Scottish Sanitary Survey Programme

Sanitary Survey Report
Production Area: Point of Hamna Ayre & Muckle Roe
SIN: SI 374 763 08 & SI 221 433 08
Date

Cefas

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Report Distribution – Point of Hamna Ayre & Muckle Roe

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I. Executive Summary

A sanitary survey was undertaken at Point of Hamna Ayre based on a failure assessment of historical results against classification for sites subject to classification changes since 2006. The Muckle Roe site was also surveyed due to the relative proximity of the two.

Muckle Roe is an island located in St. Magnus Bay on the west side of Mainland Shetland. The Muckle Roe shellfish production area is located along the south shore of the island. The Point of Hamna Ayre production area is located to the south of Muckle Roe, along the west shore of Papa Little island. The area is relatively sparsely populated. Point of Hamna Ayre and Muckle Roe are both long line mussel aquaculture fisheries. Both areas may be harvested year round in accordance with market demand.

The principal sources of faecal contamination to the fishery are diffuse agricultural pollution mainly from sheep farmed along the south shore of Muckle Roe and from sheep grazing on Papa Little island. There are a small number of private septic tanks around Muckle Roe. Wildlife is likely to be present in modest numbers and will contribute to background levels of contamination.

Historical monitoring of *E. coli* in shellfish indicates that higher results tended to occur at Point of Hamna Ayre, where a greater number of results exceeding 230 *E. coli* MPN/100 g were seen.

There was an increase in the general level of contamination over a five year period. This is reflected in a higher proportion of results greater than 230 *E. coli* MPN/100 g being seen from mid-2009 onwards (although the highest individual result was seen in 2007). Higher results were seen towards the middle of the year, but there was no statistically significant effect of season. There was a statistically significant correlation with tidal state at Point of Hamna Ayre, with higher results seen around spring tides. A significant positive correlation was found between *E. coli* result and rainfall in the previous 2 days at both production areas; and also for the previous 7 days at Muckle Roe.

The stream most likely to impact on the microbiological quality of Muckle Roe is that immediately adjacent to it. Following rainfall, the streams at Hamna Ayre will contribute to contamination at the Point of Hamna Ayre fishery. Following heavy rain, it is likely that direct land run-off will carry animal faecal material into the sea due to the steep nature of the landscape. The water is very deep and shelves quickly away from land, therefore contamination originating at the coast will receive significant dilution within a short distance from shore. Currents in the area are very low, indicating that contamination will not travel a long distance from source over a tidal cycle but also means that it will not be subject to much dispersion. Particle transport direction and distance may possibly be more influenced by wind-driven flow. Prevailing south-west winds will increase the north-north-easterly flows at Muckle Roe and further constrain water within the bay at Hamna Ayre.

Recommendations

No significant changes are recommended to boundaries at either production area, though small adjustments have been made to bring the boundaries in line with MHWS and land features.

The stability assessment indicated that neither area was suitable for reduced sampling frequency, therefore it is recommended that monthly monitoring be maintained at both sites.

Muckle Roe

It is recommended that the RMP be relocated to HU 3337 6301, which lies at the northeastern end of the lines, nearer to the stream and was found to have the highest levels of contamination during the shoreline survey. Sampling depth was specified to be 7-8 metres based on the observation of higher contamination levels at depth during the shoreline survey.

The recommended production area is described as the area bounded by lines drawn between HU 3266 6261 to HU 3320 6190 and between HU 3367 6321 to HU 3410 6227 to HU 3398 6225 and extending to MHWS.

Point of Hamna Ayre

It is recommended that the RMP be established at the northern end of the lines. This lies nearer to the stream and was found to have higher levels of contamination during the shoreline survey. The recommended RMP is therefore HU 3331 6156. Sampling undertaken during the shoreline survey suggested that higher contamination levels may be found nearer the surface at this site, therefore sampling depth is recommended to be 1-2 m.

The recommended production area is described as the area bounded by lines drawn between HU 3320 6187 to HU 3308 6120 and extending to MHWS.

II. Sampling Plan

PRODUCTION AREA	Point of Hamna Ayre	Muckle Roe
SITE NAME	Point of Hamna Ayre	Pobies Geo
SIN	SI 374 763 08	SI 221 433 08
SPECIES	Common mussels	Common mussels
TYPE OF FISHERY	Aquaculture, longline	Aquaculture, longline
NGR OF RMP	HU 3331 6156	HU 3337 6301
EAST	433310	433370
NORTH	1161560	1163010
TOLERANCE (M)	40	40
DEPTH (M)	1-2	7-8
METHOD OF SAMPLING	Hand	Hand
FREQUENCY OF SAMPLING	Monthly	Monthly
LOCAL AUTHORITY	Shetland Island Council	Shetland Island Council
AUTHORISED SAMPLER(S)		
LOCAL AUTHORITY LIAISON OFFICER		

III. Report

1. General Description

Muckle Roe is an island located in St. Magnus Bay on the west side of Mainland Shetland (see Figure 1.1). The Muckle Roe shellfish production area is located along the south shore of the island. The Point of Hamna Ayre production area is located to the south of Muckle Roe, along the west shore of the island of Papa Little. Both sites are located in the part of St. Magnus Bay called Swarbacks Minn. The area is relatively sparsely populated.

The sanitary survey was undertaken based on a failure assessment of historical results against classification for sites subject to classification changes since 2006.

Figure 1.1 Location of Point of Hamna Ayre and Muckle Roe

2. Fishery

Both Point of Hamna Ayre and Muckle Roe contain long-line mussel aquaculture fisheries, as listed in Table 2.1.

Table 2.1 Shellfish farms

Production Area	Site	SIN	Species	RMP
Point of Hamna Ayre	Point of Hamna Ayre	SI 374 763 08	Mussels	HU 332 615
Muckle Roe	Pobies Geo	SI 221 433 08	Mussels	HU 333 631

The Point of Hamna Ayre production area boundaries are described in the most recent FSA Scotland classification report as “the area bounded by lines drawn between HU 3320 6185 and HU 3308 6120 extending to MHWS”. At the time of the shoreline survey, Point of Hamna Ayre consisted of two 220 m double-headed long lines with 8 m droppers lying toward the western side of the production area.

The Muckle Roe production area boundaries are described as “the area bounded by lines drawn between HU 3364 6320 to HU 3397 6225 and between HU 3266 6261 and HU 3320 6190”. Although not specifically stated, it is implied that this extends to MHWS along the northern and southern boundaries. At the time of shoreline survey, the Pobies Geo site consisted of three 220 m double-headed long lines with 8 m droppers situated near the north end of the production area. This site is actually located in Boat Geo, southwest of Pobies Geo.

Both areas may be harvested year round in accordance with market demand. Figure 2.1 shows the relative positions of the mussel farms, production areas, SIC permit areas and seabed lease areas.

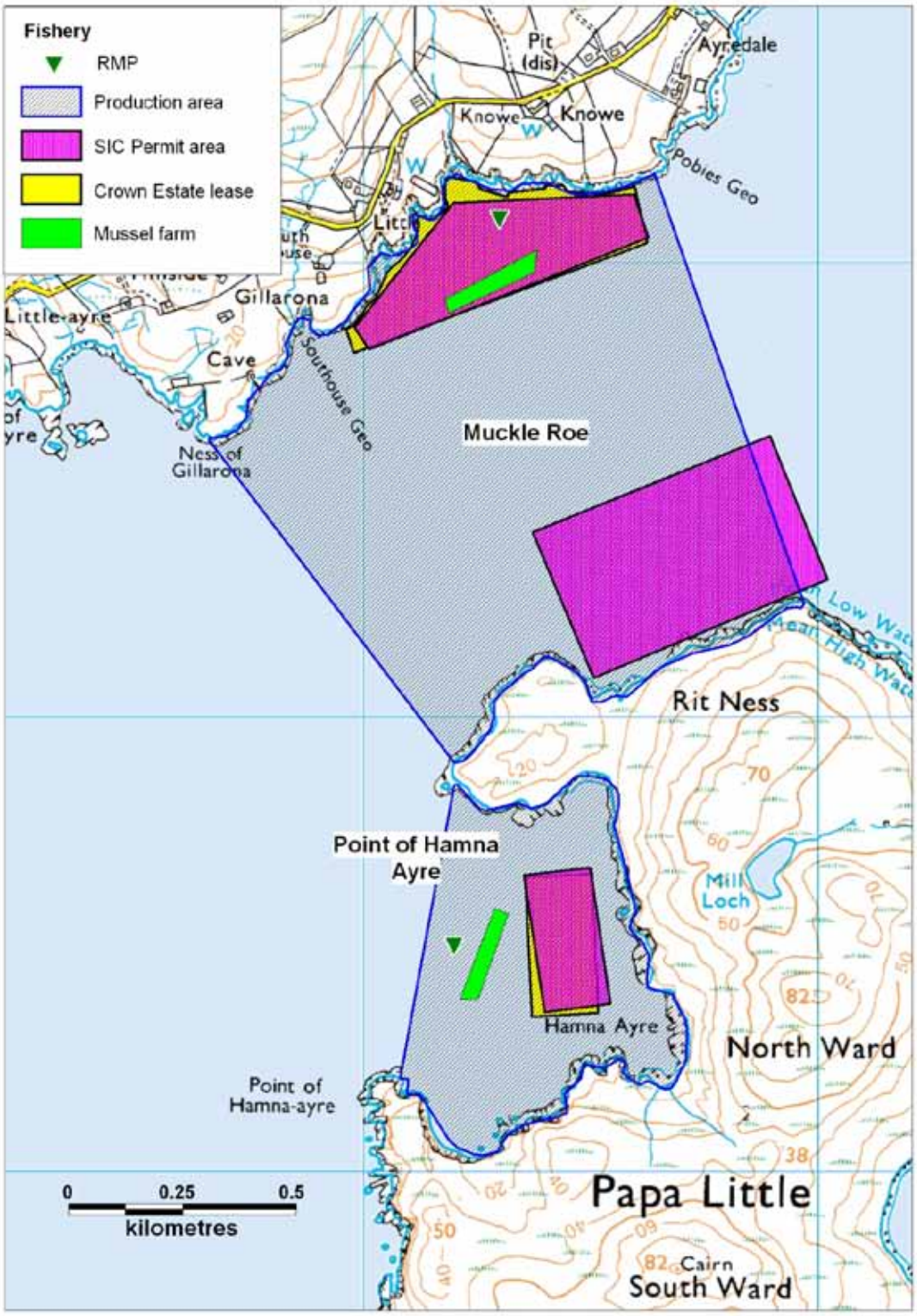

Figure 2.1 Point of Hamna Ayre and Muckle Roe Fishery

3. Human Population

Figure 3.1 shows information obtained from the General Register Office for Scotland on the population within the census output areas in the vicinity of Point of Hamna Ayre and Muckle Roe. The last census was undertaken in 2001.

Figure 3.1 Population map of Point of Hamna Ayre and Muckle Roe

The population in the surrounding area is spread amongst three census output areas, listed in Table 3.1. The large majority of the population for these three areas is likely to lie beyond the extent shown in Figure 3.1.

Table 3.1 Census output areas: Point of Hamna Ayre and Muckle Roe

Output area	Population
60RD000034	59
60RD000037	104
60RD000047	105
Total	**268**

There are no main settlements on the island of Muckle Roe, though at the 2001 census it had a population of 104. There is one B&B on Muckle Roe and a hotel further to the north on the west shore of Busta Voe. No hotels or B&B's were observed in the area surrounding the fishery during the shoreline survey. Wildlife enthusiasts and walkers visit the island, and may wild camp at any time of year. Papa Little is uninhabited.

Two anchorages were identified within the area, both of which are more than 2 km from the shellfish farms (see Figure 3.1).

4. Sewage Discharges

Information on public sewerage discharges to the waters in and around the Muckle Roe and Point of Hamna Ayre production areas was requested from Scottish Water and the Scottish Environment Protection Agency (SEPA). Scottish Water reported no public sewerage provision within the two areas.

A list of the consents provided by SEPA for discharges located within the vicinity of the fishery is provided in Table 4.1. All discharges are shown mapped in Figure 4.1.

Table 4.1 Discharge consents identified by SEPA

No.	Ref No.	NGR of discharge	Discharge Type	Level of Treatment	Consented/ design PE	Discharges to
1	CAR/R/1086299	HU 3242 6307	Continuous	Septic tank	-	soakaway
2	CAR/R/1076620	HU 3300 6315	Continuous	Septic tank	-	soakaway
3	CAR/R/1059046	HU 3308 6314	Continuous	Septic tank	-	land
4	CAR/R/1076570	HU 3308 6325	Continuous	Septic tank	-	soakaway
5	CAR/R/1045105	HU 3412 6447	Continuous	Septic tank	-	soakaway
6	CAR/R/1019472	HU 3423 6446	Continuous	Septic tank	-	land
7	CAR/R/1028195	HU 3419 6474	Continuous	Septic tank	-	soakaway
8	WPC/N/0070599	HU 3395 6355	Continuous	Septic tank	5	-

- Data not provided

Papa Little Island is uninhabited, and therefore there were no discharges adjacent to the Point of Hamna Ayre mussel farm. The remaining consents all related to private discharges to either soakaway or land along the shore of Muckle Roe. One consent was received for a marine cage fish farm, which is not listed in the table above as it is unlikely to impact on faecal indicator bacteria concentrations in the vicinity however it is shown in Figure 4.1 for reference.

Information on discharge 8, WPC/N/0070599, was obtained from the Shellfish Growing Waters report (SEPA, 2011) and had not been included in the SEPA response to the data request for this sanitary survey. The location plots north of the fishery and a short distance offshore, therefore it is presumed to discharge to sea.

Observations relating to sewage infrastructure or discharges recorded during the shoreline survey are listed in Table 4.2.

Table 4.2 Discharges and septic tanks observed during shoreline surveys

No.	Date	NGR	Description
1	17/08/2011	HU 32449 62803	Iron pipe leading down from houses and into sea
2	17/08/2011	HU 33038 63067	Outfall pipe and septic tank below house, no flow at time however signs of previous flow
3	17/08/2011	HU 33190 63216	Stream falling down embankment - two pipes leading into it below house further upstream, not flowing at the time

Discharges observed during the shoreline survey did not appear to correlate with any of the consented discharges. At least 19 homes and/or farms are visible in satellite images of the area and these must all have on-site provision

for sewage disposal. It is therefore presumed that the listed consents represent only a proportion of the septic tanks present.

Figure 4.1 Map of discharges for Muckle Roe and Point of Hamna Ayre

Of greatest significance to the fishery are the discharges observed at points 2 and 3, which lie within 200 m of the Muckle Roe mussel farm. The Point of Hamna Ayre mussel farm lies over 1km away from the nearest discharge and is unlikely to be significantly impacted by human sewage sources.

5. Geology and Soils

Geology and soil types were assessed following the method described in Appendix 2. A map of the resulting soil drainage classes is shown in Figure 5.1. Areas shaded red indicate poorly draining soils while areas shaded blue indicate more freely draining soils.

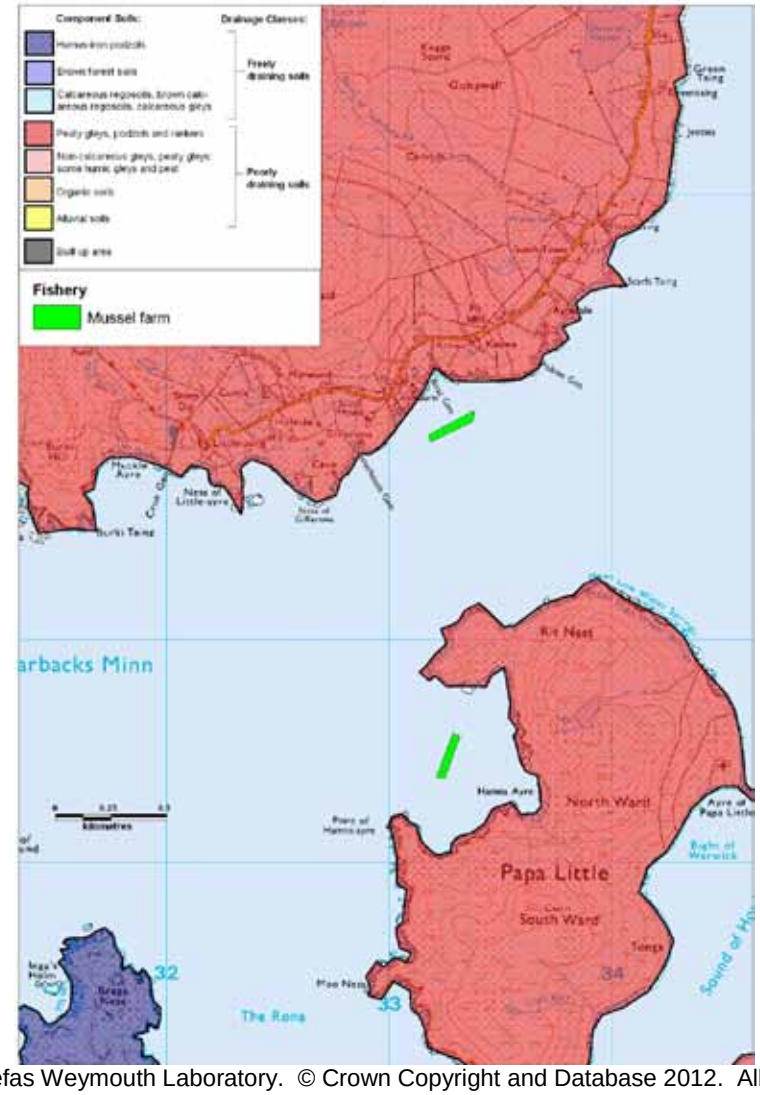

Figure 5.1 Component soils and drainage classes for Muckle Roe and Point of Hamna Ayre

Two types of soil are found in this area. The islands of Papa Little and Muckle Roe both have poorly drained peaty gleys, podzols and rankers. An area of humus-iron podzols is found along the shore southwest of Papa Little.

The potential for runoff contaminated with *E. coli* from human and/or animal waste is therefore high along the coastline adjacent to the Point of Hamna Ayre and Muckle Roe fisheries. This suggests that there is potential for septic tank discharges to land or soakaway identified in Section 4 to function ineffectively, thereby leading to contamination of nearby watercourses or the sea.

6. Land Cover

Land Cover Map 2000 data for the area is shown in Figure 6.1 below:

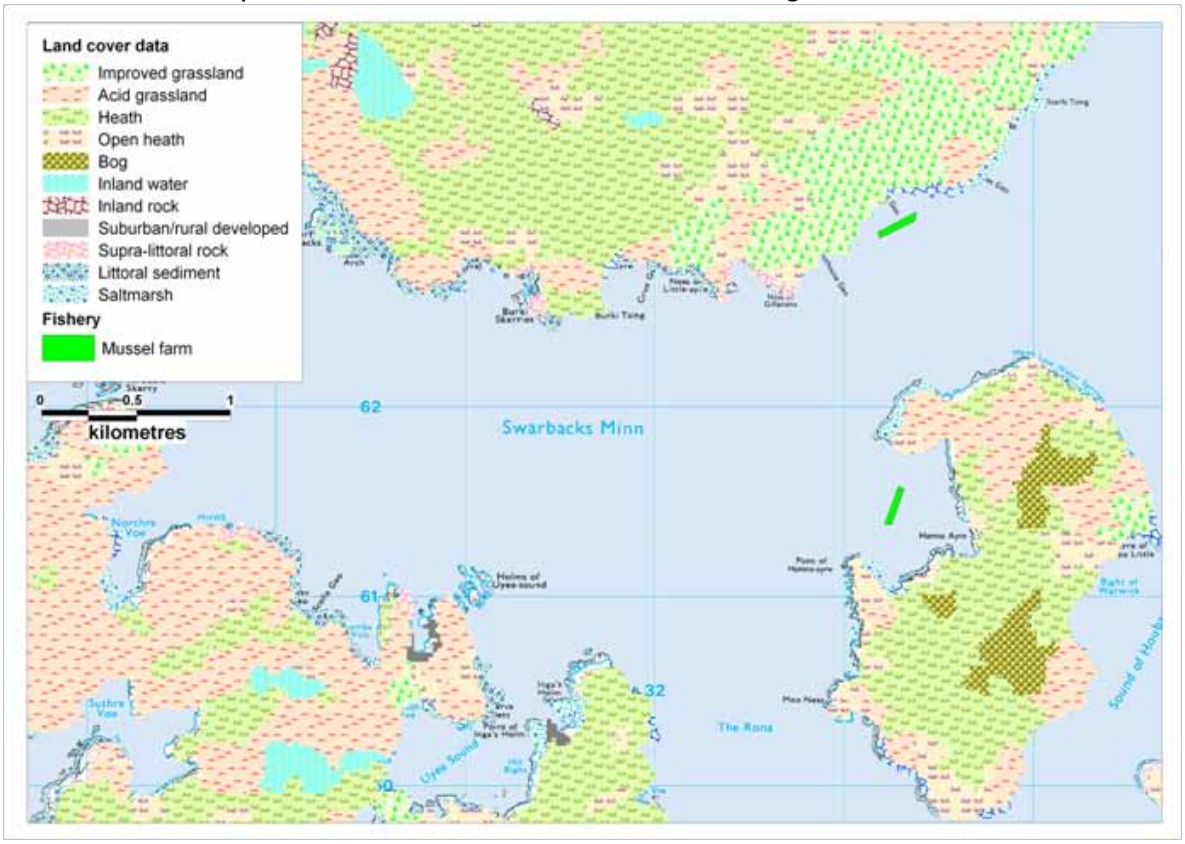

Figure 6.1 LCM2000 class land cover data for Point of Hamna Ayre and Muckle Roe

Much of the area is covered with acid grassland and heath. There are some areas of bog on Papa Little. Much of the shoreline adjacent to the Muckle Roe shellfish farm is classed as improved grassland, with an area of acid grassland to the northeast and acid grassland, heath or open heath predominating over the remainder of the area shown in Figure 6.1. These land cover types are likely to be used for rough grazing of sheep. Two small areas of 'suburban/rural developed' are shown on the coastline to the southwest of the fisheries. These areas are unpopulated and publicly available satellite imagery shows these areas to be open land with small beaches.

Faecal indicator organism export coefficients for faecal coliform bacteria have been found to be approximately 8.3×10^8 cfu km^{-2} hr^{-1} for areas of improved grassland and approximately 2.5×10^8 cfu km^{-2} hr^{-1} for rough grazing (Kay et al. 2008). The contributions from all land cover types would be expected to increase significantly after rainfall events, however this effect would be particularly marked from improved grassland areas (roughly 1000-fold) (Kay et al. 2008).

At the Muckle Roe fishery the potential for the highest contribution of faecal coliform bacteria attributable to land cover type is greatest along the shore immediately adjacent to the mussel farm where there is improved grassland.

The potential for faecal contamination related to land cover type at the Point of Hamna Ayre fishery is moderate with no clear spatial bias toward one part of the mussel farm over another.

7. Farm Animals

Information on the spatial distribution of animals on land adjacent to or near the fishery can provide an indication of the potential amount of organic pollution from livestock entering the shellfish production area. Agricultural census data to parish level was requested from the Scottish Government Rural Environment, Research and Analysis Directorate (RERAD) for Yell parish. Reported livestock populations for the parish in 2009 and 2010 are listed in Table 7.1. RERAD withheld data for reasons of confidentiality where the small number of holdings reporting would have made it possible to discern individual farm data. Any entries which relate to less than five holdings, or where two or fewer holdings account for 85% or more of the information, are replaced with an asterisk.

Table 7.1 Livestock numbers in Delting and Aithsting parishes 2009 - 2010

	Delting (149 km^2)				Aithsting (93 km^2)			
	2009		2010		2009		2010	
	Holdings	Numbers	Holdings	Numbers	Holdings	Numbers	Holdings	Numbers
Pigs	*	*	*	*	0	0	0	0
Poultry	15	253	17	258	17	226	14	160
Cattle	12	371	11	361	13	304	*	*
Sheep	65	22596	65	22846	73	19660	75	18874
Horses and ponies	5	17	*	*	7	17	6	21

The Delting agricultural parish encompasses Muckle Roe and a large portion of the northern mainland of Shetland, extending approximately 20 km north to south. The Aithsting parish is smaller, extending 13 km north to south, with the islands of Papa Little and Vementry at its northern extent. Very large numbers of sheep are kept within the parishes, with much smaller numbers of cattle and other livestock. However, it is the number of animals kept within the catchment and near shore of the fishery that will be most likely to affect water quality there.

The only significant source of spatially relevant information was therefore the shoreline survey (see Appendix 6). Observations recorded during the shoreline survey only relate to the time of the site visit on 17th August 2011. The spatial distribution of animals observed and noted during the shoreline survey is illustrated in Figure 7.1. The numbers of animals counted were dependent upon the point of view of the observer at the shoreline and therefore some animals may have been present but out of view.

Farms were located predominantly along the south shore of Muckle Roe, extending along the shore from west of the mussel farm to well north of it. Although there are no farms on Papa Little, the island is used for grazing

sheep. In both areas, sheep are allowed access to the shoreline and both animals and tracks were observed on the shore during the survey. Although only moderate numbers of sheep were observed, these animals excrete a greater mass and more faecal coliforms per day than humans (see table in Appendix 3) and therefore are likely to pose a greater risk of contamination to the fisheries. Areas at greatest risk are those nearest to the shore.

In general, sheep are brought into covered housing during the winter and therefore it would be expected that there would be either no sheep or fewer sheep on Papa Little during the winter. Large farm buildings along the Muckle Roe shore, however, suggest that significant numbers of animals are likely to be kept there during the winter months and therefore the risk of contamination to watercourses and the shoreline along this area may be higher in winter.

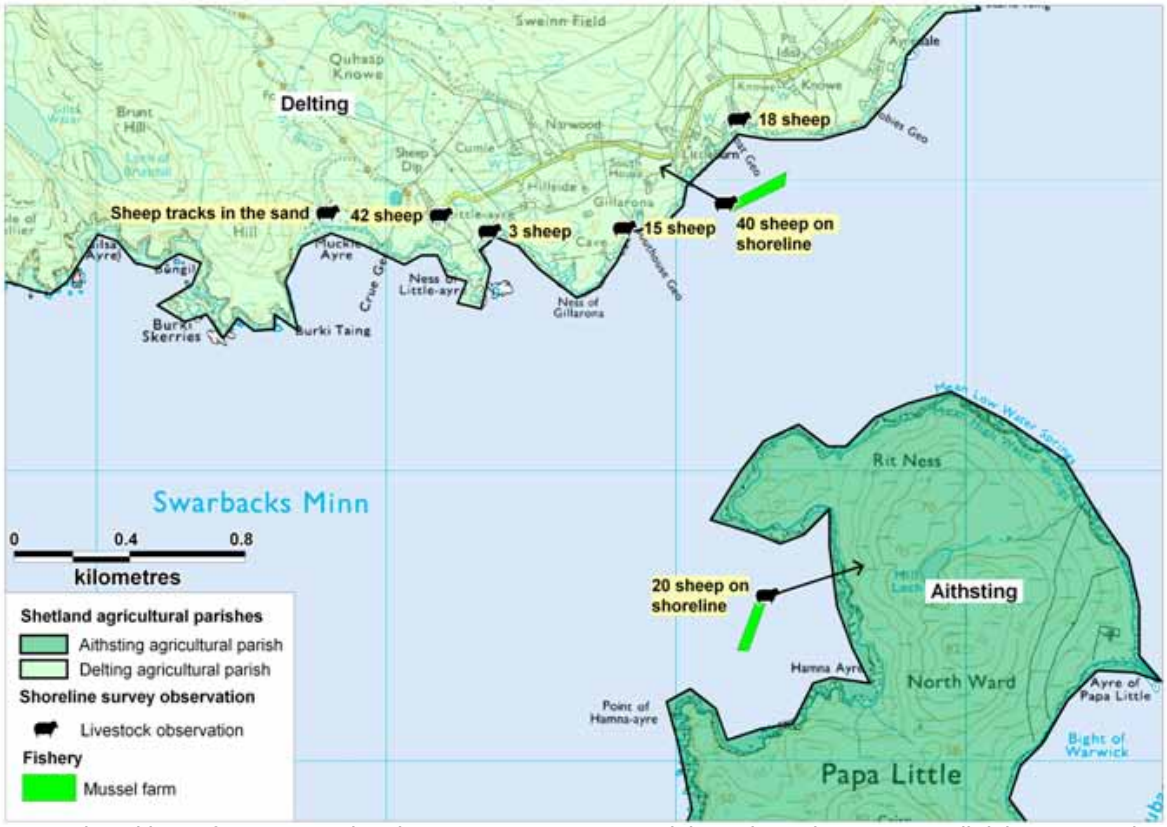

Figure 7.1 Livestock observations at Point of Hamna Ayre and Muckle Roe

8. Wildlife

Wildlife may also contribute to faecal contamination observed at fisheries. General information on the impacts of wildlife species can be found in Appendix 2. Wildlife species most likely to contribute to faecal contamination of the waters of Point of Hamna Ayre and Muckle Roe include birds, seals, and otters.

Birds

Seabird 2000 census data was queried for the area within a 5 km radius of the Point of Hamna Ayre and Muckle Roe production areas and is summarised in Table 8.1 below. This census, undertaken between 1998 and 2002, covered the 25 species of seabird that breed regularly in Britain and Ireland.

Table 8.1 Seabird counts within 5km of the site.

Common name	Species	Estimated No.*	Method
Arctic Tern	*Sterna paradisaea*	1204	Individuals on land/ occupied nests
Northern Fulmar	*Fulmarus glacialis*	8352	Occupied sites
Herring Gull	*Larus argentatus*	410	Individuals on land/Occupied territory or nests
Common Gull	*Larus canus*	252	Individuals on land/Occupied nests
Black Guillemot	*Cepphus grylle*	614	Individuals on land
Great Black-backed Gull	*Larus marinus*	222	Individuals on land/Occupied territory or nests
Lesser Black-backed Gull	*Larus fuscus*	10	Individuals on land
Black-headed Gull	*Larus ridibundus*	136	Individuals on land/Occupied territory
Great Skua	*Stercorarius skua*	34	Occupied territory
European Shag	*Phalacrocorax aristotelis*	144	Occupied nests or sites
Arctic skua	*Stercorarius parasiticus*	6	Occupied territory
Atlantic Puffin	*Fratercula arctica*	46	Individuals on land
Common tern	*Sterna hirundo*	22	Individuals on land
Black-legged Kittiwake	*Rissa tridactyla*	268	Occupied nests

* Counts for occupied sites, nests or territories were doubled to reflect the number of individuals

Records showed an estimated total 11720 seabirds within a 5km radius of the fisheries. The distribution of these relative to the mussel farms is shown in Figure 8.1. Those birds nesting nearest the fishery are most likely to contribute diffuse faecal contamination to the area, particularly after rainfall. Birds flying over or feeding in waters at the mussel farms may directly deposit droppings near the mussel lines and so would have a greater impact on water quality when this occurs. Some species, such as gulls, are likely to be present year round and may rest on mussel floats. However, the majority of seabirds will only be present near shore during the summer nesting season, which is roughly from May to August and varies by species, with some arriving earlier and others staying later. Guano deposited around nest areas, however, is likely to wash off with rainfall over a longer period of time.

Wildfowl, such as geese and ducks, are likely to be present in the area though no specific data were found on populations in or near the fisheries.

Seals

Both grey seals (*Halichoerus grypus*) and common or harbour seals (*Phoca vitulina vitulina*) are recorded in Shetland. Common seal surveys are conducted every 5 years and an estimate of minimum numbers is available through Scottish Natural Heritage.

A count of harbour seals in Shetland undertaken in August 2009 identified a population of 505 within St. Magnus Bay, mostly around Vementry, to the south of the fisheries (Duck and Morris, 2010). More detailed information from the previous count (Sea Mammal Research Unit, 2002) identified a haulout site for this species on Papa Little.

A grey seal breeding colony was reported on Muckle Roe, with an estimated pup production of 23 in 2004 (Special Committee on Seals, 2009). Adult numbers are estimated to be 3.5 times the pup population (Callan Duck, Sea Mammal Research Unit, personal communication). This suggests a potential population of 80 animals at Muckle Roe in 2004. A survey undertaken in August 2009 identified no animals at Muckle Roe and 237 grey seals in the wider area of St. Magnus Bay, most of which were seen south of the fisheries in the area around Vementry.

No seals were seen at either shellfish farm during the shoreline survey. These animals are present in the area year-round and forage widely for food. Therefore, they are presumed to be present in or around the waters of the fishery at least part of the time and are likely to contribute to background levels of faecal contamination in the areas where they are found.

Otters

Otters are known to occur throughout Shetland. Otters typically defecate in established latrines adjacent to freshwater courses. Muckle Roe has a number of streams and burns that may host otters, and any faecal contamination from these animals is likely to be carried in the streams. It is not known whether there are otters at Hamna Ayre. However, typical population densities of coastal otters are low and therefore any impact is expected to be minor.

Conclusions

Overall, the wildlife species most likely to be present in or around Hamnavoe are likely to be present in modest numbers and will contribute to background levels of contamination at the fishery. Seabirds such as gulls and cormorants may rest on the floats at the mussel farms throughout the year, however any impact from the large numbers of nesting birds in the area is likely to be highest to the west of Muckle Roe and the north of Point of Hamna Ayre during the summer to early autumn months.

Seals are known to be present in the area year round, and are likely to contribute to background levels of contamination where they are found. There

may be a seal haul out at Hamna Ayre on Papa Little, and therefore the Point of Hamna Ayre mussel farm may be more impacted by this source than the Muckle Roe site.

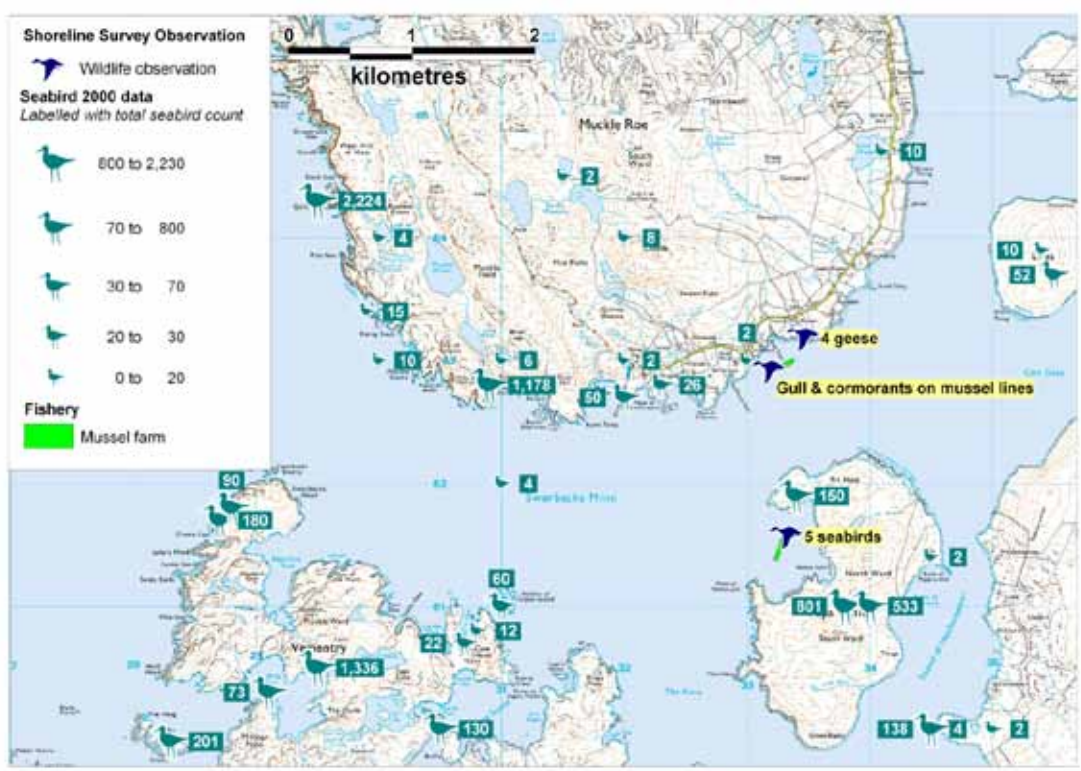

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Figure 8.1 Map of seabird distributions close to Point of Hamna Ayre and Muckle Roe

9. Meteorological data

The nearest Meteorological Office rain station is located at Lerwick, approximately 25 km to the south of Muckle Roe. Uninterrupted rainfall data was available for 2003-2010. Windfall data was available from Sumburgh, located approximately 54 km to the south of the fishery.

Conditions may differ between these stations and the fisheries due to the large distances between them. However, the data is nonetheless useful for identifying regional trends in rainfall and wind patterns.

Data for the station was purchased from the Meteorological Office and unless otherwise stated was used by Cefas for further analysis to formulate the content of this section (e.g. graphs). This section aims to describe the local rain and wind patterns in the context of the bacterial quality of shellfish at Point of Hamna Ayre and Muckle Roe.

9.1 Rainfall

High rainfall and storm events are commonly associated with increased faecal contamination of coastal waters through surface water run-off from land where livestock or other animals are present, and through sewer and waste water treatment plant overflows (e.g. Mallin et al, 2001; Lee & Morgan, 2003).

Figures 9.1 and 9.2 are graphical representations of box and whisker plots summarising the distribution of daily rainfall values by year and by month. The grey box represents the middle 50% of the observations, with the median at the midline. The whiskers extend to the largest or smallest observations up to 1.5 times the box height above or below the box. Individual observations falling outside the box and whiskers are represented by the symbol *.

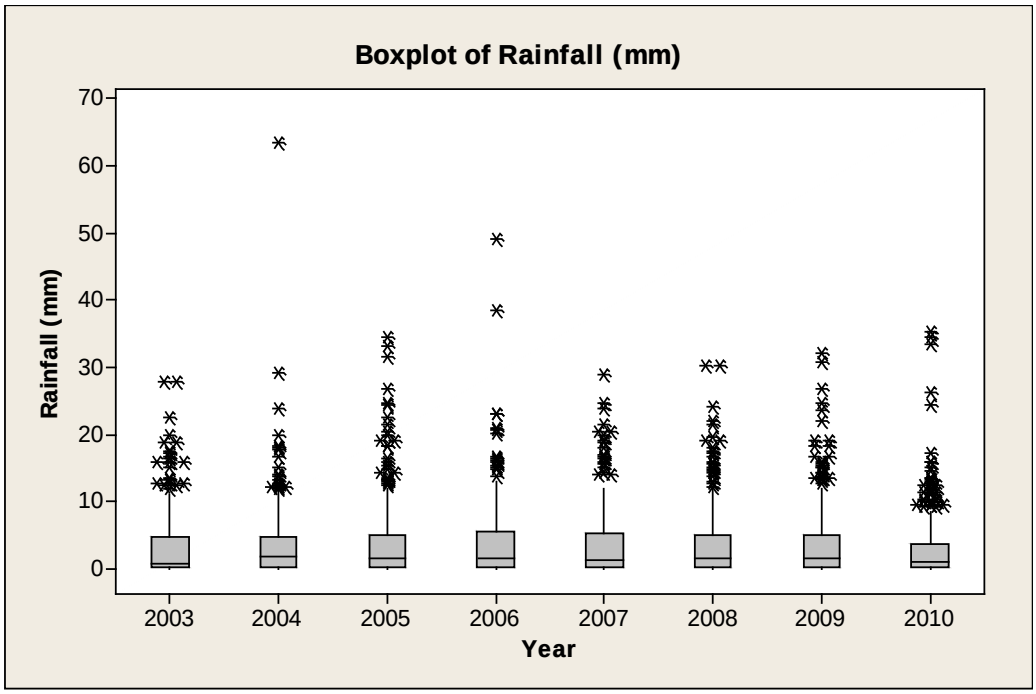

Figure 9.1: Box plot of daily rainfall values by year at Lerwick (2003 – 2007)

The daily rainfall values are shown to be similar throughout the years, with 2006 being the wettest and 2010 the driest.

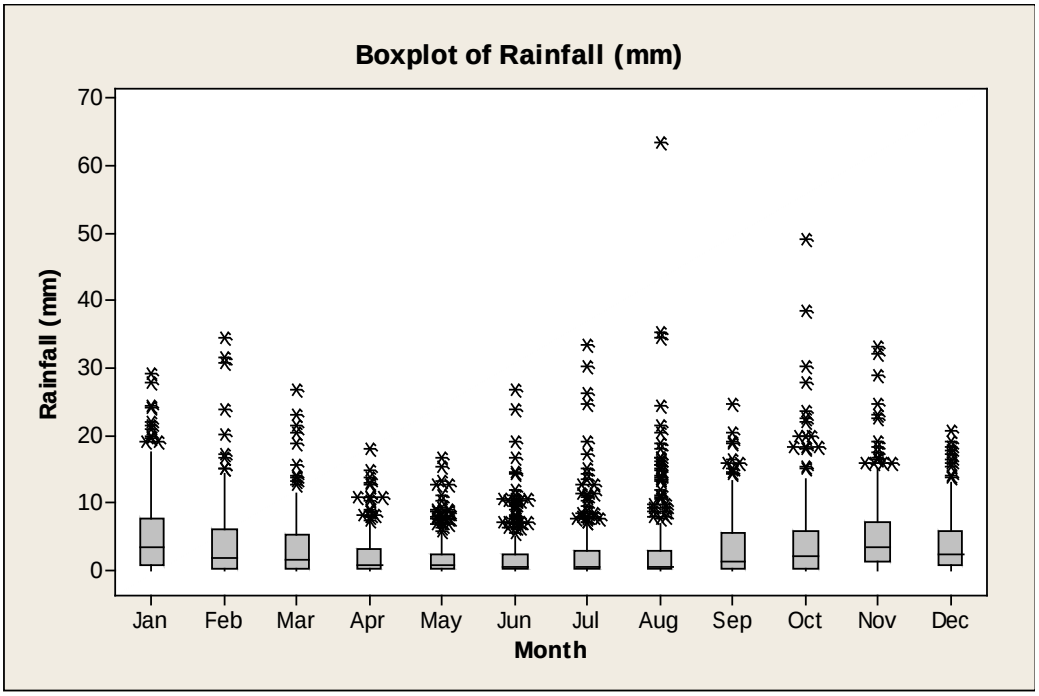

Figure 9.2: Box plot of daily rainfall values by month at Lerwick (2003 – 2007)

Daily rainfall was higher from September to March for the period examined. Extreme rainfall events (>20mm) were recorded for all months except April and May. The single highest rainfall event was recorded in August. For the period considered here, 44% of days incurred rainfall of less than 1mm and 8% of days incurred rainfall of more than 10mm.

It is therefore expected that run-off due to rainfall will be increased during the autumn and winter months, but it is important to note that faecal contamination entering the production area will occur during the summer and early autumn from the build up of faecal matter on pasture land over the drier period when livestock densities tend to be at their highest.

9.2 Wind

Wind data was collected at Sumburgh weather station and characterised by seasonal wind roses in Figure 9.3 and an annual wind rose in Figure 9.4.

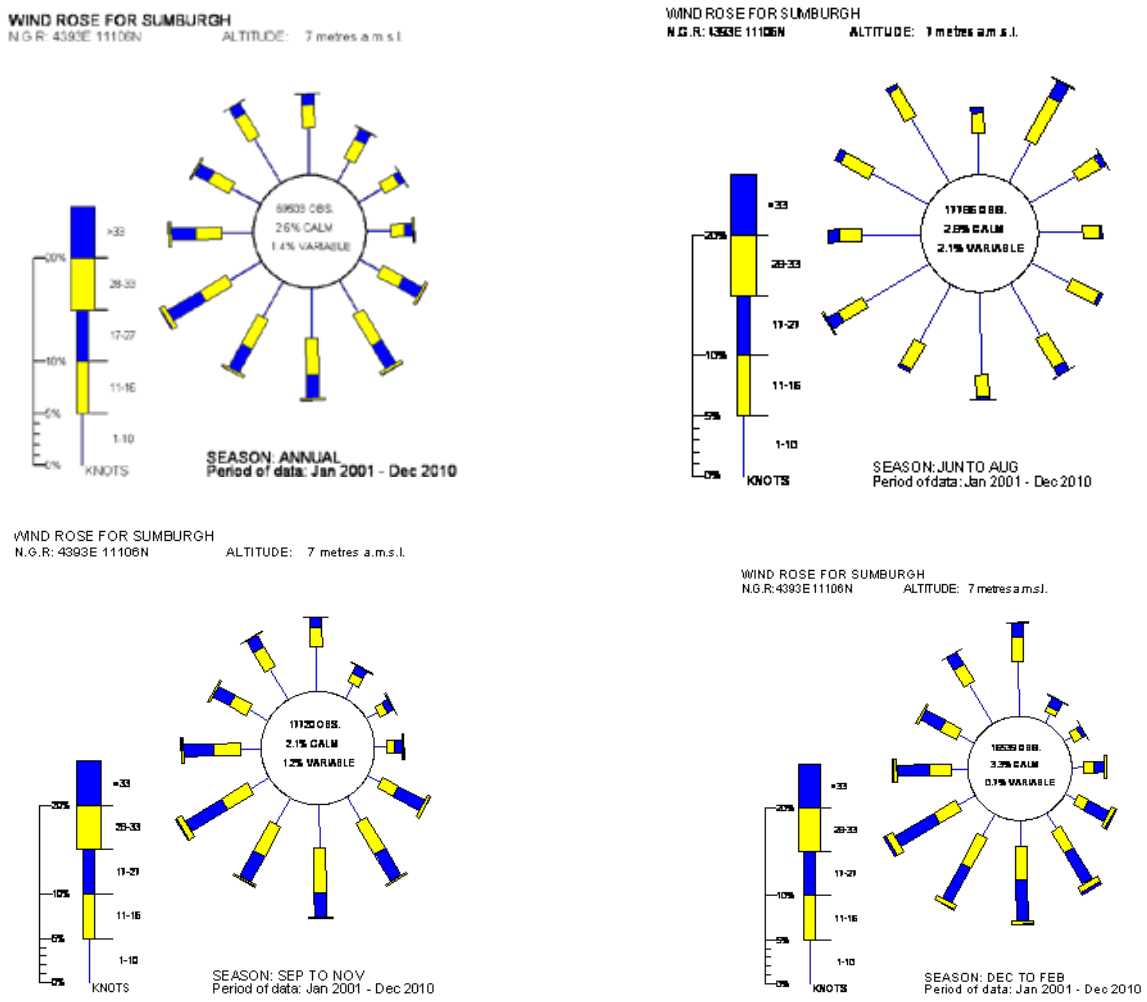

Figure 9.3 Seasonal wind roses for Sumburgh

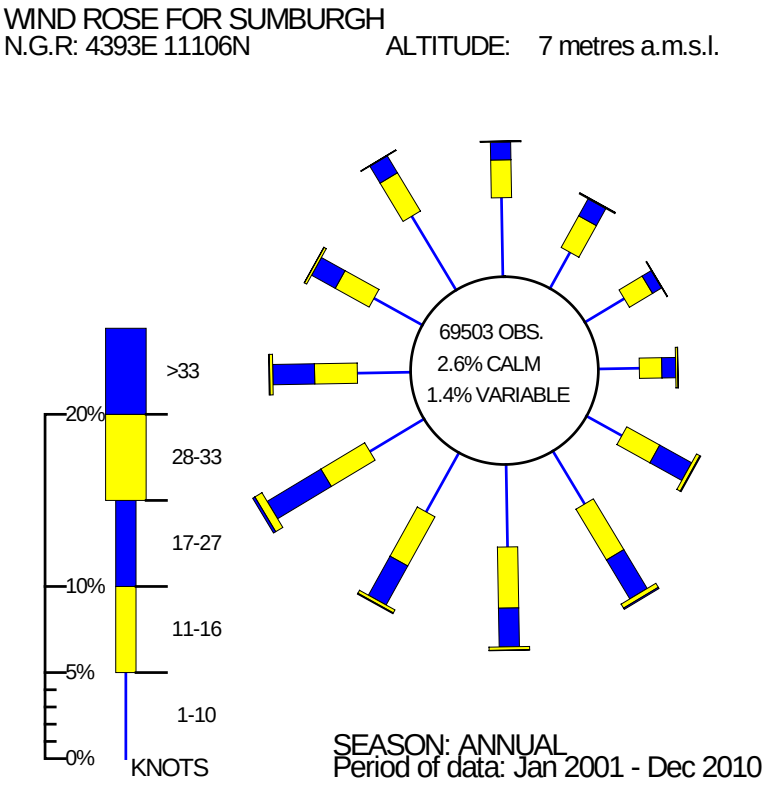

Figure 9.4 Annual wind rose for Sumburgh

Overall, the wind direction at Sumburgh was predominantly stronger from the south and south west and weakest from the north east. This pattern was similar for all months except the summer months (June to August) where there was no clear direction. In general winds are stronger in the winter then in the summer and wind direction and strength has the potential to effect the movement of surface waters and associated contamination into a fishery, particularly if the fishery is exposed to the direction of the winds. Winds typically drive surface water at about 3% of the wind speed (Brown, 1991) so a gale force wind (34 knots or 17.2 m/s) would drive a surface water current of about 1 knot or 0.5 m/s.

Strong winds may affect tide height depending on wind direction and local hydrodynamics of the site. A strong wind combined with a spring tide may result in higher than usual tides, which will carry accumulated faecal matter from livestock from above the normal high water mark into the production area.

10. Current and historical classification status

The historical and current classifications for the area are shown below in Tables 10.1 and 10.2.

Muckle Roe was first classified from January 2006 and Point of Hamna Ayre was first classified from April 2008. A nearby area, Muckle Roe: Burki Taing, was previously classified for mussels but was declassified in 2009.

Table 10.1 Muckle Roe, mussels

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
2006	A	A	A	A	A	A	A	A	A	A	A	A
2007	A	A	A	A	A	A	A	A	A	A	A	A
2008	A	A	A	A	A	A	A	A	A	A	A	A
2009	A	A	A	A	A	A	A	A	A	A	A	A
2010	A	A	A	A	A	A	A	A	A	A	A	A
2011	A	A	A	A	A	A	A	A	A	A	A	A
2012	A	A	A									

Table 10.2 Point of Hamna Ayre, mussels

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
2008				A	A	A	B	B	B	B	A	A
2009	A	A	A	A	A	A	A	A	A	A	A	A
2010	A	A	A	A	A	A	A	A	A	A	A	A
2011	A	A	A	A	A	A	A	A	A	A	A	A
2012	A	A	A									

Both areas have held a year-round A classification, apart from a period of four months in 2008 when Point of Hamna Ayre was class B.

11. Historical *E. coli* data

11.1 Validation of historical data

Data for all mussel samples taken from the Point of Hamna Ayre and Muckle Roe production areas from 1 January 2007 to 16 November 2011 (no samples were taken in December 2011) were extracted from the database and validated according to the criteria described in the standard protocol for validation of historical *E. coli* data.

Muckle Roe

Two samples were noted as rejected by FSAS and were deleted from the data set. All recorded sample locations plotted within the current production area. Two results were recorded as being invalid MPN tube combinations and these were deleted. Twenty-two results were recorded as <20 *E. coli* MPN/100 g and these were amended to a value of 10 for graphical presentation and statistical analysis. No results were recorded as >18000 *E. coli* MPN/100 g.

Point of Hamna Ayre

Two samples were noted as rejected by FSAS and were deleted from the data set. One sample plotted approximately 1km to the west of the production area. This appeared to be a one digit transcription error in recording the location of the nominal RMP and so the digit was corrected to that location. One result was recorded as being an invalid MPN tube combination and this was deleted. Fifteen results were recorded as <20 *E. coli* MPN/100 g and these were amended to a value of 10 for graphical presentation and statistical analysis. No results were recorded as >18000 *E. coli* MPN/100 g.

A $\log_{10}$ transformation was applied to the *E. coli* data from both production areas for the purpose of parametric statistical analysis.

11.2 Summary of microbiological results

A summary of all sampling and results is presented in Table 11.1.

Table 8.1 Summary of historical sampling and results

Sampling summary		
Production area	Muckle Roe	Point of Hamna Ayre
Site	Pobies Geo	Point of Hamna Ayre
Species	Common mussels	Common mussels
SIN	SI-221-433-08	SI 374-763-08
Location	Various	Various
Total no. of samples	44	44
No. 2007	8	8
No. 2008	9	9
No. 2009	9	8
No. 2010	8	9
No. 2011	10	10
Results summary		
Minimum	<20	<20
Maximum	1300	9100
Median	15	50
Geometric mean	27	52
90 percentile	130	490
95 percentile	418	2075
No. exceeding 230/110g	2 (5%)	7 (16%)
No. exceeding 1000/100g	1 (2%)	3 (7%)
No. exceeding 4600/100g	0	1 (2%)
No. exceeding 18000/100g	0	0

11.3 Overall geographical pattern of results

All sampling locations up to and including 18th August 2010 were only recorded in the database to 100 m accuracy. The original sample submission forms were checked and the sampling locations were pre-printed on the forms. At both Muckle Roe and Point of Hamna Ayre, the pre-printed 100 m grid reference used prior to 18th July 2007 reflected the locations of the nominal RMPs which are still given at those points. After that date, a different 100 m grid reference was quoted for the sampling location in each production area. The 10 m accuracy grid reference used since August 2010 for each area has remained constant. There are therefore three sampling locations recorded over time for each of the two production areas. These are shown in Figure 11.1 with the size of symbol graduated by the geometric mean result at the location. However, it is not clear as to how the recorded locations relate to the actual sampling locations and therefore care needs to be taken in interpreting any differences in the extent of contamination at each point. In addition, the geometric means at each location within a production area are derived from a different number of results and over different periods of time.

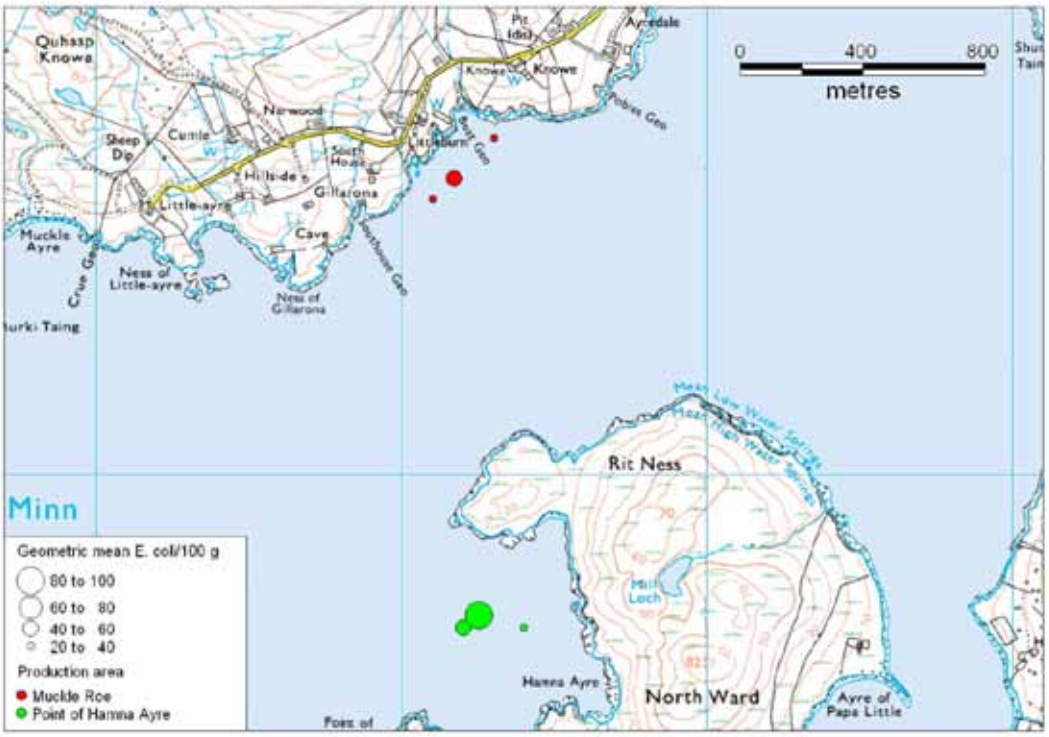

Figure 11.1 Geometric mean *E. coli* results

In general, there is an impression from Figure 11.1 of higher results at Point of Hamna Ayre than at Muckle Roe and this reflects the summary statistics presented in Table 11.1. An unpaired t-test on the two sets of data showed that the results at Point of Hamna Ayre were significantly higher than those at Muckle Roe (unpaired t-test, t=-2.13, p=0.037). A boxplot of the results from the two locations is shown in Figure 11.2.

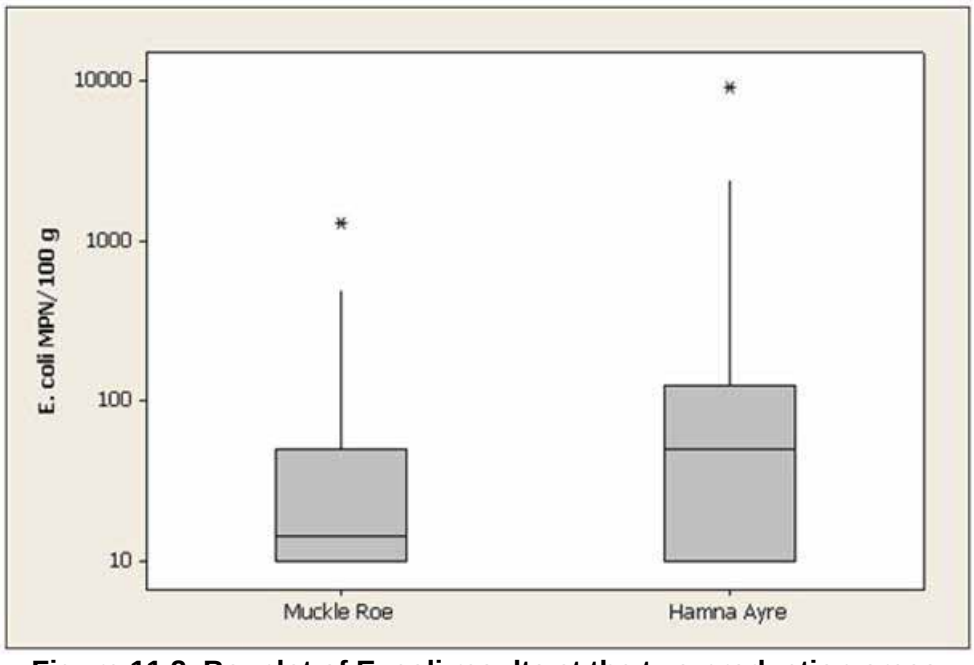

Figure 11.2 Boxplot of E. coli results at the two production areas

The two production areas had been sampled on the same date on each of 42 occasions over the period analysed in this section. The samples taken on the same dates should reflect similar environmental conditions. The log10-transformed E. coli results were therefore subjected to a paired t-test. This showed even more strongly that the results at Point of Hamna Ayre were significantly higher than those at Muckle Roe (paired t-test, t=-2.77, p=0.008).

11.4 Overall temporal pattern of results

Figures 11.3 and 11.4 present scatter plots of individual E. coli results against date, for each of the two production areas, fitted with loess smoother lines. Loess stands for 'locally weighted regression scatter plot smoothing'. At each point in the data set an estimated value is fit to a subset of the data, using weighted least squares. The approach gives more weight to points near to the x-value where the estimate is being made and less weight to points further away. In terms of the monitoring data, this means that any point on the loess line is influenced more by the data close to it (in time) and less by the data further away. The smoother line helps to highlight any apparent underlying trends or cycles.

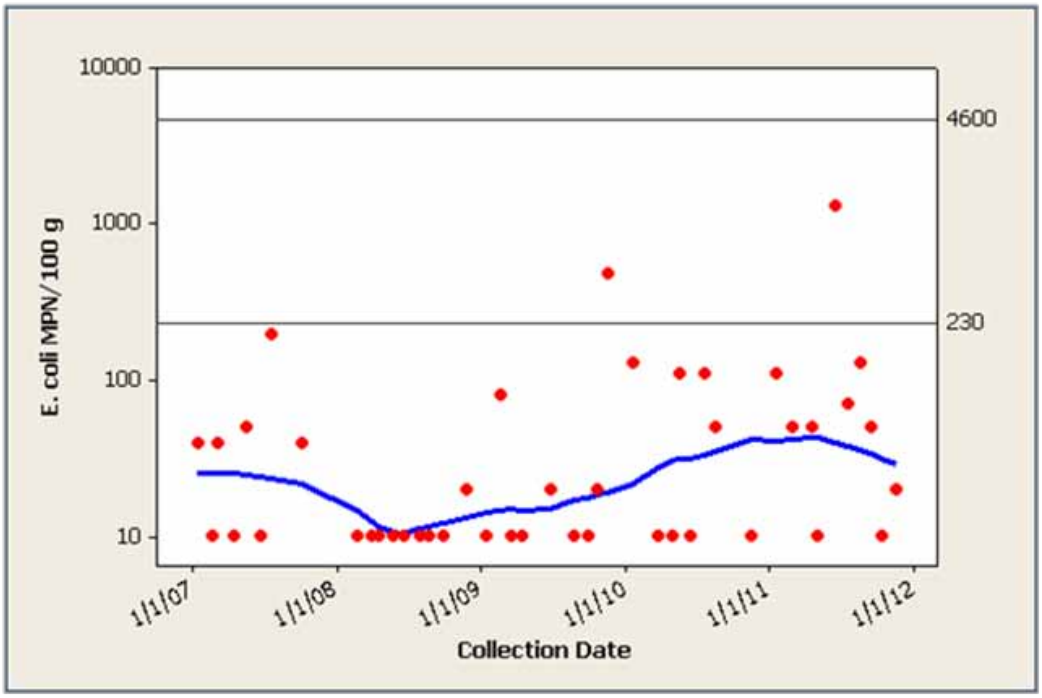

Figure 11.3 Muckle Roe; Scatterplot of *E. coli* results by date

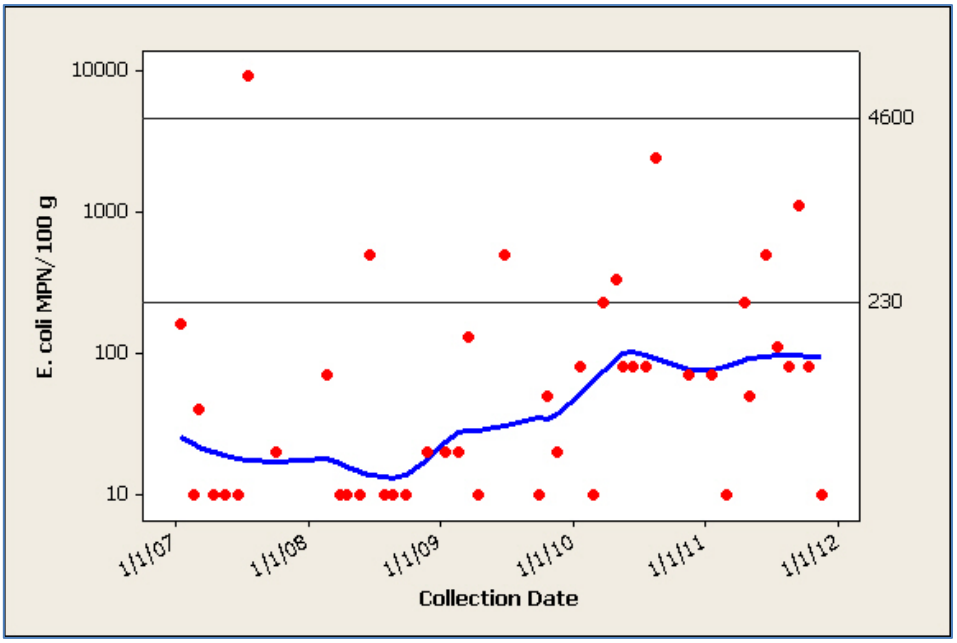

Figure 11.4 Point of Hamna Ayre; Scatterplot of *E. coli* results by date

The two figures suggest some deterioration in *E. coli* results over time although the highest result (9100 *E. coli* MPN/100 g) was seen at Point of Hamna Ayre in 2007.

11.5 Seasonal pattern of results

Season dictates not only weather patterns and water temperature, but livestock numbers and movements, presence of wild animals and patterns of human occupation. All of these can affect levels of microbial contamination, and cause seasonal patterns in results. Figures 11.5 and 11.6 present scatterplots of *E. coli* result by month for each of the two production areas.

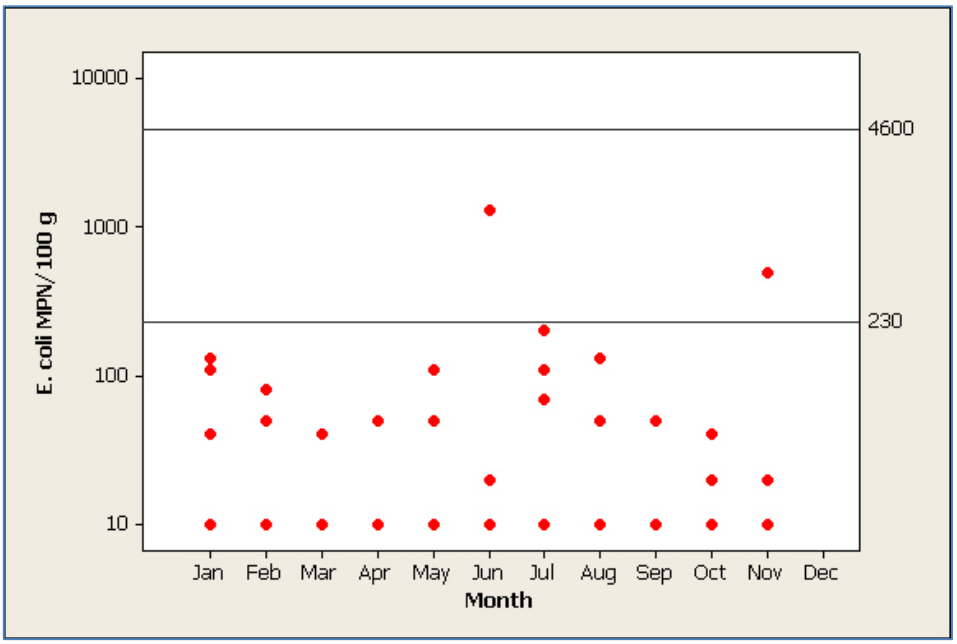

Figure 11.5 Muckle Roe; Scatterplot of results by month

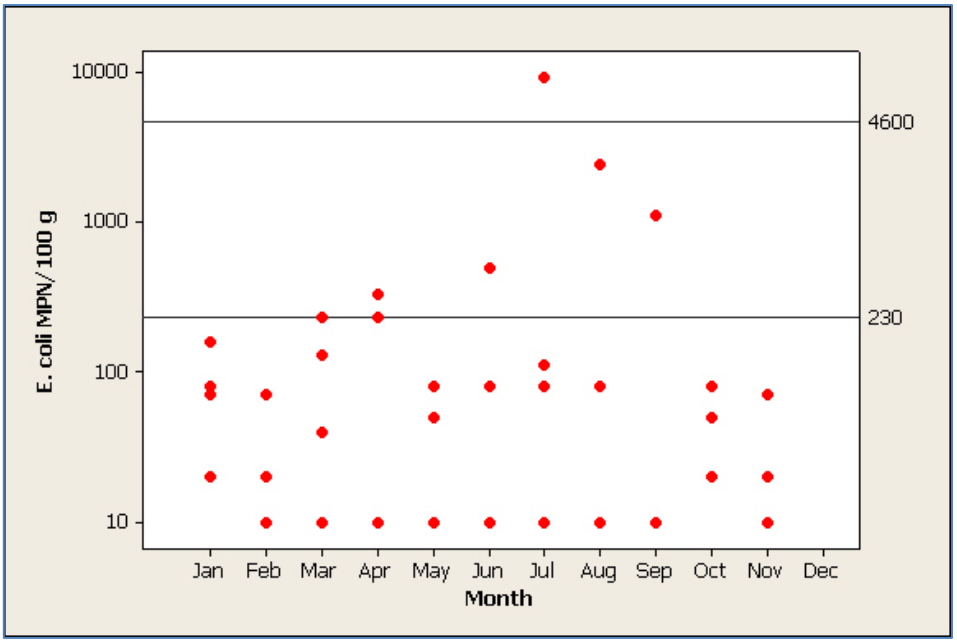

Figure 11.6 Point of Hamna Ayre; Scatterplot of results by month

The figures show some tendency towards higher results in the middle of the year. No samples were recorded in December.

For statistical evaluation, seasons were split into spring (March - May), summer (June - August), autumn (September - November) and winter (December - February). A boxplot of the results by season for each of the three areas is presented in Figures 11.7 and 11.8.

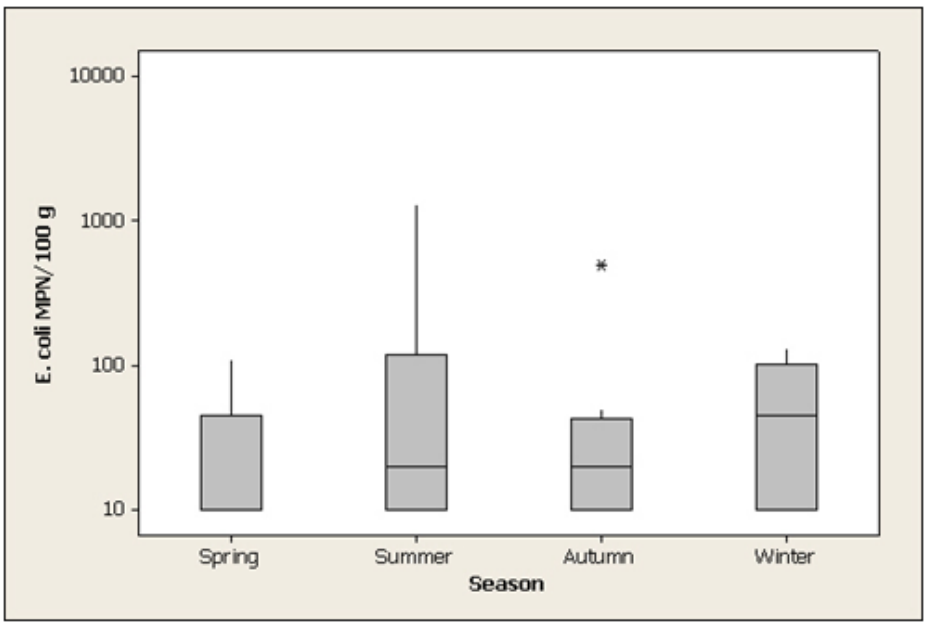

Figure 11.7 Muckle Roe; Boxplot of results by season

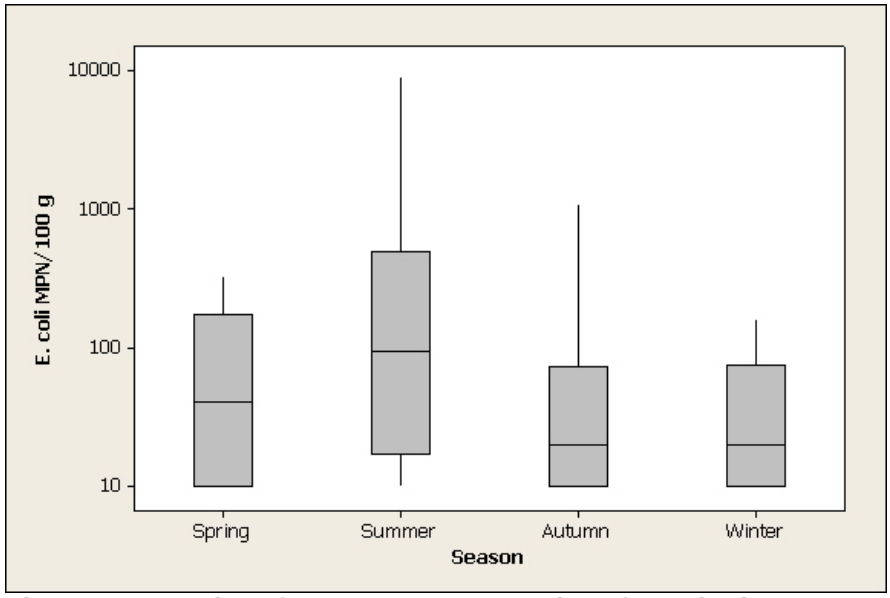

Figure 11.8 Point of Hamna Ayre; Boxplot of results by season

Although the boxplots show a tendency towards higher results in the summer, no statistically significant difference was found between results by season for either of the two production areas (One-way ANOVA, p>0.05, Appendix 6).

11.6 Analysis of results against environmental factors

Environmental factors such as rainfall, tides, winds, sunshine and temperatures can all influence the flux of faecal contamination into growing waters (e.g. Mallin *et al*, 2001; Lee & Morgan, 2003). The effects of these influences can be complex and difficult to interpret. This section aims to investigate and describe the influence of these factors individually (where appropriate environmental data is available) on the sample results using basic statistical techniques.

11.6.1 Analysis of results by recent rainfall

The nearest Meteorological Office weather station to Muckle Roe and Point of Hamna Ayre is at Lerwick, approximately 25 km to the south-south-east of the production area. Rainfall data was purchased from the Meteorological Office for the period up to 31/12/2010 (total daily rainfall in mm).

2-day Antecedent Rainfall

Figures 11.9 and 11.10 present scatterplots of *E. coli* results against rainfall in the previous two days for the two production areas. A Spearman's rank correlation was carried out between results and rainfall. A significant positive correlation was found between *E. coli* result and rainfall in the previous 2 days at both production areas (Muckle Roe: Spearman's rank correlation=0.346, p=0.045; Point of Hamna Ayre: Spearman's rank correlation=0.436, p=0.010). The effect was stronger at Point of Hamna Ayre.

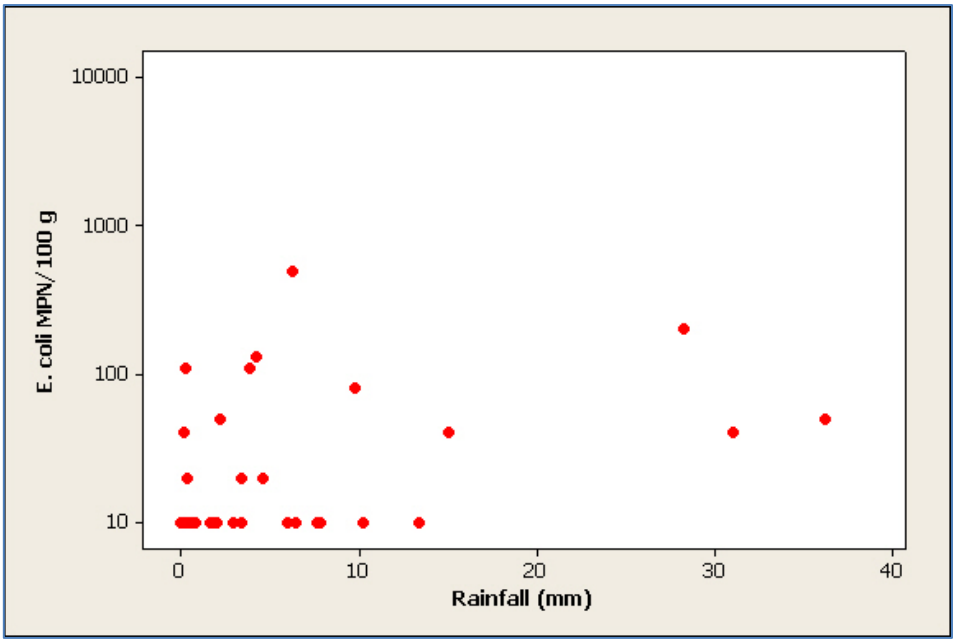

Figure 11.9 Muckle Roe: Scatterplot of result against rainfall in previous 2 days

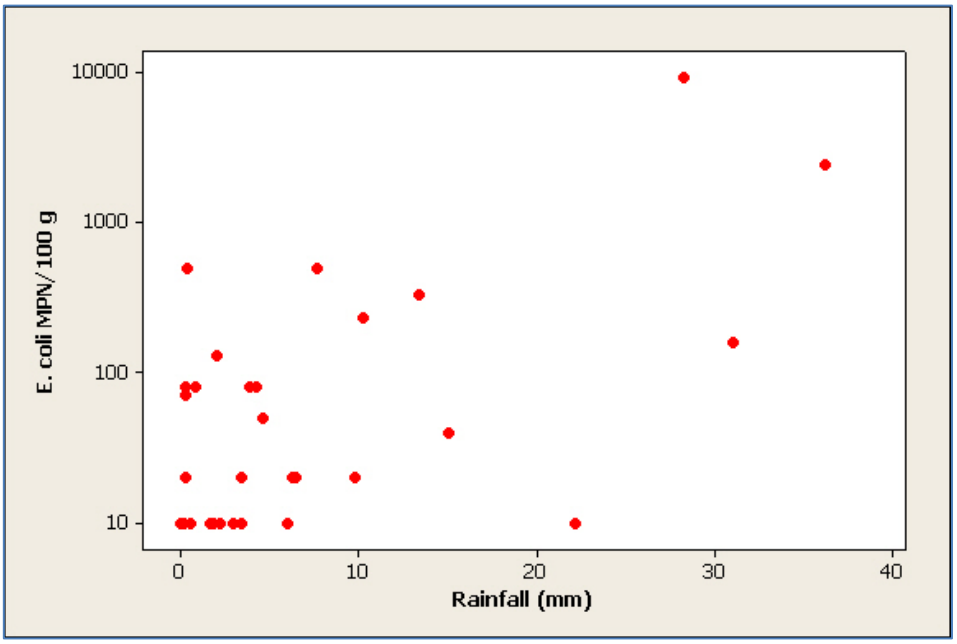

Figure 11.10 Point of Hamna Ayre: Scatterplot of result against rainfall in previous 2 days

7-day Antecedent Rainfall

As the effects of heavy rain may take differing amounts of time to be reflected in shellfish sample results in different systems, the relationship between rainfall in the previous 7 days and sample results was investigated in an identical manner to the above.

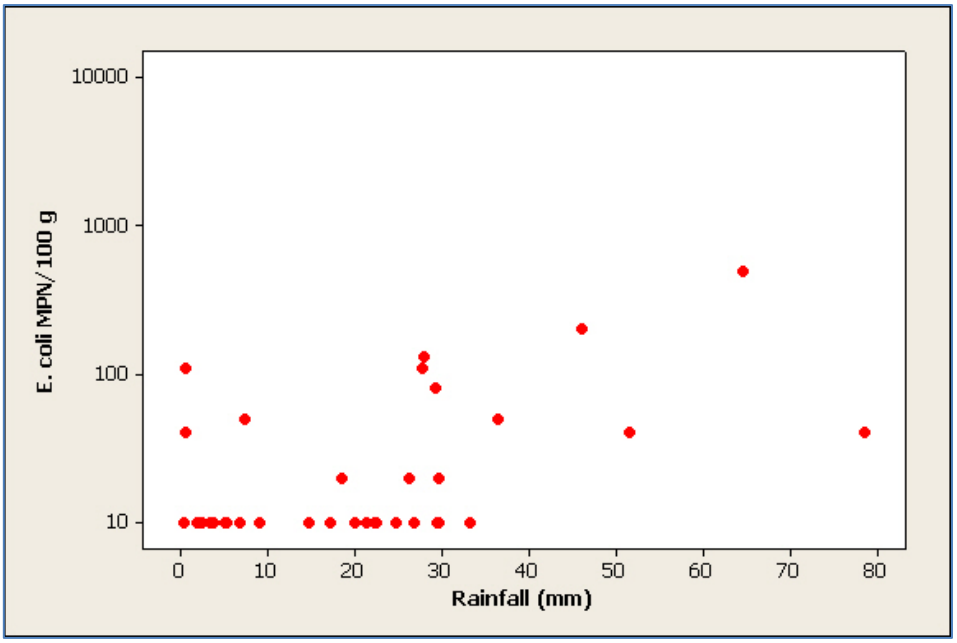

Figure 11.11 Muckle Roe: Scatterplot of result against rainfall in previous 7 days

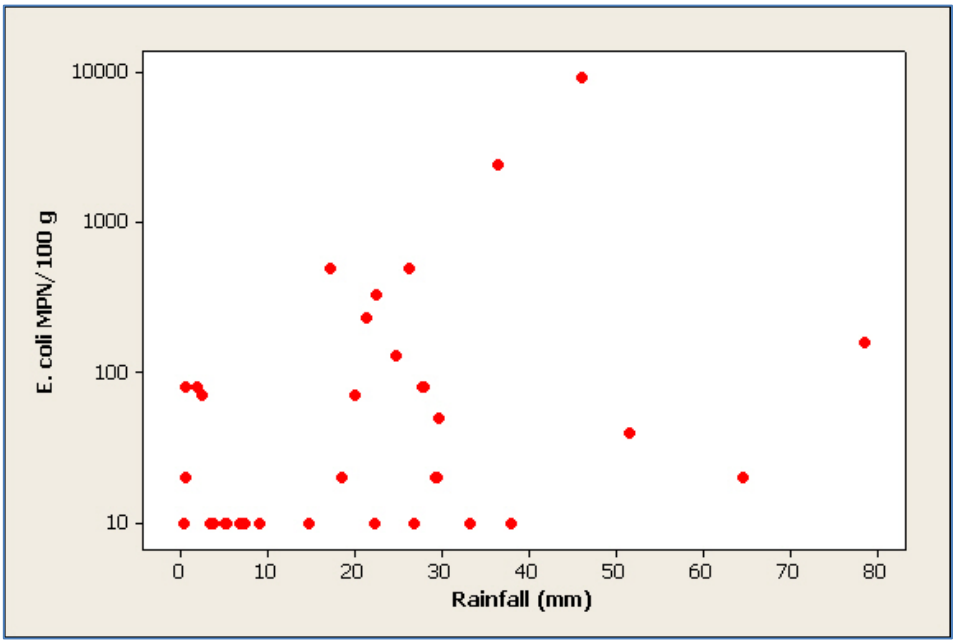

Figure 11.12 Point of Hamna Ayre: Scatterplot of result against rainfall in previous 7 days

Scatterplots of *E. coli* results against 7-day rainfall for the two production areas are presented in Figures 11.11 and 11.12. A significant positive correlation was found between *E. coli* result and rainfall in the previous 7 days at Muckle Roe (Spearman's rank correlation= 0.417, p=0.014) but not at Point of Hamna Ayre (Spearman's rank correlation= 0.320, p=0.065).

11.6.2 Analysis of results by tidal height and state

Spring/Neap Tidal Cycle

When the larger (spring) tides occur every two weeks, circulation of water and particle transport distances will increase, and more of the shoreline will be covered at high water, potentially washing more faecal contamination from livestock into the area. Figures 11.13 and 11.14 present polar plots of log_{10} *E. coli* results for the two production areas in relation to the lunar spring/neap tidal cycle. Full/new moons are located at 0º, and half moons at 180º. The largest (spring) tides occur about 2 days after the full/new moon, or at about 45º, then decrease to the smallest (neap tides) at about 225º, then increase back to spring tides. It should be noted that local meteorological conditions such as wind strength and direction can influence the height of tides and this is not taken into account.

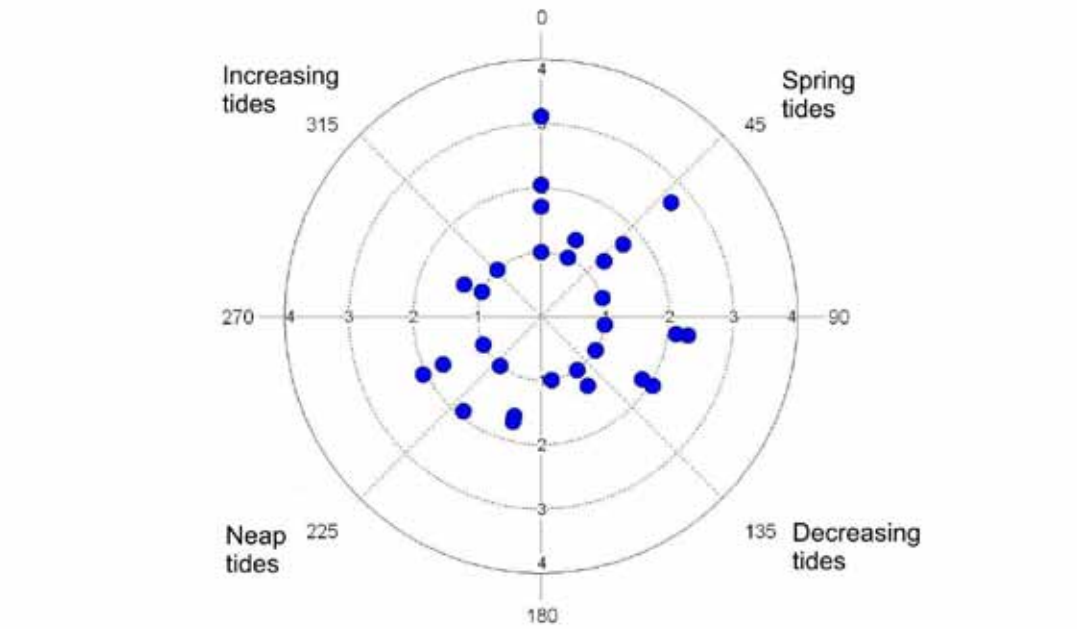

Figure 11.13 Polar plot of log_{10} *E. coli* results at Muckle Roe on the spring/neap tidal cycle

No significant correlation was found between log_{10} *E. coli* results and the spring/neap cycle at Muckle Roe (circular-linear correlation, r=0.188, p=0.269).

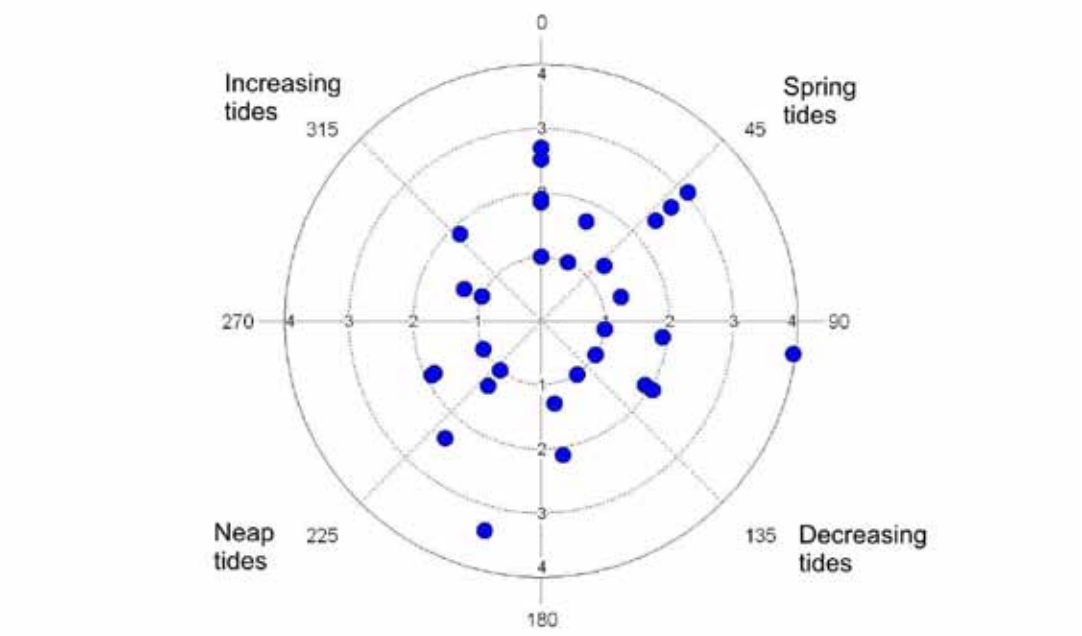

Figure 11.14 Polar plot of log_{10} *E. coli* results at Point of Hamna Ayre on the spring/neap tidal cycle

A significant correlation was found between log_{10} *E. coli* results and the spring/neap cycle at Point of Hamna Ayre (circular-linear correlation, r=0.285, p=0.049). In general, higher results were seen around the time of spring tides.

High/Low Tidal Cycle

Direction and strength of flow around the production areas will change according to tidal state on the (twice daily) high/low cycle, and, depending on the location of sources of contamination, this may result in marked changes in water quality in the vicinity of the farms during this cycle. As *E. coli* levels in some shellfish species can respond within a few hours or less to changes in *E. coli* levels in water, tidal state at time of sampling (hours post high water) was compared with *E. coli* results. Figures 11.15 and 11.16 present polar plots of log_{10} *E. coli* results on the lunar high/low tidal cycle for the two production areas. High water is located at 0º, and low water at 180º.

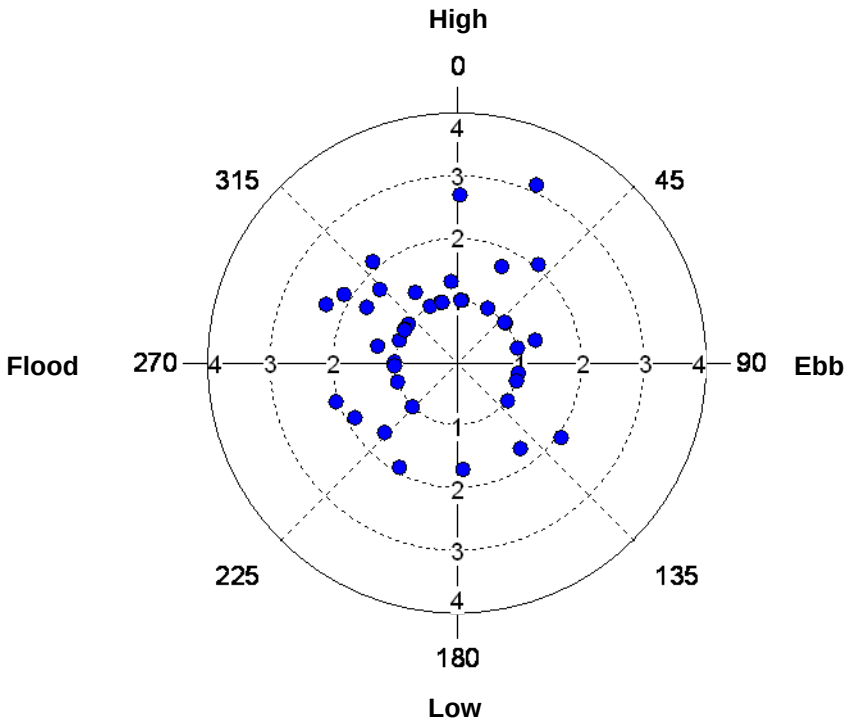

Figure 11.15 Polar plot of log_{10} *E. coli* results at Muckle Roe on the high/low tidal cycle

No significant correlation was found at Muckle Roe between log_{10} *E. coli* results and the high/low tidal cycle (circular-linear correlation, r=0.041, p=0.939).

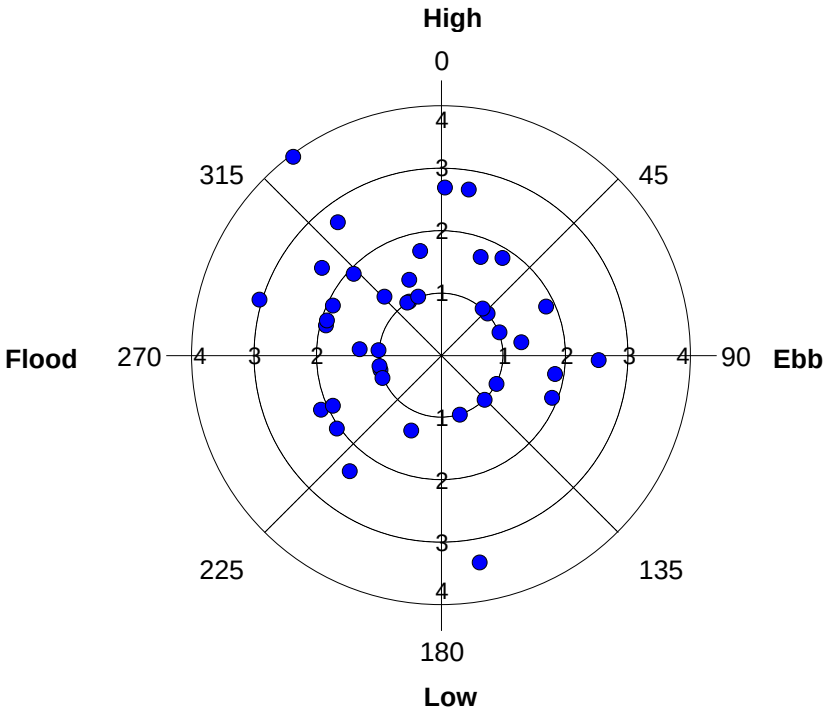

Figure 11.16 Polar plot of log_{10} *E. coli* results at Point of Hamna Ayre on the high/low tidal cycle

No significant correlation was found at Point of Hamna Ayre between $\log_{10}$ *E. coli* results and the high/low tidal cycle (circular-linear correlation, r=0.124, p=0.565).

11.6.3 Analysis of results by water temperature

Water temperature is likely to affect the survival time of bacteria in seawater (Burkhardt *et al*, 2000) and the feeding and elimination rates of shellfish and therefore may be an important predictor of *E. coli* levels in shellfish flesh. It is of course closely related to season, and so any correlation between temperatures and *E. coli* levels in shellfish flesh may not be directly attributable to temperature, but to other factors such as seasonal differences in livestock grazing patterns. Figure 11.17 presents a scatterplot of *E. coli* results against water temperature for both production areas.

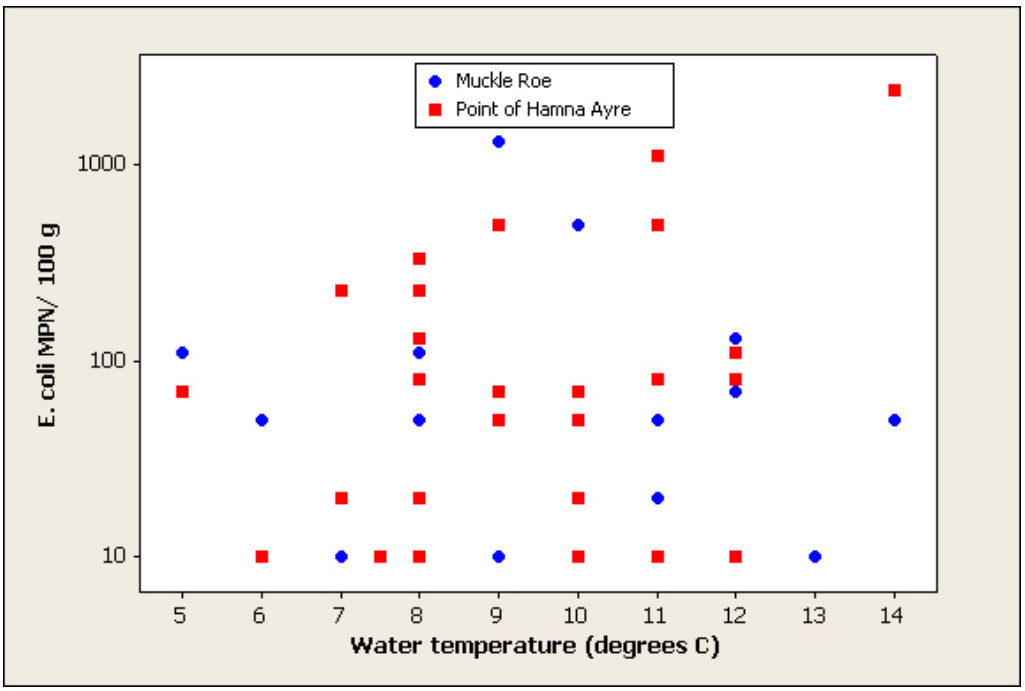

Figure 11.17 Scatterplot of result by water temperature

Water temperature was recorded for 72 of the 88 samples from the two production areas. No significant correlation was seen between $\log_{10}$ *E. coli* results and water temperature at either area (Muckle Roe: Spearman's rank correlation= -0.062, p=0.721; Point of Hamna Ayre: Spearman's rank correlation= 0.130, p=0.451).

11.6.4 Analysis of results by salinity

Salinity will give a direct measure of freshwater influence, and hence freshwater borne contamination at the site. Figure 11.18 presents a scatter plot of *E. coli* result against salinity for the two production areas. No significant correlation was found between the *E. coli* result and salinity for

either of the production areas (Muckle Roe: Spearman's rank correlation r=0.101, p=0.519; Point of Hamna Ayre r=0.173, p=0.268). Most salinity values clustered around 35 ppt, the expected value of full-strength seawater in the area. Salinity values at Muckle Roe tended to be slightly less than at Point of Hamna Ayre. The highest *E. coli* result was obtained at a salinity of 28.4 ppt. It should be noted that a small number of salinity results of 40 and above were recorded: it is unlikely that these represent valid values.

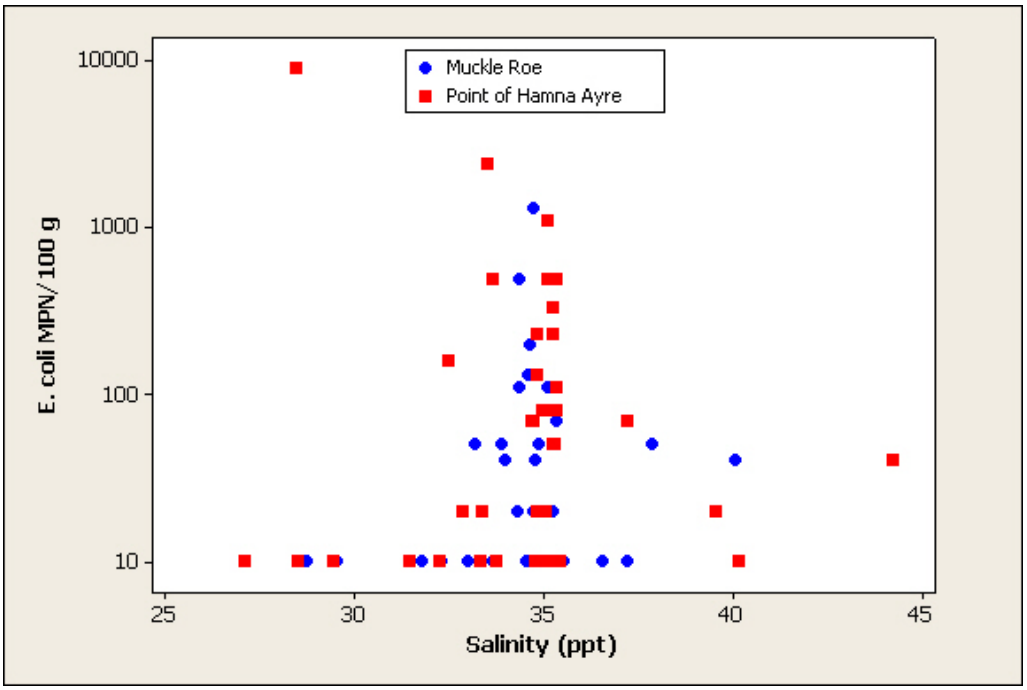

Figure 11.18 Scatterplot of result by salinity

11.7 Evaluation of results over 230 *E. coli* MPN/100g

A total of 9 samples gave a result of over 230 *E. coli* MPN/100g, details of which are presented in Tables 11.2 and 11.3.

The greatest number of results exceeding 230 *E. coli* MPN/100 g was seen at Point of Hamna Ayre. The results were seen over a large portion of the year: from April to November. Moderate to heavy levels of rainfall had occurred in the 2 days prior to sampling in most cases where data was available. The highest result occurred at one of the lower measured salinities. More of the samples had been taken on increasing or spring tides and flood or high tides than on other tidal states.

Table 11.2 Historic *E. coli* sampling results over 230 *E. coli* MPN/100g – Muckle Roe

Collection date	*E. coli* (MPN/100g)	Location	2 day rainfall (mm)	7 day rainfall (mm)	Water Temp (ºC)	Salinity (ppt)	Tidal state (high/low)	Tidal state (spring/neap)
18/11/2009	490	HU 331 629	6.2	64.6	10	34.3	High	Increasing
15/06/2011	1300	HU 3317 6297	*	*	9	34.7	Ebb	Spring

* Data unavailable

Table 11.3 Historic *E. coli* sampling results over 230 *E. coli* MPN/100g – Point of Hamna Ayre

Collection date	*E. coli* (MPN/100g)	Location	2 day rainfall (mm)	7 day rainfall (mm)	Water Temp (ºC)	Salinity (ppt)	Tidal state (high/low)	Tidal state (spring/neap)
18/07/2007	9100	HU 332 615	28.2	46.1	*	28.44	Flood	Decreasing
18/06/2008	490	HU 332 615	7.6	17.2	11	33.65	High	Increasing
24/06/2009	490	HU 332 615	0.3	26.3	11	35.11	Flood	Spring
28/04/2010	330	HU 332 615	13.4	22.4	8	35.23	Ebb	Increasing
18/08/2010	2400	HU 332 615	36.2	36.4	14	33.52	Low	Neap
15/06/2011	490	HU 3325 6154	*	*	9	35.32	High	Increasing
14/09/2011	1100	HU 3325 6154	*	*	11	35.1	Flood	Spring

* Data unavailable

11.8 Summary and conclusions

Higher results have tended to occur at Point of Hamna Ayre than at Muckle Roe. The available location data did not allow for assessment of geographical effects within each production area.

The time trend graphs showed an increase in the general level of contamination over the five year period. This is reflected in a higher proportion of results greater than 230 *E. coli* MPN/100 g being seen from mid-2009 onwards (although the highest result was seen in 2007). Although higher results tended to be seen towards the middle of the year, there was no significant effect of season. The only statistically significant correlation with tidal state was at Point of Hamna Ayre where higher results tended to be seen around spring tides. A significant positive correlation was found between *E. coli* results against rainfall in the previous 2 days at both production areas, although this correlation was stronger at Point of Hamna Ayre. There was also a significant positive correlation between *E. coli* results against rainfall in the previous 7 days at Muckle Roe, but not at Point of Hamna Ayre.

The relatively small amount of data precluded the assessment of the effect of interactions between environmental factors on the *E. coli* concentrations in shellfish.

11.9 Sampling frequency

When a production area holds a non-seasonal classification, and where at least 24 results are available over the past 3 years, and the geometric mean of those results falls within a certain range, consideration can be given to reducing the sampling frequency from monthly to bimonthly.

Both Muckle Roe and Point of Hamna Ayre hold year-round A classifications. At Muckle Roe, 27 samples had been taken over the 3 year period from December 2008 to November 2011. The geometric mean of the results was 34.7 *E. coli* MPN/100 g. At Point of Hamna Ayre, 27 samples had been taken over the same period and the geometric mean of the results was 74.9 *E. coli* MPN/100 g. Both of the geometric mean values are greater than the class A limit of 13 given in the EURL Good Practice Guide and so it is not recommended that the sampling frequency be reduced.

12. Designated Shellfish Growing Waters Data

The Muckle Roe production area falls within the East of Burki Taing, Muckle Roe designated Shellfish Growing Water (SGW). The Point of Hamna Ayre production area lies outside the southern boundary of the SGW. The Muckle Roe production area, which lies toward the southwestern extent of the SGW, was only included when the SGW boundary was extended in 2009.

The designated area is large, incorporating five classified production areas: Busta Voe Lee North, Busta Voe Lee South, Olna Firth, Gon Firth and Muckle Roe. Of these, Busta Voe Lee North and Gon Firth have already been subject to sanitary surveys.

SEPA is responsible for ensuring that monitoring is undertaken for a variety of parameters, including faecal coliforms in shore mussels. Two sampling points have been used for SGW monitoring: HU 39455 64210, near the head of Olna Firth and HU 35967 66400 at Sparl on the east shore of Busta Voe. The monitoring point at Sparl, which is closest to the Muckle Roe fishery, lies over 4.5 km to the northwest and therefore is not considered likely to accurately reflect contamination levels likely to be experienced at the fishery. Therefore sampling results from these locations are not included here. The relative positions of the SGW boundaries, mussel farms and SGW monitoring points are shown in Figure 12.1.

Since 2007, SEPA have obtained shellfish classification monitoring results (*E. coli*) under an agreement with FSAS for the purposes of SGW monitoring. Any of those results relating to the Muckle Roe fishery will have been used in the analysis in Section 11 of this report.

The area failed to meet guideline standards for faecal coliforms in all but 2 years between 2002 and 2006. However, since the inception of use of FSAS *E. coli* monitoring data in 2007, the area has passed this guideline in all years. Results in shore mussels are often found to be higher than those in mussels taken from mussel farms situated even a relatively short distance away from shore as there is greater opportunity for dispersion and dilution of contaminants away from the shoreline.

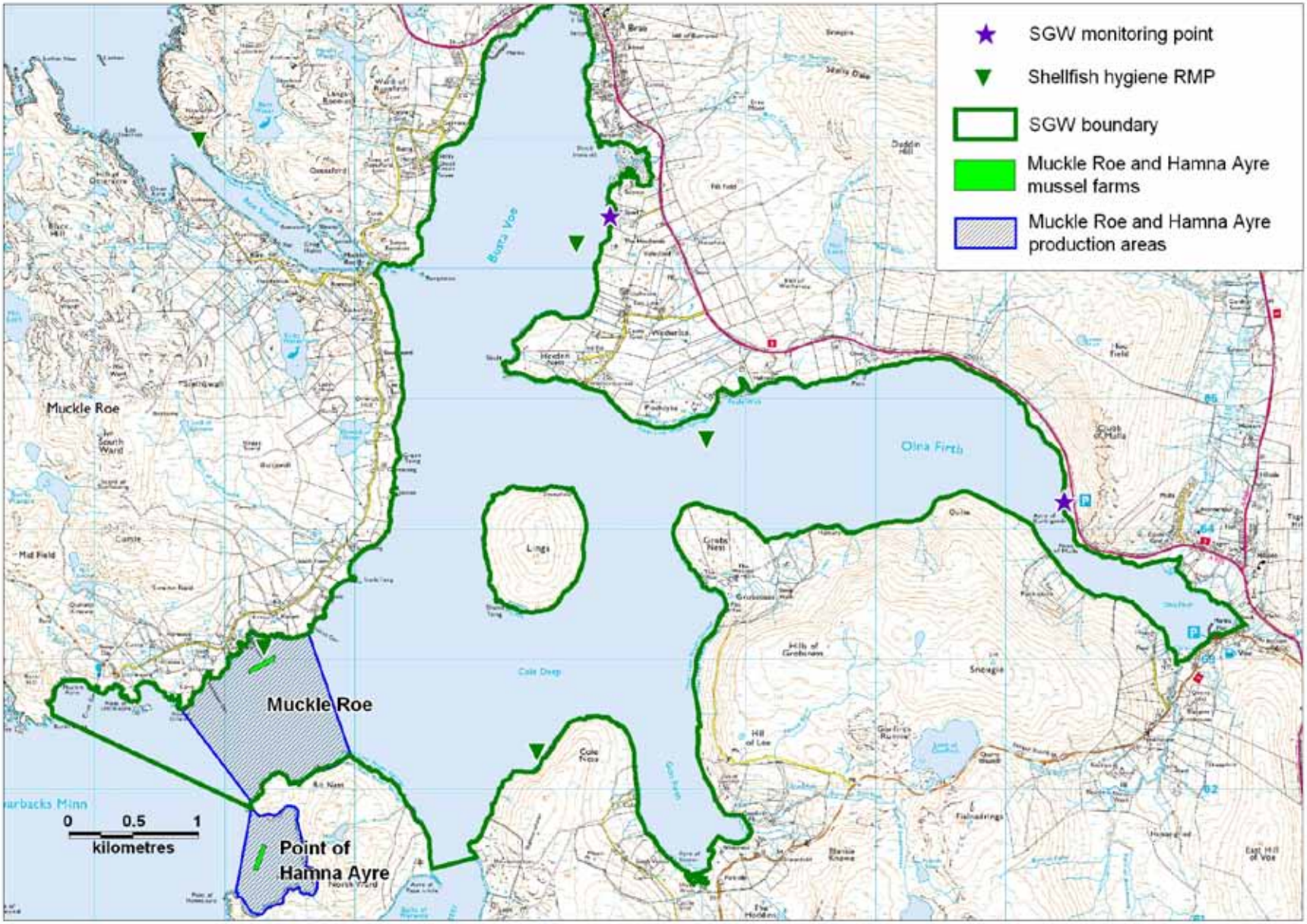

Figure 12.1 East of Burki Taing, Muckle Roe SGW map

13. River Flow

There are no gauging stations on rivers or burns along the Muckle Roe or Papa Little coastline.

The following rivers and streams were measured and sampled during the shoreline survey. These represent the largest freshwater inputs into the survey area at Muckle Roe. Two streams are marked on the OS map as entering the small Bay at Hamna Ayre on Papa Little. The weather was dry at the time of the survey and these were not running.

Table 13.1 Stream loadings for Muckle Roe

No	Grid Ref	Description	Width (m)	Depth (m)	Flow (m/s)	Flow in m^3/day	*E.coli* (cfu/ 100ml)	Loading (*E.coli* per day)
1	HU 31782 62883	Mill Burn	1	0.13	0.13	1460	40	5.8×10^8
2	HU 32550 62717	Stream	0.12	0.03	0.783	244	60	1.5×10^8
3	HU 33190 63216	Stream	0.25	0.05	0.401	433	130	5.6×10^8
4	HU 33946 63723	Burn of Scarfataing	1.01	0.05	0.096	419	210	8.8×10^8
5	HU 33860 63772	Tributary of Burn of Scarfataing	0.17	0.05	0.103	76	1300	9.8×10^8

A map showing the sampling locations and calculated loadings is shown in Figure 13.1.

The loadings were all moderate at the time of the survey, with all results $<1 \times 10^9$ *E. coli*/day. This indicates that there was not marked faecal contamination of the streams. The loadings would be expected to increase by at least tenfold following heavy rain.

The stream most likely to impact on the microbiological quality of the current Muckle Roe: Pobies Geo site is that immediately adjacent to it (stream 3). Following rainfall, the streams at Hamna Ayre may contribute to contamination at the fishery at the Point of Hamna Ayre. Following heavy rain, it is likely that direct land run-off will carry animal faecal material into the sea due to the steep nature of the landscape.

Figure 13.1 Map of river/stream loadings at Muckle Roe

14. Bathymetry and Hydrodynamics

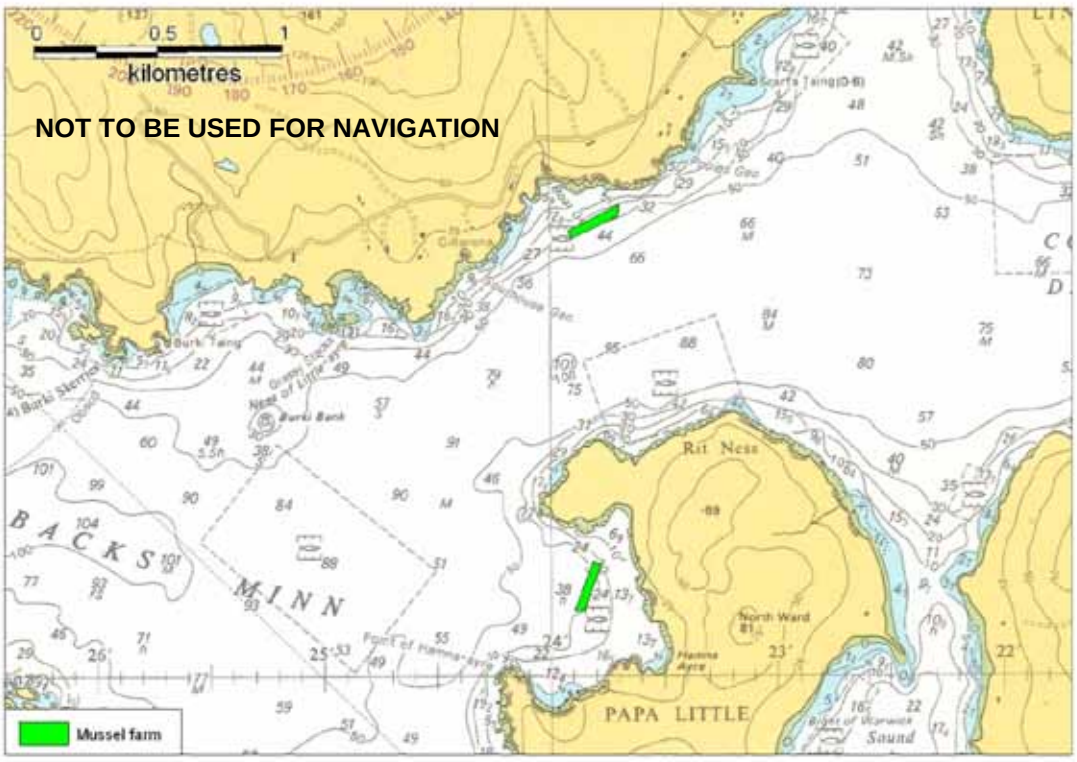

Figure 14.1 Bathymetry at Muckle Roe

Figure 14.1 shows the bathymetry in the part of Swarbacks Minn in the vicinity of Muckle Roe and Papa Little. The seabed shelves steeply from the shore and reaches depths exceeding 50 m within 200 m of the shore. Depths at the mussel lines range from approximately 20 to 40 m. There are small extents of drying areas and rocky outcrops around the coast.

14.1 Tidal Curve and Description

The two tidal curves below are for West Burra Firth, approximately 10 km from the production areas. The tidal curves have been output from UKHO TotalTide. The first is for seven days beginning 00.00 BST on 17/08/11 and the second is for seven days beginning 00.00 BST on 24/08/11. This two-week period covers the date of the shoreline survey. Together they show the predicted tidal heights over high/low water for a full neap/spring tidal cycle.

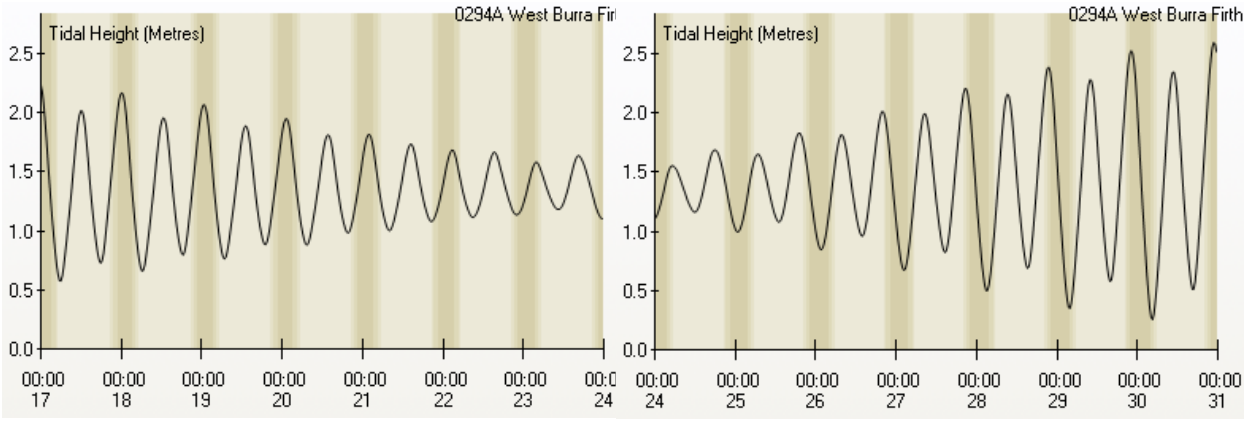

Figure 14.2 Tidal curves for West Burra Firth

The following is the summary description for West Burra Firth from TotalTide:

0294A West Burra Firth is a Secondary Non-Harmonic port.
The tide type is Semi-Diurnal.

HAT	2.7 m
MHWS	2.2 m
MHWN	1.7 m
MSL	1.39 m
MLWN	1.0 m
MLWS	0.6 m
LAT	0.1 m

Predicted heights are in metres above chart datum. The tidal range at spring tide is 1.6 m and at neap tide 0.7, so tidal ranges here are relatively small (microtidal).

14.2 Currents

There is no tidal stream information for the vicinity of the fisheries. A current meter study had been undertaken by Shetland Seafood Quality Control Ltd on behalf of Viking Salmon Ltd in support of an application for discharge from a fish farm and the data was obtained with permission of the farm owners. The location and survey period is given in Table 14.1 and the position is shown on the map in Figure 14.3. Plots of the current directions and speeds, together with the wind direction and speeds over the relevant period, are shown in Figure 14.3.

Table 14.1 Survey period for the current meter study

Location	NGR	Survey period
Boat Geo	HU 33198 62915	20/06/2000 – 06/07/2000

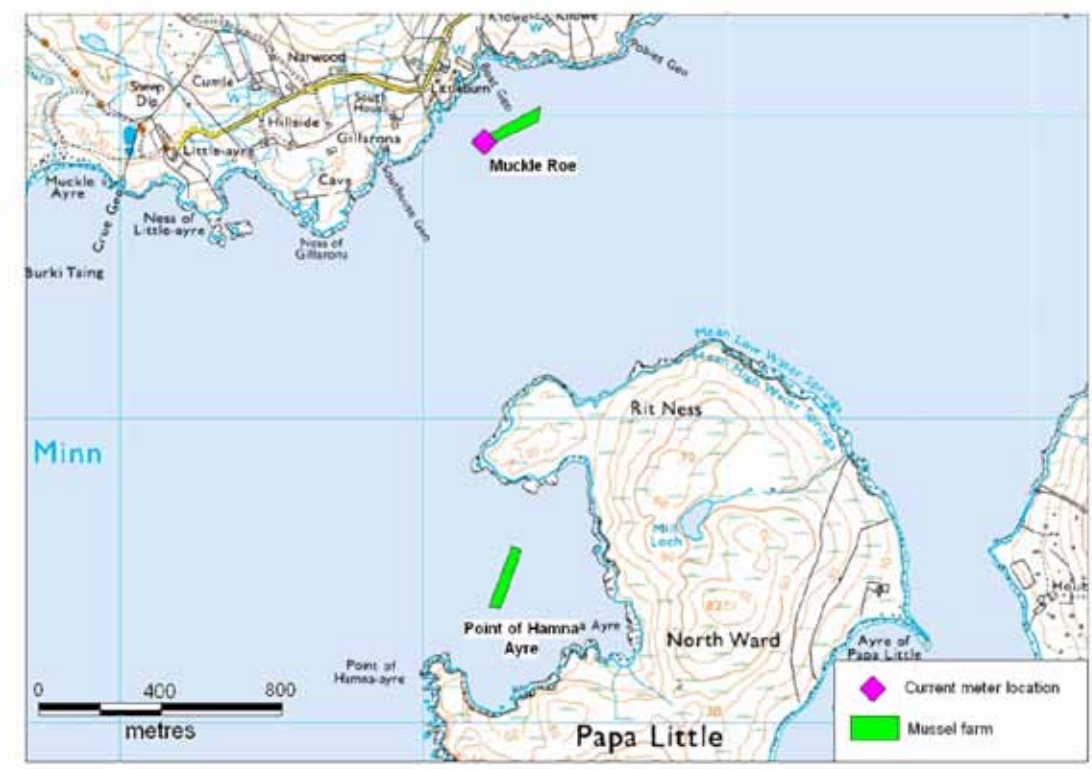

Figure 14.3 Current meter location

The current meter was located at one end of what is now the Muckle Roe (Pobies Geo) mussel fishery and so the results are directly relevant to that production area. The median and maximum current speeds recorded at the three depths are shown in Table 14.2. The median current speed of 1 cm/s (0.01 m/s; 0.02 knots) was the same at all three depths and this is very slow. The maximum speeds were approximately 10 times this, and were greatest nearest the surface. However, even the maximum speeds were relatively slow. Near the bottom, currents flowed almost exclusively to the south. At mid-depth and near the surface, the currents were more bidirectional and flowed more or less parallel to the coast. At mid-depth the flow to the east-north-east predominated and near the surface, the flow to the west-south-west predominated although the direction was somewhat more variable.

Table 14.2 Median and maximum current speeds

Depth	Current speed (cm/s)	
	Median	Maximum
Near-bottom	1.0	8.0
Mid-depth	1.0	9.0
Near-surface	1.0	11.8

At the maximum current speed, the maximum excursion over an ebb or flood tide would be in the order of 1.5 km. However, much of the time the distance potentially travelled by contaminants, ignoring any dilution or dispersion, would be expected to be less than this.

The domain for hydrodynamic modelling undertaken in support of the Papa Little Voe sanitary survey extended to the Boat Geo and Hamna Ayre areas (FSAS/Cefas, 2009). These data are therefore relevant to the Muckle Roe, Pobies Geo and Point of Hamna Ayre fisheries. The model predicted current velocities in the order of 1 to 3 cm/s at Boat Geo and less than 1 cm/s at Hamna Ayre. However, much higher current speeds were predicted in the main channel just outside Hamna Ayre. Significant effects of wind were seen in the model at modest wind speeds.

14.3 Conclusions

The area is very deep and shelves very quickly away from land. Any contamination originating at the coast will be subject to significant dilution within a short distance from shore.

Currents in the area are very low. This means that contamination will not travel a long distance from source over a tidal cycle but also means that it will not be subject to much dispersion.

At the Muckle Roe mussel lines, flows at the bottom of the lines will tend to be in the east-north-east direction and those at the top of the lines will tend to be in the west-south-west direction.

Available information for the currents in the vicinity of the Point of Hamna Ayre mussel lines indicates that speeds will be very low and contamination arising from sources within the bay at Hamna Ayre will tend to stay there.

There will be marked effects of winds which will modify the currents and the direction and distance that contaminants are carried. Prevailing south-west winds will increase the north-north-easterly flows at Muckle Roe and further constrain water within the bay at Hamna Ayre.

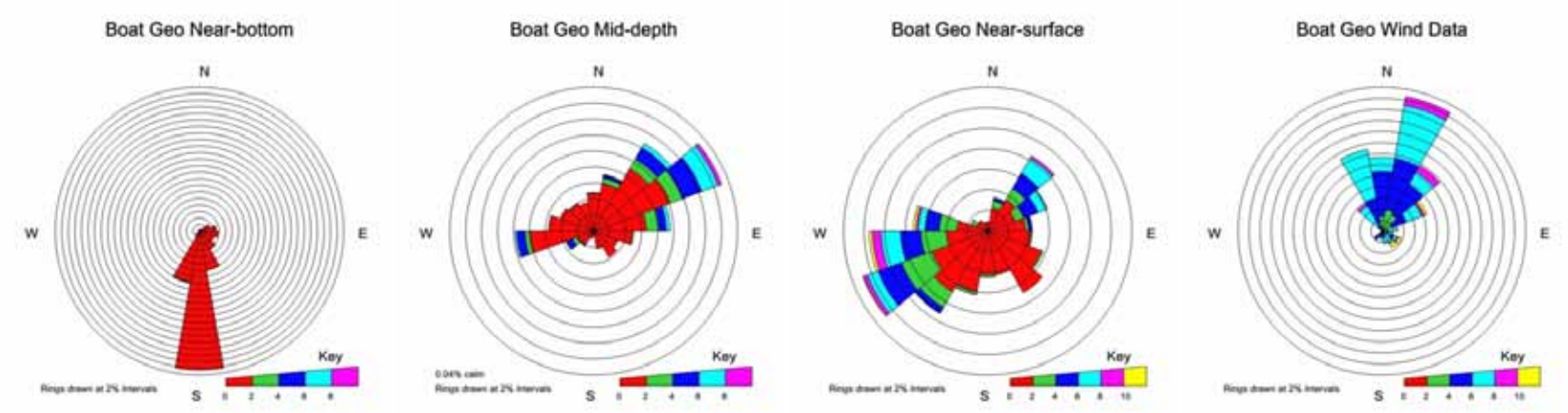

Figure 14.4 Current and wind plots for the Boat Geo current meter study

Currents measured in cm/s. Wind measured in m/s. As per convention, currents are plotted against the direction towards which they are travelling while winds are plotted against the direction from which they are travelling. The length of each segment in a plot relates to the proportion of observations lying in that direction. The speed relates to the colour key beneath each plot. The proportion that each colour takes up in an individual segment relates to the proportion of observations in that direction having speed in that range. Directions are in degrees magnetic.

15. Shoreline Survey Overview

The shoreline survey was conducted on the 17th August 2011 under mainly dry and calm weather conditions.

Both fisheries were visited on the day of the shoreline survey. The Point of Hamna Ayre fishery consisted of two double 220 m long lines with 8 m droppers. The Muckle Roe fishery consists of three double 220 m long lines with 8 m droppers. Both fisheries had sufficient stock on site for sampling at the time of the shoreline survey and are harvested all year round.

The area surrounding both fisheries is sparsely populated. Papa Little is uninhabited and there were no large settlements on the island of Muckle Roe. Several dwellings were observed on the southern shoreline of Muckle Roe adjacent to the Muckle Roe mussel farm. On the south west shoreline of Muckle Roe near Little Ayre an iron pipe was observed leading down to the sea from several dwellings. A seawater sample collected from this location had a result of 50 *E. coli* (cfu/100 ml). Two dry outfall pipes were observed on the shoreline of Muckle Roe, adjacent to the fishery in Boat Geo cove. Both pipes lead into a stream. At the southeast end of Muckle Roe near Ayredale, another outfall pipe was flowing. A freshwater sample taken from this outfall pipe had a result of 310 *E. coli* (cfu/100 ml). No sanitary debris was observed during the shoreline survey.

Livestock were observed grazing around most of the shoreline surrounding both shellfish farms. On the island of Papa Little, approximately 20 sheep were observed grazing on the shoreline. A total of approximately 172 sheep were observed grazing along the southern shoreline of Muckle Roe at the time of the shoreline survey. Livestock were able to access the shoreline and freshwater streams.

During the shoreline survey 5 seabirds were observed in the water near to the Hamna Ayre mussel lines. At Muckle Roe, 1 gull and several cormorants were observed on the mussel lines and 4 geese on the water close by.

Sea water samples taken in the close vicinity of the fishery contained little *E. coli* (<1-3 *E. coli* cfu/100 ml) in all cases. Salinity tests were carried out on the seawater samples taken from the fisheries and indicated little or no significant freshwater influence at the time.

The streams identified on the OS map to be adjacent to the Point of Hamna Ayre mussel farm were dry on the day of the shoreline survey. Fresh water samples and discharge measurements were taken at five streams draining into the Muckle Roe survey area. Fresh water samples were collected at all five streams and had *E. coli* results varying from 40 to 1300 *E. coli* (cfu/100 ml). Four of the samples were <210 *E. coli* (cfu/100 ml) and the fifth collected from the south-eastern shoreline of Muckle Roe had a result of 1300 *E. coli* (cfu/100 ml).

Mussel samples were collected from both ends of the long lines at two different depths from both fisheries. At the Point of Hamna Ayre mussel farm the two samples taken from the northern end of the long lines both had a result of 170 *E. coli* (MPN/100 g). At the southern end of the long lines the sample taken at <1 m depth had a result of 110 *E. coli* (MPN/100 g) and the sample taken at 7 m depth had a result of 20 *E. coli* (MPN/100 g). At the Muckle Roe mussel farm, at the northern end of the long lines the sample collected at a <1 m depth had a result of 80 *E. coli* (cfu/100 ml) and the sample collected at a 6 m depth had a result of 490 *E. coli* (cfu/100 ml). At the southern end of the long lines the sample taken at <1 m depth had a result of 70 *E. coli* (MPN/100 g) and the sample taken at 7 m depth had a result of 130 *E. coli* (MPN/100 g).

Figure 15.1 shows a summary map of the most significant findings from the shoreline survey for Point of Hamna Ayre and Muckle Roe.

Figure 15.1 Map of recommendations at Point of Hamna Ayre and Muckle Roe

16. Overall Assessment

Human sewage impacts

The Point of Hamna Ayre mussel farm lies adjacent to an uninhabited island and over 1km from the nearest habitation on nearby Muckle Roe. Therefore, this area is unlikely to be significantly impacted by human sewage.

The Muckle Roe mussel farm lies adjacent to the island of Muckle Roe, which had a total population of 104 at the 2001 census. The fishery lies near the end of the road along the southern shore of the island, and therefore only a small proportion of the island's population lives within the vicinity of the mussel farm. Two discharges of domestic sewage to the sea were observed along the shore adjacent to the mussel farm. A further discharge to sea, identified in the Shellfish Growing Water report (SEPA, 2011) lies approximately 1 km to the northeast. These constitute the only point sources of human sewage directly to the waters near the mussel farm.

As there is no public sewerage provision in the area, all dwellings are presumed to have private septic tanks. All of the discharges for which SEPA provided consent data were recorded as discharging either to soakaway or to land. Therefore the remaining dwellings, aside from those connected to the pipes observed during the shoreline survey, are presumed to discharge to soakaway or land. The predominant soil type is classed as poorly draining, suggesting that soakaway systems near the shore may be more prone to drainage problems and therefore more likely to lead to contamination of adjacent waters.

Therefore, the Muckle Roe mussel farm is much more likely to be affected by sources of human sewage than the Point of Hamna Ayre farm, and the majority of the potential sources lie to the north and along the western half of the Muckle Roe lines.

Agricultural impacts

Sheep were observed to have access to shoreline adjacent to both the Point of Hamna Ayre and Muckle Roe mussel farms. Although only moderate numbers of sheep were observed, these animals excrete a greater mass and more faecal coliforms per day than humans (see Appendix 3) and therefore are likely to pose a greater risk of contamination to the fisheries. Areas at greatest risk are those nearest to the shore.

Landcover on the shoreline adjacent to Muckle Roe is recorded as improved grassland, which is consistent with observations of sheep and farms along this shore. This landcover type is associated with a greater risk of rainfall-related runoff of faecal contamination from livestock. Landcover on Papa Little is predominantly acid grassland and heath, both of which are utilised for rough grazing of sheep. Land used for rough grazing is associated with a moderate risk of rainfall-related faecal contamination.

Wildlife impacts

Seabirds such as gulls and cormorants may rest on the floats at the mussel farms, and therefore deposit droppings directly to the fisheries throughout the year. However, any impact from the large numbers of nesting seabirds to the west of Muckle Roe and the north of Point of Hamna Ayre is likely to be highest during the summer when birds are tending to nests and into early autumn, when the onset of rainier weather is likely to wash accumulated guano from around the nesting sites into the sea.

Seals are known to be present in the area year round, and are likely to contribute to background levels of contamination where they are found. The Point of Hamna Ayre mussel farm may be more impacted by this source than the Muckle Roe site due to the potential presence of hauled-out animals.

Seasonal variation

There is likely to be a small increase in human population during the summer months, when small numbers of tourists may be present on Muckle Roe. Visitor use of Papa Little is expected to be extremely limited due to its inaccessibility.

Sheep populations are likely to vary significantly through the seasons, with numbers roughly twice as high from spring to autumn due to the presence of lambs. There is also likely to be variation in location based on season, with larger numbers of sheep kept on farms along the Muckle Roe shore and few or no sheep kept on Papa Little during the winter. Therefore, the risk of contamination to watercourses and the shoreline along Muckle Roe would be potentially higher in winter and the risk at Point of Hamna Ayre most likely lower during winter.

Evaluation of historical *E.coli* sampling results indicates that although there appeared to be a tendency for sampling results to be higher in summer, no statistically significant difference was found in results by season for either production area.

Rainfall varies markedly across the seasons, with much drier conditions occurring from April to August than during the remainder of the year. Sporadic, heavy rainfall events during the drier months are likely to lead to a ‘first flush’ effect of higher levels of contaminants carried in runoff and therefore may lead to episodes of higher contamination at the fishery following heavy rainfall. The onset of wetter weather in September may lead to greater movement of contamination from grazed areas over a longer period of time.

Rivers and streams

A total of five streams were sampled and measured along the Muckle Roe fishery during the shoreline survey, all of which contained moderate loadings of *E. coli* ($<1x10^9$ *E. coli*/day). This indicates that there was not marked faecal contamination of the streams. The loadings would be expected to increase by at least tenfold following heavy rain.

The stream most likely to impact on the microbiological quality of the current Muckle Roe: Pobies Geo site is that immediately adjacent to it (stream 3).

The streams at Hamna Ayre were not observed to be flowing at the time of survey, however following rainfall these streams would be expected to carry diffuse contamination from sheep grazed on the island and would therefore contribute to contamination at the Point of Hamna Ayre site. Following heavy rain, it is likely that direct land run-off will carry animal faecal material into the sea due to the steep nature of the landscape.

Movement of contaminants

The area is very deep and shelves very quickly away from land. Any contamination originating at the coast will be subject to significant dilution within a short distance from shore. Due to low current speeds, contamination will not travel a long distance from source over a tidal cycle and therefore will not be subject to much dispersion.

At the Muckle Roe mussel lines, flows at the bottom of the lines will tend to be in the east-north-east direction and those at the top of the lines will tend to be in the west-south-west direction.

At the Point of Hamna Ayre site, contamination arising from sources within the bay at Hamna Ayre will tend to stay within the embayment due to limited water movement and the prevailing wind direction keeping circulation entrained within the bay.

There will be marked effects of winds which will modify the currents and the direction and distance that contaminants are carried. Prevailing south-west winds will increase the north-north-easterly flows at Muckle Roe and further constrain water within the bay at Hamna Ayre.

Therefore, for both sites only sources in close proximity to the fisheries are likely to contribute to contamination levels there. These arise predominantly from sources near the shore.

Temporal and geographical patterns of sampling results

Higher results have tended to occur at Point of Hamna Ayre than at Muckle Roe. The available location data did not allow for assessment of geographical effects within each production area.

The time trend graphs showed an increase in the general level of contamination over the five year period. This is reflected in a higher proportion of results greater than 230 *E. coli* MPN/100 g being seen from mid-2009 onwards (although the highest result was seen in 2007). Although higher results tended to be seen towards the middle of the year, there was no significant effect of season. The only statistical significant correlation with tidal state was at Point of Hamna Ayre where higher results tended to be seen around spring tides.

Results from samples taken during the shoreline survey also confirmed higher levels of contamination at the Muckle Roe site than at Point of Hamna Ayre. At Muckle Roe, results were found to be higher at the bottom of the lines than nearer the surface. Results were higher at the northeastern end of the lines than at the southwestern end, suggesting contaminants arising from the near shore may be moving northward along the coast at depth rather than at the surface.

However, at Point of Hamna Ayre, where there was a difference in results based on depth, it was the one taken nearer the surface that was higher. Sample results were higher at the northern end of these lines than at the southern end.

A stability assessment was conducted on both areas, and results indicated that reduced monitoring frequency could not be recommended.

Conclusions

The Point of Hamna Ayre and Muckle Roe production areas show very different profiles with regards to sources of faecal contamination. Historical monitoring results indicate that the Point of Hamna Ayre production area is subject to higher levels of faecal contamination than Muckle Roe. However, the microbiological data conflicts with what could be assumed from the information on potential pollution sources as there were greater numbers of septic tanks and livestock along the shore at Muckle Roe. Both areas are subject to diffuse contamination from livestock, the numbers and seasonality of which are likely to vary considerably.

Movement of contaminants differs, with contaminants at Hamna Ayre likely to be constrained within the bay, while those along Muckle Roe show flow along the coast varying with depth. This may explain the higher results overall at Point of Hamna Ayre. Therefore, the evidence suggests these two areas should continue to be monitored separately.

The only significant spatial information with regard to contamination in shellfish were results obtained during the shoreline survey and these suggested that contamination levels at that time were higher at the northern end of the lines for both sites.

17. Recommendations

Due to the significant differences found in contamination levels and predicted movement of contaminants at the two production areas, it is recommended that they continue to be monitored separately.

Point of Hamna Ayre

Production area

No significant change is recommended to boundaries, though small adjustments have been made to bring the boundaries in line with MHWS and land features.

The recommended production area is described as the area bounded by lines drawn between HU 3320 6187 to HU 3308 6120 and extending to MHWS.

RMP

It is recommended that the RMP be established at the northern end of the lines. This lies nearer to the stream and was found to have higher levels of contamination during the shoreline survey. The recommended RMP is therefore HU 3331 6156.

Tolerance

A sampling tolerance of 40 meters is recommended to allow for some movement of the lines.

Depth of sampling

Sampling undertaken during the shoreline survey suggested that higher contamination levels may be found nearer the surface at this site, therefore sampling depth is recommended to be 1-2 m. If sufficient stock for sampling cannot routinely be provided from the top of the lines, it is recommended that a sampling basket be suspended at this depth. Samples taken from a sampling bag or basket must have been in place for a minimum of two weeks to ensure that results are representative of the location.

Frequency

The stability assessment indicated that the area was not suitable for reduced sampling frequency, therefore it is recommended that monthly monitoring be maintained.

Muckle Roe

Production area

No significant change is recommended to boundaries, though small adjustments have been made to bring the boundaries in line with MHWS and land features.

The recommended production area is described as the area bounded by lines drawn between HU 3266 6261 to HU 3320 6190 and between HU 3367 6321 to HU 3410 6227 to HU 3398 6225 and extending to MHWS.

RMP

It is recommended that the RMP be established at the northeastern end of the lines. This lies nearer to the stream and was found to have the highest levels of contamination during the shoreline survey. The recommended RMP is therefore HU 3337 6301.

Tolerance

A sampling tolerance of 40 meters is recommended to allow for some movement of the lines.

Depth of sampling

Sampling undertaken during the shoreline survey suggested that higher contamination levels may be found at depth at this site, therefore sampling depth is recommended to be 7- 8 m (at the bottom of the lines). If sufficient stock for sampling cannot routinely be provided from the bottoms of the lines, it is recommended that a sampling basket be suspended at this depth. Samples taken from a sampling bag or basket must have been in place for a minimum of two weeks to ensure that results are representative of the location.

Frequency

The stability assessment indicated that the area was not suitable for reduced sampling frequency, therefore it is recommended that monthly monitoring be maintained.

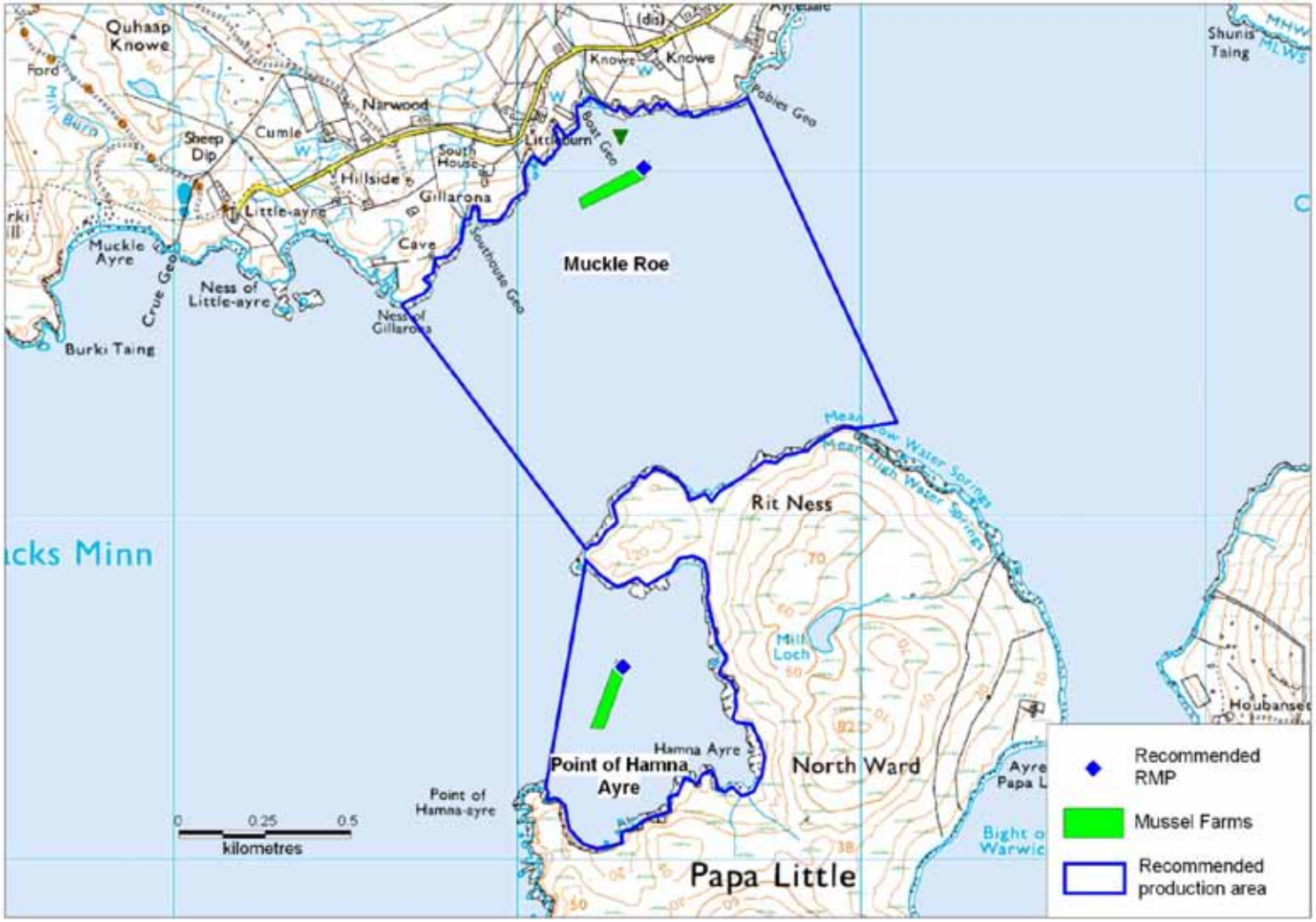

Figure 16.1 Map of recommendations at Point of Hamna Ayre and Muckle Roe

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19. List of Figures and Tables

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2. **General Information on Wildlife Impacts**
3. **Tables of Typical Faecal Bacteria Concentrations**
4. **Statistical Data**
5. **Hydrographic Methods**
6. **Shoreline Survey Report**

Geology and Soils Assessment Method

Component soils and their associations were identified using uncoloured soil maps (scale 1:50,000) obtained from the Macaulay Institute. The relevant soils associations and component soils were then investigated to establish basic characteristics. From the maps seven main soil types were identified: 1) humus-iron podzols, 2) brown forest soils, 3) calcareous regosols, brown calcareous regosols, calcareous gleys, 4) peaty gleys, podzols, rankers, 5) non-calcareous gleys, peaty gleys: some humic gleys, peat, 6) organic soils and 7) alluvial soils.

Humus-iron podzols are generally infertile and physically limiting soils for productive use. In terms of drainage, depending on the related soil association they generally have a low surface % runoff, of between 14.5 – 48.4%, indicating that they are generally freely draining.

Brown forest soils are characteristically well drained with their occurrence being restricted to warmer drier climates, and under natural conditions they often form beneath broadleaf woodland. With a very low surface % runoff of between 2 – 29.2%, brown forest soils can be categorised as freely draining (Macaulay Institute, 2007).

Calcareous regosols, brown regosols and calcareous gleys are all characteristically freely draining soils containing free calcium carbonate within their profiles. These soil types have a very low surface % runoff at 14.5%.

Peaty gleys, peaty podzols and peaty rankers contribute to a large percentage of the soil composition of Scotland. They are all characteristically acidic, nutrient deficient and poorly draining. They have a very high surface % runoff of between 48.4 – 60%.

Non-calcareous gleys, peaty gleys and humic gleys are generally developed under conditions of intermittent or permanent water logging. In Scotland, non-calcareous gleys within the Arkaig association are most common and have an average surface % runoff of 48.4%, indicating that they are generally poorly draining.

Organic soils often referred to as peat deposits and are composed of greater than 60% organic matter. Organic soils have a surface % runoff of 25.3% and although low, due to their water logged nature, results in them being poorly draining.

Alluvial soils are confined to principal river valleys and stream channels, with a wide soil textural range and variable drainage. However, the alluvial soils encountered within this region have an average surface % runoff of 44.3%, so it is likely that in this case they would be poorly draining.

These component soils were classed broadly into two groups based on whether they are freely or poorly draining. Drainage classes were created based on information obtained from the both the Macaulay Institute website

and personal communication with Dr. Alan Lilly. GIS map layers were created for each class with poorly draining classes shaded red, pink or orange and freely draining classes coloured blue or grey. These maps were then used to assess the spatial variation in soil permeability across a survey area and it's potential impact on runoff.

Glossary of Soil Terminology

Calcareous: Containing free calcium carbonate.

Gley: A sticky, bluish-grey subsurface layer of clay developed under intermittent or permanent water logging.

Podzol: Infertile, non-productive soils. Formed in cool, humid climates, generally freely draining.

Rankers: Soils developed over noncalcareous material, usually rock, also called 'topsoil'.

Regosol: coarse-textured, unconsolidated soil lacking distinct horizons. In Scotland, it is formed from either quartzose or shelly sands.

General Information on Wildlife Impacts

Pinnipeds

Two species of pinniped (seals, sea lions, walruses) are commonly found around the coasts of Scotland: These are the European harbour, or common, seal (*Phoca vitulina vitulina*) and the grey seal (*Halichoerus grypus*). Both species can be found along the west coast of Scotland.

Common seal surveys are conducted every 5 years and an estimate of minimum numbers is available through Scottish Natural Heritage.

According to the Scottish Executive, in 2001 there were approximately 119,000 grey seals in Scottish waters, the majority of which were found in breeding colonies in Orkney and the Outer Hebrides.

Adult Grey seals weigh 150-220 kg and adult common seals 50-170kg. They are estimated to consume between 4 and 8% of their body weight per day in fish, squid, molluscs and crustaceans. No estimates of the volume of seal faeces passed per day were available, though it is reasonable to assume that what is ingested and not assimilated in the gut must also pass. Assuming 6% of a median body weight for harbour seals of 110kg, that would equate to 6.6kg consumed per day and probably very nearly that defecated.

The concentration of *E. coli* and other faecal indicator bacteria contained in seal faeces has been reported as being similar to that found in raw sewage, with counts showing up to 1.21×10^4 CFU (colony forming units) *E. coli* per gram dry weight of faeces (Lisle *et al* 2004).

Both bacterial and viral pathogens affecting humans and livestock have been found in wild and captive seals. *Salmonella* and *Campylobacter* spp., some of which were antibiotic-resistant, were isolated from juvenile Northern elephant seals (*Mirounga angustirostris*) with *Salmonella* found in 36.9% of animals stranded on the California coast (Stoddard et al 2005). *Salmonella* and *Campylobacter* are both enteric pathogens that can cause acute illness in humans and it is postulated that the elephant seals were picking up resistant bacteria from exposure to human sewage waste.

One of the *Salmonella* species isolated from the elephant seals, *Salmonella typhimurium*, is carried by a number of animal species and has been isolated from cattle, pigs, sheep, poultry, ducks, geese and game birds in England and Wales. Serovar DT104, also associated with a wide variety of animal species, can cause severe disease in humans and is multi-drug resistant (Poppe et al 1998).

Cetaceans

As mammals, whales and dolphins would be expected to have resident populations of *E. coli* and other faecal indicator bacteria in the gut. Little is known about the concentration of indicator bacteria in whale or dolphin

faeces, in large part because the animals are widely dispersed and sample collection difficult.

A variety of cetacean species are routinely observed around the west coast of Scotland. Where possible, information regarding recent sightings or surveys is gathered for the production area. As whales and dolphins are broadly free ranging, this is not usually possible to such fine detail. Most survey data is supplied by the Hebridean Whale and Dolphin Trust or the Shetland Sea Mammal Group and applies to very broad areas of the coastal seas.

It is reasonable to expect that whales would not routinely affect shellfisheries located in shallow coastal areas. It is more likely that dolphins and harbour porpoises would be found in or near fisheries due to their smaller physical size and the larger numbers of sightings near the coast.

Birds

Seabird populations were surveyed all over Britain as part of the SeaBird 2000 census. These counts are investigated using GIS to give the numbers observed within a 5 km radius of the production area. This gives a rough idea of how many birds may be present either on nests or feeding near the shellfish farm or bed.

Further information is gathered where available related to shorebird surveys at local bird reserves when present. Surveys of overwintering geese are queried to see whether significant populations may be resident in the area for part of the year. In many areas, at least some geese may be present year round. The most common species of goose observed during shoreline surveys has been the Greylag goose. Geese can be found grazing on grassy areas adjacent to the shoreline during the day and leave substantial faecal deposits. Geese and ducks can deposit large amounts of faeces in the water, on docks and on the shoreline.

A study conducted on both gulls and geese in the northeast United States found that Canada geese (*Branta canadiensis*) contributed approximately 1.28×10^5 faecal coliforms (FC) per faecal deposit and ring-billed gulls (*Larus delawarensis*) approximately 1.77×10^8 FC per faecal deposit to a local reservoir (Alderisio and DeLuca, 1999). An earlier study found that geese averaged from 5.23 to 18.79 defecations per hour while feeding, though it did not specify how many hours per day they typically feed (Bedard and Gauthier, 1986).

Waterfowl can be a significant source of pathogens as well as indicator organisms. Gulls frequently feed in human waste bins and it is likely that they carry some human pathogens.

Deer

Deer are present throughout much of Scotland in significant numbers. The Deer Commission of Scotland (DCS) conducts counts and undertakes culls of deer in areas that have large deer populations.

Four species of deer are routinely recorded in Scotland, with Red deer (*Cervus elaphus*) being the most numerous, followed by Roe deer (*Capreolus capreolus*), Sika deer (*Cervus nippon*) and Fallow deer (*Dama dama*).

Accurate counts of populations are not available, though estimates of the total populations are >200,000 Roe deer, >350,000 Red deer, < 8,000 Fallow deer and an unknown number of Sika deer. Where Sika deer and Red deer populations overlap, the two species interbreed further complicating counts.

Deer will be present particularly in wooded areas where the habitat is best suited for them. Deer, like cattle and other ruminants, shed *E. coli*, *Salmonella* and other potentially pathogenic bacteria via their faeces.

Other

The European Otter (*Lutra lutra*) is present around Scotland with some areas hosting populations of international significance. Coastal otters tend to be more active during the day, feeding on bottom-dwelling fish and crustaceans among the seaweed found on rocky inshore areas. An otter will occupy a home range extending along 4-5km of coastline, though these ranges may sometimes overlap (Scottish Natural Heritage website). Otters primarily forage within the 10 m depth contour and feed on a variety of fish, crustaceans and shellfish (Paul Harvey, Shetland Sea Mammal Group, personal communication).

Otters leave faeces (also known as spraint) along the shoreline or along streams, which may be washed into the water during periods of rain.

References:

Alderisio, K.A. and N. DeLuca (1999). Seasonal enumeration of fecal coliform bacteria from the feces of Ring-billed gulls (*Larus delawarensis*) and Canada geese (*Branta canadensis*). *Applied and Environmental Microbiology*, 65:5628-5630.

Bedard, J. and Gauthier, G. (1986) Assessment of faecal output in geese. *Journal of Applied Ecology*, 23:77-90.

Lisle, J.T., Smith, J.J., Edwards, D.D., andd McFeters, G.A. (2004). Occurrence of microbial indicators and *Clostridium perfringens* in wastewater, water column samples, sediments, drinking water and Weddell Seal feces collected at McMurdo Station, Antarctica. *Applied and Environmental Microbiology*, 70:7269-7276.

Scottish Natural Heritage. http://www.snh.org.uk/publications/on-line/wildlife/otters/biology.asp. Accessed October 2007.

Tables of Typical Faecal Bacteria Concentrations

Summary of faecal coliform concentrations (cfu 100ml-1) for different treatment levels and individual types of sewage-related effluents under different flow conditions: geometric means (GMs), 95% confidence intervals (Cis), and results of t-tests comparing base- and high-flow GMs for each group and type.

Indicator organism	Base-flow conditions				High-flow conditions			
Treatment levels and specific types: Faecal coliforms	n^c	Geometric mean	Lower 95% CI	Upper 95% CI	n^c	Geometric mean	Lower 95% CI	Upper 95% CI
Untreated	252	1.7×10^{7} * (+)	1.4×10^{7}	2.0×10^{7}	282	2.8×10^{6} * (-)	2.3×10^{6}	3.2×10^{6}
Crude sewage discharges	252	1.7×10^{7} * (+)	1.4×10^{7}	2.0×10^{7}	79	3.5×10^{6} * (-)	2.6×10^{6}	4.7×10^{6}
Storm sewage overflows					203	2.5×10^{6}	2.0×10^{6}	2.9×10^{6}
Primary	127	1.0×10^{7} * (+)	8.4×10^{6}	1.3×10^{7}	14	4.6×10^{6} (-)	2.1×10^{6}	1.0×10^{7}
Primary settled sewage	60	1.8×10^{7}	1.4×10^{7}	2.1×10^{7}	8	5.7×10^{6}		
Stored settled sewage	25	5.6×10^{6}	3.2×10^{6}	9.7×10^{6}	1	8.0×10^{5}		
Settled septic tank	42	7.2×10^{6}	4.4×10^{6}	1.1×10^{7}	5	4.8×10^{6}		
Secondary	864	3.3×10^{5} * (-)	2.9×10^{5}	3.7×10^{5}	184	5.0×10^{5} * (+)	3.7×10^{5}	6.8×10^{5}
Trickling filter	477	4.3×10^{5}	3.6×10^{5}	5.0×10^{5}	76	5.5×10^{5}	3.8×10^{5}	8.0×10^{5}
Activated sludge	261	2.8×10^{5} * (-)	2.2×10^{5}	3.5×10^{5}	93	5.1×10^{5} * (+)	3.1×10^{5}	8.5×10^{5}
Oxidation ditch	35	2.0×10^{5}	1.1×10^{5}	3.7×10^{5}	5	5.6×10^{5}		
Trickling/sand filter	11	2.1×10^{5}	9.0×10^{4}	6.0×10^{5}	8	1.3×10^{5}		
Rotating biological contactor	80	1.6×10^{5}	1.1×10^{5}	2.3×10^{5}	2	6.7×10^{5}		
Tertiary	179	1.3×10^{3}	7.5×10^{2}	2.2×10^{3}	8	9.1×10^{2}		
Reedbed/grass plot	71	1.3×10^{4}	5.4×10^{3}	3.4×10^{4}	2	1.5×10^{4}		
Ultraviolet disinfection	108	2.8×10^{2}	1.7×10^{2}	4.4×10^{2}	6	3.6×10^{2}		

Source: Kay, D. et al (2008) Faecal indicator organism concentrations in sewage and treated effluents. *Water Research* 42, 442-454.

Comparison of faecal indicator concentrations (average numbers/g wet weight) excreted in the faeces of warm-blooded animals

Animal	Faecal coliforms (FC) number	Excretion (g/day)	FC Load (numbers /day)
Chicken	1,300,000	182	2.3×10^{8}
Cow	230,000	23,600	5.4×10^{9}
Duck	33,000,000	336	1.1×10^{10}
Horse	12,600	20,000	2.5×10^{8}
Pig	3,300,000	2,700	8.9×10^{8}
Sheep	16,000,000	1,130	1.8×10^{10}
Turkey	290,000	448	1.3×10^{8}
Human	13,000,000	150	1.9×10^{9}

Source: Adapted from Geldreich 1978 by Ashbolt et al in World Health Organisation (WHO) Guidelines, Standards and Health. 2001. Ed. by Fewtrell and Bartram. IWA Publishing, London.

Statistical Data

Results for: Muckle Roe

One-way ANOVA: Log_EC versus Season

```
Source  DF      SS     MS     F      P
Season   3   0.877  0.292  1.03  0.389
Error   40  11.342  0.284
Total   43  12.219

S = 0.5325   R-Sq = 7.18%   R-Sq(adj) = 0.22%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean   StDev  ---+---------+---------+---------+------
1      13  1.2340  0.3778  (-----------*-----------)
2      13  1.5704  0.6801              (-----------*-----------)
3      10  1.3894  0.5231      (-------------*------------)
4       8  1.5449  0.4805           (--------------*--------------)
                          ---+---------+---------+---------+------
                           1.00      1.25      1.50      1.75

Pooled StDev = 0.5325


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Season

Individual confidence level = 98.94%


Season = 1 subtracted from:

Season    Lower  Center   Upper  -------+---------+---------+---------+--
2       -0.2233  0.3365  0.8962              (----------*----------)
3       -0.4448  0.1555  0.7557          (-----------*-----------)
4       -0.3303  0.3110  0.9522            (------------*------------)
                                -------+---------+---------+---------+--
                                    -0.50      0.00      0.50      1.00


Season = 2 subtracted from:

Season    Lower   Center   Upper  -------+---------+---------+---------+--
3       -0.7812  -0.1810  0.4193   (-----------*-----------)
4       -0.6667  -0.0255  0.6158      (-----------*------------)
                                -------+---------+---------+---------+--
                                    -0.50      0.00      0.50      1.00


Season = 3 subtracted from:

Season    Lower  Center   Upper  -------+---------+---------+---------+--
4       -0.5214  0.1555  0.8324         (------------*-------------)
                                -------+---------+---------+---------+--
                                    -0.50      0.00      0.50      1.00
```

Results for: Point of Hamna Ayre

One-way ANOVA: Log_EC versus Season

```
Source  DF      SS     MS     F      P
Season   3   3.596  1.199  2.44  0.078
Error   40  19.613  0.490
Total   43  23.210

S = 0.7002   R-Sq = 15.49%   R-Sq(adj) = 9.16%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean   StDev  -----+---------+---------+---------+----
1      13  1.5815  0.6141       (---------*--------)
2      12  2.1800  0.9445                  (----------*---------)
3      10  1.5392  0.6281    (----------*----------)
4       9  1.4888  0.4643  (-----------*----------)
                          -----+---------+---------+---------+----
                             1.20      1.60      2.00      2.40

Pooled StDev = 0.7002


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Season

Individual confidence level = 98.94%


Season = 1 subtracted from:

Season    Lower   Center   Upper  ---------+---------+---------+---------+
2       -0.1527   0.5985  1.3497                  (--------*---------)
3       -0.8317  -0.0424  0.7470          (--------*---------)
4       -0.9065  -0.0927  0.7210         (---------*---------)
                                  ---------+---------+---------+---------+
                                        -0.80      0.00      0.80      1.60


Season = 2 subtracted from:

Season    Lower   Center   Upper  ---------+---------+---------+---------+
3       -1.4444  -0.6409  0.1626   (---------*---------)
4       -1.5187  -0.6912  0.1363  (---------*----------)
                                  ---------+---------+---------+---------+
                                        -0.80      0.00      0.80      1.60


Season = 3 subtracted from:

Season    Lower   Center   Upper  ---------+---------+---------+---------+
4       -0.9126  -0.0503  0.8119         (---------*----------)
                                  ---------+---------+---------+---------+
                                        -0.80      0.00      0.80      1.60
```

Hydrographic Methods

The new EU regulations require an appreciation of the hydrography and currents within a region classified for shellfish production with the aim to "determine the characteristics of the circulation of pollution, appreciating current patterns, bathymetry and the tidal cycle." This document outlines the methodology used by Cefas to fulfil the requirements of the sanitary survey procedure with regard to hydrographic evaluation of shellfish production areas. It is written as far as possible to be understandable by someone who is not an expert in oceanography or computer modelling. A glossary at the end of the document defines commonly used hydrographic terms e.g. tidal excursion, residual flow, spring-neap cycle etc.

The hydrography at most sites will be assessed on the basis of bathymetry and tidal flow software only. Selected sites will be assessed in more detail using either: 1) a hydrodynamic model, or 2) an extended consideration of sources, available field studies and expert assessment. This document will consider the more basic hydrographic processes and describes the common methodology applied to all sites.

<u>Background processes</u>

Currents in estuarine and coastal waters are generally driven by one of three mechanisms: 1) Tides, 2) Winds, 3) Density differences.

Tidal flows often dominate water movement over the short term (approximately 12 hours) and move material over the length of the *tidal excursion*. Tides move water back and forth over the tidal period often leading to only a small net movement over the 12 hours tidal cycle. This small net movement is partly associated with the *tidal residual* flow and over a period of days gives rise to persistent movement in a preferred direction. The direction will depend on a number of factors including the bathymetry and direction of propagation of the main tidal wave.

Wind and density driven current also lead to persistent movement of water and are particular important in regions of relatively low tidal velocities characteristic of many of the water bodies in Scottish waters. Whilst tidal flows generally move material in more or less the same direction at all depths, wind and density driven flows often move material in different directions at the surface and at the bed. Typical vertical profiles are depicted in Figure 1. However, it should be understood that in a given water body, movement will often be the sum of all three processes.

In sea lochs, mechanisms such as "wind rows" can transport sources of contamination at the edge of the loch to production areas further offshore. Wind rows are generated by winds directed along the main length of the loch. An illustration of the waters movements generated in this way is given in Figure 2. As can be seen the water circulates in a series of cell that draw material across the loch at right angles to the wind direction. This is a particularly common situation for lochs with high land on either side as these tend to act as a steering mechanism to align winds along the water body.

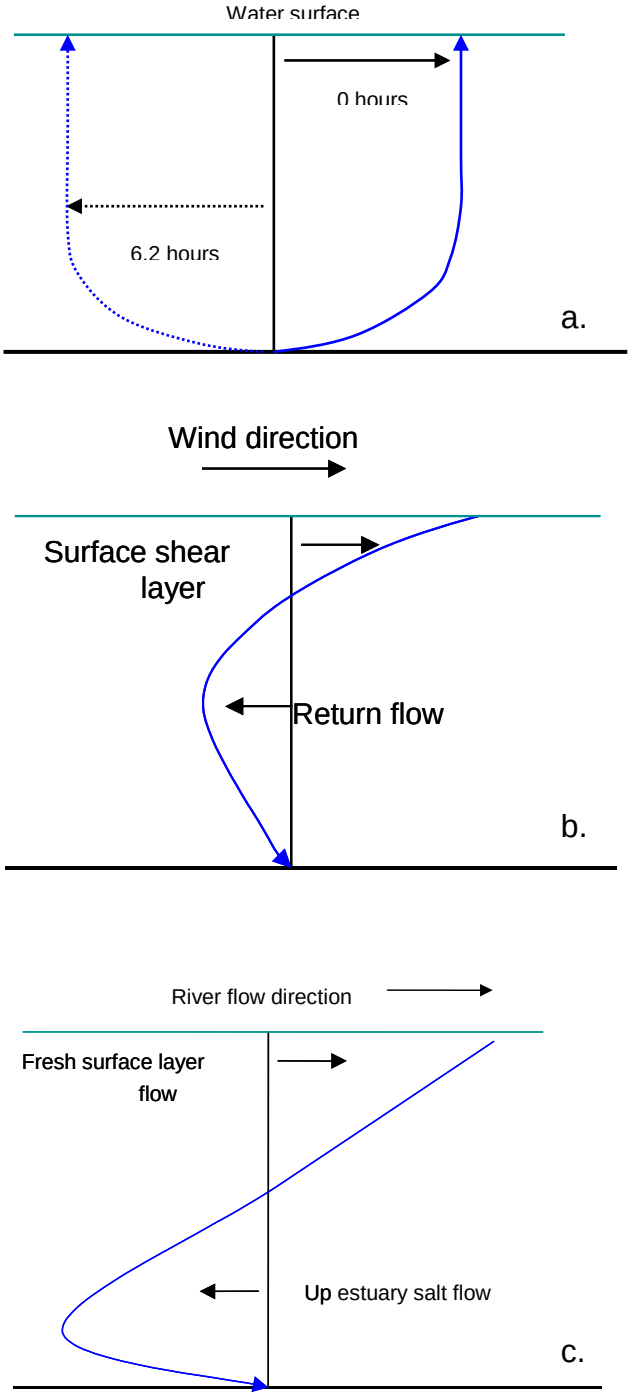

Figure 1. Typical vertical profiles for water currents. The black vertical line indicates zero velocity so portions of the profile to the left and right indicate flow moving in opposite directions. a) Peak tidal flow profiles. Profiles are shown 6.2 hours apart as the main tidal current reverses direction over a period of 6.2 hours. b) wind driven current profile, c) density driven current profile.

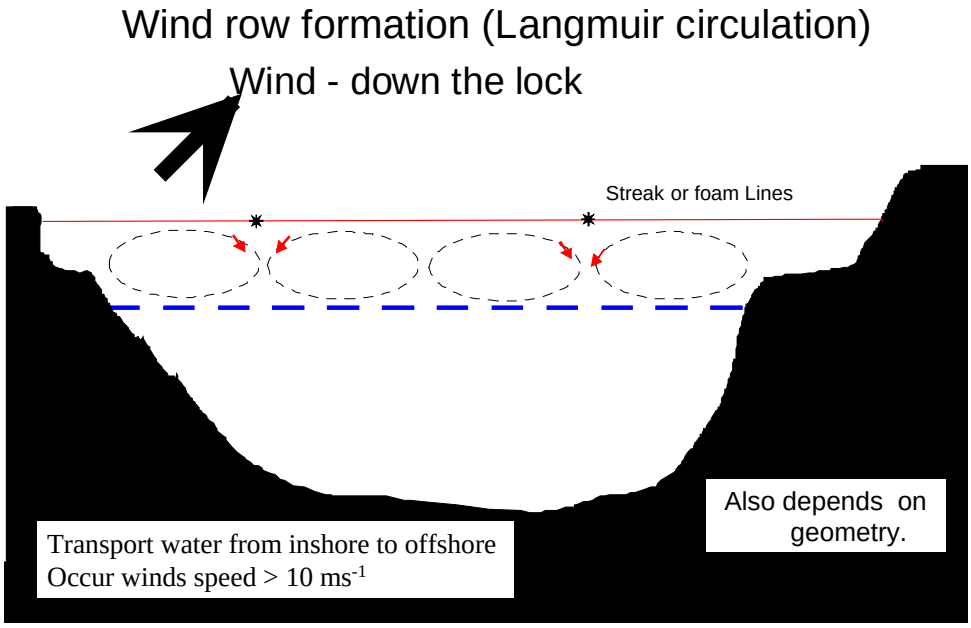

Figure 2. Schematic of wind driven 'wind row' currents. The dotted blue line indicates the depth of the surface fresh(er) water layer usually found in sea lochs.

Non-modelling Assessment

In this approach the assessment requires a certain amount of expert judgment and subjectivity enters in. For all production areas, the following general guidelines are used:

1. Near-shore flows will generally align parallel to the shore.
2. Tidal flows are bi-directional, thus sources on either side of a production area are potentially polluting.
3. For tidal flows, the tidal excursion gives an idea of the likely main 'region of influence' around an identified pollutant source.
4. Wind driven flows can drive material from any direction depending on the wind direction. Wind driven current speeds are usually at a maximum when the wind direction is aligned with the principle axis of the loch.
5. Density driven flows generally have a preferred direction.
6. Material will be drawn out in the direction of current, often forming long thin 'plumes'.

Many Scottish shellfish production areas occur within sea lochs. These are fjord-like water bodies consisting of one or more basins, deepened by glacial activity and having relatively shallow sills that control the mixing and flushing processes. The sills are often regions of relatively high currents, while the basins are much more tranquil often containing higher density water trapped below a fresh lower density surface layer. Tidal mixing primarily occurs at the sills.

The catalogue of Scottish Sea Loch produced by the SMBA is used to quantify sills, volume fluxes and likely flow velocities. Because the flow is so constrained by the rapidly varying bathymetry, care has to be used in the extrapolation of direct measurements of current flow. Mean flow velocities can be estimated at the sills by using estimates of the sill area and the volume change through a tidal cycle. This in turn can be used to estimate the maximum distance travelled in a tidal cycle in the sill area. Away from the sill

area, tidal velocities are general low and transport events are dominated by wind or density effects. Sea Lochs generally have a surface layer of fresher water; the extent of this depends on freshwater input, sill depth and quantity of mixing.

In addition to movement of particles by currents, dilution is also an important consideration. Dilution reduces the effect of an individual point source although at the expense of potentially contaminating a larger area. Thus class A production areas can be achieved in water bodies with significant faecal coliform inputs if no transport pathway exists and little mixing can occur. Conversely a poor classification might occur where high mixing causes high and permanent background concentrations arising from many weak diffuse sources.

References

European Commission 1996. Report on the equivalence of EU and US legislation for the Sanitary Production of Live Bivalve Molluscs for Human Consumption. EU Scientific Veterinary Committee Working Group on Faecal Coliforms in Shellfish, August 1996.

Glossary

The following technical terms may appear in the hydrographic assessment.

Bathymetry. The underwater topography given as depths relative to some fixed reference level e.g. mean sea level.

Hydrography. Study of the movement of water in navigable waters e.g. along coasts, rivers, lochs, estuaries.

Tidal period. The dominant tide around the UK is the twice daily one generated by the moon. It has a period of 12.42 hours. For near shore so-called rectilinear tidal currents then roughly speaking water will flow one way for 6.2 hours then back the other way for 6.2 hours.

Tidal range. The difference in height between low and high water. Will change over a month.

Tidal excursion. The distance travelled by a particle over one half of a tidal cycle (roughly~6.2 hours). Over the other half of the tidal cycle the particle will move in the opposite direction leading to a small net movement related to the tidal residual. The excursion will be largest at Spring tides.

Tidal residual. For the purposes of these documents it is taken to be the tidal current averaged over a complete tidal cycle. Very roughly it gives an idea of the general speed and direction of travel due to tides for a particle over a period of several days.

Tidal prism. The volume of water brought into an estuary or sea loch during half a tidal cycle. Equal to the difference in estuary/sea loch volume at high and low water.

Spring/Neap Tides. The strongest tides in a month are called spring tides and the weakest are called neap tides. Spring tides occur every 14 days with neaps tides occurring 7 days after springs. Both tidal range and tidal currents are strongest at Spring tides.

Tidal diamonds. The tidal velocities measured and printed on admiralty charts at specific locations are called tidal diamonds.

Wind driven shear/surface layer. The top metre or so of the surface that generally moves in the rough direction of the wind typically at a speed that is a few percent (~3%)of the wind speed.

Return flow. Often a surface flow at the surface is accompanied by a compensating flow in the opposite direction at the bed (see figure 1).

Stratification. The splitting of the water into two layers of different density with the less dense layer on top of the denser one. Due to either temperature or salinity differences or a combination of both.

Shoreline Survey Report

Production Areas:

Production Area	Site	SIN	Species
Point of Hamna Ayre	Point of Hamna Ayre	SI 374 763 08	Mussels
Muckle Roe	Pobies Geo	SI 221 433 08	Mussels

Species: Common mussels
Harvester: Jim Georgeson – Suthravoe Shellfish
Local Authority: Shetland Islands Council
Status: Existing site

Date Surveyed: 17/08/2011
Surveyed by: Jessica Larkham – Cefas
Sean Williamson – NAFC
Existing RMP: Muckle Roe – Pobies Geo: HU 333 631
Point of Hamna Ayre: None
Area Surveyed: See Figure 1.

Weather observations

17/08/2011 – Calm, dry and sunny. Wind 1.3 knots, 14.4˚C.

Site Observations

Specific observations made on site are mapped in Figure 1 and listed in Table 1. Water and shellfish samples were collected at sites marked on Figures 2 and 3. Bacteriology results are given in Tables 2 and 3. Photographs are presented in Figures 4 – 19.

Fishery

The Point of Hamna Ayre fishery consists of two double 220 m long lines with 8 m droppers. The fishery had sufficient stock on site for sampling at the time of the shoreline survey and the site is harvested all year round.

The Mucke Roe fishery consists of three double 220 m long lines with 8 m droppers. The fishery had sufficient stock on site for sampling at the time of the shoreline survey and the site is harvested all year round.

Sewage/Faecal Sources

Human
There are no large settlements on the island of Muckle Roe. Several dwellings were observed on the southern shoreline of Muckle Roe adjacent to the Muckle Roe mussel farm. There are no dwellings on the island of Papa Little. At the beginning of the shoreline walk, on the south west shoreline of Muckle Roe near Little Ayre an iron pipe was observed leading down to the sea from several dwellings. On the southern shoreline of Muckle Roe adjacent to the fishery in the Boat Geo cove, two outfall pipes were observed leading into a

stream. Neither outfall pipe was flowing at the time of the shoreline survey. At the southeast end of the Muckle Roe shoreline near Ayredale, there was another flowing outfall pipe. No sanitary debris was observed during the shoreline survey.

Livestock
Livestock were observed grazing around most of the shoreline surrounding both shellfish farms. On the island of Papa Little, adjacent to the Point of Hamna Ayre mussel farm, approximately 20 sheep were observed grazing on the shoreline. At the southwest end of the Muckle Roe shoreline, a large number of sheep tracks were observed in the sand on the beach of Hamna Ayre. Slightly further east along the shoreline near Little Ayre, approximately 42 sheep were observed scattered over two fields and 4 sheep were observed close to a stream leading down to the shoreline. On the shoreline west of the fishery south of Gillarona a further 15 sheep were observed. Directly adjacent to the Muckle Roe fishery, 45 sheep in total were observed grazing directly on the shoreline. A further 70 sheep were observed on the southeastern shoreline of Muckle Roe, near South Town.

Seasonal Population
No hotels or B&B's were observed in the area. The island of Muckle Roe is likely to be popular with wildlife enthusiasts and walkers, therefore holiday accommodation may be available elsewhere on the island.

Boats/Shipping
No boats were observed during the shoreline survey and there are no ferry routes or piers and/or marinas in the vicinity of either fishery.

Land Use
The majority of the land adjacent to both fisheries is mainly rough grassland with some boggy areas.

Wildlife/Birds
During the shoreline survey 5 seabirds were observed in the water near to the Hamna Ayre mussel lines. At Muckle Roe, 1 gull and several cormorants were observed on the mussel lines and 4 geese on the water close by.

General observations

Recorded observations apply to the date of survey only. Animal numbers were recorded on the day from the observer's point of view. This does not necessarily equate to total numbers present as natural features may obscure individuals and small groups of animals from view.

Dimensions and flows of watercourses are estimated at the most convenient point of access and not necessarily at the point at which the watercourses enter the sound.

Figure 1. Shoreline Observations

Table 1 Shoreline Observations

No.	Date	Time	NGR	East	North	Associated photograph	Associated sample	Description
1	17/08/2011	09:24	HU 33213 61380	433213	1161380		HAMUSSEL 1, HAMUSSEL 2, HASW1	Corner of Point of Hamna Ayre mussel farm, location of mussel samples HAMUSSEL1 (7 m depth), HAMUSSEL2 (1 m depth) and seawater sample HASW1
2	17/08/2011	09:35	HU 33252 61379	433252	1161379			Corner of Point of Hamna Ayre mussel farm (shore side)
3	17/08/2011	09:39	HU 33672 61197	433672	1161197		HASW2	Approx one dozen sheep on the shoreline. Location of seawater sample HASW2. Taken in the bay offshore from the streams identified on the OS map, all dry at the time of the shoreline survey
4	17/08/2011	09:44	HU 33319 61567	433319	1161567	Figure 4		5 seabirds, 20 sheep on shoreline
5	17/08/2011	09:46	HU 33288 61579	433288	1161579	Figure 5	HAMUSSEL3, HAMUSSEL4, HASW3	Corner of Point of Hamna Ayre mussel farm, seaward side. Location of mussel samples HAMUSSEL3 (7 m depth), HAMUSSEL4 (1 m depth) and seawater sample HASW3
6	17/08/2011	09:59	HU 33188 62889	433188	1162889			Corner of Muckle Roe mussel farm
7	17/08/2011	10:04	HU 33176 62918	433176	1162918	Figure 6	MRMUSSEL1, MRMUSSEL2, MRSW1	Corner of Muckle Roe mussel farm, location of mussel samples MRMUSSEL1 (7 m depth), MRMUSSEL2 (1 m depth) and seawater sample MRSW1. 1 gull & cormorants on the lines. Approx 40 sheep in fields, down from houses adjacent to mussel lines
8	17/08/2011	10:19	HU 33345 63008	433345	1163008		MRMUSSEL3, MRMUSSEL4, MRSW2	Location of mussel samples MRMUSSEL 3 (6 m depth) and MRMUSSEL4 (1 m depth) and seawater sample MRSW2
9	17/08/2011	10:24	HU 33383 63029	433383	1163029			Corner of Muckle Roe mussel farm
10	17/08/2011	10:25	HU 33376 62980	433376	1162980			Corner of Muckle Roe mussel farm
11	17/08/2011	13:33	HU 31782 62883	431782	1162883	Figure 7	MRFW1	Beginning of shoreline walk. Stream, Width 1.0 m, Depth 0.13 m, Flow 0.130 m/sec, Standard Deviation 0.015, location of freshwater sample MRFW1
12	17/08/2011	13:39	HU 31801 62885	431801	1162885			Sheep tracks in the sand
13	17/08/2011	13:46	HU 32192 62877	432192	1162877			Approx 42 sheep spread over two fields
14	17/08/2011	13:51	HU 32360 62822	432360	1162822	Figure 8	MRFW2	Stream, Width 0.50 m, Depth 0.03 m, Flow 0.387 m/sec, Standard Deviation 0.011, location of freshwater sample MRFW2. 4 sheep close to stream.

No.	Date	Time	NGR	East	North	Associated photograph	Associated sample	Description
15	17/08/2011	14:01	HU 32449 62803	432449	1162803	Figure 9	MRSW3	Iron pipe flowing into sea leading down from houses, location of seawater sample MRSW3
16	17/08/2011	14:04	HU 32457 62813	432457	1162813			Field drain
17	17/08/2011	14:07	HU 32550 62717	432550	1162717		MRFW3	Small stream leading down to the beach, Width 0.12 m, Depth 0.03 m, Flow 0.783 m/sec, Standard Deviation 0.094, location of freshwater sample MRFW3
18	17/08/2011	14:16	HU 32826 62833	432826	1162833	Figure 10		Approx 15 sheep in field adjacent to shoreline
19	17/08/2011	14:32	HU 33038 63067	433038	1163067	Figure 11		Outfall pipe and septic tank below house, no flow at time of the shoreline survey however signs of previous flow
20	17/08/2011	14:34	HU 33083 63125	433083	1163125			Field drain
21	17/08/2011	14:44	HU 33190 63216	433190	1163216	Figures 12 & 13	MRFW4	Stream, two pipes further upshore leading into it, not flowing, Width 0.25 m, Depth 0.05 m, Flow 0.401 m/sec, Standard Deviation 0.018, location of MRFW4
22	17/08/2011	14:57	HU 33221 63208	433221	1163208			Approx 18 sheep
23	17/08/2011	15:03	HU 33454 63183	433454	1163183			4 geese
24	17/08/2011	15:11	HU 33723 63325	433723	1163325	Figure 14		Farm above shoreline
25	17/08/2011	15:14	HU 33786 63432	433786	1163432	Figure 15	MRFW5	Flowing outfall pipe, location of freshwater sample MRFW5. Flow 250 ml/2 secs
26	17/08/2011	15:26	HU 33946 63723	433946	1163723	Figure 16	MRFW6	Stream, Width 1.10 m, Depth 0.05 m, Flow 0.096 m/sec, Standard Deviation 0.012, location of fresh water sample MRFW6
27	17/08/2011	15:34	HU 33860 63772	433860	1163772	Figures 17 & 18	MRFW7	Stream running through field of approx 70 sheep, Width 0.17 m, Depth 0.05 m, Flow 0.103 m/sec, Standard Deviation 0.004, location of MRFW7
28	17/08/2011	15:40	HU 33877 63834	433877	1163834	Figure 19		Two culverts running into stream previously sampled and measured

Photographs referenced in the table can be found attached as Figures 4 – 19.

Sampling

Water and shellfish samples were collected at sites marked on the maps in Figures 2 and 3 respectively. Bacteriology results follow in Tables 2 and 3. Samples were transferred to a cool box with ice packs after sampling then delivered by hand on the same day to the SSQC laboratory at the NAFC Marine College in Scalloway. Samples were then processed the day after sampling.

Samples of seawater were tested for salinity by the laboratory using a salinity meter under controlled conditions. These results are shown in Table 2, given in units of grams salt per litre of water. Note that this is equivalent to ppt.

Table 2. Water sample *E. coli* results

No.	Sample Ref.	Date	Position	Type	*E. coli* (cfu/100 ml)	Salinity (g/L)
1	HASW1	17/08/2011	HU 33213 61380	Seawater	<1	35.5
2	HASW2	17/08/2011	HU 33672 61197	Seawater	19	35.6
3	HASW3	17/08/2011	HU 33288 61579	Seawater	<1	35.6
4	MRSW1	17/08/2011	HU 33176 62918	Seawater	3	35.4
5	MRSW2	17/08/2011	HU 33345 63008	Seawater	<1	35.2
6	MRSW3	17/08/2011	HU 32449 62803	Seawater	50	31.8
7	MRFW1	17/08/2011	HU 31782 62883	Freshwater	40	
8	MRFW2	17/08/2011	HU 32360 62822	Freshwater	50	
9	MRFW3	17/08/2011	HU 32550 62717	Freshwater	60	
10	MRFW4	17/08/2011	HU 33190 63216	Freshwater	130	
11	MRFW5	17/08/2011	HU 33786 63432	Freshwater	310	
12	MRFW6	17/08/2011	HU 33946 63723	Freshwater	210	
13	MRFW7	17/08/2011	HU 33860 63772	Freshwater	$1.2x10^3$	

Table 3. Shellfish sample *E. coli* results

No.	Sample Ref.	Date	Position	Site	Species	Depth (m)	*E. coli* MPN/100 g
1	HAMUSSEL1	18/08/2011	HU 33213 61380	Point of Hamna Ayre	Common mussels	7	20
2	HAMUSSEL2	18/08/2011	HU 33213 61380	Point of Hamna Ayre	Common mussels	<1	110
3	HAMUSSEL3	18/08/2011	HU 33286 61579	Point of Hamna Ayre	Common mussels	7	170
4	HAMUSSEL4	18/08/2011	HU 33286 61579	Point of Hamna Ayre	Common mussels	<1	170
5	MRMUSSEL1	18/08/2011	HU 33176 62918	Muckle Roe	Common mussels	7	130
6	MRMUSSEL2	18/08/2011	HU 33176 62918	Muckle Roe	Common mussels	<1	70
7	MRMUSSEL3	18/08/2011	HU 33345 63008	Muckle Roe	Common mussels	6	490
8	MRMUSSEL4	18/08/2011	HU 33345 63008	Muckle Roe	Common mussels	<1	80

Figure 2. Water sample results

Figure 3. Shellfish sample results

Photographs

Figure 4. Approx 20 sheep on shoreline

Figure 5. Hamna Ayre mussel farm

Figure 6. Approx. 20 sheep in fields adjacent to mussel lines & 1 gull on mussel lines

Figure 7. Stream, location of freshwater sample MRFW1

Figure 8. Stream, location of freshwater sample MRFW2, 4 sheep close to the stream

Figure 9. Iron pipe flowing into the sea, location of seawater sample MRSW3

Figure 10. Approx 15 sheep in field adjacent to shoreline

Figure 11. Outfall pipe and septic tank leading down from house, no flow

Figure 12. Stream, location of freshwater sample MRFW4

Figure 13. Pipes (not flowing) leading into stream shown in Figure 12

Figure 14. Farm above shoreline

Figure 15. Flowing outfall pipe, location of freshwater sample MRFW5

Figure 16. Stream, location of freshwater sample MRFW6

Figure 17. Stream, location of freshwater sample MRFW7

Figure 18. Approx 70 sheep in the same field as the stream in Figure 17

Figure 19. Two culverts running into stream shown in Figure 17