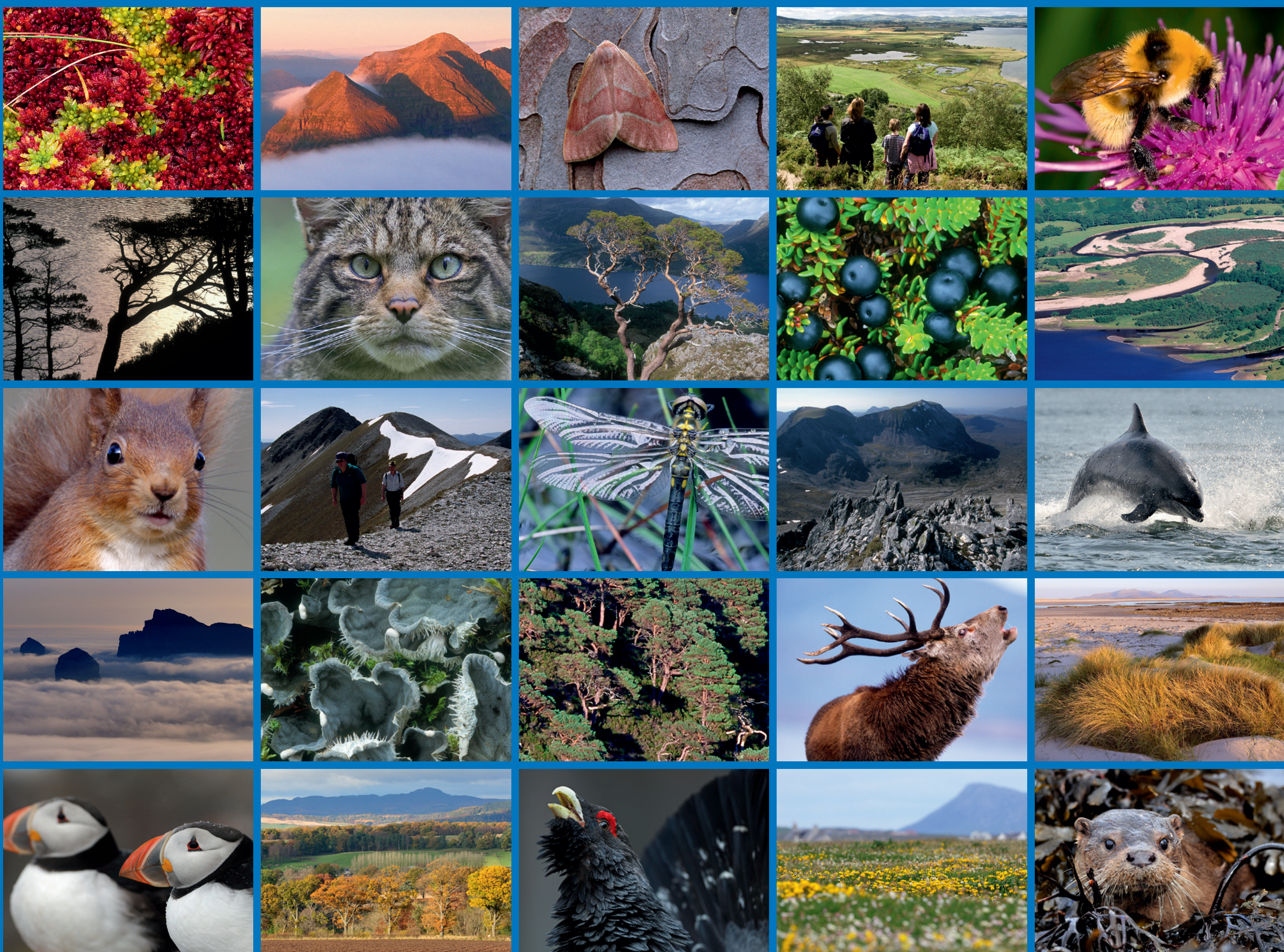
Scottish Natural Heritage
Commissioned Report No. 396

Restocking of the native oyster, Ostrea edulis, in Shetland: habitat identification study



COMMISSIONED REPORT

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Restocking of the native oyster, *Ostrea edulis*, in Shetland: habitat identification study

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COMMISSIONED REPORT

Summary

Restocking of the native oyster, *Ostrea edulis*, in Shetland: habitat identification study

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Background

The native European oyster, *Ostrea edulis*, is a sessile, filter-feeding, bivalve mollusc, distributed widely from Norway in the north to Morocco in the south. Wild populations were once abundant around the Scottish coast and, during the 1800s, the main Scottish fishing stocks were located in the Firth of Forth, Loch Ryan, Orkney, Shetland and West Loch Tarbert. The largest of these fisheries were the Firth of Forth and Loch Ryan, with the main current Scottish stock located along the west coast. As a result of its widespread decline, the species has been included in the UK Biodiversity Action Plan and is listed as an OSPAR priority species. This study aimed to identify suitable areas around Shetland for restocking *O. edulis* in the hope that, in the long term, native oyster beds will become self-seeding. Areas were identified from historical accounts, current records and cartographic tools.

Main findings

- Historically, 29 areas around Shetland have been identified as locations containing *O. edulis*. The majority of these were located on the west coast.
- Of these 29 areas, Lang Sound and South Voe, between East and West Burra, were regarded as the most important oyster fishery in Shetland.
- The decline of the Shetland oyster fishery was probably due to a combination of overfishing during the 1890s and severe winter weather conditions during 1914.
- No *O. edulis* specimens were found during the survey; however, Roe Sound and Tresta Voe were the most suitable surveyed areas for potential restocking. Weisdale Voe and Stromness Voe were identified as potential sites for future investigations.
- Historical information on previous fishing grounds was not found to be a suitable methodology for locating present-day *O. edulis* stocks. A combination of habitat maps and recent sightings of live *O. edulis* is thought to be of more benefit.

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1 INTRODUCTION

Wild native European oyster (*Ostrea edulis*) populations were once abundant throughout most of Europe, supporting thriving fishing industries. Evidence of the widespread use of oysters, as a source of nutritious food, dates as far back as the pre-Viking era of Shetland (Moore, 1992), as well as the Roman occupation (Edwards, 1997) on mainland Britain. Records showed that the Romans not only exploited native British stocks but also exported them back to Rome (Edwards, 1997). Prior to the industrialisation of the oyster fishery, oysters formed a staple part of the diet of many poorer coastal communities (Edwards, 1997). With the industrialisation of the fishery in the middle of the nineteenth century, as a result of an increase in steam technology and rail networks, *O. edulis* populations declined due to the overexploitation on the fishing grounds (Edwards, 1997; Smith *et al.*, 2006). By the end of the nineteenth century and beginning of the twentieth century, the decline in population size was attributed not only to overfishing, but also to disease (Montes *et al.*, 1991; van Banning, 1991; Beaumont *et al.*, 2002; Laing *et al.*, 2005) and habitat loss (Beaumont *et al.*, 2006; Laing *et al.*, 2006). By the 1940s, many of the wild European populations had become scarce (Kennedy & Roberts, 1999). A series of unusually cold winters during the 1930s and 1940s resulted in mass mortalities throughout *O. edulis* populations (Orton, 1940). Additional factors contributing to the decline of *O. edulis* fisheries included predation and competition (Korringa, 1952a; MacKenzie, 1970; Drinkwater & Howell, 1985; Goodlad, 1994; Harding, 1996; UMBS, 2007), reduced water quality (Rothschild *et al.*, 1994; Kennedy & Roberts 1999) and the species biology, consisting of sporadic reproduction and a relatively long lifespan (Laing *et al.*, 2006).

During the 1800s in Scotland, the main *O. edulis* fisheries were located in the Firth of Forth, Loch Ryan, Orkney, Shetland and West Loch Tarbert, with the highest historical production from the Firth of Forth and Loch Ryan (UMBS, 2007). Currently, the main British stocks of *O. edulis* are situated on the Scottish west coast, the south-east and Thames estuary, the Solent and the River Fal (Jackson, 2007) and are considered to be very low in comparison with the stocks of the late 1800s (Laing *et al.*, 2005). In 1864, demand was high, with 700 million oysters consumed in London alone, but by 1920 *O. edulis* production had fallen to 40 million and, by the end of the 1960s, production was as low as three million (Edwards, 1997).

From the mid-nineteenth century pressure was placed on the government to try and halt the decline of the *O. edulis* stocks (Edwards, 1997). Governmental committees were set up and, in 1877, legislation was passed which banned the sale of *O. edulis* from 14 May to 4 August in order to protect the breeding season. Under the Sea Fisheries (Shellfish) Act of 1967, this closed season still exists today. Owing to the decline of *O. edulis* populations, the species was included in the UK Biodiversity Action Plan (UKBAP) (Anonymous, 1999), which is part of a national commitment to the International Convention on Biodiversity (Laing *et al.*, 2005), and *O. edulis* is listed as an OSPAR priority species (Hiscock *et al.*, 2005). In Scotland, all naturally occurring *O. edulis* stocks belong to the Crown Estate except where these rights have been specifically granted to other persons (Anonymous, 1999). Under the Shetland Islands Regulated Fishery (Scotland) Order 1999, *O. edulis* is a prescribed species, with the commercial fishery managed by the Shetland Shellfish Management Organisation (SSMO). Under section 7 of the regulating order, the SSMO has the power to create reserves for the purpose of, but not exclusively for, restocking prescribed species and collection of their spat.

1.1 Aims

Ostrea edulis once formed an important fishery in Shetland, but factors such as overfishing and mass mortalities, due to exposure to severe frost, have reduced populations to very low levels. In recent times oysters have been seen only rarely by divers. The decline of native oyster populations is not restricted to Shetland, and this has resulted in the inclusion of the native oyster in the UKBAP. The objectives of the species action plan for the native oyster are to maintain and expand the existing geographical distribution, and also to maintain and increase the abundance of the native oyster within UK inshore waters (Anonymous, 1999).

The aim of this project was to identify areas in Shetland that might be suitable for restocking populations of *O. edulis*. Sites were surveyed to examine their physical and biological nature in order to determine, in greater detail, their suitability for restocking. The identification of suitable sites is essential to provide any restocked oysters with the best possible environment for survival and growth. In the long term, it is hoped that, through restocking, native oyster beds will become self-seeding and may even generate further oyster beds, facilitating a revival of this species around Shetland.

2 REVIEW

2.1 Biology of the native oyster, *Ostrea edulis*

Ostrea edulis is a sessile, filter-feeding, bivalve mollusc (Airoldi & Beck, 2007) with a wide geographic distribution extending along the west coast of Europe and northern Africa from Norway in the north to Morocco in the south. The range also includes the northern Mediterranean and the Black Sea (Kennedy & Roberts, 1999; Laing *et al.*, 2005). *Ostrea edulis* is found from the low intertidal down to the sublittoral, where it is found in greater abundance, especially in association with highly productive estuarine areas (Laing *et al.*, 2005; Sobolewska & Beaumont, 2005; Airoldi & Beck, 2007). In the UK, sea lochs on the west coast of Scotland have been found to harbour scattered *O. edulis* populations which are thought to represent a stronghold in the UK population (Laing *et al.*, 2005; UMBS, 2007).

Ostrea edulis is described as a 'protandrous alternating hermaphrodite' species, which means that, at maturity, the adults first function as a male and then alternate between female and male stages (Laing *et al.*, 2005). However, exceptions have been noted, with *O. edulis* becoming a functional female at maturity following an exceptionally warm season (Dodd *et al.*, 1937). As a general rule it is not until the second summer that oysters in British waters start to function as males, with the largest individuals having the potential to function as a female later in the same year. Most older oysters in British waters have been shown to function as both male and female at least once a year (Korringa, 1952b). Fertilisation is internal, with the breeding season extending from May to August in Scotland (Millar, 1964). Brooding takes place within the mantle cavity until the larvae have a fully formed shell at about 0.170 mm (Laing *et al.*, 2005), which takes from 6 to 15 days (Millar, 1964; Newkirk & Haley, 1982; Hedgecock *et al.*, 2007).

Spawning usually occurs between late June and mid-September (Kennedy & Roberts, 1999; Hedgecock *et al.*, 2007), with maximum spawning occurring during spring tides in the Oosterschelde, The Netherlands (Korringa, 1952a). However, Cano *et al.* (1997) noted that spawning duration varied from year to year in south-east Spain, which was found to be closely linked with temperature and food availability. Once spawned, the larvae have been found to passively drift in the water column up to 10 km or more (Berghahn & Ruth, 2005) while feeding on phytoplankton (Laing *et al.*, 2005). The larval stage lasts for 2–3 weeks, depending on environmental conditions, before a foot develops (Laing *et al.*, 2005; Sobolewska & Beaumont, 2005), enabling the larvae to find a suitable site for permanent settlement and metamorphosis.

Hard substrates are preferred by settling *O. edulis* and include hard silt, muddy gravel with shells, sand and rocks (Laing *et al.*, 2005; Airoldi & Beck, 2007) although Korringa (1976) found that muddy substrates were not suitable for *O. edulis* in Norway. A more recent study, looking at the attachment preferences of *O. edulis* to differing substrates, showed a greater attachment to shells with a 'strong avoidance' of gravel or pebbles (UMBS, 2007). The study suggested that either gravel and pebble habitats were not suitable for larvae settlement or there was a high mortality of attached *O. edulis* associated with them. The presence of bivalve shells, or cultch, is widely regarded as being important for a successful, large, spat settlement (Kennedy & Roberts, 1999). Hugh-Jones (2003) reported oyster shells were the preferred shell for settlement, followed by whelks, with no spat caught on scallop shells, and Korringa (1946) reported that the best setting surface for recruiting spat was the growth rim of the adult oyster. As with spawning duration, spatfall was found to be highly variable between years, sites and populations of *O. edulis* (Newkirk & Haley, 1982; Hugh-Jones, 2003; Berghahn & Ruth, 2005; UMBS, 2007; Burke *et al.*, 2008).

Once recruited into the population, young *O. edulis* have a rapid initial growth phase over the first year and a half (Laing *et al.*, 2005), which is highly dependent on environmental conditions, especially temperature. Hugh-Jones (2003) recorded a growth rate in Loch Ryan, Scotland, of nearly half that reported by Laing *et al.* (2005), although no locations were reported by the latter authors. Low initial growth rates were also recorded in Loch Eriboll and Orkney, which was attributed to low temperatures rather than genetic variation (Beaumont & Gowland, 2002). It has been reported that *O. edulis* growth starts when temperatures reach 8–9°C in the UK (Laing *et al.*, 2005), and Korringa (1952b) noted that shell deposition would occur so long as the water temperature remained above 10°C. Davis and Calabrese (1969) examined the effects of temperature on growth of *O. edulis* from Maine, USA, and found that a temperature range of 17.5–30°C was required in order to obtain 'satisfactory growth' of 70% or more of the optimum. The authors also noted that at 10°C very little growth was recorded in *O. edulis* spat.

Environmental factors, such as temperature and salinity, have been shown to have significant effects on the biology of *O. edulis*. The effect of temperature on growth rate has already been discussed, and it is obvious from the findings that there is no definitive temperature governing the optimum growth rate of *O. edulis* throughout its geographical range. Korringa (1957) showed that a breeding temperature of 15°C is not a physiological constant within the species, as previously thought. If there was a physiologically constant breeding temperature, Korringa (1957) noted that the large *O. edulis* population which once inhabited the Firth of Forth, Scotland, would not have been able to breed as the temperature rarely reaches 15°C. Similarly, an optimum temperature range for growth of 17.5–30°C, as described by Davis and Calabrese (1969), would not be applicable in the colder waters of Scotland. *Ostrea edulis* can tolerate a change in salinity from 35‰ to 15‰, with no effect on feeding behaviour over 35 days at this lower salinity (Chanley, 1958), although additional studies have shown that prolonged low salinities seemed to inhibit feeding (Korringa, 1952b).

In Scotland, the most common predators of *O. edulis* are *Asterias rubens*, *Carcinus maenas* and *Necora puber* (Drinkwater & Howell, 1985; Harding, 1996). *Nucella lapillus* and *Pholis gunnellus* are also well-known predator species of bivalve molluscs. In addition to predators, *O. edulis* spat are subject to competition for food and space by *Anomia ephippium*, *Ascidiella aspersa*, barnacle species, *Ciona intestinalis*, *Mytilus edulis* and *Pomatoceros triqueter*, and to overgrowth by conspecific spat (MacKenzie, 1970; Drinkwater & Howell, 1985; UMBS, 2007).

2.2 Historical distribution in Shetland

The majority of information obtained on the historic locations of native European oysters around Shetland was obtained from personal communications cited in Moore (1992). Further information was obtained from an SNH commissioned report (UMBS, 2007), as well as from Janet Davies (personal communication), of the local BSAC diving club. These accounts were combined with the information obtained from Moore (1992) and are summarised below (Table 2.1 and Figure 2.1). Many of the accounts listed in the thesis of Moore (1992) are personal communications, with local people retelling stories and accounts of where their fathers and grandfathers fished. As such, the thesis is an invaluable source of information regarding the oyster fishery in Shetland.

Table 2.1 Historical locations of native oysters caught around Shetland listing the latest year of capture, the estimated total number recorded over the years, and the type of fishing method employed for capture. Blank cells denote no information.

Location	Latest year	Total number	Fishing method
Basta Voe	–	–	Picking
Bixter Voe	1988	6	Diving
Bur Wick	1989	1	Diving
Busta Voe	2008	1	Diving
Cat Firth	–	–	
Clift Sound	1926	-–	Dredging
East Burra Firth	–	1	Diving
Garderhouse Voe	1962	25	Picking
Gon Firth Voe	1990	1	Diving
Hamar Voe	1965	100	Picking
Lang Sound	1960	100	
Mid Yell Voe	1970	4	
Olas Voe	1989	–	Dredging
Roe Sound	1989	6	Dredging and diving
Ronas Voe	–	1	Dredging
Sandsound Voe	–	11	Diving
Scalloway Bay	1992	1	Diving
Scutta Voe	1980s	21	Picking
Seli Voe	–	25	
Skelda Voe	1943	200	Picking
South Voe	1900s	–	Dredging
Stromness Voe	2008	2	Diving
Sullom Voe	1992	1	Picking
Suthra Voe	1963	6	Dredging
The Firth	1992	5	Diving
Tresta Voe	1989	27	Dredging and diving
Vaila Sound	1991	3	Diving
Weisdale Voe	2005	3	Diving
Whiteness Voe	2008	7	Diving

The above data are a compilation of accounts from Moore (1992), UMBS (2007) and Janet Davies (pers. comm.).

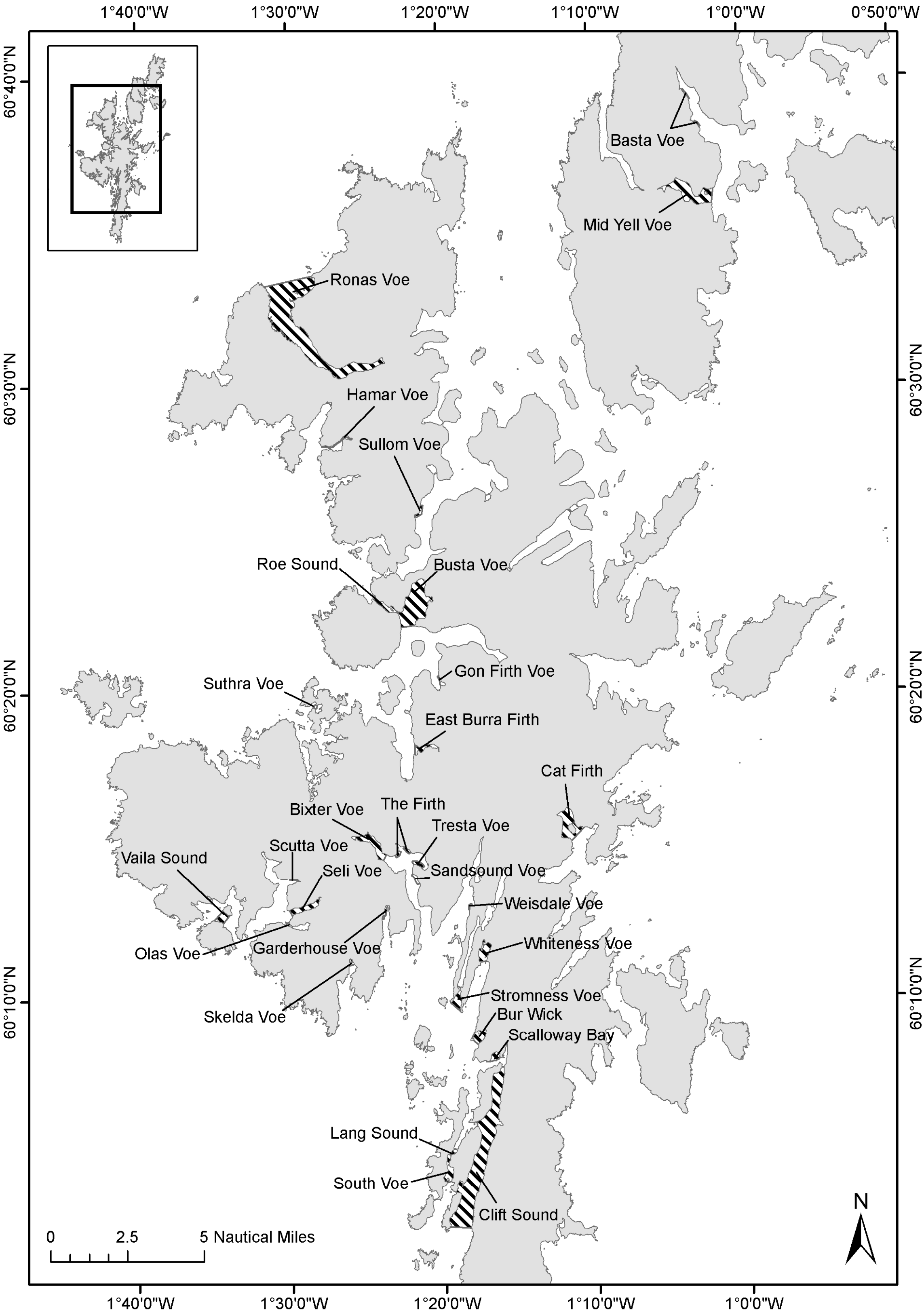

Figure 2.1 Locations of all areas around Shetland where the native oyster has been recorded.

Moore (1992) noted that all *O. edulis* finds were from sheltered locations, usually in shallow water at the head of a voe where small streams entered. With the exception of Cat Firth (where only an empty shell was found), Sullom Voe and Yell, all the areas where *O. edulis* have been found in the past are situated on the west coast of Shetland (Figure 2.1). However, Sullom Voe may be classed as an artificial stock according to Moore (1992) as the local Laird commissioned the stocking of the area, from an unknown seed source, during the 1890s. Basta Voe was the most northerly oyster fishery, with evidence of the area's importance for food found on a map originating from when the Norse settlers arrived (Moore, 1992). The area between East and West Burra (Lang Sound and South Voe; Figure 2.1) was classed, in the 1880s, as the most important oyster fishery area in Shetland as it was well documented and well remembered (Moore, 1992). More recently, several *O. edulis* specimens were found in 2008 by divers in Whiteness Voe, Stromness Voe and Busta Voe (Janet Davies, pers. comm.). All were described as being of large size with a heavy shell.

According to Moore (1992), recorded landings, cited in *Manson's Shetland Almanac*, of *O. edulis* in Shetland ceased in 1897, with the exception of one additional landing in 1913 of 200 oysters. After this, no landings were recorded. Post 1885 the official landings for Shetland were small and sporadic (UMBS, 2007), and by the end of the nineteenth century the depletion of the *O. edulis* beds in Shetland was attributed to overfishing by dredging (Moore, 1992), especially in the areas of Busta Voe and Burra. The decrease in stocks would have been further compounded by the frost of 1914, which was reported to have killed all the oysters in Lang Sound (Moore, 1992). Orton (1940) and Crisp (1964) recorded high oyster mortalities in response to a significant drop in temperature which caused the shell to gape open. This led to an increase in the quantity of mud and silt build-up, which, conversely, reduced oxygen uptake, leading to death. An additional contributing factor in the decline of *O. edulis* stocks was proposed by Goodlad (1994), who speculated that an increase in fishing intensity for cod and saith instigated a trophic cascade, causing an increase in *O. edulis* predators, such as starfish, which are naturally preyed on by the fish. However, no evidence was presented in support of this hypothesis. The prevalence of the disease bonamiasis, caused by the parasite *Bonamia ostreae*, which was associated with much of the decline in the *O. edulis* stocks in England and other regions of Europe (Laing *et al.*, 2005), was not reported to have ever reached the Shetland population (Moore, 1992; Beaumont *et al.*, 2002).

3 SURVEY

3.1 Methods

Four areas were chosen for sampling on the west coast of Shetland based on accounts of the historical presence of oysters (Figure 2.1), sediment type, water depth and sources of pollution and disturbances (see section 6 for a full description). The data were overlaid in a GIS mapping format, which allowed easy identification of potential areas to sample. Criteria for choosing suitable sites included site access and suitable intertidal zone; spatial distribution between potential sites; and the quantity of oysters found, reliability of the source data, and how recent oyster sightings were. The chosen areas were Roe Sound, The Firth and Tresta Voe (also referred to here as Bixter), Whiteness Voe and the area between West and East Burra referred to here as Burra (Table 3.1, Table 3.2 and Figure 3.1). Three sites were sampled within each area of the low intertidal (section 3.1.1) and, where possible, four sites within each area of the sublittoral (section 3.1.2).

3.1.1 Low intertidal sampling

Intertidal sampling commenced on 27 October 2008 and was carried out over 4 days (Table 3.1). A 50 m transect line was randomly positioned parallel to the shore at a height corresponding with low water springs (LWS). The positioning of the transect was highly dependent on the area of shore available, and therefore a full random positioning was not always possible. The transect line was marked at 10 m intervals, and at each interval, inclusive of the start and end of the transect, four 0.25 m^2 quadrats (two on each side of the transect line) were randomly dropped. This equated to a total of 6 m^2 of surveyed substratum per transect. Within each quadrat, counts were made of all live oysters, other shellfish species (especially bivalves) and any potential oyster predators. Particular note was made of any horse mussels (*Modiolus modiolus*), blue mussels (*Mytilus edulis*) and any other bivalve species as they share the same ecological niche as *O. edulis*. In addition, the per cent coverage of substratum type was recorded. Sediment types were classified according to size, with each sediment type discussed between the samplers prior to sampling in order to ensure consistency throughout the survey (Table 3.3). Two random sediment cores were taken, where possible, per transect at the 10 and 40 m marks, which were submitted for sediment particle size analysis.

Table 3.1 Locations of intertidal sites in each of the four areas and the date when they were sampled.

Area	Site	Sample date	Latitude	Longitude
Bixter	B1int	29/10/2008	60°14′31.63″	001°21′6.56″
Bixter	B2int	29/10/2008	60°14′57.23″	001°22′53.07″
Bixter	B3int	29/10/2008	60°15′0.31″	001°22′41.40″
Burra	Bu1int	30/10/2008	60°5′2.84″	001°19′19.07″
Burra	Bu2int	30/10/2008	60°4′57.84″	001°19′40.20″
Burra	Bu3int	30/10/2008	60°4′55.07″	001°19′45.27″
Roe Sound	R1int	28/10/2008	60°22′48.90″	001°23′25.45″
Roe Sound	R2int	28/10/2008	60°22′49.04″	001°23′19.64″
Roe Sound	R3int	28/10/2008	60°22′49.94″	001°23′9.81″
Whiteness	W1int	27/10/2008	60°11′13.30″	001°17′11.62″
Whiteness	W2int	27/10/2008	60°11′15.57″	001°17′16.09″
Whiteness	W3int	27/10/2008	60°11′48.11″	001°16′59.09″

3.1.2 Sublittoral sampling

A remotely operated vehicle (ROV; VideoRay Pro 3) was used for the sublittoral sampling, which took place on 5 December 2008 (Burra), 6 January 2009 (The Firth and Tresta Voe) and 7 January 2009 (Roe Sound). It was not possible to sample Whiteness Voe because of the lack of a suitable access point and unfavourable weather conditions. Fifty metre transects were carried out, parallel to the shore, at four sites, ranging in depth from 1 m down to 9 m (Table 3.2 and Figure 3.1), within each area. The transect line consisted of a plastic-coated 3 mm wire, weighted and buoyed at each end, with white rectangular plastic markers (75 mm by 85 mm) located every 5 m. A laptop was connected to the control box of the ROV via a USB connection using the DVD Maker (KWORLD™) hardware and the DVD MovieFactory™ 4 SE software (Ulead), which enabled a digital colour recording (*.MPG) of each transect to be taken for later analysis. Species counts and abundance estimates were made at each marker along the transect, as detailed in the intertidal sampling. In addition, the presence/absence of flora and fauna was recorded between markers and an estimation of the hardness of the sediment was made. An indication of sediment type and the hardness of the sediment could be estimated by setting the ROV down onto the sediment and examining how deep into the sediment the transect end weight sank. By driving the ROV the length of the transect line, and just above the sediment, a minimum of 40 m^2 of substrate was surveyed per transect.

Table 3.2 Locations of sublittoral sites in each of the four areas and the date when they were sampled. Positions and depths refer to the start of the transect.

Areas	Site	Depth (m)	Sample date	Latitude	Longitude
Burra	Bu01sub2	2	05/12/2008	60°4′12.6″	001°20′11.6″
Burra	Bu02sub5	3	05/12/2008	60°4′11.1″	001°20′11.3″
Burra	Bu03sub2	2.5	05/12/2008	60°4′57.2″	001°19′34.6″
Burra	Bu04sub5	4	05/12/2008	60°5′00.0″	001°19′35.5″
Roe Sound	R12sub2	3.5	06/01/2009	60°22′58.8″	001°24′21.7″
Roe Sound	R13sub5	5	06/01/2009	60°23′00.3″	001°24′19.6″
Roe Sound	R14sub2	3	06/01/2009	60°22′47.5″	001°23′37.1″
Roe Sound	R15sub5	8	06/01/2009	60°22′47.4″	001°23′39.5″
The Firth	F05sub2	2.2	06/01/2009	60°14′52.5″	001°22′43.7″
The Firth	F06sub5	8	06/01/2009	60°14′40.8″	001°22′35.9″
The Firth	F07sub2	1	06/01/2009	60°14′45.8″	001°23′01.0″
The Firth	F08sub5	9	06/01/2009	60°14′43.3″	001°22′56.0″
Tresta	T09sub2	1	06/01/2009	60°14′21.3″	001°21′42.8″
Tresta	T10sub5	2	06/01/2009	60°14′23.2″	001°21′41.4″
Tresta	T11sub2	2	06/01/2009	60°14′20.0″	001°21′18.8″

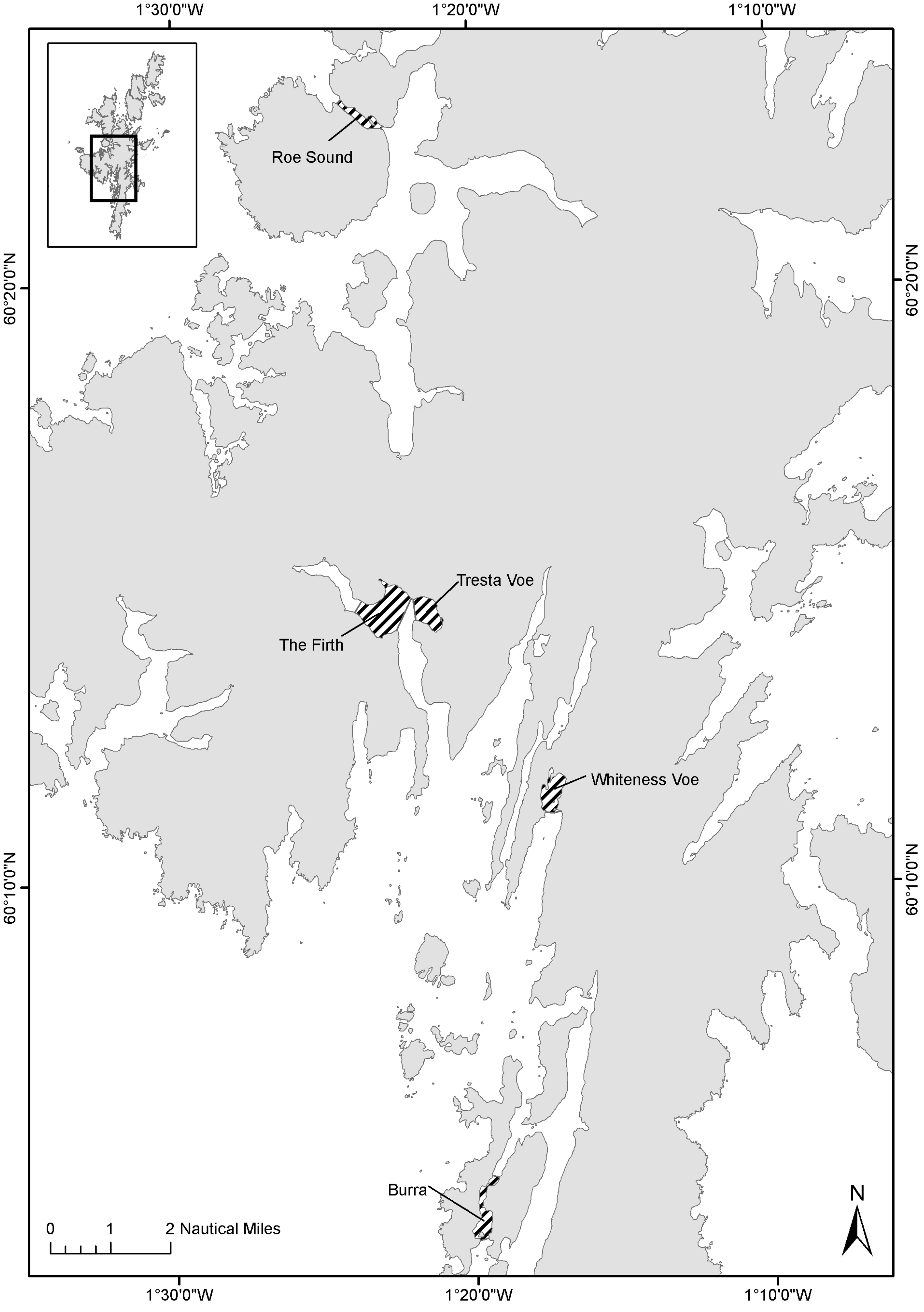

Figure 3.1 Locations of intertidal and sublittoral sampling areas. In the intertidal sampling, The Firth and Tresta Voe were combined into one area, Bixter.

3.2 Results

3.2.1 Low intertidal

Live bivalves and empty bivalve shells were found in the intertidal of all four areas surveyed, although variation within areas was recorded (Figure 3.2). No significant differences were found in either number of live bivalves between areas (Kruskal–Wallis, $P = 0.275$) or predator numbers between areas (Kruskal–Wallis, $P = 0.103$). Empty bivalve shells, however, were found to differ significantly between areas (Kruskal–Wallis, $P = 0.001$). The greatest number of live bivalves and empty shells was recorded at Burra, accounting for, respectively, 48% and 52% of the total number counted. Roe Sound had the lowest number of live bivalves (14% of total) and Whiteness Voe had the lowest number of empty shells (9% of total). The latter area was also found to have the highest number of recorded predators (50% of total), with Roe Sound found to have the second highest predator count (37% of total). No predators were found at any of the intertidal sites at Bixter. *Mytilus edulis* was the most common bivalve recorded, both living ($n = 277$) and empty shell ($n = 263$). Only two other bivalve species were found, namely *Cerastoderma edule* (at Burra and Whiteness Voe; $n = 3$) and *Modiolus modiolus* (Whiteness Voe; $n = 1$). Only five species of empty shells were identified throughout the intertidal (Figure 3.3). In addition to the three live species, *Ostrea edulis* and *Ensis* species were also recorded, as well as some unknown species (Figure 3.3). The two *O. edulis* shells were found at Burra, site Bu3int.

Nucella lapillus was the most abundant predator found ($n = 49$), with the majority, 55%, in Whiteness Voe and the remainder in Roe Sound (39%) and Burra (6%). Two *Asteria rubens* and two *Carcinus maenas* specimens were also found as well as one *Buccinum undatum*. The last two species were both found at Burra while *A. rubens* were found at Burra and Roe Sound.

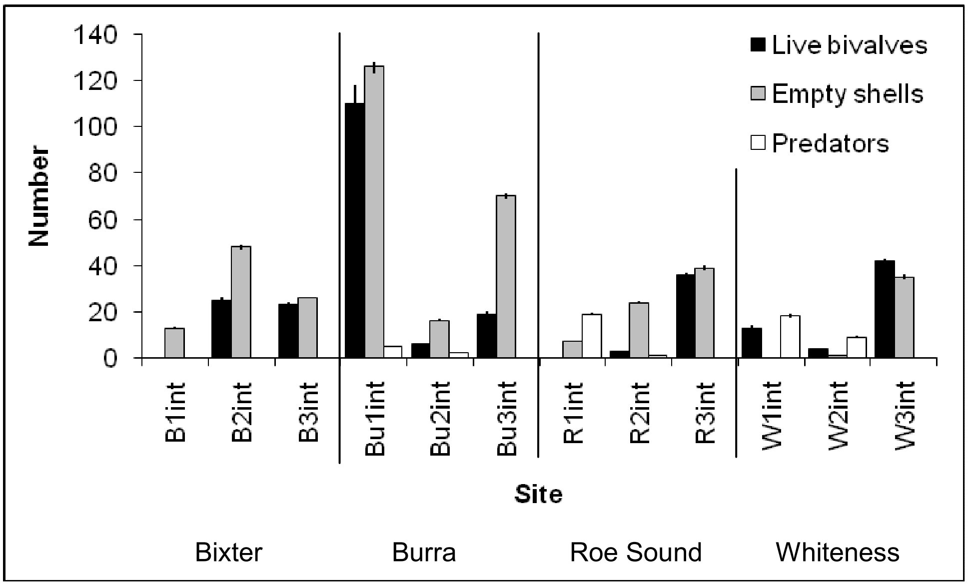

Figure 3.2 Quantity of live bivalve species, empty bivalve shells and potential oyster predators found within a 6 m^2 sampling area at each site. 95% confidence intervals are shown.

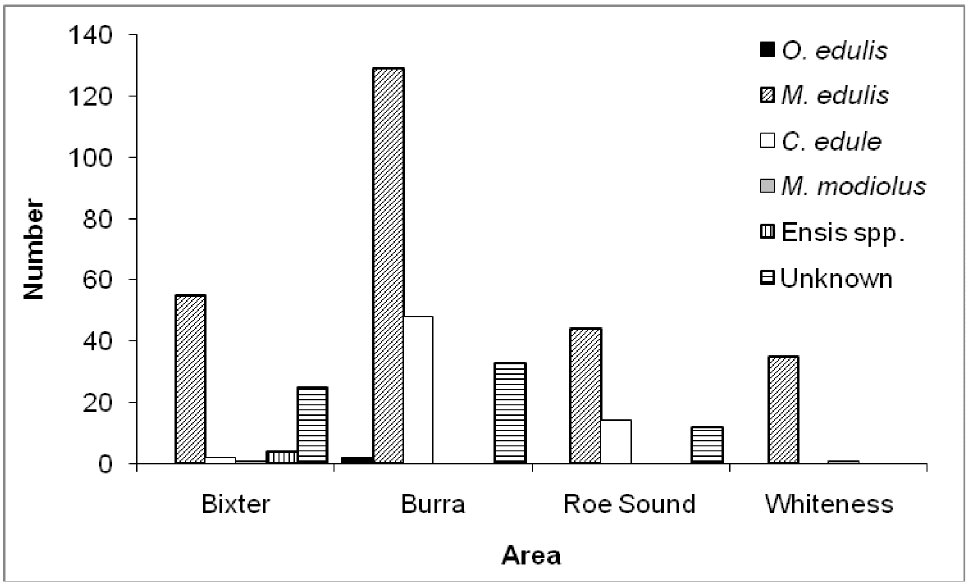

Figure 3.3 Numbers of empty shells found at the four sample areas.

A total of 10 sediment types were identified throughout the intertidal (Table 3.3). Overall, gravel was found to be the most abundant sediment which was found at all four areas along with pebbles, stones, large rocks and rock (Table 3.3 and Figure 3.4). More than 50% of the sediment recorded at Bixter and Roe Sound was gravel, while at Burra and Whiteness a combination of gravel with mud and gravel with pebbles contributed to over 50% of the sediment, respectively (Figure 3.4).

Table 3.3 Sediment types identified from the intertidal sampling, with a corresponding size range and their overall ranked abundance (ranked on a scale of 1 to 10, with 1 being the most abundant and 10 the least) from all four areas.

Sediment type	Identification guide*	Rank of overall abundance
Rock	Bedrock	5
Boulder	>400 mm	9
Large rocks	≤400 mm; >20 mm	4
Pebbles	≤20 mm; >10 mm	2
Stones	≤10 mm; >5 mm	3
Gravel	≤5 mm; >1 mm	1
Shell	Broken shell material	8
Sand	≤1 mm	7
Mud		6
Mussels	Live mussels	10

*The size range for each sediment type was used purely as a guide.

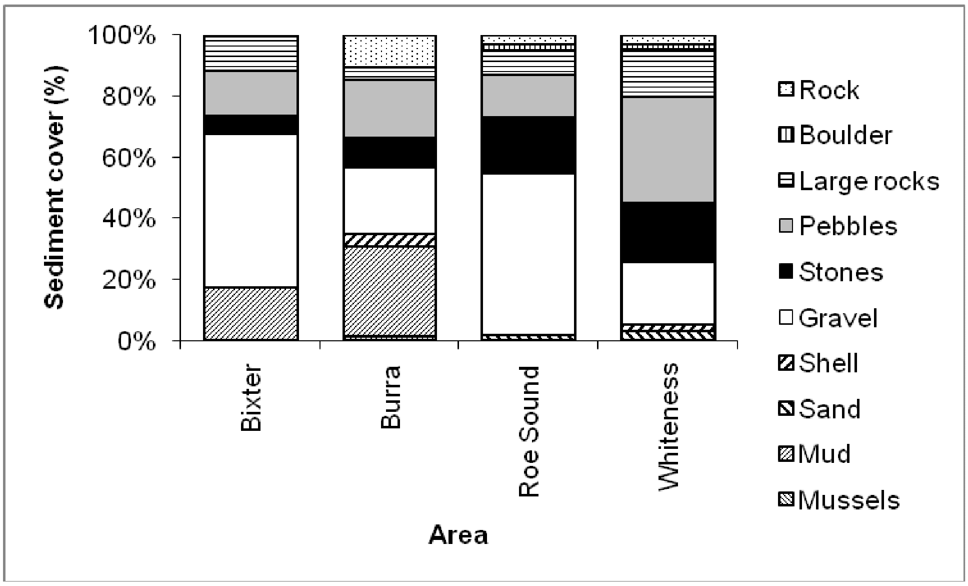

Figure 3.4 Sediment cover in the intertidal of each area.

Because of the sediment types at each site, it was possible to obtain only five core samples. These were located at Bixter (two samples at site B1int), Burra (two samples at site Bu3int) and Whiteness (one sample at site W2int). Both samples at Bixter were classed, according to the Wentworth scale, as medium sand, while the samples at Burra and Whiteness were all fine sand (Table 3.4). Both samples from Burra had a high silt fraction, while the silt fraction at Bixter was found to be much lower. Whiteness had the highest coarse fraction of 68% and Burra the lowest at 1%.

Table 3.4 Results of the particle size analysis on five intertidal sediment samples, with each sample classified according to the Wentworth scale.

Area	Coarse fraction >2 mm (%)	Silt fraction* <63 µm (%)	Mean* (mm)	SD* (mm)	Phi*	Classification*
Bixter	36.12	1.44	0.36	0.17	1.46	Medium sand
Bixter	34.75	1.19	0.48	0.21	1.06	Medium sand
Burra	36.13	18.88	0.23	0.22	2.10	Fine sand
Burra	1.10	25.46	0.19	0.20	2.39	Fine sand
Whiteness	67.68	11.35	0.25	0.24	2.02	Fine sand

*Data pertain to that fraction of the sample that passed through a sieve of 2 mm aperture.

3.2.2 Sublittoral

Identified live bivalves and unidentified shell fragments were found in all areas with the exception of Burra (Figure 3.5). No *Ostrea edulis* specimens, live or empty shells, were recorded at any of the sublittoral sample sites during this study. Live bivalves consisted of *Aequipecten opercularis* (The Firth, Tresta Voe and Roe Sound), *Arctica islandica* (The Firth), *Modiolus modiolus* (The Firth), *Pecten maximus* (Tresta Voe) *and Venerupis senegalensis* (Roe Sound). Five main groups of species were recorded in all four areas but not at every site. These groups were crabs (dominated by *Carcinus maenas*, with the occasional specimens of *Hyas araneus*), demersal fish, hermit crabs, macroalgae (*Laminaria* species) and starfish (*Asterias rubens* and *Crossaster papposus*). Additional identified species included *Buccinum undatum* (The Firth and Tresta Voe), *Ophiura* species (The Firth), *Psammechinus miliaris* (Tresta Voe) and *Virgularia mirabilis* (The Firth). In some instances, the urchin, *P. miliaris*, may have been mistaken for a small *Echinus esculentus*. Owing to the abundance of macroalgae at site R12sub2 in Roe Sound, it was not possible to identify all species in the view of the ROV.

The five main groups recorded in all four areas, with the addition of identified bivalves and unidentified shell fragments, were analysed using the PRIMER software package (Plymouth Routines in Multivariate Ecological Research, version 6.1.5; Clarke & Gorley, 2006). After transformation of the data to presence/absence, a non-metric multidimensional (MDS) ordination was constructed based on Bray–Curtis similarities (Figure 3.6). A similarity of 50% was overlaid on the MDS, showing two distinct groupings of sites. The main sediment type (Figure 3.7) and the estimated hardness (Figure 3.8) of the sediment were also overlaid on the MDS. All Burra sites, which consisted of a soft silt substrate, were grouped together along with a soft mud site in The Firth (F06sub5) and a site in Roe Sound (R12sub2). The latter consisted of a rock substrate. The larger of the two groupings, at a 50% similarity, encompassed all the sites classified as having the main sediment consisting of sand and sand mixed with shells. With the exception of site F06sub5, mentioned previously, the remainder of sites classified as having a mud sediment were also found within this group (Figure 3.7).

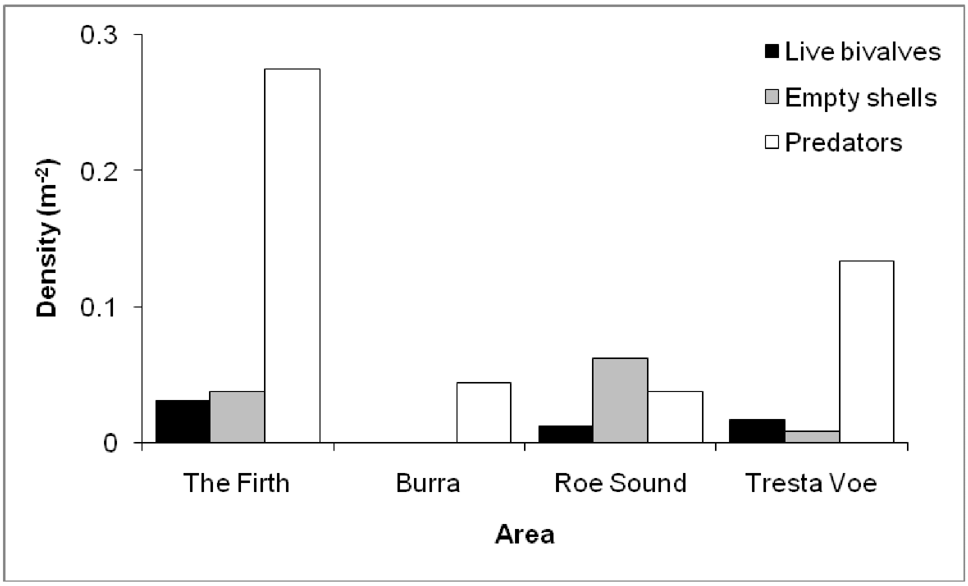

Figure 3.5 Density of live bivalves, identified empty shells and predators found within the four sublittoral sampling areas. These data do not take into account shell fragments within the sediment.

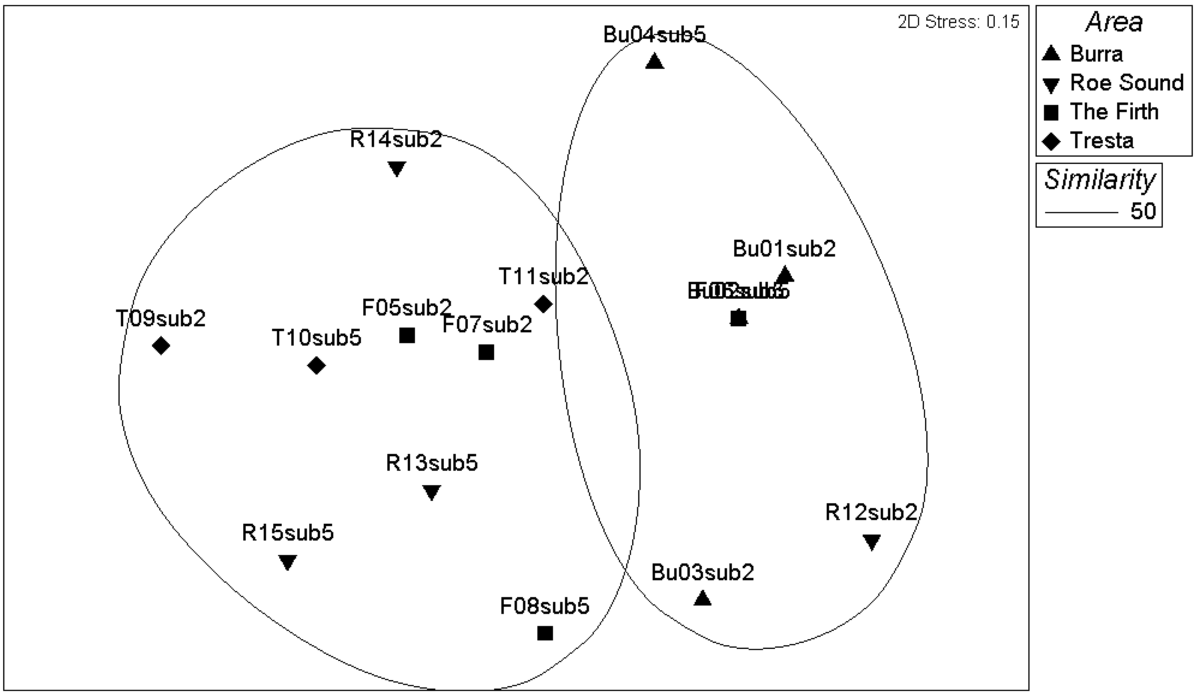

Figure 3.6 Non-metric mult-dimensional scaling (MDS) ordination, based on Bray–Curtis similarities, from sublittoral sites within the four sample areas. The 50% similarity is shown. The two overlapping sites on the right grouping are Bu02sub5 and F06sub5.

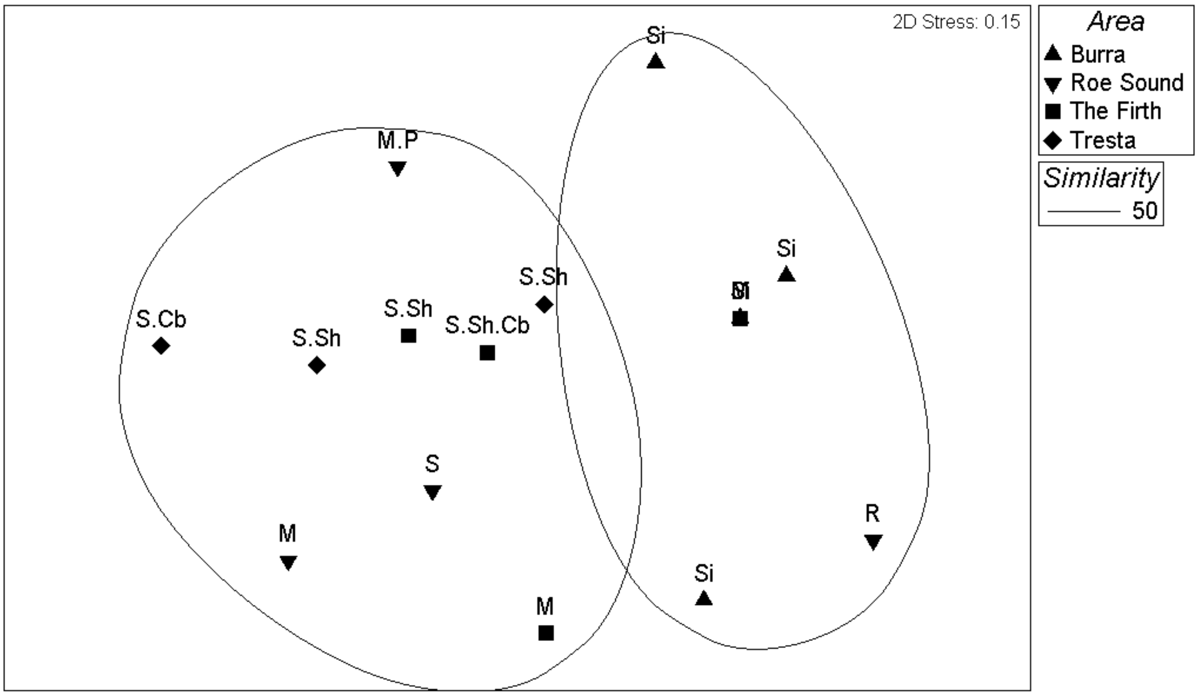

Figure 3.7 *A MDS ordination, based on Bray–Curtis similarities, from sublittoral sites within the four sample areas. The main sediment type from each site is shown along with the 50% similarity (solid line). Sediments comprised cobble (Cb), mud (M), pebbles (P), rock (R), sand (S), shell (Sh) and silt (Si).*

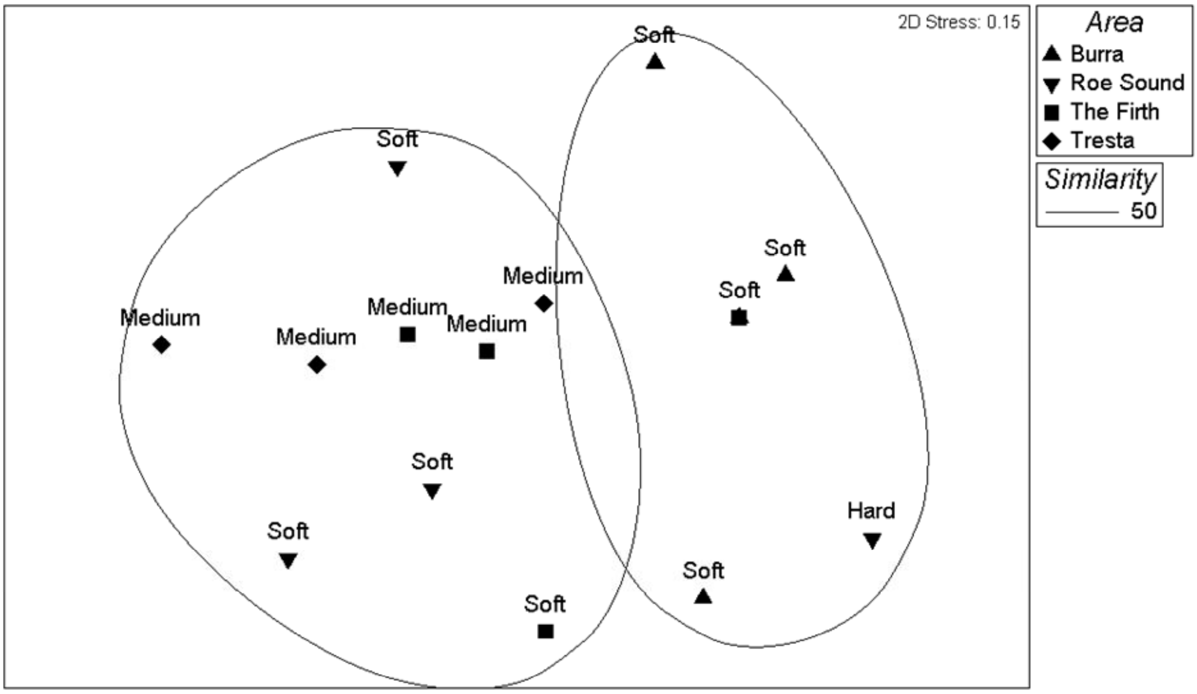

Figure 3.8 *A MDS ordination, based on Bray–Curtis similarities, from sublittoral sites within the four sample areas. An estimation of the sediment hardness is shown along with the 50% similarity (solid line).*

Out of the five main groups, with the exception of macroalgae, only starfish numbers were found to differ significantly between areas (Kruskal–Wallis, $P = 0.014$). No significant differences were found between areas for crabs (Kruskal–Wallis, $P = 0.971$), demersal fish (Kruskal–Wallis, $P = 0.179$) and hermit crabs (Kruskal–Wallis, $P = 0.164$). Live bivalves and empty shells were also analysed with no significant difference recorded between areas (Kruskal–Wallis, $P = 0.320$ and $P = 0.210$, respectively). It was necessary to carry out a Kruskal–Wallis test as the counts within each group were too low for an equivalent parametric test. However, care should be taken in the interpretation of these results because of the low numbers.

Starfish, crabs and hermit crabs were the most abundant species groups recorded. Counts from each site were transformed to an estimated density based on the actual view width of the ROV and the length which it travelled (see section 3.1.2 and Figure 3.9). The highest densities of starfish (0.45 m^{-2}) and hermit crabs (0.58 m^{-2}) were recorded in The Firth, while low densities were recorded at Burra and Roe Sound (Figure 3.9). Crab density was found to be low throughout the sampling sites with estimated maximum densities of 0.05 m^{-2}.

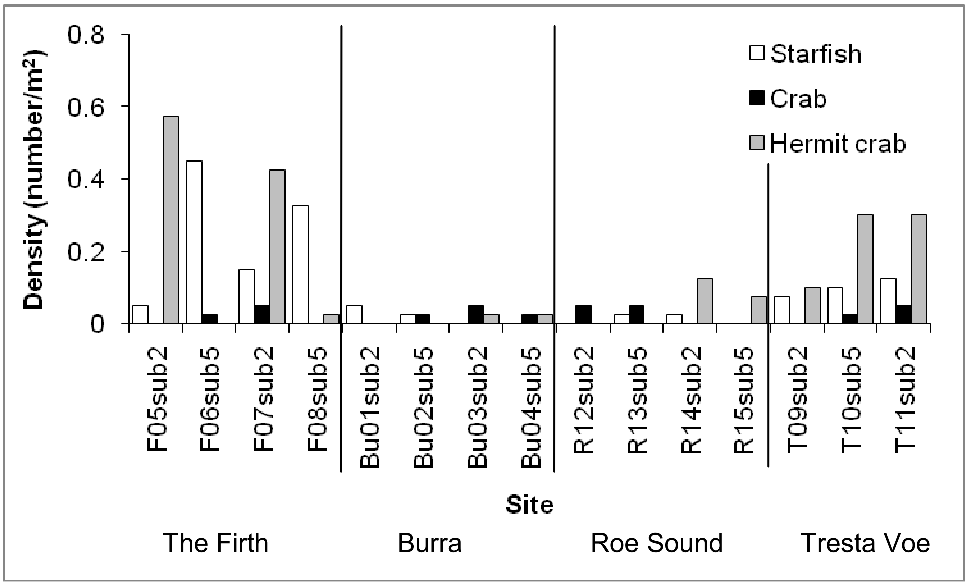

Figure 3.9 Estimated densities of starfish, crabs and hermit crabs at each site within the four sampling areas.

Mud, sand and silt were the dominant sediment types, with only one site, R12sub2 in Roe Sound, found to be dominated by bedrock (Figure 3.7 and Table 3.5). The hardness of the substrate at each site was estimated, with 60% of the sites classed as being soft (Figure 3.8 and Table 3.5). Tresta Voe and the two shallower sites at The Firth (F05sub2 and F07sub2) were regarded as being of an intermediate hardness.

Table 3.5 Sediment type and substrate hardness identified at each of the sublittoral sampling sites. Where more than one sediment type is listed, the most frequent is listed first.

Area	**Site**	**Sediment type**	**Substrate hardness**
Burra	Bu01sub2	Silt	Soft
Burra	Bu02sub5	Silt	Soft
Burra	Bu03sub2	Silt	Soft
Burra	Bu04sub5	Silt	Soft
Roe Sound	R12sub2	Rock	Hard
Roe Sound	R13sub5	Sand	Soft
Roe Sound	R14sub2	Mud and pebbles	Soft
Roe Sound	R15sub5	Mud	Soft
The Firth	F05sub2	Sand and shells	Medium
The Firth	F06sub5	Mud	Soft
The Firth	F07sub2	Sand, shells and cobbles	Medium
The Firth	F08sub5	Mud	Soft
Tresta Voe	T09sub2	Sand and cobbles	Medium
Tresta Voe	T10sub5	Sand and shells	Medium
Tresta Voe	T11sub2	Sand and shells	Medium

4 DISCUSSION

Ostrea edulis was relatively locally abundant along the west coast of Shetland up until the early 1900s, when natural stocks diminished to extremely low levels, and in some locations may actually have become locally extinct. There have been recent, occasional, sightings of large *O. edulis* specimens around Shetland, but none was found during this study. Although two *O. edulis* shells were found at one of the intertidal sites at Burra (Figure 3.2), it is thought, because of the lack of any additional shell finds in this area, that these were most probably discarded when fishing in this area was rife. There was no evidence to suggest that these two shells originated from a current *O. edulis* stock. In spite of the lack of *O. edulis* finds, valuable information was gained regarding local occurrences of predators and competitors and substrate suitability. Collation of this information will aid in increasing the probability of successful future restoration of the *O. edulis* stocks around Shetland.

Mortality of *O. edulis* is one of most important determinants of whether there would be long-term sustainability in the population. In an environment with no fishing pressure on the population, and taking into account natural mortalities due to, for example, adverse weather conditions, predation would be the single most important driving force of mortalities in an *O. edulis* population. However, the presence of predators would not automatically preclude a site from being classed as suitable, as discussed in a report on oyster conservation in Scotland, which cited the case of locating a suitable oyster cultivation site in an area with a large predator population of *Asterias rubens* (UMBS, 2007). Predators were found at all sublittoral study areas during this study, with The Firth having the largest density (Figure 3.5). This may have been due to the proximity of a mussel farm in the area supplying *A. rubens* with an abundant food supply from mussels which have dropped off the lines. The proximity of shellfish aquaculture sites was not taken into account during this study; however, it is believed that such considerations would be of great benefit to future work, especially when locating suitable sites for the recruitment of *O. edulis*.

The presence of bivalve species, both live and empty shells, would be classed as a good indicator of the suitability of a site for *O. edulis* restocking. It is widely accepted that the presence of empty shells, particularly bivalve and whelk shells, provides an ideal environment for *O. edulis* settlement (Kennedy & Roberts, 1999; Hugh-Jones, 2003; UMBS, 2007). Although empty shells were found in the sublittoral, with the exception of Burra, they were not present in sufficient quantities to justify large-scale settlement of *O. edulis* leading to a sustainable population. Korringa (1946) noted that although one female oyster has the potential to incubate and release up to 1 000 000 larvae into the water column, owing to low natural survival rates, 10 000 000 oysters would be needed, in a favourable environment, to achieve a self-sustaining population. The quantity of treated cultch (shell material for *O. edulis* settlement) which would be required for settling spat would be site specific and, in order to reduce competition from other fouling species, spreading of the cultch would also need to be locally variable, both spatially and temporally (MacKenzie, 1970). Although the sediment for the two sites in Tresta Voe and the two shallow sites in The Firth was classed as containing shells, these were shell fragments rather than whole shells. It would be necessary to add cultch to this environment if reintroductions were to be made at these sites.

Although the majority of intertidal sites were found to be of a suitable substrate for *O. edulis* settlement and recruitment, the sublittoral sites were not. *Ostrea edulis* requires a firm substrate with reduced levels of suspended silt (Harding, 1996; Laing *et al.*, 2005). A hard substrate, such as that found at one of the sites at Roe Sound, would be ideal, but the evidence suggests that this type of habitat is patchy within the area, which may prove unsuitable for *O. edulis* recruitment on a large scale. Sites at Tresta Voe, although not consisting of bedrock, were found to be firmer than those from The Firth and Burra. This was also evident from the particle size analysis, which showed a silt fraction of 1.4% at the intertidal site in Tresta Voe (referred to in Table 3.4 as Bixter) compared with 18.9% and

25.5% at the intertidal of Burra. A high silt fraction of the sediment has the potential to increase *O. edulis* mortality, especially when water temperatures are low. At low water temperatures the ability of *O. edulis* to clear silt from the mantle cavity is decreased. The build-up of silt reduces the ability of the oyster to securely close its shell (Orton, 1940; Crisp, 1964) and hence increases the probability of predation. Historically, South Voe and Lang Sound (Burra) were probably the most important *O. edulis* fishing grounds in Shetland (Moore, 1992). It was surprising, therefore, that all the sublittoral sites sampled during this study in Burra were found to be unsuitable for *O. edulis* survival due to the soft silt nature of the substrate. Not only was the substrate found to be unsuitable, but there was also a distinct lack of any bivalve species within this area. Oyster reefs have been shown to increase sediment stability (Meyer *et al.*, 1997) and provide a structurally complex environment supporting a variety of species (Meyer *et al.*, 1997; Gregalis *et al.*, 2008). The decline of the *O. edulis* stocks in the Burra area, as a result of increased fishing pressure, could have triggered a regime shift, leading to an environment which would not be suitable for *O. edulis* settlement and recruitment because of lack of firm substrate and a reduced number of species.

A potential major problem which this study highlights is the lack of evidence of an existing natural *O. edulis* stock. Such a stock is currently considered necessary, in conjunction with added cultch and an adequate quantity of spatfall, for the restoration of *O. edulis* grounds (Laing *et al.*, 2006). However, the more recent *O. edulis* finds, by local divers, were of large, presumably mature, individuals. This may suggest that natural standing stocks of *O. edulis* are present in Shetland waters, but there is no indication as to the quantity of spat which these stocks may produce or how dispersed the population is. Only once natural reproduction surpasses natural mortality (Korringa, 1946) will the oyster stock become sustainable and, even then, it would not be advisable to fish the stock at historic fishing levels (Laing *et al.*, 2006). After carrying out an economic cost–benefit analysis on the restoration of *O. edulis* stocks in the UK, Laing *et al.* (2006) concluded that importing half-grown *O. edulis* would be the most economically beneficial approach to stock replenishment but risks importing non-native species unless they were hatchery reared. This may negate the need to locate natural stocks, but there would still be a requirement to identify suitable habitat and to lay treated cultch. However, the importation of stocks from other geographic areas has inherent problems of its own, such as disease introductions, altering the genetic diversity of the local population, and introduction of non-native species (Bierne *et al.*, 1998; Beaumont *et al.*, 2002, 2006; Sobolewska & Beaumont, 2005; Laing *et al.*, 2006; Smith *et al.*, 2006). In addition, *O. edulis* has been shown to have an optimum temperature range within its natural geographic area (see section 2.1). These factors need to be taken into account when restocking an area that is currently free from disease and non-native species associated with *O. edulis*.

Identifying areas suitable for *O. edulis* restocking can be a costly process with regards to time and money. Habitat and seabed data could prove invaluable, especially with datasets of an increased accuracy, in reducing these costs. By combining habitat and seabed data with recent, reliable *O. edulis* sightings and incorporating into the dataset information on shellfish aquaculture (as discussed above) and exposure (as described by Thomas, 1986; and modified by Burrows *et al.*, 2008), the accuracy of the resultant maps (see section 6) would be greatly increased and would highlight potential restocking sites. From the present mapping data and information gathered during this study, additional areas which may be of potential importance to future restocking would include Weisdale Voe and Stromness Voe. Both are relatively large areas but we believe further investigations would be warranted as *O. edulis* specimens were found by divers in both of these areas during 2005 and 2008, respectively (Table 2.1). In addition, Tresta Voe and Roe Sound would require further investigation, especially in the sublittoral. From this survey work the latter two areas showed the greatest potential for *O. edulis* restocking sites but, owing to their large size, both areas would require further sublittoral investigations.

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6 APPENDIX

Habitat maps were collated (Figure 6.1 and Figure 6.2) from information gathered by the Scottish Sustainable Marine Environment Initiative (SSMEI) project (2008) and bathymetry data from EDINA Marine Digimap. Map layers were as follows: bathymetry; sediment type; shellfish farming grounds; species regions; shellfish grounds and habitat; kelp forest; dredging and disposal sites; development restrictions; and waste discharge (Table 6.1). Suitability of the aspects within each layer were then defined.

Table 6.1 Layers used in the construction of the O. edulis *habitat maps with the suitability of each layer listed.*

Layer hierarchy	Suitable	Unsuitable
Bathymetry	Depths ≤50 m	Depths >50 m
Sediment type	Shallow sediments	Deep sediments
Shellfish farming regions	*Mytilus edulis* *Crassostrea gigas*	None
Species regions	*Modiolus modiolus* beds	Maerl beds *Zostera* species
Shellfish grounds and habitat	*Necora puber*	*Aequipecten opercularis** *Cancer pagurus* *Buccinum undatum* *Nephrops norvegicus* *Pecten maximus**
Kelp forest	All	None
Dredging and disposal	None	All
Development restrictions	None	All
Waste discharge	None	All

**Aequipecten opercularis* and *P. maximus* grounds were not fully excluded as they were represented by purple hatchings (see Figure 6.1 below).

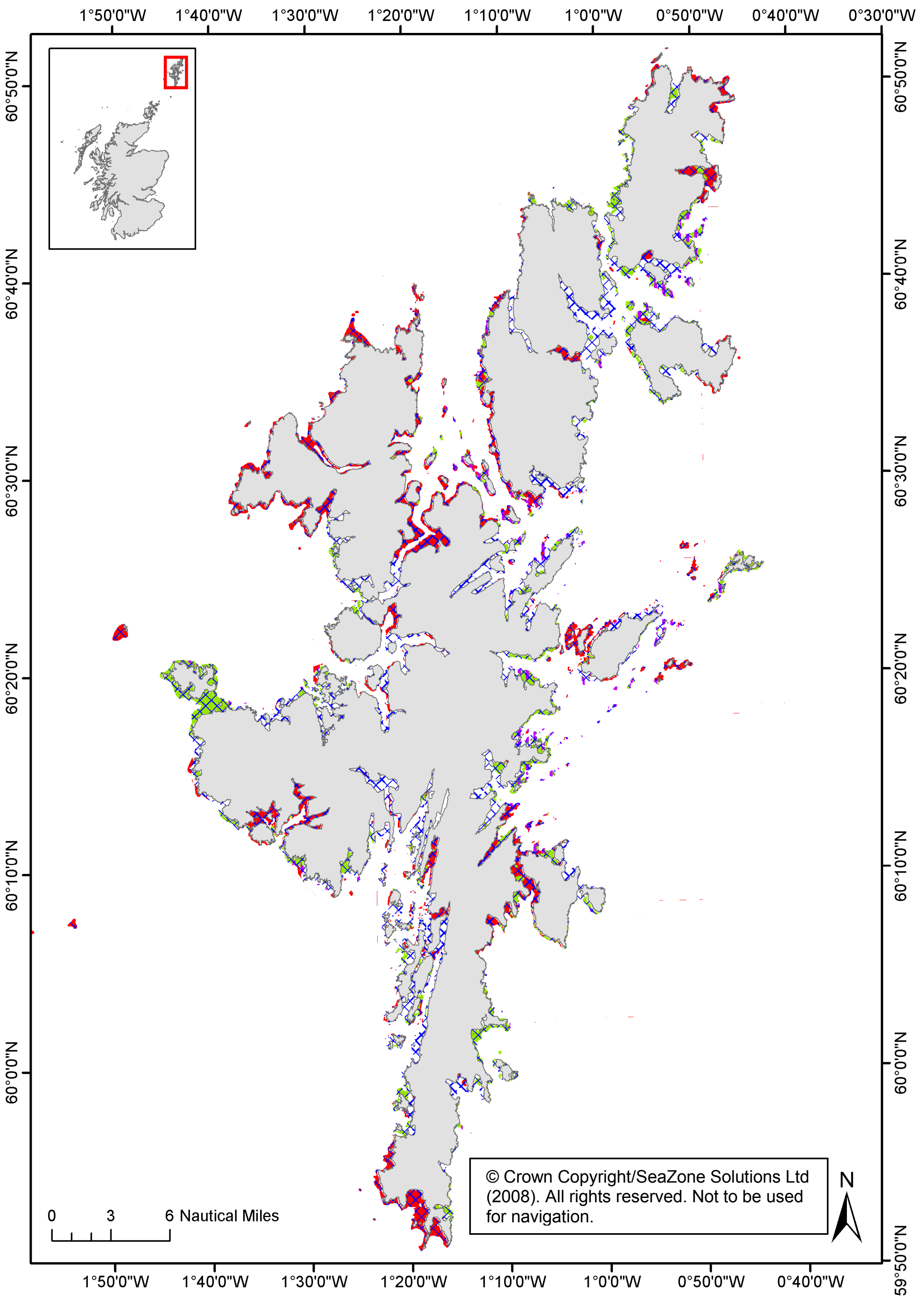

Figure 6.1 Habitat map for O. edulis *in Shetland. Hatched blue areas represent potential* O. edulis *sites. Areas of kelp are coloured green and potentially unsuitable sites are red. Purple vertical and horizontal hatchings are scallop and queen scallop grounds, respectively. A combination of blue hatching over a red background suggests a potential site but with a low probability.*

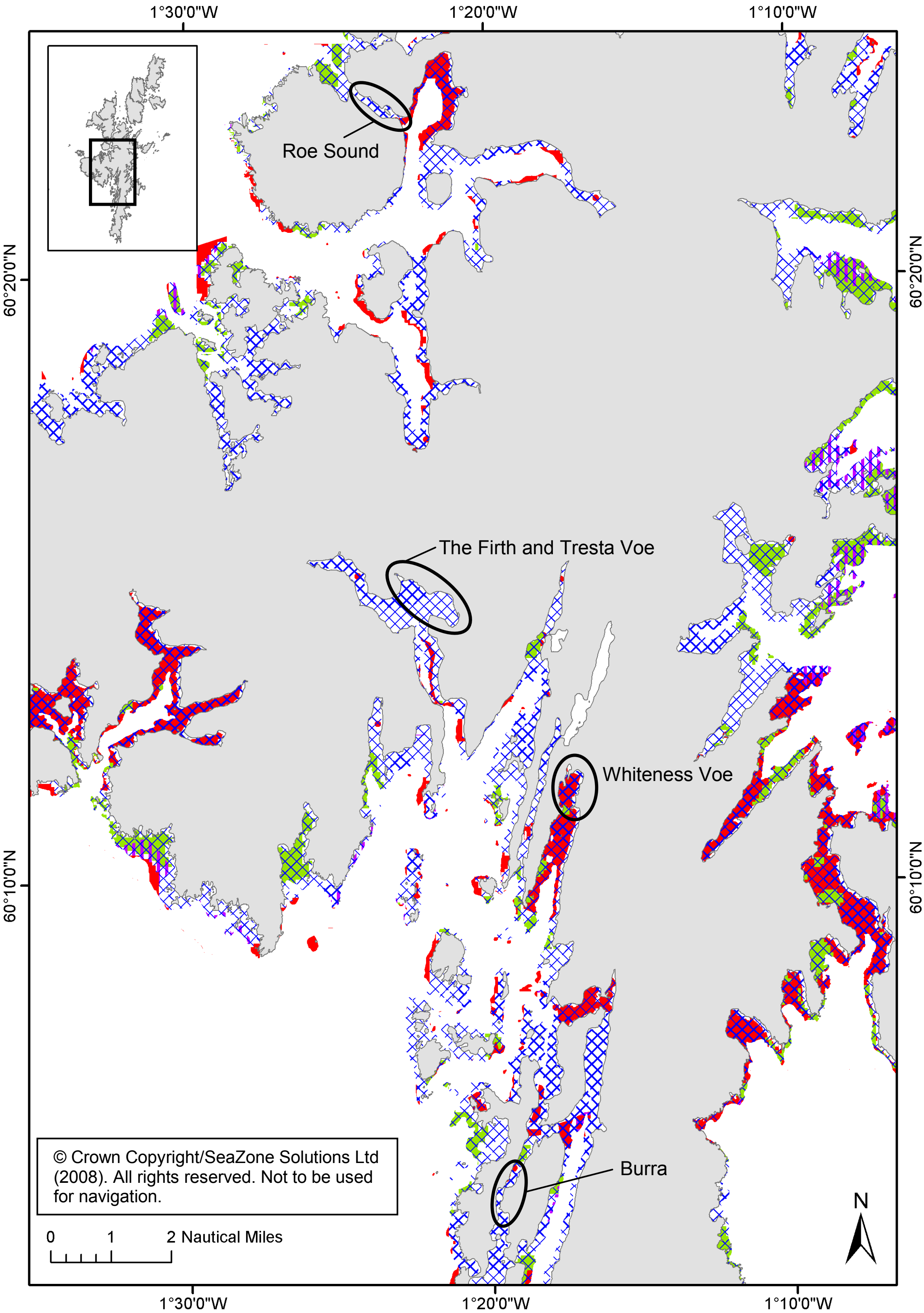

Figure 6.2 Habitat map of the chosen study sites (circled). The blue hatching and red background of Whiteness Voe refers to unspecified development restrictions imposed by the local council. See Figure 6.1 for a description of the colour coding.

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