Scottish Sanitary Survey Project

Sanitary Survey Report
Loch Seaforth
LH 484 & LH 193
April 2011

Report Distribution – Loch Seaforth

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

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1. General Description

Loch Seaforth is located on the east coast of Lewis, the largest and most northerly of the western isles, and forms part of the boundary between Lewis and Harris. There is little in the way of human habitation along much of the shoreline. The main body of the loch is open to the south. Seaforth Island lies in the centre of the loch and above the island the upper loch turns north eastward and then finally eastward toward its head. The land surrounding the loch is steeply-sided, particularly along its southern end.

Figure 1.1 Location of Loch Seaforth

2. Fishery

The sanitary survey was prompted by an application for classification of a new site in Loch Seaforth, to the west of Seaforth Island (Eilean Shiophoirt). This area lies north of the classified Loch Seaforth production area. Areas considered in this survey are summarised in Table 2.1.

Table 2.1 Loch Seaforth production areas and sites

Production Area	Site	SIN	Species	Sampling point
Eilean Shiophoirt	East Coast Mussels (Seaforth Island East)	LH 484 811	Common mussels	NB 2138 1140
Loch Seaforth	Loch Seaforth (Seaforth South)	LH 193 126	Common mussels	NB 218 071 (RMP)

Eilean Shiophoirt

The East Coast Mussels (LH 484 811) site is not currently classified, and does not fall within a designated shellfish production area. The proposed seabed lease area boundaries for the mussel farm are lines drawn between NB 2114 1193 to NB 2173 1038 to NB 2191 1045 to NB 2134 1201. Samples are currently reported as being taken from NB 2138 1140.

At the time of shoreline survey, this site consisted of two 200m mussel longlines from which 8m droppers were suspended. These were deployed in early 2008, and at the time of survey held stock of a harvestable size. Planning records at Comhairle nan Eilean Siar indicate that these lines are intended to be 300 m long and refer to the site as Seaforth Island East.

Loch Seaforth

Current production area boundaries are given as the area bounded by lines drawn between NB 2065 0800 to NB 2166 0800 then from NB 2047 0600 to NB 2263 0600 extending to MHWS. At the time of shoreline survey, the Loch Seaforth site consisted of four 300 m mussel longlines. Some stock was present on one of these lines but the majority had been harvested. This site lies only partially within the Loch Seaforth production area and does not lie within the boundaries of existing Crown Estate leases. A planning application was lodged with Comhairle nan Eilean Siar in on 27 September 2010 for the area corresponding with the locations of the lines as observed during the shoreline survey, in which this site is referred to as Seaforth South.

Both sites are under the same ownership. Time of harvesting is demand driven, and takes place primarily during the spring/summer at times when Shetland mussel sites are closed for biotoxins and unable to supply the market. It is planned that in future the Loch Seaforth site will be used primarily for spat collection, and once spat has settled and established the stock will be transferred to the more sheltered East Coast mussels site for ongrowing.

Figure 2.1 shows the location of the proposed production area and existing production areas within Loch Seaforth, as well as the locations of the mussel lines as recorded during the shoreline survey.

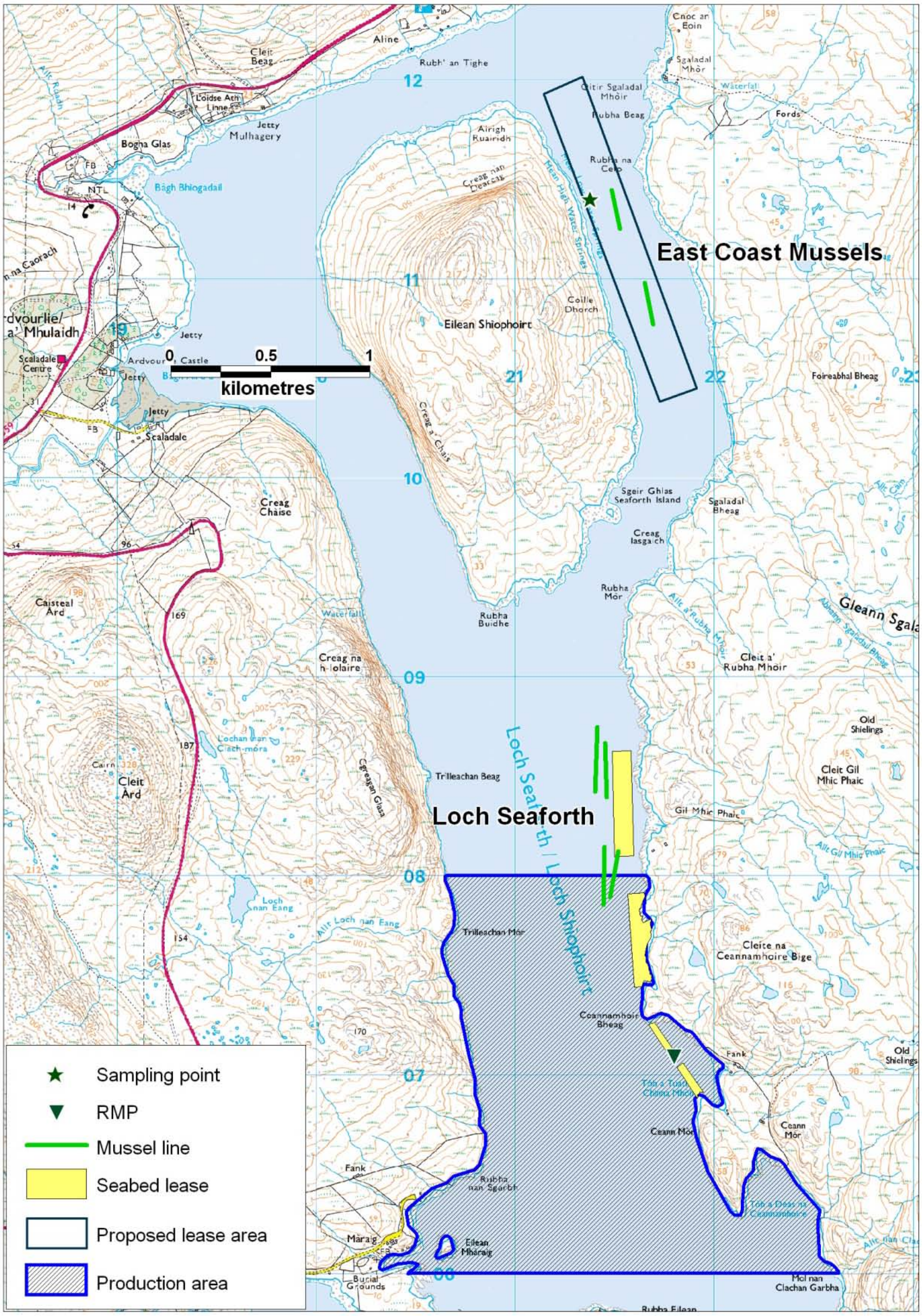

Figure 2.1 Loch Seaforth mussel fishery

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 mussel fishery in Loch Seaforth. The last census was undertaken in 2001.

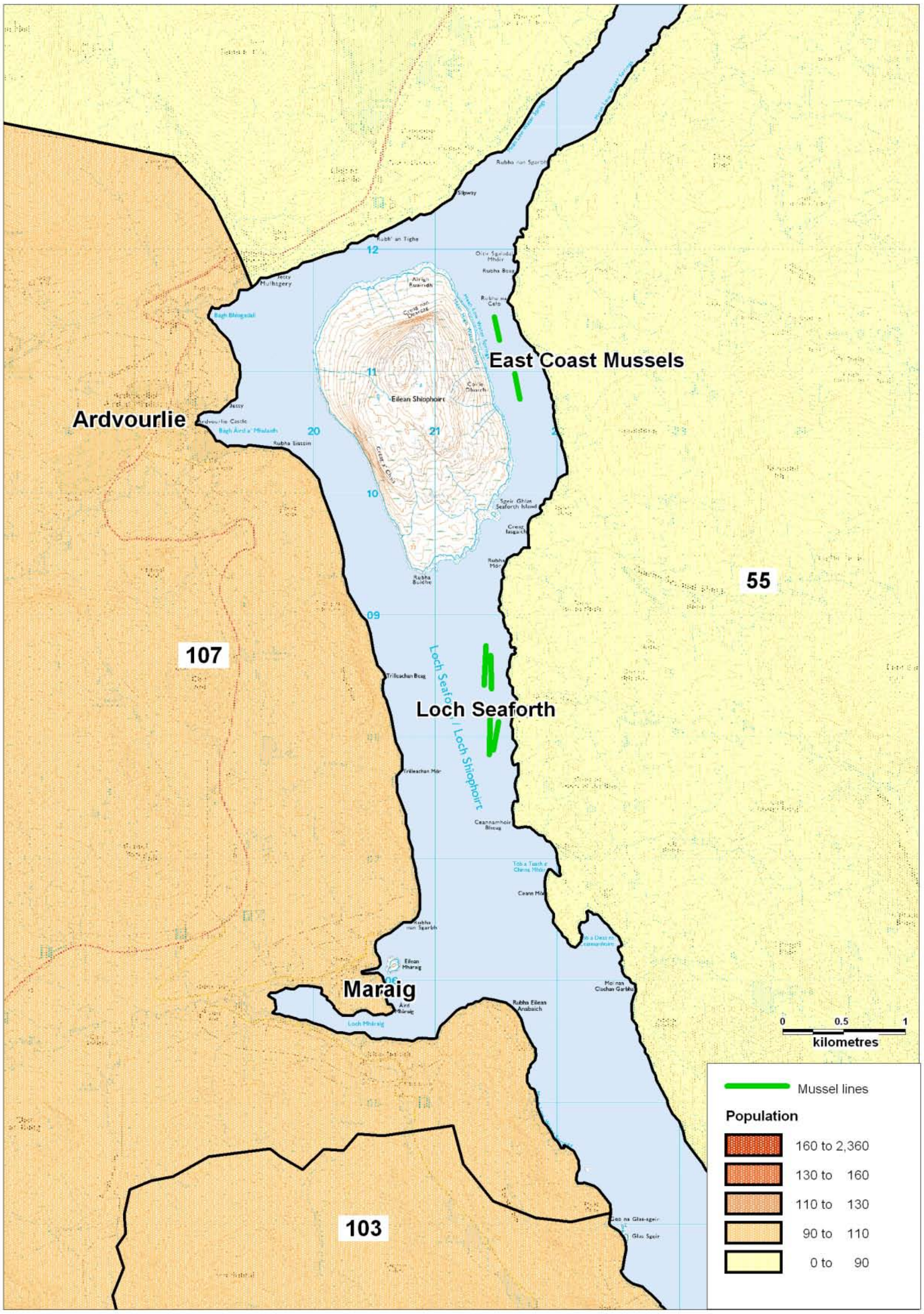

Figure 3.1 Human population adjacent to Loch Seaforth mussel fishery

There are three population census areas within the proximity of the fishery at Loch Seaforth, with populations of 107, 103 and 55. Only a small proportion of these live on the coastline. These census areas are relatively large and sparsely populated.

There are no large centres of population in the area. Seaforth Island is uninhabited. The east coast of the loch is uninhabited and inaccessible by road. Two small settlements, Ardvourlie and Maraig, are located on the west side of the loch. Overnight tourist accommodation for over 50 people is available near Ardvourlie. The Aline estate lies along the coast north of Seaforth Island, and provides accommodation for 20+ in a lodge and four cottages, offering fishing, deer stalking and game bird shooting. The Scaladale Center provides overnight lodging and outdoor activities for groups of up to 28 and also caters for daytime use by up to 60 for training or conferences. Further accommodation is located in Bowglass, just to the north of Ardvourlie.

Therefore, the visitor population is likely to exceed the permanent resident population particularly during peak season, which is likely to extend beyond the traditional summer holiday months into the main deer stalking months of September and October.

4. Sewage Discharges

Information on discharges in the vicinity of Loch Seaforth was solicited from Scottish Water and the Scottish Environment Protection Agency (SEPA). No community sewage discharges were identified for Loch Seaforth by Scottish Water.

Fifteen consented discharges in the area were listed by SEPA, details of which are presented in Table 4.2.

Table 4.1 Discharge consents identified by SEPA

No.	Ref No.	NGR of discharge	Discharge Type	Level of Treatment	Consented/ design PE	Discharges to
1	CAR/R/1048585	NB 1965 1178	Septic tank	Primary	7	Loch Seaforth
2	CAR/R/1057753	NB 1878 1145	Septic tank	Primary	5	soakaway
3	CAR/R/1057730	NB 1883 1142	Septic tank	Primary	6	soakaway
4	CAR/R/1059656	NB 1902 1063	Septic tank	Primary	5	Bagh Aird a Mhulaidh
5	CAR/R/1011524	NB 1900 1050	Septic tank	Primary	10	Loch Seaforth
6	CAR/R/1057112	NB 1922 1028	Septic tank	Primary	5	Bagh Aird a Mhulaidh
7	CAR/R/1066741	NB 1916 1024	Septic tank	Primary	5	unnamed watercourse
8	CAR/R/1066404	NB 2054 0639	Septic tank	Primary	5	Loch Seaforth
9	CAR/R/1061613	NB 2041 0618	Septic tank	Primary	5	soakaway
10	CAR/R/1056277	NB 2037 0615	Septic tank	Primary	5	soakaway
11	CAR/R/1059264	NB 2030 0610	Septic tank	Primary	5	soakaway
12	CAR/R/1059636	NB 1982 0597	Septic tank	Primary	5	Loch Seaforth
13	CAR/R/1056222	NB 1974 0594	Septic tank	Primary	5	Loch Maraig
14	CAR/R/1056273	NB 1966 0598	Septic tank	Primary	5	soakaway
15	CAR/R/1054933	NB 1942 0586	Septic tank	Primary	5	Loch Maraig
16	CAR/R/1054927	NB 1949 0568	Septic tank	Primary	5	unnamed watercourse

A further 10 consents were identified for small septic tanks along the north shore of the loch, approximately 7 km northeast of the north end of Eilean Shiophoirt. All but one discharge to soakaway. Therefore, as they are unlikely to pose a significant risk to the shellfishery, the details have not been included in the table above. No consents were provided for discharges associated with the Aline lodge properties and it should be presumed that septic discharges from the lodge and four cottages would be present in the area. However, it is not known whether these would discharge to soakaway or directly to the loch. There does not appear to be a consent associated with the Scaladale Centre, though there are smaller consented discharges in the same area.

A shoreline survey was undertaken in September 2010 and discharge observations made during the survey are listed in Table 4.3 below. All of the sewage discharges identified in the tables are shown mapped in Figure 4.1 along with the location of the fishery.

Table 4.2 Discharges and septic tanks observed during shoreline surveys

No.	Date	NGR	Description	SEPA consent ref.
1	02/09/2010	NB 1916 1027	Septic tank	CAR/R/1066741
2	02/09/2010	NB 1907 1023	Septic tank leaking onto shore	
3	02/09/2010	NB 1984 0592	Concrete septic tank	CAR/R/1059636

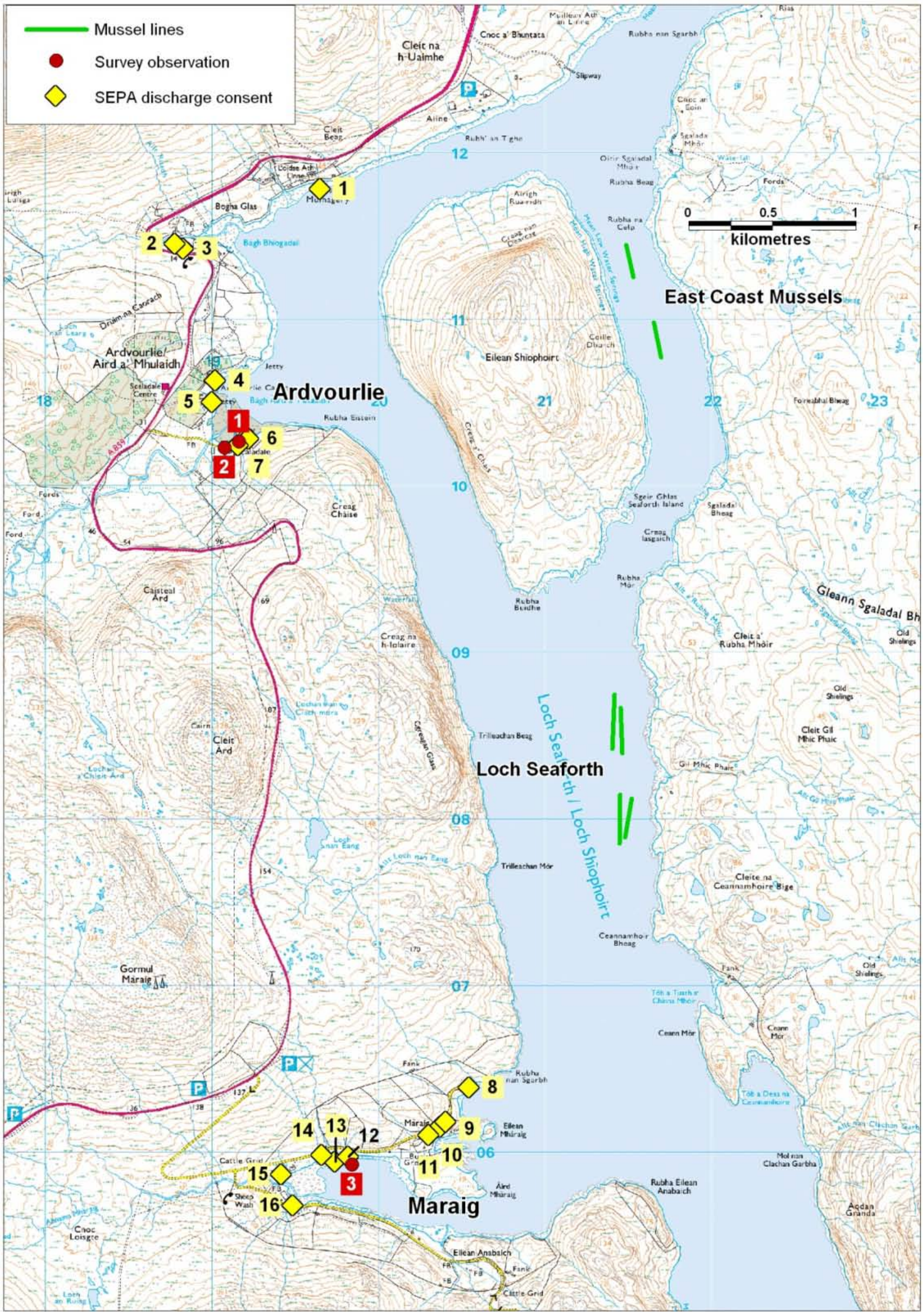

Figure 4.1 Map of discharges for Loch Seaforth

Discharges were centred around two settlements on the west shore of the loch, Ardvourlie and Maraig. The majority discharged to either watercourses or the loch. Any discharges associated with facilities at Aline would lie closest to the fishery, at just over 1 km away from the north end of the East Coast Mussels site. No discharges were identified on the eastern side of the loch, which is unpopulated.

5. Geology and Soils

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

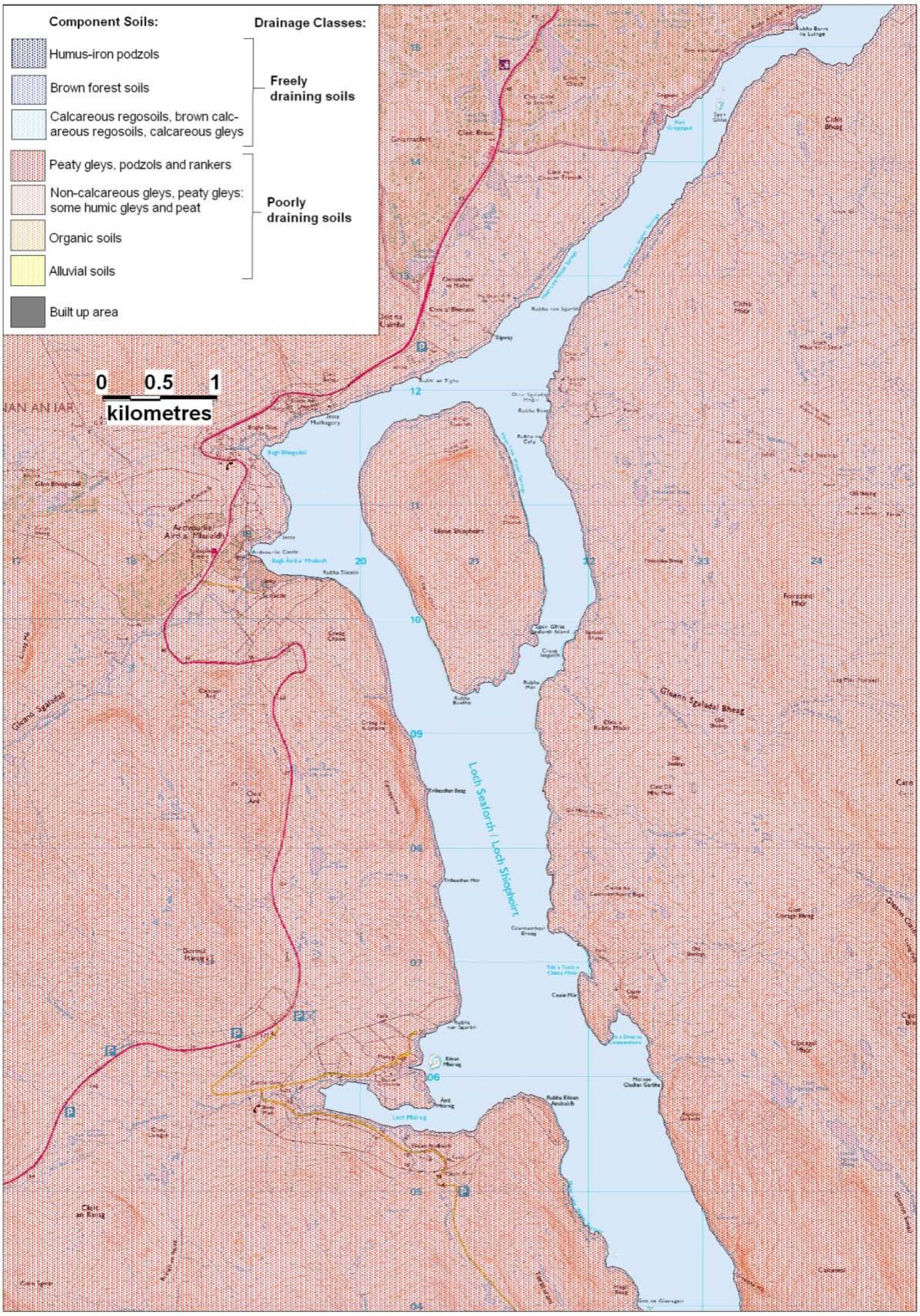

Figure 5.1 Component soils and drainage classes for Loch Seaforth

A single type of component soil is present in the area: peaty gleys, podzols and rankers. These soils are poorly draining. The steeply sloping topography found along much of the shoreline will also contribute to the tendency for rainfall to run off rather than permeate into the soil. Therefore, the potential for runoff contaminated with *E. coli* from human and/or animal waste is high for all the land surrounding Loch Seaforth.

6. Land Cover

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

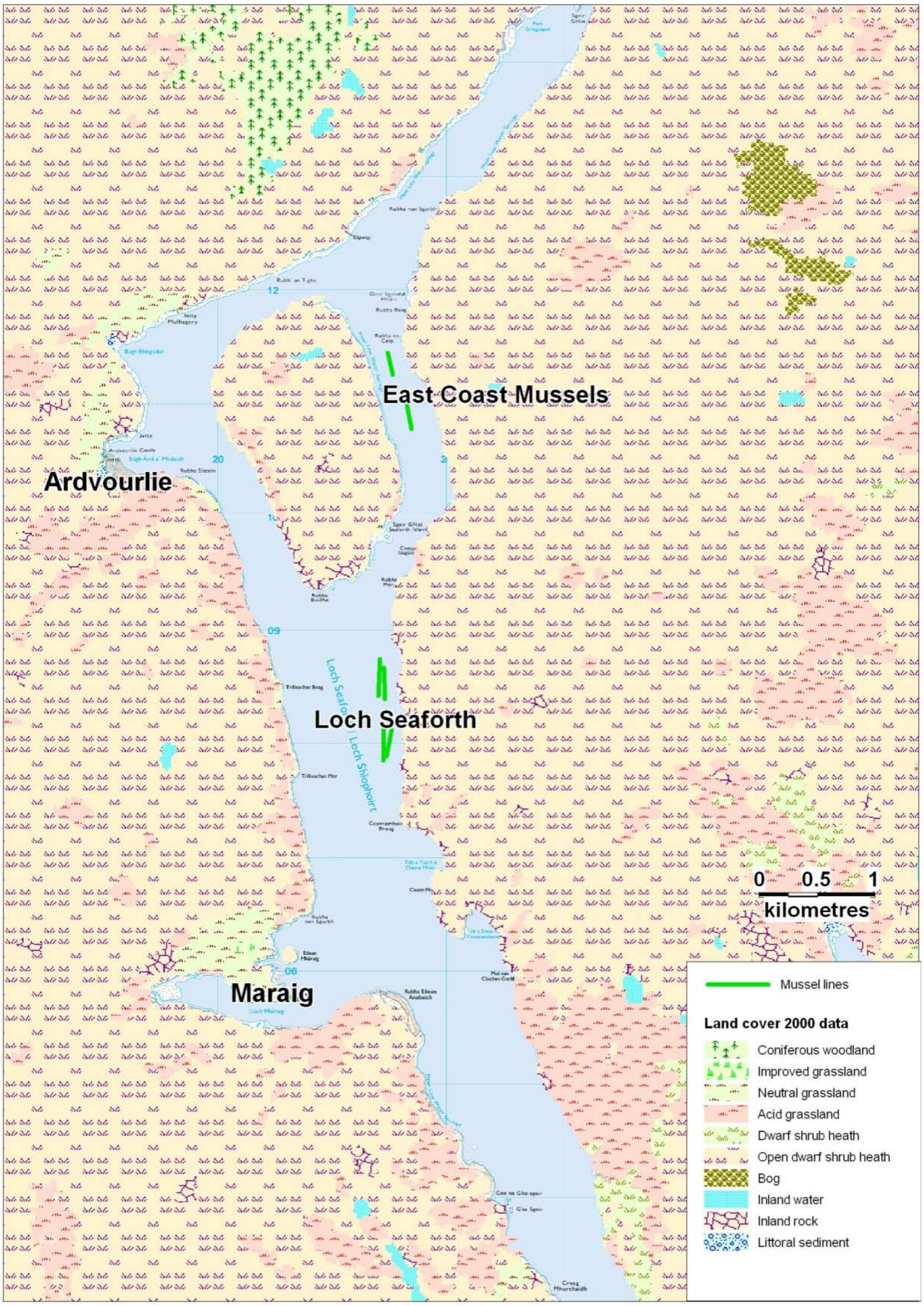

Figure 6.1 LCM2000 class land cover data for Loch Seaforth

The landcover on both sides of the fishery is predominantly classed as open dwarf shrub heath. Small areas of acid and neutral grassland, dwarf shrub heath and bog. A substantial area of acid grassland lines the southeastern shore, south of the fishery. Further areas of natural and acid grassland can be found around Arvourlie and Maraig, with acid grassland lining the shore between them. There is a large area of coniferous woodland on the north western shoreline of the loch.

Studies undertaken by Kay et al (2008) found that faecal indicator organism export coefficients for faecal coliform bacteria were highest for urban catchment areas (approx 1.2 – 2.8×10^9 cfu km^{-2} hr^{-1}) and lower for areas of improved grassland (approximately 8.3×10^8 cfu km^{-2} hr^{-1}) and rough grazing (approximately 2.5×10^8 cfu km^{-2} hr^{-1}) areas. Lowest contributions would be expected from areas of woodland (approximately 2.0×10^7 cfu km^{-2} hr^{-1}) (Kay *et al*. 2008). The contributions from all land cover types would be expected to increase significantly after marked rainfall events, however this effect would be particularly marked from improved grassland areas (roughly 1000-fold) (Kay *et al*. 2008).

There are no urban areas are present in the vicinity of the fisheries. A very small area of improved grassland is noted at Maraig. The remainder of the grassland areas particularly those on the west shore of the loch would be classed as rough grazing. While areas of heath may be grazed extensively by sheep and deer and so could be considered as rough grazing, stocking densities are likely to be much lower and therefore deposition of faecal material and hence export coefficients will be lower as well.

The risk to the mussel fisheries from faecal contamination attributable to land cover is low to moderate for both sites, with the areas of highest potential risk around the grassland areas around Maraig and Ardvourlie.

7. Farm Animals

Agricultural census data was requested for the parishes of Lochs and Harris from the Scottish Government Rural Environment, Research and Analysis Directorate (RERAD). These parishes encompass a land area of 489 km^2 and 503 km^2 respectively. The Lochs parish stretches over 30 km from north to south while the Harris parish covers the southern part of the island plus a number of smaller islands between Lewis and North Uist. Reported livestock populations for the parishes in 2008 and 2009 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 Lochs and Harris parishes 2008 - 2009

	Lochs				Harris			
	2008		2009		2008		2009	
	Holdings	Numbers	Holdings	Numbers	Holdings	Numbers	Holdings	Numbers
Pigs	*	*	*	*	*	*	*	*
Poultry	38	610	40	661	55	1,013	52	863
Cattle	41	334	41	316	37	423	39	409
Sheep	285	24,632	289	24,739	247	33,188	249	31,744
Horses and ponies	18	47	18	44	7	14	6	10

* Data withheld for reasons of confidentiality

Sheep are the predominant livestock kept in both parishes, with much smaller numbers of cattle, poultry and horses also present. Pigs are kept on a small number of holdings, though specific data could not be released. The reported numbers of sheep and poultry increased in Lochs parish from 2008 to 2009 but numbers of all reported livestock species decreased in Harris over the same period.

Due to the large size of the parishes, and the withheld data, an accurate representation of the amount of livestock directly surrounding the shellfishery is therefore only available from the shoreline survey (see Section 15 and Appendix 7). This data relates only to the time of the site visit on 1-2 September 2010 and is dependent on the point of view of the observer. The spatial distribution of animals observed and noted during the shoreline survey is illustrated in Figure 7.1.

A total of 95 sheep were observed near settled areas on the west side of the loch. Sheep are also grazed on Eilean Shiophoirt and according to the harvester had been present there two weeks before the shoreline survey. Droppings and hoof prints were observed on the east shore of the island. No other livestock were noted. Overall, livestock were not observed in large numbers in the area. Seasonally, the number of animals present is likely to increase in late spring with the birth of lambs and decrease again in the autumn when lambs are sent to market. Any impact of livestock faecal contamination is likely to be higher along the west shore, where animals are kept on or near the settlements.

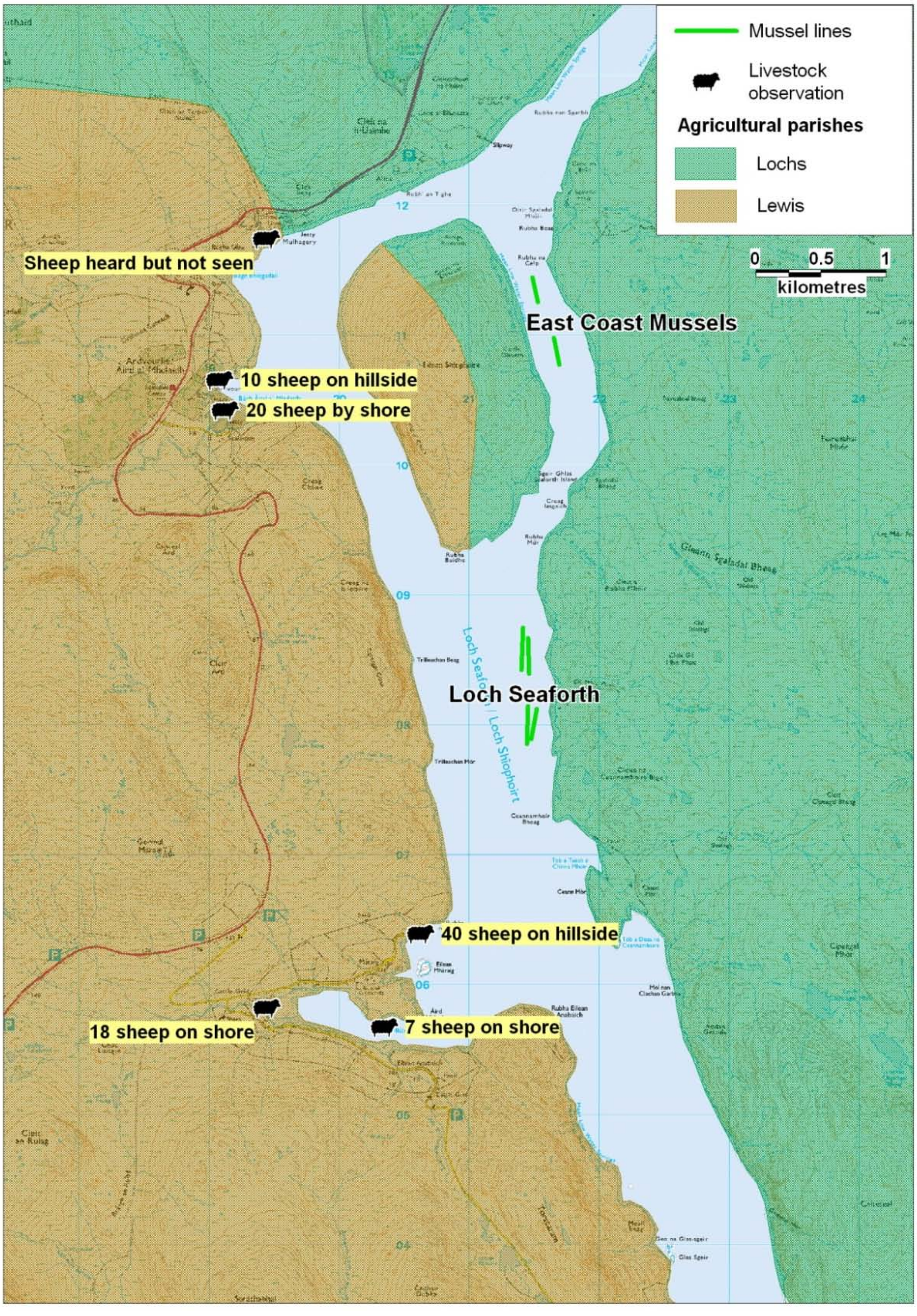

Figure 7.1 Livestock observations at Loch Seaforth

8. Wildlife

The North Harris Mountains Special Protection Area (SPA) and North Harris Special Area of Conservation lie approximately 6 km west of Loch Seaforth. The North Harris Mountains SPA was designated for its breeding population of eagles (7 pairs in 1992). The North Harris SAC was listed for its freshwater pearl mussels, natural dystrophic lakes and North Atlantic wet heath habitats and notes that otters (*Lutra lutra*) are also present.

Seals

Both grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina vitulina*) are present in Loch Seaforth. Surveys undertaken in 2007 and 2007 showed harbour seals to be present in the upper loch and grey seals in the outer loch. Approximately 20-30 individuals of each species were counted. (Natural Environmental Research Council 2009). Therefore, it is likely that seals of both species are regularly present in the area. No seals were seen during the shoreline survey.

Whales/dolphins

Porpoises were recorded near shore at the mouth of Loch Seaforth by the North Harris Trust ranger (http://www.north-harris.org/2010/12/13th-december-porpoises-loch-seaforth/) in late 2010, indicating that these animals are present in the area. Although it is unlikely that larger whale species would venture up the loch, smaller animals such as porpoises or dolphins may and so it must be presumed that they could be present at least near the southernmost of the two mussel farms.

Otters

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

Birds

There were no Seabird 2000 records for a 10 km radius surrounding Loch Seaforth. There is little in the way of intertidal area that would host wading bird species. Eagles are recorded in the area, but while their numbers are significant in terms of conservation they are unlikely to pose a significant risk of faecal contamination to the fisheries in Loch Seaforth. A small number of seabirds were observed during the shoreline survey, and the locations of these are shown in Figure 8.1.

Bird's species such as gulls or cormorants are likely to be present year round and also to rest on the floats, and therefore directly deposit faecal material to the waters around the fishery: this was observed during the shoreline survey. However, this is difficult to predict in terms of time or exact location therefore any impact will be presumed to be evenly distributed across the fishery.

Deer

Deer census records from the Deer Commission for Scotland for 2006 showed a significant population of red deer located in the hills to the west of Loch Seaforth. Records totalled over 100 animals, however the majority of these were seen greater than 4 km inland. The Eishken Deer Forest lies to the east of the loch, therefore a significant population of deer is also likely to inhabit the eastern shore. The shoreline survey identified that the sampling officer for the area noted that deer were present on the heath land around the loch in similar numbers overall to the sheep.

Therefore deer may represent a similar source of faecal contamination to sheep in the area, with faecal contamination most likely to be carried to the loch via freshwater streams and burns.

Summary

A variety of wildlife species are known to be present in the area and are likely to contribute to background levels of faecal contamination present in the waters of Loch Seaforth. Of these, seals and seabirds such as gulls are most likely to occur in the vicinity of the fisheries and may directly deposit faecal material to the waters near the shellfish farm. However, the presence and movements of these animals are likely to be highly variable and their impact at any given time difficult to predict. Faecal contamination levels from birds may be higher in the vicinity of the floats used to support the mussel lines, where they are likely to rest.

Deer are believed to be present in significant numbers and are most likely to contribute to levels of diffuse faecal contamination carried to the fishery via freshwater runoff from land. Deer Commission census data showed a significant population present to the west of the loch in 2006, however deer are likely to be present along the east side of the loch as well. Any impacts to the fisheries from this source are likely to be highest near the outlet of streams and burns along the shore.

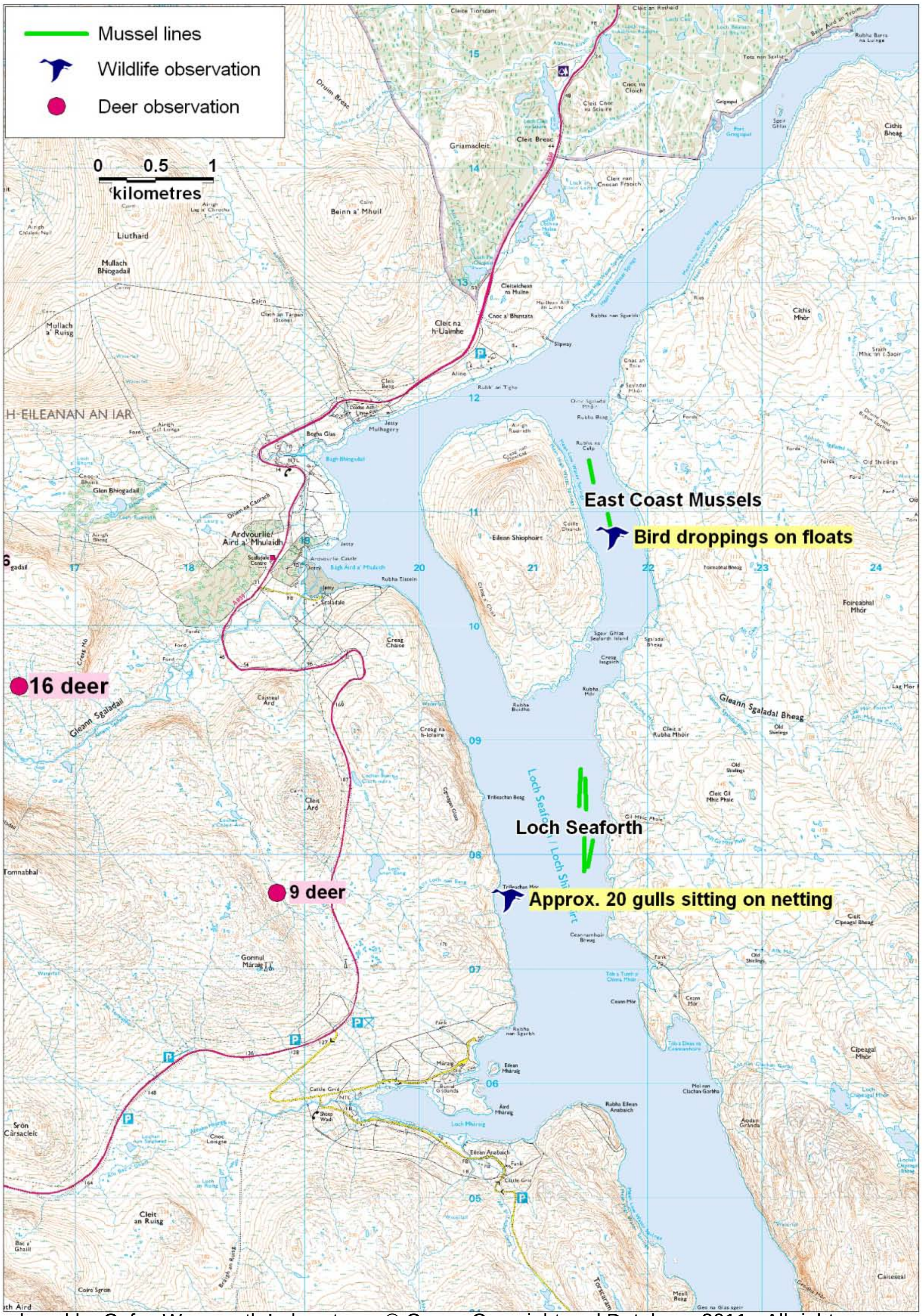

Figure 8.1 Map of wildlife observations at Loch Seaforth

9. Meteorological data

The nearest weather station for which nearly complete rainfall records were available is located at Harris: Borve Lodge, about 23 km to the south west. Rainfall data was available for 2003-2009 inclusive, aside from 19 days during the period 2006 to 2008, and the month of December 2009. The nearest weather station for which wind data was available is located at Stornoway, about 35km to the north east of Loch Seaforth. Whilst overall wind patterns may be broadly similar at the two, local topography will skew these patterns in different ways, and conditions at any given time are likely to differ due to the distance between them. This section aims to describe the local rain and wind patterns and how they may affect the bacterial quality of shellfish at Loch Seaforth/Eilean Shiphoirt East.

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 present box and whisker plots summarising the distribution of individual daily rainfall values by year and by month. The grey box represents the middle 50% of the observations, with the median identified by a further line within the box. 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 *.

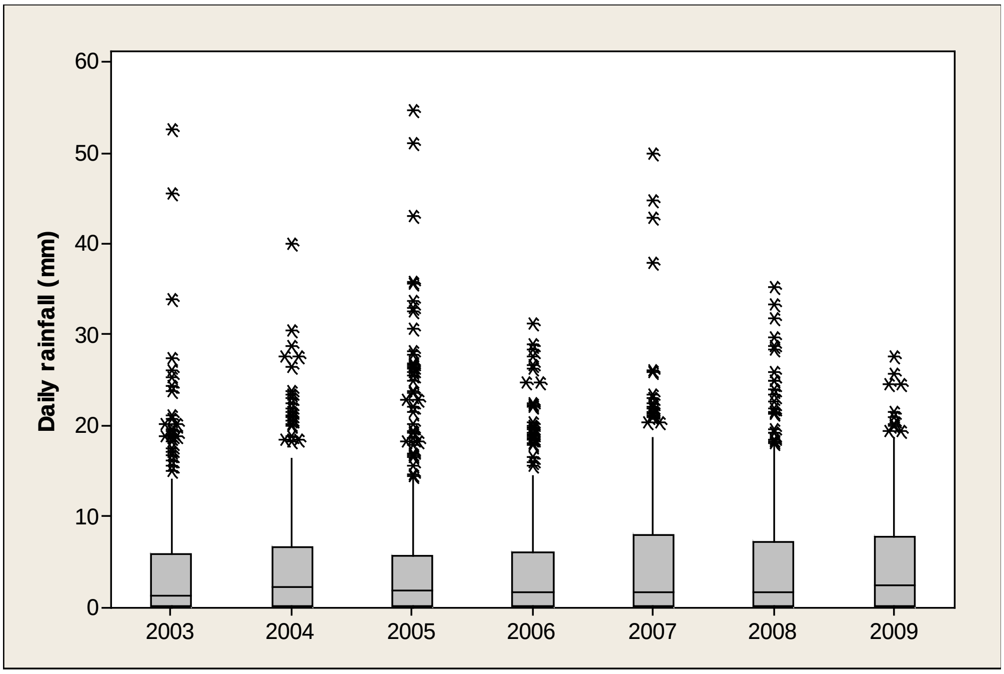

Figure 9.1 Box plot of daily rainfall values by year at Harris: Borve Lodge, 2003-2009

Figure 9.1 shows that rainfall patterns were very similar between the years presented here, with 2003 the driest and 2009 the wettest. Peak daily rainfall over this period was highest in 2003, 2005 and 2007 and lowest in 2009.

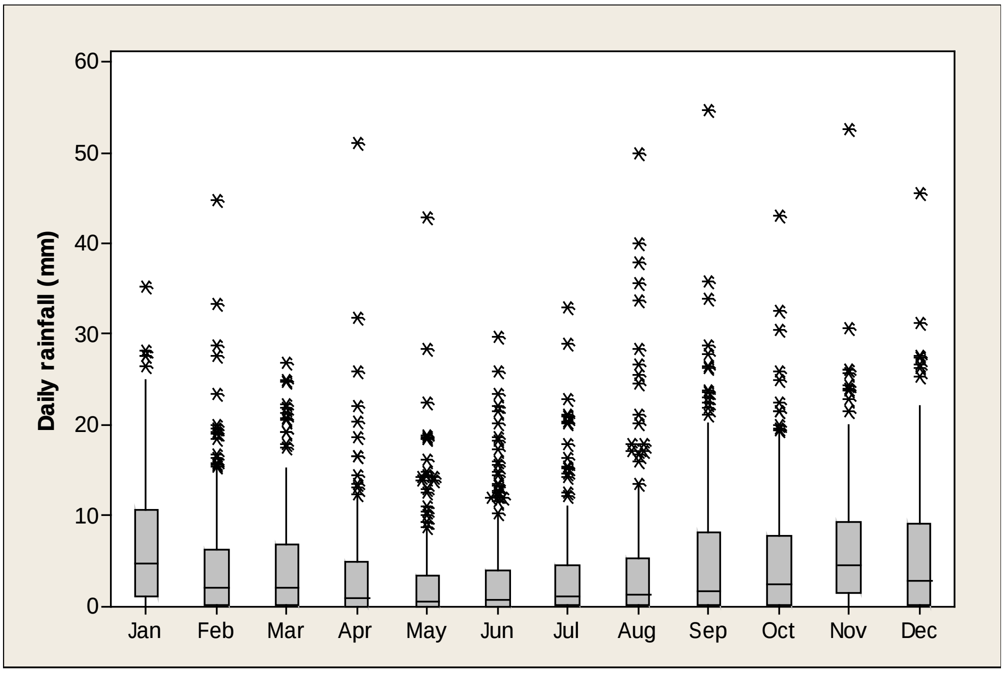

Figure 9.2 Box plot of daily rainfall values by month at Harris: Borve Lodge, 2003-2009

Weather was wettest from September to January and driest in May and June. More extreme rainfall events (in which over 20mm fell in a day) occurred during all months except February, with no obvious seasonal pattern so it is concluded that these may occur at any time of the year. For the period considered here (2003-2009), 40% of days experienced rainfall less than 1 mm, and 16% of days experienced rainfall of 10 mm or more.

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 dry periods and when stock levels are at their highest.

9.2 Wind

Wind data collected at the Stornoway weather station is summarised by season and presented in Figures 9.3 to 9.7.

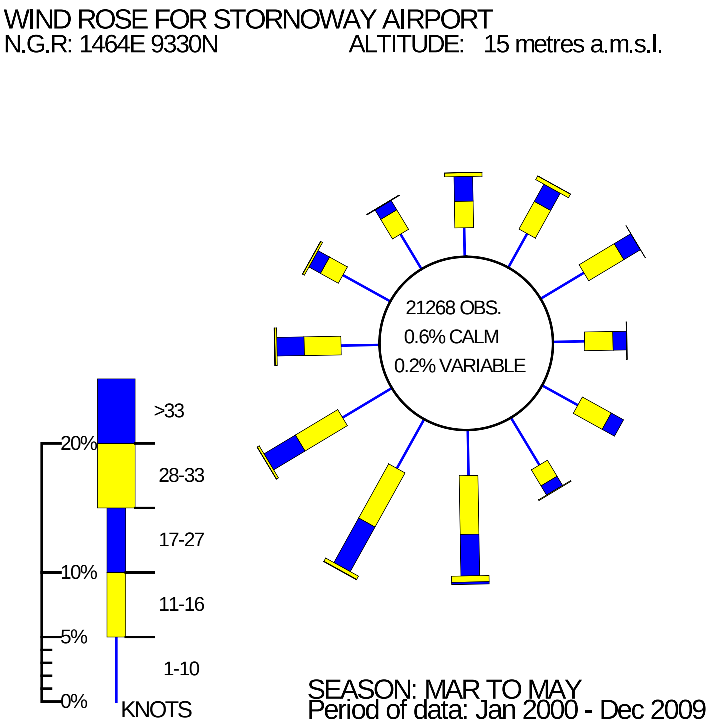

Figure 9.3 Wind rose for Stornoway (March to May)

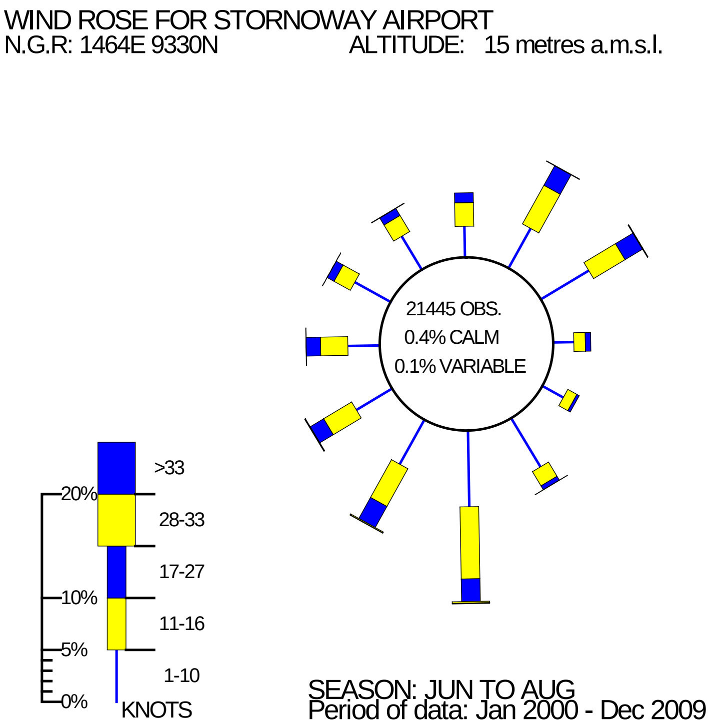

Figure 9.4 Wind rose for Stornoway (June to August)

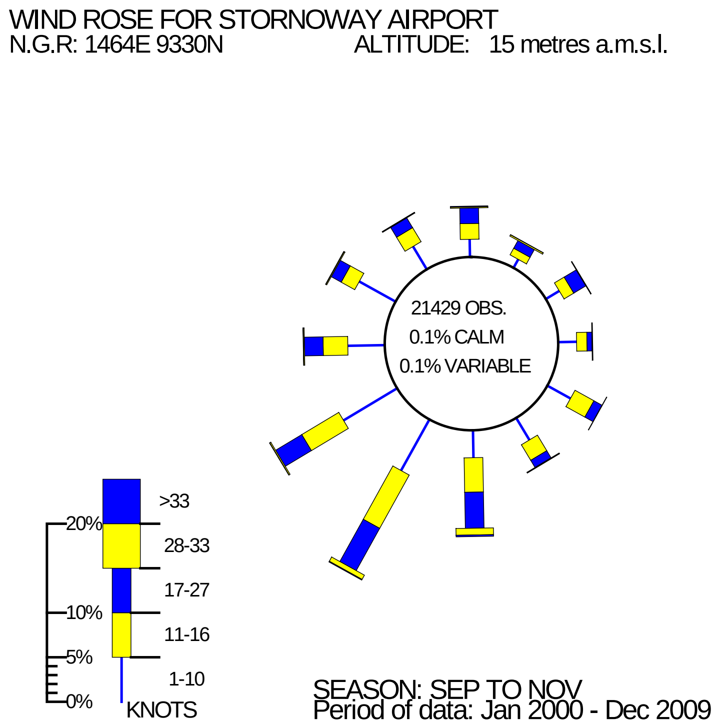

Figure 9.5 Wind rose for Stornoway (September to November)

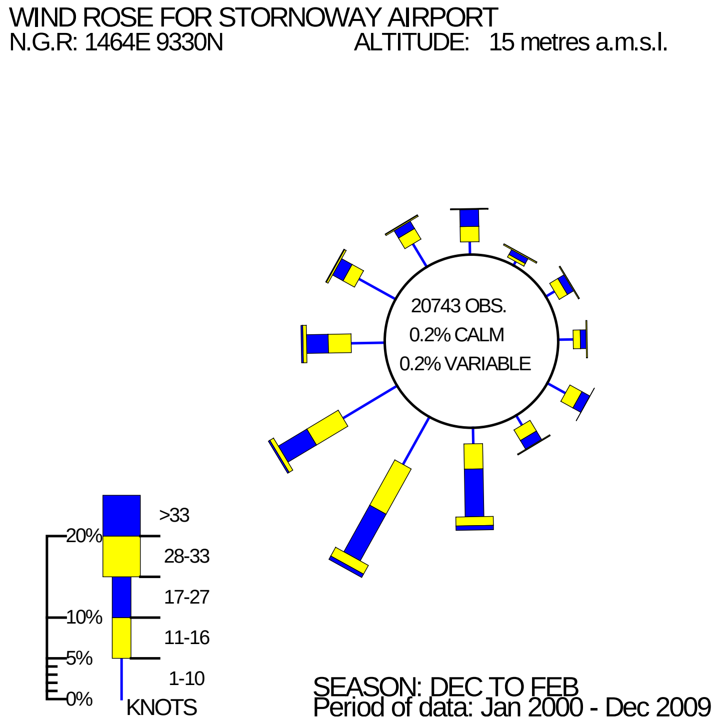

Figure 9.6 Wind rose for Stornoway (December to February)

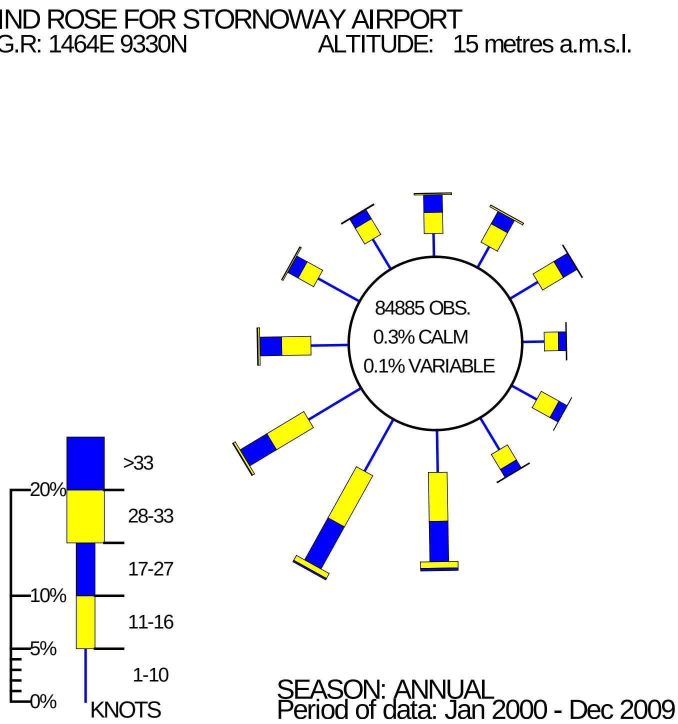

Figure 9.7 Wind rose for Stornoway (All year)

The prevailing wind direction at Stornoway is from the south west. 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 Stornoway airport is low lying and so the weather station is relatively exposed to wind from all directions. Loch Seaforth has a north to south aspect, lying in a steep sided valley with the surrounding hills rising to over 500 m in places. It is therefore likely that winds will be funnelled up and down the loch, and so wind patterns will be more skewed along the north south axis than at Stornoway.

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 may significantly alter the pattern of surface currents at Loch Leurbost, particularly those from the north or south. Strong winds may affect tide height depending on wind direction and local hydrodynamics. A strong wind 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.

10. Current and historical classification status

Classification records for Loch Seaforth were available from 2002, when it was first given a provisional classification. Table 10.1 presents a summary of the site classification since 2002.

Table 10.1 Classification history, Loch Seaforth

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002	b	b	b	a	a	a	a	a	a	a	a	a
2003	A	A	A	A	A	B	B	B	B	B	A	A
2004	A	A	A	A	A	A	A	B	B	A	A	A
2005	A	A	A	A	A	A	A	B	B	A	A	A
2006	A	A	A	A	A	A	A	B	B	A	A	A
2007	A	A	A	A	A	B	B	B	B	A	A	A
2008	A	A	A	A	A	B	B	B	B	A	A	A
2009	A	A	A	A	A	B	B	A	A	A	A	A
2010	A	A	A	A	A	A	A	A	A	A	A	A
2011	A	A	A									

Lower case denotes provisional classification

The area has held a seasonal classification for all but the last year, when it was classified A year-round. The months most consistently classified B were August and September, though all the summer months have been class B at some point in time.

11. Historical *E. coli* data

11.1 Validation of historical data

All shellfish samples taken Loch Seaforth and Eilean Shiophoirt from the beginning of 2002 up to the 14th April 2010 were extracted from the database and validated according to the criteria described in the standard protocol for validation of historical *E. coli* data.

A total of 11 Loch Seaforth samples were reported from NB 217 074, which falls approximately 30 m outside the production area. These were included in the analysis as the sampling location was only reported to an accuracy level of 100 m.

All samples were received by the testing laboratory within two days of collection. Two samples had no reported result, so could not be used in the analysis. A total of 14 samples had the result reported as <20, and were assigned a nominal value of 10 for statistical assessment and graphical presentation.

All *E. coli* results are reported in most probable number (MPN) per 100 g of shellfish flesh and intravalvular fluid.

11.2 Summary of microbiological results

A summary of all sampling results to 14 April 2010 is presented by site in Table 11.1.

Table 11.1 Summary of historical sampling and results

Sampling Summary		
Production area	Loch Seaforth	Eilean Shiphoirt East
Site	Loch Seaforth	East Coast Mussels
Species	Common mussels	Common mussels
SIN	LH-193-126-08	LH-484-811-08
Location	7 locations	NB 2138 1140
Total no of samples	60	3
No. 2002	6	0
No. 2003	7	0
No. 2004	7	0
No. 2005	6	0
No. 2006	8	0
No. 2007	6	0
No. 2008	9	0
No. 2009	8	0
No. 2010	3	3
Results Summary		
Minimum	<20	<20
Maximum	9100	20
Median	60	
Geometric mean	76.7	12.6
90 percentile	805	
95 percentile	2420	
No. exceeding 230/100g	13 (22%)	
No. exceeding 1000/100g	6 (10%)	
No. exceeding 4600/100g	1 (2%)	
No. exceeding 18000/100g	0 (0%)	

Only three samples were taken from the new site within Eilean Shiphoirt East at the time this analysis was undertaken, so although these were used in the geographical assessment of levels of contamination throughout the whole survey area, there were insufficient samples for more detailed analysis of temporal trends, seasonality and environmental effects at this site.

11.3 Overall geographical pattern of results

Figure 11.1 presents a thematic map of geometric mean *E. coli* result by reported sampling location where greater than 5 results were reported from the same location.

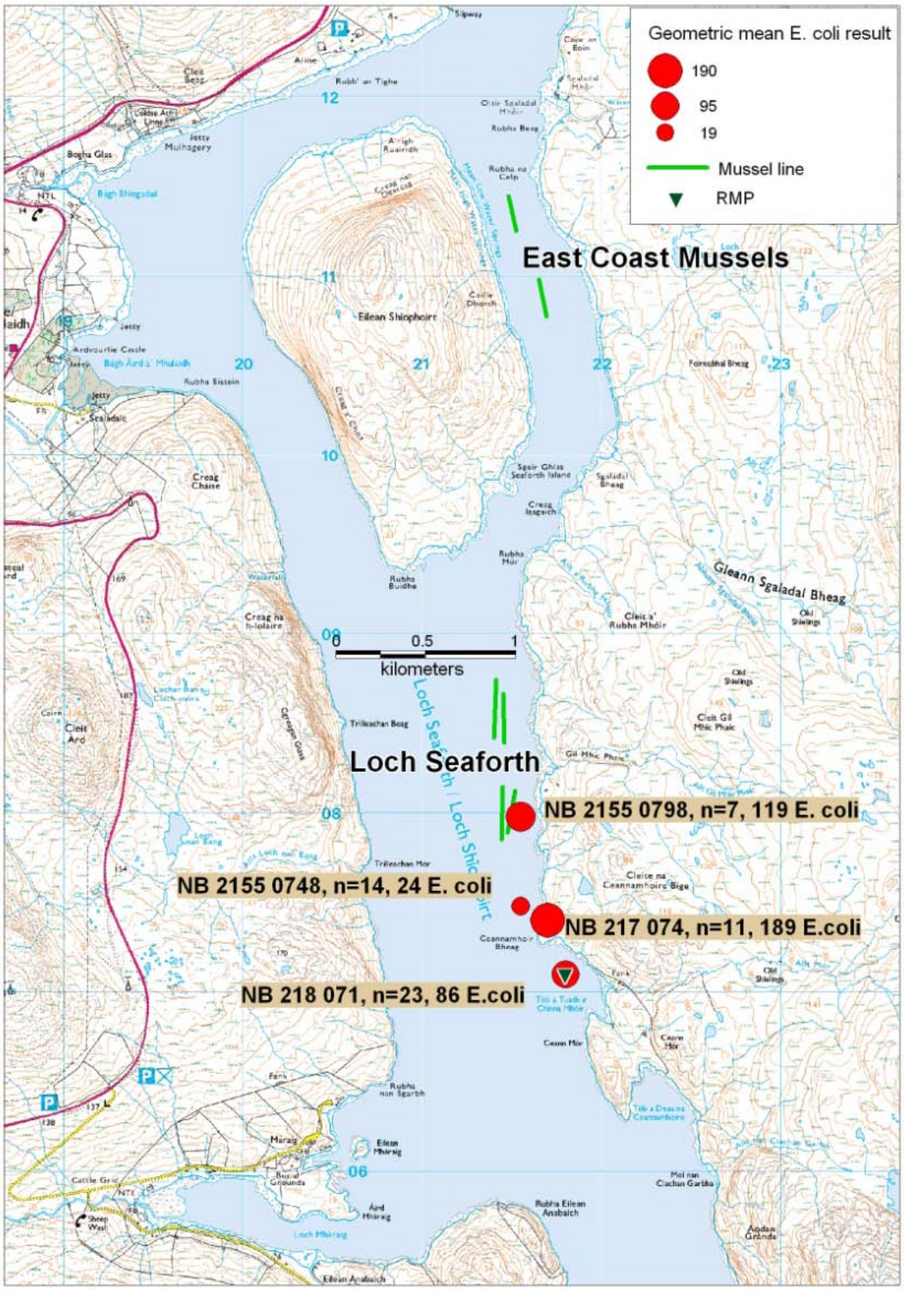

Figure 11.1 Map of geometric mean *E. coli* results by reported sampling location

No clear geographical trends are apparent in Figure 11.1. A comparison of results from sampling locations from which more than 5 samples were reported reveals a significant difference (One-way ANOVA, p=0.011, Appendix 6). A post ANOVA test reveals that results for NB 217 074 (11 samples, 2005-2006) were significantly higher than those for NB 2155 0748 (14 samples, 2008-2010). Whether this difference is a geographical or temporal effect is uncertain. These two locations are close together, and may actually be closer as the former of the two is only identified to 100 m accuracy.

Locations where fewer than 5 samples were taken are shown mapped in Figure 11.2.

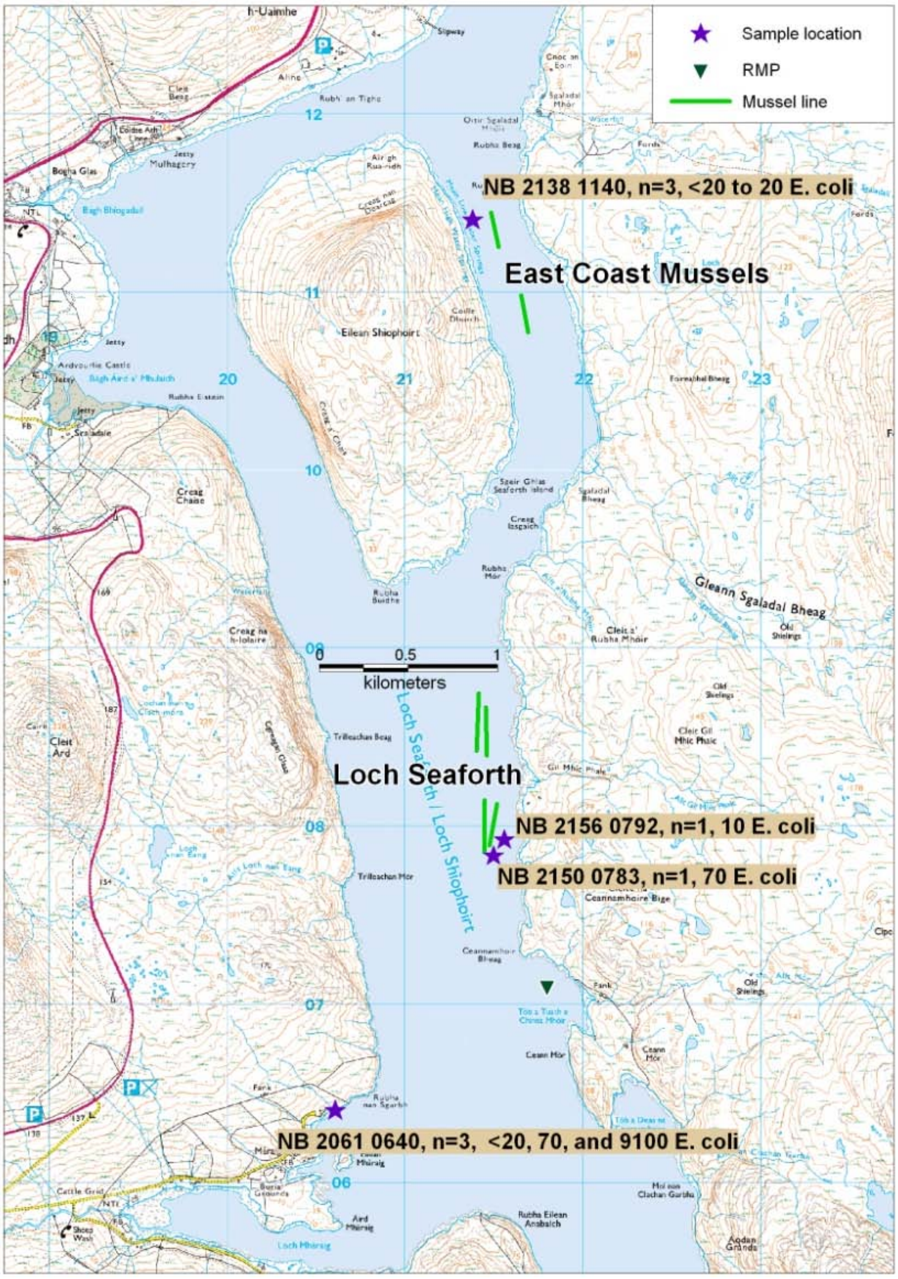

Figure 11.2 Map of individual *E. coli* results by reported sampling location

These included all samples taken from the East Coast Mussels site up to 14 April 2010, when this analysis was originally undertaken. Three samples were reported in 2008 from the west shore of the loch to the south of the current mussel farm locations. One of these had the highest result obtained during classification monitoring in the loch, however there is currently no fishery at this location. On each of the three days when samples were taken from East Coast Mussels, samples were also taken from the Loch Seaforth site, and results were identical for the two sites on all three occasions (<20, <20 and 20 *E. coli* MPN/100g at both sites). Results from subsequent paired sampling up to January 2011 were identical for both sites on only 2 of 5 occasions. Results were higher at Loch Seaforth than at East Coast Mussels on 2 out of the remaining 3 sampling occasions.

11.4 Overall temporal pattern of results

Figure 11.2 presents a scatter plot of individual results against date (Loch Seaforth only), fitted with trend lines calculated using two different techniques. It is fitted with a line indicating the geometric mean of the previous 5 samples, the current sample and the following 6 samples, referred to as a rolling geometric mean (black line). It is also fitted with a loess line (blue line), which 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. These trend lines help to highlight any apparent underlying trends or cycles.

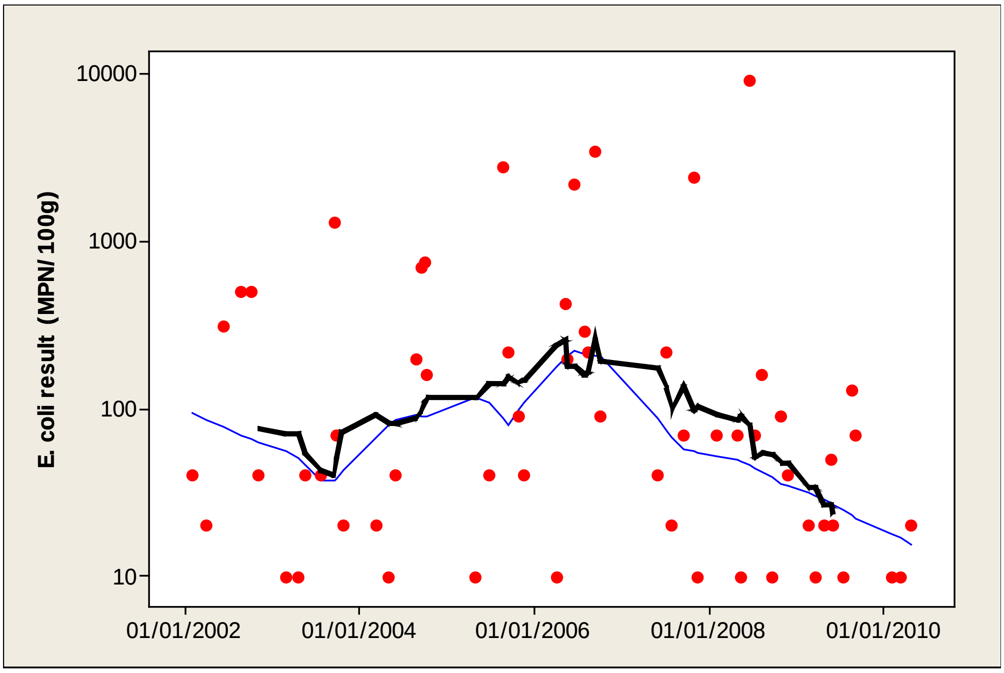

Figure 11.3 Scatterplot of *E. coli* results by date with rolling geometric mean (black line) and loess line (blue line)

Figure 11.2 suggests an overall improvement in results from 2007 onwards. No results of over 230 *E. coli* MPN/100 g were recorded between June 2008 and April 2010. However, results of sampling subsequent to this period showed one result of 490 *E. coli* MPN/100 g which occurred on 30 June 2010.

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 11.3 presents a scatterplot of *E. coli* result by month with a loess line to highlight any trends.

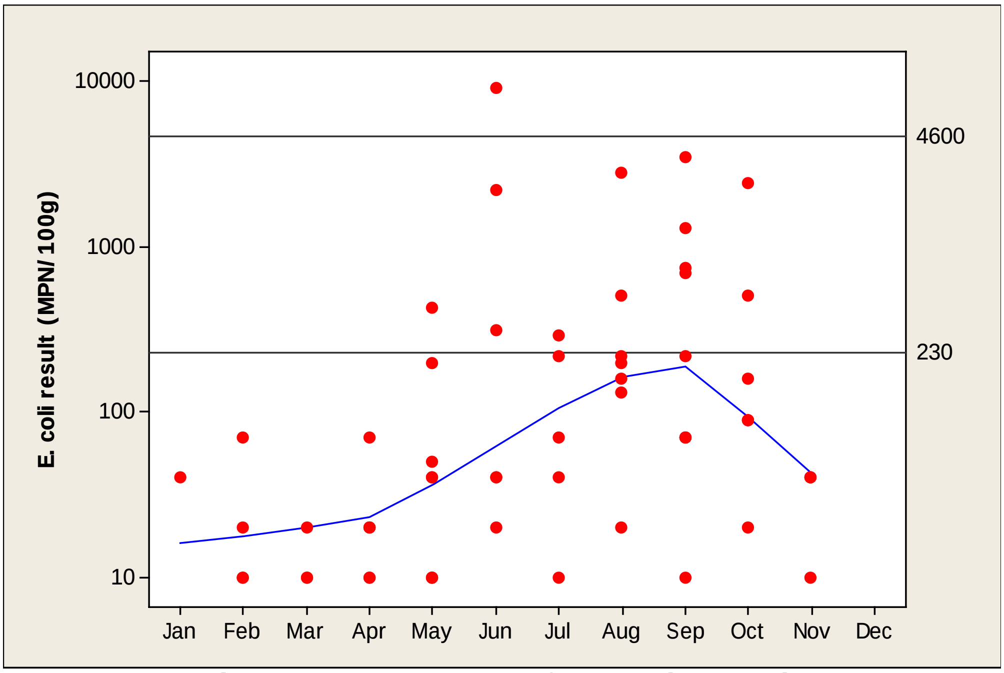

Figure 11.4 Scatterplot of results by month

Results were generally higher during the warmer months of the year, and all results greater than 230 *E. coli* MPN/100 g arose between May to October. However, no samples were taken in December and only one was taken in January.

For statistical evaluation, seasons were split into spring (March - May), summer (June - August), autumn (September - November) and winter (December - February).

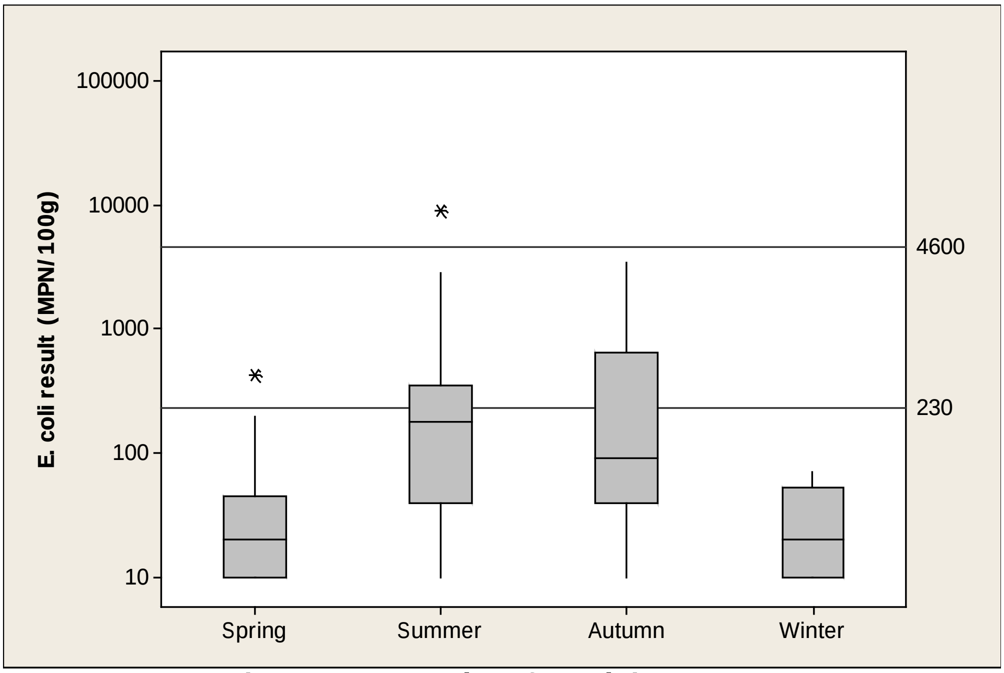

Figure 11.5 Boxplot of result by season

A significant difference was found between results by season (One-way ANOVA, p=0.001, Appendix 6). A post ANOVA test (Tukeys comparison, Appendix 6) indicates that results for the summer and autumn were significantly higher than those for the spring.

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 weather station is at Harris: Borve Lodge, about 23 km to the south west of the production area. Rainfall data was purchased from the Meteorological Office for the period 1/1/2003 to 31/12/2009 (total daily rainfall in mm). Figure 11.5 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.

Two-day antecedent rainfall

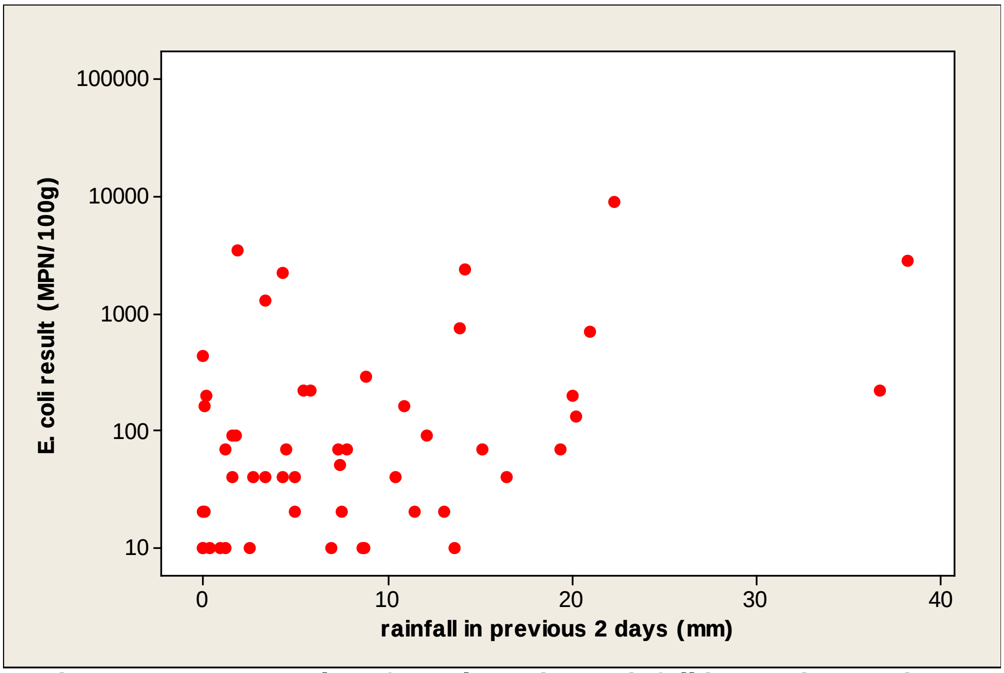

Figure 11.6 Scatterplot of result against rainfall in previous 2 days

A positive correlation was found between *E. coli* result and rainfall in the previous 2 days (Spearman's rank correlation=0.334, p<0.01, Appendix 6). *E. coli* results of <20 MPN/100 g were not found after rainfall of 15 mm or greater during the two days prior to sampling. However, results greater than 1000 *E. coli* MPN/100 g coincided with 2-day rainfall values as low as 2 mm.

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.

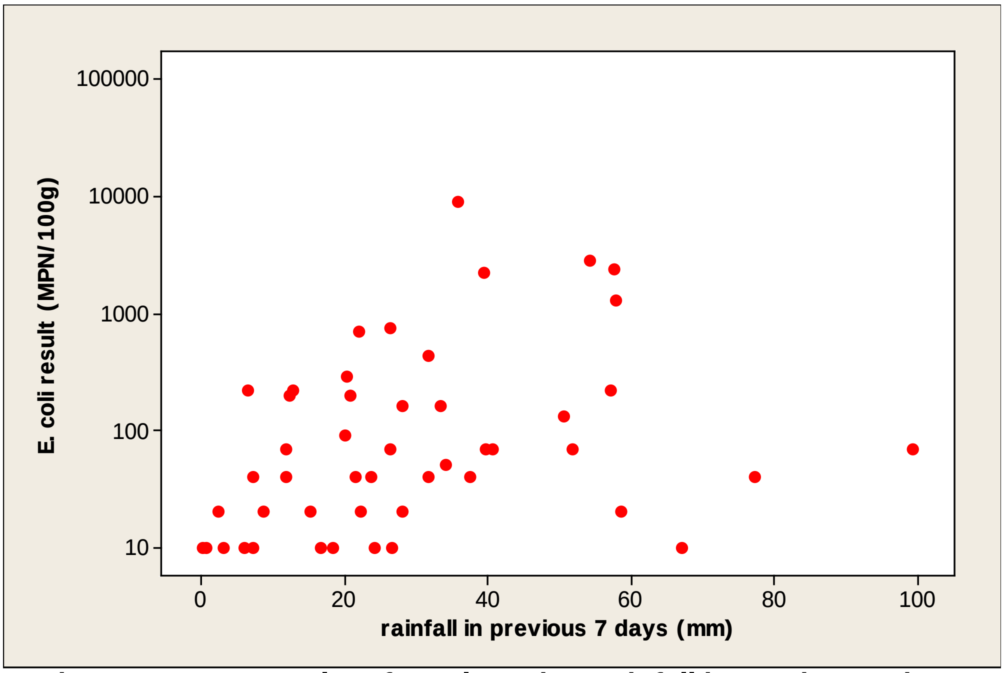

Figure 11.7 Scatterplot of result against rainfall in previous 7 days

A positive correlation was found between *E. coli* result and rainfall in the previous 7 days (Spearman's rank correlation= 0.397, $p<0.005$, Appendix 6). The highest results coincided with moderate rainfall values, whilst results coinciding with very high preceding rainfall levels (60 mm or greater) were all well below 230 *E. coli* MPN/100 g.

11.6.2 Analysis of results by tidal height and state

Spring/neap tidal cycle

When the larger (spring) tides occur every two weeks, circulation of water and particle transport distances will increase, and more of the shoreline will be covered at high water, potentially washing more faecal contamination from livestock into the area. Figure 11.7 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. Results of under 230 *E. coli* MPN/100g are plotted in green, those between 230 and 1000 *E. coli* MPN/100g are plotted in yellow, and those over 1000 *E. coli* MPN/100g are plotted in red. 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.

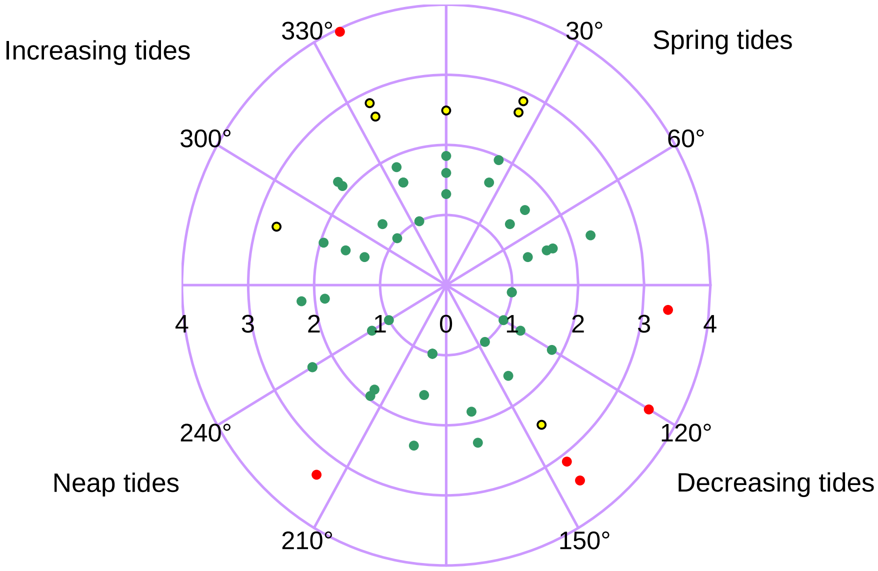

Figure 11.8 Polar plot of $\log_{10}$ *E. coli* results on the spring/neap tidal cycle

No statistically significant correlation was found between *E. coli* results and the spring/neap cycle (circular-linear correlation, r=0.074, p=0.729, Appendix 6). More results over 1000 MPN/100 g occurred during decreasing or neap tides and more results between 230 and 1000 MPN/100 g were found during increasing or spring tides. Sampling effort was relatively evenly spread around the tidal cycle.

High/low tidal cycle

Direction and strength of flow around the production areas will change according to tidal state on the (twice daily) high/low cycle, and, depending on the location of sources of contamination, this may result in marked changes in water quality in the vicinity of the farms during this cycle. As *E. coli* levels in some shellfish species can respond within a few hours or less to changes in *E. coli* levels in water, tidal state at time of sampling (hours post high water) was compared with *E. coli* results. Figure 11.8 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. Results of under 230 *E. coli* MPN/100g are plotted in green, those between 230 and 1000 *E. coli* MPN/100g are plotted in yellow, and those over 1000 *E. coli* MPN/100g are plotted in red.

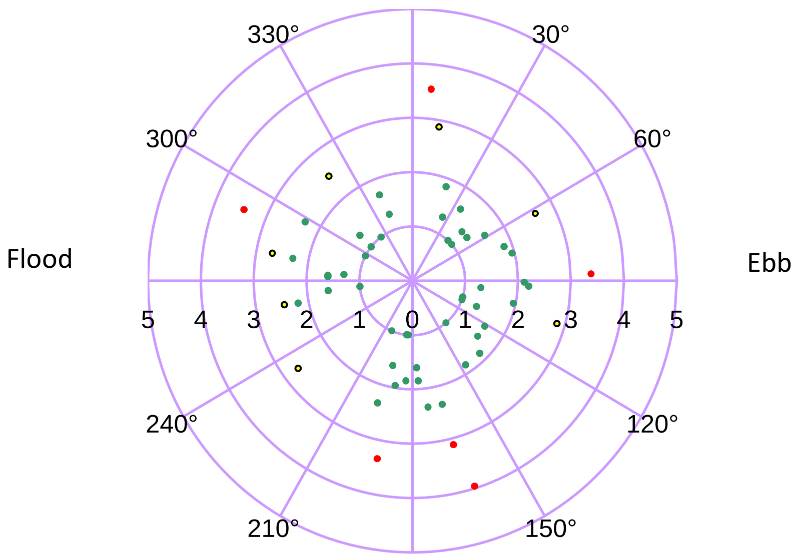

Figure 11.9 Polar plot of $\log_{10}$ *E. coli* results on the high/low tidal cycle

No significant correlation was found between *E. coli* results and the high/low tidal cycle (circular-linear correlation, r=0.107, p=0.523, Appendix 6).

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. It was not possible to compare *E. coli* levels with water temperature as this was only recorded on three sampling occasions.

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 11.9 presents a scatter plots of *E. coli* result against salinity.

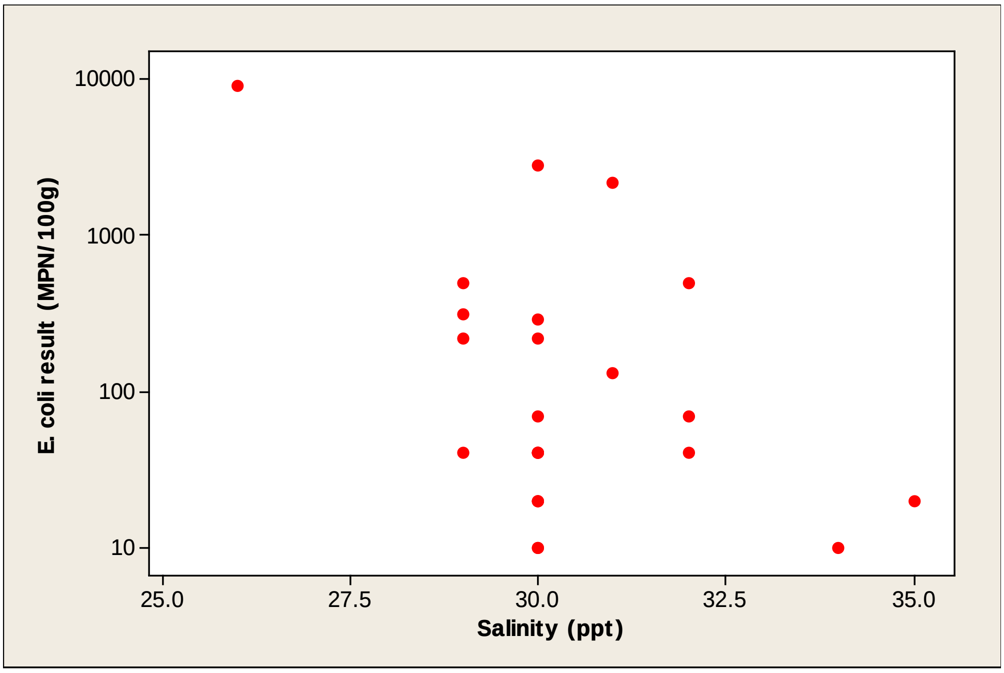

Figure 11.10 Scatterplot of result by salinity

Although Figure 11.9 suggests a tendency for higher results at lower salinities, no statistically significant correlation was found between the *E. coli* result and salinity (Spearman's rank correlation= -0.284, p>0.05, Appendix 6). The highest result also had the lowest recorded salinity.

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

A total of 6 samples gave a result of over 1000 *E. coli* MPN/100g, details of which are presented in Table 11.2.

Table 11.2 Historic *E. coli* sampling results over 1000 *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)
16/09/2003	1300	NB218071	3.4	58	*	*	Low	Decreasing
25/08/2005	2800	NB217074	38.2	54.3	13.5	30	Flood	Decreasing
20/06/2006	2200	NB217074	4.3	39.4	*	31	Low	Neap
12/09/2006	3500	NB218071	1.9	*	*	*	High	Decreasing
30/10/2007	2400	NB 2155 0798	14.2	57.6	*	*	Ebb	Decreasing
17/06/2008	9100	NB 2061 0640	22.3	35.8	*	26	Low	Increasing

*Data unavailable

These high results all arose during the summer or autumn months, and were taken from a variety of locations. Where available, rainfall records indicate these high results arose after a relatively wet week. They were taken under a variety of tidal conditions, although more were taken at decreasing tides or neap tides.

11.8 Summary and conclusions

When both the East Coast Mussels and the Loch Seaforth sites were sampled on the same dates, results were identical on over half the occasions, and of the three occasions when results differed they were higher at the Loch Seaforth site than at East Coast Mussels. On one of these occasions, the result at Loch Seaforth was greater than 230 *E. coli* MPN/100g whilst the sample from East Coast Mussels was below this value. This suggests that while there are not large differences in the levels of contamination experienced at these two sites, the Loch Seaforth site may occasionally be subject to higher levels of contamination than East Coast Mussels.

Within the Loch Seaforth site, a significant difference was found between mean results from two of the reported sampling locations. However, as one of the locations was only reported to 100 m accuracy and the locations are close together and not sampled at the same time, it is not clear whether this is a true geographic variation or a temporal one. Therefore it is not possible to make any firm conclusions regarding geographical patterns in levels of contamination in shellfish within the Loch Seaforth site.

In terms of overall temporal trends, an overall improvement in results was noted from 2007 onwards, with no results of over 230 *E. coli* MPN recorded since June 2008. A significant seasonal effect was found, with results for the summer and autumn significantly higher than those for the spring. It was not possible to compare *E. coli* levels with water temperature as this was only recorded on three sampling occasions.

Positive correlations were found between *E. coli* results and rainfall in the previous 2 and 7 days. Although there appeared to be a tendency for higher results at lower salinities, no significant correlation was found between the *E. coli* results and salinity.

No correlation between levels of *E. coli* in shellfish and tidal state on either the spring/neap or high/low tidal cycles was found.

It should be noted that 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 has held the same (non-seasonal) classification for 3 years and the geometric mean of the results falls within a certain range it is recommended that the sampling frequency be decreased from monthly to bimonthly. This is not appropriate for Loch Seaforth as it has held seasonal classifications within the last three years.

12. Designated Shellfish Growing Waters Data

There are no designated Shellfish Growing Waters within Loch Seaforth.

13. River Flow

There are no gauging stations on any of the watercourses entering Loch Seaforth.

The watercourses listed in Table 13.1 were measured and sampled during the shoreline survey. These represent the most significant freshwater inputs into the area. The weather was dry at the time of the survey and no significant rainfall had fallen in the previous three days.

The locations are shown on the map presented in Figure 13.1. 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 Seaforth

No.	Position	Description	Width (m)	Depth (m)	Flow (m/s)	Discharge (m^3/d)	*E. coli* (cfu/100 ml)	*E. coli* loading (cfu/day)
1	NB 22071 07014	Allt Mòr	1.40	0.15	0.039	708	10	7.1×10^7
2	NB 21760 08240	Allt Gil Mhic Phaic	2.20	0.10	0.087	1650	10	1.7×10^8
3	NB 22116 09990	Abhainn Sgaladail Bheag	3.60	0.23	0.207	14800	<10	$<1. \times 10^9$
4	NB 21837 11897	Abhainn Sgaladail Mhòir	5.80	0.11	0.086	4740	10	4.7×10^8
5	NB 19440 11734	Abhainn à Mhuil	1.10	0.08	0.371	2820	10	2.8×10^8
6	NB 18987 11491	Abhainn Bhìoigadail	4.40	0.06	0.268	6110	50	3.1×10^9
7	NB 18983 10248	Abhainn Sgaladail	1.30	0.05	1.204	6760	40	2.7×10^9
8	NB 20647 07646	Allt Loch nan Eang	0.80	0.20	0.123	1700	10	1.7×10^8
9	NB 19445 05815	Abhainn Mhàraig	9.60	0.11	0.202	18400	20	3.7×10^9

E. coli concentrations in the watercourses were all very low. However, the volume of discharge from many of the watercourses was high and this meant that the loading contributed to the environment by many of them was moderate, despite the low concentrations. Under rainfall conditions, the loadings would be expected to increase at least tenfold.

Watercourses 1, 2, 3 and 4 have the potential to contribute relatively directly to contamination in the area of the mussel lines in their vicinity. Number 8 may impact on the mussel lines opposite if a wind-driven current is flowing in the correct direction. Watercourses 5, 6, 7 and 9 will contribute to the background *E. coli* in this area of the loch but are unlikely to impact directly on the contamination at the mussel lines.

A large number of other streams are shown on the OS map. However, most of these were not flowing at the time of the survey. These would also contribute to the contamination of the loch when flowing under rainfall conditions.

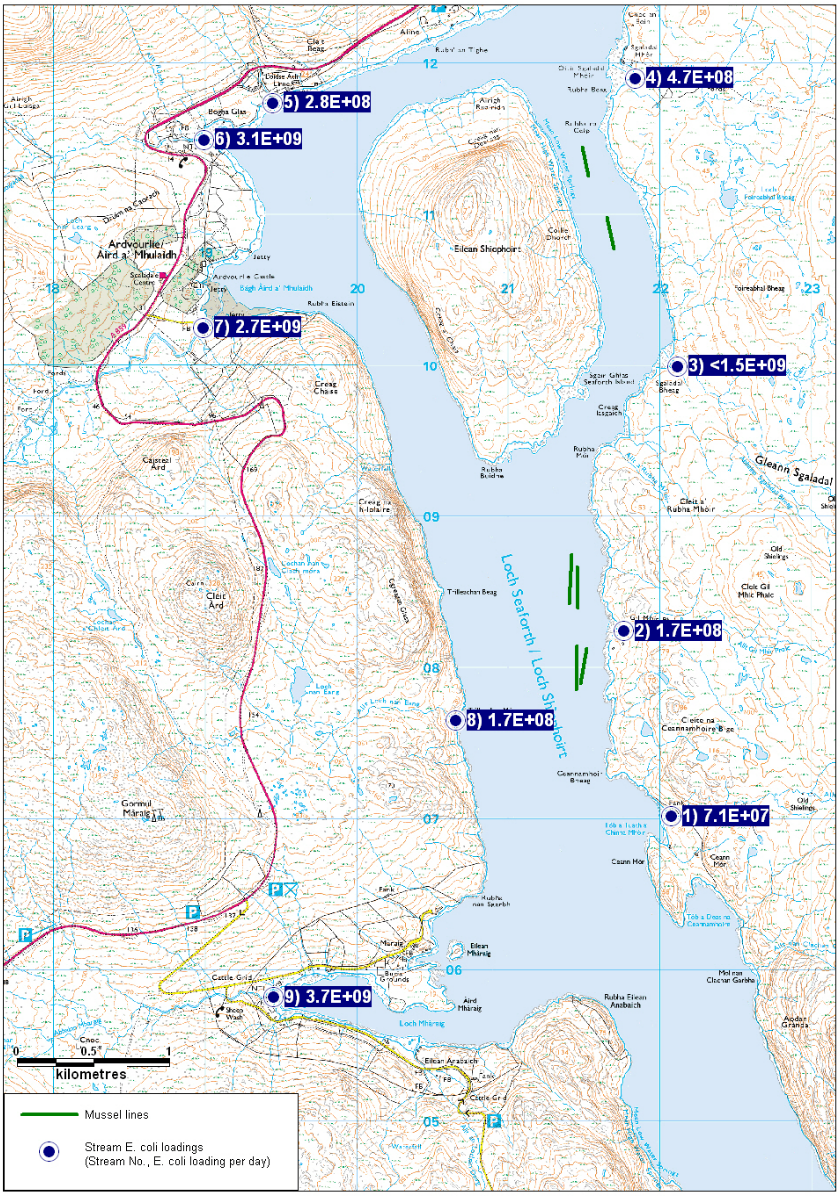

Figure 13.1 Map of watercourse loadings in the vicinity of the mussel lines at Loch Seaforth

14. Bathymetry and Hydrodynamics

The OS map and Hydrographic Chart for the area are shown in Figures 14.1 and 14.2 respectively.

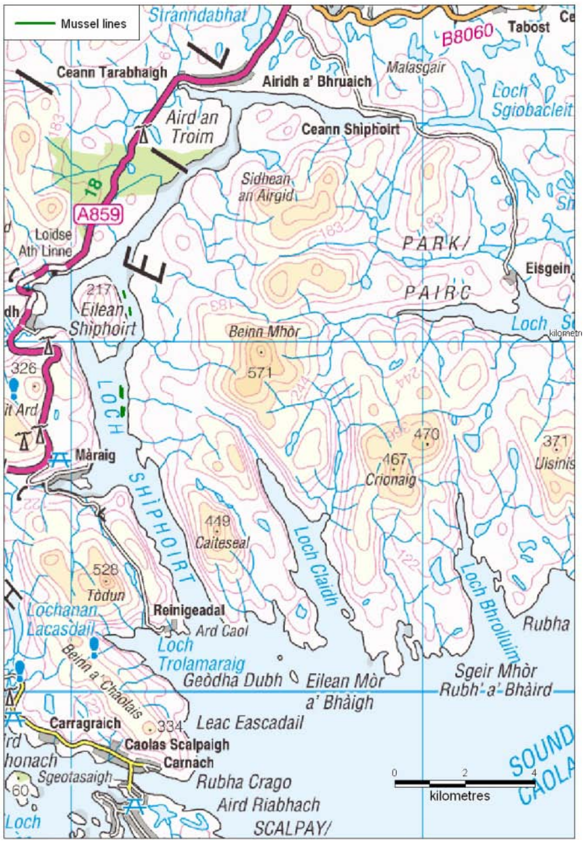

Figure 14.1 OS map of Loch Seaforth

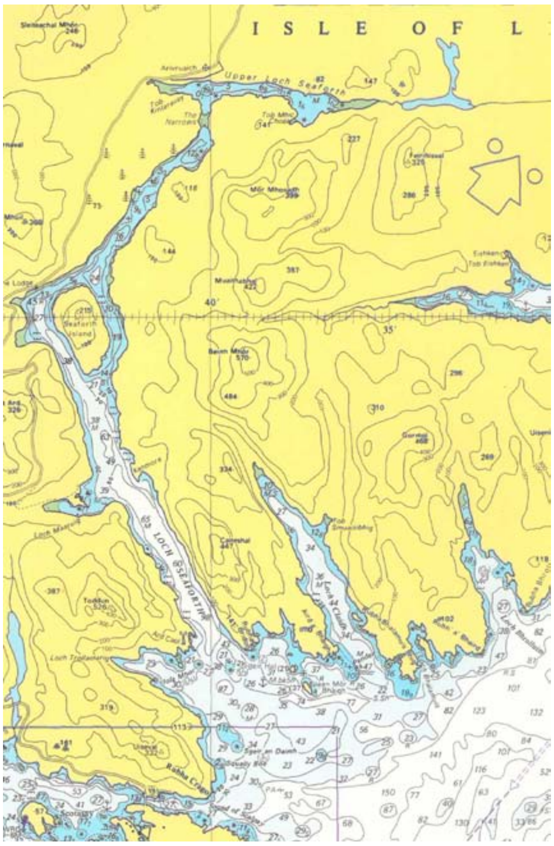

Figure 14.2 Loch Seaforth Bathymetry

Loch Seaforth forms the eastern boundary between Lewis and Harris. It is approximately 23 km in length with the mouth at the southern end. The outer part is approximately 10 km in length and lies in a SSE to NNW direction. The middle section is approximately 7 km in length and lies in a SSW to NNE direction. The inner section is approximately 6 km long and lies almost W to E. The maximum depth of the loch is 98 m (Edwards and Sharples, 1991). There are a number of drying areas within the loch. There are three sills. One is at the mouth of the loch at a depth of 38 m. The second is within the middle section of the loch, at a depth of 5 m. The third is towards the northern end of the middle section of the loch, at an intertidal area marked on the chart as "The Narrows". Depths at the fisheries are approximately 10 m for those to the east of Eilean Shìophiort and approximately 20 m for those to the south of the island.

14.1 Tidal Curve and Description

The two tidal curves below are for East Loch Tarbert, a straight line distance of approximately 8 km from the mouth of Loch Seaforth but approximately 13 km by sea. The tidal curves have been output from UKHO TotalTide. The first is for seven days beginning 00.00 BST on 01/09/10 and the second is for seven days beginning 00.00 BST on 08/09/10. Together they show the predicted tidal heights over high/low water for a full neap/spring tidal cycle, including the dates of the shoreline survey.

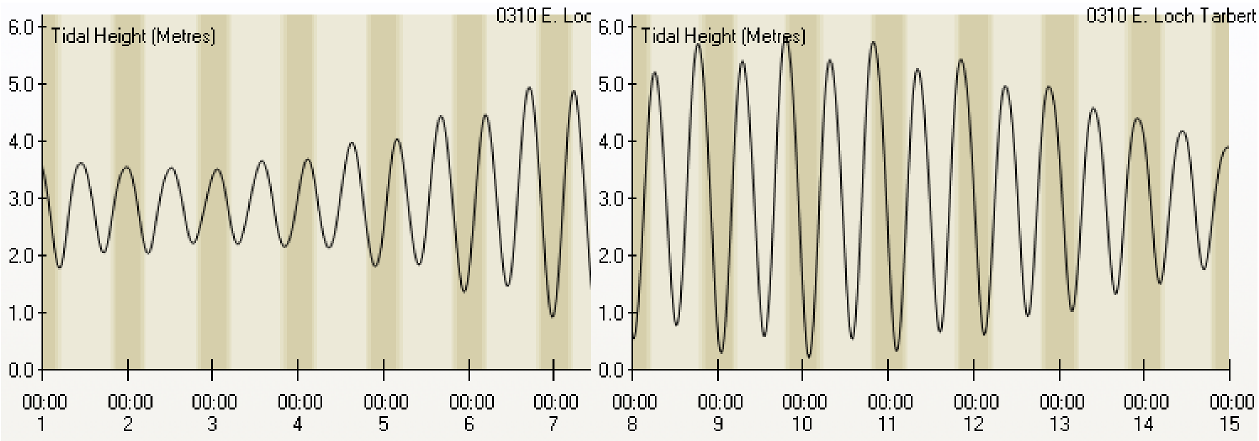

Figure 14.3 Tidal curves for East Loch Tarbert

The following is the summary description for East Loch Tarbert from TotalTide:

0310 E. Loch Tarbert is a Secondary Non-Harmonic port.
The tide type is Semi-Diurnal.

HAT	5.9 m
MHWS	5.0 m
MHWN	3.7 m
MSL	3.05 m
MLWN	2.1 m
MLWS	0.8 m
LAT	0.1 m

Predicted heights are in metres above Chart Datum. The tidal range at spring tide is 4.2 m, and at neap tide 1.6 m, and so tidal ranges in the area are moderate.

14.2 Currents

No tidal stream information was available for the coastal waters within Loch Seaforth from the UKHO.

SEPA provided current meter data for three locations within Loch Seaforth. The locations are shown in Figure 14.4 and the survey periods are given in Table 14.1.

Table 14.1 Current meter survey periods

Location	NGR	Survey period
Ardvourlie	NB 1970 1040	11/11/1997 – 26/11/1997
Trilleachan Mor	NB 2087 0736	17/06/2005 – 11/07/2005
Noster	NB 2284 0348	10/03/2005 – 25/03/2005

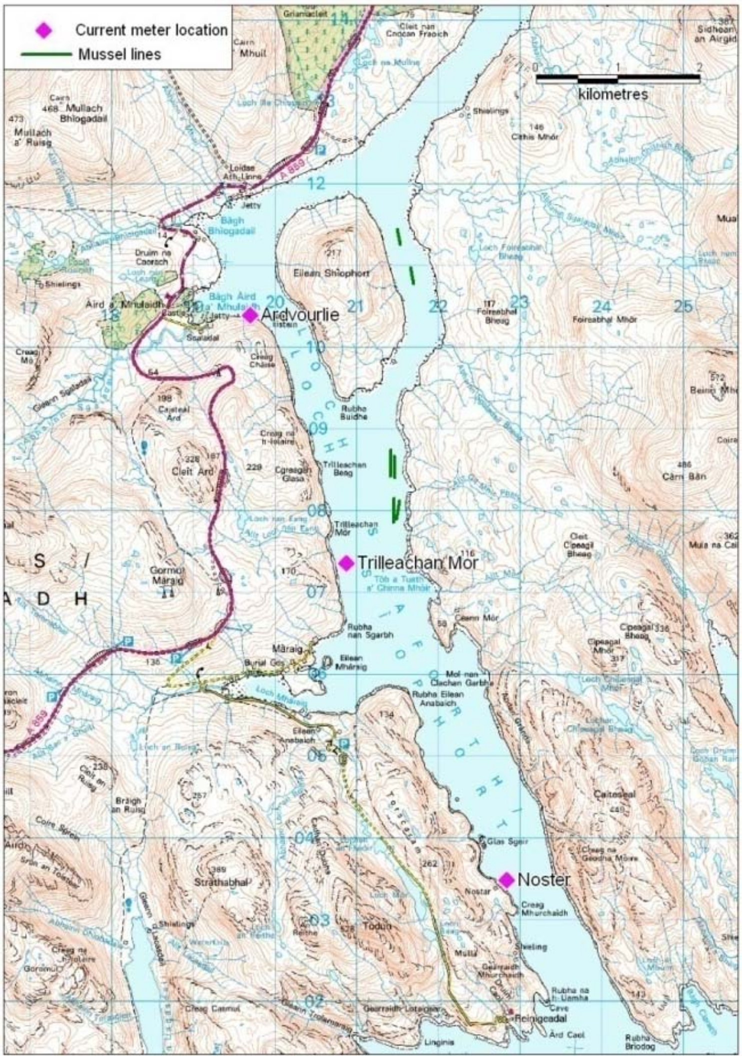

Figure 14.4 Current meter locations in Loch Seaforth

Plots of the current direction and speed at this location, together with the wind direction and speed over the relevant period, are shown in Figure 14.7. No mid-depth data was available for Ardvourlie. For Trilleachan Mor, there was only a five metre difference in depth between the near surface (28 m from seabed) and mid-depth (23 m from seabed) readings.

The Ardvourlie near bottom readings show a very high proportion (>35%) of zero current speed values (shown as the empty circle at the centre of the circular plot). The proportion of zero values for the near-surface readings is much lower, at approximately 2.7%, but this is still higher than seen at other locations. It is not clear as to whether this is due to data recording problems or to peculiarities in the currents in the area. If the latter, this may be due to the presence of Eilean Shìophort. The data for Trilleachan Mor and Noster show that the currents at those locations predominantly flow parallel to the shore. In general, the currents were strongest on the ebb tide. However, at Noster, strongest currents were seen on the flood tide near-bottom and on the ebb-tide near-surface. This may have been influenced by the wind direction during the survey period.

Mean current speeds at Ardvourlie and Noster were between 2.5 and 6 cm/s (0.05 to 0.12 knots), with maxima ranging from 15 to 27 cm/s. At Trilleachan Mor, the mean current speeds were between 5 and 6 cm/s (0.1 to 0.12 knots). However, the maxima varied between 28 and 119 cm/s. The latter value was obtained at near-bottom: apart from three values above 45 cm/s, the remainder of the 1687 records showed current speeds less than 30 cm/s.

Edwards and Sharples (1991) give the current speeds at sill 1 as 9 cm/s and sill 2 as 73 cm/s, which lies within the range of the data above.

Using the mean speed of approximately 6 cm/s as the peak flow during ebb or flood, contaminants would travel less than 1 km over a tidal cycle, ignoring dilution and dispersion. Assuming a worst case of approximately 30 cm/s, this would increase to approximately 4 km.

14.3 Salinity Profiles

Two salinity profiles were undertaken at the time of the shoreline survey. The location of the two profiles is shown in Figure 14.7 and the results are presented in Table 14.2. The salinities were all in the range 36.3 to 36.6 ppt and showed only 0.2 to 0.3 ppt difference between the surface and 10 m depth at the two locations. Thus, at the time of the shoreline survey, there did not appear to be any significant effect of freshwater inputs on salinity in general and no evidence of stratification. However, a greater freshwater effect might be observed after heavy rainfall.

Edwards and Sharples (1991) gave a low fresh to tidal flow ratio for Loch Seaforth of 5, with a calculated salinity reduction of 0.2 ppt. This is consistent with the observations from the shoreline survey.

Table 14.2 Salinity profiles in Loch Seaforth

Profile	Position	Depth (m)	Salinity (ppt)	Temperature (°C)
1	NB 2148 1144	0	36.3	13
		2.5	36.4	12.9
		5	36.4	12.8
		7.5	36.5	12.8
		10	36.6	12.6
2	NB 2141 0875	0	36.4	12.8
		2.5	36.5	12.7
		5	36.5	12.7
		7.5	36.6	12.5
		10	36.6	12.4

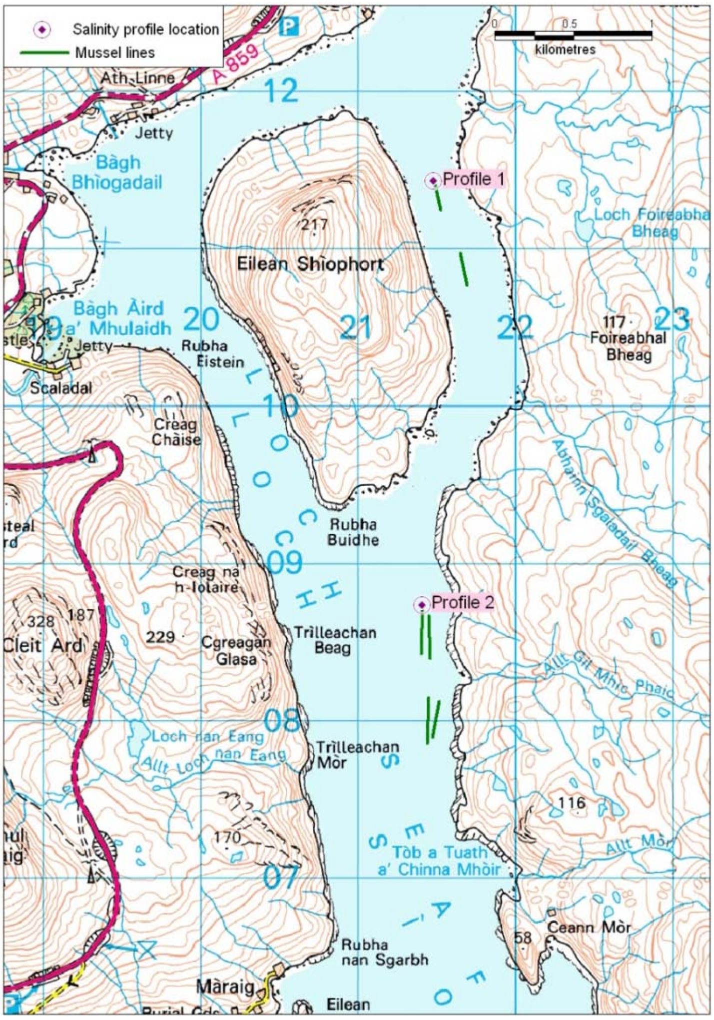

Figure 14.5 Salinity profile locations in Loch Seaforth

14.3 Conclusions

The presence of the two sills in the middle section of the loch will limit transfer of contaminants from the inner loch towards the fishery. Within the outer section of the loch, in the location of the fisheries, currents are generally weak. Currents generally tend to flow parallel to the shore, with some modification near the surface and at mid-depth in periods of strong winds.

Sources of faecal contamination that impact significantly at the fisheries would be likely to be located relatively near to them and on the same side of the loch. In particular, sources to the west of Eilean Shìophoirt would be unlikely to impact at any of the mussel lines over the period of a single tidal cycle and subsequent dilution is likely to be too high for such sources to have a significant effect on water quality at the lines.

There is little evidence for stratification in the loch but it would be expected that the impact from watercourses would be higher at the surface than at depth.

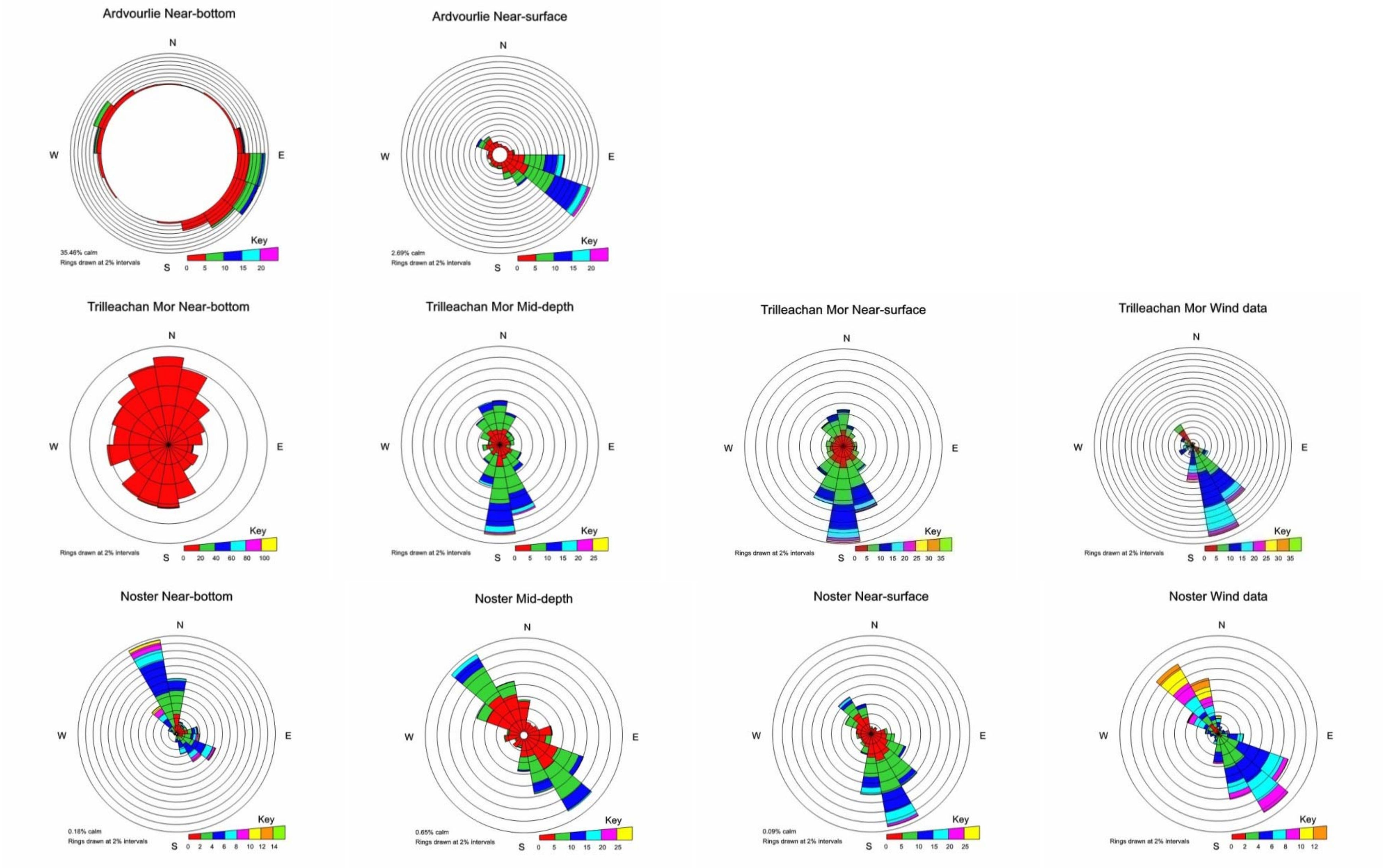

Figure 14.1 Current and wind plots

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

15. Shoreline Survey Overview

The shoreline survey was conducted on the 1st and 2nd September 2010 under dry and calm weather conditions.

Two mussel farm sites were observed and the boundaries recorded with assistance from the harvester during the shoreline survey. East Coast Mussels consisted of two 200 m long lines, with 8 m droppers. These were deployed in 2008 and had stock of harvestable size. Loch Seaforth consisted of four 200 m long lines. At the time of the survey, some stock was present on one of these lines but the majority of stock had been harvested. Time of harvesting is demand driven, and takes place during the spring/summer at times when Shetland mussel sites are closed for biotoxins and unable to supply the markets. It is planned that in future the Loch Seaforth site will be used primarily for spat collection, and once spat has settled and established the stock will be transferred to the more sheltered East Coast mussel site for ongrowing.

There are no large settlements in the area surrounding Loch Seaforth. The east coast of the loch is uninhabited and inaccessible by road. A few houses lie on the west side of the loch around Ardvourlie and Maraig. A total of four septic tanks were recorded, two at each of these settlements. Of these, three had overflows or were leaking onto the shore.

No livestock was observed on the east shoreline of Loch Seaforth, although some hoof prints and droppings (presumed to be from sheep) were noted while sampling streams. On the west shoreline sheep were recorded in the vicinity of Aird a' Mhulaidh (approximately 30 animals) and Maraig (approximately 66 animals).

A few gulls and cormorants were seen around the area, with approximately 20 gulls resting on the salmon farm cages. Bird droppings were also seen on the mussel floats at both sites indicating that these are also used by resting seabirds. Deer were reported to frequent the area, however none were observed during the course of the shoreline survey.

Seawater samples taken in the vicinity of the mussel lines contained low levels of *E. coli* (<10 cfu/100ml) in all cases. Salinity profiles taken at the mussel sites indicated no significant freshwater influence at the time of the survey.

Freshwater samples and discharge measurements were taken at most of the streams discharging close to the mussel sites. The streams were of varying size and drained areas of rough grassland with some areas of heath land. A total of nine streams were sampled and all returned low results of between <10 and 50 *E. coli* cfu/100 ml.

Mussel samples were taken from both sites at varying depths and all returned results of <20 *E. coli* MPN/100 g.

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

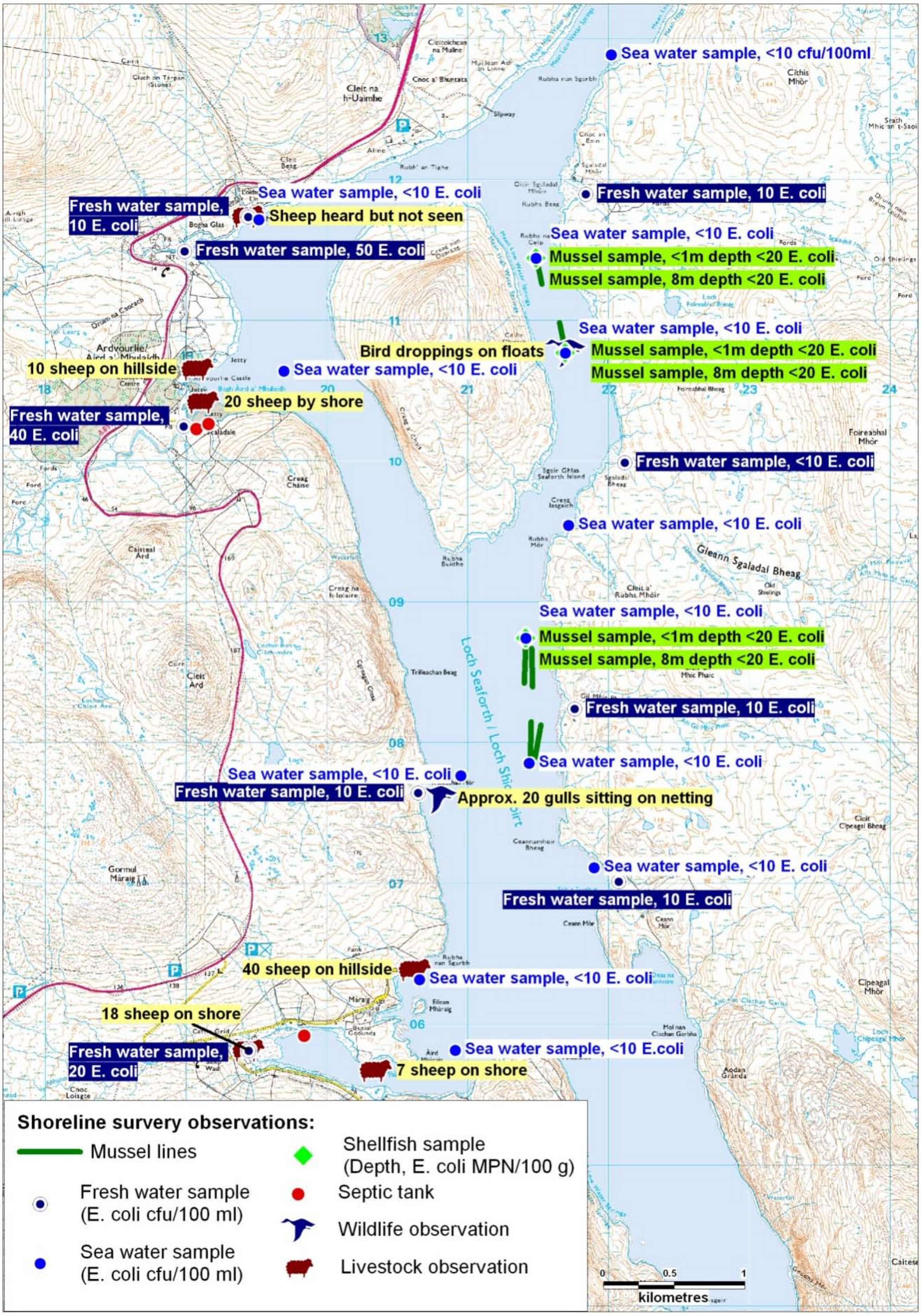

Figure 15.1 Summary of shoreline survey findings for Loch Seaforth

16. Overall Assessment

Human sewage impacts

Sources of human sewage to the waters around the fishery are associated with a limited number of individual homes and holiday accommodation on the west shore of the loch near Ardvourlie and Maraig. Given the depth of the loch and the distance of the mussel farms from the west shore, the sewage discharges there are most likely to contribute to background levels of contamination more broadly and are unlikely to directly impact the fishery at its current location. The eastern shore of the loch, nearest the mussel farms, is uninhabited.

Agricultural impacts

Agricultural activity in the vicinity of the fishery is predominantly extensive sheep rearing. Sheep were observed near Ardvourlie and Maraig on the west shore, and possible sheep droppings were observed on the east shore. Sheep are most likely to be present on or near the inhabited areas on the west shore and their numbers will be higher in summer, when lambs are present, than in winter. The impact of faecal contamination from these animals is likely to be highest along the west shore of the loch, with a general contribution to background levels of contamination most likely at the fishery itself.

Wildlife impacts

Wildlife species most likely to impact the fishery are seabirds, seals and deer. Of these, birds and seals are most likely to be present at the fishery and to have a direct impact on water quality. Gulls and cormorants rest on the mussel floats, and are likely to routinely contribute faecal bacteria to the waters near these floats. Seals are likely to forage throughout the area, and the timing and location of any faecal contribution from these animals is unpredictable. Deer are likely to be present in significant numbers throughout the area, and particularly along the western shore where they were noted as part of a deer census. Faecal matter from these animals is most likely to be carried to the fishery in streams and other fresh watercourses so any impact would be highest where watercourses discharge to the loch near to the mussel farms. All wildlife in the immediate vicinity of the loch are likely to contribute to background contamination levels in the loch.

Seasonal variation

Both human and livestock populations are likely to be highest in the area during the summer months. Holiday accommodation is near Ardvourlie is likely to be most fully occupied during the summer and autumn months, however the area is remote and the total number of visitors present at any given time is expected to be fewer than 100.

Daily rainfall records indicate higher mean daily rainfall occurs during the period from September to January, with drier weather in May and June. However, peak rainfall amounts in excess of 20 mm per day were recorded in all months and therefore short-term increases in rainfall-associated runoff could occur at any time of year.

Peak shellfish *E. coli* monitoring results were found to occur between May and October, and all results in excess of 230 *E. coli* MPN/100 g occurred during these months. However, sampling effort was concentrated in these months. No samples were taken in December, only one was taken in January, and two were taken in November and March. Nevertheless, this finding is consistent with observed seasonal increases in faecal coliform export coefficients from grazed lands (Kay et al 2008).

Rivers and streams

Watercourses measured and sampled during the shoreline survey showed low levels of contamination, though when flow was considered their calculated daily loadings were reasonably high despite the dry weather in the days preceding the survey. It is expected that the loading would be higher after rainfall and that watercourses discharging nearest the mussel farms would have the greatest effect on *E. coli* levels there, and large streams were located along the shore to the east of both fisheries. Both sites were located within 200 m of shore, however the Loch Seaforth site was situated approximately 250 m at its closest point from a measured stream. The northern inshore end of the southern set of lines would be most likely to receive direct influence from diffuse contamination carried via the Allt Gil Mhic Phaic. Streams on the western shore of the loch are less likely to impact the mussel farms along the eastern shore, but would be expected to contribute to background levels of contamination within the loch in general.

Movement of contaminants

Current speeds as measured along the western side of the loch are slow and calculated particle transport distances would be around 1 km at neap tides and a maximum of 4 km at springs.

Sources of faecal contamination to the west of Eilean Shìophoirt would be unlikely to impact at any of the mussel lines over the period of a single tidal cycle and subsequent dilution is likely to be too high for such sources to have a significant effect on water quality at the lines.

There is little evidence for stratification in the loch but it would be expected that the impact from watercourses would be higher at the surface than at depth.

Temporal and geographical patterns of sampling results

There was some uncertainty with regards to sampling locations, particularly in 2008 when four different locations were reported, three of which were on the west side of the loch, over 2 km south of the current fishery location. Therefore, it was difficult to draw any firm conclusions regarding the geographical distribution of historical monitoring results. Samples taken during the shoreline survey indicated very low levels of contamination present at the time with no difference between sites. On the three occasions when both sites were sampled on the same date there was likewise no difference in results between sites.

Over time, results at the Loch Seaforth site appeared to have improved, with no results greater than 230 *E. coli* MPN/100 g obtained between June 2008 and April

2010, however a subsequent result of 490 *E. coli* MPN/100 g was obtained in June 2010. No results greater than 1000 *E. coli* MPN/100 g have occurred since a result of 9100 was recorded in June 2008. Given the uncertainties over sampling locations, it is not clear whether this was due to improvement over time or change in sampling location.

Conclusions

The two mussel sites within Loch Seaforth are subject to similar sources of faecal contamination from diffuse livestock and wildlife sources. The nearest human sources of faecal contamination lie just over 1km west of the north end of the East Coast Mussels site and are considered unlikely to markedly affect water quality at the shellfish farms under most conditions due to their distance, slow current speeds and water depth.

The primary sources of faecal contamination will be from streams or other watercourses located along the eastern shore of the loch near to the mussel lines. As contaminants will be carried via fresh water and in the absence of significant mixing they will tend to be found in higher concentrations near the top of the water column.

Historical monitoring results have indicated episodically high levels of contamination and significant seasonal variation with higher results occurring from May to October. Statistically significant positive correlations with rainfall during both 2 and 7 days prior to sampling are indicative of rainfall-dependent sources. However, results greater than 1000 *E. coli* MPN/100 g coincided with very low rainfall values as well as high ones, therefore rainfall is not an adequate predictor of high results.

17. Recommendations

Production area

It is recommended that both sites be included within a single production area due to the similarity of contaminating sources. The seabed lease area on which the nominal RMP lies is no longer in use and therefore has been excluded from the production area boundaries. The sampling officer identified difficulties in access for routine sampling due to the remoteness of the mussel farms and requested that the production area be extended to include a portion of the western shoreline to allow for placement of a monitoring point that can be accessed without requiring a boat. Therefore, the production area was extended to the north and west to meet the western shore, which can be accessed more reliably.

The recommended production area boundaries are described as the area bounded by lines drawn from NB 2165 0729 to NB 2100 0729 to NB 2100 0948 and from NB 2100 1181 to NB 2100 1239 and from NB 2112 1251 to NB 2168 1176 and extending to MHWS.

RMP

It is recommended that the RMP be established at a location on the western shoreline that will allow for collection of monitoring samples in all weathers. The recommended RMP is therefore NB 2105 1239. It should be noted that this location, as it lies nearer the shoreline and nearer to septic tank discharges, may potentially receive higher levels of faecal contamination than the fishery itself.

A sample may be taken either from shore mussels or from bagged shellfish. If bagged shellfish are used, they should be in place for at least 2 weeks prior to sampling to ensure that they reflect the water quality at that location.

Frequency

Due to observed seasonality in sampling results, it is recommended that monthly sampling be maintained until such time as the area qualifies for reduced sampling under a stability assessment.

Depth of sampling

As the sampling point is on the intertidal shoreline, no sampling depth is applicable.

Tolerance

A tolerance of 40 m is recommended to allow sufficient mussels to be obtained for sampling.

Other

For ease of reference, it is recommended that the sites be renamed as Seaforth Island East and Seaforth South in line with the site names given by the harvester in the planning applications.

The locations of the recommended production area boundaries and RMP are shown mapped in Figure 17.1.

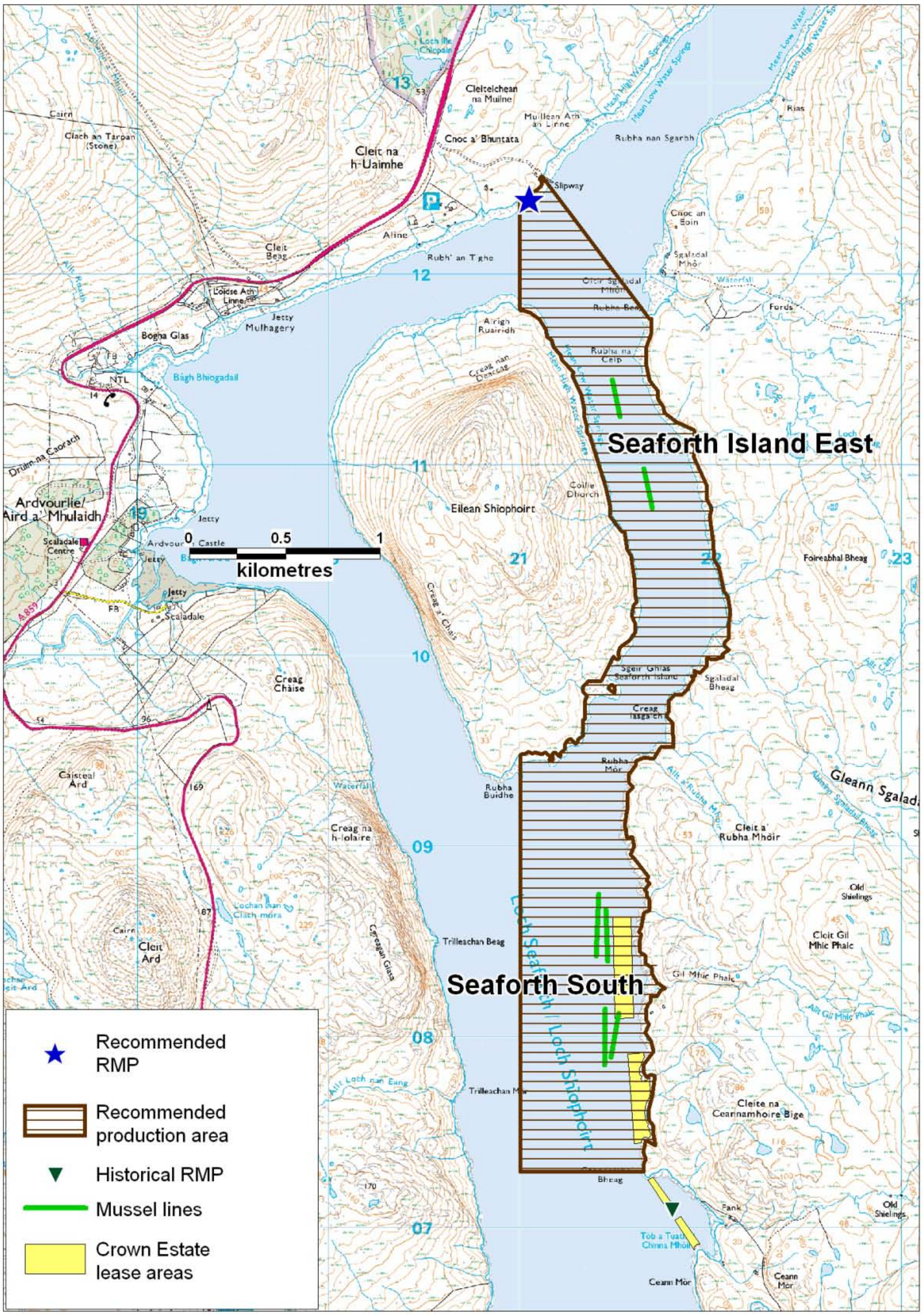

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Figure 17.1 Map of recommendations at Loch Seaforth

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Sampling Plan for Loch Seaforth

PRODUCTION AREA	Loch Seaforth
SITE NAME	Seaforth South
SIN	LH 193 126
SPECIES	Common mussels
TYPE OF FISHERY	Longline
NGR OF RMP	NB 2105 1239
EAST	121050
NORTH	912390
TOLERANCE (M)	40
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

Table of Proposed Boundaries and RMPs

PRODUCTION AREA	Loch Seaforth
SPECIES	Common mussels
SIN	LH 193 126
EXISTING BOUNDARY	Area bounded by lines drawn between NB 2065 0800 to NB 2166 0800 then from NB 2047 0600 to NB 2263 0600 extending to MHWS
EXISTING RMP	NB 218 071
RECOMMENDED BOUNDARY	Area bounded by lines drawn from NB 2165 0729 to NB 2100 0729 to NB 2100 0948 and from NB 2100 1181 to NB 2100 1239 and from NB 2112 1251 to NB 2168 1176 and extending to MHWS
RECOMMENDED RMP	NB 2105 1239
COMMENTS	Shift production area northwards and extend to incorporate new site east of Eilean Shiophoirt (Seaforth Island East). Move RMP to lie on Seaforth South mussel farm where it approaches the nearest watercourse.

Geology and Soils Assessment

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.

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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	$1.7 \times 10^{7*}$ (+)	1.4×10^{7}	2.0×10^{7}	282	$2.8 \times 10^{6*}$ (-)	2.3×10^{6}	3.2×10^{6}
Crude sewage discharges	252	$1.7 \times 10^{7*}$ (+)	1.4×10^{7}	2.0×10^{7}	79	$3.5 \times 10^{6*}$ (-)	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	$1.0 \times 10^{7*}$ (+)	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	$3.3 \times 10^{5*}$ (-)	2.9×10^{5}	3.7×10^{5}	184	$5.0 \times 10^{5*}$ (+)	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	$2.8 \times 10^{5*}$ (-)	2.2×10^{5}	3.5×10^{5}	93	$5.1 \times 10^{5*}$ (+)	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.

Section 11.3 One way ANOVA comparison of results by sampling location

```
Source   DF      SS     MS     F      P
GridRef   3   5.454  1.818  4.09  0.011
Error    51  22.663  0.444
Total    54  28.117

S = 0.6666   R-Sq = 19.40%   R-Sq(adj) = 14.66%

                                  Individual 95% CIs For Mean Based on
                                  Pooled StDev
Level          N    Mean   StDev  ---------+---------+---------+---------+
NB 2155 0748  14  1.3870  0.3905  (------*------)
NB 2155 0798   7  2.0743  0.6733            (---------*----------)
NB217074      11  2.2754  0.7294                  (--------*-------)
NB218071      23  1.9341  0.7580              (-----*----)
                                  ---------+---------+---------+---------+
                                        1.50      2.00      2.50      3.00
Pooled StDev = 0.6666

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

Individual confidence level = 98.95%

GridRef = NB 2155 0748 subtracted from:

GridRef         Lower  Center   Upper  -----+---------+---------+---------+-
---
NB 2155 0798  -0.1332  0.6873  1.5077              (-----------*-----------
)
NB217074       0.1743  0.8884  1.6025                  (----------*--------
-)
NB218071      -0.0537  0.5471  1.1479               (--------*-------)
                                       -----+---------+---------+---------+-
---
                                          -0.70      0.00      0.70      1.40

GridRef = NB 2155 0798 subtracted from:

GridRef     Lower   Center   Upper  -----+---------+---------+---------+----
NB217074  -0.6558   0.2011  1.0580        (-----------*-----------)
NB218071  -0.9052  -0.1401  0.6249    (----------*----------)
                                    -----+---------+---------+---------+----
                                       -0.70      0.00      0.70      1.40

GridRef = NB217074 subtracted from:

GridRef     Lower   Center   Upper  -----+---------+---------+---------+----
NB218071  -0.9910  -0.3413  0.3084   (--------*--------)
                                    -----+---------+---------+---------+----
                                       -0.70      0.00      0.70      1.40
```

Section 11.5 One way ANOVA comparison of *E. coli* results by season

```
Source  DF      SS     MS     F      P
Season   3   8.524  2.841  6.25  0.001
Error   56  25.465  0.455
Total   59  33.989
```

```
S = 0.6743   R-Sq = 25.08%   R-Sq(adj) = 21.06%


                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level   N    Mean   StDev  -----+---------+---------+---------+----
1      17  1.4051  0.4912         (-----*------)
2      18  2.2199  0.7920                         (-----*------)
3      20  2.1255  0.7393                       (------*-----)
4       5  1.3496  0.3728  (-----------*-----------)
                           -----+---------+---------+---------+----
                              1.00      1.50      2.00      2.50

Pooled StDev = 0.6743

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

Individual confidence level = 98.94%

Season = 1 subtracted from:

Season    Lower   Center   Upper  --------+---------+---------+---------+-
2        0.2117   0.8148  1.4179                      (-----*-----)
3        0.1321   0.7204  1.3086                     (-----*-----)
4       -0.9627  -0.0555  0.8518          (--------*---------)
                                  --------+---------+---------+---------+-
                                       -1.0       0.0       1.0       2.0

Season = 2 subtracted from:

Season    Lower   Center   Upper  --------+---------+---------+---------+-
3       -0.6739  -0.0945  0.4849             (-----*-----)
4       -1.7718  -0.8703  0.0312  (--------*--------)
                                  --------+---------+---------+---------+-
                                       -1.0       0.0       1.0       2.0

Season = 3 subtracted from:

Season    Lower   Center   Upper  --------+---------+---------+---------+-
4       -1.6675  -0.7758  0.1159   (--------*--------)
                                  --------+---------+---------+---------+-
                                       -1.0       0.0       1.0       2.0
```

Section 11.6.1 Spearman's rank correlation for *E. coli* result and 2 day rainfall

```
Pearson correlation of ranked 2 day rain and ranked ecoli for 2 day rain =
     0.334
```

n=51, p<0.01

Section 11.6.1 Spearman's rank correlation for *E. coli* result and 7 day rainfall

```
Pearson correlation of ranked 7 day rain and ranked e coli for 7 day rain =
     0.397
```

n=48, p<0.005

Section 11.6.2 Circular linear correlation for *E. coli* result and tidal state on the spring/neap cycle

CIRCULAR-LINEAR CORRELATION
Analysis begun: 21 May 2010 13:55:10

Variables (& observations)	r	p
Angles & Linear (60)	0.074	0.729

<u>Section 11.6.2 Circular linear correlation for *E. coli* result and tidal state on the high/low cycle</u>

CIRCULAR-LINEAR CORRELATION
Analysis begun: 15 June 2010 14:13:10

Variables (& observations)	r	p
Angles & Linear (60)	0.107	0.523

<u>Section 11.6.5 Spearman's rank correlation for *E. coli* result and salinity</u>

```
Pearson correlation of ranked salinity and ranked e coli for salinity = -
0.284
n=25, p>0.05
```

Hydrographic Methods

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

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

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

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

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

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

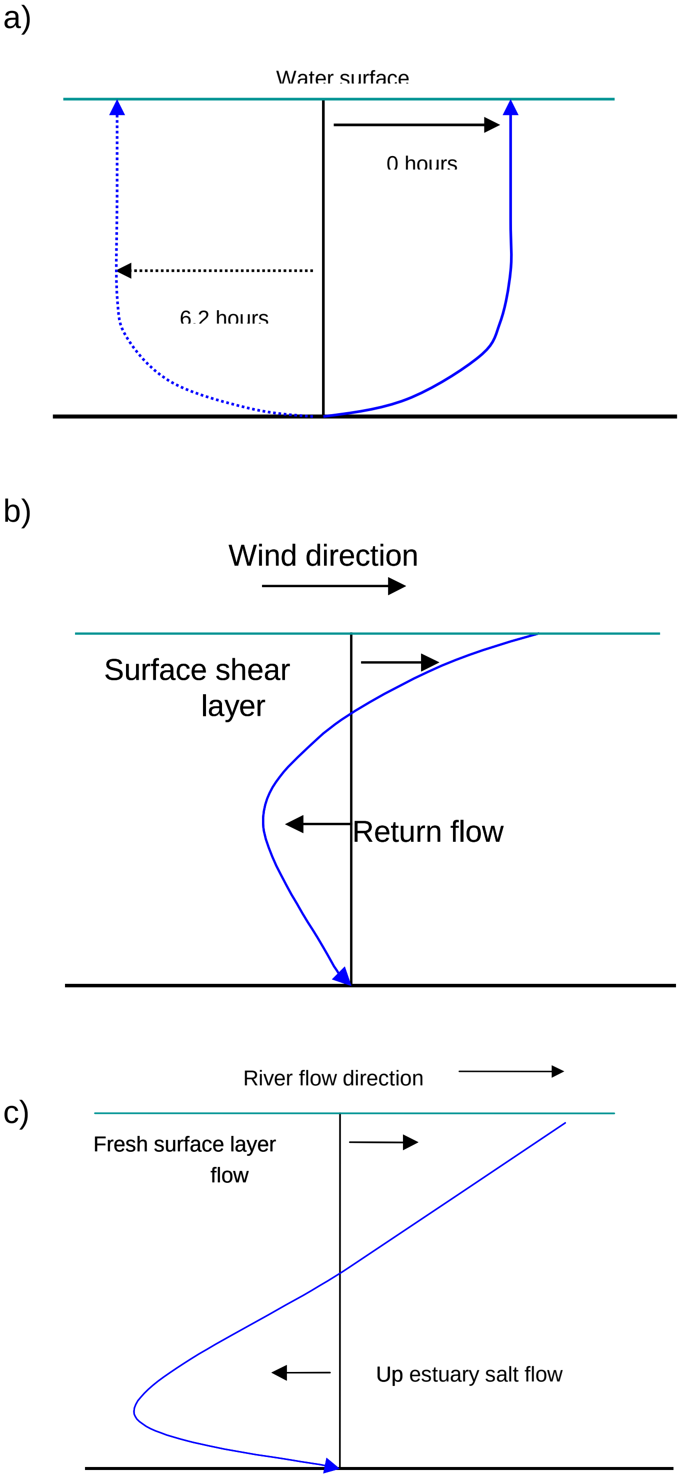

Figure 1. Typical vertical profiles for water currents. The black vertical line indicates zero velocity so portions of the profile to the left and right indicate flow moving in opposite directions. a) Peak tidal flow profiles. Profiles are shown 6.2 hours apart as the main tidal current reverses direction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

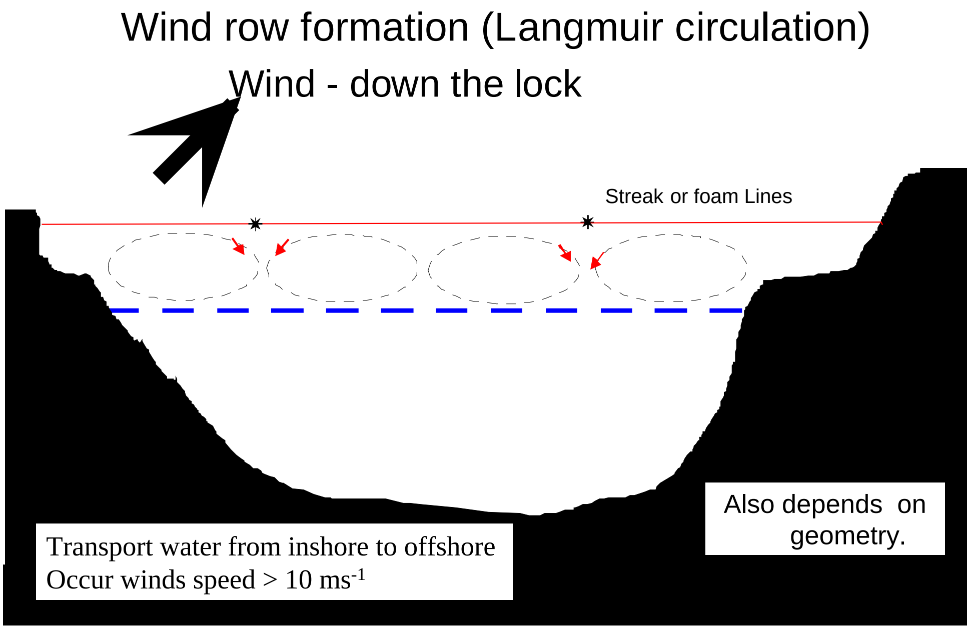

Figure 2. Schematic of wind driven 'wind row' currents. The dotted blue line indicates the depth of the surface fresh(er) water layer usually found in sea lochs.

Non-modelling Assessment

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

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

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

The catalogue of Scottish Sea Loch produced by the SMBA is used to quantify sills, volume fluxes and likely flow velocities. Because the flow is so constrained by the rapidly varying bathymetry, care has to be used in the extrapolation of direct measurements of current flow. Mean flow velocities can be estimated at the sills by using estimates of the sill area and the volume change through a tidal cycle. This in turn can be used to estimate the maximum distance travelled in a tidal cycle in the sill area. Away from the sill area, tidal velocities are general low and transport events are dominated by wind or density effects. Sea Lochs generally have a surface layer of fresher water; the extent of this depends on freshwater input, sill depth and quantity of mixing.

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

References

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

Glossary

The following technical terms may appear in the hydrographic assessment.

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

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

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

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

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

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

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

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

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

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

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

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

Shoreline Survey Report

Production Areas:

Production Area	Site	SIN	Species
Eilean Shiphoirt East	East Coast Mussels	LH 484 811 08	Common Mussels
Loch Seaforth	Loch Seaforth	LH 193 126 08	Common Mussels

Harvester: Alisdair H. Cunningham
Status: New application (LH 484) and new site (LH 193)
Date Surveyed: 1/9/2010 and 2/9/2010
Surveyed by: Paul Tyler & Alastair Cook
Area Surveyed: See Figure 1.

Monitoring Points:

Site	Nominal RMP	Sampling Point
East Coast Mussels		NB 2138 1140
Loch Seaforth	NB 218071	

Weather Observations

01/09/2010 Fine, light southerly breeze, air temperature 13°C.
02/09/2010 Fine, very light southerly breeze, air temperature 12°C.
Significant rain had not fallen since the 28th August.

Specific observations made on site are mapped in Figure 1 and listed in Table 1. Water and shellfish samples were collected at sites marked on Figures 2 and 3. Bacteriology results are given in Tables 2 and 3. Salinity profiles are presented in Table 4. Photographs are presented in Figures 4-11.

Fishery

East Coast Mussels (LH 484 811 08). This site consists of two 200m mussel longlines from which 8m droppers are suspended. These were deployed in early 2008, and at the time of survey held stock of a harvestable size. This site/area is yet to be classified.

Loch Seaforth (LH 193 126 08). This site consists of four 200m mussel longlines. At the time of survey, some stock was present on one of these lines but the majority of stock had been harvested. This site lies partially within the Loch Seaforth production area.

Both these sites are under the same ownership. Time of harvesting is demand driven, and takes place during the spring/summer at times when Shetland mussel sites are closed for biotoxins and unable to supply the markets. It is planned that in future the Loch Seaforth site will be used primarily for spat collection, and once spat has settled and established the stock will be transferred to the more sheltered East Coast mussels site for ongrowing.

Sewage/Faecal Sources

Human – There are no large settlements in the area surrounding Loch Seaforth. The east coast of the loch is uninhabited and inaccessible by road. A few houses lie on the west side of the loch around Aird a' Mhulaidh and Maraig. A total of four septic tanks were recorded, two at each of these settlements. Of these, three had overflows or were leaking onto the shore. It is likely that there are further septic tanks in these areas, presumably discharging to soakaway or to any nearby watercourses.

Livestock – The land surrounding Loch Seaforth is mainly rough grassland/heath. No livestock were seen on the east shore of Seaforth Island, although some sheep footprints and dropping were noted while sampling streams on the east shore, and the harvester advised that some sheep were present on Seaforth Island about 2 weeks before the shoreline survey. On the west shore sheep were recorded in the vicinity of Aird a' Mhulaidh (about 30 animals) and Maraig (about 66 animals).

A large number of small watercourses draining to Loch Seaforth are apparent on the Ordnance Survey map. Many of the smaller ones were not flowing at the time of survey. The larger of these were sampled and measured. All carried very low levels of *E. coli* at the time of survey (<10 to 50 cfu/100ml). Given the relatively uniform nature of the area, the smaller streams which were not sampled may be expected to carry similar low levels of contamination.

E. coli levels in sea water samples taken from various locations around the Loch all contained levels of *E. coli* below the limit of quantification of the test employed (<10 cfu/100ml).

The six common mussel samples taken from the long lines, where available, all gave *E. coli* results of <20 MPN/100g. Salinity measurements taken during the survey indicated that there was no freshwater influence on the water body at the time, with salinities all that of full strength seawater with very no stratification.

Seasonal Population

Previous surveys have identified that tourism is important to the island economy, with the largest influx of visitors occurring during the summer months. Archaeological sites and outdoor activities draw the most visitors. There are no specific local attractions apart from perhaps the presence of sea eagles in the area. There is one B&B with one guest room at Aird a' Mhulaidh, and it is possible that some homes in the area are privately owned holiday homes.

Boats/Shipping

Boat traffic in Loch Seaforth mainly consists of small vessels associated with the mussel and salmon farms, and a small inshore potting boat. A few small pleasure dinghys were seen at Aird a' Mhulaidh. None of these vessels were likely to make overboard discharges. A slightly larger vessel was seen moored by an area of salmon cages, and it is possible that this may have an onboard toilet.

Land Use

The land surrounding Loch Seaforth is mainly rough grassland/heath with a few small patches of woodland on the western shore. At the time of survey, sheep were only present around the settled areas on the west shore.

Wildlife/Birds

A few gulls and cormorants were seen around the area, with about 20 gulls resting on the salmon farm cages. Bird droppings were also seen on the mussel floats at both sites indicating that these are also used by resting seabirds.

Although none was seen during the course of the shoreline survey, the sampling officer indicated that deer are present on the heathland, possibly in similar numbers overall to the sheep.

General observations

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

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

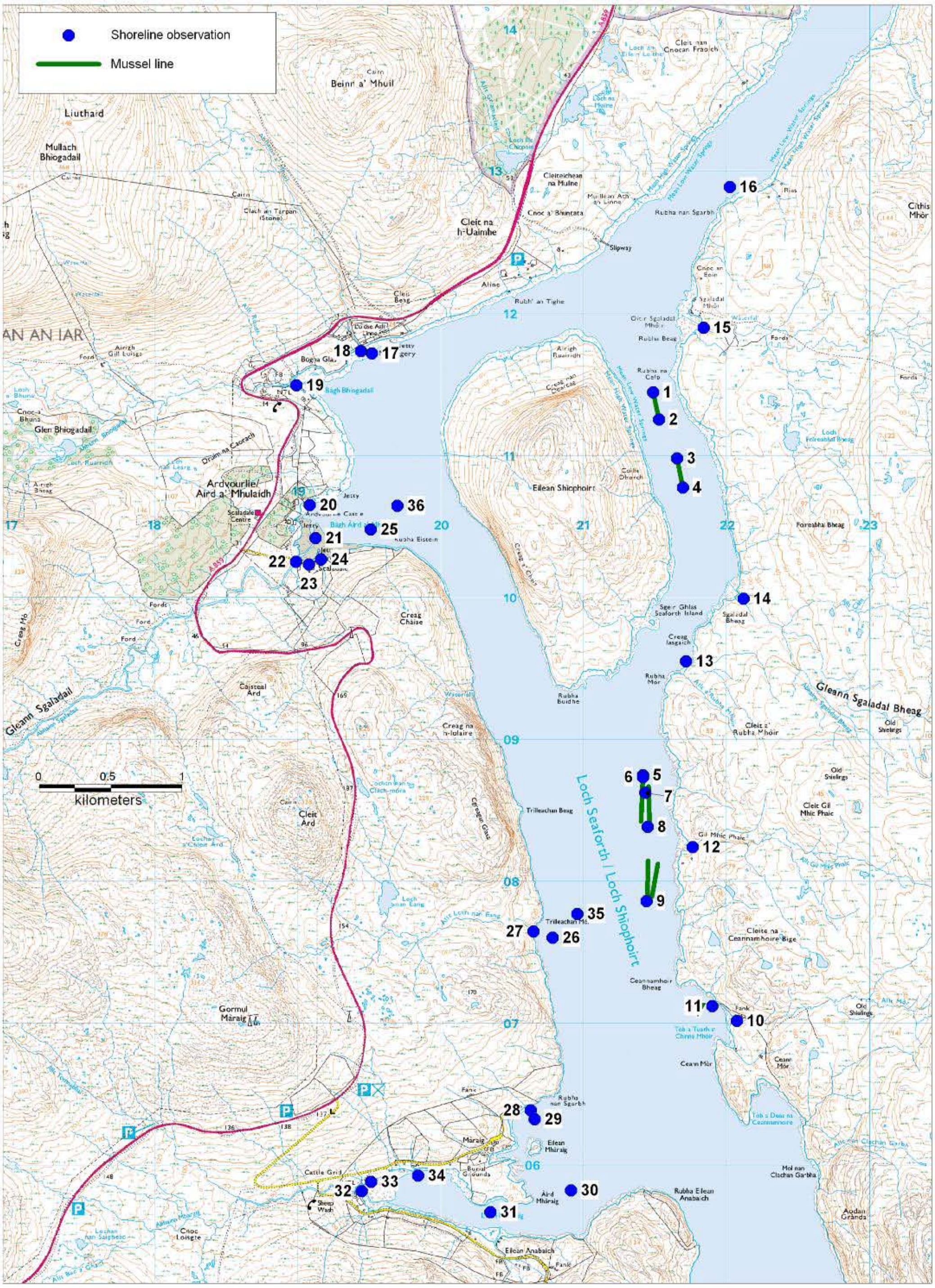

Figure 1. Map of shoreline observations

Table 1. Shoreline observations

No.	Description	Position	Photograph	Observation
1	01-SEP-10 8:34:41AM	NB 21484 11444		End of line. Seawater sample 1. Mussel samples 1 (top) and 2 (bottom). Salinity profile 1.
2	01-SEP-10 8:54:44AM	NB 21526 11251		End of line.
3	01-SEP-10 8:56:56AM	NB 21651 10978		End of line.
4	01-SEP-10 8:58:47AM	NB 21693 10771	Figure 4	End of line. Seawater sample 2. Mussel samples 3 (top) and 4 (bottom). Bird droppings on floats.
5	01-SEP-10 9:33:20AM	NB 21414 08745		End of line. Seawater sample 3. Mussel samples 5 (top) and 6 (bottom). Salinity profile 2.
6	01-SEP-10 9:52:47AM	NB 21414 08731		No observation
7	01-SEP-10 9:56:01AM	NB 21430 08623		End of line 20m E.
8	01-SEP-10 9:57:22AM	NB 21447 08381		End of line 10m NE.
9	01-SEP-10 10:03:55AM	NB 21437 07859		End of Line. Seawater sample 4.
10	01-SEP-10 10:28:35AM	NB 22071 07014		Stream 140cmx15cmx0.039m/s. Freshwater sample 5.
11	01-SEP-10 10:33:53AM	NB 21899 07118		Seawater sample 6.
12	01-SEP-10 10:47:49AM	NB 21760 08240		Stream 220cmx10cmx0.087m/s. Freshwater sample 6A.
13	01-SEP-10 10:57:54AM	NB 21715 09547		Seawater sample 7.
14	01-SEP-10 11:03:24AM	NB 22116 09990		Stream 360cmx23cmx0.207m/s. Freshwater sample 8.
15	01-SEP-10 11:19:39AM	NB 21837 11897		Stream 580cmx11cmx0.086m/s. Freshwater sample 9.
16	01-SEP-10 11:27:24AM	NB 22020 12889		Seawater sample 10.
17	02-SEP-10 9:21:52AM	NB 19515 11717		Seawater sample 11.
18	02-SEP-10 9:26:49AM	NB 19440 11734		Stream 110cmxs8cmx0.371m/s. Freshwater sample 12. Sheep heard but not seen.
19	02-SEP-10 9:41:15AM	NB 18987 11491		Stream 440cmx6cmx0.268m/s. Freshwater sample 13.
20	02-SEP-10 9:56:05AM	NB 19081 10650		10 sheep up on hill.
21	02-SEP-10 10:00:43AM	NB 19121 10416	Figure 5	20 sheep by shore.
22	02-SEP-10 10:08:38AM	NB 18983 10248		Stream 130cmx5cmx1.204m/s. Freshwater sample 14.
23	02-SEP-10 10:12:44AM	NB 19074 10229	Figure 6	Septic tank leaking onto shore.
24	02-SEP-10 10:15:59AM	NB 19160 10266	Figure 7	Septic tank.
25	02-SEP-10 10:22:43AM	NB 19507 10477		Salmon cage.
26	02-SEP-10 10:27:44AM	NB 20781 07601	Figure 8,9	Salmon cage and service boat. About 20 gulls sitting on netting.
27	02-SEP-10 10:31:59AM	NB 20647 07646		Stream 80cmx20cmx0.123m/s. Freshwater sample 15.
28	02-SEP-10 10:40:15AM	NB 20626 06384		40 sheep on hillside.

No.	Description	Position	Photograph	Observation
29	02-SEP-10 10:41:07AM	NB 20656 06321		Seawater sample 16.
30	02-SEP-10 10:44:26AM	NB 20910 05822		Seawater sample 17.
31	02-SEP-10 10:47:35AM	NB 20346 05668		7 sheep on shore.
32	02-SEP-10 10:54:45AM	NB 19445 05815		Stream 960cmx11cmx0.202m/s. Freshwater sample 15. 18 sheep on shore.
33	02-SEP-10 11:00:37AM	NB 19511 05881	Figure 10	Grey water oozing from reeds, presumably from septic tank buried in adjacent garden.
34	02-SEP-10 11:07:04AM	NB 19838 05924	Figure 11	Concrete septic tank.
35	02-SEP-10 11:11:47AM	NB 20952 07769		Seawater sample 19.
36	02-SEP-10 11:17:46AM	NB 19694 10642		Seawater sample 20.

Sampling

Water and shellfish samples were collected at sites marked on the maps in Figures 2 and 3 respectively. Bacteriology results follow in Tables 2 and 3.

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

Table 2. Water sample *E. coli* results

Sample Ref.	Date and time	Position	Type	*E. coli* (cfu/100 ml)	Salinity (g/L)
S1	01-SEP-10 8:34:41AM	NB 2148 1144	Seawater	<10	36.7
S2	01-SEP-10 8:58:47AM	NB 2169 1077	Seawater	<10	37.2
S3	01-SEP-10 9:33:20AM	NB 2141 0875	Seawater	<10	37.1
S4	01-SEP-10 10:03:55AM	NB 2144 0786	Seawater	<10	36.9
S5	01-SEP-10 10:28:35AM	NB 2207 0701	Freshwater	10	
S6	01-SEP-10 10:33:53AM	NB 2190 0712	Seawater	<10	37.1
S6A	01-SEP-10 10:47:49AM	NB 2176 0824	Freshwater	10	
S7	01-SEP-10 10:57:54AM	NB 2172 0955	Seawater	<10	36.9
S8	01-SEP-10 11:03:24AM	NB 2212 0999	Freshwater	<10	
S9	01-SEP-10 11:19:39AM	NB 2184 1190	Freshwater	10	
S10	01-SEP-10 11:27:24AM	NB 2202 1289	Seawater	<10	36.3
S11	02-SEP-10 9:21:52AM	NB 1952 1172	Seawater	<10	36.2
S12	02-SEP-10 9:26:49AM	NB 1944 1173	Freshwater	10	
S13	02-SEP-10 9:41:15AM	NB 1899 1149	Freshwater	50	
S14	02-SEP-10 10:08:38AM	NB 1898 1025	Freshwater	40	
S15	02-SEP-10 10:31:59AM	NB 2065 0765	Freshwater	10	
S16	02-SEP-10 10:41:07AM	NB 2066 0632	Seawater	<10	36.9
S17	02-SEP-10 10:44:26AM	NB 2091 0582	Seawater	<10	36.7
S18	02-SEP-10 10:54:45AM	NB 1945 0582	Freshwater	20	
S19	02-SEP-10 11:11:47AM	NB 2095 0777	Seawater	<10	36.5
S20	02-SEP-10 11:17:46AM	NB 1969 1064	Seawater	<10	36.5

Table 3. Mussel sample *E. coli* results

Sample Ref.	Date and time	Position	Site	Depth (m)	Result (*E. coli* MPN/100 g)
1	01-SEP-10 8:34:41AM	NB 2148 1144	East Coast Mussels	<1	<20
2	01-SEP-10 8:34:41AM	NB 2148 1144	East Coast Mussels	8	<20
3	01-SEP-10 8:58:47AM	NB 2169 1077	East Coast Mussels	<1	<20
4	01-SEP-10 8:58:47AM	NB 2169 1077	East Coast Mussels	8	<20
5	01-SEP-10 9:33:20AM	NB 2141 0875	Loch Seaforth	<1	<20
6	01-SEP-10 9:33:20AM	NB 2141 0875	Loch Seaforth	8	<20

Table 4. Salinity profiles

Profile	Date and time	Position	Depth (m)	Salinity (ppt)	Temperature (°C)
1	01-SEP-10 8:34:41AM	NB 2148 1144	0	36.3	13
			2.5	36.4	12.9
			5	36.4	12.8
			7.5	36.5	12.8
			10	36.6	12.6
2	01-SEP-10 9:33:20AM	NB 2141 0875	0	36.4	12.8
			2.5	36.5	12.7
			5	36.5	12.7
			7.5	36.6	12.5
			10	36.6	12.4

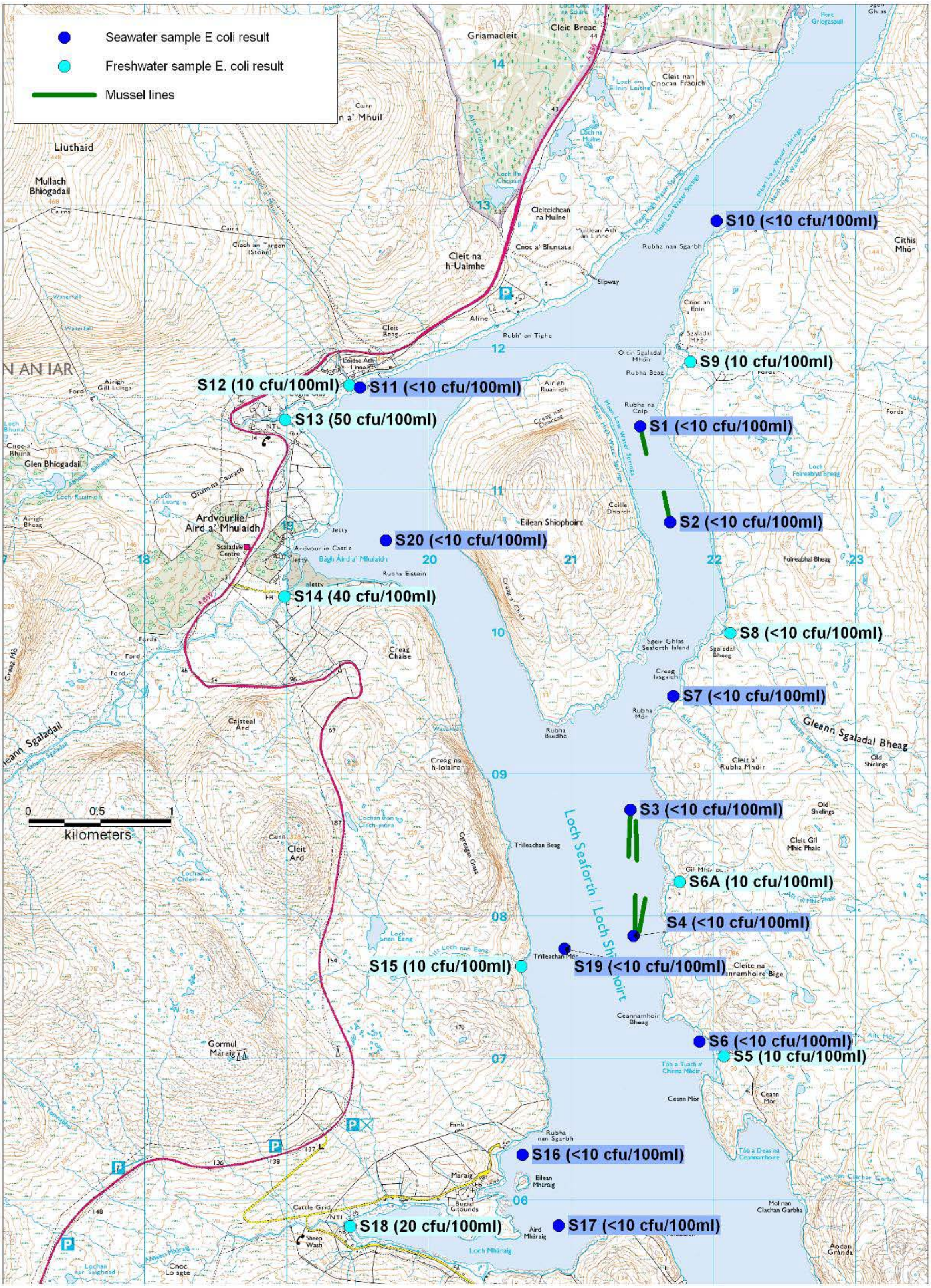

Figure 2. Water sample results

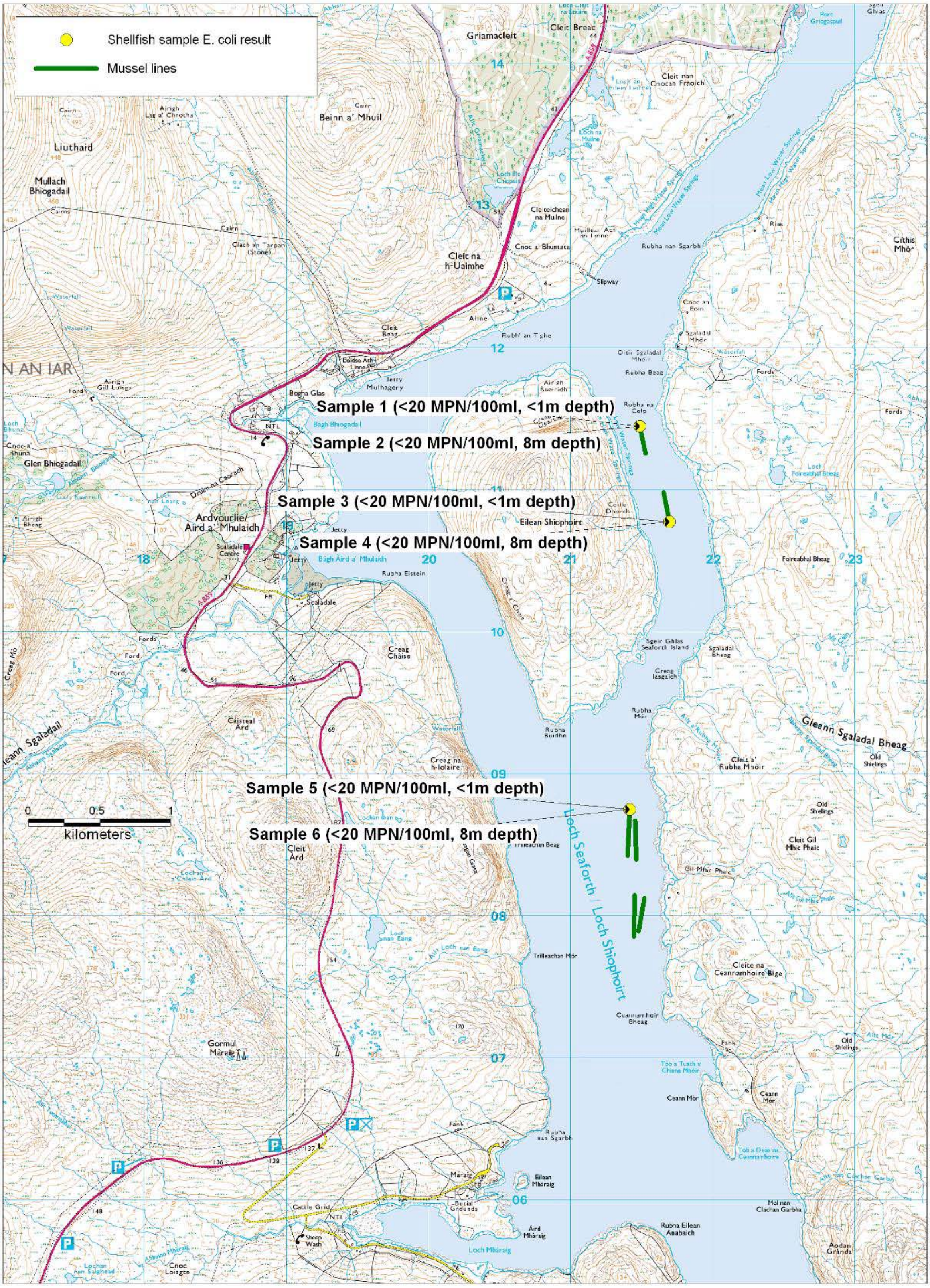

Figure 3. Shellfish sample results

Photographs

Figure 4. Bird droppings on mussel floats

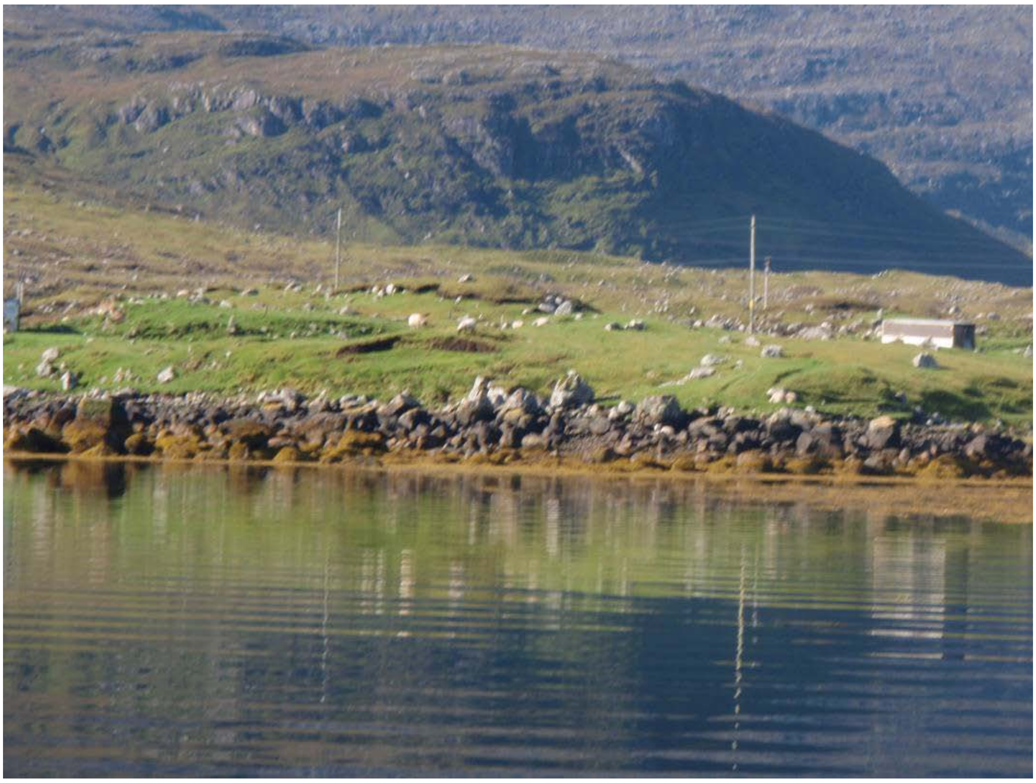

Figure 5. Sheep near shore

Figure 6. Septic tank head and leak at base

Figure 7. Septic tank near garden

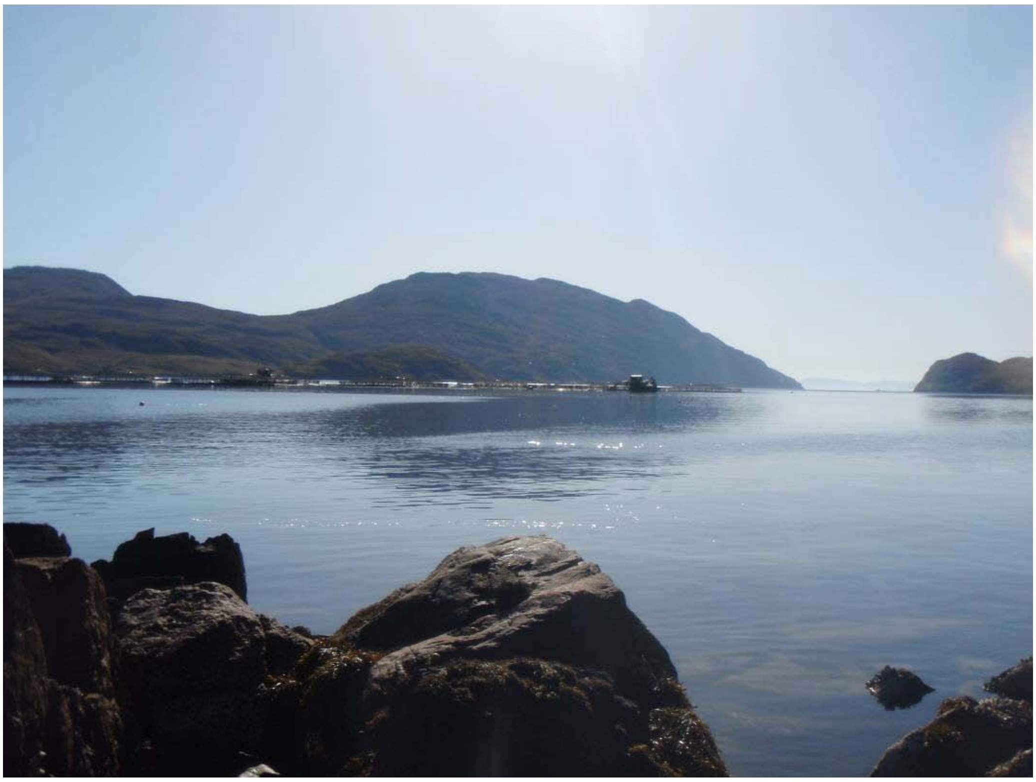

Figure 8. Service boat at salmon farm

Figure 9. Salmon cages with gulls

Figure 10. Trail of foul water from garden

Figure 11. Septic tank