Scottish Sanitary Survey Programme

Sanitary Survey Report
Production Area: Loch Roag: Eilean Teinish

SIN: LH 388 720 08

January 2012

Cefas

Food Standards Agency
food.gov.uk
Buidheann Inbhe-Bìdhe

Report Distribution – Loch Roag: Eilean Teinish

Date	Name	Agency*
	Linda Galbraith	Scottish Government
	Mike Watson	Scottish Government
	Morag MacKenzie	SEPA
	Douglas Sinclair	SEPA
	Fiona Garner	Scottish Water
	Alex Adrian	Crown Estate
	Paul Tyler	Comhairle nan Eilean Siar
	Colm Fraser	Comhairle nan Eilean Siar
	Cree Mackenzie	Harvester
	Calum Ian Mackenzie	Harvester

* Distribution of both draft and final reports to relevant agency personnel and harvesters is undertaken by FSAS.

Table of Contents

Appendices

I. Executive Summary

A sanitary survey at Loch Roag: Eilean Teinish has been undertaken as the area was first classified after 2006, when the requirement for conduct of sanitary surveys under Regulation (EC) No. 854/2004 came into force. Loch Roag is located on the west coast of the Isle of Lewis, in the Outer Hebrides. It lies approximately 35 km west of the island capital, Stornoway. The surrounding area is rugged and sparsely populated.

The Eilean Teinish production area contains a mussel farm consisting of two double-headed longlines with droppers to approximately 8 metres depth. Mussels are harvested in rotation with other farms located within Loch Roag, and harvest may be undertaken at any time of year, in accordance with market demand.

The principal sources of faecal contamination to the fishery are diffuse agricultural pollution from cattle and sheep grazed on land immediately west of the fishery and around the settlement of Riof, to the west of the southern production area boundary. The homes at Riof are on private septic tanks, a small number of which discharge either to small watercourses or to the shore of Loch Roag. The majority discharge to soakaway.

A watercourse draining a small, freshwater loch discharges to sea toward the northern end of the mussel lines.

Currents are weak in the area, and faecal contamination arising from land adjacent to the fishery is expected to have the greatest impact on water quality at the mussel farm. Contamination arising at Riof would be expected to impact the southern end of the mussel farm, however historical monitoring results suggest little or no impact there. Higher results occurred toward the mid and northern sections of the mussel farm, suggesting sources arising from the near shore or to the immediate north of the mussel lines.

It is recommended that the production area boundary be curtailed at the northern boundary to exclude the mouth of the stream north of the mussel lines. The recommended production area is the area bounded by lines drawn between NB 1162 3500 to NB 1252 3500 and between NB 1166 3440 to NB 1281 3444 and extending to MHWS.

It is recommended that the RMP be established at the northern end of the mussel farm, at NB 1178 3486.

II. Sampling Plan

PRODUCTION AREA	Eilean Teinish
SITE NAME	Eilean Teinish
SIN	LH 388 720 08
SPECIES	Common mussel
TYPE OF FISHERY	Long-line aquaculture
NGR OF RMP	NB 1178 3486
EAST	11780
NORTH	93486
TOLERANCE (M)	40 m
DEPTH (M)	1-3
METHOD OF SAMPLING	Hand
FREQUENCY OF SAMPLING	Monthly
LOCAL AUTHORITY	Comhairle nan Eilean Siar
AUTHORISED SAMPLER(S)	Paul Tyler
LOCAL AUTHORITY LIAISON OFFICER	Colm Fraser

III. Report

1. General Description

Loch Roag is a remote complex of lochs and small islands on the western coast of the Isle of Lewis. Its shores are sparsely populated and the loch supports a significant number of shellfish and salmon farms. It is approximately 8 km long and 11 km wide and split into east and west halves by the island of Great Bernera. The loch overall has a maximum depth of 40 metres, though at the production area examined for this report the maximum depth is approximately 25 metres. Eilean Teinish is located in the western section of the loch, west of Great Bernera and the smaller island of Fuaigh Mor.

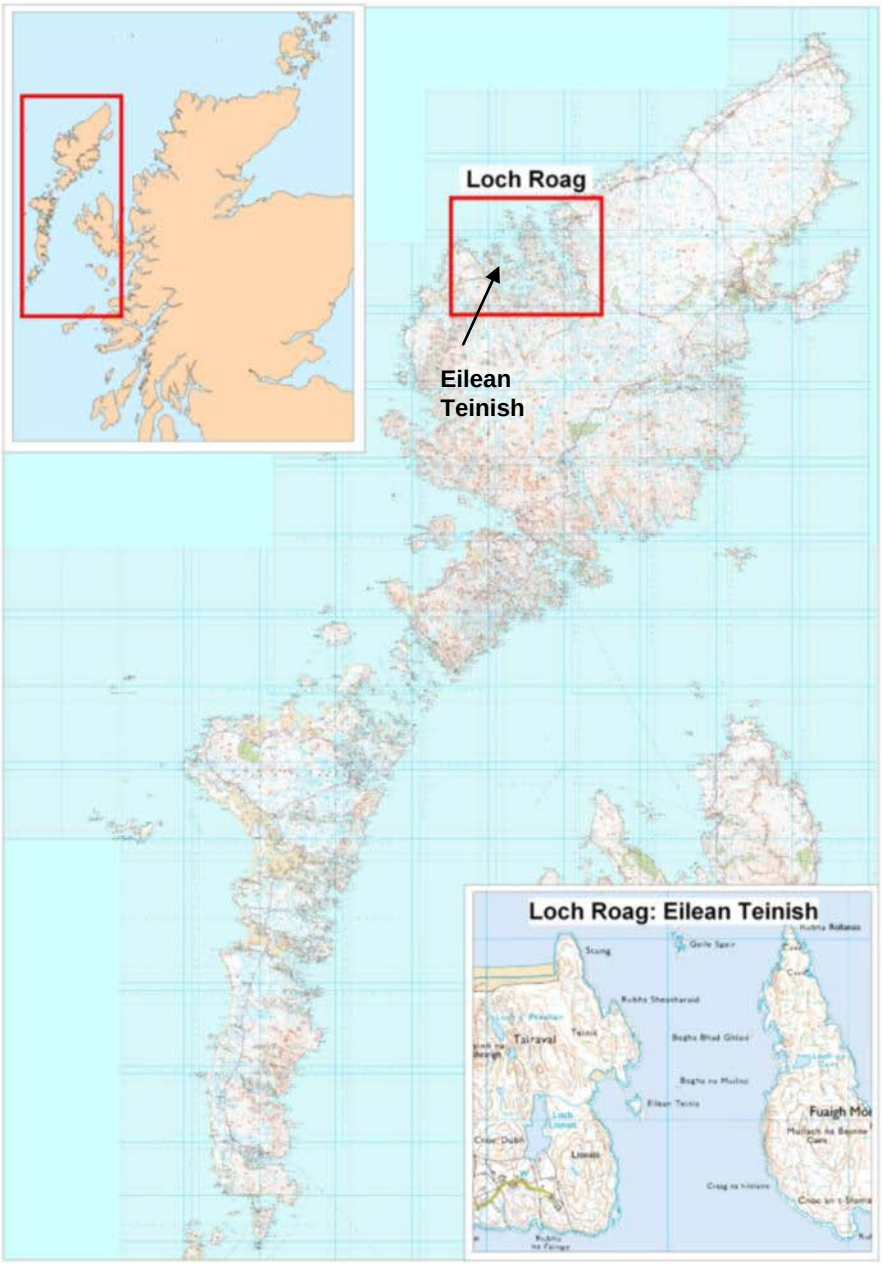


Figure 1.1 Location of Loch Roag

2. Fishery

The sanitary survey was undertaken as the production area had been newly classified since Regulation (EC) No. 854/2004 came into force on 1 January 2006. The area considered in this survey is summarised in Table 2.1 and shown on the map in Figure 2.1.

Table 2.1 Loch Roag: Eilean Teinish production area and site

Production Area	Site	SIN	Species	Sampling point
Loch Roag: Eilean Teinish	Eilean Teinish	LH 338 720 08	Common mussels	NB 119 347

Current production area boundaries are given as the “Area within lines drawn between NB 1166 3440 to NB 1281 3444 and between NB 1178 3519 and NB 1254 3516”.

At the time of shoreline survey, the Eilean Teinish site consisted of two double-headed long lines with droppers to 8 metres depth oriented north to south in the channel northeast of Riof. Mussels are harvested year round depending on stock and demand. There is a Crown Estate lease at Eilean Teinish. The site lies outwith the Loch Roag designated shellfish water.

Figure 2.1 shows the location of the production area and nominal RMP as well as the location of the mussel lines as recorded during the shoreline survey.

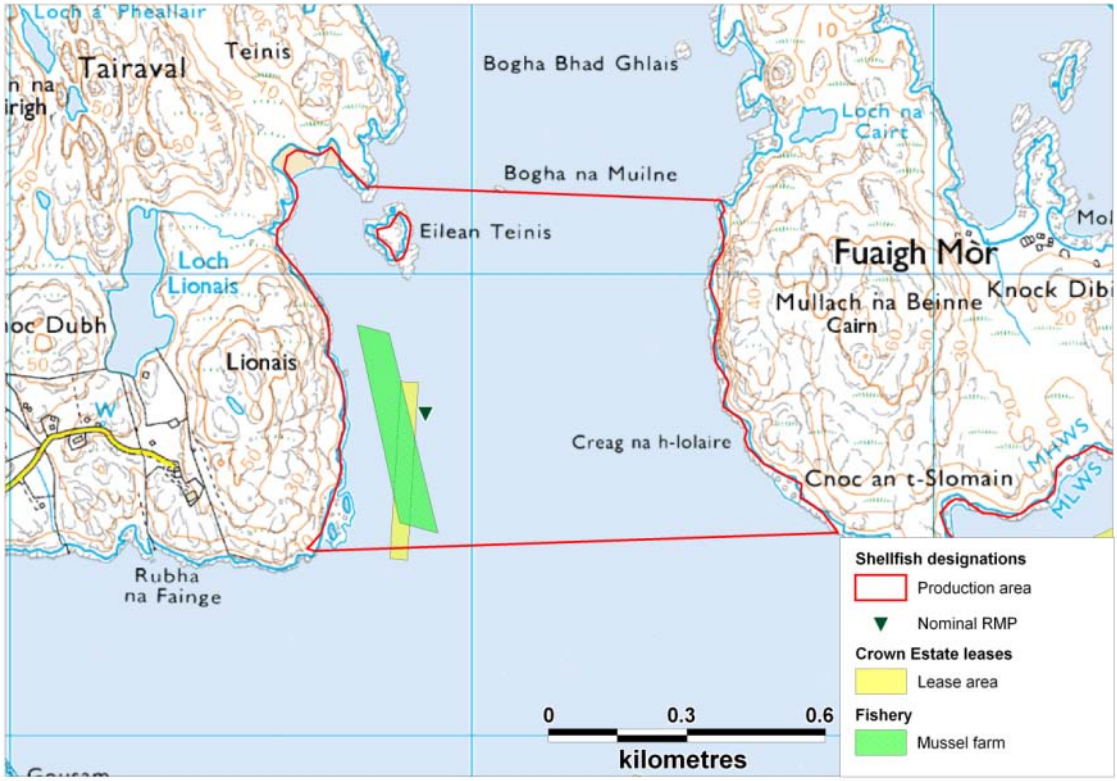


Figure 2.1 Loch Roag Eilean Teinish Fishery

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 Loch Roag: Eilean Teinish. The last census was undertaken in 2001.

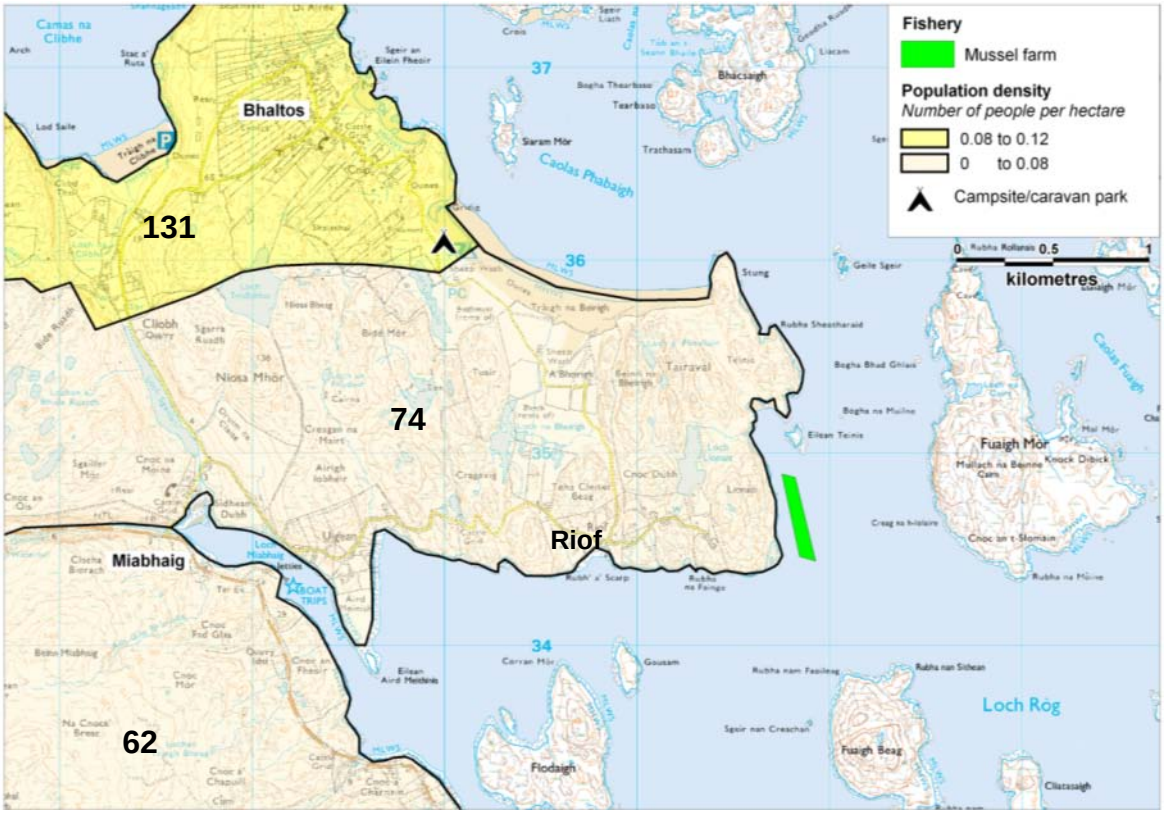


Figure 3.1 Population map of Loch Roag Eilean Teinish

Figure 3.1 shows a low population density for the census output areas adjacent to Eilean Teinish, indicating that overall the area surrounding the fishery is sparsely populated. The closest settlement to the fishery is Riof, where there is a small number of permanently occupied and holiday homes. There are further settlements, Bhaltos and Miabhaig, both located approximately 3 km from the fishery. Of these, Bhaltos is the larger.

The population in the surrounding area is spread amongst three census output areas, listed in Table 3.1. Apart from the concentrations in the three settlements identified above, population for these three areas is located along the main roads in smaller settlements and single dwellings. The shoreline immediately adjacent to the fishery is uninhabited.

Although no hotels or B&B's were observed in the area surrounding the fisheries during the shoreline survey, it was observed that many of the homes in the area appeared to be in seasonal occupation. There is a campsite and caravan park area with toilet facilities approximately 3km to the northwest of the fishery near Bhaltos.

4. Sewage Discharges

Information on sewage discharges to the area was sought from Scottish Water and the Scottish Environment Protection Agency (SEPA). Only two Scottish Water discharges were located within 5km of the mussel farms. These are listed in Table 4.1.

Table 4.1 Discharges identified by Scottish Water

Consent Ref No.	NGR of discharge	Discharge Name	Discharge Type	Level of Treatment	Consented flow m^3/day	Consented Design PE
CAR/L/1004162	NB 0951 3708	Valtos ST	Continuous	Septic tank	20	100
CAR/L/1004163	NB 0975 3678	Kneep ST	Continuous	Septic tank	7	36

An attempt was made to locate these discharges during the shoreline survey, but no pipes or evidence of tanks was found. Although the tide was low at the time of viewing, it was not a particularly low spring tide and therefore the pipes may still have been submerged. The Kneep discharge is located closest to the fishery, at 3.3 km northwest of the north end of the mussel lines, and approximately 380 metres southeast of the Valtos discharge.

SEPA provided information on a number of consented discharges, which are listed in Table 4.2. No information was provided regarding the consented flow or design Population Equivalent (PE) of these discharges. The majority appear to serve single homes and would therefore each discharge relatively very small volumes of sewage.

Table 4.2 Discharge consents identified by SEPA

No.	Ref No.	NGR of discharge	Discharge Type	Level of Treatment	Consented flow (DWF) m^3/d	Consented/ design PE	Discharges to
1	CAR/L/1004162	NB 0951 3708	Sewage	Primary	see table 4.1	see table 4.1	Caolas Phabaigh
2	CAR/L/1004163	NB 0975 3678	Sewage	Primary	see table 4.1	see table 4.1	East Loch Roag
3	CAR/R/1050801	NB 0937 3667	Sewage	Primary	-	-	soakaway
4	CAR/R/1041207	NB 1137 3450	Sewage	Primary	-	-	soakaway
5	CAR/R/1043395	NB 1136 3461	Sewage	Primary	-	-	soakaway
6	CAR/R/1061947	NB 1110 3466	Sewage	Primary	-	-	soakaway
7	CAR/R/1041208	NB 1109 3466	Sewage	Primary	-	-	soakaway
8	CAR/R/1043318	NB 1109 3447	Sewage	Primary	-	-	soakaway
9	CAR/R/1048511	NB 1096 3445	Sewage	Primary	-	-	Loch Roag
10	CAR/R/1038779	NB 1084 3446	Sewage	Primary	-	-	Loch Roag
11	CAR/R/1054897	NB 1082 3452	Sewage	Primary	-	-	Loch Roag
12	CAR/R/1054904	NB 1080 3452	Sewage	Primary	-	-	soakaway
13	CAR/R/1062064	NB 1068 3460	Sewage	Primary	-	-	land
14	CAR/R/1066368	NB 1062 3452	Sewage	Primary	-	-	U/T of Loch Roag
15	CAR/R/1047232	NB 1056 3455	Sewage	Primary	-	-	soakaway
16	CAR/R/1041209	NB 1051 3465	Sewage	Primary	-	-	soakaway
17	CAR/R/1047647	NB 1050 3475	Sewage	Primary	-	-	soakaway
18	CAR/R/1016095	NB 1054 3473	Sewage	Primary	-	-	land
19	CAR/R/1078467	NB 0967 3470	Sewage	Primary	-	-	soakaway
20	CAR/R/1077622	NB 0965 3464	Sewage	Primary	-	-	soakaway
21	CAR/R/1056466	NB 0952 3445	Sewage	Primary	-	-	land
22	CAR/R/1056400	NB 0951 3444	Sewage	Primary	-	-	soakaway

No.	Ref No.	NGR of discharge	Discharge Type	Level of Treatment	Consented flow (DWF) m^3/d	Consented/ design PE	Discharges to
23	CAR/R/1056401	NB 0951 3444	Sewage	Primary	-	-	soakaway
24	CAR/R/1064958	NB 0942 3431	Sewage	Primary	-	-	Loch Miabhaigh
25	CAR/R/1057451	NB 0940 3451	Sewage	Primary	-	-	soakaway
26	CAR/R/1057447	NB 0937 3450	Sewage	Primary	-	-	soakaway
27	CAR/R/1041205	NB 0935 3451	Sewage	Primary	-	-	soakaway
28	CAR/R/1056394	NB 0908 3436	Sewage	Primary	-	-	soakaway

U/T – unnamed tributary

Discharge consents were received for Marine Cage Fish Farms (MCFF) in the area. However, as their discharge is not expected to have sanitary content, these have only been included for information purposes.

Sewage infrastructure recorded during the shoreline survey is listed in Table 4.3.

Table 4.3 Discharges and septic tanks observed during shoreline surveys

No.	Date	NGR	Description
1	18/07/2011	NB 11086 34395	House, presumed to be on septic tank. No pipe to shore evident.
2	18/07/2011	NB 10864 34454	End of ceramic pipe, no apparent flow - no sewage fungus, though a strip of bright green algae on seabed.
3	18/07/2011	NB 10859 34473	Septic tank, discharge pipe leading downward, but no outfall pipe visible from shore
4	18/07/2011	NB 10829 34523	House with septic tank on shore side of road.
5	18/07/2011	NB 11061 34594	Concrete septic tank with small diameter pipe overflow to land/ditch - not flowing.

Few discharges were observed in the area, most of which were observed at Riof. The majority of discharges in the area are to soakaway. Of the discharges to either sea or watercourses, only two were found during the shoreline survey. Observation number 4 appears to correspond with CAR/R/1054897 (Table 4.2, No. 11) and numbers 2 and 3 may both relate to CAR/R/1038779, (Table 4.2, No. 10). No associated pipe or evidence of discharge was observed for Table 4.2, No. 9.

A camp site with toilet facilities is located along at Traigh na Beirigh, south of Kneep (Cnip). This was seen during the shoreline survey, though no outlet was observed and its location was not recorded at the time. The Scottish Camping Guide (http://www.scottishcampingguide.com/link.php?n=57&c=14, accessed 13-01-2012) reports that the site has 50 pitches, as well as wash and shower facilities. It is located approximately 2.7 km northwest of the mussel farm, beyond the headland at Stung.

No habitation or discharges were observed along the shoreline immediately adjacent to the mussel farm.

Boats are kept further to the west, within Loch Miavaig. Fishing and tour boats are likely to pass the mussel farm on their way in and out of Loch Roag, though none were observed on the day of survey. Any boats discharging septic waste overboard in the vicinity of the mussel farm may cause degradation in water quality at the fishery. However, it is not known whether and how often this might occur.

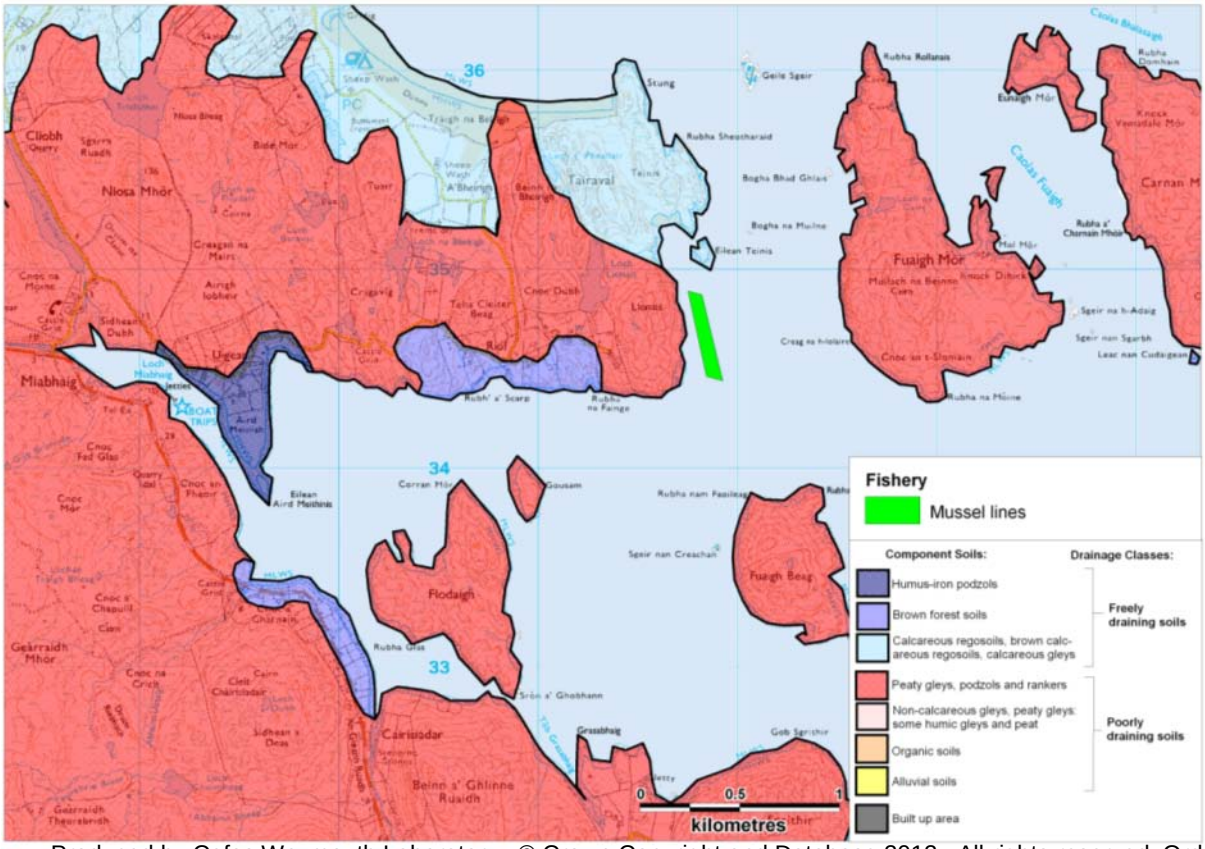
Sources arising at Riof and to a lesser extent at Miavaig may impact the southern end of the mussel lines, again depending on circulation patterns. Discharges to the sea north west of the fishery may contribute to levels of contamination at the north end of the mussel lines, depending on water circulation patterns at the site.

Produced by Cefas Weymouth Laboratory. © Crown Copyright and Database 2012. All rights reserved.
Ordnance Survey licence number [GD100035675]

Figure 4.1 Map of discharges for Loch Roag: Eilean Teinish

5. Geology and Soils

Geology and soil types were assessed following the method described in Appendix 1. 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.



Produced by Cefas Weymouth Laboratory. © Crown Copyright and Database 2012. All rights reserved. Ordnance Survey licence number [GD100035675]

Figure 5.1 Component soils and drainage classes for Loch Roag Eilean Teinish

Four types of component soil are present in this area. The most predominant is composed of peaty gleys, podzols and rankers. This soil type covers the coastline directly adjacent to the fishery, the majority of the smaller islands in the loch and much of the shoreline to the west. This soil type is classed as poorly draining.

Calcareous regosoils, brown calcareous regosols and calcareous gleys are found on the shore adjacent to the beaches north west of the fishery. Brown forest soils are found on two strips of land on the shoreline southwest of the fishery and humus-iron podzols are found on the small headland in the far western end of the loch. All three of these soil types are classed as freely draining. The majority of the inhabited area around Riof is located within an area of freely-draining soils.

Although no built-up area is recorded, northwest of the mussel farm, there is a campsite with a paved car park. The majority of land area draining to the waters around the mussel farm has poorly draining soils, including the land immediately adjacent to the mussel lines. Therefore, these areas are more likely to be subject to surface water run-off after rainfall.

6. Land Cover

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

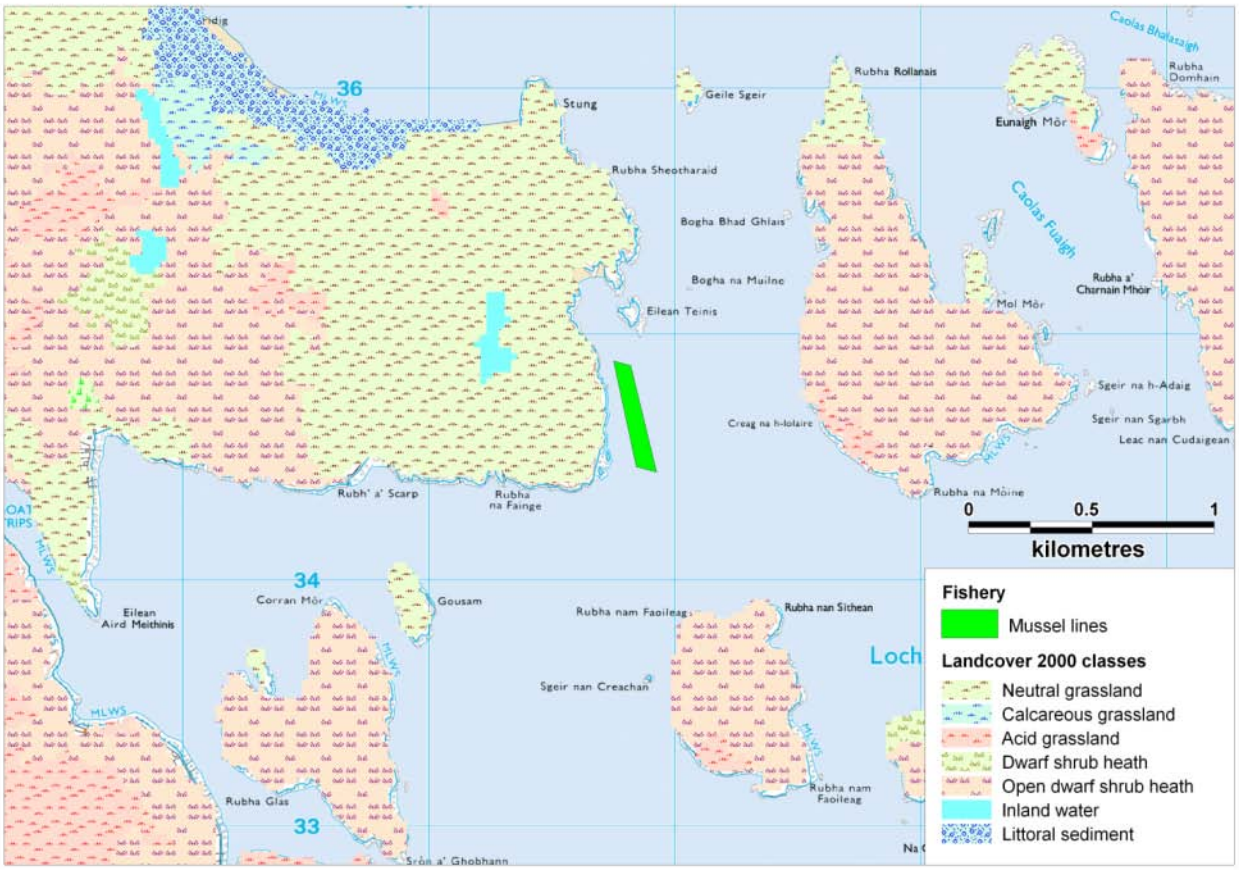


Figure 6.1 LCM2000 class land cover data for Loch Roag Eilean Teinish

The land immediately west of the fishery on the western side of Loch Roag is predominantly classed as neutral grassland. Land cover on the islands and land to the southwest of the fishery is classed as open dwarf shrub heath with some small patches of acid grassland. There are no areas of improved grassland.

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).

During the shoreline survey it was noted that much of the land surrounding the fishery is used for rough grazing. Therefore, the potential for the highest contribution of faecal coliform bacteria attributable to land cover type is greatest along the shoreline immediately west and north of the mussel farm.

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 Uig 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 Uig parish 2009 - 2010

	Uig 567 km^2			
	2009		2010	
	Holdings	Numbers	Holdings	Numbers
Pigs	10	27	10	33
Poultry	59	639	63	663
Cattle	52	345	64	400
Sheep	330	26517	303	23914
Deer	0	0	0	0
Horses used in Agriculture	*	*	*	*
Other horses and ponies	12	19	10	15

The parish area is large, extending approximately 30 km north to south and nearly the same east to west at its widest points. Sheep were the predominant livestock animals kept in the parish and outnumber the human population within the same area by over 15 to 1, based on 2001 human census data. However, the data above do not give a clear picture of the spatial distribution of animals within the parish.

Agricultural practices in Lewis were observed by Osgathorpe et al (2011) to consist predominantly of store lamb production on 'inbye' land –small, enclosed areas of lowland grass. They noted that no arable agriculture was carried out, and that the majority of crofters did not have access to upland grazing areas. This suggests that the majority of livestock within the Uig parish is likely to be kept on or very close to enclosed croft areas. During the shoreline survey, no arable farming was observed on land adjacent to the fishery.

Observations of livestock, including tracks and droppings, taken during the shoreline survey are listed in Table 7.2 and their spatial distribution shown in Figure 7.1. Livestock counts taken during the shoreline survey relate only to the time of the site visit on 18 and 22 July, 2011 and are dependent upon the viewpoint of the observer.

Table 7.2 Livestock observations from shoreline survey 2011

No.	Date	NGR	Description
1	18/07/2011	NB 11298 34436	Sheep droppings
2	18/07/2011	NB 11295 34444	Hoofprints along stream
3	18/07/2011	NB 11227 34405	Sheep droppings along the shore
4	18/07/2011	NB 11161 34400	Many sheep droppings, 2 sheep in view uphill from shore
5	18/07/2011	NB 11118 34406	Hoofprints along stream
6	18/07/2011	NB 11086 34395	Field is fenced from the shore but sheep droppings were frequent along the shore side of the fence
7	18/07/2011	NB 10984 34405	2 sheep seen up the hill and to the west, on opposite side of stream
8	18/07/2011	NB 11027 34549	7 sheep on shore side of road
9	18/07/2011	NB 11071 34609	4 cattle in field on land side of road.
10	18/07/2011	NB 11095 34633	Home with 23 sheep in field behind it.
11	18/07/2011	NB 11174 34650	27 sheep
12	18/07/2011	NB 11275 34603	8 sheep
13	18/07/2011	NB 11333 34585	8 sheep
14	18/07/2011	NB 10584 34613	Farm on the shore side of road with 32 sheep
15	18/07/2011	NB 10301 34483	Cattle droppings
16	22/07/2011	NB 11656 34476	Track poached by cattle
17	22/07/2011	NB 11702 34679	Cattle droppings
18	22/07/2011	NB 10898 34679	10 cattle east of the road
19	22/07/2011	NB 11038 34562	3 pigs

A total of 109 sheep, 14 cattle and 3 pigs were observed during the shoreline survey. All animals were seen in the vicinity of Riof. However, tracks and droppings indicated that animals also ranged over rough grazing to the east and west of Riof. Cattle droppings and hoof prints were found on steep shoreline adjacent to the fishery. During periods of heavy rain, runoff from land at this location is likely to wash faecal material from the hillside into the sea and any impact on the fishery is most likely to affect the lines nearest the shore. Livestock grazing within the catchment of Loch Lionais would impact the water quality of the loch and the stream that flows from it to the sea north of the mussel lines.

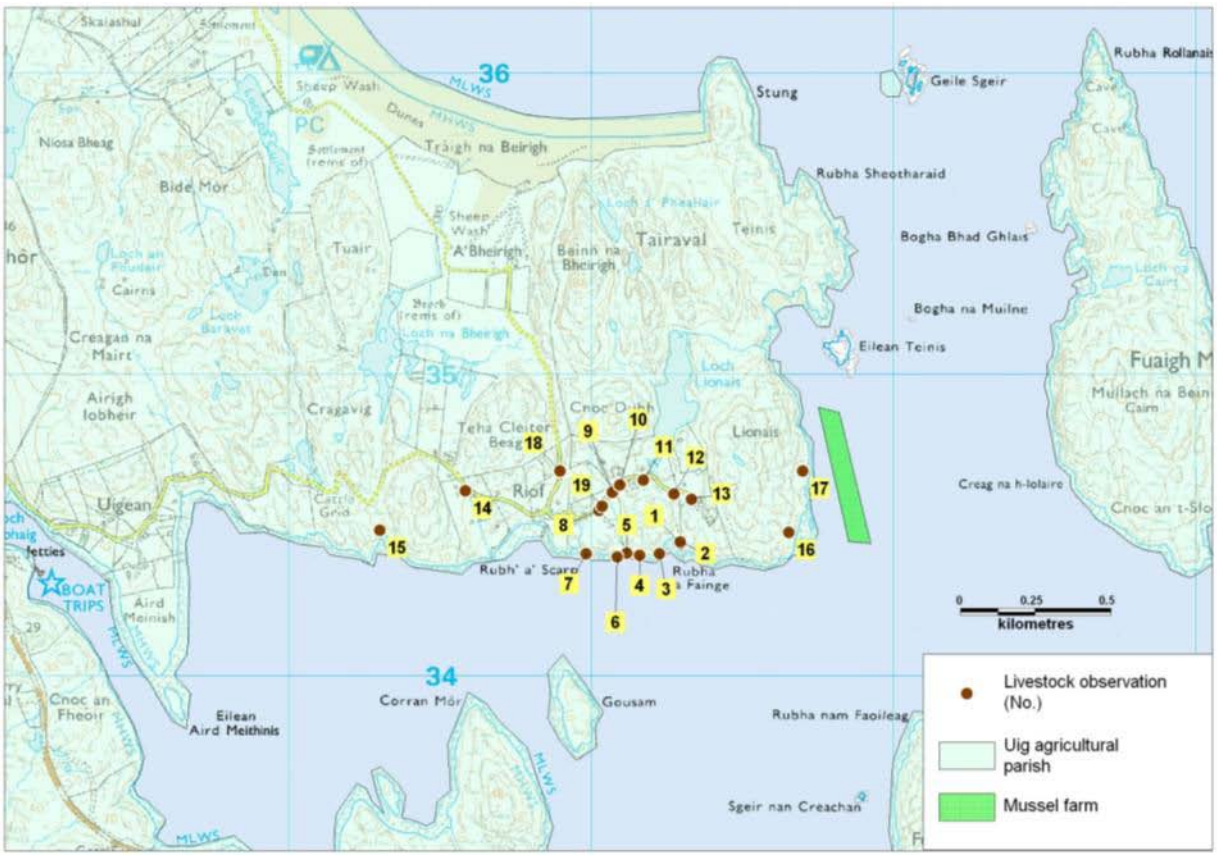


Figure 7.1 Livestock observations at Loch Roag Eilean Teinish

8. Wildlife

Wildlife is likely to be present in fishery areas and may contribute to the faecal bacterial load in a water body either via direct deposition of faeces or via diffuse runoff from land areas.

The Traigh na Berie Special Area of Conservation (SAC) is located to the northwest of the fishery area. The area was designated due to its machair habitat, which attracts a number of bird species, including geese. The Loch Roag Lagoons SAC lies on the north end of Great Bernera, to the northeast.

The following are considered most likely to be present at or near the fishery.

Seabirds
Results from the Seabird2000 census (Mitchell *et al*. 2004) were used to ascertain the likely distribution and numbers of seabirds at or near the Eilean Teinish production area. Records within 3 km of the mussel farms are listed in Table 8.1.

Table 8.1 Seabird counts within 5km of the site.

Common name	Species	Count	Method
Arctic Tern	*Sterna paradisaea*	293	Occupied nests
Herring Gull	*Larus argentatus*	7	Occupied nests
Common Gull	*Larus canus*	7	Occupied nests
Great Black-backed Gull	*Larus marinus*	1	Occupied nests
Black-headed Gull	*Larus ridibundus*	18	Occupied nests
Lesser Black-backed Gull	*Larus fuscus*	1	Occupied nests
Northern Fulmar	*Fulmarus glacialis*	3	Occupied nests

Small numbers of seabirds such as gulls and terns were observed during the survey, though their numbers and locations were not specifically recorded. No significant aggregations of birds were seen.

Waders and Wildfowl
Little information was available on the presence, numbers and seasonal variation in the populations of waders and wildfowl in Loch Roag. Some information was available pertaining to Lewis and Harris more broadly. A document on the birds of the Outer Hebrides produced by the Western Isles Natural History Society identified that the moorland and machair on Lewis & Harris were important areas for breeding waders and other birds (http://www.thewesternisles.co.uk/outer-hebrides-birds-checklist.pdf). It also suggested that Lewis & Harris did not attract the same number of wintering waders that the more southerly islands did. Given that moorland is common around the loch, it should be presumed that wading birds will contribute to background levels of faecal contamination found within the loch, particularly during the summer months when they are present. A small flock of oystercatchers were observed near Iarsiadar during the shoreline survey.

In 2008, 1914 greylag geese were found on Lewis & Harris (Mitchell *et al*, 2010) Post-moult counts of Greylag geese undertaken in August 2008 in North and South Uist indicated a strong association of the birds with grassland feeding areas (Mitchell *et al*. 2010). A large proportion of land around the proposed fishery was

recorded as open grassland and the Traigh na Berie SAC has machair habitat favoured by geese. Although neither geese nor droppings were specifically observed near Eilean Teinish during the shoreline survey, a significant number of geese were seen in the water to the east during the survey at Linngeam. Therefore, geese may contribute to background levels of faecal contamination found at the Eilean Teinish fishery.

Seals

The Western Isles hosts significant populations of both grey and common seals. The common seal population of the Outer Hebrides in 2008 was estimated at 1804, while the grey seal population was estimated to be 29700, with one breeding colony identified in outer Loch Roag (National Environment Research Council Special Committee on Seals, 2010). Both species are reported to be present in West Loch Roag. Seals forage widely for food and are likely to range throughout the loch and beyond, and therefore may only be present for a proportion of the time. These animals are likely to contribute to background faecal bacterial levels within the loch generally, and may lead to locally high levels of faecal contamination if they defecate in close proximity to the shellfish. No seals were seen during the survey, although the harvester reported that they were sometimes present in the area.

Otters

Otters are known to be present on the island and are likely to be present in Loch Roag. However, the typical population densities of coastal otters are low and their impacts on the shellfishery are expected to be very minor. No otters were seen during the shoreline survey.

Deer

Deer are known to inhabit many parts of the island so it is likely that they may be present around Loch Roag. Faecal contamination from deer is most likely to be carried to the loch via freshwater streams and burns. The Visit Hebrides website identified that the population of deer on Lewis & Harris was just over 4000. (http://www.visithebrides.com/wildlife/topten/index.php, accessed 15/08/2011).
No deer were seen during the shoreline survey.

Whales and Dolphins

Due to the shallow depths found within the area of the fishery it is considered unlikely that even the smaller cetaceans such as porpoises and dolphins will frequent waters near the mussel farms.

Summary

Wildlife species in and around Loch Roag are likely to have a limited impact on bacteriological quality of water around the fishery due to the relatively small number of animals likely to be present compared with the large and open water area of the outer loch. Seals and seabirds may potentially directly deposit faeces to waters at the mussel farm, this is likely to be limited in extent and duration and relatively unpredictable. Other wildlife sources of faecal contamination are waterfowl and deer. Faecal material from both these sources is likely to be present in streams discharging to the loch. Therefore impacts may be higher near where streams and other freshwater runoff reach the loch. Waterfowl may also directly

deposit droppings at or near the mussel lines anywhere within the fishery. Impacts from this source are likely to be higher nearer the surface of the lines.

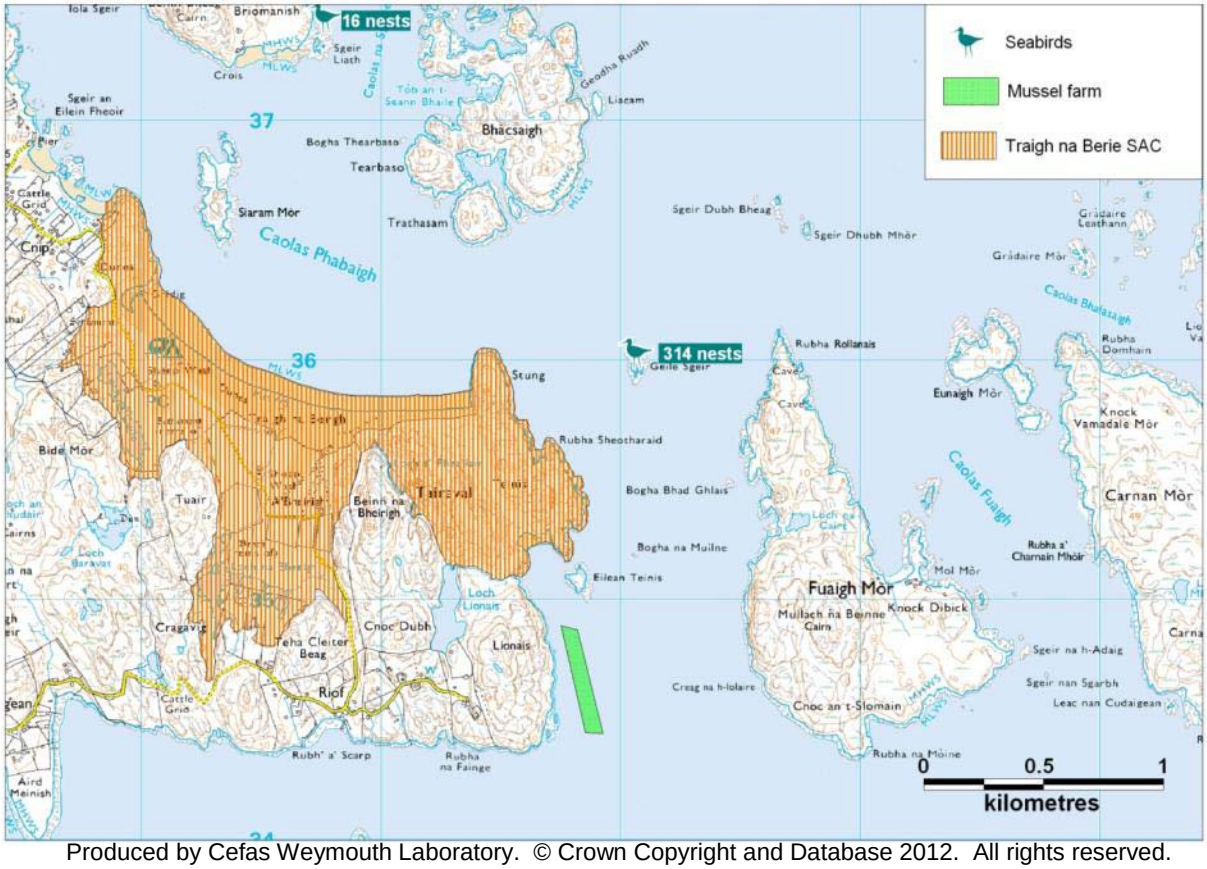


Figure 8.1 Map of seabird distributions at Loch Roag Eilean Teinish

9. Meteorological data

Both rainfall and wind data were available for Stornoway Airport, which is located approximately 32 km east of the fishery. Rainfall data was available for 2003-2009 inclusive. Rainfall data was also available for Lewis Creed, located 25 km east of the fishery. However, data was incomplete for September to December 2006, December and November, 2007 and June, 2004. Data for 2010 was complete and so this was used to supplement the Stornaway Airport data set.

Data for the stations was purchased from the Meteorological Office. Unless otherwise identified, the content of this section (e.g. graphs) is based on further analysis by Cefas. This section aims to describe the local rain and wind patterns and how they may affect the bacterial quality of shellfish at Loch Roag; Eilean Teinish.

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 a graphical representation 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 *.

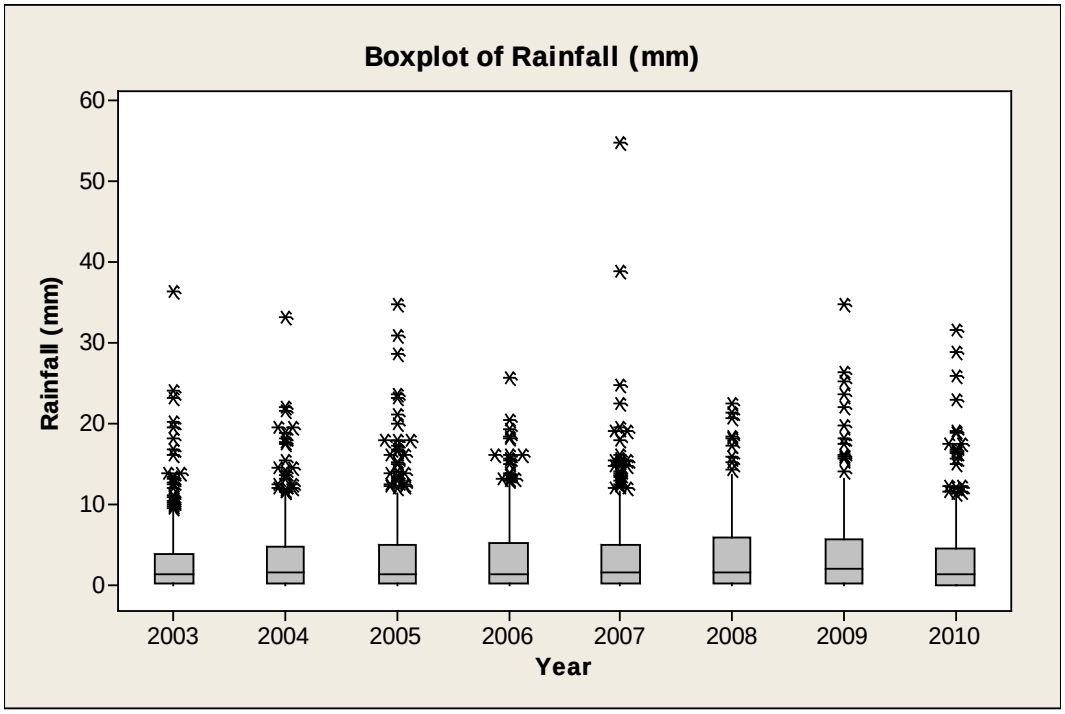


Figure 9.1 Box plot of daily rainfall values by year at Stornaway (2003 – 2009) and Lewis Creed (2010)

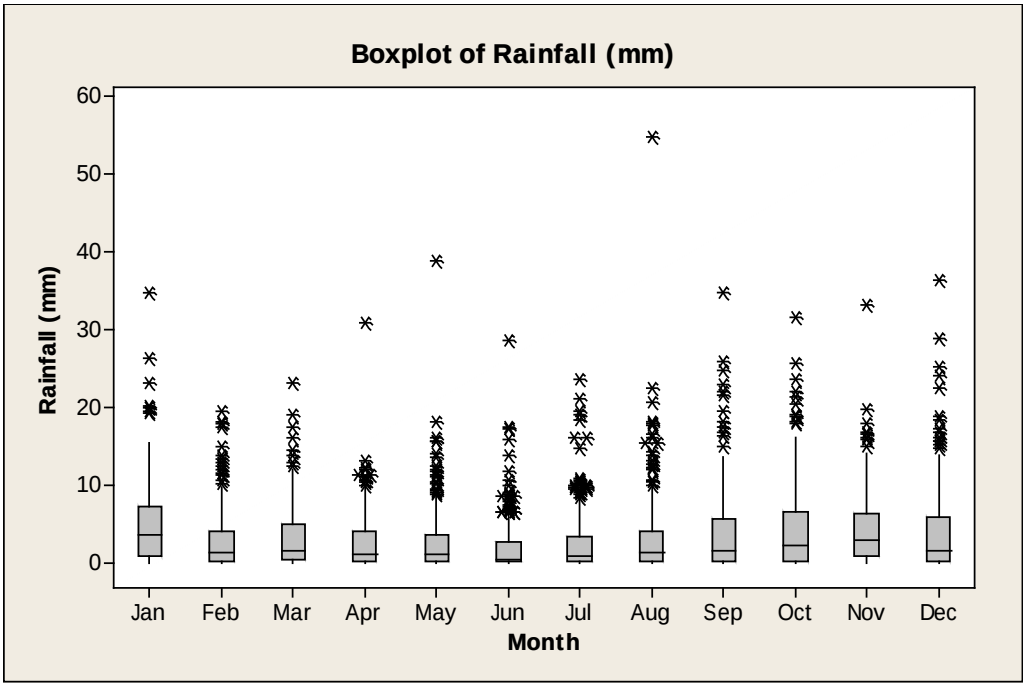


Figure 9.2 Box plot of daily rainfall values by month at Stornaway (2003 – 2009) and Lewis Creed (2010).

Daily rainfall values showed that levels were similar throughout the years with 2008 being the wettest and 2003 being the driest. A boxplot of monthly rainfall observations showed that January, October and November had the highest level of daily rainfall, with no obvious seasonal patterns with regards to extreme rainfall events (>20mm) (Figure 9.2). For the duration considered here, 41% of days experienced less than 1mm of rainfall and 7% of days experienced rainfall of 10mm or more.

In terms of rainfall affecting the level of run-off, it would be expected that this would increase during the autumn and winter months as rainfall increases.

However, extreme rainfall events over the summer and early autumn may contribute significantly to the contamination entering the production area due to the build up of faecal material over this period through higher stocking densities of livestock on nearby pastures.

It can therefore generally be expected that levels of run-off will be higher during the autumn and winter months. However, it is likely that associated faecal contamination entering the production area will be greatest when extreme rainfall events occur during summer or early autumn after a build-up of faecal matter on pastures during the drier summer months when stock levels are at their highest.

9.2 Wind

Wind data collected at the Stornaway weather station is summarised by seasonal wind roses and presented in Figures 9.3 and 9.4.

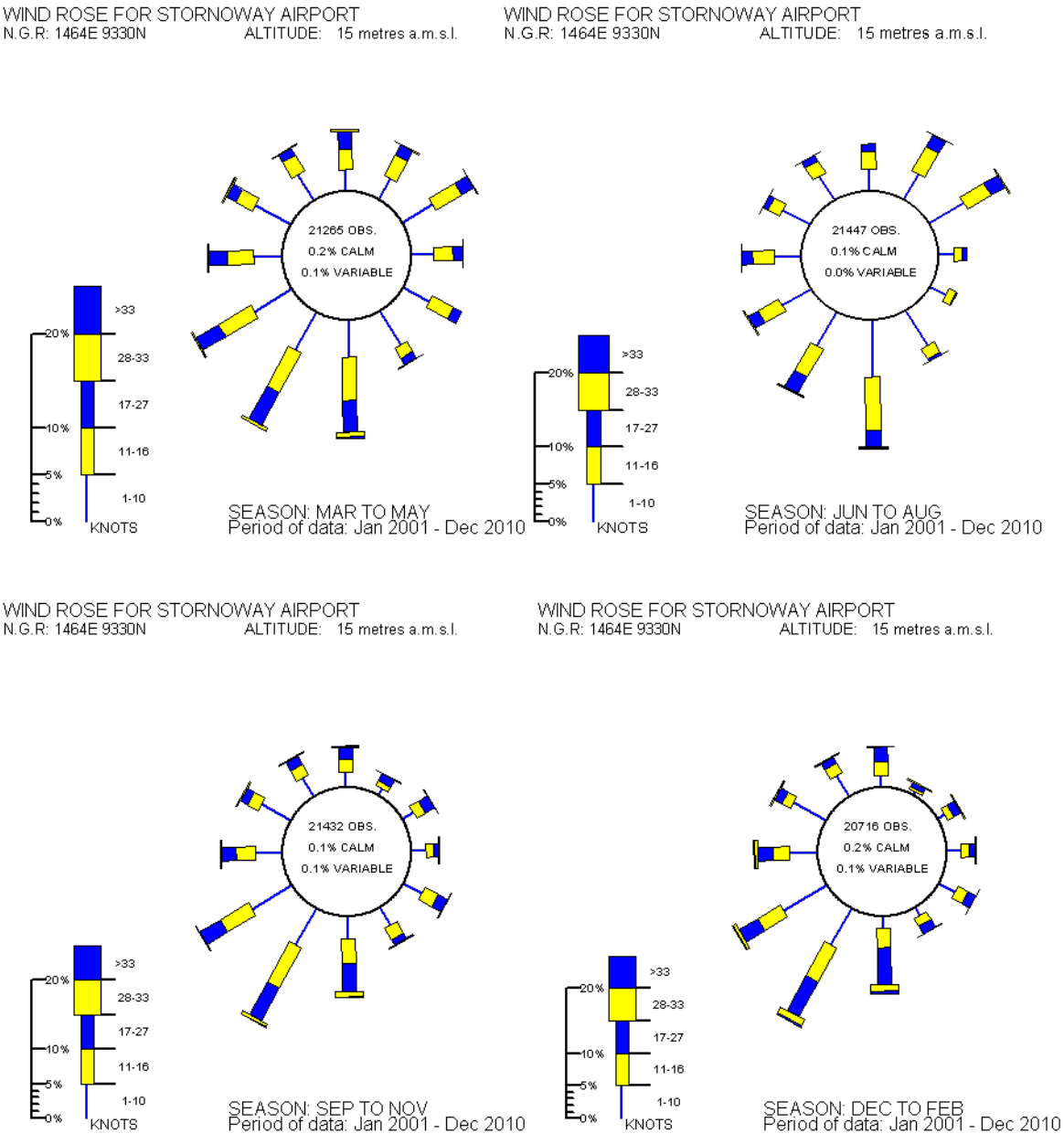


Figure 9.3 Seasonal wind roses for Stornoway Airport

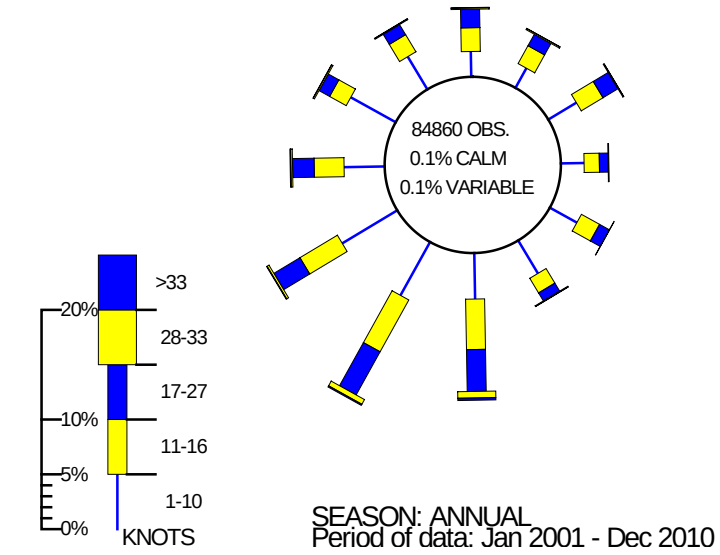


Figure 9.4 Annual wind rose for Stornoway Airport

The prevailing wind direction at Stornaway is from the southwest. There is a higher occurrence of North Easterly winds during the spring and summer. Winds are generally lightest in the summer and strongest in the winter. The terrain surrounding the Stornoway airport is relatively low lying and so the station is exposed to wind from all directions.

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. Therefore, strong winds, particularly from the north or south, would be expected to significantly alter the pattern of surface currents at Eilean Teinish. Strong winds may also affect tide height depending on wind direction and local hydrodynamics. A strong wind from the north east combined with a spring tide may result in higher than usual tides, which will carry accumulated faecal matter from livestock, in and above the normal high water mark into the production area. The site is largely sheltered from prevailing southwesterly winds.

10. Current and historical classification status

The historical and current classifications for the area are shown below in Table 10.1. Loch Roag: Eilean Teinish was first classified in 2006 and the classification status from 2006 on is shown below.

Table 10.1 Loch Roag: Eilean Teinish, mussels

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	B	B	B	B	B	A	A	A	A	A	B	B
2007	B	B	B	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									

Note: [1]For 2006, the classification listing actually states: 2006 = A - June to October B - November to May

Since April 2007, the area has therefore consistently held an A classification. Prior to that, B classifications were held in the winter and spring.

11. Historical *E. coli* data

11.1 Validation of historical data

Data for all mussel samples taken from Loch Roag: Eilean Teinish from the beginning of 2007 up to and including October 2011 were extracted from the FSAS database and validated according to the criteria described in the standard protocol for validation of historical *E. coli* data.

Five samples were noted as rejected by FSAS and were deleted from the data set. One sample plotted to the east of the production area. This appeared to be due to a recording error in one digit of the grid reference and when this was corrected the location fell within the production area and close to the present mussel lines.

Seventeen of the fifty-three samples were received at the laboratory more than 24 hours after collection but none was received more than 48 hours after collection. The recorded coolbox temperatures were all 8°C or less.

All *E. coli* results are reported in most probable number per 100g of shellfish flesh and intravalvular fluid. Fifteen samples had the result reported as <20, and were assigned a nominal value of 10 for statistical assessment and graphical presentation.

11.2 Summary of microbiological results

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

Table 11.1 Summary of historical sampling and results

Sampling Summary	
Production area	Loch Roag: Eilean Teinish
Site	Eilean Teinish
Species	Common Mussels
SIN	LH-338-720-08
Location	Various
Total no of samples	53
No. 2007	10
No. 2008	9
No. 2009	12
No. 2010	12
No. 2011	10
Results Summary	
Minimum	<20
Maximum	1700
Median	40
Geometric mean	38
90 percentile	170
95 percentile	476
No. exceeding 230/100g	5 (9%)
No. exceeding 1000/100g	2 (4%)
No. exceeding 4600/100g	0 (0%)
No. exceeding 18000/100g	0 (0%)

11.3 Overall geographical pattern of results

All sampling locations in 2007 were only recorded to 100 m accuracy. The first 5 samples of 2007 were recorded against the location of the nominal RMP (which lies just to the east of the present lines). The other five 2007 samples were recorded on the database to 100 m accuracy but grid references to 10 m accuracy were obtained from the sample submission forms. The results are thematically mapped in Figure 11.1.

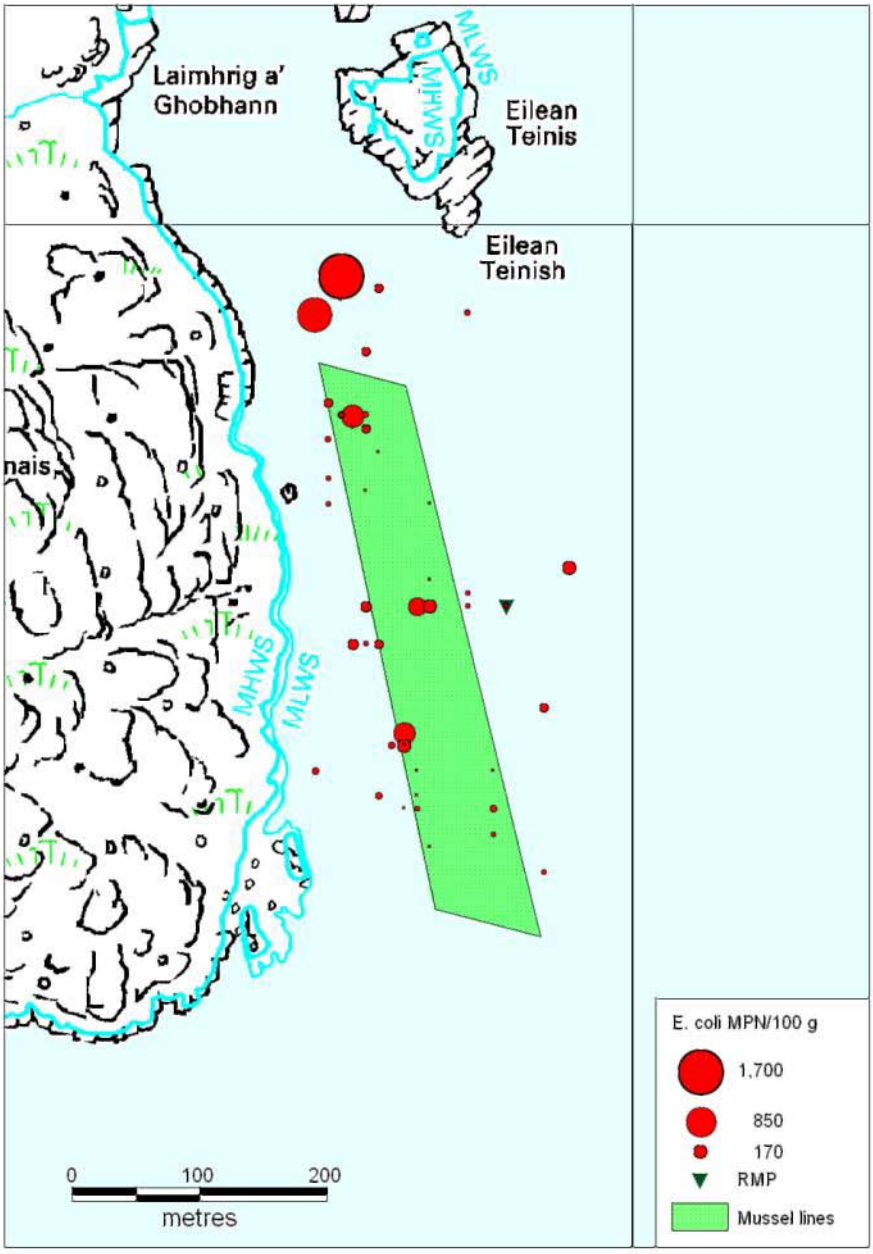


Figure 11.1 Map of individual *E. coli* results

Apart from the high results at the northern end of the lines, no other geographical patterns are apparent in Figure 11.1. An interpolated grid was generated from the *E. coli* data and is displayed over the map of the mussel lines in Figure 11.2. This shows that, apart from the red area to the north-east of the mussel lines caused by the two samples recorded as being taken at the high water mark, there is a tendency for higher results to occur towards the middle of the mussel lines, as indicated by the yellow area, going from north to south. This effect is present, but not clear, in Figure 11.1.

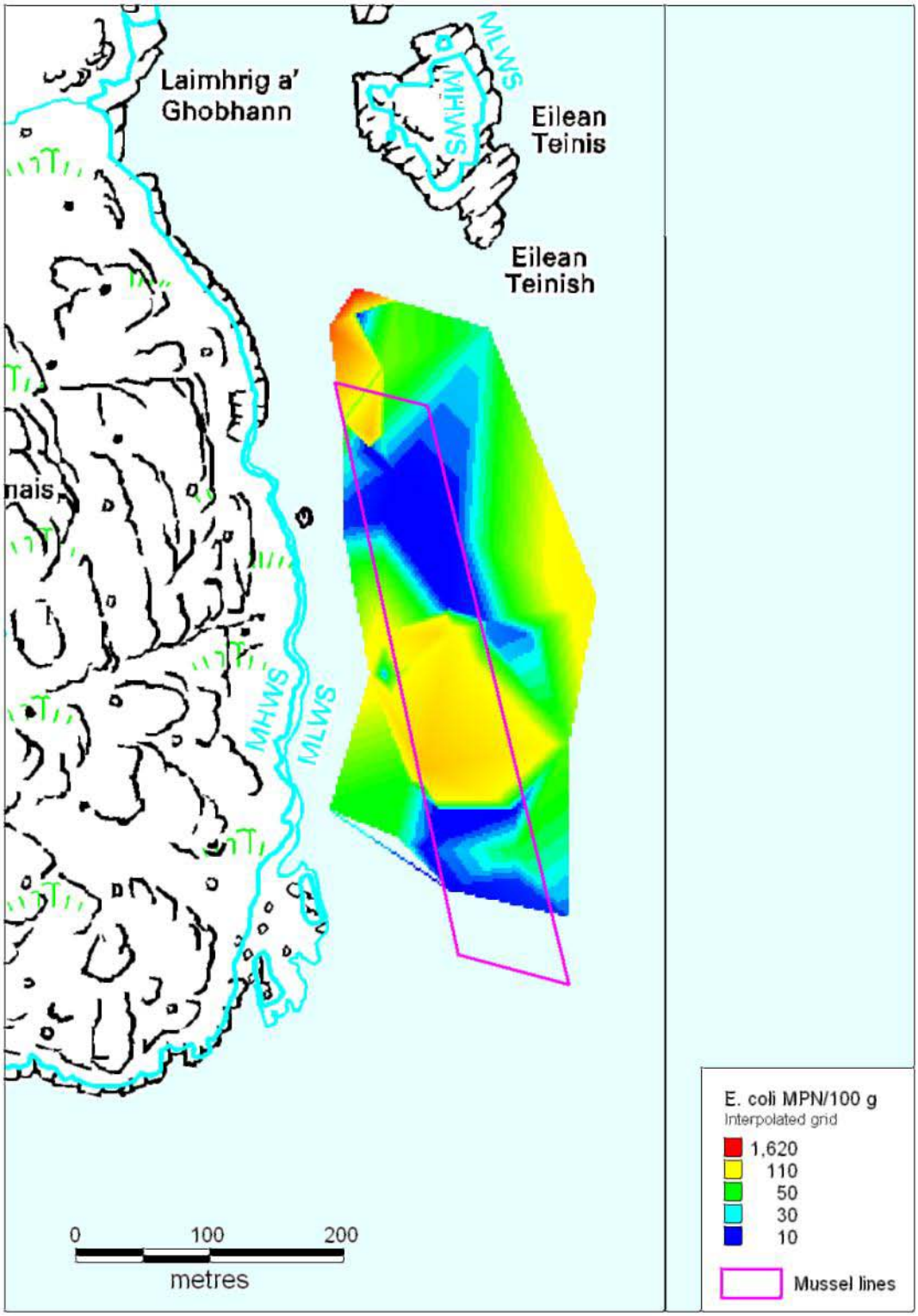


Figure 11.2 Map of interpolated *E. coli* results

11.4 Overall temporal pattern of results

Figure 11.3 presents a scatter plot of individual *E. coli* results against date, fitted with a loess smoother line. 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.

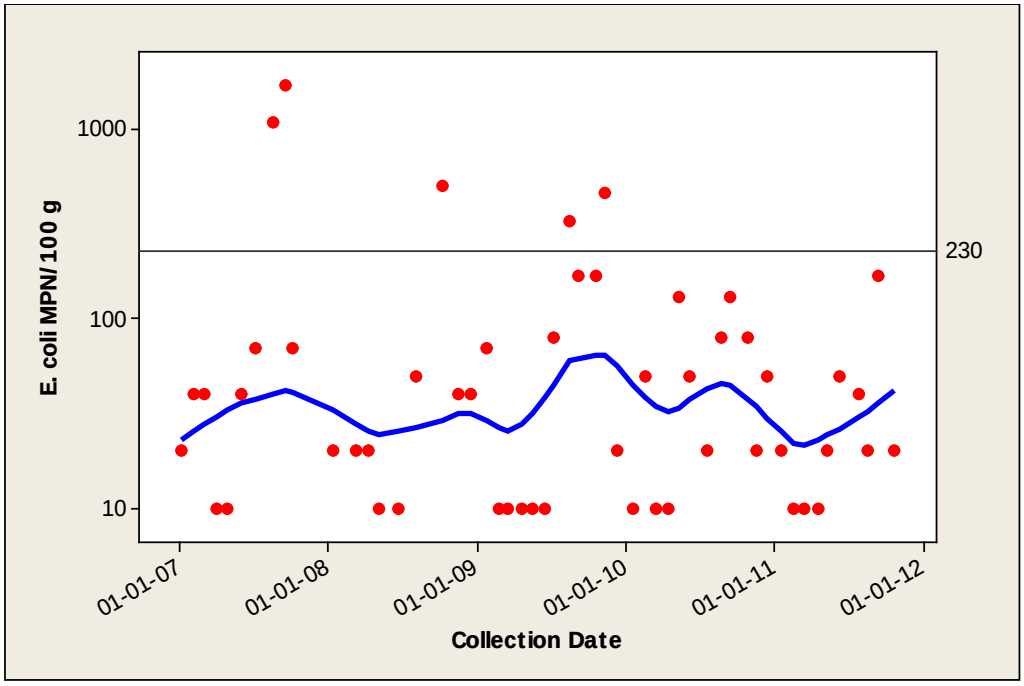


Figure 11.3 Scatterplot of *E. coli* results by date with loess line

Figure 11.3 suggests no overall change in results over the period since January 2007. However, there have been no results greater than 230 *E. coli* MPN/100 g since 2009. The trend line does show that there is a tendency to higher results in the last half of the year although the timing and magnitude of the change varies between years.

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. Figure 11.4 presents a scatterplot of *E. coli* result by month, superimposed with a loess smoother line.

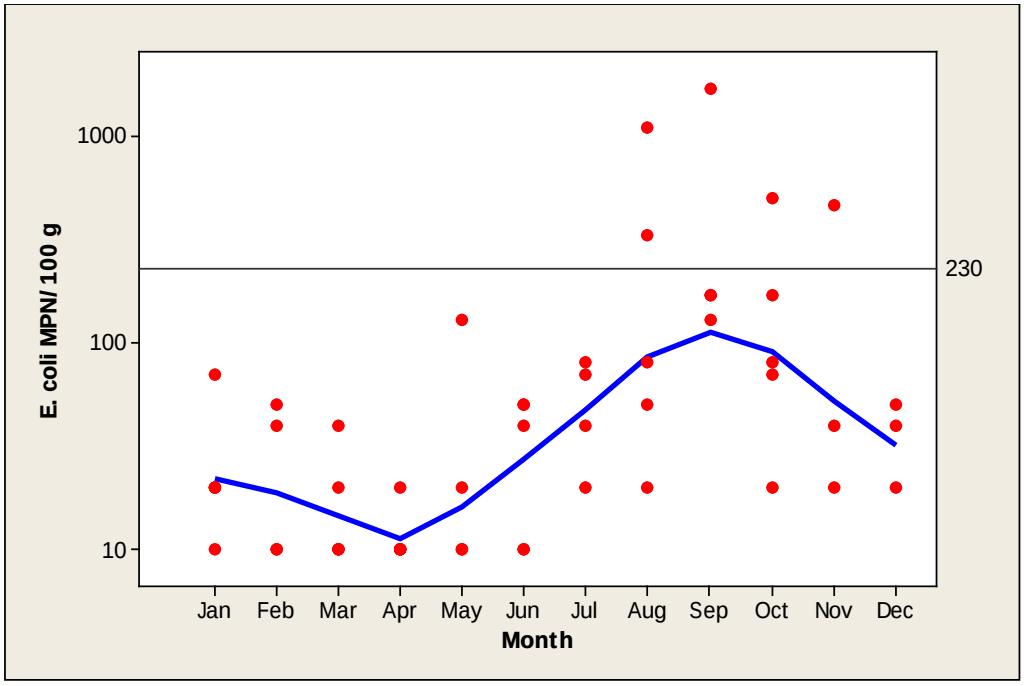


Figure 11.4 Scatterplot of results by month

Higher results were generally seen during the period August to November. No results <20 *E. coli* MPN/100 g were seen from July to December inclusive.

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 is presented in Figure 11.5.

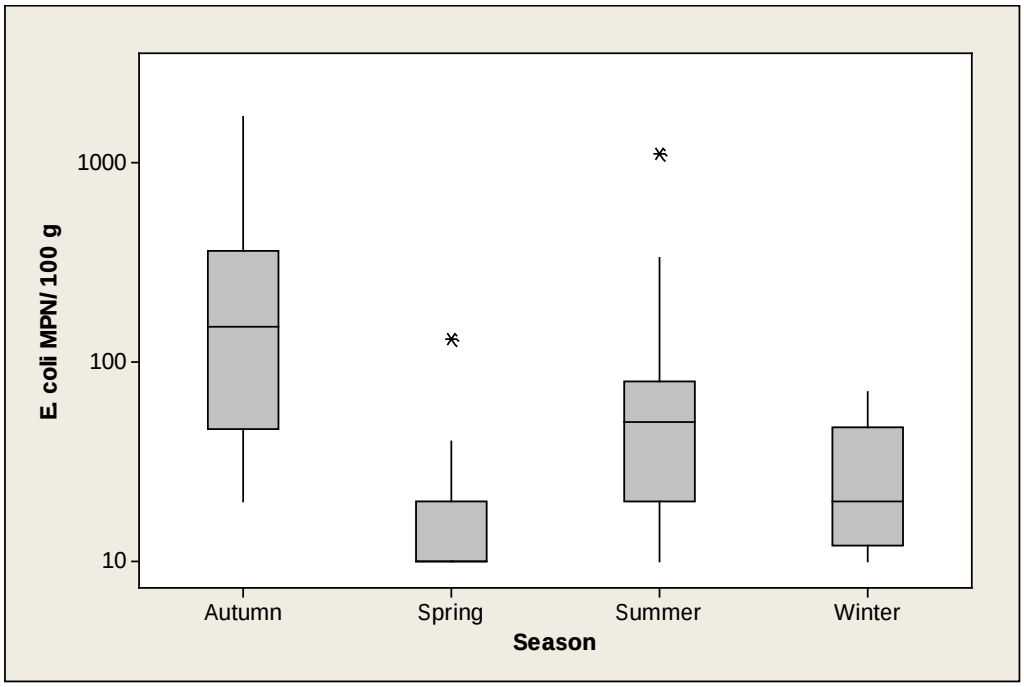


Figure 11.5 Boxplot of result by season

A significant difference was found between results by season (One-way ANOVA, p<0.001, Appendix 4). A post ANOVA test (Tukey's comparison, Appendix 4)

indicates that results for the autumn were significantly higher than those in the spring and winter. Fewer samples had been taken in November and December than in other months.

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 Loch Roag: Eilean Teinish is at Lewis: Creed Bridge, approximately 28 km to the east of the production area. However, more complete data was available for the station at Stornoway Airport, a further 6 km to the east, Rainfall data was purchased from the Meteorological Office for the period up to 31/12/2010 (total daily rainfall in mm). Daily rainfall data was not available for just one day during the period 1/01/2007 to 31/12/2010.

Two-day antecedent rainfall

Figure 11.6 presents a scatterplot of *E. coli* results against rainfall in the previous two days. A Spearman's Rank correlation was carried out between results and rainfall. No significant correlation was found between *E. coli* result and rainfall in the previous 2 days (Spearman's rank correlation=0.198, p=0.0.202, Appendix 4).

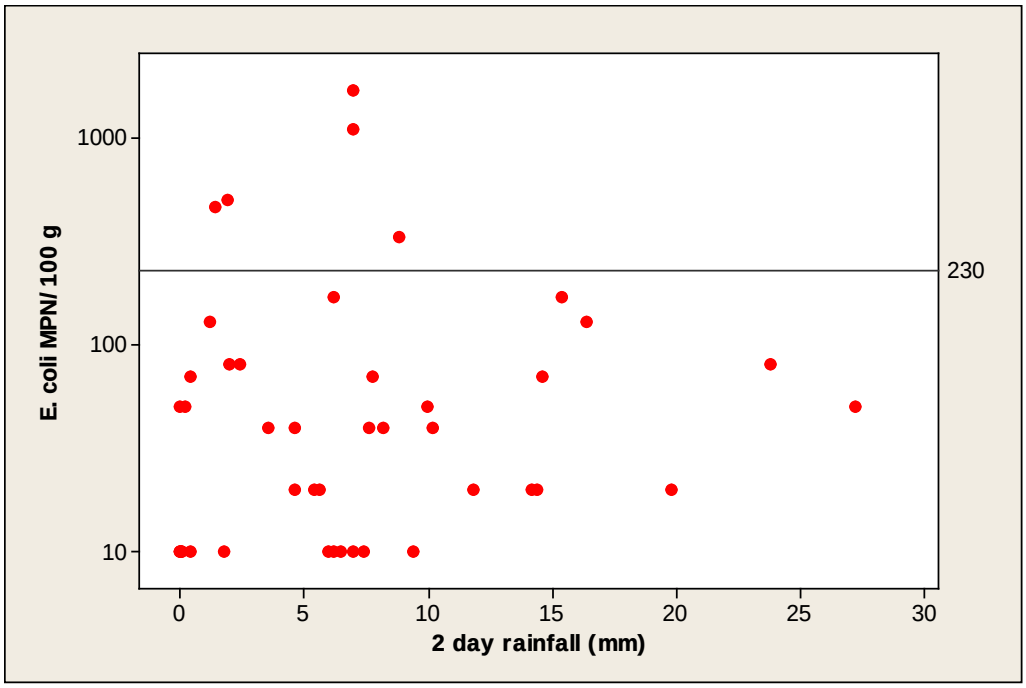


Figure 11.6 Scatterplot of result against rainfall in previous 2 days

Seven-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.

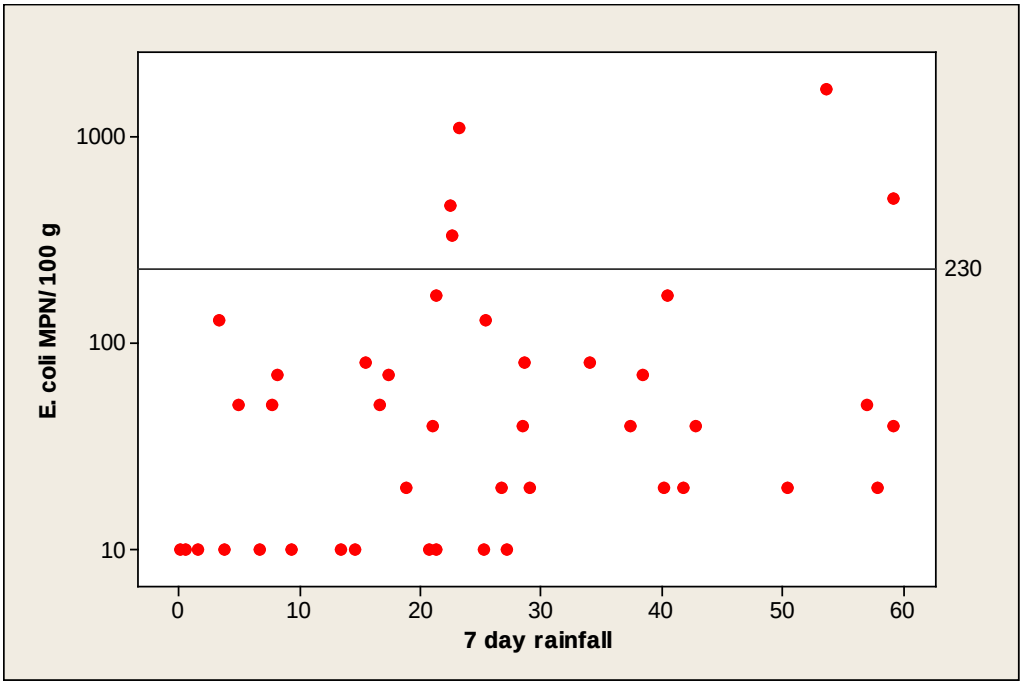


Figure 11.7 Scatterplot of result against rainfall in previous 7 days

A scatterplot of *E. coli* results against rainfall is presented in Figure 11.7. A positive correlation was found between *E. coli* result and rainfall in the previous 7 days (Spearman's rank correlation= 0.328, p=0.032, Appendix 4). Results greater than 230 *E. coli* MPN/100 g occurred after both intermediate and high rainfall values, however results <20 *E. coli* MPN/100 g were not found at rainfall values greater than 30 mm.

11.6.2 Analysis of results by tidal height and state

Spring/Neap 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. Figure 11.8 presents a polar plot of $\log_{10}$ *E. coli* results on the lunar spring/neap tidal cycle. Full/new moons occur at 0º, and half moons occur 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.

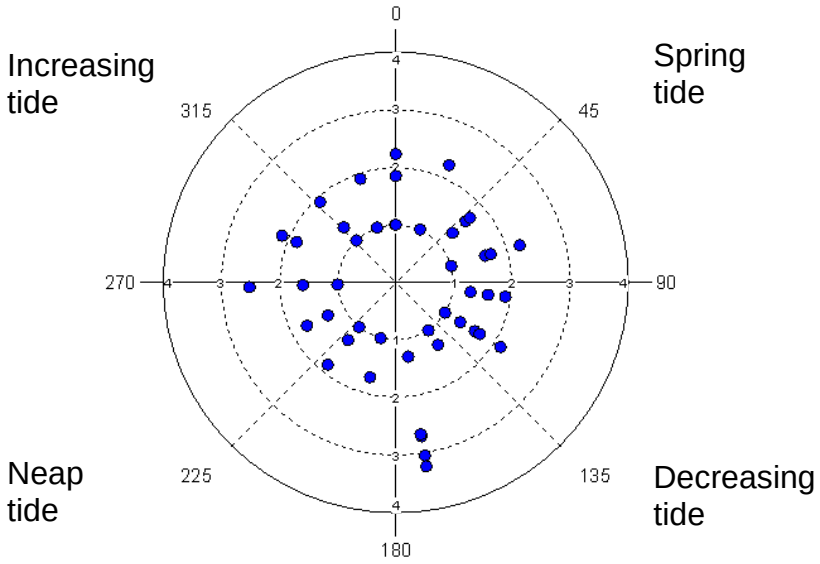


Figure 11.8 Polar plot of log_{10} *E. coli* results on the spring/neap tidal cycle

A low but significant correlation was found between *E. coli* results and the spring/neap cycle (circular-linear correlation, r=0.219, p=0.09, Appendix 4). The highest results all occurred when sampling was undertaken as tides decreased towards neaps.

High/Low 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. Figure 11.9 presents a polar plot of log_{10} *E. coli* results on the lunar high/low tidal cycle. High water is at 0º, and low water is at 180º.

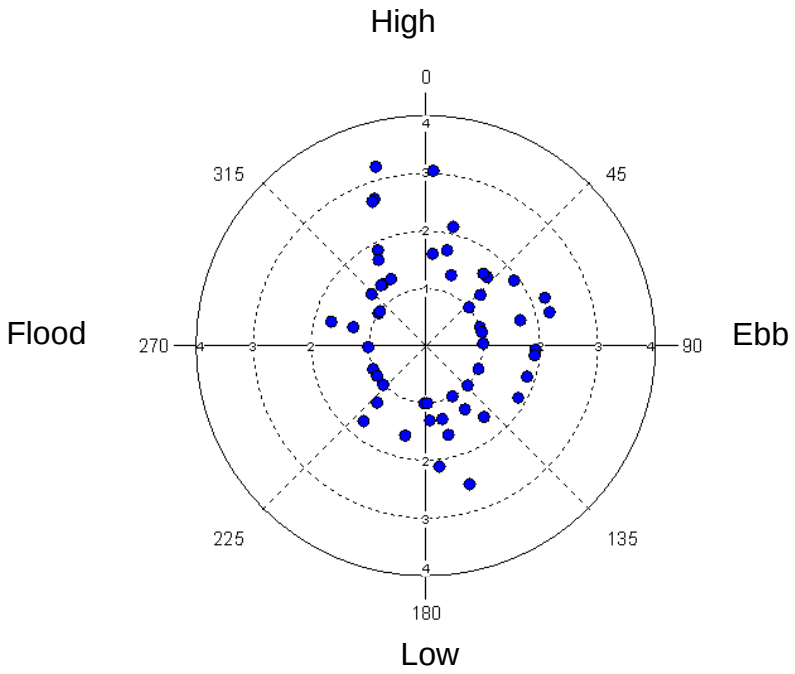


Figure 11.9 Polar plot of log_{10} *E. coli* results on the high/low tidal cycle

A significant correlation was found between *E. coli* results and the high/low tidal cycle (circular-linear correlation, r=0.344, p=0.0.003). Highest results tended to occur at or just before high water.

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 11.10 presents a scatterplot of *E. coli* results against water temperature.

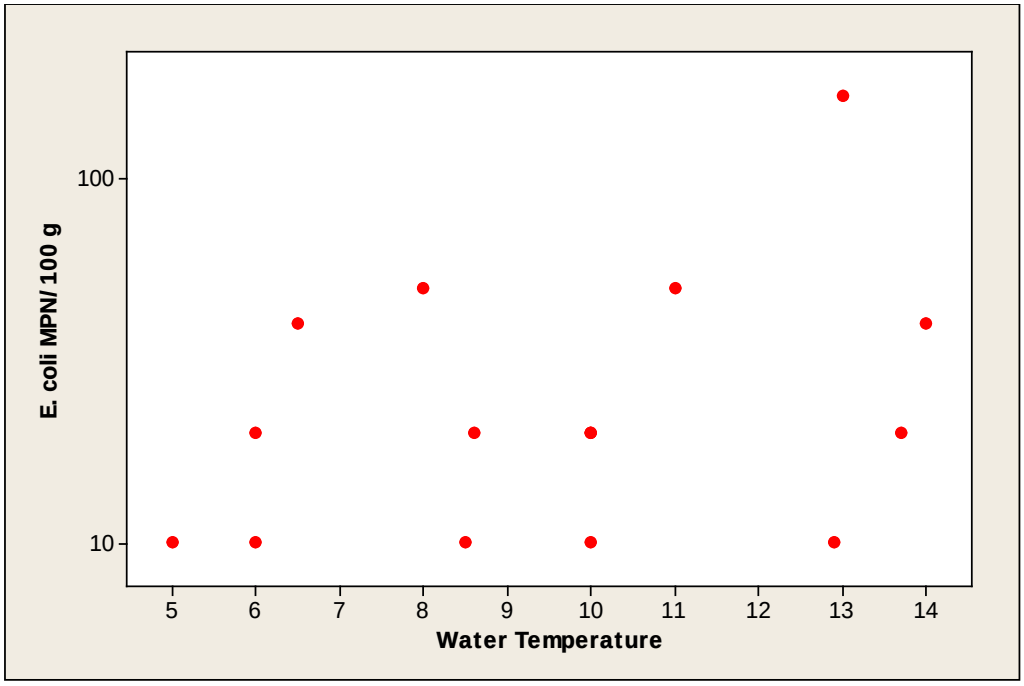


Figure 11.10 Scatterplot of result by water temperature

Water temperature was only recorded for 15 of the 53 samples. Although there appears to be a relationship in Figure 11.10, this is visually driven by the results of two samples, a low result at 5°C and a high result at 13°C, and no significant correlation was found between the two variables (Spearman's rank correlation= 0.369, p=0.175).

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 11.11 presents a scatter plot of *E. coli* result against salinity. No significant correlation was found between the *E. coli* result and salinity (Spearman's rank correlation= -0.155, p=0.287).

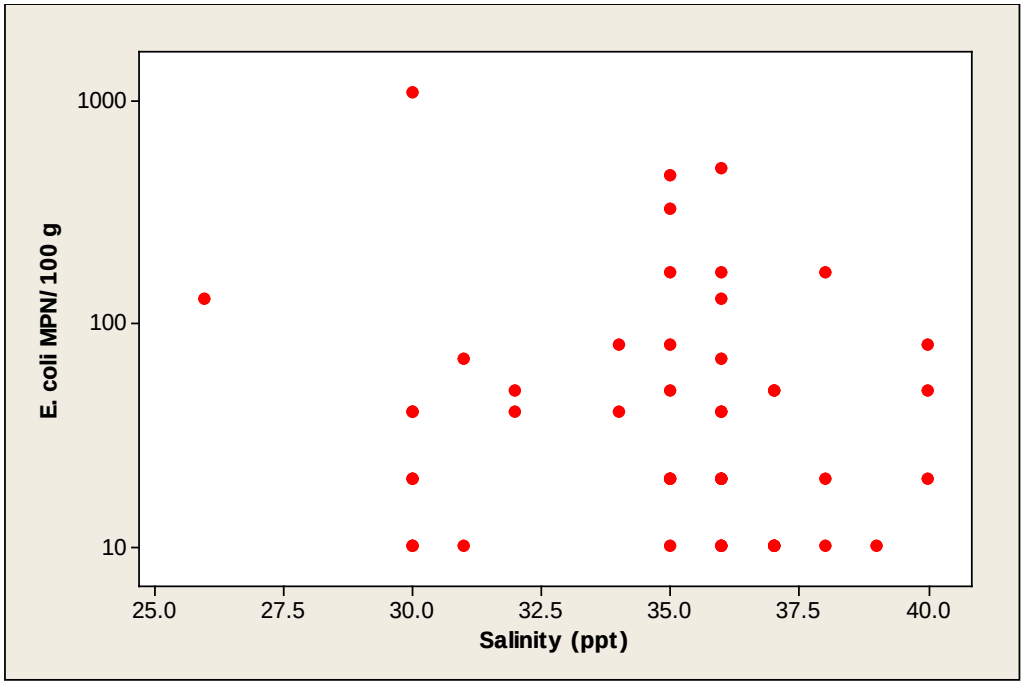


Figure 11.11 Scatterplot of result by salinity

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

A total of 5 of the 53 samples gave a result of over 230 *E. coli* MPN/100g, details of which are presented in Table 11.2.

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

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)
20/08/2007	1100	NB 117349	7.0	23.2	*	30	High	Decreasing
18/09/2007	1700	NB 117349	7.0	53.6	*	*	High	Decreasing
06/10/2008	500	NB 1178 3485	1.9	59.1	*	36	High	Decreasing
17/08/2009	330	NB 1183 3470	8.8	22.6	*	35	Low	Increasing
09/11/2009	460	NB 1182 3460	1.4	22.5	*	35	High	Decreasing

* Data unavailable

No results greater than 230 *E. coli* MPN/100 g have been seen in the production area since November 2009. As noted previously, the two highest results were seen in samples where the sampling location was reported to be at the high water mark off the northern end of the current mussel lines. All of the 5 results were seen in late summer or autumn. Significant levels of rainfall had occurred in the 7 days prior to sampling in all five cases. No water temperature data was available for any of the samples. The samples were taken under a range of water salinities, although for 3 of the 4 samples for which data was available, the salinities were high. Four of the samples were taken at or just before high water and on a decreasing tide with respect to the spring/neap cycle.

11.8 Summary and conclusions

There appeared to be a tendency for the highest *E. coli* levels to occur at the northern end of the mussel lines and moderate *E. coli* levels to occur at the middle of the mussel lines (with respect to north-south direction).

Although the time trend graph indicated that the average level of *E. coli* in the mussels has tended to be stable over the time period considered here, no results greater than 230 *E. coli* MPN/100 g have been seen since late 2009. However, there is a seasonal trend superimposed on the general level and results tend to be significantly higher in the autumn. A significant correlation was seen between *E. coli* results and rainfall in the 7 days prior to sampling, but not that in just the 2 days prior to sampling. There was also a correlation with both the spring/neap and high/low tidal cycles: higher results tended to occur on a decreasing spring/neap tide and at or just before high water.

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. Thirty-six results were available for the 3-year period from November 2008 to October 2009. The geometric mean was 34.5. This is 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 Waters Data

The Loch Roag: Eilean Teinish production area does not coincide with currently designated waters under either the European Community Shellfish Waters Directive (2006/113/EC) or the EC Bathing Water Directive (2006/7/EC). The Loch Roag Designated Shellfish Growing Water abuts the southern boundary of the production area, however its monitoring point is located over 2 km away and would not be representative of conditions at Eilean Teinish. Therefore, the SGW data are not considered here.

13. River Flow

There are no gauging stations on watercourses along the Loch Roag coastline.

The watercourses listed in Table 13.1 were the most significant observed during the shoreline survey and were measured and sampled. The locations, together with the calculated loadings, are shown in Figure 13.1. There had been heavy rain overnight and on the day prior to the first day of the shoreline survey and there were showers on the second day. Where the bacterial loading is labelled on the map, the scientific notation is written in digital format, as this is the only format recognised by the mapping software. So, where normal scientific notation for 1000 is 1×10^3, in digital format it is written as 1E+3.

Table 13.1 Watercourse loadings for Loch Roag: Eilean Teinish

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	NB 1130 3444	Stream	0.40	0.05	0.399	689	3600	2.5×10^{10}
2	NB 1112 3441	Stream	0.20	0.03	1.039	539	90000	4.8×10^{11}
3	NB 1083 3449	Stream	0.30	0.08	0.470	975	3800	3.7×10^{10}
4	NB 1067 3438	Stream	0.22	0.07	0.0302	40	7200	2.9×10^{9}

A further small stream was observed in the bay to the north-west of the mussel farm. This had a very low flow at the time of the observation and was not measured or sampled. However, the watercourse drains Loch Linish (Loch Lionais) and therefore could have significant flows after heavy rainfall. In addition, the effective catchment for the stream will be that for the loch and is thus relatively extensive compared to many of the other streams in the area.

The watercourses presented in Table 13.1 therefore represent potential sources of contamination to the southern end of the mussel lines, with the actual impact depending on the currents in the area. The streams were measured and sampled after heavy rainfall and loadings would be expected to be markedly lower after dry weather. The unmeasured stream to the north of the lines represents a potential source of contamination at that end, although the extent is unknown.

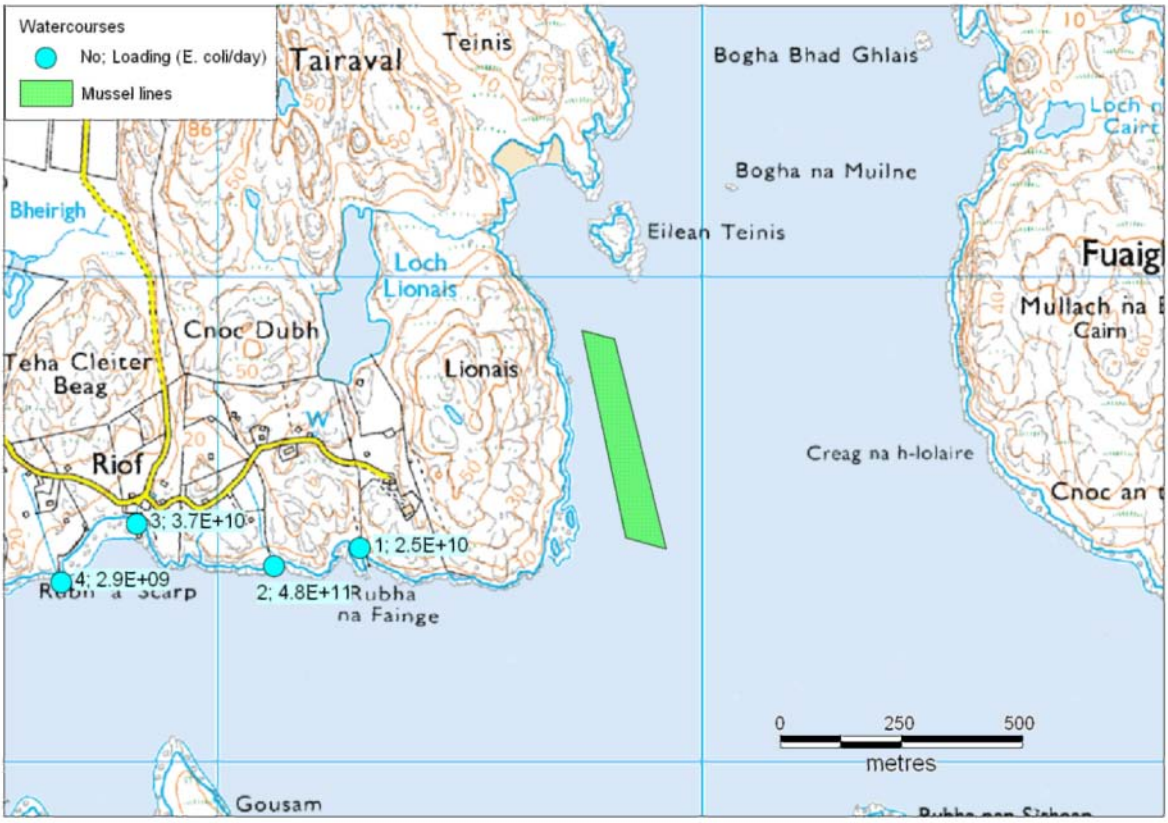


Figure 13.1 Map of watercourse loadings at Loch Roag: Eilean Teinish

14. Bathymetry and Hydrodynamics

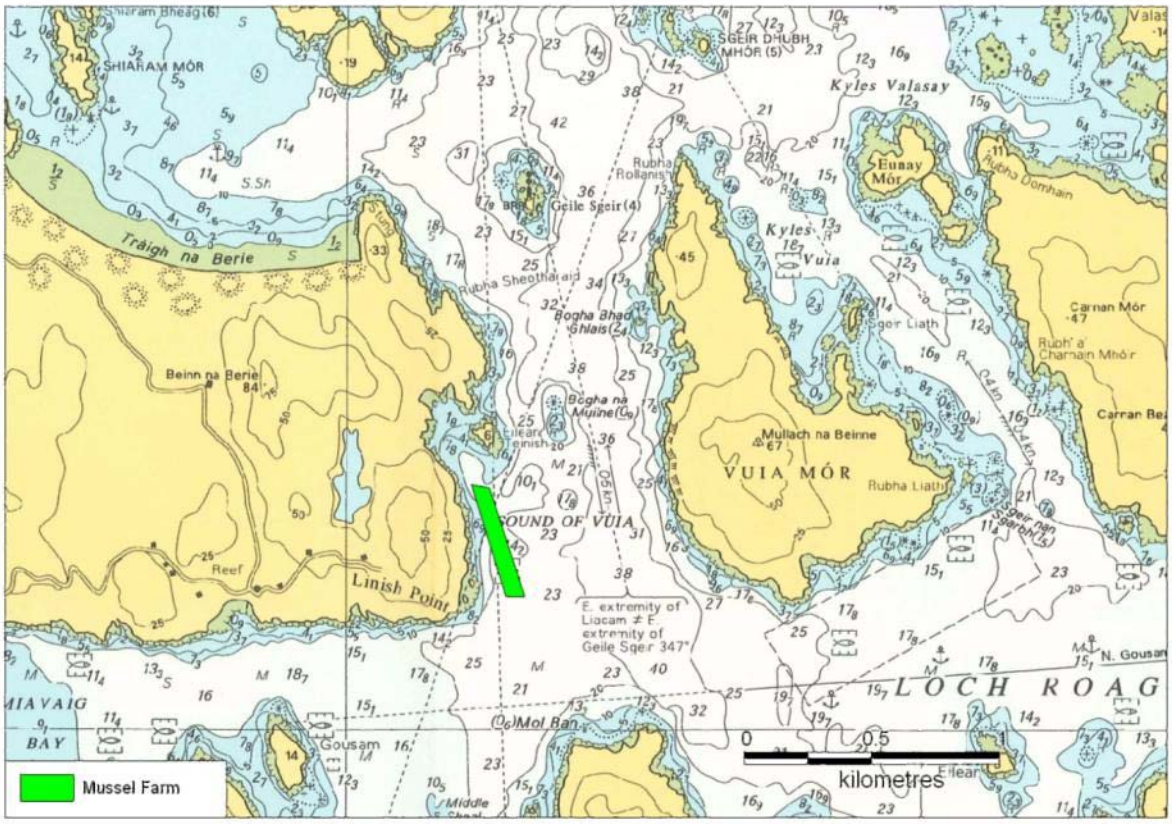


Figure 14.1 Bathymetry at Loch Roag: Eilean Teinish

Loch Roag is a large, complex sea loch situated on the western coast of the Isle of Lewis. It opens to the sea to the north. For the purposes of this report, the three areas within the broader water body will be referred to as Loch Roag West, Loch Roag and Loch Roag East. West and East Loch Roag lie either side of Great Bernera island. West Loch Roag and Loch Roag lie either side of Vuia Mòr while Loch Roag and East Loch Roag are connected by a strait between Great Bernera and the mainland of Lewis. The basin identified as Loch Roag on the chart is often included in the broader West Loch Roag term. There are a large number of islands and inlets within Loch Roag: a number of the latter are named as separate lochs. The mussel farm that is the subject of the present report lies on the western side of the Sound of Vuia, between Eilean Teinish in the north and Linish Point in the south.

Depths in the vicinity of the mussel lines are indicated to vary from 10 to more than 14 metres. It should be noted that the depths on the chart are based on an Admiralty leadline survey undertaken in 1902. The extent of drying areas is limited around the rocky shore but is more extensive around the islets by Linish Point and at the beach which lies in the bay to the north-west of Eilean Teinish.

14.1 Tidal Curve and Description

The two tidal curves below are for Little Bernera, located on the north side of Great Bernera. The tidal curves have been output from UKHO TotalTide. The first is for

seven days beginning 00.00 BST on 18/07/11 and the second is for seven days beginning 00.00 BST on 25/07/11. Together they show the predicted tidal heights over high/low water for a full neap/spring tidal cycle and cover the period during which the shoreline survey was undertaken.

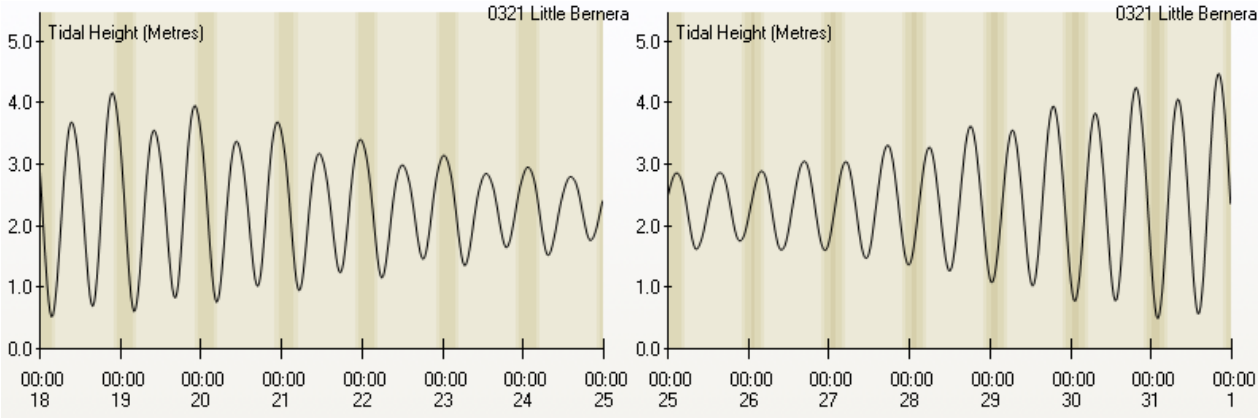


Figure 14.2 Tidal curves for Little Bernera

The following is the summary description for Little Bernera from TotalTide:

0321 Little Bernera is a Secondary Non-Harmonic port.
The tide type is Semi-Diurnal.

HAT	5.2 m
MHWS	4.3 m
MHWN	3.1 m
MLWN	1.6 m
MLWS	0.5 m
LAT	-0.1 m

Predicted heights are in metres above chart datum. The average tidal range at spring tide is 3.8 m and at neap tide 2.6 and so tidal ranges at this location are moderate (mesotidal).

14.2 Currents

Tidal stream arrows on the hydrographic chart indicate that the flood tide stream in the Sound of Vuia reaches 0.5 knots (approximately 0.25 m/s), flowing approximately southwards. They also indicate that the ebb tide stream reaches the same speed in the opposite direction.

SEPA provided current meter study data for three locations within Loch Roag. The locations are shown in Figure 14.3. The survey periods were as given in Table 14.1. Unfortunately, none of the locations were in close vicinity to the mussel farm. However, the data will inform the general assessment of current movements within Loch Roag.

Table 14.1 Survey periods for the fish farm current meter studies

Location	NGR	Survey period
Gousam	NB 11227 33758	07/07/2009-22/07/2009
Vuia Beag	NB 12109 32983	07/07/2009-22/07/2009
Kyles Vuia	NB 13514 35413	06/05/2004-03/06/2004

Polar plots of the current directions and speeds at the three locations, together with the wind direction and speeds over the relevant periods, are shown in Figure 14.4. Currents are presented in cm/s. Wind speeds are presented in m/s. As per convention, currents are plotted against the direction towards 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. Clear areas at the centre of each plot are proportional to the amount of data showing no, or negligible, current. Directions are in degrees magnetic.

The plots show that there were no or imperceptible currents at both Gousam and Vuia Beag over a large proportion of the monitoring period, with the proportions being greater at mid-depth and near-surface at Gousam than Vuia Beag. At Gousam, there is some directional component at mid-depth and near-surface but this differs between the two depths. Current speeds at the two locations were all <15cm/s (0.15 m/s; 0.3 knots).

In contrast, the plots for Kyles Vuia show a marked bidirectional current, the directions of which coincide with that of the channel and the tide stream arrows on the hydrographic chart. Maximum current speeds were in the region of 40 cm/s (0.4m/s; 0.8 knots). This is a little larger than the 0.4 knots indicated on the hydrographic chart.

At the maximum current speed of 0.25 m/s indicated on the hydrographic chart, contaminants would be expected to be taken a distance of approximately 4 km over a flood or ebb tide, ignoring any effects of dilution or dispersion. However, most currents within the area are much lower than this and transport distances would be expected to be more in the order of 1 to 2 km.

It has been calculated that the flushing time for West Loch Roag (including the Loch Roag basin) is approximately 8 tidal cycles (4 days) (Tyrer & Bass, 2005). This is a moderate flushing time: that calculated for other lochs varies between 0 and 14 days (Edwards & Sharples, 1991). Tyrer and Bass calculated the mean daily water exchange in West Loch Roag as 248 million m^3/day.

Figure 14.3 Current meter locations

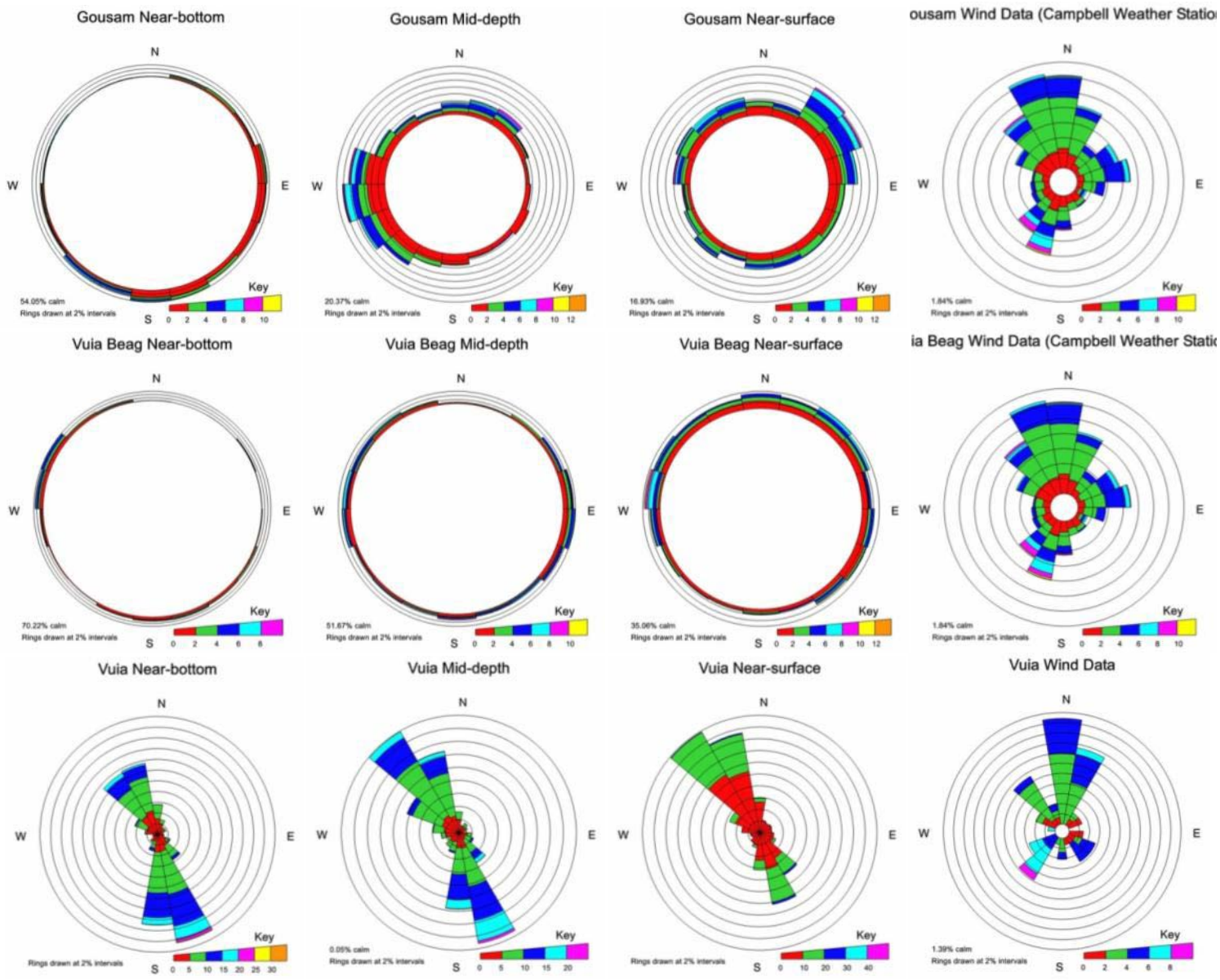


Figure 14.4 Current plots for Loch Roag

Figure 14.5 Salinity profile location

14.3 Salinity effects

One salinity profile was recorded during the shoreline survey. The location is shown in Figure 14.5 and the results are given in Table 14.2.

Table 14.2 Salinity profile results.

Profile	Date and time	Position	Depth (m)	Salinity (ppt)	Temperature (°C)
1	19/07/2011 09:57	NB 1185 3444	1	35.6	13.5
			3	35.6	13.5
			5	35.6	13.5

The profile did not show any differences in salinity or temperature between the three depths. There was no sign of any significant freshwater influence at the Eilean Teinish site. Salinity results (from laboratory analyses) for spot seawater samples taken during the survey gave results of 36.0 and 36.2 ppt respectively.

14.4 Conclusions

Currents within the area are generally weak and flows to the north and north-east predominate over much of the tidal cycle. Current flows in the vicinity of the mussel lines will follow the direction of the Sound of Vuia and will thus run parallel to the shore. Given the generally low current speeds, there is the potential for wind-driven flows to be significant. Within the Sound of Vuia, south-westerly and southerly winds will tend to increase the effects of the ebb tide and reduce the effect of the flood tide. However, there was no indication of wind effects in the current data analyses.

The line closest to the shore is likely to be impacted most by local sources. The northern end of both lines may be impacted by any contamination arising in the bay near Eilean Teinish. There is also the possibility that the southern end of both lines may be exposed to contamination arising in the eastern Reef area during ebb tides.

15. Shoreline Survey Overview

The shoreline survey was carried out on 18th, 19th and 22nd July 2011. There was heavy rain from the 17th to the early hours of 19th July and light rain for the rest of that day.

The mussel farm consisted of two double-headed long lines with droppers to 8 metres depth. The lines are oriented north to south in the channel northeast of Riof.

The main population in the area is in the small village of Riof within Loch Miavaig to the south-west of the fishery. There is some holiday accommodation in the area. Only a small number of septic tank outlets were noted at the shoreline at Riof and none were flowing at the time of the survey.

More than 100 sheep, 10 cattle and 3 pigs were seen in the vicinity of Riof. There was also evidence that cattle grazed on the steep slopes immediately to the west of the mussel lines.

Only a small number of birds were seen during the survey: no other wildlife was observed.

Four streams were measured and sampled in the vicinity of Riof and one of these returned a high *E. coli* result of 90000 cfu/100 ml indicating significant faecal contamination. A stream to the north-west of the fishery was recorded on the 22nd July but was not sampled and recorded as there was little flow at the time.

A salinity profile taken at the southern end of the mussel lines gave salinity values of 35.6 ppt and temperature values of 13.5°C at all three depths (1, 3 and 5 m).

A sample of mussels taken from the lines gave a result of <20 *E. coli* MPN/100 g and a sample of seawater taken at the same location gave a result of 1 *E. coli* cfu/100 ml. Another seawater sample taken off the western end of Riof village gave a result of 41 *E. coli* cfu/100 ml.

Figure 15.1 shows a map of the most significant findings from the shoreline survey.

Figure 15.1 Summary of shoreline survey findings for Loch Roag Eilean Teinish

16. Overall Assessment

Human sewage impacts

There are no direct sewage discharges to the Eilean Teinish production area. The nearest source of human sewage is from private dwellings in Riof, southwest of the fishery. Four consented discharges were reported to discharge to water, with the remainder discharging to land or soakaway.

A water sample taken from the stream below one of the septic tank soakaways at Riof had a result of 90000 *E. coli*/100 ml. This was an order of magnitude more contaminated than the other streams sampled and may have indicated a failing soakaway system. If that is the case, it represents the closest sewage input to the fishery at approximately 700 m from the nearest point on the mussel farm. The remaining discharges to water at Riof lie between 900 m and 1100 m west of the mussel farm. Contaminants from these sources may be carried toward the fishery on the outgoing tide.

Larger discharges can be found to the northwest at Bhaltos and Cnip. The nearest potential source to the northwest however would be the camp site at Traigh na Beirigh, which lies over 2.7 km from the northern end of the mussel lines and beyond a headland in the outer loch. Although contaminants from these sources may reach the fishery on a flooding tide, it is likely that they would be subject to significant dilution before reaching the mussel farm.

Agricultural impacts

Livestock are likely to be the largest contributors of faecal contaminants to the waters of the fishery. Both hoof prints and cattle droppings were observed on the steep hillside adjacent to the mussel farms. During periods of heavy rain, runoff from land at this location is likely to wash faecal material from the hillside into the sea and any impact on the fishery is most likely to affect the lines nearest the shore.

A total of 109 sheep, 14 cattle and 3 pigs were seen in the vicinity of Riof during the shoreline survey. Faecal contamination from these animals is most likely to be carried to the sea via freshwater streams and direct runoff from land. The streams sampled in the vicinity showed significant faecal contamination, though it was not possible to determine the relative contributions of livestock and human sources.

Wildlife impacts

Wildlife species in and around Loch Roag are likely to have a limited impact on bacteriological quality of water around the fishery due to the relatively small number of animals likely to be present compared with the large and open water area of the outer loch. Seals and seabirds may potentially directly

deposit faeces to waters at the mussel farm, this is likely to be limited in extent and duration and relatively unpredictable. Other wildlife sources of faecal contamination are waterfowl and deer. Faecal material from both these sources is likely to be present in streams discharging to the loch. Therefore impacts may be higher near where streams and other freshwater runoff reaches the loch. Waterfowl may also directly deposit droppings at or near the mussel lines anywhere within the fishery. Impacts from this source are likely to be higher nearer the surface of the lines.

Seasonal variation

There is likely to be some increase in human population during the summer holiday months though this is not quantified. The camp site at Traigh na Beirigh is able to accommodate upwards of 100 visitors, and the numbers present there are likely to be highest in July and August. It is also likely that the livestock population will be higher in summer, with larger numbers of sheep present from lambing until animals are sent off to market in the autumn. While geese are present year-round, their numbers may be higher in winter. Numbers of seabirds are likely to be higher in summer, when they are on nests and close to shore.

Rainfall varies with season, with higher rainfall observed in winter. However, extreme rainfall events were found in all months. When these events occur after periods of dry weather, as is more likely to happen in summer and autumn, higher levels of contamination are likely to be carried in runoff. Wind direction was also found to vary seasonally, with lighter winds overall and a higher incidence of northeasterly winds occurring during spring and summer. Wind-driven circulation may be significant and northeasterly winds may tend to drive contaminants arising from the southern shoreline against the shore.

An assessment of historical microbiological monitoring data indicated significant seasonal variation in *E. coli* results, with results generally higher during the period August to November.

Rivers and streams

The watercourses identified and sampled at Riof represent potential sources of contamination to the southern end of the mussel lines, with the actual impact depending on the currents in the area. The streams were measured and sampled after heavy rainfall and loadings would be expected to be markedly lower after dry weather.

The unmeasured stream to the north of the lines represents a potential source of contamination at that end, although the extent is unknown. The stream drains Loch Linish (Loch Lionais) and therefore effective catchment for the stream will be that for the loch and is thus relatively extensive compared to many of the other streams in the area. It could have significant flows after heavy rainfall.

Meteorology, hydrology, and movement of contaminants

Maximum tidal flows reported for the Sound of Vuia reach 0.5 knots, which is relatively weak. Given the generally low current speeds, wind-driven flows may be significant. South-westerly and southerly winds will tend to increase the effects of the ebb tide in the sound and reduce the effect of the flood tide. This would tend to increase the significance of sources to the south of the fishery and along the immediately adjacent shore, and decrease the significance of those arising from further outside the production area to the north.

The line closest to the shore is likely to be impacted most by local sources. The northern end of both lines may be impacted by any contamination arising in the small bay near Eilean Teinish. There is also the possibility that the southern end of both lines may be exposed to contamination arising in the vicinity of Riof during ebb tides.

Temporal and geographical patterns of sampling results

Analysis of historical monitoring data suggests no overall change in results since January 2007. However, there have been no results greater than 230 *E. coli* MPN/100 g since 2009.

Apart from the high results at the northern end of the lines for the two samples recorded as having been taken at the high water mark, there were no clear geographical patterns in the sampling results. Results at the southern end of the lines tended to be lower than those taken further north.

Conclusions

The mussel farm at Eilean Teinish is subject to predominantly limited and dilute faecal contamination.

The area of Riof, along the shore west of the southern end of the fishery, is subject to significant faecal contamination to watercourses draining the land. The watercourses receive a mix of human and livestock faecal inputs and at the time of shoreline survey carried relatively high *E. coli* loadings. However, historical monitoring results suggest that samples taken from the southern end of the mussel lines were more lightly contaminated than those taken from even a short distance further north.

Currents in the area are weak, and therefore the most significant sources of contamination are likely to be very local to the mussel lines. Prevailing winds from the southwest would tend to move surface currents northwards, suggesting that the sources at Riof may contribute at least to background levels of contamination found at the mussel farm.

Evidence of livestock presence along the hillside immediately adjacent to the fishery suggests that direct runoff from land may also carry faecal contamination to the mussel farm. The stream that discharges to the north of the lines may also carry faecal contamination from the catchment above it, which includes a small freshwater loch.

17. Recommendations

Production area

It is recommended that the production area boundary be curtailed at its northern boundary to exclude the area near the stream outlet to the north of the lines. This area is likely to be subject to higher levels of contamination particularly after rainfall. Although the Crown Estate lease on which the mussel farm is situated extends slightly beyond the southern production area boundary, it is not recommended that this boundary be adjusted from its current position as the mussel farm is contained within the boundary.

The recommended production area is described by the area bounded by lines drawn between NB 1162 3500 to NB 1252 3500 and between NB 1166 3440 to NB 1281 3444 and extending to MHWS.

RMP

It is recommended that the RMP be amended to NB 1178 3486 to reflect higher levels of contamination observed in monitoring results at the northern end of the mussel farm, close to shore.

Frequency

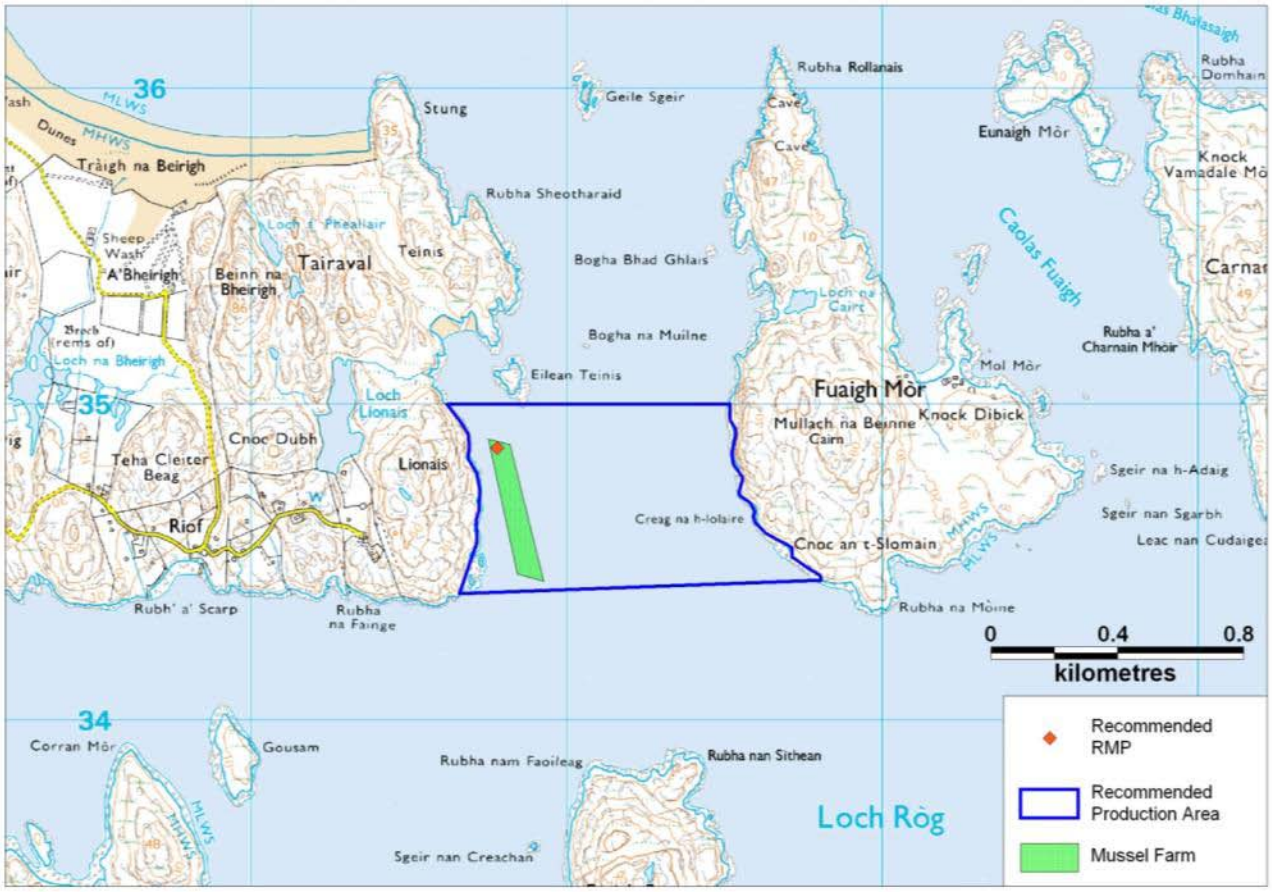
As the area did not meet the stability requirements for reduced sampling, continued monthly sampling is recommended.

Depth of sampling

It is recommended that samples be taken from within 1-3 metres depth.

Tolerance

A sampling tolerance of 40 metres is recommended to allow for movement of the lines on the anchors.



Produced by Cefas Weymouth Laboratory. © Crown Copyright and Database 2012. All rights reserved. Ordnance Survey licence number [GD100035675]

Figure 17.1 Map of recommendations at Loch Roag Eilean Teinish

18. References

Brown J. (1991). The final voyage of the Rapaiti. A measure of surface drift velocity in relation to the surface wind. *Marine Pollution Bulletin*, 22, 37-40.

Burkhardt, W., Calci, K.R., Watkins, W.D., Rippey, S.R., Chirtel, S.J. (2000). Inactivation of indicator microorganisms in estuarine waters. *Water Research*, Volume 34(8), 2207-2214.

Edwards, A. and F. Sharples. (1991) Scottish sea lochs: a catalogue. Scottish Marine Biological Association: 1991 revision, Oban. 250pp.

Kay, D, Crowther, J., Stapleton, C.M., Wyler, M.D., Fewtrell, L., Anthony, S.G., Bradford, M., Edwards, A., Francis, C.A., Hopkins, M. Kay, C., McDonald, A.T., Watkins, J., Wilkinson, J. (2008). Faecal indicator organism concentrations and catchment export coefficients in the UK. *Water Research* 42, 442-454.

Lee, R.J., Morgan, O.C. (2003). Environmental factors influencing the microbial contamination of commercially harvested shellfish. *Water Science and Technology* 47, 65-70.

Mallin, M.A., Ensign, S.H., McIver, M.R., Shank, G.C., Fowler, P.K. (2001). Demographic, landscape, and meteorological factors controlling the microbial pollution of coastal waters. *Hydrobiologia* 460, 185-193.

Mitchell, P. Ian, S. F. Newton, N. Ratcliffe & T. E. Dunn. (2004). Seabird Populations of Britain and Ireland, Results of the Seabird 2000 Census (1998-2002). T&AD Poyser, London.

Mitchell, C., Griffin, L., Trinder, M. & Newth, J. (2010). The population size of breeding greylag geese *Anser anser* in Scotland in 2008/09. *Scottish Natural Heritage Commissioned Report No. 371*

National Environment Research Council Special Committee on Seals (2010). Scientific advice on matters related to the management of seal populations: 2010. Sea Mammal Research Unit, St. Andrews University. http://www.smru.st-and.ac.uk/documents/389.pdf accessed 28/11/11.

Osgathorpe, L., Park, K., Goulson, D., Acs, S., Handley, N. (2011). The trade-off between agriculture and biodiversity in marginal areas: Can crofting and bumblebee conservation be reconciled? *Ecological Economics* 70: 1162-1169.

Tyrer A. And Bass N. 2005. *A proposed rationale for the ratification of the Site Optimisation Plan for salmon farming in Loch Roag, Lewis, Western Isles*. Report to the Western Isles Aquaculture Association. 90 pp.

Visit Hebrides. http://www.visithebrides.com/wildlife/topten/index.php, accessed 15/08/2011.

19. List of Figures and Tables

Appendices

1. **Geology and Soils Assessment Method**
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

All *E. coli* data was log transformed prior to statistical tests.

One-way ANOVA: Log_EC versus Season

```
Source  DF      SS     MS      F      P
Season   3   6.596  2.199  10.87  0.000
Error   49   9.908  0.202
Total   52  16.504

S = 0.4497   R-Sq = 39.96%   R-Sq(adj) = 36.29%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level    N    Mean   StDev  ------+---------+---------+---------+---
Autumn  12  2.1125  0.5745                       (------*-----)
Spring  15  1.1746  0.3182  (----*-----)
Summer  14  1.7224  0.5466             (-----*-----)
Winter  12  1.3876  0.2979     (------*-----)
                           ------+---------+---------+---------+---
                               1.20      1.60      2.00      2.40

Pooled StDev = 0.4497


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

Individual confidence level = 98.94%


Season = Autumn subtracted from:

Season    Lower   Center    Upper  ---+---------+---------+---------+------
Spring  -1.4009  -0.9379  -0.4748  (------*-------)
Summer  -0.8604  -0.3900   0.0803           (------*-------)
Winter  -1.2130  -0.7249  -0.2368     (-------*-------)
                                  ---+---------+---------+---------+------
                                  -1.20     -0.60      0.00      0.60


Season = Spring subtracted from:

Season    Lower  Center   Upper  ---+---------+---------+---------+------
Summer   0.1036  0.5478  0.9921                        (------*-------)
Winter  -0.2500  0.2130  0.6760                    (-------*------)
                                 ---+---------+---------+---------+------
                                 -1.20     -0.60      0.00      0.60


Season = Summer subtracted from:

Season    Lower   Center   Upper  ---+---------+---------+---------+------
Winter  -0.8052  -0.3348  0.1355            (------*-------)
                                  ---+---------+---------+---------+------
                                  -1.20     -0.60      0.00      0.60
```

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.

Background processes

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.

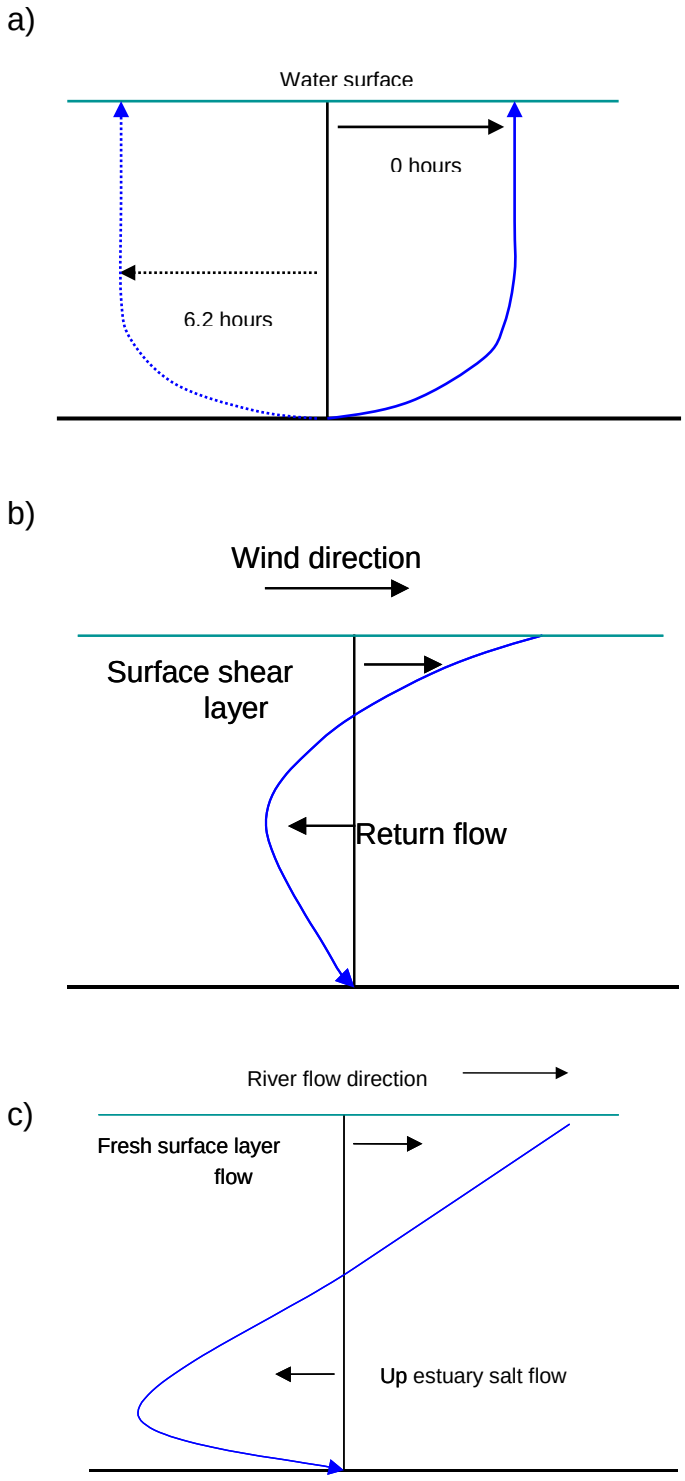


Figure 1. Typical vertical profiles for water currents. The black vertical line indicates zero velocity so portions of the profile to the left and right indicate flow moving in opposite directions. a) Peak tidal flow profiles. Profiles are shown 6.2 hours apart as the main tidal current reverses direction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

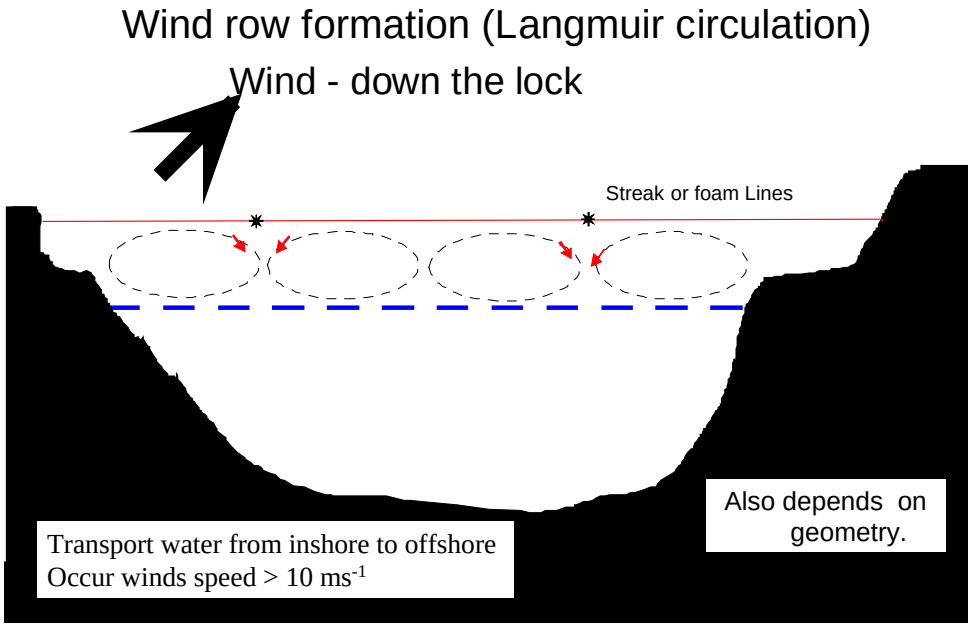


Figure 2. Schematic of wind driven 'wind row' currents. The dotted blue line indicates the depth of the surface fresh(er) water layer usually found in sea lochs.

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

Prod. area:	Loch Roag: Eilean Teinish
Site name:	Eilean Teinish (LH 338 720 08)
Species:	Common mussel
Harvester:	Cree Mackenzie/Calum Ian Mackenzie
Local Authority:	Comhairle nan Eilean Siar
Status:	Existing
Date Surveyed:	18-19, 22 July 2011
Surveyed by:	Michelle Price-Hayward, Ron Lee
Nominal RMP:	NB 119 347
Area Surveyed:	From Riof around headland to Reef Beach, Cnip and Bhaltos

Weather observations

18 July. Cloudy/misty, rain, winds N to NW F3-4, Temp 13C. Heavy rain overnight and previous day.
19 July. Heavy rain overnight. Overcast. Light rain and mist, winds N F4-5, Temp. 12C.
22 July. Dry, partly cloudy, breezy. Temp 12C.

Fishery

The Eilean Teinish mussel farm consisted of two double-headed long lines with droppers to 8 metres depth oriented north to south in the channel northeast of Riof.

Sewage/Faecal Sources

Farming and livestock

Sheep and cattle are grazed extensively throughout the area. Cattle droppings and hoofprints were found along the shore adjacent to the mussel farm. A total of 102 sheep were observed, though the terrain was rough and could have obscured an unknown additional number of animals. Most of these were seen near Riof. Ten cattle were observed in a field east of the road junction in Riof. Four were seen on the 18th, and it is likely that these four were included in the count of 10 observed on the 22nd. Their numbers are much smaller than of sheep. Three pigs were seen in a fenced field east of Riof. No arable farming was observed on land adjacent to the fishery. The settlements of Cnip (also spelled Kneep) and Bhaltos (Valtos), which lie 3.2 km to the northwest of the fishery, were visited as they were to have had public septic tanks. However, no outfalls were identified from the shoreline and no other infrastructure was seen.

Seasonal Population

A number of the homes in the area are in seasonal occupation, either as holiday homes or self-catering rentals. The nearest campsite was at Reef beach, approximately 3km to the northwest and not mapped. There were public conveniences at the beach.

Boats/Shipping

Only one small rowboat was observed near the fishery. More boats are kept further to the west, within Loch Miavaig. Fishing and tour boats are likely to pass the mussel farm on their way in and out of Loch Roag, though none were observed on the day of survey.

Land Use

Land in the area is used for extensive livestock rearing and crofting. There are a few homes in the area, some of which will only be occupied seasonally.

Land Cover
Land cover near and adjacent to the fishery is steep, rough grassland with rocky outcrops, with some bog and heather. Much of the area was grazed by livestock.

Watercourses
A number of small streams and areas of direct runoff from land were observed. A stream was observed near the north end of the mussel farm, however it was not measured or sampled at the time. As the weather continued dry, and water flows in other rivers were dropping, this stream was not revisited for sampling.

Wildlife/Birds
Small numbers of seabirds such as gulls and terns were observed during the survey, though their numbers were not specifically recorded. No significant aggregations of birds were seen. No seals were seen during the survey, although the harvester reported that they were sometimes present in the area.

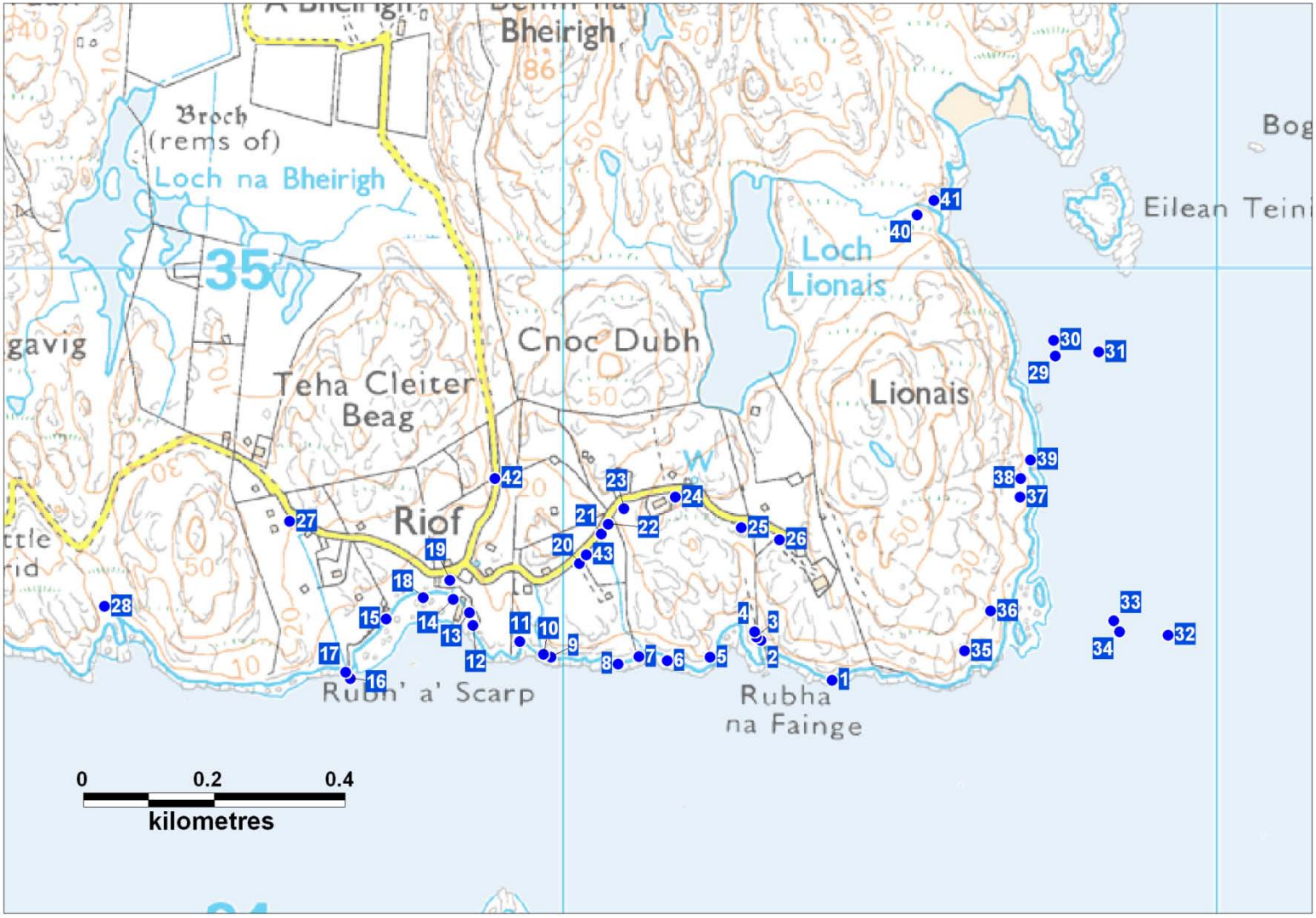


Figure 1. Map of survey observations – Eilean Teinish

Table 1. Shoreline Observations

No.	Date	Time (GMT)	NGR	East	North	Associated photograph	Description
1	18/07/2011	08:14:42	NB 11413 34370	111413	934370		No evidence of discharge pipes at shore, salmon farm just offshore, landcover heath
2	18/07/2011	08:25:28	NB 11305 34431	111305	934431		Small stream running under vegetation and dropping through rocks to shore here, no measurement or sample
3	18/07/2011	08:28:44	NB 11298 34436	111298	934436		Sheep droppings
4	18/07/2011	08:30:04	NB 11295 34444	111295	934444	Figure 3	Stream: 40 cm x 5 cm, flow 0.399 m/s, SD 0.005. Water sample 1. Hoofprints along stream, plastic and other waste washed up on shore, old row boat.
5	18/07/2011	08:43:24	NB 11227 34405	111227	934405		Other end of bay from observation 5, marshy with land runoff and sheep droppings alon the shore between these points
6	18/07/2011	08:46:44	NB 11161 34400	111161	934400		Many sheep droppings, 2 sheep in view up hill from shore
7	18/07/2011	08:49:20	NB 11118 34406	111118	934406		Stream: 20 cm x 3 cm, flow 1.039 m/s, SD 0.027. Water sample 2.
8	18/07/2011	08:57:41	NB 11086 34395	111086	934395		House, presumed to be on septic tank. No pipe to shore evident. Although the field is fenced from the shore, sheep droppings were frequent along the shore side of the fence
9	18/07/2011	09:04:38	NB 10984 34405	110984	934405		2 sheep seen up the hill and to the west, on opposite side of stream in 11
10	18/07/2011	09:05:57	NB 10972 34410	110972	934410		Small stream, houses uphill. Appears to be drainage runoff rather than permanent stream. Not measured or sampled.
11	18/07/2011	09:08:50	NB 10936 34429	110936	934429		Small stream, gravel bed so may be permanent. Not measured or sampled.
12	18/07/2011	09:20:35	NB 10864 34454	110864	934454	Figure 4	End of ceramic pipe, no apparent flow - no sewage fungus, though a strip of bright green algae on seabed.
13	18/07/2011	09:23:12	NB 10859 34473	110859	934473	Figure 5	Septic tank, discharge pipe leading downward, but no outfall pipe visible from shore
14	18/07/2011	09:28:26	NB 10834 34494	110834	934494		Stream: 30 cm x 8 cm, flow 0.470 m/s, SD 0.011. Water sample 3. Green algae growing on seabed where stream discharges. Small numbers of mussel and cockle shells on shore.
15	18/07/2011	09:38:34	NB 10732 34464	110732	934464		Small stream, shore marshy here, houses up hill along stream. Not measured or sampled.
16	18/07/2011	09:45:31	NB 10677 34373	110677	934373		Water sample 4, seawater sample.
17	18/07/2011	09:49:50	NB 10670 34382	110670	934382		Stream: 22 cm x 7 cm, flow 0.0302 m/s, SD 0.006. Water sample 5. Houses upstream.
18	18/07/2011	10:00:34	NB 10788 34496	110788	934496		Small, shallow stream adjacent to house. Not measured or sampled. Marshy land with much drainage between points 15 and 19
19	18/07/2011	10:02:45	NB 10829 34523	110829	934523		House with septic tank on shore side of road.
20	18/07/2011	10:08:30	NB 11027 34549	111027	934549		House, farm buildings, 7 sheep on shore side of road.
21	18/07/2011	10:09:56	NB 11061 34594	111061	934594		Concrete septic tank with small diameter pipe overflow to land/ditch - not flowing.
22	18/07/2011	10:10:42	NB 11071 34609	111071	934609		4 cattle in field on land side of road.
23	18/07/2011	10:11:41	NB 11095 34633	111095	934633		Home with 23 sheep in field behind it

No.	Date	Time (GMT)	NGR	East	North	Associated photograph	Description
24	18/07/2011	10:14:09	NB 11174 34650	111174	934650		27 sheep
25	18/07/2011	10:16:17	NB 11275 34603	111275	934603		8 sheep
26	18/07/2011	10:17:23	NB 11333 34585	111333	934585		8 sheep
27	18/07/2011	10:25:35	NB 10584 34613	110584	934613		Farm on the shore side of road with 32 sheep
28	18/07/2011	10:32:31	NB 10301 34483	110301	934483		Cattle droppings
29	19/07/2011	09:43:43	NB 11755 34866	111755	934866		Eilean Teinish - 2 double-headed longlines, 8 m droppers. Mussel sample 1, 0-1.5m depth, water sample LRET-1
30	19/07/2011	09:49:08	NB 11752 34890	111752	934890		Corner of mussel farm (taken approximately at anchor float)
31	19/07/2011	09:49:48	NB 11821 34872	111821	934872		Corner of mussel farm (taken approximately at anchor float)
32	19/07/2011	09:54:26	NB 11927 34439	111927	934439		Corner of mussel farm (taken approximately at anchor float)
33	19/07/2011	09:55:42	NB 11844 34461	111844	934461		Corner of mussel farm (taken approximately at anchor float)
34	19/07/2011	09:57:54	NB 11853 34444	111853	934444		Salinity profile: 5m - 35.6 ppt/13.5C. 3m - 35.6 ppt/13.5C. 1m - 35.6 ppt/13.5C
35	22/07/2011	15:12:19	NB 11616 34415	111616	934415		View over fishery from headland east of Riof
36	22/07/2011	15:35:29	NB 11656 34476	111656	934476		Track poached by cattle
37	22/07/2011	15:42:55	NB 11701 34650	111701	934650	Figure 6	Photo of Eilean Teinish lines
38	22/07/2011	15:45:58	NB 11702 34679	111702	934679		Land drainage - wet but not flowing, cattle droppings
39	22/07/2011	15:48:11	NB 11717 34707	111717	934707		Land drainage - seeping
40	22/07/2011	16:10:25	NB 11543 35082	111543	935082	Figure 7	Stream, photo
41	22/07/2011	16:13:15	NB 11569 35104	111569	935104	Figure 8	Land drainage – mostly dry with a small dribble. Wide ditch suggests flow higher after rain
42	22/07/2011	16:58:48	NB 10898 34679	110898	934679		10 cattle east of the road
43	22/07/2011	17:04:32	NB 11038 34562	111038	934562		3 pigs

Photographs referenced in the table can be found attached as Figures 3-8.

Sampling

Water and shellfish samples were collected at sites marked on the map. Samples were transferred to either Biotherm 25 or Biotherm 10 boxes with ice packs and shipped to Glasgow Scientific Services on the day collected for *E. coli* analysis. In all cases, samples were received and analysed on the day following collection. Sample temperatures on arrival ranged between 6.2 and 9.4 C, with samples taken on 19 July arriving above the recommended temperature range of 2-8C. Investigations undertaken by the National Reference Laboratory (NRL) have shown no significant effect on sample *E. coli* concentrations with up to 48 hours' storage at temperatures ≤10ºC. Sample results have been included in Tables 2 and 3.

Seawater samples were tested for salinity by the laboratory and results reported in mg Chloride per litre. These results have been converted to parts per thousand (ppt), and are shown in Table 2.

Salinity and temperature were recorded at 1 meter, 3 meters and 5 meters depth at a single location using a YSI ProPlus CT probe. The resulting profile is reported in Table 4.

Table 2. Water Sample Results

No.	Date	Sample	Grid Ref	Type	E. coli (cfu/100ml)	Salinity (ppt)
1	18/7/2011	LRMW1	NB 1130 3444	Freshwater	3600	
2	18/7/2011	LRMW2	NB 1112 3441	Freshwater	90000	
3	18/7/2011	LRMW3	NB 1083 3449	Freshwater	3800	
4	18/7/2011	LRMW4	NB 1068 3437	Seawater	41	36.0
5	18/7/2011	LRMW5	NB 1067 3438	Freshwater	7200	
6	19/7/2011	LRETW1	NB 1176 3487	Seawater	1	36.2

Table 3. Shellfish Sample Results

No.	Date	Sample	Grid Ref	Type	E. coli (MPN/100g)
1	19/07/2011	LRETEIN	NB 1176 3487	Mussel	<20

Table 4. Salinity profiles

Profile	Date and time	Position	Depth (m)	Salinity (ppt)	Temperature (°C)
1	19/07/2011 09:57	NB 1185 3444	1	35.6	13.5
			3	35.6	13.5
			5	35.6	13.5

Water and shellfish sampling locations are shown mapped in Figure 2.

Contamination levels in freshwater ranged from 1 to 90000, with all samples containing >1000 E. coli/100 ml coming from sources along the shore of Riof. The least contaminated water sample came from at the northern end of mussel farm.

The shellfish samples taken during the survey contained no detectable *E. coli* in 100 g of shellfish flesh and intravalvular fluid.

Figure 2. Sample results – Eilean Teinish

Photographs

Figure 3. Stream

Figure 4. End of ceramic septic pipe

Figure 5. Septic tank

Figure 6. View of Eilean Teinish lines from west shore

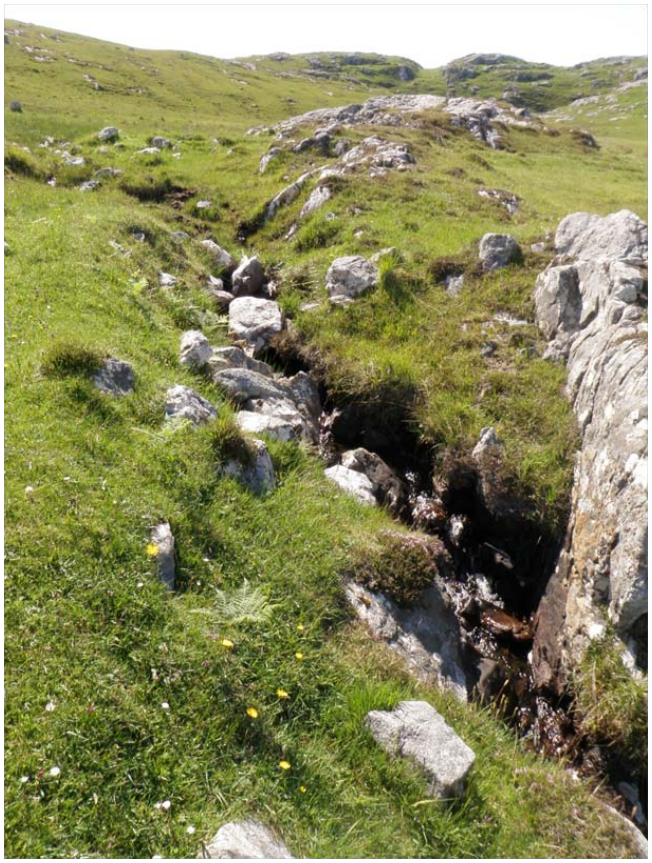


Figure 7. Stream flowing on west shore

Figure 8. Mostly dry drainage bed