by season for each prey.
N, (Number of vertebrae identified): Spring = 1142, Summer = 1135, Autumn = 1101 and Winter = 1210.
Figure 3.5. Seasonal variation in prey species. Results are by Percentage Frequency of Occurrence.
N, (Number of vertebrae identified): Spring = 1142, Summer = 1135, Autumn = 1101 and Winter = 1210.

Table 3.3. Chi-squared tests for the seasonal variation in the prey species. A significant result indicates that the species was not found in spraints equally during the seasons.
******p<0.001; ns=p>0.05***

SPECIES	χ^2	df	p
Viv. Blenny	21.2	3	***
5 Bd Rockling	53.7	3	***
Butterfish	3.9	3	ns
Saithe	57.8	3	***
Sea Scorpion	49.8	3	***

Flatfish	24.9	3	***
Common Eel	82.9	3	***
Shore Crab	27.4	3	***
Conger Eel	9.4	3	ns
Sand Eel	95.0	3	***

Variation in spraint composition along the geological coastal zones

Figures 3.6 and 3.7 summarise the diet in relation to the seven geological coastal zones. Figure 3.6 shows the individual species in relation to the different geological coastal zones and Figure 3.7 the total diet for each individual geological coastal zone.

Kendall's Coefficient of Concordance (W) for agreement between the zones for the five important prey species was calculated. There was a high degree of concordance among the geological coastal zones (W=0.91, χ^2=25.3, df=6, p<0.001) and the number of prey species from the different geological coastal zones was very predictable.

Spearman Rank Correlation Coefficients were calculated between the annual spraint contents from the different geological coastal zones and the results are shown in Table 3.4. Significant correlations existed between the diet as analysed from spraint analysis and most of the geological coastal zones except between the Torridonian and the Tertiary Intrusive zone and the Lewisian and the Landslip zone. The Torridonian zone had higher percentages of Saithe, Sea Scorpion and Common Eel than the Tertiary Intrusive zone and the Landslip had a higher percentage of Saithe, low numbers of Sea Scorpion and an absence of Flatfish compared to the Lewisian zone. Chi-squared tests for the variation of each species in the seven geological coastal zones are shown in Table 3.5.

No significant difference occurred between the occurrence of Viviparous Blenny and the seven geological coastal zones, however very highly significant differences occurred between Butterfish, Five-Bearded Rockling, Saithe, Sea Scorpion, Flatfish, Common Eel, Sand Eel and Conger Eel and the seven geological coastal zones.

Highly significant statistical differences occurred between Shore Crab and Butterfish and the geological coastal zones. Five-Bearded Rocklings were found less often in the Lewisian (14%), Torridonian (15%) and Mesozoic (16%) and occurred more often in the Landslip zone (27%); Butterfish occurred in higher numbers in the Mesozoic (13%) and lower numbers in the Tertiary Lava (9%) and Landslip (9%) zones. Saithe was found more often in the Tertiary Lavas (11%), Tertiary Intrusive (17%) and Landslip (16%) zones and occurred in low numbers in the Lewisian zone (7%). Flatfish was absent from the Cambrian and Landslip geological coastal zones; Common Eel was absent from the Cambrian and Tertiary Intrusive zones and appeared most in the Torridonian zone (10%) and Sand Eel was absent in the Torridonian, Tertiary Lavas and Landslip but occurred most in the Tertiary Intrusive zone (7%)

Variations existed also in the "Other" category: Angler occurred in small proportions in the Lewisian/Moine (4%), and the Tertiary Lava zone (2%) but was absent from all other zones; mammals were only found in the Mesozoic zone (0.9%); and birds were present in the Lewisian/Moine (2%), Mesozoic (3%), Tertiary Lavas (4%) and the Landslip zone (2%) but were absent from all other zones. However, because of the low frequency of occurrence of birds and mammals these differences were not significant.

Figure 3.6. Variation in prey species in spraints along the geological coastal zones. Since differnt numbers of spraints were sampled in each zone the results are expressed as Percentage Frequency of Occurrence. Data represents 1,480 spraints (4588 occurrences). Number of spraints sampled in each zone (with number of individual vertebrae shown in brackets), Lewisian = 184 (572), Torridonian = 216 (675), Cambrian = 108 (341), Mesozoic = 480 (1468), Tertiary Lavas = 200 (624), Tertiary Intrusives = 108 (339), Landslip = 184 (569)

Figure 3.7. Variation in prey species in the different geological coastal zones. Since differnt numbers of spraints were sampled in each zone the results are expressed as Percentage Frequency of Occurrence. Data represents 1,480 spraints (4588 occurrences). Number of spraints sampled in each zone (with number of individual vertebrae shown in brackets), Lewisian = 184 (572), Torridonian = 216 (675), Cambrian = 108 (341), Mesozoic = 480 (1468), Tertiary Lavas = 200 (624), Tertiary Intrusives = 108 (339), Landslip = 184 (569)

Table 3.4. Spearman Rank Correlation Coefficients between the seven geological coastal zones (df=9)

Zone	**Lewisian**	**Torridon.**	**Cambrian**	**Mesozoic**	**Tertiary Lava**	**Tertiary Intrusive**	**Landslip**
Lewisian	XX	**	**	***	**	**	ns
Torridonian		XX	*	***	***	ns	*
Cambrian			XX	**	**	***	**
Mesozoic				XX	***	*	**
Tertiary Lava					XX	**	*
Tertiary Intrusive						XX	**

Very highly significant	*********	***p<0.001***
Highly significant	********	***p<0.01***
Significant	*******	***p<0.05***
Not significant	***ns***	***p>0.05***

Table 3.5. Chi-squared tests for the geological variation in the prey species. A significant result indicates that the species was not found in the spraints equally in the geological coastal zones.
****** = p<0.001; ** = p<0.01; ns = p>0.05***

SPECIES	χ^2	df	p
Viv. Blenny	10.2	6	ns
5 Bd Rockling	39.7	6	***
Butterfish	17.6	6	**
Saithe	34.6	6	***
Sea Scorpion	55.5	6	***
Flatfish	60.2	6	***
Common Eel	97.9	6	***
Shore Crab	20.2	6	**
Conger Eel	43.3	6	***
Sand Eel	151.2	6	***

DISCUSSION

Limitations of Data

The study was carried out over four years from December 1990 to February 1994 on 20 sections of coastline, each 500m long. In total these represented some 3% of the total Skye coastline, with equal representation of the seven geological coastal zones. Thus the survey areas are relatively small, and it also has to be borne in mind that otters sprainting in the various geological coastal zones could have been feeding in other areas. However, otters pass food remains within a few hours, and the mean distance between the sample area and the next geological coastal zone was 32km. Therefore, given that the size of the otter's coastal range is between 3.5 and 4.5 km for females and 20 to 30 km for males (personal observation) and (Kruuk, 1995), it is not likely that the proximity of the other geological coastal zones, would have affected the results in terms of otter diet as analysed by spraint analysis.

The small size of the mesh of the sieve used for the preparation of the faeces for analysis ensured that all hard remains from commonly eaten prey were identified.

The problems of interpreting data from spraint analysis have been widely discussed in the literature, and it appears that no single method provides a true picture of the importance of the different constituents of the diet (Rowe-Rowe, 1977; Wise et al, 1981; Kruuk et al, 1993).

Percentage Frequency of Occurrence of prey remains is the most easily applied spraint analysis method, and it has been used in numerous studies (Mason and Macdonald, 1986; Carss, 1996; Beja, 1991). However, there seems to be little agreement among authors on precisely how to interpret the results.

The method of Percentage Frequency of Occurrence relies on the presence of undigested hard parts and both soft-bodied animals and large animals, where only the flesh is eaten, will leave no remains in the spraints (Putman, 1984). Food which has a relatively large proportion of soft material will be under-estimated and hard parts of some prey will be broken up or digested; these methods will therefore only give an indication of what otters have eaten. As different types of fish have different numbers of bones (Wheeler, 1969) and some bones are more prone to breakage than others (Castel, 1976), the relationship between the number of bones counted and the number of fish consumed may be tenuous. Overall, minor items will be over-estimated and frequently occurring items under-estimated. Most authors do mention this limitation, but many still claim that it gives a reasonable picture of the diet quoting the feeding trials undertaken by Erlinge (1968). Erlinge tested the accuracy of Percentage Frequency of Occurrence by giving food of a known composition to captive otters. Spraints from these otters were collected and analysed and the relative proportions of the prey categories eaten were in close agreement with the frequency analysis. However, his results were not tested statistically.

Rowe-Rowe (1977) suggested that the analysis of otter spraints calculated by frequency gave a reasonably true picture of the relative importance of the food taken but he also did not test this statistically.

Kruuk et al (1993) showed similar results from four captive otters with a strong correlation between the percentage of fish fed to the otters and the percentage frequency of identifiable remains found in the spraints (r_s=0.9; $p<0.001$).

Carss (1996) also undertook feeding trials on four tame captive otters over a month period, and attempted to put confidence estimates on the analysis of spraints using Percentage Frequency of Occurrence. He found strong positive correlations between the values obtained for each of the ten prey groups and their true proportions in the diet, but found it gave a poor estimate of the true proportions of prey by number or biomass for the ten prey groups. (The methods over-estimated the true proportions by 5% to 2900% and under-estimated by 12.5% to 50%). He therefore concluded that for prey which does leave remains, Percentage Frequency of Occurrence allowed dietary items to be ranked with a high degree of accuracy, but gave poor estimates of the true percentage proportions of the various prey groups in the diet. Carss also found that prey was over-estimated if sequentially deposited spraints are collected regularly from frequently used sites.

The assumption that each occurrence of a prey item in different spraints represents a single individual animal is not necessarily true; Carss (1996) found the remains of seven similarly sized fish were recorded in a single spraint and therefore spraints cannot be assumed to represent a single prey item.

In Shetland, Kruuk and Moorhouse (1990) used direct observations to assess the diet of otters and his results showed close agreement with those undertaken by Herfst (1984) using spraint analysis by Percentage Frequency of Occurrence. The inaccuracies of this method are therefore assumed to be acceptable within the aims and limitations of this study.

Given these difficulties, frequency analysis has the advantage of being relatively quick compared to more complex and not necessarily more accurate methods of analysis. (Counting all vertebrae and volumetric analysis have not been found to be more accurate [Watt, 1995]).

Any bias which does occur is likely to operate on all the samples equally. Thus, they should not affect conclusions with regard to seasonal and area related trends within a taxon (Wise et al, 1981) or comparisons with other studies using similar methods of analysis.

A further problem could be pseudo-replication whereby one meal contributes to a number of spraints. It is not inconceivable that some adjacent spraints may have come from the same meal. However, this potential difficulty in statistical analysis has been ignored in this and previous studies.

The seasonal and geologically (area) related patterns of the presence of the prey species in the spraints showed consistency between the years.

It is impossible to determine the contribution of prey that leave no solid remains at all. It is known from direct observations that soft bodied species or species where only soft parts are eaten, such as Lumpsucker, Dogfish and Cephalopods, are rather uncommon in the diet of otters. I have therefore assumed, as in other studies, that this problem had no significant effect on my results.

Prey and Seasonality

The description of the diet using Percentage Frequency of Occurrence was in close agreement with earlier work undertaken on the Skye coastline (Yoxon and Yoxon, 1990). Comparing the data from Percentage Frequency of Occurrence and that analysed by Random Sampling there was close agreement ($p<0.001$). Thus the Random Sampling method which is considerably faster could be used for larger long term spraint surveys to give an estimate of the important prey species in the diet of otters.

Otters took mainly marine benthic fish throughout the year, but an exception to this is the dominance of free-swimming Saithe which was taken in large numbers in the autumn and winter seasons. Kruuk and Moorhouse, (1990) found that Saithe was taken in significant numbers in November and January; they concluded that although abundant all through the year, in the summer especially Saithe was only found in large numbers in open water outside the seaweed zone, where they were not preyed upon by otters.

In the current study, otter diet was dominated by five key prey species, which accounted for over 75% of the diet, namely Viviparous Blenny, Five-Bearded Rockling, Butterfish, Saithe and Sea Scorpion, and this showed little variation between the years 1991, 1992 and 1993, with

Viviparous Blenny dominating the diet in these years. The "Other" component however, was greater in 1991, accounting for 10% of the total diet. This was due to the large numbers of frogs and birds found that year.

The seasonal variation was significant for all species except Butterfish and Conger Eel. Five-Bearded Rockling, which was found in greater numbers in the winter months, Saithe and Sea Scorpion was found more often in the autumn and winter and low numbers in the spring. Kruuk and Moorhouse (1990) showed on Shetland that Rocklings comprised a steady 15-19% of the diet throughout the year and although on Skye they had a winter peak of 26%, they did occupy between 14-26% of the diet throughout the year. Rocklings have also been found in large numbers in otter spraints in the Severn estuary (Badsha and Sainsbury, 1978), in Galway Bay, Ireland (Murphy and Fairley, 1985) and from Loch Broom (Mason and Macdonald, 1980), which suggests that Rocklings may be an important source of winter prey in otters from Shetland in the north to Ireland in the south.

Kruuk and Moorhouse (1990) suggested that in spring otters had greater difficulty in obtaining food and this coincides with otters taking less profitable species, such as Stickleback and Crabs. They therefore concluded that if food shortage were to have an effect on otters it would be most likely in the spring. The Skye data would also seem to support this case, with the lowest occurrence of the five key prey species in spring.

Common Eel showed a marked peak in the spring and summer but was absent in the winter months, a result in agreement with previous studies, Kyne et al (1989), Mason and Macdonald (1986), McFadden and Fairley (1984) and Watt (1995). Summer is the time when the yellow immature eels are most active in warmer waters (Miller and Nicholls, 1980), and are therefore more likely to be taken by otters.

Predation on frogs only occurred in the spring, which corresponds with the breeding season, confirming observations by Fairley (1984) that otters may specialise on frogs at this time of the year. Weber (1990) in north east Scotland also found otters exploiting frogs in the late winter and spring; his results showed that in that area amphibians accounted for between 13-47% of the diet. However, Erlinge (1967) found in Sweden that the proportions of amphibians in the diet varied according to habitat.

These observations suggest that the occurrence of amphibians (frogs) in the diet is related to their availability. In my study area the otters forage on the coast and the availability of frogs will be limited except in the spring when they are congregating to breed in some of the freshwater pools used by otters to wash and drink.

Diet in relation to the geology of the coastal zones

Spraints from different geological coastal zones were analysed separately. Due to the small coastal length sampled only a small number of otters contributed to the spraint samples from each geological coastal zone.

The variation along the seven geological coastal zones was significant for all species except Viviparous Blenny which dominated the diet in all zones. Very highly significant differences occurred between Butterfish, Five-Bearded Rockling, Saithe, Sea Scorpion, Flatfish, Common Eel, Sand Eel and highly statistical significant differences occurred between Shore Crab and Butterfish and the geological coastal zones. Five-Bearded Rocklings were found less often in the Lewisian and Torridonian coastal zones; Saithe was found more often in the Tertiary Lavas, Tertiary Intrusive and Landslip zones and Viviparous Blenny was found more often in the Landslip zone. Flatfish was absent from the Cambrian and Landslip geological coastal zones; Common Eel was absent from the Cambrian and Tertiary Intrusive zones and appeared most in the Torridonian zone and Sand Eel was absent in the Torridonian, Tertiary Lavas and Landslip but occurred most in the Tertiary Intrusive zone.

Variations existed also in the "Other" category: Angler occurred in small proportions in the Lewisian/Moine (4%), and the Tertiary Lava zone (2%) but was absent from all other zones; mammals were only found in the Mesozoic zone (0.9%); and birds were present in the Lewisian/Moine (2%), Mesozoic (3%), Tertiary Lavas (4%) and the Landslip zone (2%) but were absent from all other zones. However, because of the low frequency of occurrence of birds and mammals these differences were not significant.

Thee important conclusion is that the relative occurrence of fish species in spraints from the seven geological coastal zones varied but the importance of the five key prey species (Viviparous Blenny, Five-Bearded Rockling, Butterfish, Sea Scorpion and Saithe) cannot be underestimated. There was some slight variation but these species dominate the diet in all seven zones.

Comparisons with Other Studies

Studies of the diet of coastal otters have been undertaken in Shetland (Kruuk et al 1987; and Kruuk and Moorhouse, 1990), in Norway (Heggberget and Moseid, 1994), on Loch Broom (Mason and Macdonald, 1980) and on Mull (Watt, 1995) and the data presents some interesting comparisons with this study.

Table 3.6 compares the results from five studies. The Spearman Rank Correlation Coefficient was calculated comparing the different areas and the results are shown in Table 3.7.

Table 3.6. Comparing principal prey taxa consumed by otters in four areas of Scotland and Norway. Data from Skye and Mull are from spraint analysis using Percentage Frequency of Occurrence. Data from Norway and Loch Broom were analysed using Relative Frequency of Occurrence. Shetland data was from direct observation. n = the number of spraints sampled, or for Shetland the number of prey identified. The number in brackets is the number of individual vertebrae.

SPECIES	SKYE	MULL	LOCH BROOM	SHETLAND	NORWAY
n Occurrences	1,480 (4,588)	958	50	2028	1074

Zoarces viviparus	30.5	0	8.6	33.8	7.9
Chirolophis ascan.	0	5.1	10.7	0.1	0
Gadidae	28.4	17.1	15.7	25.1	17.5
Pholis gunnellus	10.8	25.8	11.4	9.9	12.4
Cottids	5.9	11.8	2.1	17.5	12.8
Flatfish	4.4	3.1	7.9	1.9	11.4
Anguilla anguilla	3.5	7.3	8.6	0.2	1.6
Crab	3.5	7.3	17.9	0.2	1.6
Conger conger	3.3	0.2	0	0	0
Spinachia sp	0.8	0	2.1	0.2	7.7
Gobius sp	0.7	2.6	2.1	0	4.9
Salmonidae	0.5	0.1	2.1	0	2.0

Table 3.7. Spearman Rank Correlation Coefficients (r_S) comparing data from Skye, Mull, Loch Broom, Shetland and Norway.

	MULL	**LOCH BROOM**	**SHETLAND**	**NORWAY**
SKYE	ns	ns	***	**
MULL		*	ns	ns
LOCHBROOM			ns	ns
SHETLAND				**

ns=not significant (p>0.05), *=significant (p<0.05), **=highly significant (p<0.01), ***=very highly significant (p<0.001)

Significant correlations can be seen between the data from Skye, Shetland and Norway and from Shetland and Norway. There was also a significant correlation between Mull and Loch Broom.

Several differences have emerged in the composition of spraints between Skye and Mull, with Viviparous Blenny dominating the diet in Skye but being absent from the diet on Mull (Watt, 1991), even though it is relatively common near the Marine Biological Station near Oban (Koop, 1987). In fact, Five-Bearded Rocklings were taken in very much lower numbers on Mull than on Skye where they were one of the dominant prey species. On Mull, Butterfish dominated the diet but was taken in much lower numbers in all the other study areas. Despite these differences, all these studies have in common that otters were feeding mostly on small benthic prey. This suggests that even within the food category 'fish', otters are highly selective foragers specialising on easily caught prey species.

Chapter 4

Distribution of otter prey species

Synopsis

In order to study the variation in prey of the Eurasian otter (*Lutra lutra*), the availability of inshore (<12m depth) fish on the Isle of Skye was investigated using unbaited, stationary, funnel traps during the months of June to September over the four year period of 1991-1994 (inclusive). The traps were set in the seven geological coastal zones to study the availability of fish in these different areas. Over the period of 504 trap days, 344 fish and 302 crabs were caught.

The five key fish prey species as outlined in Chapter 3 accounted for 46% of the total catch and 87.5% of the total fish catch: Butterfish (*Pholis gunnellus*) 20.3%, Viviparous Blenny (*Zoarces viviparus*) 19.5%, Five-Bearded Rockling (*Ciliata mustela*) 19.2%, Sea Scorpion (*Taurulus bubalis*) 18.9%, and Saithe (*Pollachius virens*) 9.6%. Shore crabs were caught in large numbers accounting for 47% of the total catch, but they were absent in the traps from the Cambrian and Landslip geological coastal zones. It may be on Skye that if fish resources become scarce there are an abundant supply of shore crabs for the otter to eat.

The results are compared with data on otter diet obtained using spraint analysis described in Chapter 3 and there was a good correlation between species composition of the benthic fauna and the otter diet as analysed from spraint analysis ($p<0.001$).

The geological coastal zones were examined for the five key prey species and no significant differences occurred in Butterfish or Five Bearded Rockling. However, statistically significant differences were apparent for Viviparous Blenny which was present in far greater numbers in the Cambrian (28%) and Landslip (32%) zones and low in numbers in the Mesozoic (12%); Sea Scorpion which was found in high numbers in the Tertiary Lava zone (36%) and absent in the Landslip; Saithe which was found in high numbers in the Landslip zone (19%) and absent in the Tertairy Lavas and Flatfish which was found in high numbers in the Torridonian (10%) and absent in the Cambrian, Tertiary Intrusives and Landslip zone. The results were compared with other studies on Shetland and Mull and show that greater number of fish species are available in the waters around Shetland than around the Islands of Mull or Skye.

CONTENTS

INTRODUCTION

This chapter describes the relative densities of otter prey around the coastline of the Isle of Skye and relates these to diet and habitat.

To understand fully the effect of food resources on otter ecology it is essential to know the availability and abundance of fish species and how this prey is distributed in different types of habitat. The availability and dispersion of prey can have major effects on range size and population dynamics of terrestrial carnivores (Macdonald, 1983; Kruuk and Parish, 1982), and these variables may therefore effect the population of the Eurasian otter (*Lutra lutra*) which lives on the coastal fringe around the Isle of Skye.

Along the Skye coastline otters forage mostly in the sea and the most important prey species as analysed from spraint analysis are Viviparous Blenny, Five-Bearded Rockling, Butterfish, Saithe and Sea Scorpion (Chapter 3). Geographical differences of littoral fish assemblages are likely to have major consequences for the abundance of potential prey for Eurasian otters living along the coast.

Previous studies on Shetland (Kruuk and Moorhouse, 1990; Herfst, 1984; Kruuk et al, 1987) showed that otter diet varied on a seasonal and area-related basis and that although Butterfish were the most abundant fish in areas foraged by otters, they were not the dominant fish found in the diet: this consisted of Rocklings and Viviparous Blenny. Shore crabs, although very abundant, were rarely eaten by otters; this contrasted with research on Mull where Watt (1991) found that not only did Butterfish, Sea Scorpion and Common Eel dominate the diet but also that shore crabs made up an important part of this diet, especially in the summer and autumn months.

In this chapter, I describe the availability of fish species around the coastline of the Isle of Skye, using unbaited fish traps over a four year period and compare this availability with evidence of prey eaten as shown by spraint analyses. The results are then compared with work undertaken in Shetland and on the Isle of Mull.

The main questions are:

1. What is the relative density of fish available to the otter along the Skye coastline?
2. Does the density of fish species vary along the seven geological coastal zones?
3. How does the availability of fish caught compare with the diet obtained from spraint analysis?
4. How does diet and fish density differ between this and other studies?

METHODS

Study areas

For the purpose of this study, the coast was divided into sections according to the geology; six of these sections correlated with the areas used for spraint analysis in Chapter 3, but because of difficulty in transporting the traps the other sections were chosen as near as possible to a road. These 12 sections, each 500m long, are shown in Table 4.1 and Figure 4.1.

The seabed was covered in algae: *Ascophyllum nodosum* and *Fucus vesiculosus* nearshore with *Laminaria saccharina* in more sheltered areas and *Laminaria hyperborea* on more exposed coasts.

The tidal range varied considerably throughout the year with a spring range of 4.5m to a neap range of 1.6m. Surface sea water temperatures fluctuate very little during the year from 7°C in February to 13°C in July.

Figure 4.1. Map showing the coastal sections used in the fish trapping

Table 4.1 The geology of the trapping areas as shown on map (Figure 4.1), and the number of trap days in each area. (One trap set for 24 hours is defined as one trap day)

Area	**Geology**	**Number of Trap Days**
Duisdale	Lewisian	48
Loch na Dal	Torridonian	48
Kyleakin	Torridonian	36
Ob-Allt	Torridonian	24
Sgianadin	Cambrian	18
Camas Malag	Cambrian	12
Ardnish	Mesozoic	108
Loch Beag	Tertiary Lava	36
Aird	Tertiary Lava	54
Ard Dorch	Tertiary Intrusive	40
MacCoitir's Cave	Landslip	22

Trapping Techniques

Six traps were laid in each coastal section shown in Figure 4.1 and Table 4.1. Fish and crabs were collected over a four year period from 1991-1994 during the months of June to September.

Unbaited traps identical to those described by Kruuk, Nolet and French (1988) were used to monitor the numbers of inshore fish. Similar traps have also been used to monitor populations of freshwater fish (Alabaster, 1959; Stott, 1970), and they have many advantages in that they require little labour and can be used in deep water.

The fish traps used in this study were composed of Netlon and were made in a similar way to Kruuk et al (1988) and Watt (1991). Netlon is a heavy duty plastic with holes of 7mm diameter separated by strands of 3mm width. The traps were made measuring 50cm long with a diameter of 27cm and with a funnel leading into them from one side ending at 7cm diameter.

Traps were set in each 500m coastal section at spacings averaging 85m apart and at projected High Water depths of 2-3m; these depths were approximated using the High and Low Water Marks on the 1:25,000 Ordnance Survey maps. The depth of between 1-3m is the optimum depth at which otters prefer to feed (Kruuk, 1995) and was therefore the ideal depth at which to set the trap in order to obtain a representative sample of fish available for the otter.

The traps were set during the day at or near the time of low water. Six traps were used in each area and they were weighted down with a stone placed under the funnel; a long rope was attached and secured to a rock to pull the trap in and secure in case of rough weather.

They were left for 24 hours and then the fish were removed from the inspection hatch in the side of the trap. The fish were identified using the keys of Miller and Nicholls (1980), Wheeler (1978) and Erwin and Picton (1987).

Fish caught in the traps were counted and the percentage occurrence was calculated as the number of occurrences of the fish relative to the total number of occurrences of all fish.

STATISTICAL TREATMENT

The Chi-squared test for association was used to compare results between the geological coastal zones. Spearman Rank Correlation Coefficients (r_S) were used to compare relationships between the trapping data and the results from spraint analyses.

RESULTS

Total Catch

A total of 344 fish and 302 crabs were caught over the period of 504 trap days. Table 4.2 shows the number of fish and crabs caught and gives a mean catch of 0.68 ±0.1 fish, yielding 12 individual fish species. The mean number of crabs caught was 0.59±0.26 crabs per trap day. I have divided the data between fish caught and crabs caught since given the large number of crabs in each catch and the insignificance of crabs in the diet as analysed by spraint analysis they would have dominated the results. Figure 4.2 shows the percentage of total number of fish caught for each species between 1991 and 1994.

The total fish catch data was dominated by five species accounting for 87.5% of trapped fish; these were Butterfish (20.3%), Viviparous Blenny (19.5%), Five-Bearded Rockling (19.2%), Sea Scorpion (18.9%), and Saithe (9.6%). Six other species were caught in the traps but in much smaller numbers; flatfish were the most commonly caught of these species but accounted for only 4.6% of the total catch. As traps were only laid during June to September no seasonal variation in fish availability could be investigated. However, the most important species were caught in large enough numbers to allow analyses of area-related variation based on the seven geological coastal zones.

Table 4.2. Total number of fish caught. Data represents 504 trap days, and a total of 344 fish caught.

Species	Scientific	Total catch (n)	Percentage
Butterfish	*Pholis gunnellus*	70	20.3
Viviparous Blenny	*Zoarces viviparus*	67	19.5
Five-Bearded Rockling	*Ciliata mustela*	66	19.2
Sea Scorpion	*Taurulus bubalis*	65	18.9
Saithe	*Pollachius sp*	33	9.6
Flatfish	*Pleuronectidae sp*	16	4.6
Sea Trout	*Salmo trutta*	9	2.6
Conger Eel	*Conger conger*	8	2.3
Common Eel	*Anguilla anguilla*	5	1.5
Sea Stickleback	*Gasterosteus sp*	3	0.8
Sea Snail	*Liparis liparis*	2	0.7

TOTAL		344	100

Figure 4.2. Percentage of fish caught from 1991-1994. Data represents 504 trap days with 344 occurrences.

Variation between Geological Coastal Zones

Variation in the composition of the species assemblages between the geological coastal zones was analysed using the trapping data. The collection sites were classified using the geological coastal zones outlined in Chapter 1 and Figure 4.3 shows the mean number of fish caught in each geological coastal zone. Significant differences did occur in the number of fish caught in the geological coastal zones; the highest catch occurred in the Landslip zone (1.3 fish per trap) compared with a low in the Tertiary Intrusive zone (0.4 fish per trap), (χ^2= 29.3, df=6, p<0.001). Figure 4.4 shows the mean number of crabs caught in each geological coastal zone and again significant differences did occur in the number of crabs caught in each geological coastal zone with a mean number of 0.3 crabs caught in the Lewisian zone and no crabs caught in the Cambrian or Landslip zones. (χ^2=42.3, df=6, p<0.001).

Figure 4.5 shows the individual fish species in relation to the different geological coastal zones and Figure 4.6 compares the individual species to the geological coastal zones. The data shows the mean number of fish caught per trap day and is given as a percentage. A Chi-squared test for heterogeneity was performed to test the differences between geological coastal zones and the catch of the five Key prey species (The other species were caught in numbers too low to make the Chi-squared test meaningful) and the results are shown in Table 4.3. Figure 4.5 shows lower numbers of Butterfish, Viviparous Blenny and Five-Bearded Rockling are present in the Tertiary Lavas zone than in any of the other zones.

There were no significant differences between the geological coastal zones in the occurrence of Butterfish and Bearded Rockling, (p>0.05). However, statistically significant differences were apparent for Viviparous Blenny (χ^2=17.4, df=6, p<0.01) which was present in far greater numbers in the Cambrian (28%) and Landslip (32%) zones and low in numbers in the Mesozoic (12%); Sea Scorpion (χ^2=22.5, df=6, p<0.001) which was found in high numbers in the Tertiary Lava zone (36%) and absent in the Landslip and Saithe (χ^2=22.7, df=6, p<0.001) which was found in high numbers in the Landslip zone (19%) and absent in the Tertairy Lavas. With regard to the other species Flatfish was found in high numbers in the Torridonian (10%) and absent in the Cambrian, Tertiary Intrusives and Landslip zone; Sea Trout was only caught in the Tertiary Lava zone; Conger Eel was only caught in the Lewisian and Torridonian zones and Common Eel only caught in the Torridonian and Mezozoic coastal zones.

Figure 4.3. Mean number of fish caught per trap day in the geological coastal zones (Total number of fish caught/number of trap days). Data represents 504 trap days with 344 occurrences.

Figure 4.4. Mean number of crabs caught per trap day in the geological coastal zones. (Total number of crabs caught/number of trap days). Data represents 504 trap days with 302 occurrences.

Figure 4.5. Variation in fish caught in the different geological coastal zones.

The data shows the mean number of fish in each geological coastal zone given as a percentage.
Data represents 504 trap days with 344 occurrences. Trap days in each geological coastal zone are: Lewisian = 48, Torridonian = 108, Cambrian = 30, Mesozoic = 108, Tertiary Lavas = 94, Tertiary Intrusive = 94, Landslip = 22.

Figure 4.6. Individual fish species in relation to the different geological coastal zones.
The data shows the mean number of fish in each geological coastal zone given as a percentage.
Data represents 504 trap days with 344 occurrences. Trap days in each geological coastal zone are Lewisian = 48, Torridonian = 108, Cambrian = 30, Mesozoic = 108, Tertiary Lavas = 96, Tertiary Intrusives = 94, Landslip = 22
Table 4.3. Chi-squared tests for geological variation in the fish species.
A significant result indicates that there were significant differences in the numbers of species found in the traps in the different geological coastal zones. **p<0.001, *p<0.05, ns p>0.05.

Species	χ^2	**df**	**p**
Butterfish	10.1	6	ns
Viviparous Blenny	17.4	6	**
5-Bd Rockling	9.4	6	ns
Sea Scorpion	22.5	6	***
Saith	22.7	6	***

Comparisons between fish trapping and spraint analysis
Comparisons were made between the data from fish trapping and the diet as analysed by spraint analysis as outlined in Chapter 3. The data was re-calculated to represent only the spraints collected in the geological coastal zones from the months June to September, which were the same months that the traps were laid and the results are shown in Table 4.4.

Spearman Rank Correlation Coefficients (r_s) were calculated between percentage by numbers for both spraints and trapping data for all fish species. There was a close correlation between the fish trapping data and the diet as analysed by spraint analysis (r_s=0.82, df=10, p<0.001). Certain differences did however occur: Viviparous Blenny occurred in spraints at 33% but was only found in the traps at 19%; Sea Scorpion only occurred in spraints at 10% but was found at 18% in the traps. Comparing shore crabs (*Carcinus maenas*) caught in traps with the number found in spraints, the percentage of occurrence of shore crabs in traps was 47% compared to 3.4% in spraints.

Table 4.4. Comparisons between otter diet analysed from spraint analysis and fish caught in the fish traps. The spraint data has been corrected for seasonality. (Data represents 504 trap days with 344 occurrences, and 740 spraints with 2172 occurrences.)

FISH CAUGHT	SCIENTIFIC	% OCCURRENCE IN TRAPS	% FREQUENCY OF OCCURRENCE IN SPRAINTS
Butterfish	*Pholis gunnellus*	20.3	11.0
Viviparous Blenny	*Zoarces viviparus*	19.5	33.2
5-Bd Rockling	*Ciliata mustela*	19.2	17.7
Sea Scorpion	*Taurulus bubalis*	18.9	10.0
Saithe	*Pollachius virens*	9.6	13.1
Flatfish	*Pleuronectidae*	4.6	4.9
Sea Trout	*Salmo trutta*	2.6	0
Conger Eel	*Conger conger*	2.3	3.8
Common Eel	*Anguilla anguilla*	1.5	4.8
Sea Stickleback	*Gasterosteus sp*	0.8	0.4
Sea Snail	*Liparis liparis*	0.7	1.1

Geology Variation

Comparisons between spraint analysis and trapping data from the individual geological coastlines were made using Spearman Rank Correlations Coefficients. The results are shown below in Table 4.5. Highly significant correlations occurred between the Lewisian, Tertiary Intrusive and Landslip geological coastal zones and a significant correlation between the Mesozoic coastal zone. No correlations existed in Torridonian coastal zone where Viviparous Blenny occurred in larger numbers in the spraints than in the traps; the Cambrian zone where Conger Eel and Sea stickleback where present in the spraints but not found in the traps and the Tertiary lava zone where Viviparous Blenny was found in greater numbers in the spraints and Common Eel and Sea trout where found in the spraints but not in the traps and Sea Scorpion was found in larger numbers in the Spraints than the traps.

Table 4.5. Spearman Rank Correlation Coefficients between fish trapping data and spraint analysis in the seven geological coastal zones. Data shows actual numbers of fish caught and vertebrae found in the spraints.

Zone 1: Lewisian/Moine

Species	**Scientific**	**Number in spraints**	**Number in traps**
Butterfish	*Pholis gunnellus*	18	6
Viviparous Blenny	*Zoarces viviparus*	88	11
Rockling	*Ciliata mustela*	21	10
Sea Scorpion	*Taurulus bubalis*	15	5
Saithe	*Pollachius sp*	12	6
Flatfish	*Pleuronectidae sp*	12	3
Conger Eel	*Conger conger*	6	3
Common Eel	*Anguilla anguilla*	6	0
Sea Stickleback	*Gasterosteus sp*	3	0
Sea Snail	*Liparis liparis*	3	2

r_s=0.92, df=9, p <0.001

Zone 2: Torridonian

Species	**Scientific**	**Number in spraints**	**Number in traps**
Butterfish	*Pholis gunnellus*	15	17
Viviparous Blenny	*Zoarces viviparus*	91	13
Rockling	*Ciliata mustela*	12	15
Sea Scorpion	*Taurulus bubalis*	6	11
Saithe	*Pollachius sp*	9	7
Flatfish	*Pleuronectidae sp*	6	8
Conger Eel	*Conger conger*	6	5
Common Eel	*Anguilla anguilla*	9	2

r_s=0.59, df=7, p>0.05

Zone 3: Cambrian

Species	**Scientific**	**Number in spraints**	**Number in traps**
Butterfish	*Pholis gunnellus*	12	6
Viviparous Blenny	*Zoarces viviparus*	30	7
Rockling	*Ciliata mustela*	20	4
Sea Scorpion	*Taurulus bubalis*	6	5
Saithe	*Pollachius sp*	11	3

Conger Eel	*Conger conger*	4	0
Sea Stickleback	*Gasterosteus sp*	10	0

r_s=0.68, df=6, p>0.05

Zone 4: Mesozoic

Species	Scientific	Number in spraints	Number in traps
Butterfish	*Pholis gunnellus*	105	19
Viviparous Blenny	*Zoarces viviparus*	226	9
Rockling	*Ciliata mustela*	131	11
Sea Scorpion	*Taurulus bubalis*	31	21
Saithe	*Pollachius sp*	81	9
Flatfish	*Pleuronectidae sp*	57	3
Conger Eel	*Conger conger*	13	0
Common Eel	*Anguilla anguilla*	41	3
Sea Stickleback	*Gasterosteus sp*	2	0
Sea Snail	*Liparis liparis*	9	0

r_s=0.66, df=9, p<0.05

Zone 5: Tertiary Lavas

Species	Scientific	Number in spraints	Number in traps
Butterfish	*Pholis gunnellus*	9	5
Viviparous Blenny	*Zoarces viviparus*	47	10
Rockling	*Ciliata mustela*	28	9
Sea Scorpion	*Taurulus bubalis*	3	20
Saithe	*Pollachius sp*	21	0
Flatfish	*Pleuronectidae sp*	5	2
Sea Trout	*Salmo trutta*	0	9
Common Eel	*Anguilla anguilla*	5	0
Sea Snail	*Liparis liparis*	2	0

r_s=0.12, df=8, p>0.05

Zone 6: Tertiary Intrusives

Species	Scientific	Number in spraints	Number in traps
Butterfish	*Pholis gunnellus*	9	11
Viviparous Blenny	*Zoarces viviparus*	23	9
Rockling	*Ciliata mustela*	17	10

Sea Scorpion	*Taurulus bubalis*	8	3
Saithe	*Pollachius sp*	15	3
Flatfish	*Pleuronectidae sp*	3	0
Conger Eel	*Conger conger*	5	3

r_s=0.89, df=6, p<0.001

Zone 7: Landslip

Species	Scientific	Number in spraints	Number in traps
Butterfish	*Pholis gunnellus*	11	6
Viviparous Blenny	*Zoarces viviparus*	53	8
Rockling	*Ciliata mustela*	39	7
Sea Scorpion	*Taurulus babalis*	3	0
Saithe	*Pollachius sp*	22	5
Sea Trout	*Salmo trutta*	3	0
Conger Eel	*Conger conger*	5	0
Common Eel	*Anguilla anguilla*	3	0

r_s=0.90, df=7, p<0.001

DISCUSSION

Limitations of data

The data as interpreted from fish trapping has certain limitations because the traps will be selective for species and size. More bottom-living than free-living fish will be caught as the traps are placed on the seabed, and the size of the aperture in the funnel will limit the size of the fish caught. This will therefore bias the estimates of the relative abundance of trapped species. Kruuk et al (1987) showed that Rocklings are much more likely to be caught than Viviparous Blenny, and Butterfish was very difficult to catch in the type of trap used in the survey. Traps will also only catch a small proportion of the population present, and it is necessary to question if we can relate catch to fish density around the fish trap.

These assumptions have already been discussed by many scientists elsewhere. Stott (1970) showed that within a given range of temperatures, trap catches may be representative of known fish densities. It is still not certain what activity causes fish to enter traps (Stott, 1970), but this should not stop the use of unbaited fish traps being adequate if factors effecting the trap success are constant in all areas being surveyed. Stott also pointed out that only a small proportion of the fish population in a given area will be caught by unbaited fish traps (9% for perch population per day). However, given that this influence will be constant for all traps it should not affect the overall conclusions with regard to the total catch and geologically related differences.

It should also be noted that temperature probably did not play an important part in influencing the trap data. Traps were only set in the summer months June to September each year, and the sea temperature during the study ranged from 10.5 to 13°C (± 1.5). This was not likely to be sufficient to effect fish activity as stated by Stott (1970).

With these limitations in mind, several conclusions can be made with regard to communities of inshore demersal fish around the Isle of Skye coastline.

Species Composition

Small bottom-living fish made up the dominant part of the trapping data at all times and in all years (Table 4.2). These data agreed with similar studies in other areas with coastal otters (Mason and Macdonald, 1980; Kruuk and Moorhouse, 1990; Heggberget, 1993; Watt, 1991 and 1995), and this indicates that these species are very important for the sustainability of coastal otters in northern and north west Scotland and also Norway.

The five key prey species dominated the trapping data, accounting for 87.5% of the total catch data. Both the trapping data and the diet as analysed by spraint analysis can be regarded as biased as has been discussed, but nevertheless certain correlations do exist between the two methods. A strong correlation existed between the fish trapping data and the diet as analysed by spraint analysis which further suggests that the diet as analysed by spraint analysis gave a reasonable picture of the true diet of the otter. This was also shown to be the case in Shetland where Kruuk and Moorhouse (1990) used direct observations to assess the diet of otters; their results also showed close agreement with those undertaken by Herfst (1984) using spraint analysis by Percentage Frequency of Occurrence.

Butterfish were present in greater numbers in the trapping data than occurred in the spraint analysis and this differs from the results found by Kruuk et al (1988) and Heggberget (1993) who found a low trapping efficiency for this species.

Some species which were found in the spraints were not represented at all in the trapping data, eg Angler (*Lophius piscatorius*), Conger Eel (*Conger conger*), Gobies (*Gobius* sp) and Lumpsucker (*Cyclopterus lumpus*). Angler fish only represent 0.8% of the diet from spraint analysis and they occur generally in deeper water where they lie completely still waiting to catch small fish. This lack of free movement will inhibit them from entering the trap. Lumpsucker represent 0.5% of the diet from spraint analysis but as adults are large in size they would not be able to get into the trap funnel. However, in the summer months young Lumpsuckers are plentiful in rock pools. Gobies represent some 0.5% of the diet from spraint analysis, and these bottom-living fish could have been expected in the trap data. All these species represent only 5.1% of the total diet from spraint analysis and play little significance in the overall results.

Shore crabs were caught in large numbers accounting for 47% of the total catch, but were not found in large numbers in the spraints (3.5%). However, Watt (1995) found crabs were a very common and sometimes dominant item in the otter diet on Mull. However, he also showed that because of the large handling time, it was not energy efficient for an otter to catch crabs, unless they were foraging in areas where they had extremely low hunting success. It may be on Skye that if fish resources become scarce there are an abundant supply of shore crabs for the otter to eat.

Geological Variation

The density of fish caught was significantly different between the geological coastal zones ($p<0.001$), with the highest in the Landslip zone (1.3 fish per trap day) and lowest in the Tertiary Intrusive zone (0.4 fish per trap day), with numbers in the other zones varying between 0.6-0.9 fish per trap day. An otter would therefore have a greater density of fish available in the Landslip and Lewisian zone (which have fish caught in densities above the overall mean) than in the Tertiary Intrusives and Lavas (which have densities below the overall mean). These differences could be attributed to the slope of the coastline with 43% of the Tertiary Intrusive coastlines having a slope greater than $68\text{-}78^0$ and the Landslip zone only having 3% of the coastlines over $68\text{-}78^0$ (Chapter 2). The slope would affect the depth of water and Butterfish, Sea Scorpion, Five-Bearded Rocklings and Viviparous Blenny generally are not found in abundance in water depths over 20m and would therefore be expected to be at very low density in the Tertiary Intrusive zone.

The communities of inshore demersal fish which are available for marine feeding otters in all geological coastal zones was constant for Butterfish and Five-Bearded Rockling, however differences were apparent for Viviparous Blenny which was present in far greater numbers in the Cambrian and Landslip zones and low in numbers in the Mesozoic; Sea Scorpion which was absent in the Landslip zone; Saithe which was found in high numbers in the Landslip zone and absent in the Tertiary Lavas and Flatfish which was found in high numbers in the Torridonian and absent in the Cambrian, Tertiary Intrusives and Landslip zone. The five key prey species dominated the diet in all the coastal zones although in lower numbers in the Tertiary Lava coastal zone.

The rest of the species only make up 8.6% of the total catch, but various differences are also apparent. Flatfish was not caught in the Cambrian, Tertiary Intrusive or Landslip zones; Sea Trout was only caught in the Tertiary Lava zone; and Common and Conger Eels were caught in the Torridonian in far greater numbers than in any other coastal zone.

Comparisons were made between the density of fish on the geological coastal zones and the diet as analysed from spraint analysis. Correlations existed between the Lewisian, Mesozoic, Tertiary Intrusive and Landslip coast zones.all geological coastal zones except the Tertiary Lavas. No correlations existed in Torridonian, Cambrian and Tertiary Lava coastal zone.

Comparisons with Other Studies

The fish available to coastal otters has also been studied in some detail in Shetland (Kruuk et al 1987; Kruuk and Moorhouse, 1990) and on Mull (Watt, 1991 and 1995). Since twin funnel traps were used on both Mull and Shetland, and were more effective at catching certain species my data had to be corrected for this. Kruuk et al (1988) used both single funnel and twin funnel traps and worked out correction factors which have been applied to my data, and are shown in Table 4.6. No correction factors were used for the Common Eel as no data was available for this species Table 4.7 compares the data between Skye, Shetland and Mull.

Table 4.6. Correction factors used for main fish caught on the Isle of Skye. Correlation factors are based on Kruuk et al (1988)

Species	Catch in twin funnel traps	Catch in single funnel traps	Correction factor
Viviparous Blenny	45	41	1.1
Butterfish	8	9	0.89
5-Bd Rockling	81	28	2.8
Sea Scorpion	5	7	0.71
5 Spined Stickleback	17	12	1.42
Non-Rockling Gadoid	184	38	4.84
Shore crabs	115	160	0.72

Table 4.7. Average numbers of main fish caught per trap day in Mull, Shetland and Skye. The Shetland data is adapted from Kruuk, Nolet and French (1988) and the Mull data is taken from Watt (1995). The figures are calculated by dividing total catch by total number of trap days. The Skye data has correction factors applied since only single funnel traps were used as opposed to twin funnel traps on Mull and Shetland.

FISH TAXON	ISLE OF MULL (Loch Spelve)	SHETLAND (Lunna Ness)	ISLE OF SKYE (Total)
Viviparous Blenny	0.000	0.825	0.146
Yarrell's Blenny	0.003	0.000	0.000
Butterfish	0.143	0.189	0.120
5-Bd Rockling	0.109	0.324	0.367
Non-Rockling Gadoid	0.217	0.317	0.470
Sea Scorpion	0.050	0.056	0.092
Common Eel	0.079	0.025	0.026
Shore crab	1.383	1.143	0.145

The data shows that greater numbers of Viviparous Blenny and Shore Crabs are available on Shetland than Skye, but Skye had slightly larger numbers of Non-Rockling Gadoid (Saithe and Pollack) and Sea Scorpion than Shetland and Mull.

Diet selection models suggest that where fish is abundant, animals should be more selective than where fish is scarce. It would therefore be expected that Shetland otters would develop better selective foraging strategies than seen in this study on Skye. There is supporting evidence that this is the case.

In Shetland, Viviparous Blenny was present in greater numbers than on the Isle of Skye and made up the dominant part of the diet. In Shetland, however, Butterfish, a lightweight fish, were not consumed in large numbers despite being found in far greater densities in the traps than Viviparous Blenny and Rockling (Kruuk and Moorhouse, 1990). On Mull, however, Butterfish were prominent in the diet with Rocklings and Viviparous Blenny being rare (Watt, 1995).

In the Skye data, the dominant fish item found in spraint was Viviparous Blenny. Although the dominant species found in the traps (Corrected for using single funnel traps) was Non-Rockling Gadoids and Five-Bearded Rockling, it would seem that, as on Shetland, otters on Skye prefer to consume Viviparous Blenny and Rocklings compared to the lighter Butterfish species even though Butterfish are easier for an otter to find (Kruuk, 1995).

The data from fish trapping and spraint analysis are strongly correlated, but the availability of fish did differ with low numbers of Butterfish, Viviparous Blenny and Rockling in the Tertiary Lava zone. This suggests that although the diet as analysed by spraint analysis was similar in each geological zone the availability of fish was not, and this may limit the otter population in these geological coastal zones.

Chapter 5

Sprainting and otter activity in relation to geology

Synopsis

Data were collected from 1993-1995 on the distribution of holts, sprainting points, spraint numbers, freshwater pools and otter activity (Otter Variables) along seven different geological coastal zones on the coastline of the Isle of Skye. Sprainting evidence showed a strong seasonality with 72% more spraints being found in the winter than in the summer months. This is not attributed to otters producing more spraints in winter but to the fact that they spraint more in the intertidal zone in summer than in the winter months. Most sprainting in summer (70%) was observed to take place in the intertidal zone, in places which would be flooded within hours, and most spraints were deposited before and after feeding bouts, suggesting a short term rather than a long term function.

There were strong correlations between otter activity and holts in both the extensive and intensive study. No correlation existed between sprainting numbers and otter activity in the intensive study but a significant correlation did exist in the extensive study. The number of freshwater pools correlated with activity in the intensive study, but no correlation was found in the extensive study. However, the number of freshwater pools and all other variables correlated in both the intensive and extensive study and it was concluded that the availability of freshwater pools for an otter to wash and drink is one of the most important requirements for finding otters along the Skye coastline.

Of the geological coastal zones, the Torridonian zone had a higher proportion of all the 'otter variables' than any other zone [mean numbers per 500m section (otters/hour = 2.4, holts = 0.4, sprainting points = 2.5, spraint numbers = 6.3 and freshwater pools = 1.4)] compared with the lowest numbers in the Tertiary Intrusive zone [mean numbers per 500m section (otters/hour = 0, holts = 0.04, sprainting points = 1.5, spraint numbers = 3, freshwater pools

= 0.6)]. The increased activity on the Torridonian coastal zone is attributed to this zone having the greatest number of freshwater pools, a gently sloping shoreline with a boulder intertidal zone and native woodland adjacent to the High Water Mark.

CONTENTS

INTRODUCTION

In the previous chapters I have shown that the geology of the coastal zone has a pronounced effect on the coastal type (e.g. boulder, sandy shore), the slope of the coastline, the width of the intertidal zone and the inland vegetation. The Torridonian coastal zone has a high percentage of boulder coastline, and a high proportion of native woodland adjacent to the High Water Mark compared, for example, with the Tertiary Lava zone which has a mostly rock outcrop coastal composition and little native woodland adjacent to the High Water Mark.

I have also shown (Chapter 3) that the diet, as evidenced from spraint analysis varied along the geological coastal zones for all species except Viviparous Blenny which dominated the diet in all coastal zones. The availability of prey as measured by traps along the different geological coastal zones was studied using unbaited fish traps and it was shown (Chapter 4) that the availability of prey species did not vary for Butterfish and Five Bearded Rockling but did significantly for all other species. A lot of evidence suggests that among animals the nature and abundance of food available are two of the most powerful factors determining the existence and size of a population (Dowdeswell, 1984). However population limiting factors are complicated and a population can be also be limited by crowding, where the population will decrease when its size is above a particular level and increase when its size is below that level (Nicholson, 1957 and 1958; Begon et al, 1999; Sinclair, 1989). Clearly population limiting is complicated and not just related to the availability of food and the

aim of this chapter is investigate what other factors limit the Skye otter population and to consider the various ways of analysing otter presence, which include direct observation, numbers of holts, sprainting points and spraints and to estimate variation in these factors along the different geological coastal zones. Otters on Skye rely almost totally on the marine environment for their foraging and 97% of otter sightings are from this coastal zone (Yoxon and Yoxon, 1990). Environmental variables, such as the number of holts, have been used with a high degree of accuracy to calculate otter numbers (Moorhouse, 1988; Kruuk et al, 1989). On the Isle of Skye some coastlines are seen to have high density populations of otters while others have few (personal observations) and this could be due to the different coastal geology of these shorelines.

I studied the coastline in small intensive study areas and in an extensive study which included 60% of the island's coastline. During this research I was also able to investigate the relationship between otter activity and sprainting along the coastline of the Isle of Skye.
The main questions being asked are:

1. What is the relationship to sprainting and otter activity?
2. What are the ways of analysing otter presence on a coastline?
3. What relationship exists between otter activity and holts, sprainting points, sprainting numbers and freshwater pools (Otter Variables)?
4. What relationship exists between the otter variables and the coastal zones?

STUDY AREAS AND METHODS

The island was divided into 500m coastal sections and each study section was sampled by walking in an acute zig-zag pattern which took in the shoreline and also the inland vegetation 100m from high water. The intensive studies were made on a monthly basis from 1993-1995 on 500m sections of the coastline. the extensive study was made by trained volunteers during the months of August to September in 1994. More information on this is given later in the chapter.

The research was conducted in three parts looking at the following variables, which are referred to as "otter variables":

1. <u>Sprainting behaviour</u>

Sprainting behaviour was studied on two Mesozoic coastlines representing 20 x 500m sections of coastline listed below and shown in Figure 5.1.

1. 5km of coastline on the Ardnish peninsula west of Broadford.
2. 10km of coastline from Camas Malag to Boreraig to the south of Broadford.

Spraints were collected on a monthly basis from 26 sprainting points along the coastline. Sprainting on land is seasonal (Conroy and French, 1987), and it was more difficult to find spraints in the summer than in the winter. Kruuk (1992) showed that otters spraint less per hour per visit in the summer than in the winter. However, having identified the key sprainting points made it easier to find spraints during the low summer season; old spraints will disintegrate within one month. (personal observation and Kruuk, 1986). During the monthly visits records were kept of the otters seen and individual animals were identified using pink patterns on their nose, cuts on their ears, scars, and females with cubs in their home ranges. Records were kept of behaviour before and after sprainting. The sections where visited on a randon bases to avoid visiting the same section at low tide, or morning or afternoon.

2. Numbers of Sprainting Points
Sprainting points were defined as places where one or more spraints or piles of spraints were found. In the coastal environment, spraints are found most frequently on rocky coasts, on well-marked sites at the mouths of rivers, on otter runs or at certain times of the year at the entrance to holts (Conroy and French, 1985, 1987). The droppings add nitrogen to the surrounding area making sprainting points very obvious: grassy areas tend to be very green with a prominent growth of nitrophylous grasses.

3. Number of Spraints
In order to assess the seasonal variation, all spraints were counted on a monthly basis on the same sections of coast.

4. Direct observations of otters (with telescope and binoculars)
Observations were made from a vantage point for 30 minutes in each 500m section before a search of the coastline to count spraints and look for the freshwater pools. During this observation, the coastline was scanned using 10X40 binoculars and a X30 telescope.

5. Number of freshwater pools
A freshwater pool was defined as an area of standing water with a minimum width or length of 0.5m and minimum depth of 0.1m. It was found from personal observation that otters show no signs of utilising pools with dimensions less than this. All freshwater pools which met these criteria were counted and measured and it became evident from the survey that most of these pools had sprainting points adjacent to them but pools without sprainting points were also counted and measured.

The maximum width (W), maximum depth (D) and maximum length (L) of the pools were measured and the approximate volume of each pool was calculated from the following equation:

Volume = Π x (L+W⁄4) x D⁄2 (Wesley 1961)

6. Numbers of holts
Otter holts are very variable and for the purpose of this study they were divided into three distinct types.

Major holts: Defined as a tunnel system with signs of regular use by otters (Kruuk et al, 1989). The evidence of use consisted of tracks, flattened grass, fresh spraints and the characteristic odour in the holt. On Skye, I found holts consisted dominantly of rock piles within 50m of the shore. If two holts were more than 10m apart they were considered separate.

Minor holts: Tunnels with only one entrance where activity is not as apparent as above, although there are signs of regular use by otters.

Lie-ups: Otters use resting places throughout their home range and these are mostly hollows under rocks or within reed/rush beds. They have a path leading to them and a sprainting point associated with them.

For the purpose of analysis only the major and minor holts were included in the count of holt numbers.

Sprainting behaviour was studied from 1990-1993 on a monthly basis and from 1993-1995 observations were extended to cover the various geological coastal zones and 14 sections were studied on a monthly basis. The sections were chosen randomly with at least one in each geological zone. Only one section was chosen from the Cambrian zone as this only represents 1.4% of the Skye coastline and only one from the Tertiary Intrusive zone because of difficulty of access and remoteness and the dangerous aspect of the coastline. Each section was visited for 30 minutes each month and observations were made of spraint numbers and otter activity. If an otter was observed, the time spent in that section was often increased to record the activity. The minimum total time spent in each section was 12 hours with a total of 270 hours spent in the field over the two year period. The study areas are shown in Figure 5.1.

During the summer from August to September 1994, trained volunteers were used to look at another 622 coastal sections accounting for 55% of the Skye coastline. The volunteers came in four groups of 12 for 10 days each. (Total days spent in the field 40 days or 480 man/woman days). Using the Earthkind's boat "Ocean Defender", I was also able to extend the research to cover the small offshore islands of Staffin, Flodigarry, Trodday, Ascribs, Mingay, Isay, Harlosh, Wiay, Tarner and Oronsay.

In September 1995, 29 sections on the Isle of Raasay were also looked at in detail. This gave the total time spent by volunteers in the field of 326 hours.

Each 500m section was surveyed for sprainting points, spraint numbers, freshwater pools and holts by a trained team consisting of three people and the technique is outlined in the Methodology in Chapter 2. A sample of the recording sheet is shown in Appendix 1 and photographs of the otter variables are shown in Plate 5.1. All the Mesozoic and Cambrian coastal zones were surveyed, and over 50% of the Lewisian/Moine and Torridonian were surveyed. Only 21% of the Landslip zone and 37% of the Tertiary Lava coastal zone were surveyed.

The Chi-squared test was used to compare otter variables in the geological coastal zones and Spearman Rank Correlation Coefficients (r_s) were used for the relationship between the different otter variables.

Figure 5.1. Coastal sections studied in the intensive and extensive studies

Plate 5.1. Examples of Otter Variables on Skye
Holt on Torridonian coastline, Sleat peninsula
Freshwater pool, on Mesozoic coastline, Strathaird peninsula

RESULTS

Sprainting

Sprainting in relation to otter activities

There were 469 otter sightings covering 197 hours of actual observation. On most occasions otters were observed foraging, but detailed records were only kept when otters were seen sprainting on land or in the intertidal zone. There were 126 observations made of otters sprainting, representing only 22% of total otter sightings. Of these sprainting sightings, 70% occurred in the intertidal zone.

The observations were divided as follows and are shown in Table 5.1.

1. Swimming-Sprainting-Swimming (S-SP-S)
Otters travelled along the coastline. They would swim, come to land and spraint within 30 seconds, and then swim again.

2. Fishing-Sprainting-Swimming (F-SP-S)
Otters fished before coming on to land to spraint, and then moving away to fish in another area.

3. Fishing-Eating-Sprainting-Swimming (F-E-SP-S)
As (2) but the otter would land a larger fish to eat for about 3-5 minutes before returning to forage again.

4. Fishing-Sprainting-Fishing (F-SP-F)
As (2) but the otter goes directly back to fishing.

5. Mating-Sprainting-Swimming (M-SP-S)
Otters were seen to run and play frantically in and out of the water before mating. After mating the male sprainted on an intertidal rock before moving off.

6. Swimming-Sprainting-Fishing (S-SP-F)
The otter would swim, spraint and then start to fish.

7. Travelling-Sprainting-Fishing (T-SP-F)
Travelling on land before sprainting and then fishing.

8. Swimming-Sprainting-Travelling (S-SP-T)
Otters would swim to a sprainting point, spraint and then travel on land.

The great majority of spraints (50%) were deposited after fishing and before moving away from the area, and 14% occurred when the otters were seen to swim, spraint and swim, which would indicate the continual marking of the home range. Similar results came from Shetland (Kruuk, 1992) where otters sprainted before and after a feeding bout.

Otters sprainted mostly in the intertidal zone, except for occasions when sprainting was associated with travelling on land. Intertidal sprainting occurred on small rocky outcrops after fishing and on many occasions the spraint would only last about 30 minutes before the incoming tide washed it away.

Figure 5.2 shows seasonal variation in intertidal and terrestrial sprainting. There was a marked variation in sprainting with 62% more spraints deposited in the spring and summer in the intertidal zone than in the autumn and winter (χ^2=33.18, df=3, p<0.001), while in the terrestrial zone 47% more sprainting was done in the autumn and winter than in the spring and summer (χ^2=9.6, df=3, p<0.05).

It can be clearly seen therefore that otters prefer to spraint more often in the intertidal zone in the spring and summer and more often in the terrestrial zone in the autumn and winter.

Table 5.1. Observations of otter activity before and after sprainting. (S - Swimming; SP - Sprainting; F - Fishing; E - Eating; M - Mating; T - Travelling on Land). n=126.

ACTIVITY	INTERTIDAL	TERRESTRIAL	TOTAL
S-SP-S	24	5	29
F-SP-S	37	4	41
F-E-SP-S	15	8	23
F-SP-F	3	0	3
M-SP-S	2	0	2
S-SP-F	0	3	3
T-SP-F	0	7	7
S-SP-T	7	11	18
TOTAL	88	38	126

Figure 5.2. Seasonal variation in intertidal and terrestrial sprainting

Seasonal variation in spraint numbers

A total of 871 spraints were counted from the seven geological coastal zones and the seasonal variation for each geological coastal zone is shown in Figure 5.3. A total of 348 spraints were counted in the winter compared to 125 in the summer; this shows that nearly three times as many spraints were found in the winter months than in the summer months and this relationship existed in all geological coastal zones.

Figure 5.3. Seasonal variation in spraint numbers in the seven geological coastal zones from 1993-1995 (n = 871)

Correlations between the otter variables

Spearman Rank Correlation Coefficients were calculated to see if a relationship existed between the otter variables in both the intensive and extensive study. For the extensive study, correlations were calculated for all the seven geological coastal zones. Since the data was collected in August and September 1994 in all zones no correction for seasonality was made. For the intensive study all geological coastal zones were visited on a monthly basis throughout the year. The results are shown in Tables 5.2 and 5.3. Table 5.2 shows the correlations in the extensive study from August to September 1994 and Table 5.3 shows the correlations in the intensive study for all months from 1991-1995.

In the geological coastal zones where otters were observed, significant correlations were found between otter utilisation and holts in the Lewisian, Torridonian, Mesozoic and Landslip zones with no correlation in the Tertiary Intrusive zone. Significant correlations occurred between freshwater pools and otter activity in all zones except the Landslip zone in the extensive study. There was no correlation between otter activity and sprainting points and spraint numbers in all zones except the Tertiary Intrusive which showed a significant correlation between otter activity and sprainting points.

The number of holts showed a highly significant correlation with spraint numbers and sprainting points in all zones, and sprainting points and spraint numbers correlated with the numbers of freshwater pools in all coastal zones. In the intensive study all geological coastal zones were looked at together and the results are shown in

Table 5.3.

Table 5.2. Spearman Rank Correlation Coefficients between the otter variables for the extensive study. Data is from August to September 1994. z values are shown in brackets.
(ns=not significant, p>0.05, *p<0.05,**p<0.01, ***p<0.001)

Lewisian/Moine (n=71)

	Holts	Spraint Points	Spraint No's	Pools
Otters	0.38 (3.18) ***	0.22 (1.84)**	0.18(1.51)ns	0.66(5.52)***
Holts	X X	0.48(4.01)***	0.43(3.59)***	0.05(5.43)***
Spraint Points		X X	0.96(8.03)***	0.65(5.43)***
Spraint No's			X X	0.75(6.26)***

Torridonian (n=85)

	Holts	Spraint Points	Spraint No's	Pools
Otters	0.32 (2.93)**	0.04 (0.36)ns	0.06(0.55)ns	0.46(4.21)***
Holts	X X	0.53(4.85)***	0.49(4.49)***	0.33(3.02)***
Spraint Points		X X	0.93(8.52)***	0.64(5.86)***
Spraint No's			X X	0.63(5.77)***

Cambrian (n=17)

No otters were observed

	Holts	Spraint Points	Spraint No's	Pools
Holts	X X	0.61(2.44)**	0.52(2.08)**	0.21(0.84)ns
Spraint Points		X X	0.97(3.88)***	0.57(2.28)**
Spraint No's			X X	0.54(2.16)**

Mesozoic (n=99)

	Holts	Spraint Points	Spraint No's	Pools
Otters	0.19 (1.89)*	0.24 (2.37**	0.22(2.17)**	0.54(5.34)***
Holts	X X	0.42(4.15)***	0.35(3.46)***	0.19(1.88)*
Spraint Points		X X	0.87(8.61)***	0.56(5.54***
Spraint No's			X X	0.51(5.04)***

Tertiary Lavas (n=206)

No otters were observed

	Holts	Spraint Points	Spraint No's	Pools
Holts	X X	0.26(3.72)***	0.25(3.58)***	0.20(2.86)**
Spraint Points		X X	0.97(13.8)***	0.74(10.5)***
Spraint No's			X X	0.74(10.5)***

Tertiary Intrusive (n=104)

	Holts	Spraint Points	Spraint No's	Pools
Otters	0.04 (0.41)ns	0.18 (1.82)*	0.15(1.52)ns	0.56(5.68)***
Holts	X X	0.31(3.14)***	0.32(3.24)***	0.11(1.11)ns
Spraint Points		X X	0.98(9.95)***	0.69(7.00)***
Spraint No's			X X	0.69(7.00)***

Landslip (n=41)

	Holts	Spraint Points	Spraint No's	Pools
Otters	0.39 (2.46)**	0.17 (1.07)ns	0.14(0.88)ns	0.26(1.64)ns
Holts	X X	0.45(2.84)**	0.37(2.34)**	0.10(0.63)ns
Spraint Points		X X	0.95(6.00)***	0.57(3.60)***
Spraint No's			X X	0.63(3.98)***

Table 5.3. Spearman Rank Correlation Coefficients between the otter variables for the intensive study from 1991 to 1995. n = 184. z values are shown in brackets. (ns=not significant, p>0.05, *p<0.05, **p<0.01, ***p<0.001)

	Holts	Spraint Points	Spraint No's	Pools
Otters	0.40(5.41)***	0.16(2.16)*	0.15(2.02)*	0.18(2.43)**
Holts	X X	0.48(6.4)***	0.42(5.68)***	0.38(5.14)**
Spraint Points		X X	0.52(7.03)***	0.38(5.14)***
Spraint No's			X X	0.39(5.27)***

Very highly significant correlations occurred between otter activity and holt numbers, holts and sprainting points and spraint numbers; sprainting points and spraint numbers and freshwater pools; and spraint numbers and freshwater pools. Highly significant correlations also occurred between otter activity and freshwater pools and holts and freshwater pools and significant correlations also occurred between otter activity and sprainting points and spraint numbers.

Variation in otter activity over the different geological coastal zones

Intensive Study

Fourteen 500m coastal sections were surveyed from February 1993 to February 1995. histograms of each otter variable are shown in Figure 5.4.

Visual observations of otter activity were recorded as otters seen per hour in each 500m coastal section. (30 minutes were spent in each section per month and the number of otters seen recorded; otters per hour was calculated by dividing the total number of otters seen by the hours spent watching). Table 5.4 shows Chi-squared tests for all the otter variables and highly significant differences were found between all these variables and the geological coastal zones.

The greatest number of otters was seen in the Torridonian coastal zone (2.2 otters per hour observation) compared with none observed in the Tertiary Lava and Intrusive coastal zones. Holt numbers were also greater in the Torridonian zone, amounting to 1.3 holts per 500m coastal section compared with no holts found in the sections surveyed in the Tertiary Intrusive and Lava coastal zones.

Sprainting points were present in all zones from one per 500m section in the Tertiary Intrusive zone to six per 500m section for the Torridonian zone. Total spraint numbers were greatest in the Landslip and Torridonian zone and lowest in the Tertiary Intrusive.

The final variable was the number of freshwater pools available to the otters and the greatest number available was again found in the Torridonian zone (4.4 per 500m coastal section) compared with none found in the Tertiary Intrusive zone.

Overall the Torridonian coastal zone had the greatest number of all otter variables and is the most favoured habitat for otters in this study area.

Figure 5.4. Variation in otter sightings, holt numbers, sprainting points, spraint numbers and freshwater pools in relation to the geological coastal zones in the intensive study.

Table 5.4. Chi-squared tests for otter variables in relation to geology (=p<0.001, **=p<0.05, ns=p>0.05). The null hypothesis is that no difference in the otter variables between the geological coastal zones can be ascribed to chance.***

VARIABLE	χ^2	**df**	**p**
OTTER ACTIVITY	29.1	6	***
HOLTS	32.4	6	***
SPRAINTING POINTS	65.0	6	***
SPRAINT NUMBERS	83.4	6	***
FRESHWATER POOLS	59.7	6	***

<u>Extensive Study</u>

The volunteers carried out a survey of 622 x 500m coastal sections accounting for 60% of the Skye coastline, and representing 320 hours observation of the coastal sections. The percentage of the geological coastal sections and number of sections surveyed in each coastal zone are shown in Table 5.5. Figure 5.5 shows the variation in otter sightings, holt numbers, sprainting points, spraint numbers and freshwater pools in relation to the geological coastal zone in the extensive study. The null hypothesis was set up that no differences existed between the otter variables and the geological coastal zones that could not be ascribed to chance and Table 5.6 shows the Chi-squared results for these otter variables. Very highly significant differences occurred between sprainting points and spraint numbers and the geological coastal zones, highly significant differences were found comparing otter activity and freshwater pools and significant differences occurred when comparing holt numbers in the different geological coastal zones.

Table 5.5. Number of 500m sections surveyed in each geological coastal zone and the percentage of the total coastal area covered by that particular geological type (Total Geology).
(Activity is number of times otters observed in 30 minutes of observation in each 500m coastal zone. Sprainting points, spraint numbers, holts and pools were found in a 50m wide strip along each section). Results show the mean numbers per 500m coastal section with the standard error.

GEOLOGY	SECTIONS SURVEYED	% TOTAL GEOLOGY	OTTERS	HOLTS	SPRAINT POINTS	SPRAINTS	POOLS
LEWISIAN	71	74	0.03±0.02	0.13±0.05	0.98±0.20	2.30±0.71	0.42±0.14
TORRIDON	84	62	0.23±0.07	0.45±0.08	2.5±0.28	6.3±0.56	1.36±0.16
CAMBRIAN	17	100	0	0.2±0.16	1.78±0.68	4.6±0.68	0.5±0.22
MESOZOIC	99	100	0.12±0.05	0.29±0.06	1.83±0.20	4.5±0.54	0.69±0.10
TERT LAVA	206	37	0	0.05±0.02	1.51±0.15	2.95±0.31	0.61±0.07
INTRUSIVE	104	98	0.02±0.01	0.07±0.03	1.11±0.2	2.72±0.39	0.47±0.10
LANDSLIP	41	21	0.05±0.03	0.34±0.01	2.39±0.45	4.49±0.72	0.73±0.21

Figure 5.5. Variation in otter sightings, holt numbers, sprainting points, spraint numbers and freshwater pools in relation to the geological coastal zones in the extensive study.

Table 5.6. Chi-squared tests for the variation in otter activity, holt numbers, sprainting points, spraint numbers and freshwater pools in the seven geological coastal zones.
(=p<0.001, **=p< 0.05, *=p<0.01, ns= p>0.05)***

VARIABLE	χ^2	**df**	**p**
OTTER ACTIVITY	13.2	6	**
HOLTS	12.1	6	*
SPRAINTING POINTS	23.5	6	***
SPRAINT NUMBERS	58.9	6	***
FRESHWATER POOLS	17.9	6	**

A total of 36 otters were observed by volunteers and most were seen in the sea moving along the coast between areas; in all cases they were no more than 40m from the shore. The majority were observed on Torridonian coastlines (mean = 0.23 otters per 500m coastal section observed in 30 minutes of observation) compared with no otters observed in the Tertiary Lava coastal zone after 102 hours of observation. Holt numbers (mean = 0.45), sprainting points (mean = 2.5), spraint numbers (mean = 6.4) and freshwater pools (mean = 1.4) were higher in the Torridonian zone than in any other.

Sprainting points and spraint numbers were lowest in the Tertiary Intrusive zone (1.2 and 3 respectively) and freshwater pools lowest in number in the Landslip zone (0.4 per 500m coastal section).

Freshwater Pools

The majority of freshwater pools occurred in the Torridonian coastal zone accounting for 1.36±0.16 pools per 500m coastal section compared with 0.61±0.07 pools per 500m coastal section for the Tertiary Lava zone.

The maximum width (W), maximum depth (D) and maximum length (L) of the pools utilised by otters was measured and the approximate volume of each pool was calculated using the equation already mentioned.

Comparisons of pool volumes in the different geological zones are shown in Table 5.7. For all pools used by otters the mean volume was 1.77 m^3 (SE=0.24).

However, since the sample mean is calculated for every measurement in the sample, the data will be biased by a few samples at the extreme ends of the scale which will affect the sample mean by pulling it towards the end. For this reason, the median is also shown where these measurements have this skewed distribution. The median is not effected by the precise values of the extreme measurements.

Table 5.7. Comparisons of pool volume (m^3) between the geological coastal zones.

CATEGORY	n	MIN	MAX	MEAN	STANDARD ERROR	MEDIAN
TOTAL	391	0.001	42	1.77	0.24	0.36
LEWISIAN	30	0.0012	5.8	0.64	0.25	0.09
TORRIDONIAN	109	0.02	12.6	1.12	0.18	0.3
CAMBRIAN	6	0.001	2.4	0.83	0.4	0.5
MESOZOIC	57	0.001	42	2.02	0.89	0.3
TERT LAVAS	121	0.001	36	2.08	0.47	0.45
TERT INTRUSIVE	44	0.02	33	1.95	0.76	0.39
LANDSLIP	24	0.02	22.8	3.71	1.35	0.8

Pool volume varied from 0.001 to 42m^3. The highest pool volumes were found in the Mesozoic (42m^3) and the Tertiary Lava (36m^3) with the largest pools in the Cambrian zone being only 2.4m^3. A Kruskal-Wallis analysis of variance was used to compare the distribution of volumes on all geological coastal zones and showed the following result: χ^2=18.1, df=6, p=0.059. Therefore, when comparing the medians there is no evidence that they come from different populations and no geological variation in the size of the freshwater pools was recorded.

Comparisons between intensive and extensive sampling and some conclusions with regard to geology and otters

Comparisons between the intensive and extensive study were undertaken and the results are shown in Table 5.8 and Figure 5.6. The intensive study has been corrected by just counting spraints from August to September, the same months as the extensive study. Overall, more activity, holts, sprainting points and freshwater pools were found in the intensive study compared to the extensive study. This is possibly due to the fact that the volunteers do not have the experience of tracking and watching otters and so observe less. The exception to this was in the Tertiary Intrusive zone where all the variables were greater in the volunteer study. This may be explained by the small sample for the zone in the intensive study.

Spearman Rank Correlation Coefficients were calculated to compare the variables in each geological coastal zone and highly significant correlations occurred in all the zones ($p<0.001$) with the exception of the Tertiary Intrusive zone ($p>0.05$), possibly again due to the small sample in the intensive study.

By comparing the variables in the seven geological coastal zones for the intensive and extensive studies, certain predictable patterns emerge with greater activity, more holts, more sprainting points, more spraints and more freshwater pools occurring in the Torridonian coastal zone in both the intensive and extensive than any other geological coastal zone. Low numbers of all these variables occurred in both the Tertiary Intrusive and Tertiary Lava coastal zones.

Table 5.8. Comparisons between otter activity, holt numbers, sprainting points, spraint numbers and freshwater pools in the seven geological coastal zones for the Intensive (Int) and Extensive (Ext) study. (Values are mean values for the 500m coastal sections corrected for seasonality)

Geology	Activity		Holts		Spraint Pts		Spraint No's		Pools	
	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext
Lewisian	0.2	0.03	0.5	0.13	1.5	0.98	3	2.3	0.5	0.42
Torridon	1.12	0.23	1.33	0.45	5.6	2.5	6.2	6.3	4.3	1.36

Cambrian	0.29	0	1	0.2	2	1.78	3.6	4.6	3	0.5
Mesozoic	0.52	0.12	1	0.29	2.5	1.83	3.8	4.5	1	0.69
Tert Lava	0.03	0	0	0.05	2.3	1.51	2.7	2.95	2	0.61
Tert Int	0	0.02	0	0.07	1	1.11	1	2.72	0	0.47
Landslip	0.39	0.05	0.5	0.34	4.5	2.39	3.2	4.49	2	0.73

Figure 5.6. Comparisons between otter activity, holt numbers, sprainting points, spraint numbers, freshwater pools and geology in relation to the intensive and extensive studies.

DISCUSSION

The interpretation of the results are based on the following assumptions:
(i) All holts, freshwater pools, sprainting points, spraints and otters were observed and counted correctly during both surveys.

(ii) The sections sampled were a true representation of the Skye coastline and represented random distribution over the different geological coastal zones.

With regard to (i) in the intensive study the sections were visited on a monthly basis over a two year period and it would be difficult for me to miss any holts or other signs in this intensive survey. In the extensive study the volunteers were given a test section and had to obtain 80% accuracy on this; if the group did not obtain this, their results were not used. In four test sections used for the counting of holts, volunteers underestimated the number of holts by 18% but accurately counted all the other variables in a 25km section of coastline. Overall this would underestimate the number of otter holts in all geological coastal zones and not affect the overall conclusion of the results.

With regard to (ii) the intensive sections were chosen at random and were representative of all geological coastal zones. In the extensive study 100% of the Mesozoic and Cambrian coastlines were visited and over 50% of the Lewisian/Moine and Torridonian were surveyed. Only 21% of the Landslip zone and 37% of the Tertiary Lava coastal zone were surveyed. Overall 55% of the Skye coastline was surveyed and this sampling intensity was high (Norton-Griffiths, 1973).

Practical difficulties did exist in surveying some of the coastline due to dangerous cliffs such as the Torvaig to Bearreraig Bay Landslip section and the Torridonian section from Loch na Beiste to Rubha na Caillich. The Tertiary Lava area from Idrigill Point to Waterstein Head was also difficult to survey due to the difficult terrain.

Relationship between spraints and otter activity

Otters showed a marked seasonality in sprainting with a three-fold increase in spraint numbers observed in the winter months. This seasonality was seen to occur in all geological coastal zones and was not attributed to otters producing more droppings in the winter but for their preference to deposit more spraints in the intertidal zone in the spring and summer months. This compares with work on Shetland by Conroy and French (1987) who counted more spraints in the early spring and winter and low numbers in the summer and found that this pattern was repeated on different coastal types. Kruuk (1992) also found more spraints deposited on land in the winter months than in the spring and summer, and attributed this seasonality in sprainting to coincide with a peak in numbers of potential prey in midsummer (when there are fewer spraints) and a trough in winter and spring (the times of most spraints).

Looking at the total number of spraints during the survey, 70% were deposited in the intertidal zone as distinct from on land, compared with 32% found on Shetland by Kruuk (1992). Exactly what spraints signify is complicated to ascertain; the majority on the Isle of Skye were deposited after fishing (50%), which is similar to Shetland where Kruuk and Moorhouse (1991) found that 66% of sprainting occurred before or after fishing, and on Skye 14% were also deposited when the otter moved along its home range.

Kruuk (1992) argued that the scent marks were functional for no more than a few hours and signified the use of resources rather than any long term aim (an otter would fish and then spraint on land or wash in a freshwater pool and then spraint next to it); he rejects the sexual communication function of spraints and partly rejects the marking out of territorial boundaries by the fact that larger numbers of spraints are not found on the boundaries. He suggests that spraints signify the use of resources like freshwater pools, feeding patches etc and the high percentage of spraints deposited in the intertidal zone would support the hypothesis that spraints have a short term function rather than long term significance. On many occasions the spraints were only present for a matter of hours before the tide covered them and it would seem that, with the large number of spraints being deposited in the intertidal zone, the spraint's function is for such short term communication.

Like many carnivores, the otter has scent-producing organs and an anal scent is deposited on the spraint. However, relatively little is known of the chemistry of social odours in carnivores (Albone, 1984) and the actual communication function is the subject of much debate. There have been many proposed functions including individual or group recognition and these are not attributed to a single chemical compound but to differences in the relative concentrations of the constituents of this complex chemical mixture. These differences have not only been reported in the Eurasian otter (*Lutra lutra*) (Trowbridge, 1983), but also in the stoat (*Mustela erminea*) (Brinck et al, 1983), brown hyena (*Hyaena brunnea*) (Mills et al, 1980), red fox (*Vulpes vulpes*) (Albone and Perry, 1976) and the European badger (*Meles meles*) (Gorman et al, 1984).

The exact chemical composition of spraint of the Eurasian otter was analysed by Trowbridge (1983), who extracted the scent from the spraint using ether and subjected the extract to gas chromatography analysis. The scent was found to consist of over 100 separate compounds and one compound was found to form a high proportion in all samples; this was also less volatile and lasted a long time so she concluded that this might be the compound that spelled "otter" to any other animals.

Using trials with captive otters, Trowbridge (1983) also found that they were able to distinguish individuals by smelling the spraint, and that over 80% of the spraints could be accurately identified by the captive otter. Mason and Macdonald (1980) at Loch Broom in north west Scotland used the spraint of a captive otter and put it on spraint piles in the natural environment to compare how many of these sites were visited compared to some controlled areas. They found that the wild otters responded to these foreign spraints by sprainting more often on these piles than on the controlled sections.

In Russia, Rozhnov and Rogoschik (1994) found that the Eurasian otter was able to distinguish between its own spraint and that of other otters and their results showed that this could be up to 30 days after the spraint was deposited.

While the debate about the exact significance of spraints will continue it cannot be questioned that they do play an important role in the social organisation of otters. The otter is a complex creature living a complex life in which the social order is maintained by the transmission of information between individuals by sight, sound or in the odour on the spraint. It would, however, seem likely that sprainting is associated with the utilisation of food resources more than anything else. The strong association of sprainting before and after fishing and the high percentage in the intertidal zone after fishing would seem to signal the exploitation of that area of fish and would be a signal to other otters to keep away as it would be detrimental for them to arrive at this feeding area to find another otter had depleted it.

In both the intensive and extensive studies highly significant correlations existed between holt numbers and otter activity and highly significant correlations occurred between all geological coastal zones and all variables. No correlations existed between sprainting points and spraint numbers and otter activity in the intensive study but a significant correlation did exist in the extensive study.

Spraints have been used for many years to survey otter populations (Mason and Macdonald, 1986; Green and Green, 1980, 1987 and 1997; Strachan et al, 1990; and Andrews et al, 1993). Conroy and French (1987) found significant correlations between the number of spraints and the number of otters seen over large stretches of coast in Shetland but also found certain stretches of coast had more otters than would be expected from the number of spraints counted. They concluded that the only variable that can be used with any statistical certainty to represent otter activity in a 500m coastal section is the number of holts, and the interpretation of otter activity using spraint numbers or sprainting points should be treated with caution.

Kruuk (1987) argues that spraints are inherently difficult criteria on which to base evidence of otter numbers because they will be effected by several behavioural or individual variables, for instance seasonality, defecating in water, reproductive effect. On Skye, I found correlations between sprainting and otter activity only in the extensive study, but these correlations only represent otter utilisation of a particular 500m section and spraint numbers, and to use this to estimate actual otter numbers would require far more work in this field. However, one of the major requirements for any conservation programme is an accurate monitoring system and it would seem that for the otter in England which is nocturnal and secretive, the use of spraints is the only acceptable method with which to monitor them.

Freshwater Pools

Freshwater pools are used by otters to maintain the insulating properties of their fur by washing out the salt contamination (Kruuk and Balharry, 1990). Otters, unlike most marine mammals, have a very thin adipose tissue layer (Pond and Mattacks, 1985), (Tarasoff, 1974), and rely instead on a thin layer of air trapped in their fur (Kruuk and Balharry, 1990). Kruuk and Balharry (1990) also showed that the fur of an otter lost much of its thermal insulation after five soakings in salt water.

The necessity for the Eurasian otter to visit freshwater pools frequently has been demonstrated from observations in Shetland (Kruuk and Balharry, 1990), (Yoxon, personal observation) and also from other species of otter: the Cape Clawless Otter (*Aonyx capensis*) in South Africa where Van der Zee (1981) observed them frequently visiting freshwater pools after foraging in the sea; and Dr Carlos Olavarria in Chile (personal communication) showed that the Marine Otter (*Lutra felina*) visits freshwater pools or streams after being immersed in salt water.

It has been well documented by Kruuk et al (1989) that there is a dependence on freshwater pools which were strongly correlated with the occurrence of otter holts along the Shetland coastline. It is also clear that geology plays an important part in the distribution of freshwater pools along the Isle of Skye coastline, with correlations between geology and otter utilisation.

Lovett (1994) and Lovett et al (1997), also looked at freshwater pools on the Torridonian sandstone coastline on the Isle of Skye and showed that pool utilisation was related to three factors, namely pool depth, amount of short grass surrounding the pool and the percentage of pool substrate composed of flat rock.

In work undertaken by the International Otter Survival Fund, Priestley (1996) found a positive correlation between salinity of the pool and the presence or absence of spraint. Sprainting was concentrated within a very narrow salinity range and there is a clear relationship between sprainting and low salinity pools. Although he did not find a critical salinity above which otters would disregard a pool for bathing, he clearly showed that the otter prefers to wash in water of low salinity (Approx $\leq$0.5%NaCl) .

On Skye, correlations between otter activity and the number of freshwater pools existed in both the intensive and extensive studies except for the Landslip zone in the extensive study. Highly significant correlations occurred between sprainting points and spraint numbers in both studies and it is therefore concluded that the availability of freshwater pools for an otter to drink and wash is critical in finding an otter population in a particular coastal section, and the Torridonian coastal section has the most favourable conditions for these freshwater pools.

Relationship between geology and otter activity
By comparing the variables in the seven geological coastal zones in both studies certain predictable patterns emerge with more activity, holt numbers, sprainting points, spraint numbers and freshwater pools being found on the Torridonian coastal zone compared with all others. Both the Tertiary Lavas and Tertiary Intrusive showed low numbers of each.

Until now, little was known about the relationship between otter utilisation and geology.
On Shetland, Milner (1975) categorised major coastal types and identified eight major coastal types using 81 physical and 18 geological attributes. Conroy and French (1985) classified the Shetland coast using over 200 attributes which were grouped into seven headings. Still on Shetland, Kruuk (1989) grouped the coast into six types based on evidence from maps, reports and prior knowledge of the area. He found a strong relationship between numbers of holts and peaty coasts with little agriculture and no high cliffs; he found a negative association between holts and tall cliffs.

On Orkney there are few otters, in sharp contrast to Shetland, (Kruuk, 1995). This difference could possibly be attributed to distribution of prey species but it seems likely that Orkney shores are just as productive as those of Shetland. Green and Green (1997) stated, "that despite the productive nature of Orkney's fresh and coastal waters, the otter population was less dense than those of other island regions or parts of mainland Scotland". A more likely reason for the difference is the geology of the Orkney coast, which makes it a less suitable habitat for otters.

The Torridonian sandstone on Skye is impervious and has very low porosity (Dr Tim Astin, Department of Geology, Reading University, personal commmunication), allowing freshwater pools to build up readily on the coastal fringe. By contrast, Devonian sandstone has a high degree of porosity and permeability (many oil reservoirs are present in Devonian sandstone), and so it would be difficult for freshwater pools to build up on these rock types in the same numbers as on the Torridonian sandstone. The Orkney landscape is composed of Devonian sandstone and is well drained with rich farmland. The low density of otters from Dunnett Head to the Moray Firth could equally be a consequence of the geology of the coastal fringes, which also consist of Devonian sandstone.

In Skye, the coasts most favoured by otters are the Torridonian and Mesozoic coastlines with the Tertiary Intrusive and Lavas being the least favoured. Chapter 1 showed certain other attributes possessed by these different geological coastlines.

In detail we see the Torridonian coastal zone was dominated by heights of 5-10m at a distance of 25m from High Water, with no heights greater than 50m. The intertidal make-up was dominated by boulder shore line and the inland vegetation was grassland with an abundance of native woodland. The Tertiary Intrusive and Lavas had dominant heights of 50-100m with 8% of heights over 100m; the intertidal make-up was dominated by rock outcrop and the inland vegetation grassland with little native woodland.

It can be concluded, therefore, that when looking at habitat use by otters the Torridonian coastal zone was favoured because it possessed the greatest number of freshwater pools, had gently sloping shorelines with a boulder intertidal zone and plenty of native woodland adjacent to the High Water Mark for cover. The gently sloping shoreline will give the otter a wider area in which to feed as they are limited by depth of water (Kruuk, Wansink and Moorhouse, 1990).

The least favoured habitat, the Tertiary Intrusive, had a low density of freshwater pools, steeply sloping shorelines with a rock outcrop intertidal zone with little native woodland cover.

Chapter 6

A model of the effect of environmental variables on the presence of otters along the coastline of the Isle of Skye

Synopsis

A survey of the distribution of otters (*Lutra lutra*) along the coastline of the Isle of Skye has revealed that although the otter is common in some coastal types they are relatively uncommon in others. It has been shown in other chapters that although food availability plays a role in limiting the otter population on the Tertiary Lava zone it does not seem to be the limiting factor for otter distribution along the other geological coastal zones. Other factors like the geological composition, the width of the intertidal zone, the intertidal make up, the slope of the coastline, the inland vegetation or the number of freshwater pools could play a part in otter distribution and utilisation of this coastal zone. These factors have led me to apply a quantitative method taking into account four scalable and three categorical variables of the environment which may or may not influence otter distribution. The technique was based on a logestic regression model. I recorded the presence (1) and absence (0) of otters in 500m coastal sections (based on otter sightings, holts and spraints) and compared these binary dependent variables with a set of independent variables on 622 sites around the Skye coastline. The analysis shows that this method can be used to characterise combinations of factors to predict if otters are likely to occur on a particular coastline. The geology, the height 25m from the High Water Mark (which is an indication of the slope of the coastline), and the number of freshwater pools all have an effect on the utilisation of the coastal zone by otters. The Torridonian, Mesozoic and Landslip coastlines have a positive effect on finding otters while all other coastlines have a negative effect. Although the model is primarily of theoretical importance, it could be used as a tool to locate coastlines which are of potential conservation importance for otters.

CONTENTS

INTRODUCTION

The preceding chapters have shown that on the Isle of Skye the geology of the coastal zone has an effect on the number of freshwater pools, intertidal make up, slope of the coastline, width of coastal fringe and inland vegetation. I have also shown that although the diet as it appears from spraint analysis is similar on all the geological coastlines, the availability of prey is lower on the Tertiary Lava coastline. The distribution of otters is not even; there are places where the population density was found to be high (eg. Torridonian coastlines), while in other areas there were few signs (eg. Tertiary Lava coastline). In this chapter, I want to explore what other factors may affect the otter population on the other geological coastlines by bringing together several environmental variables to try and predict the presence or absence of otters around the coastline.

In earlier studies in other areas, a variety of factors have been used to predict the presence or absence of otters. Mason (1997) found that heavy metals and organochlorines correlate with the absence or decline of otters but in non-polluted areas, as on the north west coastline of Scotland, other factors are important such as the presence of bankside vegetation (Mason and Macdonald, 1986), water depth (Glimmerveen and Ouwerkerk, 1984), peaty coastlines and the presence of freshwater pools (Kruuk et al, 1989). In Ireland (Lunnon and Reynolds, 1991) found that two habitat quality factors, namely water pollution and bankside vegetation, had an effect on otter presence or absence, and in Hungary, Kemenes and Demeter (1995) looked at various environmental variables and found that depth of water and the density of bankside vegetation are the two factors which have the greatest influence on the occurrence of otters in particular sites.

On Skye, the occurrence of otters is influenced by several characteristics of the habitat. In order to obtain a more realistic picture of the combined effect of a variety of environmental factors on the distribution of otters around the Skye coastline, I employed a quantitative multivariate method and looked at the variables and their relationships which might influence the occurrence of otters.

METHODS

The Isle of Skye can be divided into into 1139 x 500m coastal sections as outlined in Chapter 5, of which 621 were surveyed.

The utilisation of a particular 500m coastline by otters was ascertained using three methods:

1. Direct observation of otter activity, or
2. Presence of holts, or
3. A sprainting point.

A score of 1 was assigned if otters utilised the 500m section by any of the above three criteria, a score of 0 if no signs of otter were found. Statistical analysis was done using SPSS Version 6 for Windows.

The variables used in the study

<u>*Scalable variables*</u>

At each 500m section three scalable and four categorical variables were recorded. The scalable variables are shown in Table 6.1.

A freshwater pool was defined as an area of standing water with a minimum width or length of 0.5m and minimum depth of 0.1m and has been described in the previous Chapter 5. It was found from personal observation that otters show no signs of utilising pools with dimensions less than this.

<u>*Categorical variables*</u>

In logistic regression the codes of the independent variables must be meaningful (Norusis, 1994). It is not valid to take a nominal variable such as vegetation, assign an arbitrary code from 1-5 and then use the resulting variable in the model. For this reason, the four categorical variables were recoded to create a new set of variables that correspond in some way to the original categories. The new coded variables then for example scrub vegetation then compares scrub vegetation with the average effect on the prescence of otters of all the other vegetation types. The categorical variables are shown in Table 6.2.

In my model I wanted to compare the effect of each category to the average effect of all the categories, and used the deviation default coding and the coefficients of the new variables created to represent the effect of the new variable on the average effect of all the other categories (Norusis 1994). With this coding system, the logistic regression coefficients show how much better or worse each category is compared to the average effect of all the categories. The number of new variables required to represent a categorical variable will be one less than the number of categories. The coefficients of a categorical variable are relative, and the results for geology and vegetation should all be quoted rather than just one in isolation.

Table 6.1. Scalable variables recorded during the survey of the distribution of otters around the Skye coastline

PARAMETER	SCALE
Width of Tidal Zone (W)	Maximum width of each 500m section
Height 25m from HWM (H)	The height was recorded in the centre of each 500m section 25m from the High Water Mark.
Number of Pools (P)	Number of pools in each 500m section

Table 6.2. Categorical variables recorded during the survey of the distribution of otters on the Isle of Skye

PARAMETER	CATEGORY
Geology (G)	1=Lewisian/Moine 2=Torridonian 3=Cambrian 4=Mesozoic 5=Tertiary Lavas 6=Tertiary Intrusive 7=Landslip
The dominant boulder size in each 500m section.	1>20cm 2<20cm
Intertidal Make- Up(I)	1=Muddy 2=Sandy 3=Shingle 4=Boulder 5=Rock Outcrop
Inland Vegetation (V)	1=Heather 2=Scrub 3=Grassland 4=Native Wood 5=Plantation

Model

Logistic regression analysis uses presence-absence data on the dependent variable (otter utilisation) to produce a regression model giving the probability of the occurrence of otters on a 500m section of coast given particular values of independent variables (environmental attributes). A detailed account of the technique is given in Norusis (1994).

The model can be written in terms of the probability of otters occurring (the ratio of the probability that they will occur to the probability that they will not).

$$\frac{Prob\ (otter)}{Prob\ (no\ otter)} = e^{B0+B1X1.....BsXs}$$

Where B_1 and B_s are coefficients estimated from the data, X is the independent variable and e is the base of the natural logarithms.

Then e raised to the power B_i is the factor by which the odds change when the *i*th independent variable increases by one unit. If B_i is positive this factor will be greater than 1 and the odds are therefore increased. If B_i is negative the factor will be less than 1, which means the odds are decreased. When B_i is 0 the factor will be equal to 1, which leaves the odds unchanged.

For several independent variables the model can be written:

Probability of otter utilising section (Prob O) = $\frac{1}{1+e^{-z}}$

e = base of natural logarithms
z = linear combination of the environmental attributes, and can be written:
z = B0+B1X1+ B2X2.....BsXs

A plot of logistic regression curve for z values between 5 and -5 is S-shaped. The relationship between the independent variables and the probability is non-linear, and the probability estimates will always be between 0 and 1, regardless of the value of z. If the estimated probabilities of an otter occurring were less than 0.5, I predicted otters would not be present and if the probability was greater than 0.5, I predicted otters would be present.

Backward stepwise regression was used for this model. In this all variables are first entered in the model in a single step. The variables are then examined for removal one by one. Once no more variables meet removal criteria, or when the model is identical to the previous one the algorithm stops.

Many ways exist to see if the model fits the data. In my study I used classification tables to compare my predictions to the observed outcomes. I also used a graph to see the distribution of the predicted probabilities.

RESULTS

Table 6.3 shows the parameter estimates for the logistic regression model for backward stepwise regression based on the available data. The geology of the coastal section , which although showed a relationship between height and pools in chapter 5 was included in this calculation so that a full comparison in the logistic regression model could be made. Significant results were obtained for the variables Geology, [Lewisian, (Geology 1), Torridonian, (Geology 2), Tertiary Lavas (Geology 5)], and also from freshwater pools and height. The coefficient for the Landslip (Geology 7) which is not displayed is no longer 0 but the negative of the sum of the displayed coefficients and is:

-(-1.093+0.982-0.204+0.473-0.611-0.405) = 0.85

The linear combination of environmental variables can be written:

z = 2.9(P) - 0.013(H) - 1.09(Lewisian) + 0.98(Torridonian) - 0.61(Tertiary Lava) + 0.85(Landslip) - 0.3064.

Where H = height and P = freshwater pools.

If the geology was obmitted from the calculation the equation would be written:
z = 2.9(P) - 0.014(H) - 0.47

The positive logistic regression coefficient (B) values in Table 6.3 indicates that having more Torridonian (Geology 2) and Landslip (Geology 7) coastlines would increase the probability of finding otters, and increasing the number of freshwater pools would have a positive effect on finding otters. A negative logestic regression coefficient (B) of the height marker and the Lewisian, (Geology 1) and Tertiary Lava (Geology 5), indicates that increasing the slope of the shoreline and having more of these geological coastal types would have a negative effect on finding otters. The values for the geology are only relative, and Table 6.3 for geology shows that the Lewisian (Geology 1) has a negative effect on finding otters compared with the average effect of all the other variables.

The degree to which a unit change in these independent variables changes the odds of finding otters is not equal: the odds of finding otters are much more resistant to a unit change in the number of pools (Exp(B)=18.2) than any other variables.

The other variables investigated, are not in the equation and are shown in Table 6.4, because these logistic regression coefficients were not significantly different from 0. They can therefore be expected to have only a small effect on the probability of finding otters.

Table 6.3. Results of backward stepwise regression model
B: Logistic regression coefficient
SE: Standard error of the logistic regression coefficient
Sig: Significance of Wald statistic. (The Wald statistic has a chi-square distribution. When a variable has a single degree of freedon the Wald statistic is the square of the ratio of the coefficient to its standard error)
R: Partial correlation coefficient of the individual variable
Exp(B): Factor by which the odds of finding otters change when the individual unit increases by one unit
Variables in the equation

VARIABLE	B	S.E	WALD	df	SIG	R	EXP(R)
GEOLOGY			38.51	6	0.00	0.18	
GEOLOGY(1)	-1.09	0.31	12.04	1	0.00	-0.11	0.34
GEOLOGY(2)	0.98	0.33	8.64	1	0.00	0.09	2.67
GEOLOGY(3)	-0.20	0.52	0.15	1	0.69	0.00	0.82
GEOLOGY(4)	0.47	0.25	3.53	1	0.06	0.04	1.60

GEOLOGY(5)	-0.61	0.21	8.74	1	0.00	-0.89	0.54
GEOLOGY(6)	-0.41	0.25	2.59	1	0.11	-0.03	0.67
HEIGHT	-0.01	0.01	5.24	1	0.02	-0.06	0.98
POOLS	2.90	0.33	76.11	1	0.00	0.29	18.24
CONSTANT	-0.31	0.17	3.22	1	0.07		

GEOLOGY(1) = Lewisian, GEOLOGY(2) = Torridonian, GEOLOGY(3) = Cambrian, GEOLOGY(4) = Mesozoic, GEOLOGY(5) = Tertiary Lava, GEOLOGY(6) = Tertiary Intrusive. HEIGHT = Height 25m from High Water Mark. POOLS = number of freshwater pools.

Table 6.4. Variables not in the backward stepwise regression model
Sig: Significance of Wald statistic
R: Partial correlation coefficient of the individual variable

VARIABLE	SCORE	df	SIG	R
BOULDER	0.81	1	0.37	0.00
COAST	5.35	4	0.25	0.00
COAST(1)	0.04	1	0.83	0.00
COAST(2)	0.71	1	0.40	0.00
COAST(3)	0.00	1	0.90	0.00
COAST(4)	0.76	1	0.38	0.00
VEG	2.23	4	0.69	0.00
VEG(1)	0.51	1	0.47	0.00
VEG(2)	0.24	1	0.63	0.00
VEG(3)	0.82	1	0.37	0.00
VEG(4)	0.51	1	0.47	0.00
WIDTH	0.01	1	0.90	0.00

BOULDER = Boulder size, COAST(1) = Mud, COAST(2) = Sandy, COAST(3) = Silty, COAST(4)= Boulder. VEG(1) = Heather, VEG(2) = Scrub, VEG(3) = Grassland, VEG(4) = Native Woodland.

Diagnostics

Testing the goodness fit of the model

The classification Table 6.5 shows that 257 sites without otters were predicted correctly by the model not to have otters; similarly at 251 sites where the model predicted the positive presence of otters, signs were indeed found. However, at 34 sites the model predicted the presence of otters but no signs were found and at 79 sites where the model predicted no otters, signs were found. Therefore, 88.3% of the survey sites without otters were predicted by the model not to have otters, whereas 76.1% of sites where signs of otters were found were predicted to have otters by the model. Therefore, the model overall predicted accurately the presence or absence of otters in over 81% of all cases.

The table does not, however, reveal the distribution of the estimated probabilities of where otters are and are not found. Table 6.5 only shows whether or not the estimated probability is greater than 0.5. Figure 6.1 shows a histogram of the estimated probabilities of finding and not finding otters. If our model successfully distinguishes the two groups, the cases for which an event has occurred (signs of otters have been found [1]), should be to the right of 0.5, while those cases who have not had the event (no signs of otters have been found [0]), should be to the left of 0.5. The more the groups cluster at their respective ends the better the model. This was indeed the case for the majority of cases and Figure 6.1 shows that the model is slightly better at predicting the absence of otters than the presence with no predicted probabilities of not finding otters above 0.6 but one case with estimated probabilities of finding otters below 0.25. Upon examination of the 100 cases close to the probability of one which predict the presence of otters, 60 of these come from the Torridonian sandstone coastal zone.

Table 6.5. Classification table for the goodness fit of the logistic regression model on the otter survey data on Skye. O = No otters, 1 = Otters present.

	PREDICTED		PERCENTAGE CORRECT
	0	1	
OBSERVED			
0	257	34	88.32%
1	79	251	76.06%

OVERALL 81.80%

Figure 6.1. Histogram of estimated probabilities of finding and not finding otters. Frequency shows the number of cases. (1 = Finding otters, 0 = Not finding otters)

DISCUSSION

The number of freshwater pools and the geology of the coastal zone are the two factors (out of the seven considered in the study), which have the greatest influence on the presence or absence of otters on Skye. The importance of the availability of freshwater pools was the conclusion of previous studies in Shetland (Kruuk and Balharry, 1990), in South Africa, (Van der Zee, 1981) and on Skye (Lovett et al, 1997). This has also been demonstrated in Chapter 5 of this study. However, the confirmation that geology has an effect on the distribution of otters is a new finding with Torridonian coastlines and Landslip coastlines the most favoured as shown by the multiple regression model.

Another interesting prediction from the analysis is that the inland vegetation, the intertidal make up, the width of the tidal zone and the size of the boulders on the coastline have no, or very little, effect on the occurrence of otters along the coastline. The fact that inland vegetation does not seem to have an effect on otters on Skye is interesting as in many other studies (Kemenes and Demeter 1995), (Mason and Macdonald 1986) the bankside vegetation on river systems was one of the most important variables that had an influence on otter utilisation. More important is that if we look at the degree of unit change in the number of freshwater pools or the length of Torridonian coastline and the slope of the coastline we see the first two variables, and especially the number of freshwater pools, have a much more profound effect on finding otters. This means that otter populations are extremely sensitive to a reduction in the number of freshwater pools along the coastline. From a practical conservation point of view, it is essential to preserve or even create more freshwater pools along a coastline in order to sustain the otter population.

Considering the predictive value of the model, it can be concluded that this model was accurate at correctly predicting the presence or absence of otters around the Skye coastline in over 81% of cases. The estimated probability plots revealed that the model is slightly better at predicting the absence of otters than the presence as shown in Figure 6.1 with one estimated probability of finding otters below 0.25.

Therefore, it can be concluded that the logistic regression analysis is a useful tool in assessing the effect of the different variables and for finding which of these variables have a positive effect on finding otters around the Skye coastline. It is becoming increasingly important in conservation to predict the occurrence of otters by habitat characteristics alone (Dubuc et al, 1990) as an alternative to long field surveys. The method will, therefore, help otter conservation by finding areas with an optimum set of environmental variables, which can then be explored in greater detail and the suitability of otter habitats established.

CHAPTER 7

An estimate of the number of otters on the Isle of Skye

Synopsis

The number of holts of the Eurasian otter (*Lutra lutra*) in a 100m wide strip along the Isle of Skye coastline was estimated in a survey of 55% of the coastline. The total number of holts calculated for mainland Skye was 192.2 and a total of 294 if the offshore islands were taken into account. Holts were found to be more common on the Torridonian coastlines (0.9 holts per km coastal section) and they were lowest in the Tertiary Lava zone (0.1 holts per km).

The total number of otters was calculated from the number of female otters occupying holts in four study areas, and by using the number of resident females as an index for known males and transients. I therefore estimate the otter population on Skye and its offshore islands is 354.

CONTENTS

INTRODUCTION

Numbers of the Eurasian Otter (*Lutra lutra*) in Europe have declined through much of its range and the species is considered "vulnerable" by IUCN (Foster-Turley et al, 1990). However, only few estimates of numbers are available and there is a need for more quantitative information on numbers and distribution.

In 1995 the British otter population was estimated to be about 7,350 (Harris et al, 1995), of which 350 were in England, 400 in Wales and 6,600 in Scotland. However, this population estimate is based on little more than a guess and a limited amount of data on population densities in different habitat types. In England and Wales the figure was calculated from the length of rivers in each water authority region and then working out the home range of females on these rivers. However, the figure takes no account of different habitats or the fact that there may be an unknown number of animals in each range (Kruuk and Moorhouse, 1991). The Scottish figure is based on Jefferies (Harris et al, 1995) estimating the population as 1,000 in the north west coast of Scotland, 1,200 on the Western Isles, Kruuk's figures for Shetland (Kruuk et al, 1989) and the remainder in river systems on the mainland using linear relationships. Harris et al (1995) however, state that the above population estimates were based on a limited amount of data on population densities in different habitats and that any improvement in the estimate could result in a change of up to ±50%.

The only scientific estimate of otter numbers has come from Shetland where Kruuk et al (1989) conducted a survey of holts covering 35% of the coast in Shetland, and worked out a relationship between resident females and holt numbers. They estimated a Shetland population of 700-900 otters (Kruuk et al, 1989).

Otters are relatively common on Skye and in the north west Scottish Highlands, and although they are diurnal an accurate count of numbers would be difficult and time consuming. The animals are also difficult to spot in a once-only survey and therefore there could be considerable inaccuracies. An intensive study of spraints and holt numbers was therefore undertaken in addition to direct observation.

In this chapter I use the number of active holts used by resident females to estimate otter numbers on the Isle of Skye around the coastline.

METHODS

Chapter 5 has shown that correlations between spraint numbers and otter activity were only demonstrated in the extensive study and difficulties have been shown to exist in trying to correlate otter activity with spraint numbers;

for example, spraint numbers can vary seasonally. Various other studies have shown that results from spraint surveys are always unreliable when trying to estimate actual otter numbers (Conroy and French, 1987; Kruuk and Conroy, 1987; Kruuk et al, 1986).

In Shetland there was a good correlation between otter numbers and holt numbers (Moorhouse, 1988, Kruuk et al, 1989), enabling the number of holts to be used as an index for the number of otters. It was also apparent on Skye (Chapter 5) that statistically significant correlations existed between otter activity and the number of holts in both the extensive and intensive studies. Therefore, it may be possible on Skye to use holts which are in use as an index for otter numbers along the coastline.

Census of holts

An otter holt has been defined in Chapter 5 as a tunnel system with usually more than one entrance showing regular usage by otters. During August to September 1994 trained volunteers were used to examine 622 x 500m coastal sections accounting for 60% of the Skye coastline. Volunteers noted otter holts, otter activity, sprainting points and spraints in each 500m section. Each 500m section was visited for 30 minutes and the search for holts consisted of walking along the coast in a zigzag pattern and looking at all likely sites. The holts are often very conspicuous, with well-marked sprainting points.

Each section was assigned to one of seven geological classifications as described in Chapter 2. Each coastal section was numbered and the data on each section recorded on the standard data sheet, shown in Appendix 1 of Chapter 2.

The variances for the estimates of holt numbers in each geological zone (h), and for the estimate of the total number were calculated using the method of Kruuk et al (1989), in which

$$\text{Variance } (Y_h) = N_h = \frac{(N_h - n_h}{n_h} \quad * \quad s^2$$

Where

$$s^2 = \frac{1}{n_h - 1 *} \left[\sum R_h{}^2 - \frac{(\Sigma R_h)2}{n_h} \right]$$

Y_h= total number of holts in each geological zone, N_h= number of sections present in each geological zone, n_h= number of sections sampled in a geological coastal zone, R_h= number of holts recorded in each section sampled.

For an estimate of the total number of holts on Skye.

$$Y = \Sigma(Y_h)$$

and

Variance (Y) = Σ Var(Y_h)

Relationship between numbers of otters and holts

It has already been mentioned that a correlation exists between holts and the number of otters observed in that area, and Moorhouse (1988) quantified this relationship and estimated the number of otters living along 20km of coastline. He used two methods to identify the otters: individual otters could be recognised by characteristic patterns of white and yellow markings on the throat or lips; secondly, 13 otters were tagged with coloured ear-tags and in each month the number of ear-tagged and non ear-tagged otters was recorded and the number of otters present was calculated from the ratio of the number of tagged animals and non-tagged animals (Lincoln index, Southwood, 1966). The numbers of holts were then related to the number of resident females and the number of resident females to the numbers of transient otters.

On Skye, four study areas were looked at in detail and it was possible over a 12 month period to identify individual otters and relate this to the number of holts in use at a particular time. It was possible to estimate the number of otters living in the four study areas using a direct observation method: the individuals could be recognised by pink patterns on the nose; females with cubs could be readily seen and identified; "battle scars" on otters (nicks out of ears, scars in fur, etc) could help to recognise individuals.

Counts were made of otter holts being used in set coastal areas on the Isle of Skye, shown in Figure 7.1. The definition of a holt has already been described and I assumed it was utilised if there were recent spraints within 10m of the holt entrance. Four areas were intensively studied:

1. Bogha an t-Sasunnaich to Ard Dorch: 18km of Torridonian and Mesozoic coastline during 12 months of 1995. (This coastal section had five resident females).

2. Camas Malag to Boreraig: 8.5km of mostly Mesozoic coastline during 12 months of 1992. (This coastal section had two resident females)

3. Drumfearn: 4km of Torridonian coastline during 12 months of 1994. (This coastal section had one resident female)

4. Loch na Dal: 3.5km of Torridonian coastline during 12 months of 1993. (This coastal section had one resident female).

Each coastal section was visited for a minimum of one hour every month throughout the 12 month period. From April to October the four areas were visited on a weekly basis for a minimum of two hours giving a minimum time of observation in each section of 61 hours. Each section was also visited throughout the months of April to September on wildlife trips and a minimum time of two hours was spent in each section. (The wildlife trip consisted of groups of 8-10 people watching the coastline for otters). In view of the length of time spent in each section, I am confident that all the resident otters were counted correctly.

The holts were identified over many years of work in each area (I started watching otters in these areas in 1988). The sections above accounted for the intensive study.

Certain assumptions are made in this estimate:

a) All holts were counted
b) All otters in each area were identified correctly
c) The sections sampled were representative of the Skye coastline
d) The ratio for the number of otters and number of holts was constant for all geological coastal zones
e) The ratio of numbers of females, males, non-residents and cubs was constant.

These assumptions and their implications will be discussed in the final section of this chapter.

Figure 7.1. Map showing the four areas used in the study

RESULTS

Numbers of otters and holts

Figure 7.2 shows the relationship between holts per resident female otter range in the 100m coastal strip in the four study areas of Torridonian and Mesozoic coastline compared with the number of resident adult females there. A total of 21 holts were found and a mean of 45% of all the holts were used by otters at any one time. There is a strong positive correlation between the two parameters over the four study areas over the 12 month period ($r=0.93$, $df=47$, $p<0.001$). These study areas were also used by adult resident males, other adult/juvenile otters. Their ranges were larger than the resident females and an estimate was made of how many would be present in the study areas.

The mean number of otters and holts being used in each of the four study areas are shown in Table 7.1.

Figure 7.2. The relationship between holts per resident female otter range in the 100m coastal strip in the four study areas of Torridonian and Mesozoic coastline compared with the number of resident adult females there.

Table 7.1. Mean numbers of otters and holts in the study areas. (Other unknown = mix of males and females whose sex could not be identified).

Area	Coastal Length	Resident Females	Cubs	Males	Other Unknown	Holts in Use
1	18km	4.8±0.13	2.3±0.43	1.8±0.12	0.5±0.15	8.5±0.31
2	4.3km	2	1	0.7±0.21	0.5±0.22	4.5±0.22
3	4km	1.1±0.14	1.6±0.30	0.7±0.18	0.57±0.20	2.4±0.20
4	3.5km	1	0.75±0.13	0.25±0.12	0.5±0.19	1.7±0.25
Total	29.8km	8.9±0.38	5.7±0.86	3.5±0.63	2.1±0.76	17.1±0.98

The estimate for the total number of adult otters in all four areas is 14.5 ±1.99 (one otter per 2.1km of coastline). In the study areas 8.9 were resident females (0.52 females per holt), 3.5 resident males, and 2.1 other adult otters. Therefore 61% were females and 24% resident adult males.

Number of holts counted

A total of 622 x 500m sections were surveyed with 117 holts being counted for mainland Skye. The number of holts per 500m section in all geological coastal zones are shown in Table 7.2. In all, holts were recorded on only 18.8% of the sections surveyed of the Skye coastline, and the total number of holts estimated for Skye are calculated in Table 7.3.

The variation between the holts and the geological coastal zones was relatively large, and a one-way analysis of variance showed a highly significant difference between the geological coastal zones ($F=11.3$, $df=621$, $p<0.001$). Holts occurred in greater density in the Torridonian coastal zone (0.45 holts per 500m section), with the next most important coastal type for holts being the Landslip coastline (0.34 holts per 500m section); this is compared with a low in the Tertiary Lava zone (0.06 holts per 500m section).

Table 7.2. Coastal sections of 500m length in different geological coastal zones

Geology	Total sections (N_h)	Sections Counted (n_h)	% Counted	No of Holts Counted (H_h)	Holts per 500m section	SE
Lewisian	91	71	78	9	0.13	0.06
Torridonian	131	84	64	38	0.45	0.08
Cambrian	17	17	100	5	0.29	0.16
Mesozoic	119	99	73	27	0.27	0.06
Tert Lavas	538	206	38	12	0.06	0.17
Tert Int	113	104	92	7	0.07	0.02
Landslip	130	41	32	14	0.34	0.10
TOTALS	1139	622		112		

Table 7.3. Number of holts calculated for the different geological coastal zones

Geology	Estimate of No. of Holts (Y_n)	Variance (Y_g)	SE	95% confidence
Lewisian	11.8	0.082	0.29	0.58 (4.9)
Torridonian	59.0	0.46	0.68	1.36 (2.3)
Cambrian	4.9	0.63	0.79	1.58 (32)
Mesozoic	32.1	0.031	0.18	0.36 (1.12)
Tert Lavas	32.3	0.26	0.51	1.02 (3.16)
Tert Intrusive	7.9	0.009	0.09	0.18 (2.3)
Landslip	44.2	8.35	2.89	5.78 (13.1)
Total	192.2	8.65	5.54	11.08 (5.8)

Total numbers of otters on the Isle of Skye

Using the results from this study, 61% of all the otters were adult females and 24% resident adult males.

Thus the total numbers of otters can be calculated by multiplying the number of resident females by $\frac{100}{61} = 1.64$

Therefore, from Table 7.2 it can be seen that there are a total of 192.2 holts with 0.52 resident females per holt and the total number of adult otters is 1.64 x the number of resident females. I estimate the total resident female population on Skye to be 100. Using the above equation, the total Skye otter population is 163 adult otters.

In this study, Table 7.1, there were 8.7 resident females which had 5.7 cubs or 0.67 cubs per female otter. From this, the cub population can be estimated to be 67 (100 X 0.67) and a total otter population on Skye including cubs as 230.

Holts and otter density in relation to the different geological coastal zones

Table 7.4 shows holt numbers and estimated otter numbers in relation to the different geological coastal zones. Holt and otter density is higher than average in the Torridonian coastal zone and lower than average in the Tertiary Lava and Intrusive zones.

Table 7.4. Holt and otter numbers in each of the seven geological coastal zones. The figures in brackets show the estimated number of holts and otters per km for the Skye mainland.

GEOLOGY	HOLT NUMBERS	ESTIMATED OTTER NO'S
Lewisian	11.5 (0.26)	13.8 (0.30)
Torridonian	59.3 (0.9)	71.2 (1.09)
Cambrian	5.0 (0.6)	6.0 (0.71)
Mesozoic	32.4 (0.7)	39.0 (0.66)
Tert Lavas	31.3 (0.1)	37.6 (0.14)
Tert Intrusive	7.6 (0.1)	9.2 (0.16)
Landslip	44.2 (0.7)	53.1 (0.82)

Skye's Adjacent Islands

The island of Skye also has many islands adjacent to its coastline, and movement of otters between these islands occurs on a regular basis (personal observation). Therefore, these islands must be included in order to estimate the total population in the Skye area. Figure 7.3 shows the islands which have been surveyed and the islands used for the population estimate. Table 7.5 shows the number of 500m sections in each geological coastal zone for these offshore islands. It was not possible to visit all of them and estimates for the geological coastal zones not visited are shown in brackets and based on the mainland Skye survey.

The total otter population for the offshore islands is calculated as 53.5 females with a total of 87.7 adult otters and 35.8 cubs, giving a total population of 123.5. Therefore, the total otter population for Skye and its offshore islands is 353 otters.

Figure 7.3. The offshore islands used in the population estimate.

Table 7.5. Geological coastal zones on Skye's offshore islands. Figures in brackets are estimates for the holts per 500m section based on the Skye mainland data.

GEOLOGY	Total sections (N_h)	Sections counted (n_h)	No of holts counted	Holts per 500m section	SE	Estimate numbers of holts
Lewisian	114	0		{0.13}		{14.8}

Torridonian	120	10	5	0.5	0.22	60
Cambrian	6	0		{0.29}		{1.7}
Mesozoic	28	7	3	0.42	0.2	11.8
Tert Lavas	44	31	2	0.06	0.05	2.8
Tert Int	75.4	27	1	0.03	0.06	2.3
Landslip	22	0		{0.43}		{9.5}
Total						102.9

DISCUSSION

Based on the data, I have estimated 192.2 major holts for the Skye coastline, and 102.9 holts for the coastline of the offshore islands. This gives an estimate for total holt numbers of 294.2. The estimate for coastal otters on Skye is derived by working out a relationship between resident females and active holts and a relationship between resident females and other otters, and thus the Skye and adjacent island population is estimated to be 354. This estimate is based on the numbers present at a particular point in time plus births, minus deaths, plus immigrants minus emigrants. Stubbs (1977) has shown that animals from permanent habitats like the vertebrates tend to show an undercompensating or exactly compensating mortality, and this would clearly be relevant when considering the Skye population. My estimate is however likely to be an underestimate because of otters living in inland freshwater systems. From personal observations I have seen otters in Loch Suardal, Loch Coruisk and other inland freshwater lochs.

The figure of 354 is based on this survey of 60% of the coastline and the following assumptions:

1. 60% of the Skye coastline is a fair representation of the entire Skye coastline. The sampling of 60% is very high compared with the 35% achieved in studies on Shetland (Kruuk et al, 1989), (Jolly, 1969).

2. All otter holts were found during the survey. All holts were found in the intensive survey as otters had been tracked in these areas over many years. With the volunteer survey some holts may have been overlooked due to the extensive nature of the area surveys and this would have underestimated holt numbers. This underestimation could be expected to have occurred equally on all geological coastal zones.

3. The total number of otters in the study areas was estimated correctly.

4. The number of holts per otter in the different geological coastal zones was constant. The regression in Figure 7.2 shows otter numbers against holts for both the Torridonian and Mesozoic coastal sections. The close correlation shows that the above assumption is true for at least these two geological coastal sections (these had the highest densities of holts). However, it may be that in the Tertiary Lava coastal zone, for example, otters are utilising fewer holts than otters in the Torridonian coastal section. At Eabost in north west Skye I studied a 1km coastal section chosen randomly for two years and only observed otters on two occasions. I also identified no holts when I surveyed 20km of this coastline. It was therefore difficult to build up any relationships between holt numbers and otters in the Tertiary Lava coastal sections.

The effect of otters using fewer holts on the Tertiary Lava coastal zone would be to underestimate the total number of otters on Skye. For example, an estimate of otters along the Tertiary Lava coastal sections used only half the holts compared with the Torridonian. This would have the effect of increasing the estimate of the adult otter population from 163 to 218 a 34% increase in the Skye otter population. More work is needed to compare otter numbers and holt utilisation in the different geological coastal zones.

5. The relationship between the sexes of the resident otters and the transient animals was the same in all areas as in the study areas. This was relatively constant in the four study areas and the ratio of cubs to females was also constant. However, once again I had no way of testing this in the Tertiary Lava coastal zone. The Tertiary Lava zone may have more transients or more resident males and this would have lowered the overall estimate.

Intensive v Extensive Study

In order to test whether volunteers missed holts in the extensive study, three areas which were both intensively and extensively surveyed were compared as shown in Table 7.6.

The study area Camas Malag to Boreraig was not covered by the volunteers in the extensive study.

Overall, the volunteers were found to be inaccurate by 18.8% when counting holts over a 25km of shore line. Applying this correction factor to the previous estimate would increase the estimated otter population to 415.

The results can be compared to those of Kruuk et al (1989) who found 0.331 resident females per holt and the total number of adult otters was 1.83 x the number of resident females. He estimated the total number of adult otters on Shetland as 718 and in his study area this represented one otter per 1.2km coast, a similar figure to that found by Watson in an earlier study on Shetland (1978). On Skye in my study area, the otter density was one otter per 0.9km of coast for the Torridonian zone but only one otter per 8.3km of coast for the Tertiary Lava and Intrusive zones.

I have shown on Skye that geology effects otter numbers. The same may be true for other areas of coastline. Heggberget (1995) in Norway found one otter per 1.75-2.6km of island coastline and one otter per 4.7-7km of coastline on the mainland coast. She used a linear relationship to extrapolate a total population of between 10,000 to 15,000 animals. In Heggberget's sections of Norwegian coast the geology is variable with Pre-Cambrian basement, Devonian sediments, intrusive rocks and Cambrian and Ordovician complex fold structures. It is likely that in Norway this varied geology would also have a profound effect on the coastal type which in turn would influence otter numbers so that a straight linear calculation is extremely difficult to interpret.

Despite the difficulties of estimating otter numbers and the errors due to the above assumptions, I am confident that the otter population on Skye and its adjacent islands is around the 354 figure. This gives an average of one otter per 2.2km of coastline, a figure lower than that on Shetland where Kruuk et al (1989) estimated one otter per 1.2km of coast. Reasons for this could be the greater biomass of prey species available on Shetland than on Skye (Chapter 4).

Table 7.6. Comparison between intensive and extensive study

AREA	kms	Holts (Intensive)	Holts (Extensive)
Ob-Allt to Dunan	18	10	9
Drumfearn	4	3	3
Loch na Dal	3.5	3	1
Total	25.5	16	13

Chapter 8

Conclusions and Conservation Implications

Synopsis

The habitat requirements for the Eurasian otter on the Isle of Skye have been studied throughout this thesis. Certain geological coastlines have been shown to be more favourable to otters than others. The Torridonian coastline in particular has a greater number of variables favourable to the otter than any other zone: it has more gently sloping shorelines, more native inland vegetation, more boulder intertidal zones and more freshwater pools. Consequently, the Torridonian has a higher density of otters than any other zone on the Isle of Skye.

The diet of the otter obtained from spraint analysis showed that five key prey species made up 75% of the diet (Viviparous Blenny, Five-Bearded Rockling, Butterfish, Saithe and Sea Scorpion). These five key prey species accounted for 86% of the fish available as prey as shown by trapping data and again were the major prey found in the seven geological coastal zones. Clearly these species are of critical importance for the survival of the otter around the coastline of the Isle of Skye.

The study revealed that what is important to the otter is the number of freshwater pools, the slope of the shoreline and the inland vegetation. The highest density of otters was found on the Torridonian coastline with 0.27 otters per kilometre and lowest on the Tertiary Lavas with 0.03 otters per kilometre.
The island's otter population appears to be stable but increasingly under threat from coastal developments and road mortalities. If it is going to be preserved a sound coastal management plan is required which takes into account otter conservation when proposed development is considered. The otter density is ranked along the Skye coastline and areas which are especially important for conservation are identified i.e. Loch Eishort and Loch Slapin; these should be incorporated into this management plan.

CONTENTS

Overall conclusions of chapters

The overall aims of this thesis were to study the habitat requirements of the Eurasian otter population on the Isle of Skye, to estimate population figures, and then to use the results in constructing a conservation strategy for this population.

It has been well documented over the last 40 years how the Eurasian otter population has declined in Western Europe (Chanin and Jefferies, 1978 and Chanin, 1991), but recent surveys, albeit based on spraints, do show a slow recovery in Britain (Strachan et al, 1990) and (Green and Green, 1997). The Joint Nature Conservation Committee (JNCC) in their Review of British Mammals gave estimated figures for otter numbers in the UK (Harris et al, 1996) with a total breeding population in the mid 1980's of 7,350, with 350 in England, 6,600 in Scotland and 400 in Wales. Whilst there are arguments as to how accurate these and subsequent figures are, they do give some idea of how rare otters are in the UK set against populations of 400,000 badgers, 240,000 foxes and 462,000 stoats.

The Isle of Skye, like the rest of the north west seaboard of Scotland and the Shetland Isles, is clearly totally different from other areas in Europe where otters occur. These areas are relatively unspoilt, have kilometres of undisturbed habitat and an abundant supply of food, which contrasts with the heavily overpopulated parts of England, where otters are only seen on rare occasions.

The theme linking the preceding chapters is to see if the geology of the coastal zone effects otter populations; if it does, it provides a basis for a conservation management plan for the otter on the Isle of Skye.

Chapter 1 introduced the reader to the overall aim of the thesis, outlined previous research and considered the need for this type of research on the Isle of Skye.

Chapter 2 described the geology of the island and showed that geology effects the height of the land 25m from the High Water Mark, the intertidal make up and the inland vegetation. The Torridonian coastline had a lack of heights over 50m, and generally had gently sloping shorelines compared with the other zones. The intertidal make up of all the coastal zones was dominated by boulder coastline, except for the Tertiary Lava coastline which was dominated by rock outcrop. Finally, the inland vegetation also varied on the different coastlines and there was greatest cover in the Torridonian (24% native wood, 23% scrub) and lowest in the Tertiary Lava (7% native wood, 11% scrub).

In Chapter 3, spraint analysis showed that five key prey species make up over 75% of the diet. The five key prey species are Viviparous Blenny, Five-Bearded Rockling, Butterfish, Saithe and Sea Scorpion and with the exception of Saithe, which is free-swimming, they are all small benthic fish. The diet as analysed by spraint analysis correlated with the diet of otters in Shetland (Kruuk and Moorhouse, 1990), and Norway (Heggberget and Moseid, 1994). Chapter 3 showed that the variation along the seven geological coastal zones was significant for all species except Viviparous Blenny which dominated the diet in all zones, however the 5 Key prey species dominated the diet in all zones and are an important factor which limits the otter population on the Isle of Skye coastline.

The difference of prey availability was looked at in Chapter 4, using unbaited fish traps which were placed in the seven geological zones and the fish caught were identified over a four year period. The five key prey species outlined in Chapter 3 accounted for over 86% of the total catch. The highest catch occurred in the Landslip zone (mean number of 1.3 fish per trap) compared with a low in the Tertiary Intrusive zone (mean number of 0.4 fish per trap).

Looking at the availability of prey in the seven geological coastal zones no significant differences occurred in Butterfish or Five Bearded Rockling. There were staistically significant differences were apparent for Viviparous Blenny which was present in far greater numbers in the Cambrian and Landslip zones and low in numbers in the Mesozoic; Sea Scorpion which was found in high numbers in the Tertiary Lava zone and absent in the Landslip; Saithe which was found in high numbers in the Landslip zone and absent in the Tertairy Lavas and Flatfish which was found in high numbers in the Torridonian and absent in the Cambrian, Tertiary Intrusives and Landslip zone.

The results of prey availability were compared with the diet as analysed by spraint analysis in Chapter 3 and there was a good correlation between species composition of the benthic fauna and the otter diet.

These results were compared to studies of otters on Shetland (Kruuk et al, 1989) and Mull (Watt, 1991 and 1993). A greater number of prey species were available in Shetland than on Skye or Mull, which contribute to Shetland having a greater otter population than either Mull or Skye. Chapter 5 looked at the function of sprainting and related otter activity to geology. The results were based on an intensive study from 1991 to 1995 and an extensive study using trained volunteers from August to September 1994.

The numbers of spraints were extremely seasonal with 72% more spraints being found in the winter than the summer months. In summer, most sprainting occurred in the intertidal zone, often in places which would be flooded in a matter of hours, and most were deposited before and after feeding bouts, which would indicate a use of resources rather than a territorial marker. In both the intensive and extensive studies correlations existed between otter activity and holt numbers and significant correlations occurred between holt numbers and spraints, sprainting points and freshwater pools in all geological coastal zones. No correlations existed between otter activity and the numbers of spraints in the intensive study but a significant correlation did exist in the extensive study. Comparing all the above variables and the seven geological coastal zones certain predictable patterns emerged with more 'variables' being found in the Torridonian coastal zone than any other. The two Tertiary zones showed the lowest numbers of all variables.

Chapter 5 showed clear preferences of otters for different geological coastal zones, with increased signs and activity in the Torridonian and Mesozoic and low activity in the Tertiary Intrusive and Lava zones; this difference was attributed to greater numbers of freshwater pools, gently sloping shorelines with a boulder intertidal zone and native and scrub woodland adjacent to the High Water Mark in the Torridonian and Mesozoic coastline. Chapter 5 also showed the importance of freshwater pools for otters; these are crucial not only for drinking but also for washing their fur free of salt in order to maintain insulating properties. The requirements for otters to visit freshwater pools frequently has been demonstrated from observations in Shetland (Kruuk and Balharry, 1990), and on Skye (Lovett, 1994; Priestley, 1996).

In Chapter 6 a model was developed to predict the presence and absence of otters around the Skye coastline by using all these environmental variables. It shows how increasing the number of freshwater pools has a positive effect on finding otters around the coastline, and that increasing the height marker, which is a reflection of coastal slope has a negative effect. When the Torridonian, Mesozoic and Landslip coastlines were compared to the average effect of all the other geological coastal zones they had a positive effect on the likelihood of finding otters whilst all other geological coastlines have a negative effect.

The preceding chapters have shown that although food is a major limiting factor, the availability of prey in the different geological coastlines is relatively constant other than for the Tertiary Lava zone and therefore other factors limit the distribution of otters on Skye. Otters are limited by the slope of the shoreline and the availability of freshwater pools, which in turn are limited by the geology of the coastline. It has been shown that the Torridonian coastline and the Mesozoic coastline have more favourable habitats because they possess the greatest number of freshwater pools, and have statistically more gently sloping shorelines. In contrast, the Tertiary coastal zones are the least favourable habitats because they have the least number of freshwater pools and have steeply sloping shorelines. The logistic regression model could be a useful tool in assessing the distribution of otters in other areas of north west Scotland, and could help the future conservation of the otter. The implications of these findings will be discussed later in this section.

Chapter 7 estimated the otter population on the Isle of Skye and its adjacent islands using a similar method used by Kruuk et al (1989) which used correlations between holts and otters to estimate populations. Correlation between otter activity and holts was also apparent on the Isle of Skye as shown in Chapter 5. The total number of otters was calculated by correlating the number of known female otters in four intensive study areas with the number of holts and by using the number of known females as an index for known males, transients and cubs. This relationship was then extrapolated to the number of holts counted during the extensive survey and this produced a population for Skye and its offshore islands of 354 otters. The Torridonian coastline had the highest density of otters with 1.1 otters per kilometre and the lowest number was found on the Tertiary Lavas and Intrusives with 0.12 otters per kilometre of coastline. However, the population estimate is for coastal otters on Skye only and is based on the work of volunteers who were shown to count fewer (around 19%) holts than a skilled observer.

Conservation Implications

Counting actual numbers of mammals is very difficult and even if species can be easily seen many uncertainties about the estimate become apparent. Over the years, otter population estimates have been based on four methods:

1. In 1977-1979 otter spraint surveys were used to give information on otter distribution and relative density (Jefferies, 1983).

2. Linear and area relationships have been used to estimate otter numbers: Harris et al (1996) used linear relationships from rehabilitated otters in East Anglia, producing figures of 24.9 km^2 per adult otter in low density

areas such as England and Wales and 14.4 km^2 per adult otter in high density areas such as waterways in Scotland. Kruuk et al (1993) used a linear relationship of one otter per 15.1km of stream in Deeside. Heggberget (1995) in Norway used a straightforward linear relationship of 3.8-5.7 otters per 10km of island coast and 1.2-2.1 otters per 10km of mainland coast to produce a figure of 10,000-15,000 on the Norwegian coast from More to Troms. Katchanovsky (1996) in Russia gave densities of otters using tracks in the snow and worked out a relationship of one adult otter to 13.9 km of river system.

I believe caution should be used when interpreting otter populations from these simple linear relationships, as on Skye otter densities along the coastline vary considerably due to the differences in geology. As mentioned in Chapter 5, in Heggberget's (1995) Norway survey the coastal sections have a variety of rock types which in turn will give rise to a variety of habitats and different otter population figures.

The map in Figure 8.1 brings together my research into a practical way of implementing a conservation strategy for otters on Skye. This geological map of Skye shows that certain areas are more important for otters than others, and from this, special protection for important conservation areas for otters on the Isle of Skye could be implemented. The map ranks otter density into five rankings with Rank 1 representing otter density of 1.1 per kilometre to Rank 5 representing less than 0.1 otters per km. It can clearly be seen that the southern part of the island and also a large part of the area to the north of Portree possess the most important otter populations on Skye, and the areas around Broadford, Kyleakin, Elgol and the lochs of na Dal, Slapin and Eishort in the Sleat peninsula are the most favourable. If conservation measures are to be implemented for the otter on the Isle of Skye then these are the areas in which the most effort should be put. The island's estimated population of 352 is small but it is an important component of the Eurasian population in Britain and Europe. It is vulnerable to pollution (oil spill), disease and coastal development, and sound coastal management should be implemented to protect the otter in these sensitive areas.

Skye's coastline is crucial for the survival of the otter, but it is also important for the economic future of the island. The coastal zone is under increased pressure which, if not checked, will threaten both its environmental and economic foundations. It is widely agreed by many organisations that a co-ordinated and integrated coastal management plan is required to achieve a balance between ecologically-sustainable economic development and the maintenance of the conservation value. To date on Skye, economic advancement has always taken priority over conservation; this has been the case with fin-fish farming and the government's bulldozing of known otter holts for the construction of the Skye road bridge.

If we are to conserve the otters on Skye we must have total and effective management of this coastal zone, and must develop a policy similar to that developed for land use, which will identify permissible and non-permissible uses of the coastal zone. Coastal zoning should be undertaken identifying what is and is not allowed on this coastal fringe.

The coastline should be divided into:

1. Areas important for conservation (otters, etc)
2. Areas suitable for intensive development
3. Areas where only limited development can occur

Some of the better habitats for otters on Skye, namely Loch Eishort, Loch Slapin and Loch na Dal, should be fully protected, and the kinds of activity allowed to take place should be limited. In these areas maximum levels of use must be determined.

With this in mind I can now look at the potential threats to otters on Skye.

Figure 8.1. Coastal ranking for the Eurasian otter (Lutra lutra) density along the Isle of Skye coastline

Threats to otters on Skye

Any potential change in human coastal use may be viewed as a hazard to otters and I would like finally to look at some of the potential threats to otters and how these threats could be put into a coastal zone management plan. The coastal zone, the interface of land and sea, is an area where resource opportunities attract a growing number of uses which could lead to potential threats for the otter.

Canessa (1990) identified six "user" categories for coastal use around Skye:

1. Primary resources (Fish, Shellfish, Fish Farming, Aggregates, Oil)
2. Transportation and communication
3. Military activities
4. Waste disposal
5. Recreation and tourism
6. Conservation

Each of these will be considered in relation to their potential effect on the otter.

1. Primary Resources

a) Biological Resources

Marine Farming

Salmon farming flourishes on Skye, with 24 salmon farms currently in operation (Ross, 1997) out of which five are located on Rank 1 otter habitat (Figure 8.1). Otters are not generally considered a major problem at marine salmon farms; permission must be sought from the Scottish Office if otters are to be removed from salmon farms (Ross, 1997) and to my knowledge only one licence has been granted. Fish farms may occasionally be visited by otters (Kruuk, 1995), but in an intensive study area he often found otters swimming close to a fish farm but never taking any interest in the salmon. On Skye at Harlosh, during the volunteer survey the spraints of the otter were orange all along the home range. As canthaxanthin is used in fish feed to colour the salmon flesh and there is a nearby salmon farm, it would suggest that the otter was taking some canthaxanthin pigmented fish. This chemical has been linked to cancer in humans in Germany and America but at this stage it is not known if it poses a threat to otters.

Recent speculation has been raised about a possible link between paralytic shellfish poisoning (PSP) in Scottish coastal waters and over-nutrification from salmon farms (Berry, 1996). At this stage it is not known if this is a potential problem for otters.

Due to these potential pollution problems, over-nutrification of the sea bed and disturbance factors, the planning control process should take full account of otters and the risk of predation related problems in determining planning applications for all new salmon farms. If possible any new farms should be discouraged from Rank 1 to 3 of otter habitat. The provision of shore base facilities may contravene both the Wildlife and Countryside Act (1981) and the EEC Habitats Directive (1993) and the Conservation (Natural Habitats, etc) Regulations (1994) if they disturb or damage otter holts and these aspects must also be considered.

Shellfish Farming

Shellfish farming has grown over the last ten years on Skye, mainly being mussel, scallops and oysters. To my own knowledge, the shellfish farms have little or no effect on otters. At Drumfearn a large farm has had a healthy population of otters living on the adjacent shoreline for 10 years. The only proviso is that shore base facilities may effect habitat and holts and again these come under the Wildlife and Countryside Act (1981) and EEC Habitats Directive (1993) and the Conservation (Natural Habitats, etc) Regulations (1994).

Fishing

The main fishery around Skye is shellfish, especially prawns, using creel boats and trawlers. Creel boats number about 100 and catch velvet and brown crab and lobster as well as prawns. These do pose potential serious threats to the otter and in 1977 the JNCC Joint Otter Group looked at the threat to otters from creel fishing. Between 1975-1984 some 88 otters were known to drown in fish and crustacean traps in Britain (Green et al, 1984). On Skye in 1990 I was informed of four otters in a week drowning in lobster pots from one boat at Armadale, Skye. Data from Mull (Birch, 1996) puts the figure at five in 1991 and one recorded incident in 1995.

Although otter casualties are accidental and no blame can be made on the fishermen more data on this mortality is required. Unfortunately, many fishermen are reluctant to give information because they are too embarrassed about the problem.

b) Mineral resources

Oil

Since 1981, a consortium of three companies have had an exploration licence for north west Skye. The Minch basin, a potential oil reservoir, runs from north Skye into the Minch and many oil companies have exploration blocks in this area. The estimated oil potential from Skye is hundreds of barrels per day with a potential of thousands of barrels a day from the Minch itself. Since the exploration licences apply to Rank 5 (the poorest areas for otters), any oil incident may not have a profound effect on the overall otter population but will have a damaging local effect.

The transportation of oil and the threat of major oil spills on otters will be looked at in the transport section later in this chapter, but the consequences of a major oil spill will undoubtedly be serious.

Aggregate Extraction

Two companies currently carry out onshore coastal aggregate extraction; one has effected approximately 1.5km of coastline at Kyleakin but the other, at Sconser, has had little effect on the coastline. In 1991, the Department of Transport sponsored ARUP (DOE 1992) to report on the potential for coastal superquarries in Scotland. Two of these quarries were located on Skye and Raasay: one at Loch Slapin and the other at Holoman Bay on Raasay. If these quarries ever come into use they will have a direct impact on the otter and otter habitat and a full survey of the impact of such developments should be implemented sooner, rather than later. The Loch Slapin proposed site will effect some Rank 1 otter coastline (Figure 8.1), but the Holoman Bay site will only effect Rank 5 coastline.

2. Transportation and Communication

a) Sea

The only potential major problem is the transportation of oil through the Minch, the threat of oil pollution from oil development on Skye and in the Minch and BP tankers unloading oil at Portree for storage at the wharf. Oil tanker activity is a threat as an increasing number are using the Minch, the waterway between Skye and the Outer Hebrides. In the last two years alone, two tankers have been in trouble in these waters but no serious problem has yet occurred. Highland Council agree that there is a real risk of an oil disaster in the Minch.

The only historically recent oil disasters which have effected otters are the Exxon Valdez which ran aground on Blight Reef in north east Prince William Sound, off Alaska, in March 1989 and the Braer which grounded in Shetland in January 1993. In the Exxon oil disaster more than 45 million litres of crude oil spilled and 878 Sea Otters (*Enhydra lutris*) were found to be effected (Estes, 1992). Research showed that the effect of this spill was still felt over a year later with changes in prey species diversity available for the Sea Otter. Duffy et al (1994) showed that American River Otters (*Lutra canadensis*) in the oiled area had significantly lower body mass than otters in non-oiled areas as well as elevated haptoglobin levels suggesting that these otters were experiencing toxicological effects from oil contamination.

In Shetland, Conroy and Kruuk (1995) assessed the effects of the Braer oil spill on the Eurasian otter population, and in September 1993 they found that no holts were occupied in a 25km section of coast around where the Braer had grounded; however, no survey of occupied holts had been done prior to the Braer oil spill. In addition no spraints or animals were seen. In November 1993 some spraints were found but still no holts were being occupied, and they concluded that the total lack of any evidence of otter utilisation of this coast suggests strongly that otter activity had decreased since the Braer. Fish traps laid in the area also failed to catch any bottom living fish, the main prey of otter.

Clearly, more work is needed on the effects of oil spills on otters, but rather than place the emphasis on the immediate effects, more long term studies are required to adequately evaluate any future catastrophe.
On Skye, if an oil spill does occur, most effort should be directed into stopping contamination effecting the Rank 1 coastlines and primarily Lochs Eishort, na Dal and Slapin on the south west side of the island (Figure 8.1).

b) Road

Like many wild mammals, otters are frequently killed on the road; data from Otter Watch (IOSF, 1997) reports that 89% of recorded otter deaths occur on the road. Green and Green (1997) also state that between 1986 and 1995, 86% of all otter deaths reported occurred on the road. In England on the River Glaven in Norfolk, five otters died on the road in six years (Mason and Macdonald, 1986), and in Saxony, Germany, 10% of the otter population falls victim to road kills (Mason and Macdonald, 1986). Following the unification of Germany there was a 500% increase in otter road mortality (Korbel, 1995). However, otter road casualties are easy to find and this will bias the results as it is difficult to know of other causes of mortality; the relative importance of otter road mortality is therefore impossible to assess.

On Skye 41% of road mortalities are occurring near Mesozoic coastlines, 31% near Tertiary Lava coastlines and only 13.5% near Torridonian coastlines. No correlation was apparent between the geology of the coastline and the number of otters killed although this did not take into account the type of road, number of roads near a particular coastline or the length of that coastline. Clearly there is much more research needed into this subject.

On Skye and in the Highlands road mortality is increasing mainly due to the increased road traffic. On many roads where habitat is good, certain black spots can be identified, and on the main trunk road (A87, formerly A850) between Kyleakin and Portree on Skye there are many such black spots where otters are regularly killed. Road mortality is therefore a serious problem for otters on Skye, although the data will be biased as more otters will be found on roads than in more remote parts. However, the numbers being reported are far less than the true numbers actually being knocked down, as I have on occasions been notified many years later of a road mortality that was not used in the data analysis.

On Shetland, Kruuk and Conroy (1991) found 42% of otter mortalities occurred on the road, but concluded that food shortage was the most probable cause of death to most otters on Shetland. In Norway, Heggberget (1991) found that more otters were killed by drowning in fish traps and nets than on the roads. This does not seem to be the case on Skye where road traffic is increasing at a rate of 5% per annum and increased road mortality can clearly be seen to be linked to increased road traffic.

3. Military Activities

The British Underwater Test and Evaluation Centre (BUTEC) operates from the Kyle of Lochalsh to test and evaluate weapons launched by ships and submarines. The weapons are tested in a 10 $mile^2$ in the Inner Sound but as these are at considerable water depths to my knowledge they have had no effect on otters.

4. Waste Disposal

The coastal waters around Skye have long been used to dispose of waste and this relies on the dispersion and dilution concept. There are several industries operating on Skye which require licences to discharge. Most trade effluent is suspended solids except for the sheep fleece-processing plant at Loch Bay which discharges quantities of chromium, and the distillery at Talisker which discharges quantities of copper.

The chromium from the sheep fleece-processing plant is a potential source of concern for the wellbeing of otters in Loch Bay. Chromium in water does not readily dissolve but will stick to dirt particles and fall to the sea bed. Chromium is toxic at high levels, causing lung disease, kidney and liver damage and birth defects. However, chromium is not taken up or stored in the bodies of fish and therefore will probably not accumulate in otters at these high risk levels.

The effect of copper on otters has not been researched but an increase in copper intake can cause liver problems in other animals. However, the quantities concerned at the distillery are low and are likely to have little effect.

There have been tentative links between distilleries and an increase in the number of otters (Meadows, 1997; Ogilvie, 1994). Over many years discharges from distilleries have increased the nitrates and phosphates in the water, which have significantly increased the number of molluscs and fish. Both the otters and distillery require freshwater and I believe any correlation should be investigated further.

Leisure and recreational consultants who prepared a local plan for Skye's Tourist Board described Skye as having a litter problem, and much of this is present in the coastal environment. The effect this has on otters, although local, can be serious: in 1997 in the IOSF Wildlife Hospital two otters were received which had been seriously injured by litter in the form of plastic cable ties and twine. Without medical attention these otters would have died and there is always the threat of otters becoming trapped in discarded nets or rope and drowning.

5. Recreation and Tourism

The Gaelic culture, rugged scenery and wildlife make Skye a popular tourist destination. Private and leisure moorings are scattered around the coastline and on a single day some 25 yachts and small boats were tied up at Portree and Armadale.

Although in 1997 there was a drop in tourism, generally there has been a steady increase from 184,000 in 1978 to 600,000 in 1988 with the current figure standing at about 660,000. With this increased pressure we see a degradation of the local environment with destruction of footpaths and increased road traffic. The impact of the increased road traffic has already been discussed.

Many visitors just pass through but there is a general increased interest in wildlife, and this increased interest may in itself have an impact on local wildlife. The Otter Hide at Kylerhea attracts some 20,000 visitors and at the height of the season it is difficult to observe otters regularly. It is, however, difficult to say if this is due to the people pressure or other factors, such as increased day length providing more opportunity for fishing.

Final conclusions and conservation priorities for otters on Skye

The otters on Skye are undoubtedly doing well; I have been observing otters on the island since 1985 and there is no reason to believe that they are declining. The Isle of Skye is an island where the fauna is generally thriving with 40 animal species and over 148 bird species including populations of sea and golden eagle, seals and many cetaceans around the coastline (Yoxon and Yoxon, 1990).

My initial research was started not only because of my interest in otters but because I wanted to do something practical for their conservation. Many laws, regulations, and conservation management programmes are available to protect the otter but the problem with any conservation programme is that each location is unique; the conservation of the 350 otters in England is very different from the conservation of the 350 otters on the Isle of Skye. Action plans and frameworks are filled with rules and regulations which are difficult to implement as they generally have no legal enforcement (Foster-Turley, 1990; Mason and Macdonald, 1994; Harris et al, 1995). The recent JNCC "A Framework for Otter Conservation 1995-2000" puts seven objectives for the conservation of the otter in the UK:

1. Survey and monitor populations to determine the UK resource
2. Maintain and enhance current populations through good habitat management
3. Monitor, assess and reduce prevalent threats
4. Promote expansion of populations by natural recolonisation of areas
5. Implement and enforce relevant legislation and policy
6. Improve knowledge of ecology and conservation through appropriate research
7. Promote education and awareness of the status and needs of otters.

While my thesis work has not achieved all these objectives it has partially fulfilled objectives 1, 3 and 6, and has provided considerable data, and has shown that the geology of the coastline does have an effect on otter density and otter utilisation of the coastline. If development of the coastline is going to occur then prime Rank 1 otter habitats should be taken into account so that coastal development can go ahead with limited impact on the island's otter population.

The Future

The completion of any thesis will inevitably raise other questions which were not considered at the beginning. Some of these questions have been raised in the discussions of the preceding chapters, but undoubtedbly further research is required in many areas; for instance, little is known about the freshwater otter populations on the island, how they interact with the coastal otter population, and how these relate to the resources available. Inland otters utilising freshwater systems live within a short distance of their coastal relatives and there may be frequent interaction between these two populations.

The long term effect of road traffic mortality has to be researched not only on Skye but in the Highlands and Islands as a whole. We know very little about the impact of increased road use on otters. At present this impact does not seem to be limiting the population, but since over 70% of mortalities are associated with A-class roads (Green and Green 1997), any road improvements with an increased traffic speed will pose an increased threat.

Total mortality has to be looked at in more detail: deaths in lobster and crab creels still cause concern and are often under-recorded; deaths occurring in snares are hardly ever being prosecuted. A more accurate co-ordinated approach to otter mortality has to be developed so that information can be shared and used between interested parties to ensure effective conservation.

The otters on Skye rely for most of their diet on five-key prey species outlined in chapters 3 and 4. Little is known of the ecology of these species and what effect the otters are having on these prey populations. Kruuk (1995) showed that it was unlikely that otters would have a major influence on the shore community, because otters generally fished in narrow strips of water usually less than 3m in deep and all the prey species appeared to go down to depths greater than this. He argued that otters were only creaming off the edges of the available prey populations. However, have other species that only live in shallow water been seriously affected by otter predation? Clearly much more work is required on the populations of these fish species, their population dynamics and their response to predation.

Very little is known on Skye about the dispersion of otters. Although it has been established that otters can move long distances away from the area where they were reared (Kruuk and Moorhouse, 1991), little is understood about how they find new territories, interact with inland otters or their mortality rates during dispersion. Many problems would burden an otter utilising a freshwater system on Skye that moved to the coast: how would it learn to wash in freshwater pools for example, as well as learning to forage in an unfamiliar territory.

The above questions show what still has to be achieved in otter ecology. Attempting to answer them they will undoubtedly uncover more and more questions still needing answers in order to understand better what actually is important to otters and what we as humans need to do to safeguard their long term future.

REFERENCES

Please contact the author for a complete list of the references