Scottish Sanitary Survey Project

Sanitary Survey Report
Loch Fyne: Ardkinglas
AB 147
July 2008

Report Distribution – Loch Fyne : Ardkinglas

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

** Distribution of draft and final reports to harvesters is undertaken by the relevant local authority.

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1. General description

Loch Fyne is a fiordic loch over 70 km in length. There are two sills, one at Minard and one at Otter Ferry. The maximum depth in the loch is more than 180 m.

The Ardkinglas production area is one of five in the loch and is situated approximately 2km from the head. The Fyne and Shira rivers enter the loch near the production area but there are many other small watercourses that enter the loch near the shellfisheries.

The village of Cairndow lies at the north-east limit of the production area while the town of Inveraray lies approximately 5 km from the south-west limit. The small villages of Ardno and St Catherines lie on the southern shore of the production area.

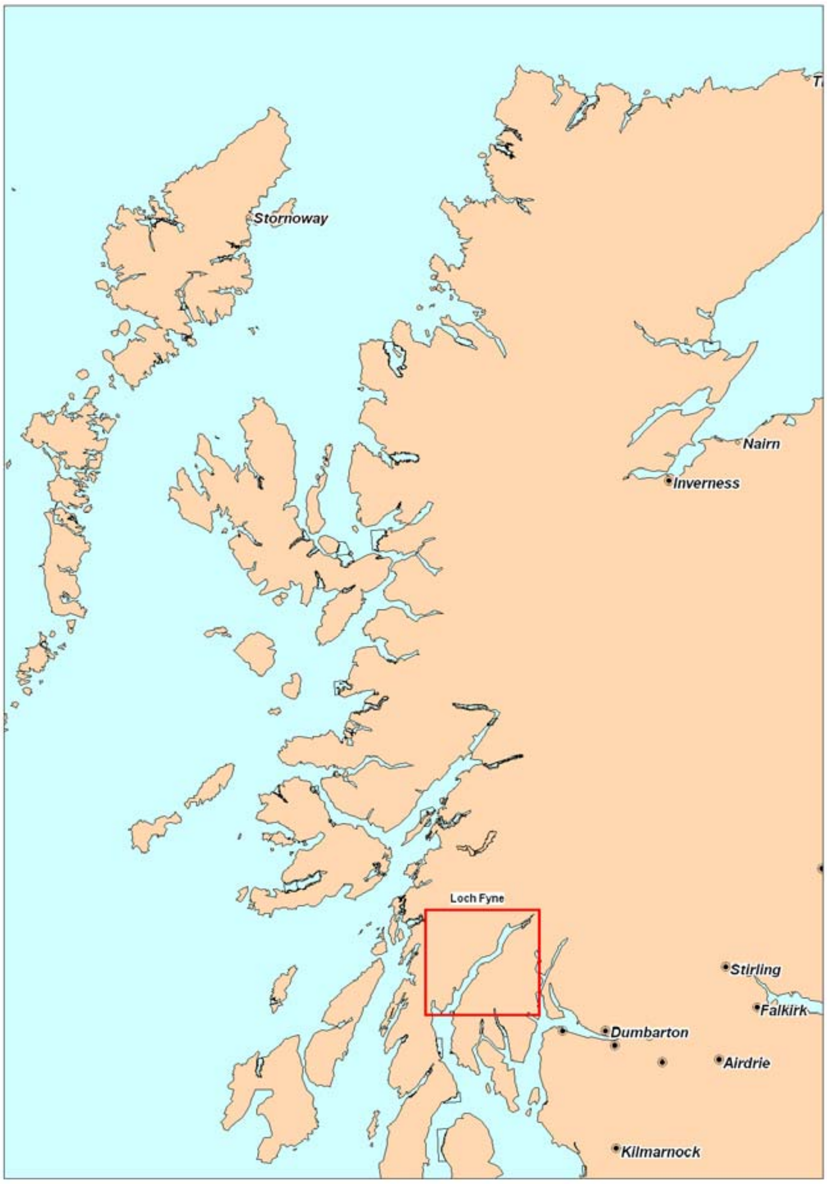

Figure 1.1 Location map for Loch Fyne

2. Fishery

The fishery at Loch Fyne Ardkinglas is comprised of two long line mussel (*Mytilus* sp.) farms and one area of oyster trestle farms, associated with three Crown Estates leases as listed in Table 2.1 below:

Table 2.1 Loch Fyne: Ardkinglas FSAS listed production sites

Site	SIN	Species
The Shore	AB 147 036 08	Common mussels
The Point	AB 147 035 08	Common mussels
Policy Gates	AB 147 034 08	Common mussels
The Shore	AB 147 036 13	Pacific oysters
The Point	AB 147 035 13	Pacific oysters
Policy Gates	AB 147 034 13	Pacific oysters

Current production area boundaries are given as the area bounded by lines drawn between NN 1500 1002 and NN 1500 0865 and between NN 1770 1155 and NN 1770 1095. There are three RMPs for the Loch Fyne Ardkinglas production area. The first is located on the Policy Gates site and the reported RMP grid reference is NN 155 089 – this does not coincide with any of the currently farmed locations for either species. The second is located on The Point site and the reported RMP grid reference is NN 170 105. The third is located on The Shore site and the reported grid reference is NN 164 099. The RMPs apply to both species.

There are two main areas of mussel lines. These do not correspond directly to any of the three named sites in the production area. The dropper lines are 10 m in length. Long lines attached to floats are laid out in parallel lines anchored at either end within the approved lease area. Vertical lines containing plastic pegs (droppers) are attached to the long lines. New lines are placed before or during spawning between May and early June and spat settle on to the droppers from the surrounding water. The spat are then left to grow for up to three years before reaching marketable size. Rotation of the mussels is undertaken separately within each area. Harvesting is undertaken during the period from October to March/April.

During the shoreline survey twelve relatively discrete sets of Pacific oyster trestles were identified along the southern bank of the loch, stretching across the three sites named above. Harvesting normally takes place all year-round. At the time of the shoreline survey the size of oysters varied markedly between some of the sets of trestles, with some sets only containing juvenile stock.

Figure 2.1 shows the relative positions of the mussel lines and oyster trestles, Food Standard Agency Scotland designated Production Area, SEPA shellfish growing waters and the Crown Estates lease areas.

In addition to the shellfish cultured within the production area, oysters are bought in from other production areas, held in holding tanks which are effectively an extension of the production area as non-disinfected water from the loch is used in these tanks. They are then depurated and distributed.

The overall volume of shellfish produced in and/or distributed from this production area is high.

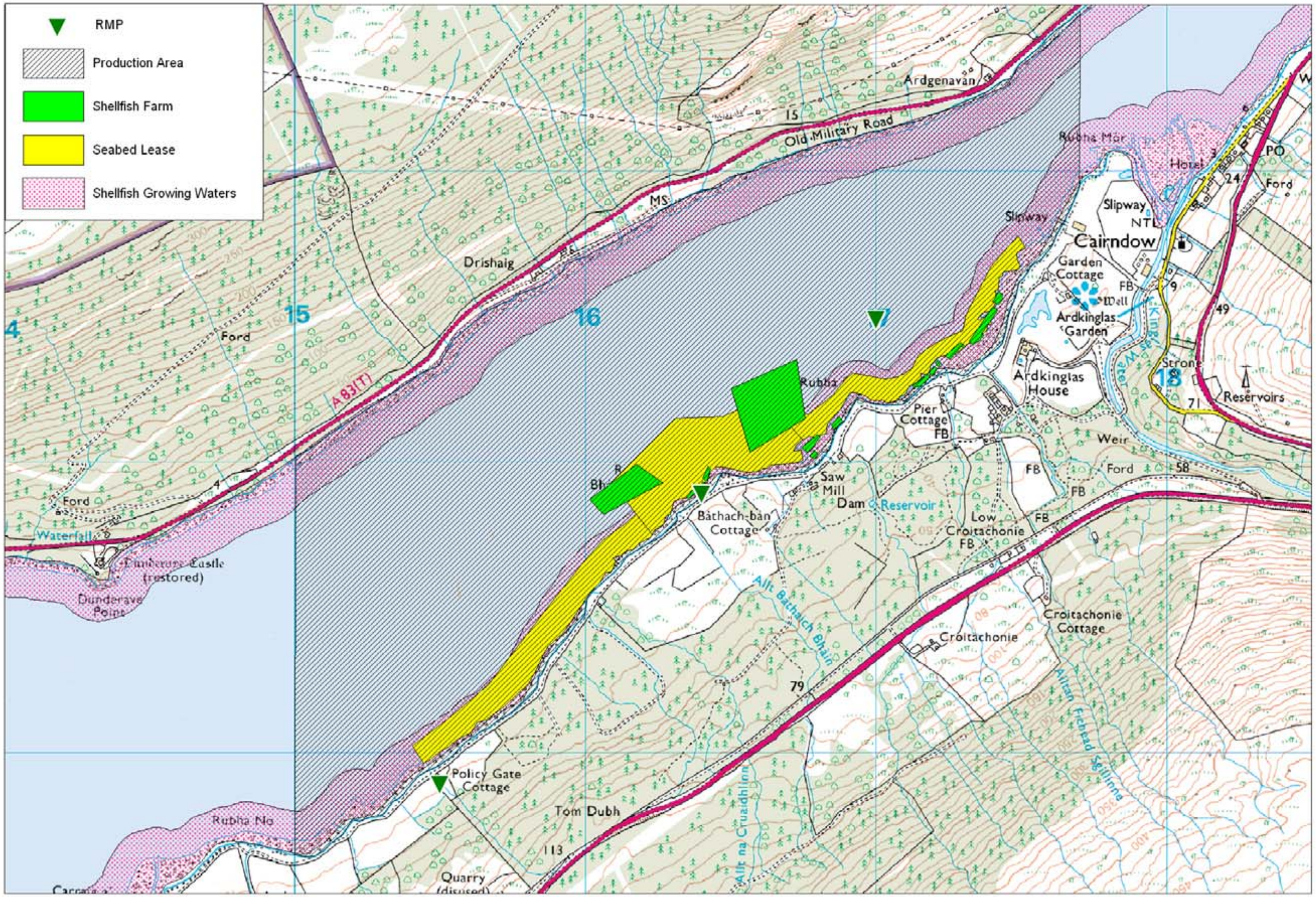

Figure 2.1 Loch Fyne Ardkinglas Fishery

3. Human population

The figure below shows information obtained from the General Register Office for Scotland on the population within the census output in the vicinity of Loch Fyne Ardkinglas.

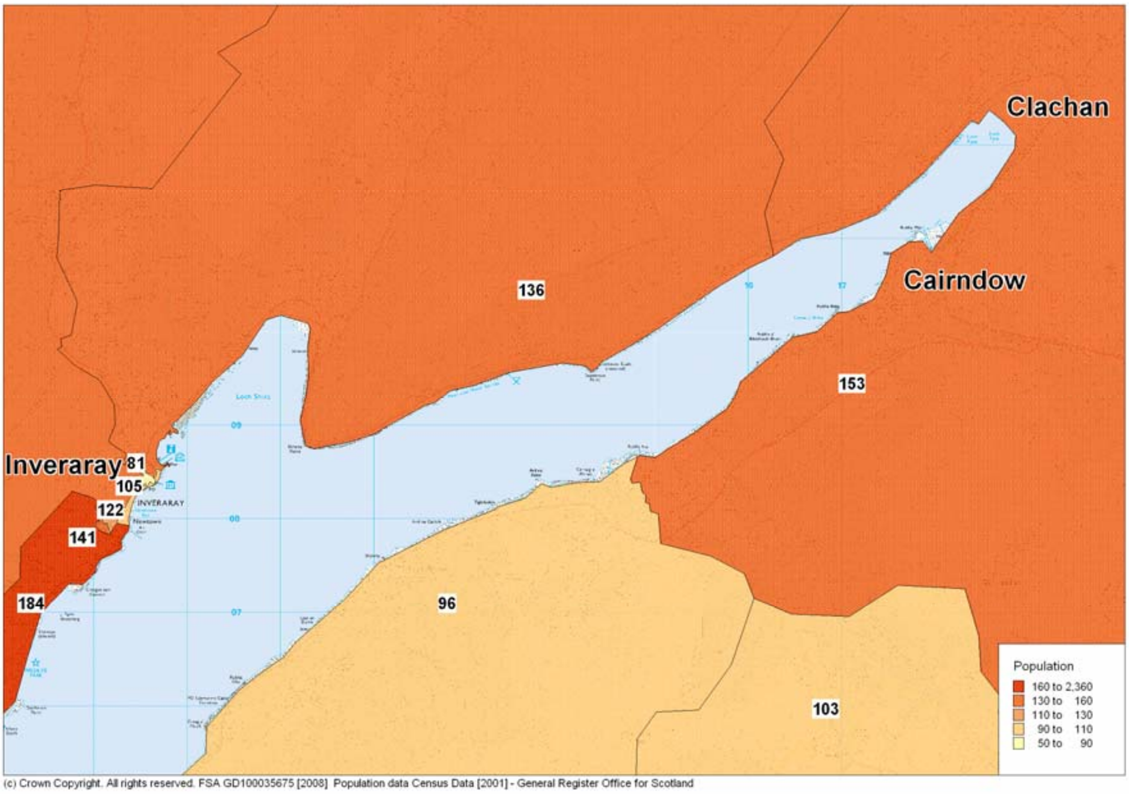

Figure 3.1 Population map for Loch Fyne Ardkinglas

The population for the eight census output areas bordering immediately on Loch Fyne Ardkinglas are:

60QD000032	96
60QD000033	153
60QD000073	136
60QD000070	81
60QD000072	105
60QD000563	141
60QD000069	184
60QD000029	103

There are few settlements surrounding the area of Loch Fyne Ardinkglas. On the far eastern end of the loch is the settlement of Clachan and on the southeast corner of the loch is the larger settlement of Cairndow. Most of the population is concentrated in the southeast (Cairndow) area of this part of the loch and any associated faecal pollution from human sources will be concentrated in these areas. The larger settlement of Inverary lies approximately 5 km to the west of the production area.

4. Sewage Discharges

Community septic tanks and sewage discharges were identified by Scottish Water for the area around Loch Fyne Ardkinglas. They are detailed in Table 4.1.

Table 4.1 Discharges identified by Scottish Water

NGR	Discharge name	Discharge Type	Level of Treatment	Consented design PE
NN 0961 0794	Inverarary	Continuous	Septic Tank	721
NN 0954 0827	Inveraray Satellite PS No1, CSO & EO	Intermittent	Screened overflow	101
NN 0987 0844	Inveraray Transfer PS No1, CSO & EO	Intermittent	Screened overflow	320
NN 0961 0794	Inveraray Transfer PS No2, CSO & EO	Intermittent	Screened overflow	721
NN 181 113	Cairndow	Continuous	Septic Tank	34

No sanitary or microbiological data were available for these discharges.

A number of discharge consents have been issued by SEPA and are listed in Table 4.2. At the time of writing this report, we did not have the details of the consent number WPC/W.20373.

Table 4.2 Discharge consents issued by SEPA

Ref No.	NGR of discharge	Discharge Name	Discharge Type	Discharges To	Consented flow	Consented/ design PE
CAR/R/1017707	NN 1925 1328	Clachan power station	Septic Tank	River Fyne	-	5
CAR/R/1020675	NN 1797 1029	Strone house & cottage	Septic Tank	Land	-	12
CAR/R/1014576	NN 1667 0988	New house	Septic Tank	Land	-	6
CAR/R/1011086	NN 1343 0821	Beech Cottage	Septic Tank	Loch Fyne	-	5
WPC/W/20373	NN 125 078	-	Sewage effluent		-	-
CAR/R/1010614	NN 1237 0767	The Lodge, St Catherines	Septic Tank	Loch Fyne	-	8
CAR/R/1013856	NN 1224 0753	New house	Septic Tank	Land	-	5
CAR/L/1008718	NN 0961 0794	Invererary WTW final effluent	Treated effluent	Loch Fyne	633 m^3/day	Not stated
CAR/L/1000461	NN 0830 0770	Inveraray WTW effluent	Backwash water	Allt na Roinn Learna	5.3 L/s	-

A number of septic tanks and/or outfalls were recorded during the shoreline survey or were subsequently determined by the local authority. Their locations have been included in the mapped discharges in Figure 4.1. Observed septic tanks, covers and/or discharge pipes, including results from any associated samples, are listed in Table 4.3.

Table 4.3 Discharges and septic tanks observed during the shoreline survey

No	NGR	Description	Sample No.	Type	E.coli (cfu/100ml)
1	NN 09544 08313	Sewage pumping station	-	-	-
2	NN 09535 08254	End of 150 mm iron pipe; no flow	-	-	-
3	NN 09571 08265	Approximately 350 mm diameter rubberised pipe through concrete outer; sealed off	-	-	-
4	NN 09593 08271	500 mm concrete pipe with plastic sections; end about 8 m further out	-	-	-
5	NN 18896 12633	Stream with presumed septic tank outlet from Loch Fyne complex	-	-	-
6	NN 15865 10602	Bright green algal growth at shoreline behind house	63	Sea water	380
7	NN 16795 09948	Depuration plant toliet septic tank	-	-	-
8	NN 16794 09961	Outfall from depuration plant toliet septic tank	-	-	-
9	NN 17688 10850	Panfish septic tank 1	-	-	-
10	NN 17674 10820	Panfish septic tank 2	-	-	-
11	NN 17654 10849	Outfall for Panfish septic tanks 1 & 2	-	-	-

[1]or subsequently identified by the local authority

The outfalls for the Panfish septic tanks and the Loch Fyne Oysters depuration plant toilets discharge directly into the production area on the south shore where the shellfish are cultured. The Panfish plant has approximately 50 employees, and the depuration plant has less than 10. Both these establishments would only be in full use during working hours. A SEPA consented private discharge (CAR/R/1014576, population equivalent of 6) is also reported to discharge near the south shore of the production area, but this was not seen on the shoreline survey, and is either buried and the outfall was underwater at the time of survey, or discharges to soakaway or to a watercourse. Just to the east of the production area boundaries, a Scottish Water communal septic tank at Cairndow with a population equivalent of 34 discharges to the southern shoreline. Also at Cairndow is a SEPA consented private discharge which either discharges to soakaway or to a watercourse. SEPA originally reported that a new sewage works is planned for Cairndow which will incorporate the whole community. However, subsequent information from Scottish Water indicated that the improvement scheme was abandoned due to poor uptake amongst houses on private septic tanks.

At the head of the loch is a private outfall from the Loch Fyne complex. SEPA report that this is due for upgrading.

Approximately 5 km to the west of the production area is the settlement of Inverary, where there is a Scottish Water communal septic tank discharge with a population equivalent of 721, as well as some intermittent discharges. SEPA reported that problems with these discharges were being addressed at the time of the shoreline survey by ongoing resewerage works.

The Panfish, Cairndow and LFO depuration plant outfalls are likely to be most significant to the shellfishery, particularly towards its eastern end. Other discharges further afield are likely to be of much less significance.

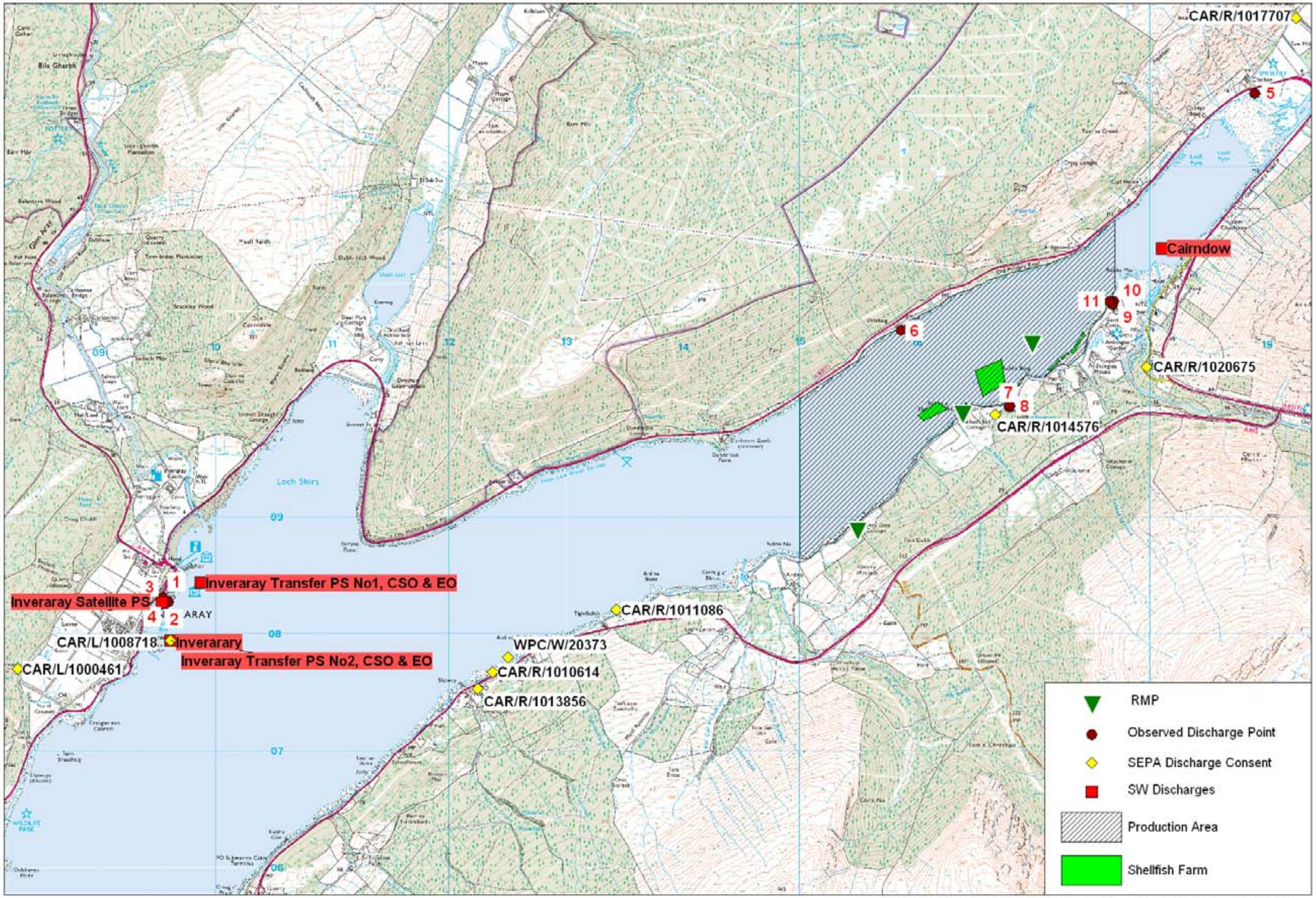

Figure 4.1 Map of discharges at Loch Fyne Ardkinglas

5. Geology and soils

Component soils and their associations were identified using uncoloured soil maps (scale 1:50,000) obtained from the Macaulay Institute. The relevant soil 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.

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% and can be classified as freely draining soils.

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

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 the regions mapped have an average surface percentage runoff of 44.3%, so it is likely that in this case they would be poorly draining.

Maps were been produced using these seven soil type groups and whether they are characteristically freely or poorly draining. The map of component soils and their associated drainage classes for the area surrounding upper Loch Fyne is provided in Figure 5.1.

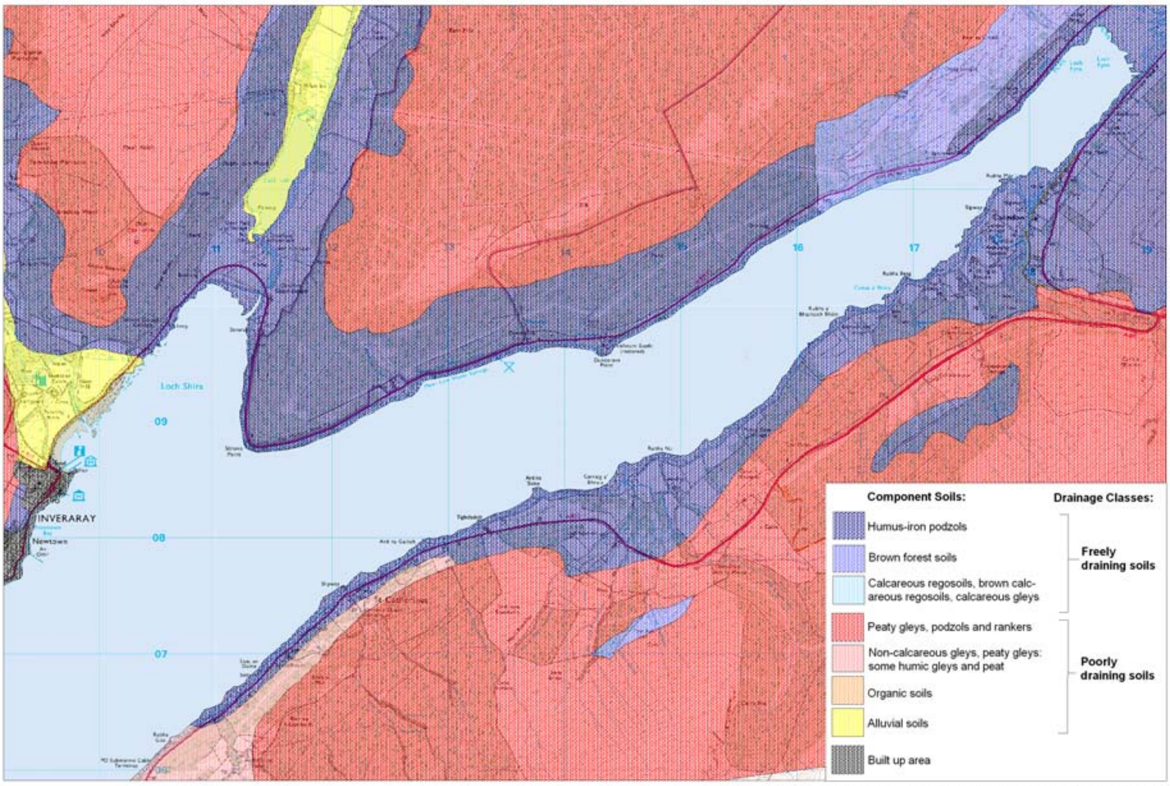

Figure 5.1 Component soils and drainage classes for Loch Fyne Ardkinglas

There are five main types of component soils visible in this area. The most dominant is composed primarily of peaty gleys, (peaty) podzols and (peaty) rankers. This soil type dominates much of the inland on both sides of the Loch Fyne Ardkinglas production area.

The second dominant component soil is humus-iron podzols. This soil type runs along the length of the eastern side of the loch and along the majority of the western side of the loch, until it reaches the third component soil type; brown forest soils.

The fourth component soil type is alluvial soils and these occur near Inveraray at the River Aray and to the north of Inveraray at the Gearr Abhainn river. The final component soil type is composed of non-calcareous gleys, peaty gleys, some humic gleys and peat. This soil type covers a small strip of land opposite Inveraray on the eastern coastline. There is also a built-up area where the town of Inveraray is situated.

In the more freely draining soils found along the eastern and western coastline of Loch Fyne Ardkinglas, surface runoff is reduced as the permeability of the soil has increased.

In poorly draining soils found further inland on either side of Loch Fyne Ardkinglas, surface run off is likely to be high as peaty gleys, podzols and rankers are often waterlogged. Runoff from these areas will affect streams and rivers that discharge into Loch Fyne.

In the case of Loch Fyne Ardkinglas, the potential for runoff contaminated with *E. coli* from animal waste is high along both sides of the loch.

Gossary 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.

6. Land cover

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

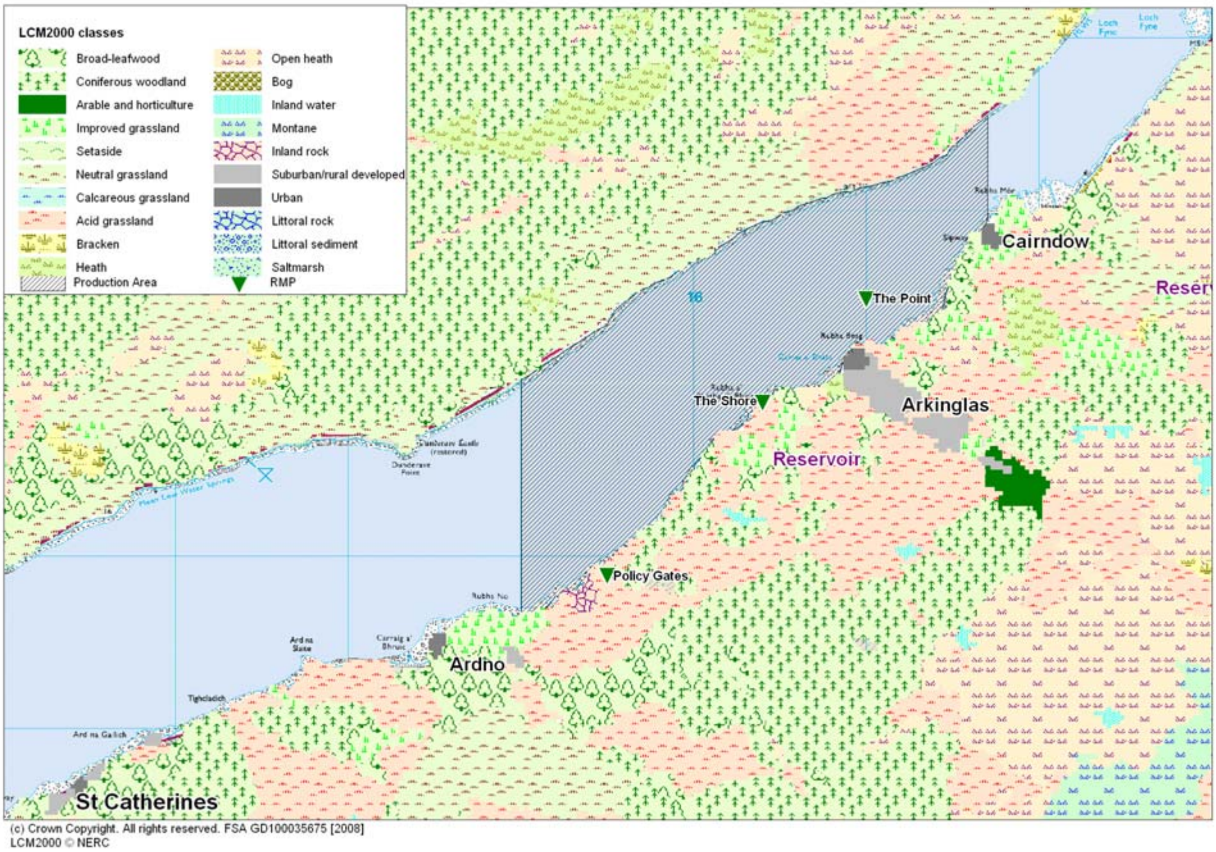

Figure 6.1 LCM2000 class data map for Loch Fyne Ardkinglas

On the northern side of upper Loch Fyne neutral grassland, acid grassland and woodland dominate the shoreline. The woodland is a mixture of deciduous, with forested coniferous above. There are also some small areas of open heath, heath and bracken further inland. The land cover on the southern shore of the loch is more mixed, with patches of improved grassland, acid grassland, broad-leaf wood, coniferous woodland and neutral grassland. On the eastern coastline near Policy Gates there is an area of supra-littoral rock. Near Ardkinglas on the southern shore there is an area of land of arable and horticultural nature.

The faecal coliform contribution would be expected to be highest from developed areas, such as Ardkinglas and Cairndow (approx 1.2 – 2.8×10^9 cfu km^{-2} hr^{-1}), with intermediate contributions from the improved grassland which is present in patches along the shoreline adjacent to the fishery (approximately 8.3×10^8 cfu km^{-2} hr^{-1}) and lowest from the other land cover types (approximately 2.5×10^8 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, this being expected to be highest, at more than 100-fold, for the improved grassland. Following periods of logging activity, surface runoff from recently cleared ground is likely to carry some topsoil into the loch, and this may give rise to sporadic localised increases in contamination levels in runoff.

7. Farm Animals

Regulation (EC) No. 854/2004 requires the competent authority to:

(a) make an inventory of the sources of pollution of human or animal origin likely to be a source of contamination for the production area;
(b) examine the quantities of organic pollutants which are released during the different periods of the year, according to the seasonal variations of both human and animal populations in the catchment area, rainfall readings, waste-water treatment, etc.

With regard to potential sources of pollution of animal origin, agricultural census data to parish level was requested from the Scottish Government. The request was declined on the grounds of confidentiality because the parishes in most cases contained only a small number of farms making it possible to determine specific data for individual farms. The only significant source of information was therefore the shoreline survey (see Appendix), which only relates to the time of the site visit on 10th – 12th October 2007.

The shoreline survey identified very few livestock around the shoreline of the loch apart from several sheep grazing on the southwest (approx. 110 sheep) and northeast corners (approx. 28 sheep) of the production area. Although sheep were viewed in both areas the geographical spread of contamination would be concentrated towards the south west shoreline. It should therefore be assumed that this factor should be taken into account when identifying the location of a representative monitoring point (RMP).

There is no local information available concerning the seasonal numbers of livestock surrounding the Loch Fyne Ardkinglas area. The spatial distribution of animals observed and noted during the shoreline survey is illustrated in Figure 7.1.

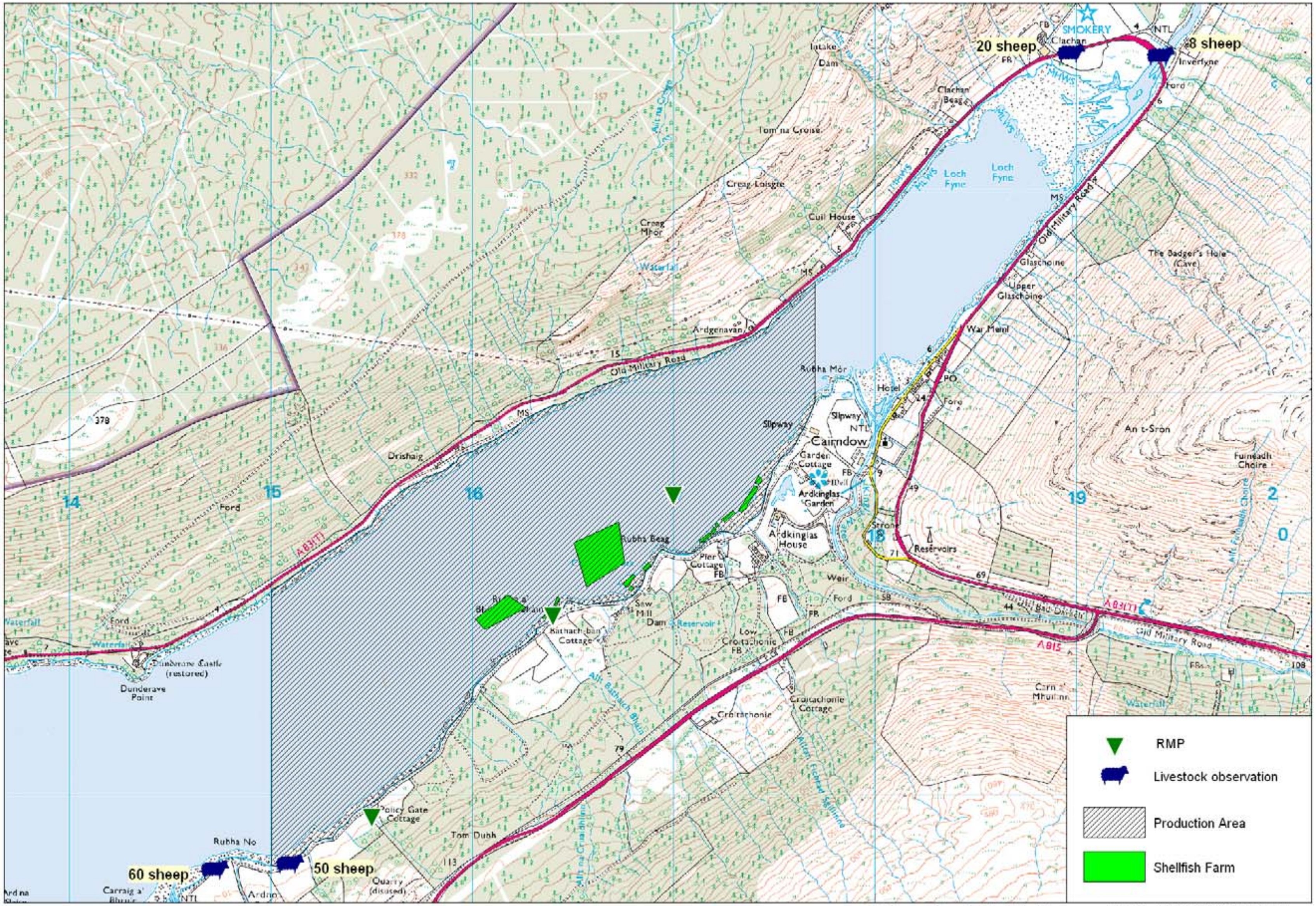

Figure 7.1 Map of livestock observations at Loch Fyne Ardkinglas

8. Wildlife

8.1 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. For the survey area named 'Clyde Estuary', covering the area from Southend to Loch Ryan (and presumably including Loch Fyne), a total count of 991 was recorded when the area was last surveyed (1996).

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. There are no breeding colonies reported in or near Loch Fyne, however it could be expected that grey seals might be found foraging in the loch from time to time.

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 x 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).

Seals will forage widely for food and it is likely that seals will feed near the mussel farms at some point in time. The population is relatively small in relation to the size of the area concerned and is highly mobile therefore it is likely that any impact will be unpredictable. None was seen during the course of the shoreline survey.

8.2 Cetaceans

A variety of cetacean species are routinely observed around the west coast of Scotland.

Table 8.1 Cetacean sightings in 2007 – Western Scotland.

Common name	Scientific name	No. sighted*
Minke whale	*Balaenoptera acutorostrata*	28
Killer whale	*Orcinus orca*	183
Long finned pilot whale	*Globicephala melas*	14
Bottlenose dolphin	*Tursiops truncatus*	369
Risso's dolphin	*Grampus griseus*	145
Common dolphin	*Delphinus delphis*	6
Harbour porpoise	*Phocoena phocoena*	>500

*Numbers sighted are based on rough estimates based on reports received from various observers and whale watch groups. Source: Hebridean Whale and Dolphin Trust.

As Loch Fyne has two sills with mean depths of 16 and 20 m, it may be expected that few, if any larger cetaceans frequent upper Loch Fyne, though dolphins are more likely to enter and feed in the area. Their presence, however, is likely to be sporadic and unpredictable and so will not be taken into account with regard to establishing sampling plans for Loch Fyne production areas. None was seen during the course of the shoreline survey.

8.3 Birds

A number of seabird species are known to breed in Argyll & Bute and the most significant of these are described in Table 8.2.

Of these, only the cormorants and gulls are likely to be breeding in the area of Loch Fyne in appreciable numbers. Distribution of nesting sites near the harvesting areas is not known. Though nesting occurs in early summer, these birds are likely to be present in the area throughout the year. Impact to the fisheries is likely to be very localised where birds rest on floats or oyster trestles.

Wading birds are present on the intertidal areas of the loch, though information on numbers and specific locations was not available at the time this report was written. There are no RSPB reserves at Loch Fyne.

Waterfowl (ducks and geese) and wading birds are present in Loch Fyne at various times from autumn through winter. Few of these birds would be expected to be present during the summer months. As Loch Fyne does not host large overwintering populations, the presence of these birds is likely to be variable.

Table 8.2 Breeding seabirds of Argyll & Bute

Common name	Species	Population	Common name	Species	Population
European Shag	*Phalacrocorax aristotelis*	3341	Great Cormorant	*Phalacrocorax carbo*	231*
Black-headed Gull	*Larus ridibundus*	586	Common Gull	*Larus canus*	2683
Lesser Black-backed Gull	*Larus fuscus*	3235	Herring Gull	*Larus argentatus*	15370
Great Black-backed Gull	*Larus marinus*	1736	Black-legged Kittiwake	*Rissa tridactyla*	8976
Common Tern	*Sterna hirundo*	1362	Arctic Tern	*Sterna paradisaea*	1823
Common Guillemot	*Uria aalge*	42697	Black Guillemot	*Cepphus grille*	3046
Razorbill	*Alca torda*	9056	Atlantic Puffin	*Fratercula arctica*	2597*

*Population number based on Apparently Occupied Sites, Territories, Nests or Burrows. These may equate to more than one adult.

Overwintering geese would tend to be found on farm fields and open grassland. Open grassland is present along large parts of the southern shore. These birds are most likely to be present during the autumn and winter months, so tentatively they may have a greater impact during the winter. No estimates of numbers were available at the writing of this report and so it is not possible to properly evaluate their contribution. No significant aggregations of birds were seen on the shoreline survey.

8.4 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. Much of the land surrounding upper Loch Fyne is wooded. While no population data was available for this area, it can be presumed that they host populations of deer (deer tracks were seen on the shoreline survey).

Deer, like cattle and other ruminants, shed *E. coli*, *Salmonella* and other potentially pathogenic bacteria via their faeces and it is likely that some of the indicator organisms detected in the streams feeding into Loch Fyne will be of deer origin, and it may be expected that their contribution is year round, but minor.

8.5 Other

The European Otters (*Lutra lutra*) is present around Scotland with some areas hosting populations of international significance. Coastal otters, such as those likely to be found in Loch Fyne, 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. While otters are known to occur around the Loch Fyne area, it is not considered to be home to a substantial population. None was seen during the course of the shoreline survey.

8.6 Summary

Wildlife impacts to the fisheries in Loch Fyne are likely to be localised and unpredictable and will therefore not be explicitly taken into account in determining the sampling plan. However, the effect of such contamination should be detected intermittently during regular monitoring based on the plan.

9. Meteorological data

The weather station within 15 km of the production site with the fewest missing records is located at Inverary Castle, approximately 6 km to the west of the production area. Rainfall data was purchased from the Meteorological Office for the period 1/1/2003 to 31/12/2007 (total daily rainfall in mm). For this period of 1826 days, a total of 239 days records were missing. It is likely that rainfall experienced at Inverary castle is very similar to that experienced at the production area due to their close proximity. Wind data was not recorded at this station.

The nearest weather station is for which wind data is available is at Glasgow: Bishopton, approximately 45 km to the south east of the production area. It is likely that the wind patterns here are broadly similar but not identical to those at Loch Fyne: Ardkinglas, but it is likely that there are some differences in the wind on any given day. It is also possible that local topography may affect wind patterns differently.

This section aims to describe the local rain and wind patterns and discuss how they may affect the bacterial quality of shellfish within Loch Fyne: Ardkinglas.

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 summarise the pattern of rainfall recorded at Inverary. These box and whisker plots summarize the distribution of individual daily rainfall values (observations) by year (Figure 9.1) or by month (Figure 9.2). The grey box represents the middle 50% of the observations, with the median at the midline. The whiskers extend to the largest or smallest observations up to 1.5 times the box height above or below the box. Individual observations falling outside the box and whiskers are represented by the symbol *. It is not appropriate to present annual totals, or mean monthly totals as some data is missing.

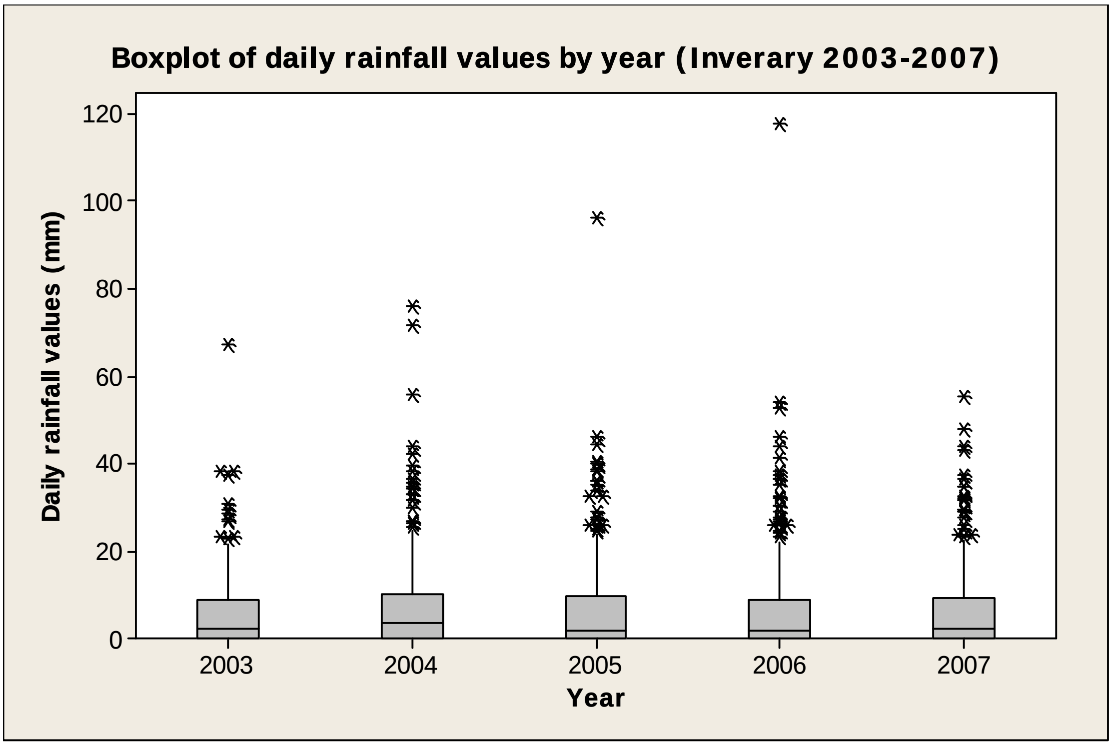

Figure 9.1 Boxplot of daily rainfall values by year, 2003-2007
(no data for April 2003, August 2003, August 2004, August 2005, data incomplete for August 2006, September 2006, October 2006, November 2006, December 2006, November 2007 and December 2007).

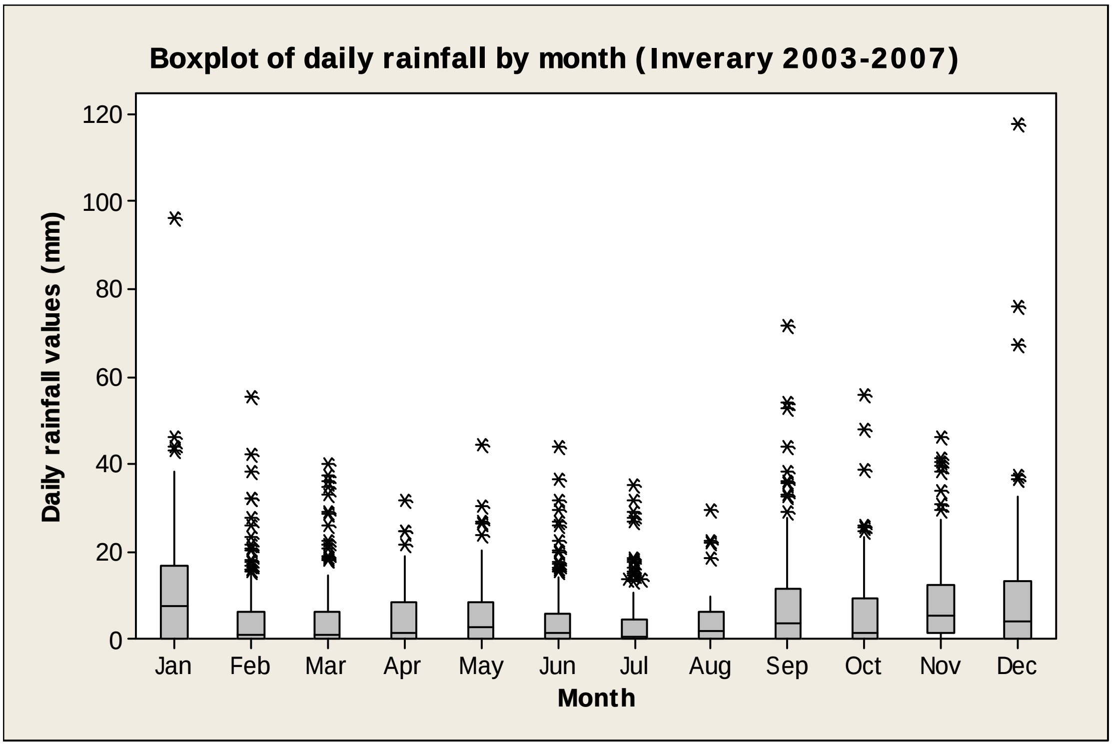

Figure 9.2 Boxplot of daily rainfall values by month, 2003-2007
(no data for April 2003, August 2003, August 2004, August 2005, data incomplete for August 2006, September 2006, October 2006, November 2006, December 2006, November 2007 and December 2007).

For the period considered here, 24.9% of days where records were available experienced no rainfall, and 37.1% of days experienced rainfall of 1mm or less. The wettest months were September, November, December and January.

It can therefore be expected that levels of rainfall dependant faecal contamination entering the production area will be higher during the autumn and winter months. It is possible that there is a build-up of faecal matter on pastures during the drier summer months when stock levels are at their highest which results in more significant faecal runoff in the autumn at the onset of the wetter months.

9.2 Wind

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

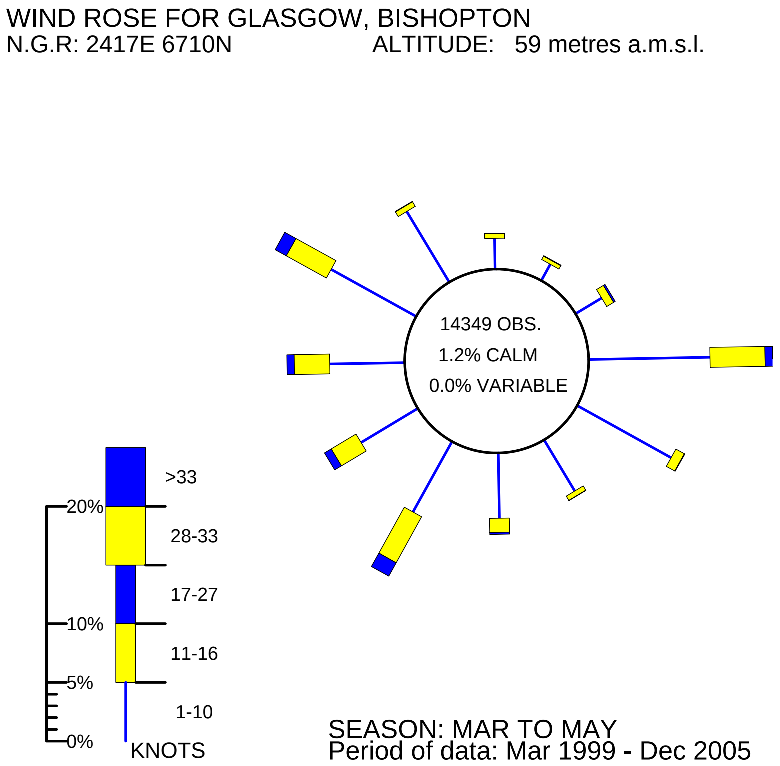

Figure 9.3 Wind rose for Glasgow: Bishopton (Spring)

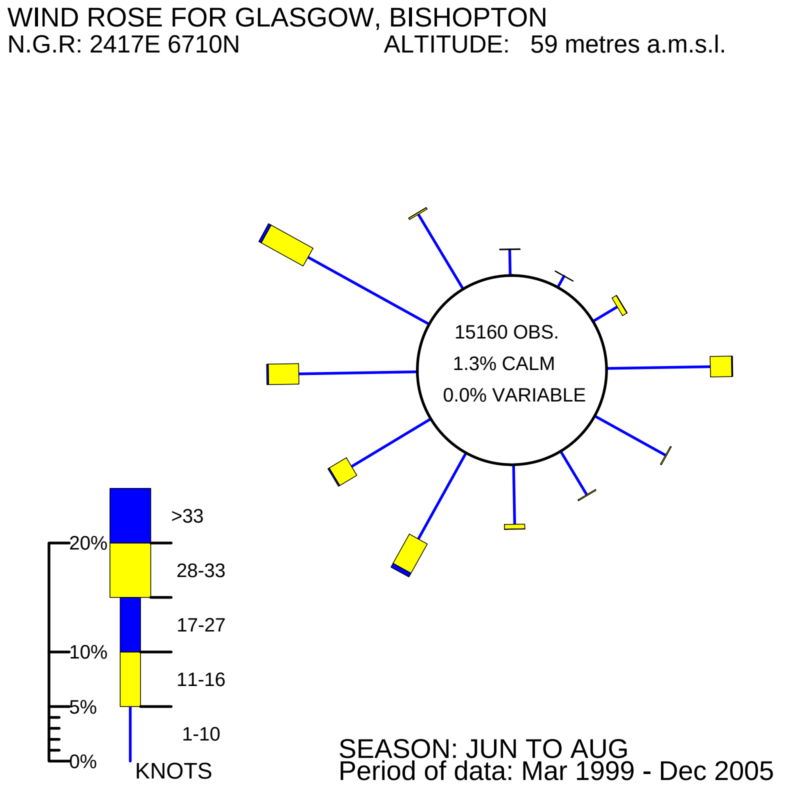

Figure 9.4 Wind rose for Glasgow: Bishopton (Summer)

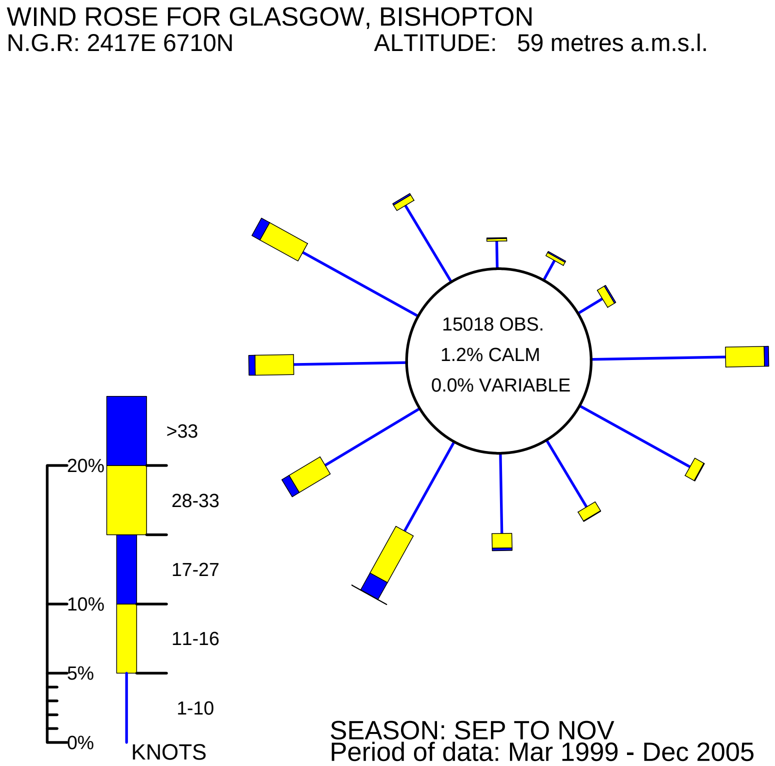

Figure 9.5 Wind rose for Glasgow: Bishopton (Autumn)

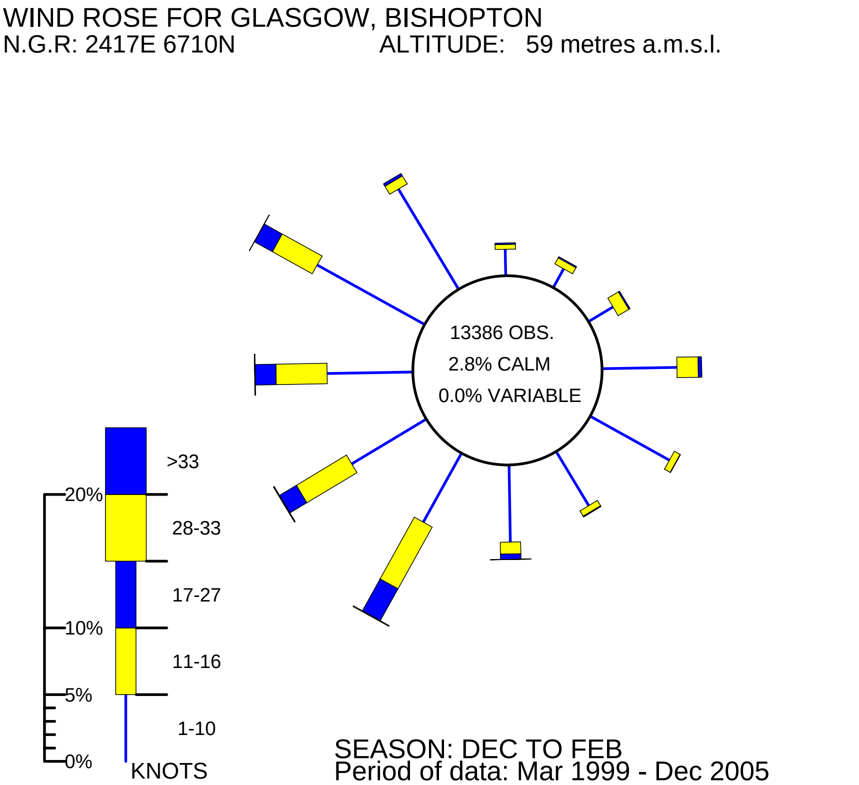

Figure 9.6 Wind rose for Glasgow: Bishopton (Winter)

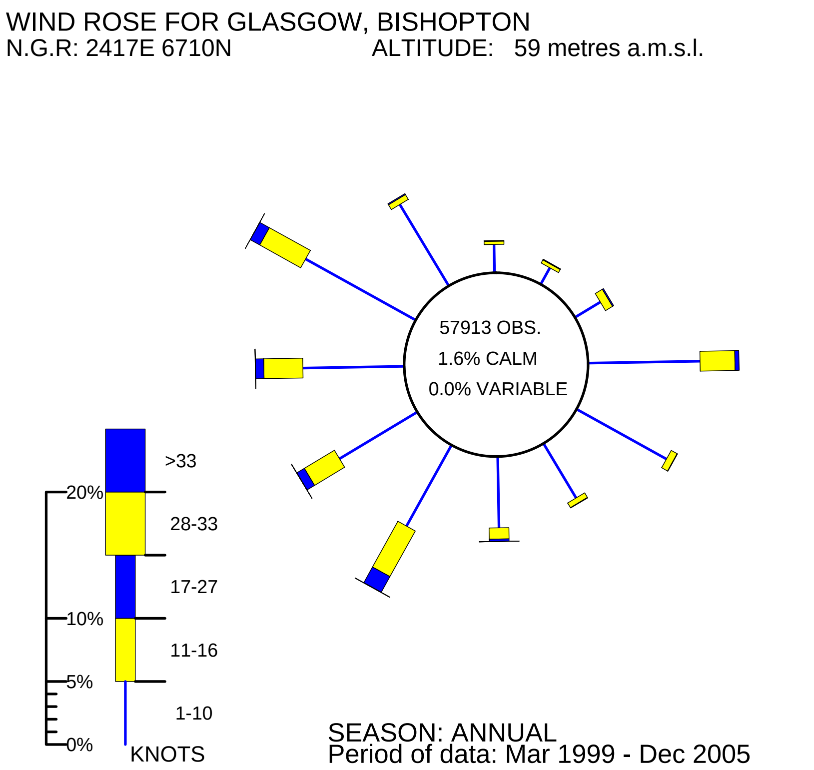

Figure 9.7 Wind rose for Glasgow: Bisopton (Annual)

Glasgow is not one of the windier areas of Scotland, with a low frequency of gales compared to places such as the Western Isles and the Shetlands. The wind roses show that the overall prevailing direction of the wind is from the west, and the strongest winds come from this direction. Stronger winds are also experienced from the east, presumably due in part to local topography - Bishopton is in the Clyde Valley, which has an east west aspect. Winds are generally lighter during the summer months and stronger in the winter.

Loch Fyne has a south west to north east aspect, facing the open Atlantic to the west. It is about 60 km long and about 3 km wide, and is surrounded by hills rising to over 500 m in places. The loch will receive shelter from winds from most directions, but is more open to a south westerly wind or north easterly winds which would be funnelled up or down the Loch by the surrounding hills. The production area is near the head of the loch, so would be most exposed to south westerly winds.

A strong south westerly wind combined with a spring tide may result in higher than usual tides which will carry accumulated faecal matter from livestock, above the normal high water mark, into the loch.

Although tidally driven circulation of water in the Loch is important due to its tidal range, wind effects are likely to cause significant changes in water circulation. 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 in the direction of the wind. These surface water currents create return currents which may travel along the bottom or sides of the loch depending on bathymetry. Either way, strong winter winds will increase the circulation of water and hence dilution of contamination from point sources within the loch. There may be some instances where contamination from settlements may be carried to production sites by wind driven currents. An example may be a north easterly wind carrying contamination from the settlement of Cairndow along the shore towards the production sites.

10. Current and Historical Classification Status

The area has been classified for mussel and Pacific oyster production since before 2001. The classification history since 2001 is presented in Table 10.1 for mussels, and in Table 10.2 for Pacific oysters. Currently, the area is classified as a year seasonal A/B and is with three production sites listed for both species, associated with three adjoining Crown Estates leases (The Shore, The Point and Policy Gates). A map of the current production area is presented in Figure 10.1.

Table 10.1 Classification history (mussels)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	A	A	A	A	A	B	B	B	B	B	B	A
2002	A	A	A	A	A	A	A	B	B	B	A	A
2003	A	A	A	A	A	A	A	B	B	B	A	A
2004	A	A	A	A	A	A	B	B	A	A	A	A
2005	A	A	A	A	B	B	B	B	B	B	B	A
2006	A	A	A	A	B	B	B	B	B	B	B	A
2007	A	A	A	A	A	B	B	B	B	B	B	B
2008	A	A	A									

Table 10.2 Classification history (Pacific oysters)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	A	A	A	A	A	B	B	B	B	B	B	A
2002	A	A	A	A	A	A	A	B	B	B	A	A
2003	A	A	A	A	A	A	A	B	B	B	A	A
2004	A	A	A	A	A	A	A	B	B	B	A	A
2005	A	A	A	A	A	B	B	B	B	B	A	A
2006	A	A	A	A	A	B	B	B	B	B	A	A
2007	A	A	A	A	A	B	B	B	B	B	B	A
2008	A	A	A									

Classifications for the two species are similar, predominantly A with periods of B classification in the summer and autumn.

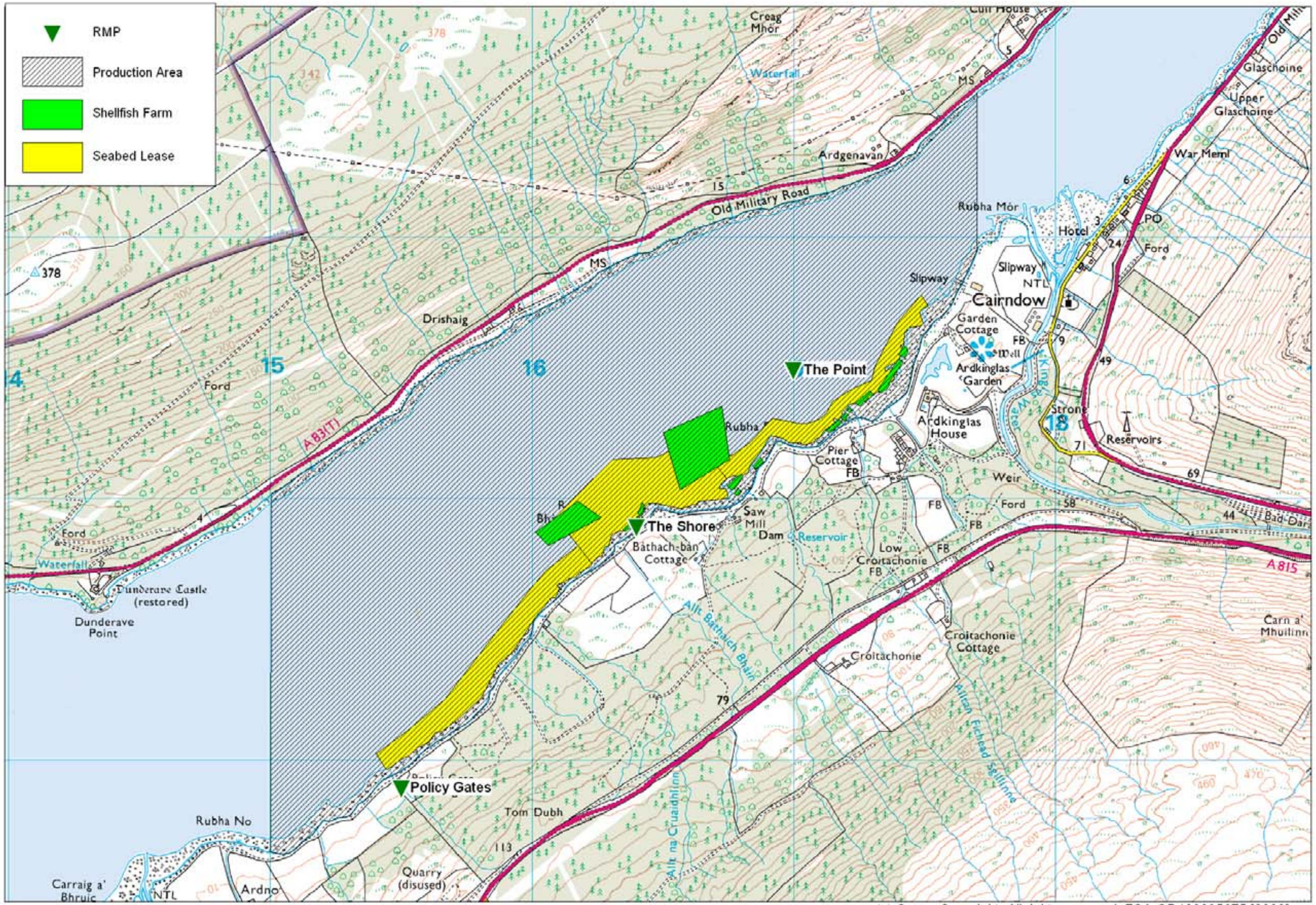

Figure 10.1 Map of Loch Fyne: Ardkinglas production area

11. Historical E. coli data

11.1 Validation of historical data

All shellfish samples taken from Loch Fyne: Ardkinglas up to the end of 2007 were extracted from the database and validated according to the criteria described in the standard protocol for validation of historical *E. coli* data. No samples were excluded from the analysis on the basis of major geographical discrepancies. 22 mussel samples and 34 Pacific oyster samples had the result reported as <20, and were assigned a nominal value of 10 for statistical assessment and graphical presentation. One mussel and two oyster samples had the result reported as >18000, and were assigned a nominal value of 36000 for statistical assessment and graphical presentation. All *E. coli* results are reported in most probable number per 100g of shellfish flesh and intravalvular fluid.

11.2 Summary of microbiological results by site

A summary of mussel sampling and results by reported sampling location is presented in Table 11.1, and a summary of oyster sampling results is presented in Table 11.2.

Despite their differing physiology and culture methods, levels of *E. coli* are very similar in both species in terms of both geometric mean result, and percentages of results exceeding threshold values.

Table 11.1 Summary of results from Loch Fyne: Ardkinglas (mussels)

Sampling Summary								
Production area	Loch Fyne: Ardkinglas	Loch Fyne: Ardkinglas	Loch Fyne: Ardkinglas	Loch Fyne: Ardkinglas	Loch Fyne: Ardkinglas	Loch Fyne: Ardkinglas	Loch Fyne: Ardkinglas	Loch Fyne: Ardkinglas
Site	The Point	The Point	The Point	The Point	The Point	The Shore	Policy Gates	All
Species	Common mussels	Common mussels	Common mussels	Common mussels	Common mussels	Common mussels	Common mussels	Common mussels
SIN	AB 14703408	AB 14703408	AB 14703408	AB 14703408	AB 14703408	AB 14703608	AB 14703408	AB 147
NGR	NN170107	NN170105	NN166102	NN166101	NN162098	NN164099	NN155089	All
Total no of samples	3	70	7	1	2	12	3	98
No. 1999	3	7	0	0	0	0	0	10
No. 2000	0	12	0	0	0	0	0	12
No. 2001	0	12	0	0	0	0	0	12
No. 2002	0	10	0	0	0	0	1	11
No. 2003	0	10	0	0	1	0	1	12
No. 2004	0	10	0	0	1	0	1	12
No. 2005	0	9	0	0	0	0	0	9
No. 2006	0	0	0	0	0	11	0	11
No. 2007	0	0	7	1	0	1	0	9
Results Summary (*E. coli* mpn/100g)								
Minimum	500	<20	20	500	<20	<20	<20	<20
Maximum	3500	>18000	160	500	110	3500	20	>18000
Median	1400	70	40	500	60	55	10	70
Geometric mean	1350	88.3	44.7	500	33.2	65.7	12.6	82.9
90 percentile	3080	750	106	500	100	493	18	750
95 percentile	3290	3190	133	500	105	1850	19	3500
No. exceeding 230/100g	3 (100%)	21 (30%)	0 (0%)	1 (100%)	0 (0%)	3 (25%)	0 (0%)	28 (29%)
No. exceeding 1000/100g	2 (67%)	6 (9%)	0 (0%)	0 (0%)	0 (0%)	1 (8%)	0 (0%)	9 (9%)
No. exceeding 4600/100g	0 (0%)	3 (4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (3%)
No. exceeding 18000/100g	0 (0%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (1%)

Table 11.2 Summary of results from Loch Fyne: Ardkinglas (Pacific oysters)

Sampling Summary					
Production area	Loch Fyne: Ardkinglas	Loch Fyne: Ardkinglas	Loch Fyne: Ardkinglas	Loch Fyne: Ardkinglas	Loch Fyne: Ardkinglas
Site	The Point & Policy Gates	The Point	The Shore	Policy Gates	All
Species	Pacific oysters	Pacific oysters	Pacific oysters	Pacific oysters	Pacific oysters
SIN	AB 14703413 & AB 14703513	AB 14703413	AB 14703613	AB 14703413	AB 147
NGR	NN162098	NN177105	NN164099	NN155089	All
Total no of samples	60	1	57	64	182
No. 1999	6	0	6	0	12
No. 2000	8	0	12	3	23
No. 2001	7	0	8	8	23
No. 2002	5	1	5	10	21
No. 2003	7	0	7	10	24
No. 2004	6	0	7	12	25
No. 2005	7	0	6	9	22
No. 2006	6	0	5	12	23
No. 2007	8	0	1	0	9
Results Summary (*E. coli* mpn/100g)					
Minimum	<20	90	<20	<20	<20
Maximum	>18000	90	>18000	9100	>18000
Median	110	90	70	60	70
Geometric mean	131	90	81.2	83.9	96.2
90 percentile	1160	90	600	1700	1280
95 percentile	5400	90	1220	2400	2370
No. exceeding 230/100g	21 (35%)	0 (0%)	15 (26%)	16 (25%)	52 (29%)
No. exceeding 1000/100g	7 (12%)	0 (0%)	5 (9%)	10 (16%)	22 (12%)
No. exceeding 4600/100g	4 (7%)	0 (0%)	1 (2%)	2 (3%)	7 (4%)
No. exceeding 18000/100g	1 (2%)	0 (0%)	1 (2%)	0 (0%)	2 (1%)

11.3 Overall geographical pattern of results

Figure 11.1 presents a map geometric mean result by reported sampling locations (with OS grid reference, site, number of samples and sampling dates) for mussels. Figure 11.2 presents the same for Pacific oysters.

There is poor agreement between the actual location of the mussel lines, the Crown Estates leases, and the reported mussel sampling locations. Although it is likely that the mussel lines may have been moved at times, some of the reported sampling locations are in the intertidal zone (just over 100 m from the mussel ropes) and one is on land (more than 100m away from any current mussel ropes, but within 100 m of the production area), so some at least are almost certainly inaccurate, even given the 100 m level of accuracy from estimating a grid reference from an ordnance survey map. Prior to the start of the Official Control sampling programme in March 2007, mussel samples were collected by LFO staff, and the exact location from which the samples were taken cannot now be verified. Once the OC sampling progamme started, mussel samples were taken by OC samplers at NN166101 (7 samples) and NN166102 (1 sample).

A comparison of all mussel results by reported sampling location indicates no significant difference (One-way ANOVA, p=0.056, Appendix 4). Although the actual location where OC samplers had sampled from March 2007 is definitely recorded accurately, the samples are too close together and too few in number for any geographical analysis. As a consequence, all mussel samples will be considered together in the following analyses.

Table 11.3 Historic mussel E. coli sampling results over 4600 mpn/100g

Collection date	E. coli result (mpn/100g)	Location sampled	Site	Inverary rainfall in previous 7 days
19/09/2000	5400	NN170105	The Point	No data
21/06/2004	9100	NN170105	The Point	30.5 mm
06/09/2005	>18000	NN170105	The Point	No data

Of potential relevance to the setting of the RMP is the sampling location of abnormally high results. These all came from NN 170105, at the eastern end of the production area, although the accuracy of the sampling location cannot be verified as these samples were taken prior to the establishment of the OC sampling programme and it must be noted that a high proportion of all mussel samples were taken from this location. Two of the samples were taken in September, and one was taken in June.

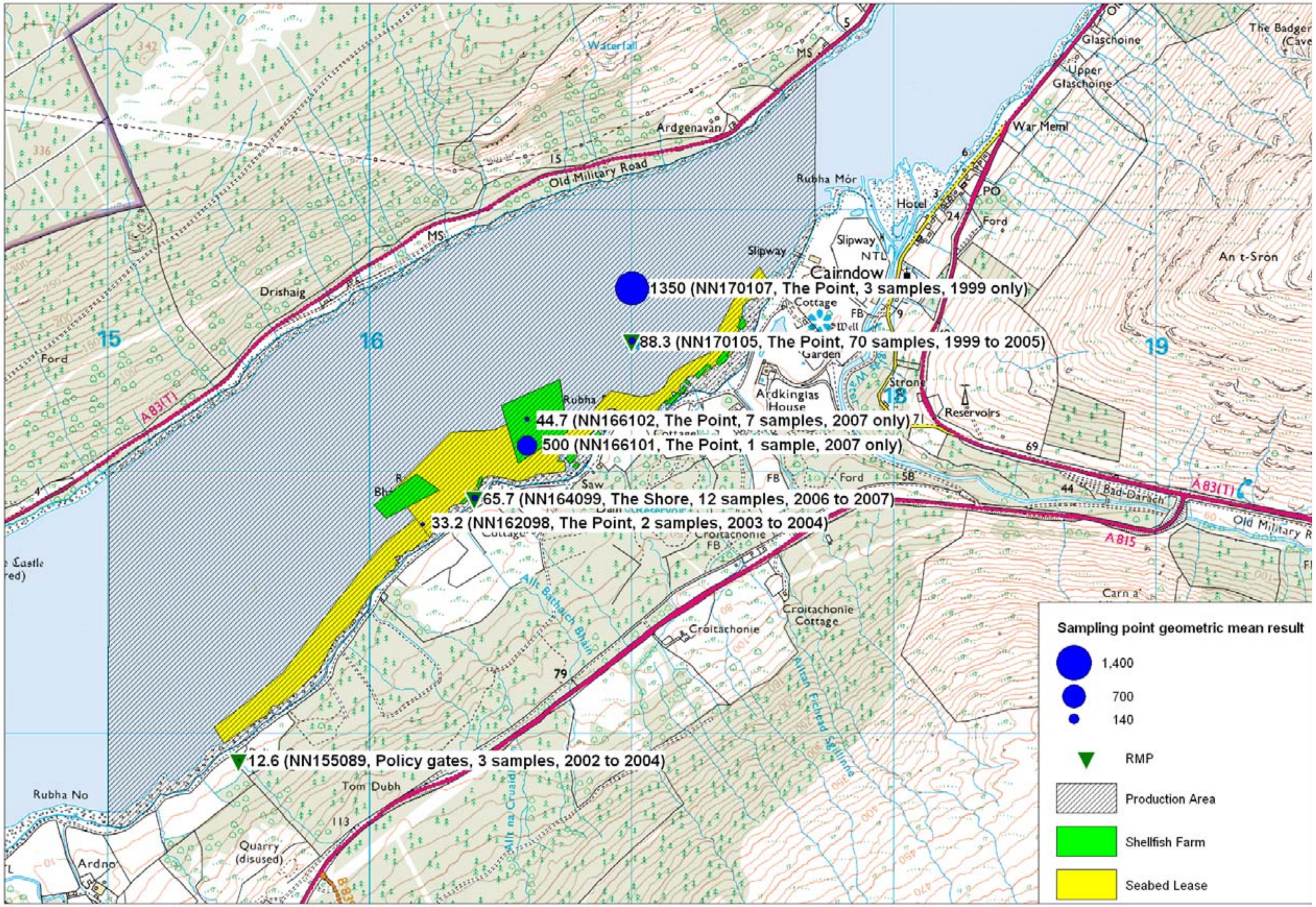

Figure 11.1 Map of mussel sampling points and geometric mean result

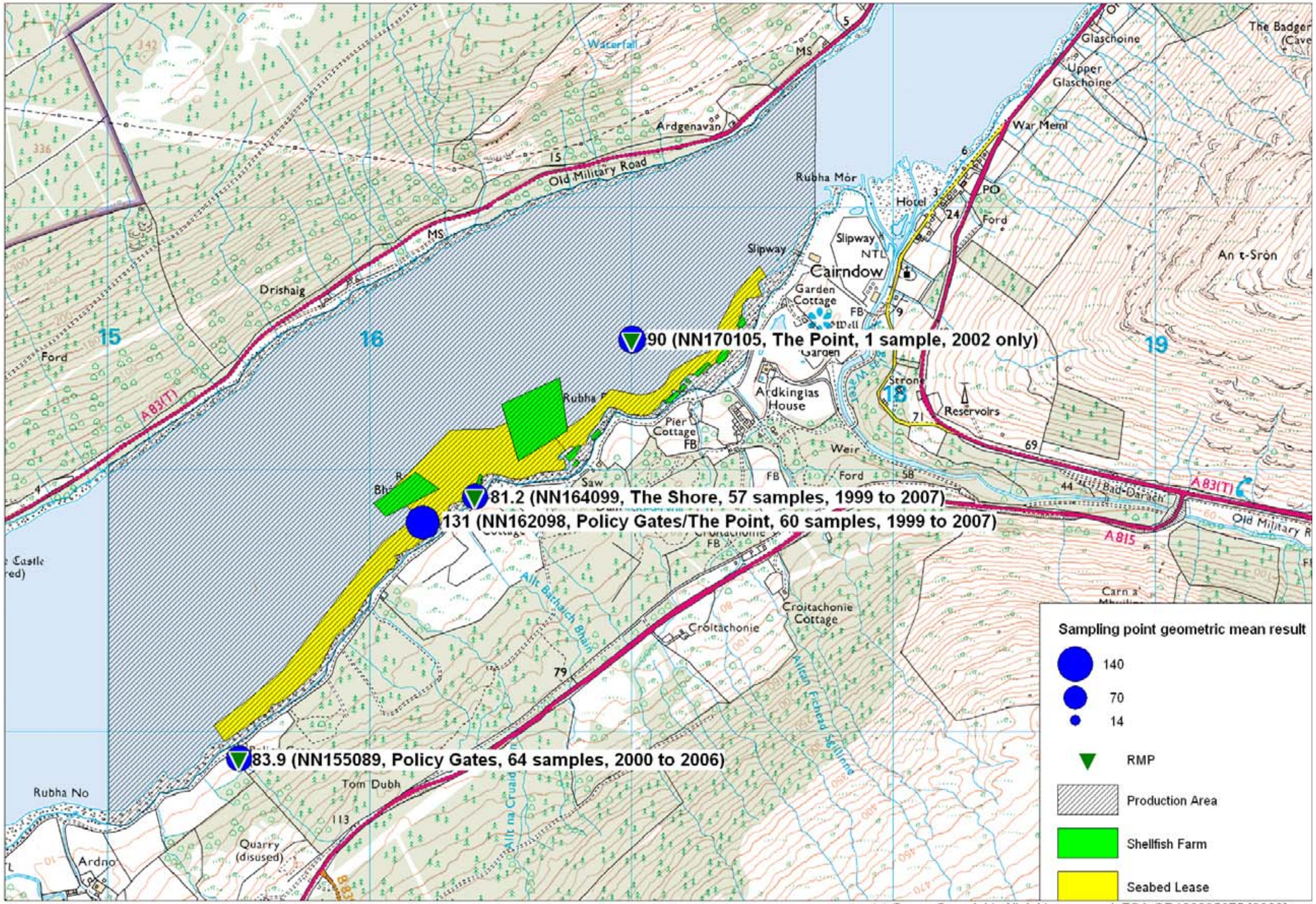

Figure 11.2 Map of Pacific oyster sampling points and geometric mean result

Aside from one sample taken from NN170705 in 2002, the oyster sampling locations all fall within 100 m of the intertidal zone and the Crown Estates leases. There is however poor agreement between the site names used at the sampling points and the site names for the Crown Estates leases. One of the points sampled for oysters was several hundred metres away from any trestles seen on the shoreline survey, but it is quite likely that trestles have been moved from time to time. Prior to the start of the Official Control sampling programme in March 2007, oyster samples were collected by LFO staff, and the exact location from which the samples were taken cannot now be verified. Once the OC sampling progamme started, all oyster samples were taken by OC samplers at NN162098.

Histiorically, for both the mussel and oyster production area, there are three located RMPs. These three RMPs are at the same sites for both oyster and mussels, and are referred to (from east to west) as The Shore, The Point and Policy Gates. The allocated RMP for The Shore coincides with oyster trestles and a Crown Estates Lease, and is within 200 m of the mussel lines. The allocated RMP for The Point is more than 100 m away from trestles, mussel lines, and the Crown Estates Lease. The RMP for Policy Gates lies on land, but is within 100 m of the Crown Estates lease. Since the start of the OC sampling programme in March 2007, one RMP has been sampled for oysters (Policy Gates), and one RMP has been sampled for mussels (The Point). Samples were taken from the nearest available shellfish to the RMPs location.

Highest geometric mean oyster results were from NN 162098. However, a comparison of all oyster results by reported sampling location indicates no significant difference (One-way ANOVA, p=0.492, Appendix 4). As a consequence, all Pacific oyster samples will be considered together in the following analyses.

Table 11.4 Historic oyster E. coli sampling results over 4600 mpn/100g

Collection date	*E. coli* result (mpn/100g)	Location sampled	Site	Inverary rainfall in previous 7 days
19/09/2000	9100	NN155089	Policy Gates	No data
23/08/2001	>18000	NN164099	The Shore	No data
06/09/2005	5400	NN155089	Policy Gates	No data
06/09/2005	9100	NN162098	The Point	No data
10/10/2006	5400	NN162098	The Point	No data
05/06/2007	>18000	NN162098	Policy Gates	34.9 mm
10/07/2007	5400	NN162098	Policy Gates	23.3 mm

Of potential relevance to the setting of the RMP is the sampling location of abnormally high results. These have originated from all three of the major reported sampling locations. All high results have occurred during the period from June to October. The majority (5 of 7) were obtained in the period 2005 to 2007 inclusive, suggesting increased peak levels of contamination in recent years.

11.4 Overall temporal pattern of results

Figures 11.3 and 11.4 present scatter plots of individual results against date for all mussel samples taken from Loch Fyne: Ardkinglas. Both are fitted with trend lines to help highlight any apparent underlying trends or cycles. Figure 11.3 is fitted with a line indicating the geometric mean of the previous 5 samples, the current sample and the following 6 samples. Figure 11.4 is fitted with a loess smoother, a regression based smoother line calculated by the Minitab statistical software.

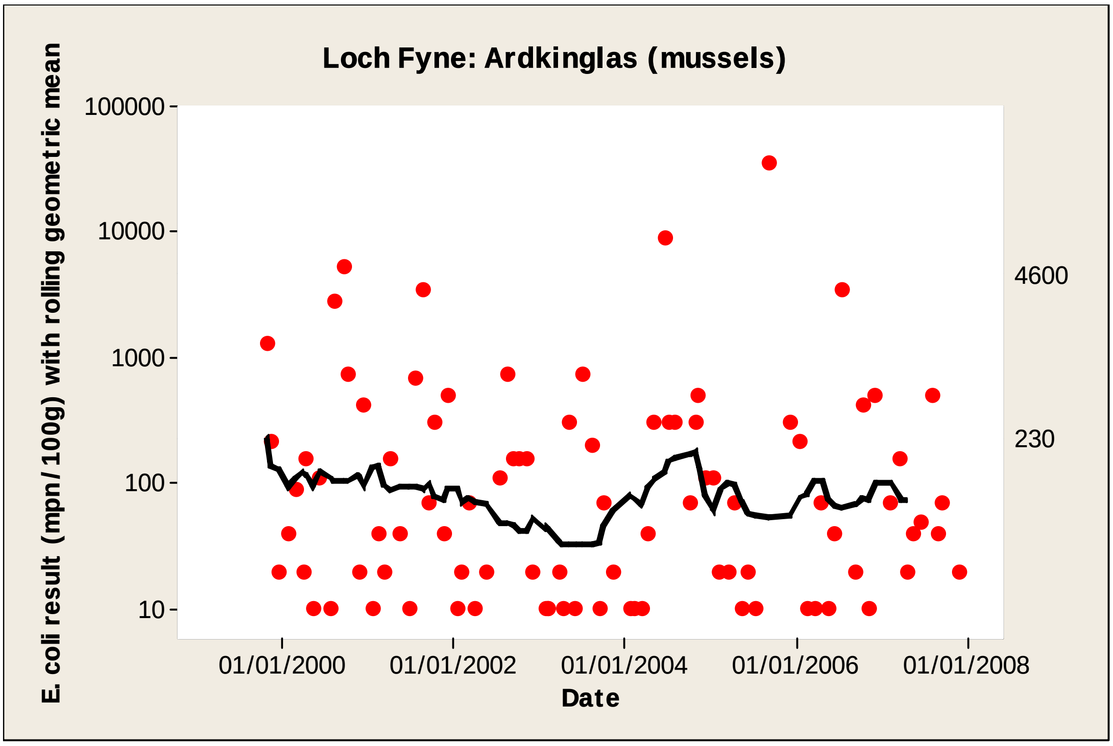

Figure 11.3 Scatterplot of results by date with rolling geometric mean (mussels)

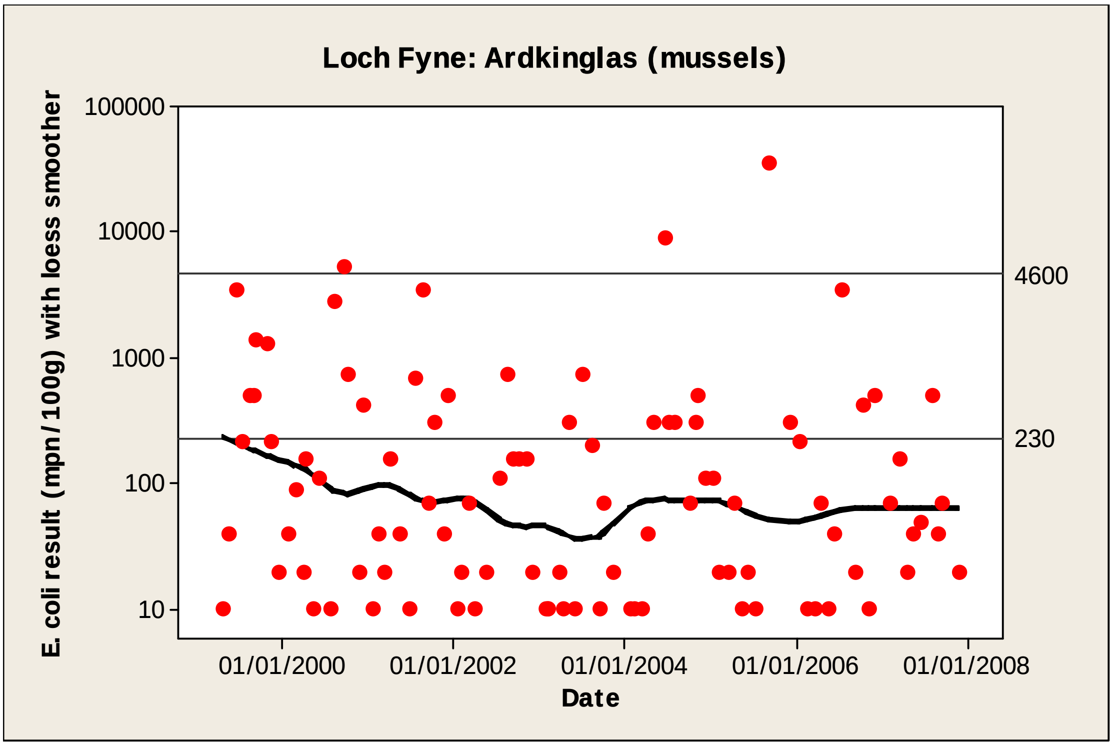

Figure 11.4 Scatterplot of results by date with loess smoother (mussels)

A slight overall improvement in the average level of results since 1999 is suggested by the trend lines in Figures 11.3 and 11.4. However, two results over 4600 have been reported since 2004.

Figures 11.5 to 11.6 present the temporal pattern of results for Pacific oysters.

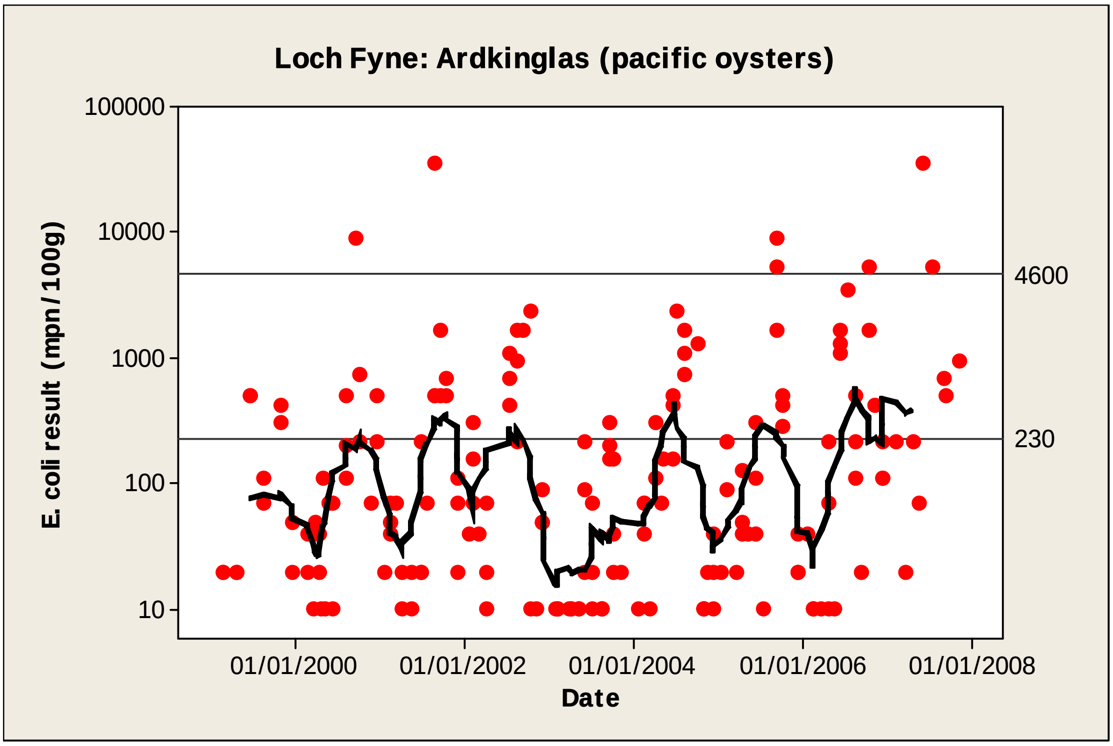

Figure 11.5 Scatterplot of results by date with rolling geometric mean (oysters)

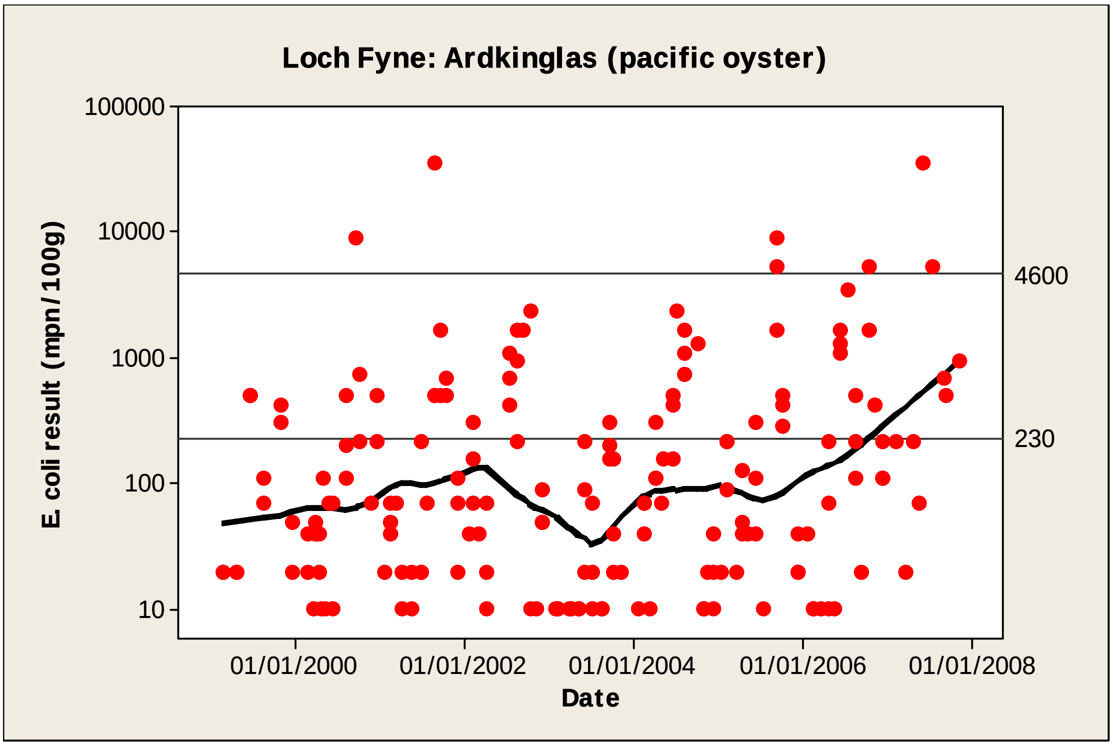

Figure 11.6 Scatterplot of results by date with loess smoother (oysters)

Figure 11.5 suggests annual cycles in levels of contamination with peaks in most years around the summer/autumn. This pattern was not seen for mussels in Figures 11.3 or 11.4. The trend line in Figure 11.6 suggests an overall deterioration in microbiological quality from 2004 onwards. This is the opposite to what was seen in mussels, but the increase in incidence of results over 4600 is similar.

11.5 Temporal pattern of results in relation to outbreaks of illness potentially associated with the production area

Two outbreaks of viral gastroenteritis in which Loch Fyne: Ardkinglas oysters were potentially implicated have occurred in 2006 and 2007. The first was first reported on 16th December 2006, in which two cases involving a total of 7 people were reported to CEFAS and involved one restaurant. The second was first reported on the 9th July 2007, and was on a much larger scale with 21 cases involving 100 people reported to CEFAS from a number of restaurants nationwide.

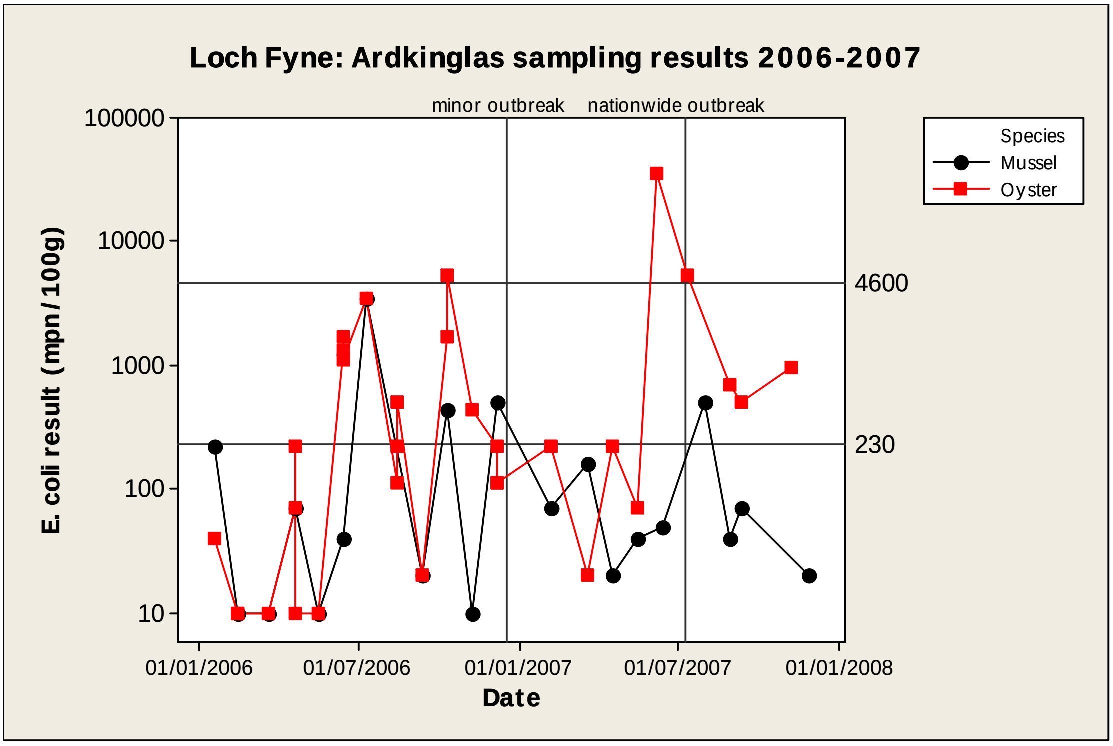

Figure 11.7 Temporal pattern of results leading up to the outbreaks of illness with timing the first reports of the outbreaks indicted

No large increase in levels of contamination was observed in samples collected immediately prior to the minor outbreak. An oyster sample collected on the 5th June 2007 yielded a result of >18000 *E. coli* mpn/100g, and the subsequent oyster sample, taken on the 10th July 2007 yielded a result of 5400 *E. coli* mpn/100g. This suggests that there was a period of very high levels of faecal contamination in oysters immediately prior to the nationwide outbreak. No major increase in contamination was observed in mussels collected on 12th June 2007 (50 *E. coli* mpn/100g) or 31st July 2007 (500 *E. coli* mpn/100g) with both samples falling within a range which could be reasonably expected from the areas classification and historical monitoring results. The oyster samples were reportedly collected from Policy Gates at NN162098 (see Figure 11.2) and the mussel samples were reportedly collected from The Point at NN 166102 (see Figure 11.1). As a peak in contamination was only observed in oysters, this suggests the event or events causing this were may have been localised – Pacific oysters tend to take up contamination, and then depurate it, more slowly than mussels and so the difference may have also been due to the elapsed time between the contamination event and sampling of the two species.

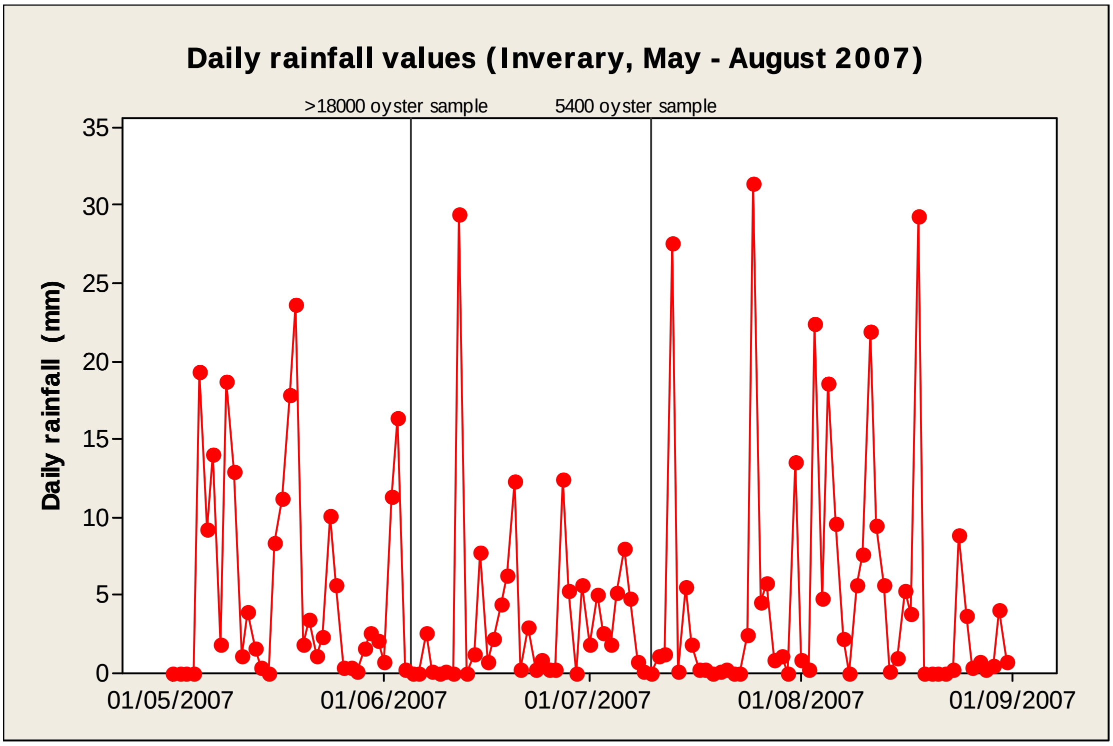

Figure 11.8 Daily rainfall values around the time of the nationwide outbreak

Figure 11.8 indicates that no exceptionally heavy rainfall occurred in the period before the 5th June 2007 (when an oyster sample yielded a result of >18000 *E. coli* mpn/100g). The mean rainfall in the 30 days up to and including the 4th June for 2003-2007 inclusive at Inverary was 156.3 mm (range 77.1 to 210.6 mm), compared to a total of 185.4 mm in 2007. This period was wetter than average in 2007, but not exceptionally so. A total of 61.2 mm of rain fell on the 16th-19th May inclusive, and a total of 27.7 mm of rain fell on the 2nd-3rd June inclusive.

11.6 Seasonal pattern of results

Season dictates not only weather patterns and water temperature, but livestock numbers and movements, presence of wild animals and patterns of human occupation. All of these can affect levels of microbial contamination, and cause seasonal patterns in results. Figures 11.9 and 11.10 present the geometric mean *E. coli* result by month (+ 2 times the standard error) for mussels and oysters respectively.

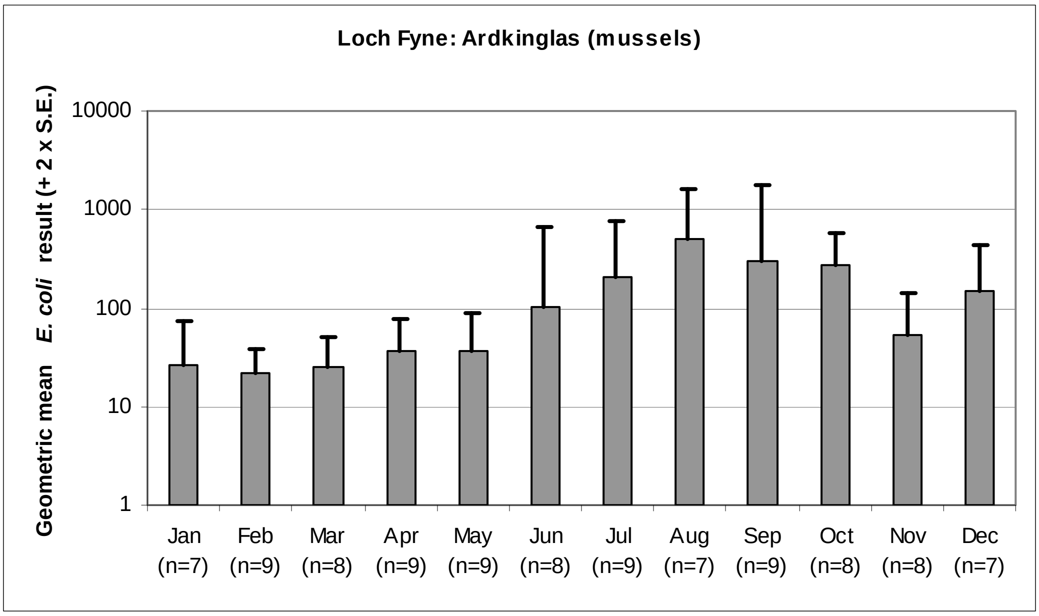

Figure 11.9 Geometric mean result by month (mussels)

Highest mean results for mussels occurred from July to October, and lowest mean results occurred from January to May.

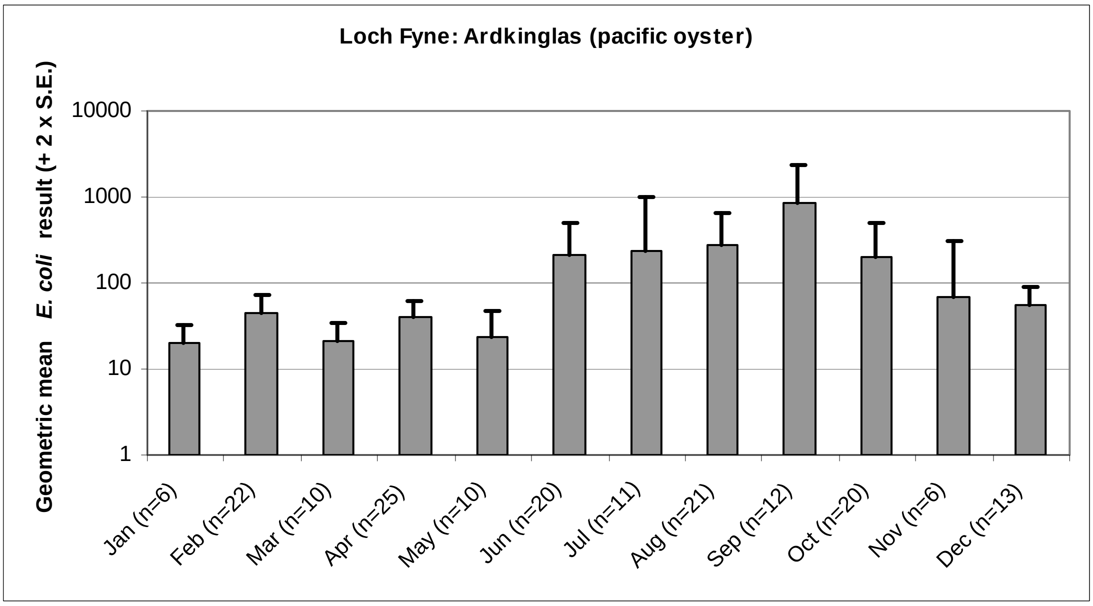

Figure 11.10 Geometric mean result by month (Pacific oysters)

Highest mean results for Pacific oysters occurred from July to October, with a peak in September. Lowest mean results occurred from January to May.

The pattern was very similar for the two species.

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

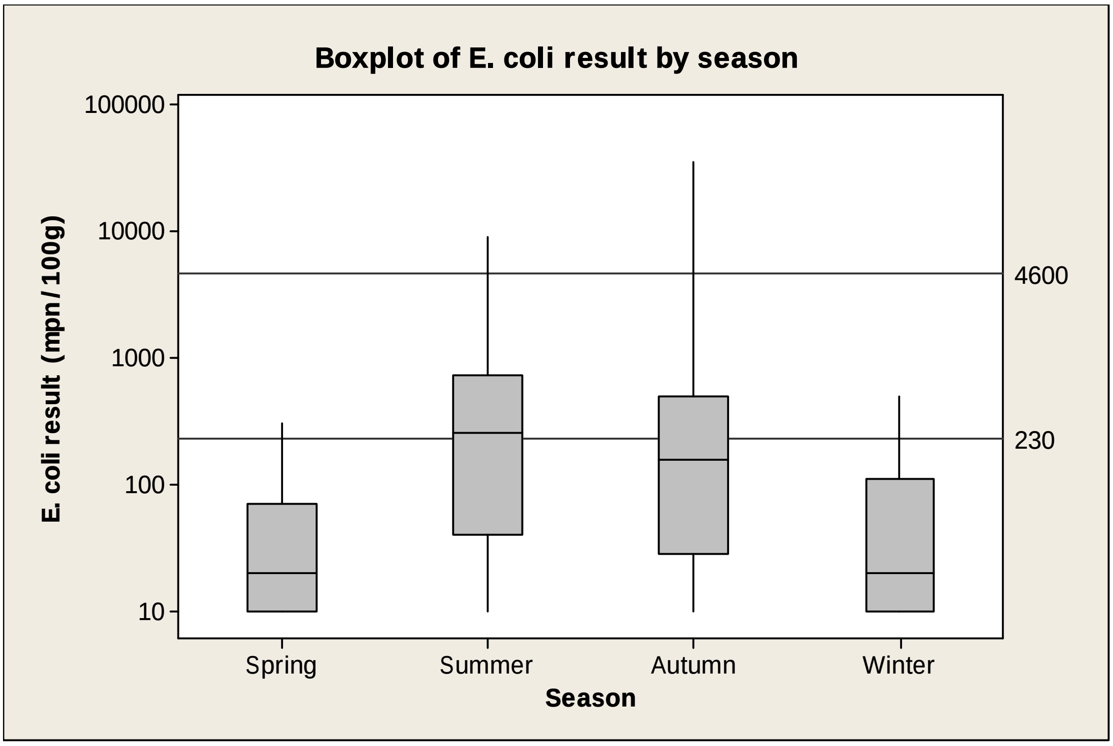

Figure 11.11 Boxplot of result by season (mussels)

For mussels, a significant difference was found between results by season (One-way ANOVA, p=0.000, Appendix 4). A post ANOVA test (Tukeys comparison, Appendix 4) indicates that results for the summer and autumn were significantly higher than those in the winter and spring.

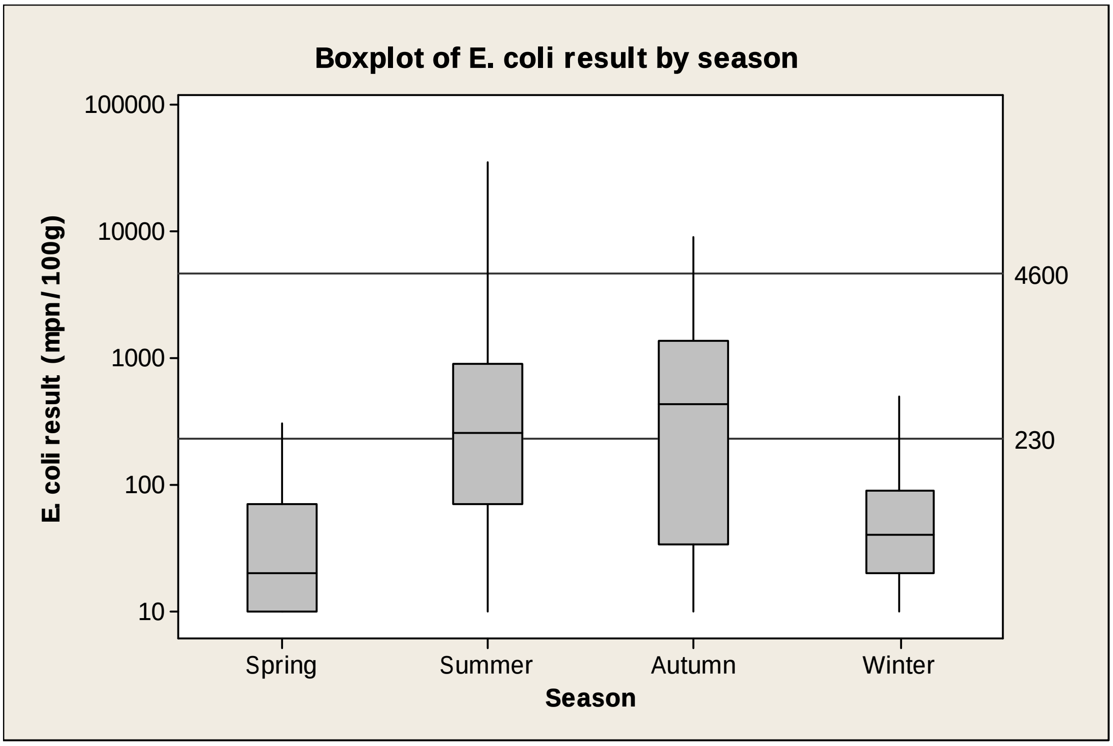

Figure 11.12 Boxplot of result by season (Pacific oysters)

For Pacific oysters, a significant difference was also found between results by season (One-way ANOVA, p=0.000, Appendix 4). A post ANOVA test (Tukeys comparison, Appendix 4) indicates that results for the summer and autumn are significantly higher than those in the winter and spring. This was the same as the seasonal pattern observed with mussels.

The periods showing significantly higher *E. coli* results for both species corresponded to those periods for which a worse classification (B) applied.

11.7 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. This analysis considers the 98 mussel samples taken from Loch Fyne: Ardkinglas from 1999 to 2007 inclusive.

11.7.1 Analysis of results by recent rainfall

The weather station within 15 km of the production site with the fewest missing records is located at Inverary Castle, approximately 6 km to the west of the production area. Rainfall data was purchased from the Meteorological Office for the period 1/1/2003 to 31/12/2007 (total daily rainfall in mm). For this period of 1826 days, a total of 239 days records were missing. The coefficient of determination was calculated for *E. coli* results and rainfall in the previous 2 days at Inverary. Figures 11.13 and 11.14 present a scatterplot of *E. coli* results against rainfall for mussels and oysters respectively. Figures 11.15 and 11.16 present boxplots of results by previous 2 days rainfall quartile for mussels and oysters respectively (quartile 1 = 0 to 0.4 mm, quartile 2 = 0.4 to 6.7 mm, quartile 3 = 6.7 to 18.65 mm, quartile 4 = more than 18.65 mm).

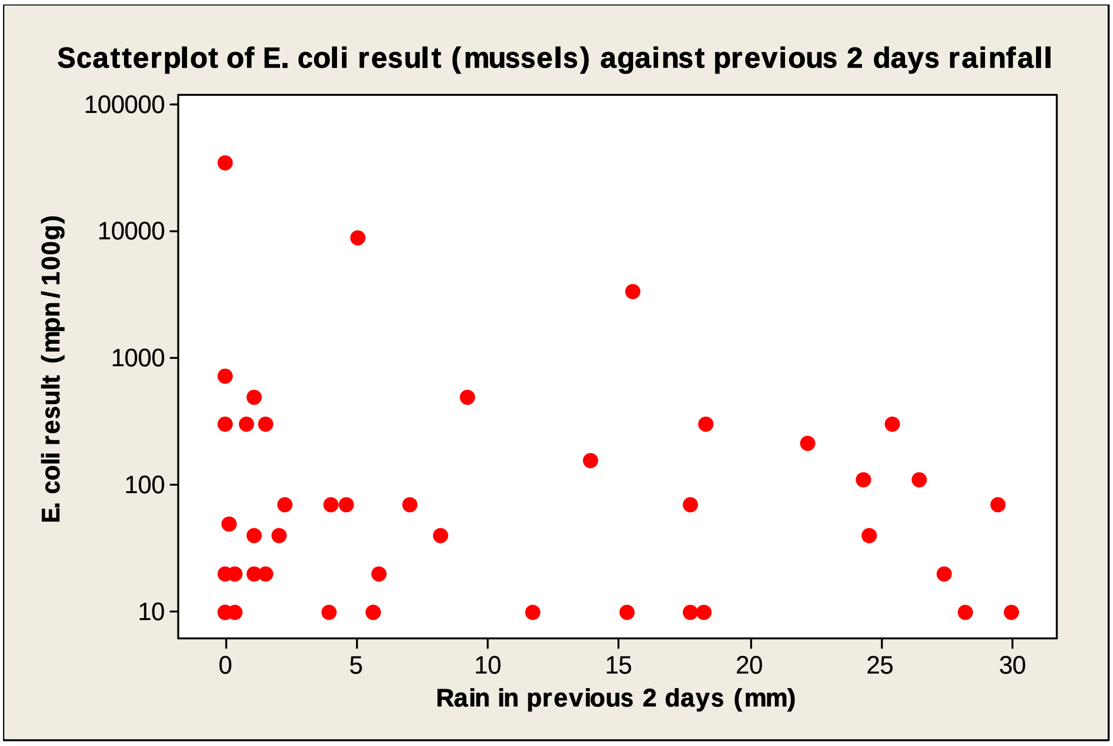

Figure 11.13 Scatterplot of result against rainfall in previous 2 days (mussels)

The coefficient of determination indicates that there was no relationship between the *E. coli* result and the rainfall in the previous two days for mussels (Adjusted R-sq=0.0%, p=0.647, Appendix 4).

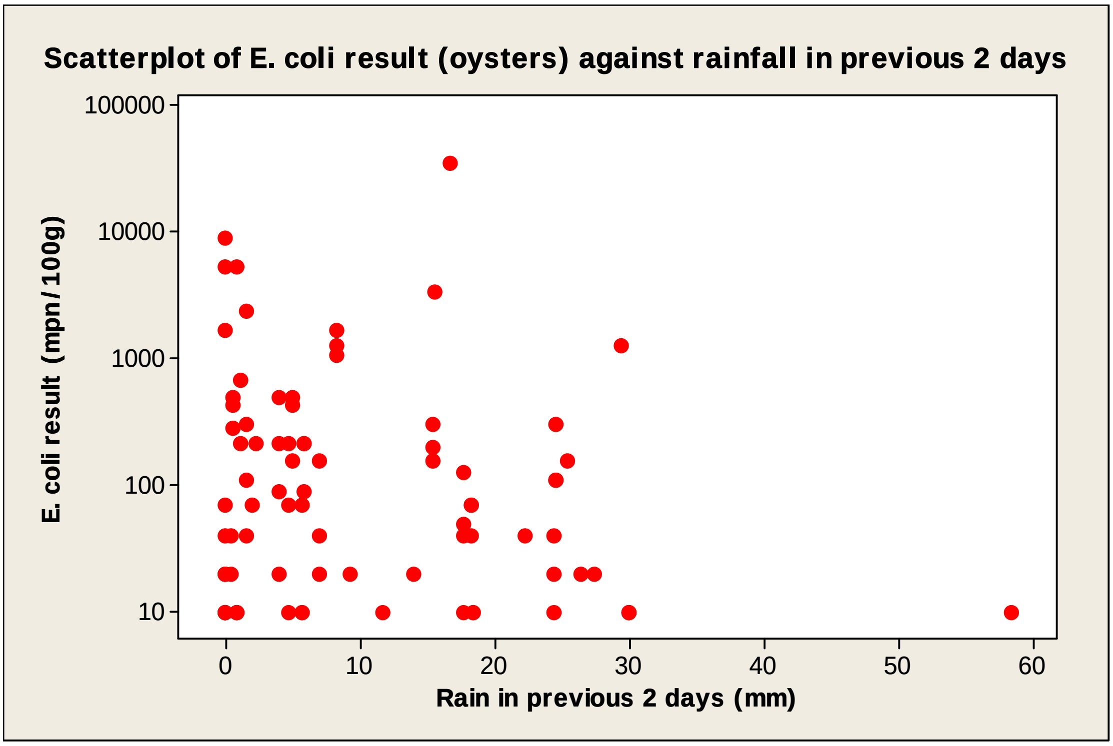

Figure 11.14 Scatterplot of result against rainfall in previous 2 days (Pacific oysters)

The coefficient of determination indicates that there was no relationship between the *E. coli* result and the rainfall in the previous two days for oysters (Adjusted R-sq=1.9%, p=0.108, Appendix 4).

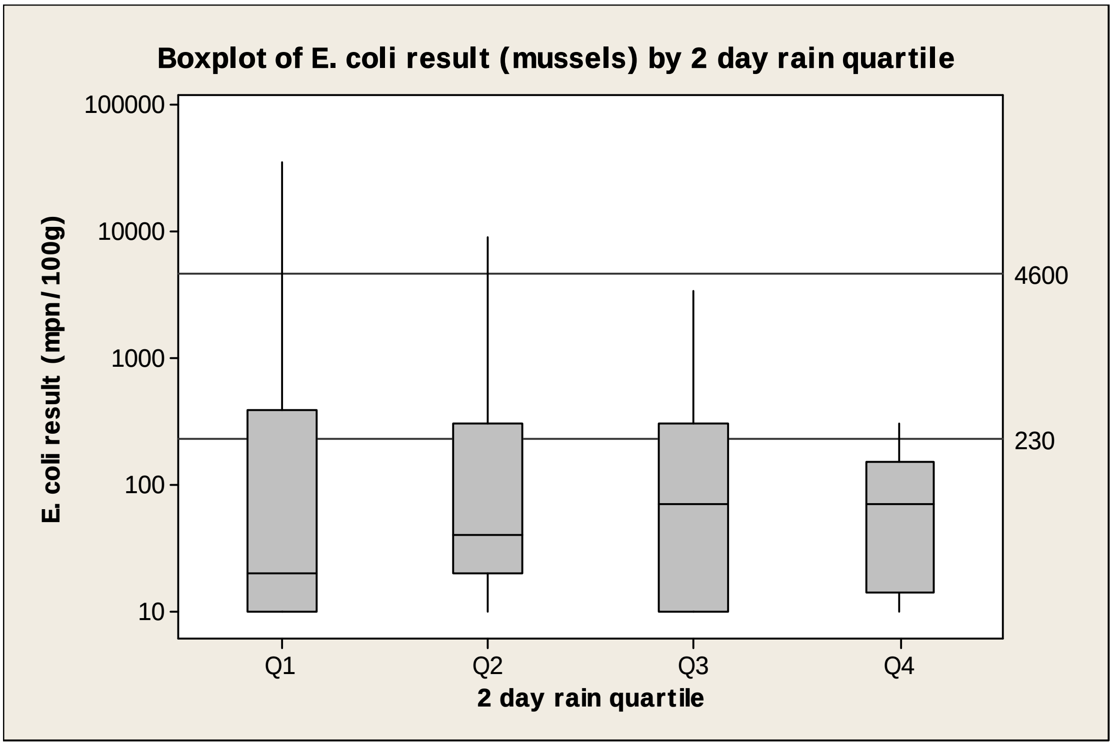

Figure 11.15 Boxplot of result by rainfall in previous 2 days quartile (mussels)

No significant difference was found between the results for each 2-day rain quartile for mussels (One way ANOVA, p=0.995, Appendix 4).

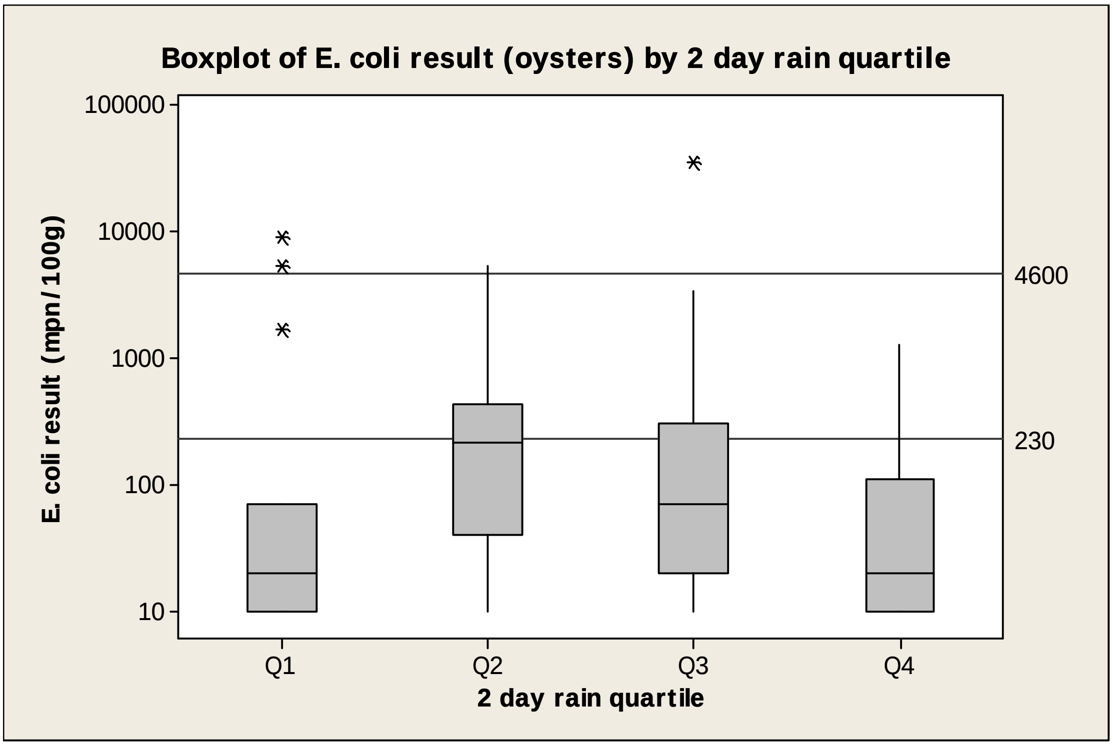

Figure 11.16 Boxplot of result by rainfall in previous 2 days quartile (Pacific oysters)

No significant difference was found between the results for each 2-day rain quartile for oysters (One way ANOVA, p=0.203, Appendix 4).

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 for Loch Fyne: Ardkinglas was investigated in an identical manner to the above. Interquartile ranges for 7 days rainfall were as follows; quartile 1 = 0 to 15.1 mm; quartile 2 = 15.1 to 34.6 mm; quartile 3 = 34.6 to 62.0 mm; quartile 4 = more than 62.0 mm.

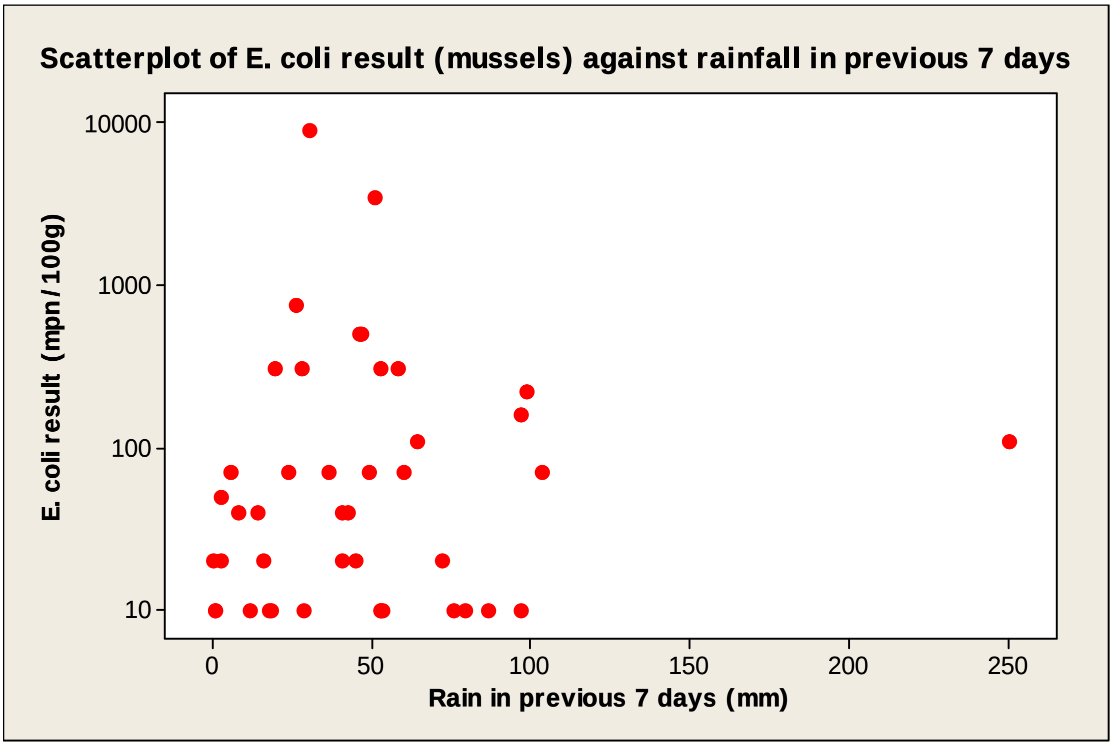

Figure 11.17 Scatterplot of result against rainfall in previous 7 days (mussels)

The coefficient of determination indicates that there was no relationship between the *E. coli* result and the rainfall in the previous 7 days for mussels (Adjusted R-sq=0.0%, p=0.536, Appendix 4).

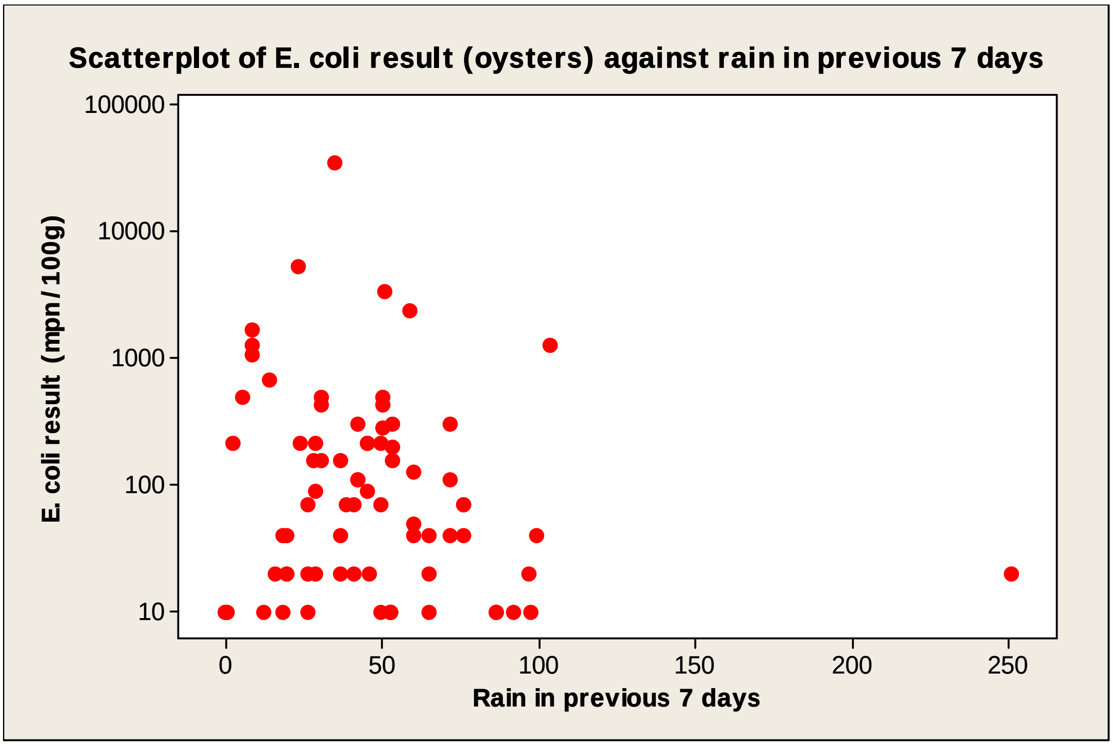

Figure 11.18 Scatterplot of result against rainfall in previous 7 days (Pacific oysters)

The coefficient of determination indicates that there was no relationship between the *E. coli* result and the rainfall in the previous 7 days for oysters (Adjusted R-sq=1.9%, p=0.118, Appendix 4).

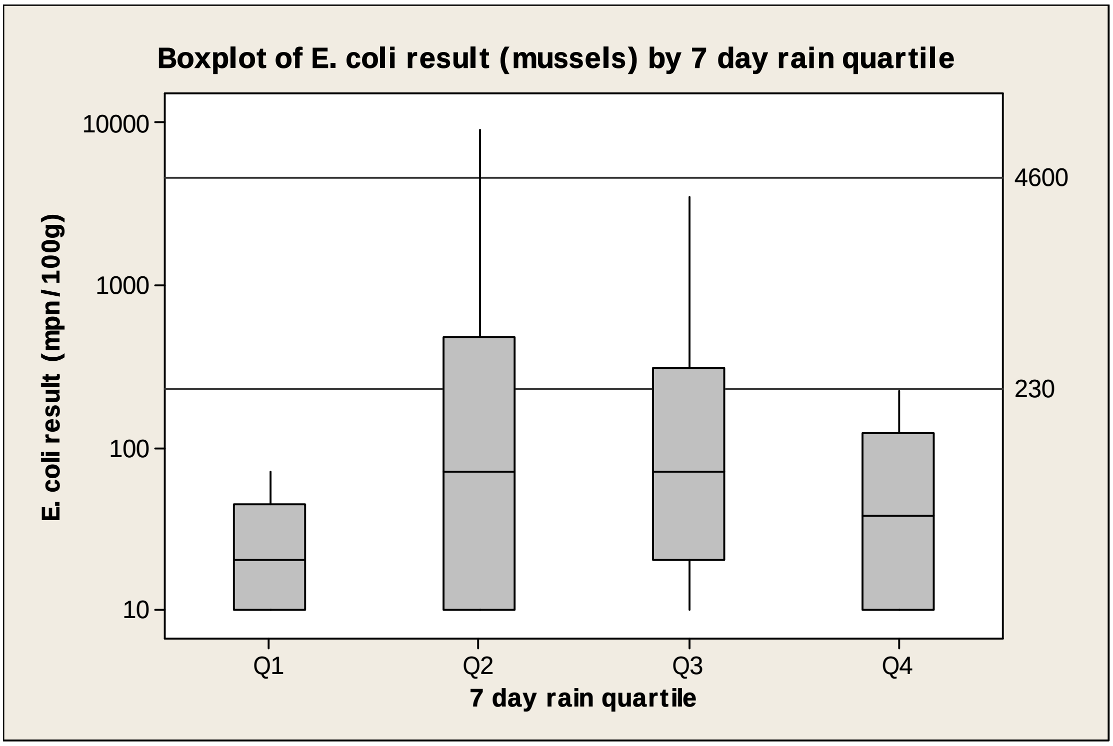

Figure 11.19 Boxplot of result by rainfall in previous 7 days quartile (mussels)

No significant difference was found between the results for each 7-day rain quartile for mussels (One way ANOVA, p=0.225, Appendix 4).

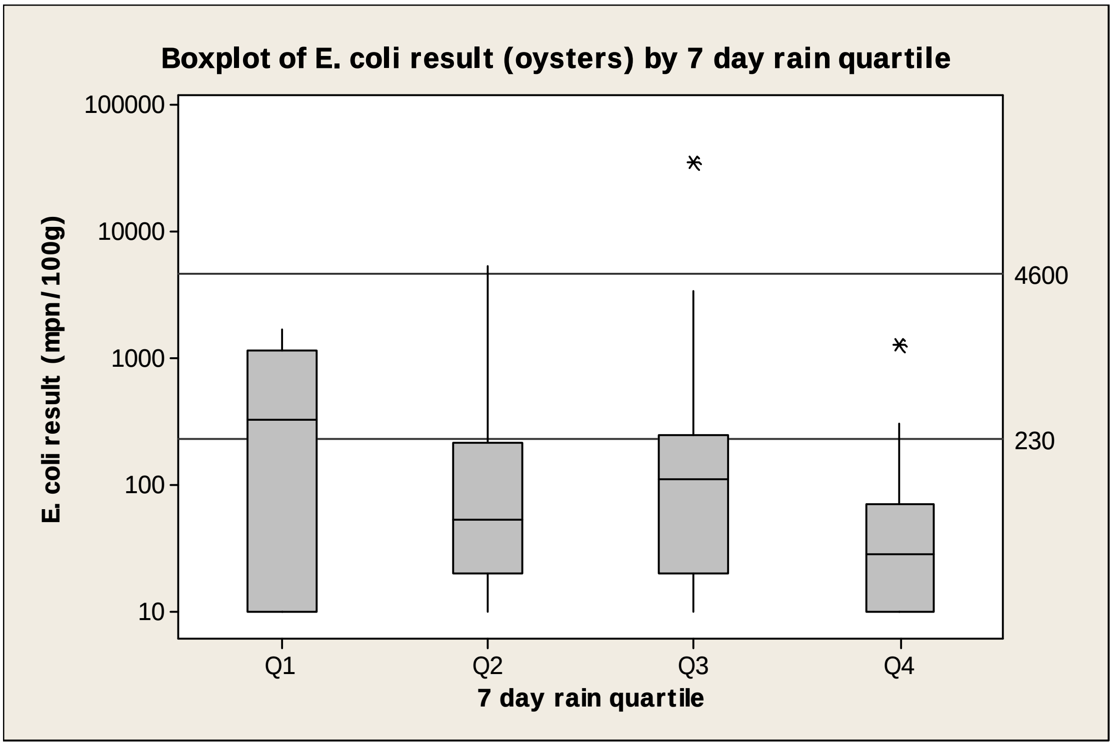

Figure 11.20 Boxplot of result by rainfall in previous 7 days quartile (Pacific oysters)

No significant difference was found between the results for each 7-day rain quartile for oysters (One way ANOVA, p=0.140, Appendix 4).

Overall, no relationship between *E. coli* result and recent rainfall was found for either species. This suggests that the most important sources of microbial contamination affecting this production area are not rainfall dependant.

11.7.2 Analysis of results by lunar state

Lunar state dictates tide size, with the largest tides occurring 2 days after either a full or new moon. With the larger tides, circulation of water in the loch will increase, and more of the shoreline will be covered, potentially washing more faecal contamination from livestock into the loch. Figures 11.21 and 11.22 present boxplots of *E. coli* results by size of tide categorised by lunar state at the time of sampling. 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.

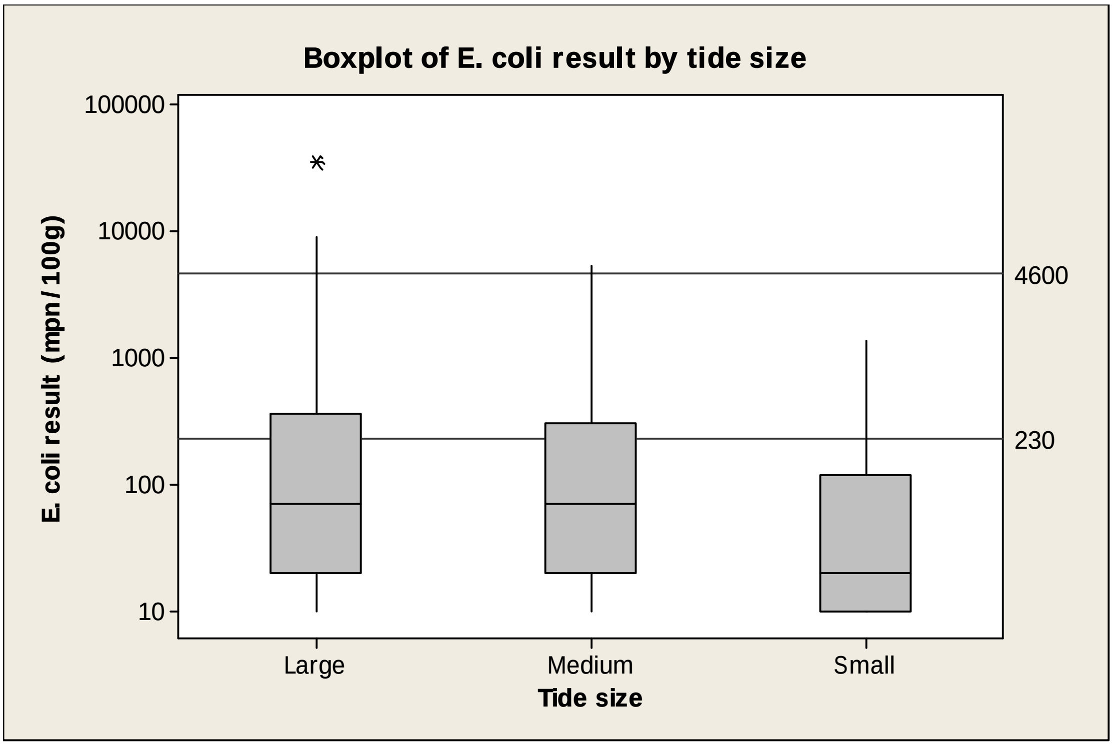

Figure 11.21 Boxplot of result by tide size (mussels)

Although Figure 11.21 gives the impression of higher results for mussels during larger tides, the effect was not statistically significant (One way ANOVA, p=0.365, Appendix 4).

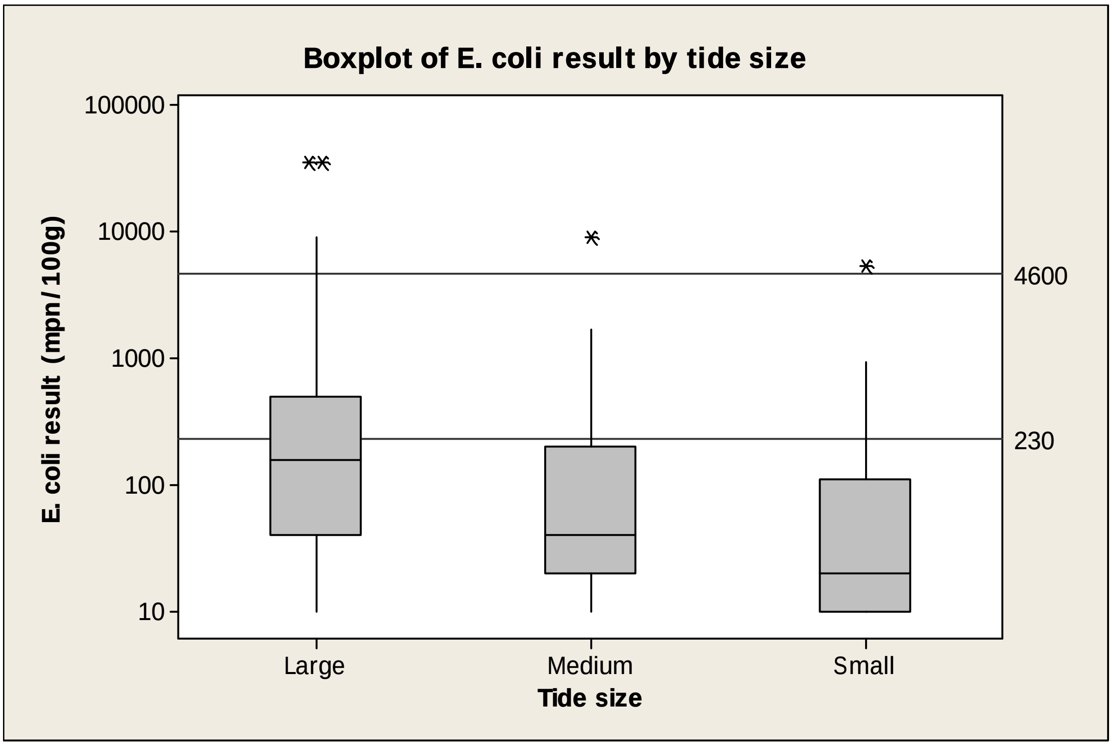

Figure 11.22 Boxplot of result by tide size (Pacific oysters)

A significant difference was found between results by tide size for oysters (One-way ANOVA, p=0.001, Appendix 4). A post ANOVA test (Tukeys comparison,

Appendix 4) indicates that higher results occurred on the large tides compared to the medium tides. Although the mean result was lowest for the samples gathered on small tides, the results for this category differed from neither of the other categories. It must be noted that few samples were gathered on small tides (11) compared to medium (83) and large tides (88).

Overall, tide size does appear to have a slight influence on result, with higher results on larger tides. The effect is only statistically significant for oysters. Tidal currents in the area are relatively weak, but larger tides will result in increased particle transport distances so the shellfish will be exposed to contamination originating from point sources which are further afield. In general, the contamination will be associated with sources that are located in the direction from which the tidal currents have flowed over the few hours prior to sampling.

11.7.3 Analysis of results by water temperature

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

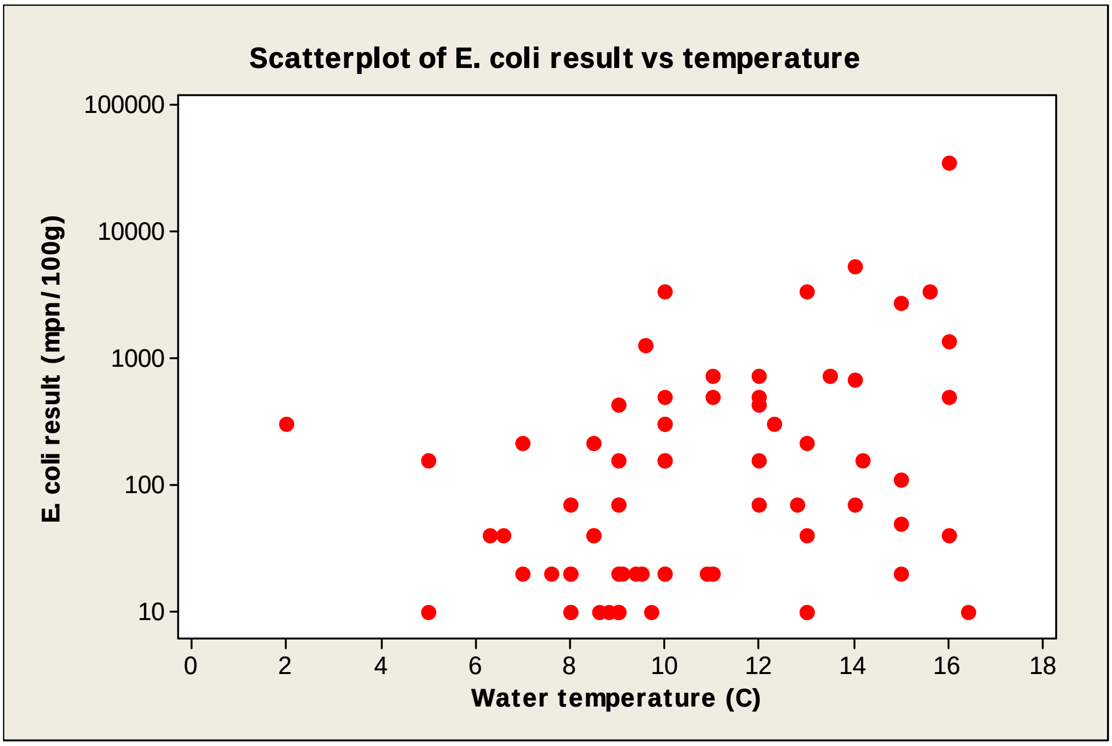

Figure 11.23 Scatterplot of result against water temperature at time of sampling (mussels)

The coefficient of determination indicates that there is a very weak positive relationship between the *E. coli* result and the water temperature at time of sampling (Adjusted R-sq=12.9%, p=0.001, Appendix 11).

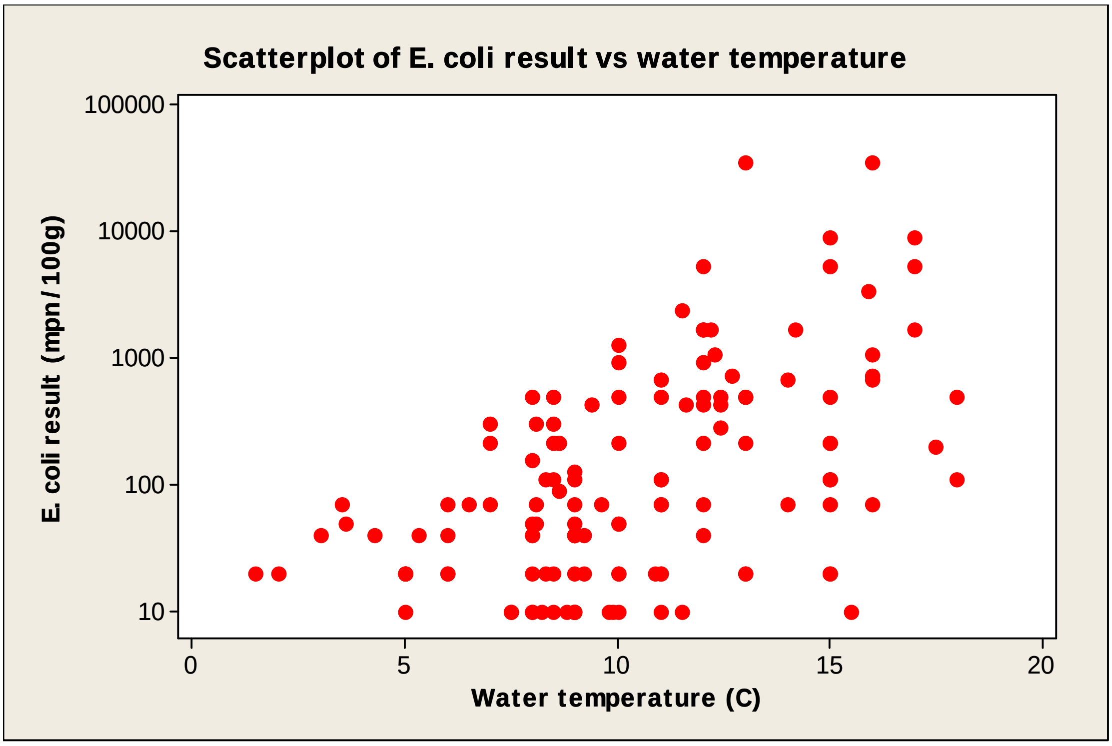

Figure 11.24 Scatterplot of result against water temperature at time of sampling (Pacific oysters)

The coefficient of determination indicates that there was a weak positive relationship between the E. coli result and the water temperature at time of sampling (Adjusted R-sq=26.8%, p=0.000, Appendix 11).

Overall, results were higher and more variable at higher water temperatures. The effect was stronger for oysters than for mussels. This may have been due to the fact that the lowest temperature at which significant filtration activity occurs is higher for Pacific oysters than for mussels.

The recorded water temperatures at time of sampling were all less than 20ºC. The temperatures recorded on receipt at the testing laboratory for 83 samples for which the information was available were all less than 8ºC, the maximum temperature for transport recommended by the National Reference Laboratory (NRL). Studies undertaken by the NRL have indicated that significant multiplication of E. coli in shellfish does not occur within 72 hours if the temperature is maintained below 20ºC. It is therefore concluded that the observed effect of temperature on the E. coli content of the mussels and Pacific oysters in Loch Fyne is not due to multiplication during transport.

11.7.4 Analysis of results by wind direction

Wind speed and direction may change water circulation patterns in the production area. Mean wind direction for the 7 days prior to each sample being collected was calculated from wind data recorded at the Glasgow: Bishopton weather station, and mean result by mean wind direction in the previous 7 days is plotted in Figure 11.25 for mussels, and 11.26 for oysters.

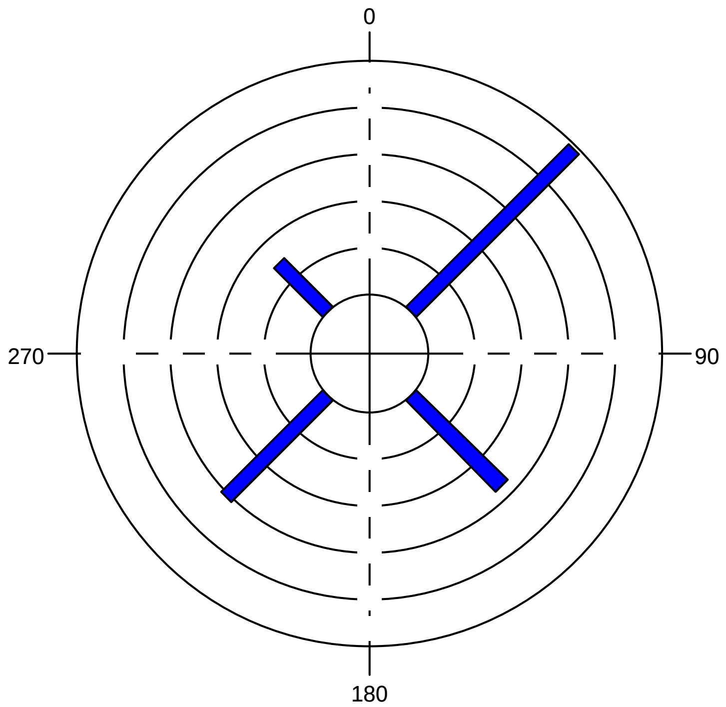

Figure 11.25 Circular histogram of geometric mean *E. coli* result by wind direction (mussels)

No significant correlation was found between wind direction and *E. coli* result in mussels (circular-linear correlation, r=0.114, p=0.633, Appendix 11).

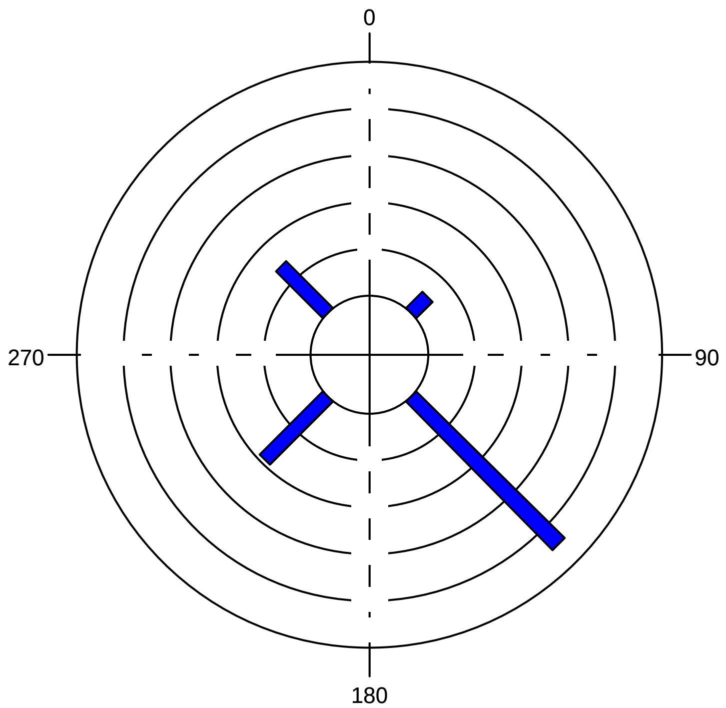

Figure 11.26 Circular histogram of geometric mean *E. coli* result by wind direction (Pacific oysters)

No significant correlation was found between wind direction and *E. coli* result in Pacific oysters (circular-linear correlation, r=0.176, p=0.10, Appendix 11).

Overall, no correlation between mean wind direction in the previous 7 days and *E. coli* result was found for either species, but this does not necessarily mean that wind is unimportant. It must also be noted that the majority of samples were collected during periods of westerly winds.

11.7.5 Summary of environmental effects

A strong seasonal effect was found, with results for both species higher in the summer and autumn compared to the winter and spring, A positive relationship was also found between water temperature and results for both species. This is likely to contribute part or all of the seasonal effect. The results would suggesting that either inputs of *E. coli* are higher in summer and autumn and/or the uptake of bacteria by the shellfish is higher in warmer water. Both uptake and depuration of *E. coli* (and other microbes) by shellfish are known to increase with temperature and the effect on observed *E. coli* concentrations will be a balance between the two. Positive correlations of shellfish *E. coli* concentrations with water temperatures have been seen in several, but not all, of the analyses undertaken in other Scottish sanitary surveys for which data has been available. At this stage it is not possible to determine whether the observed tendency towards higher concentrations of *E. coli* in the shellfish in Loch Fyne in the summer/autumn is due to higher concentrations in the polluting sources in those seasons, and effect of temperature, or a combination of the tow.

No relationship was found between results and recent rainfall, suggesting that the most important sources of contamination are not rainfall dependant. This may have been due to the absence of combined sewer overflows in the area and/or a lack of animal-associated run-off (see Sections 4 and 7 respectively). It does not appear from the analyses that the impacts from the rivers or streams with the highest loadings nearest the fisheries increases significantly with rainfall. However, this assumption would ideally be confirmed by observation. A further complication is the occurrence of stratification which would tend to limit rainfall-associated contamination to the upper freshwater layer and this may not necessarily impact on the shellfish, especially the mussels lower down lines (see Section 13).

Results were higher for both species (significantly so for oysters) when tides were larger. This suggests that some important sources of contamination are located at a distance from the production area as to impact more significantly on the growing sites on larger tides – contamination will tend to travel further on spring tides than neap tides.

No correlation was found between wind direction and magnitude of *E. coli* results.

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.

11.8 Sampling frequency

When a production area has had 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 may be decreased from monthly to bimonthly. This is not appropriate for Loch Fyne: Ardkinglas, as it has held seasonal classifications since 2001 for both mussels and Pacific oysters.

11.9 Norovirus testing

A large-scale outbreak of viral gastroenteritis in which Loch Fyne: Ardkinglas oysters were potentially implicated occurred in July 2007 (see Section 11.5). The outbreak was first reported on the 9th July 2007, and 21 incidents involving 100 people were reported to CEFAS from a number of restaurants nationwide.

As part of the follow-up investigation, Pacific oyster samples were taken on a weekly basis from one location (Saw Mill) covering the period 24/7/07 to 11/9/07. They were tested for norovirus (genogroups I and II) by PCR as described by Lowther *et al* (in press).

As part of the sanitary survey, monthly samples were taken for further norovirus testing from four locations within the production area (Ardkinglas Gardens, Pier Cottage, Saw Mill and Bathach-ban Cottage) starting 11/10/2007. Monthly testing as part of the sanitary survey continued until October 2008, at which point these results were reported in full as a separate report. This report is included as Appendix 7.

In short, norovirus testing showed a clear gradient of contamination with highest results observed at the northeastern end of the oyster farm. This indicated that the primary source of human faecal contamination to the area was coming from a point near or beyond the northern end of the fishery.

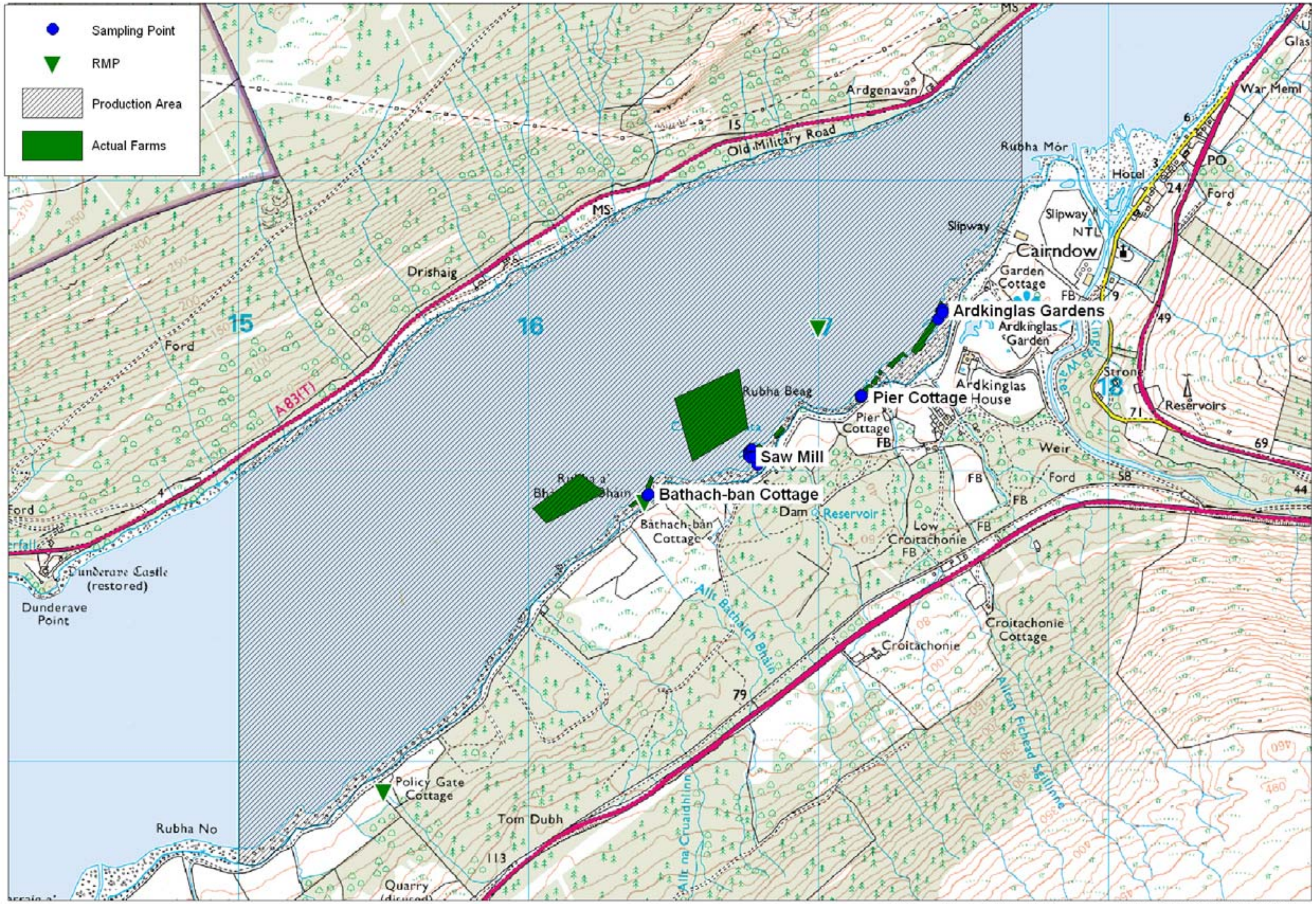

Figure 11.27 Map of norovirus sampling locations

11.10 Other relevant data

In response to the nationwide outbreak of viral gastroenteritis, in which Loch Fyne oysters were potentially implicated, Mr. Farrell of Loch Fyne Oysters undertook an independent investigative microbiological survey. This involved the collection of water samples from the loch and from shellfish holding tanks, and shellfish samples from the shellfish holding tanks. These were submitted to Bodycote Foodscan, who tested all samples for total coliforms, *E. coli*, and Salmonella. The results of this survey were kindly supplied to Cefas by Mr. Farrell, via Argyll and Bute Council.

The water and shellfish samples taken from the holding tanks are not considered in this report, as they provide no direct information on the temporal or spatial pattern of microbiological contamination within the production area.

Water sampling locations are presented in Figure 11.30, and results for *E. coli* are presented in Table 11.6.

Table 11.5 Water sampling results

Analysis date	Sample location	Estimated Grid Reference	*E. coli* (cfu/100ml)
24/07/2007	The Point	NN 137 084	10
24/07/2007	Oyster farm outfall	NN 167 101	ND
27/07/2007	Ardkinglas Bay North Section	NN 174 105	ND
27/07/2007	Pheasant Stream	NN 173 104	ND
01/08/2007	Pheasant Stream	NN 173 104	250
01/08/2007	Pier cottage outlet	NN 172 102	360
08/08/2007	Callanders Burn outlet	NN 168 100	ND
08/08/2007	Semples Garage, Inverary	NN 096 084	ND
08/08/2007	Sewage outlet, Inverary	NN 0961 0794	ND

ND = Not detected. The nominal limit of detection is 1 cfu/100ml).

It must be noted that salinity, sample collection date/time, transport conditions, and temperature on arrival at Bodyscan was not reported.

E. coli was only detected in 3 of the 9 water samples taken from the loch. Given the limit of detection of the test is 1 cfu/100ml, the six samples where *E. coli* was not detected were exceptionally clean. Highest results were obtained in water samples taken from amongst the oyster trestles on 1/8/2007.

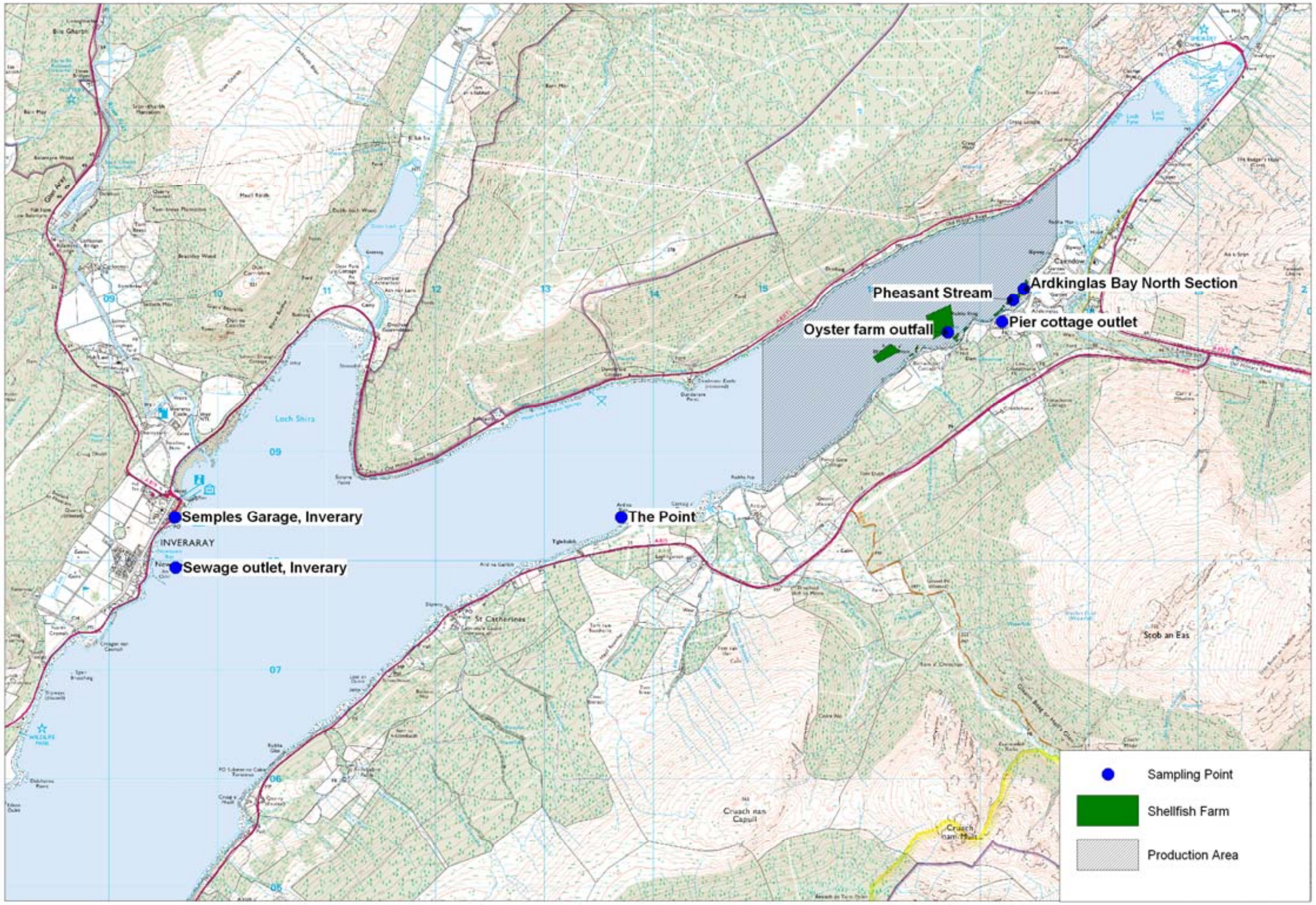

Figure 11.28 Water sampling locations

12. Designated Shellfish Growing Waters Data

The area considered in this report is also monitored by SEPA as a shellfish growing water which was designated in 1998. The growing water encompasses the entire shoreline of Loch Fyne aside from a few stretches around large settlements, and the full extent of this is not shown on Figure 12.1. There are 3 designated monitoring points, one at Loch Fyne Head (shown on Figure 12.1), one at Loch Gair approximately 30km to the southwest of the Loch Fyne: Ardkinglas production area, and one at Whitehouse Bay, approximately 40km to the southwest of the production area.

The monitoring requires the following testing:
Quarterly for salinity, dissolved oxygen, pH, temperature and visible oil
Twice yearly for metals in water
Annually for metals and organohalogens in shore mussels
Quarterly for faecal coliforms in shore mussels

Monitoring results for faecal coliforms in shore mussels from 1999 to the end of 2006 have been provided by SEPA. These results are presented in Table 12.1.

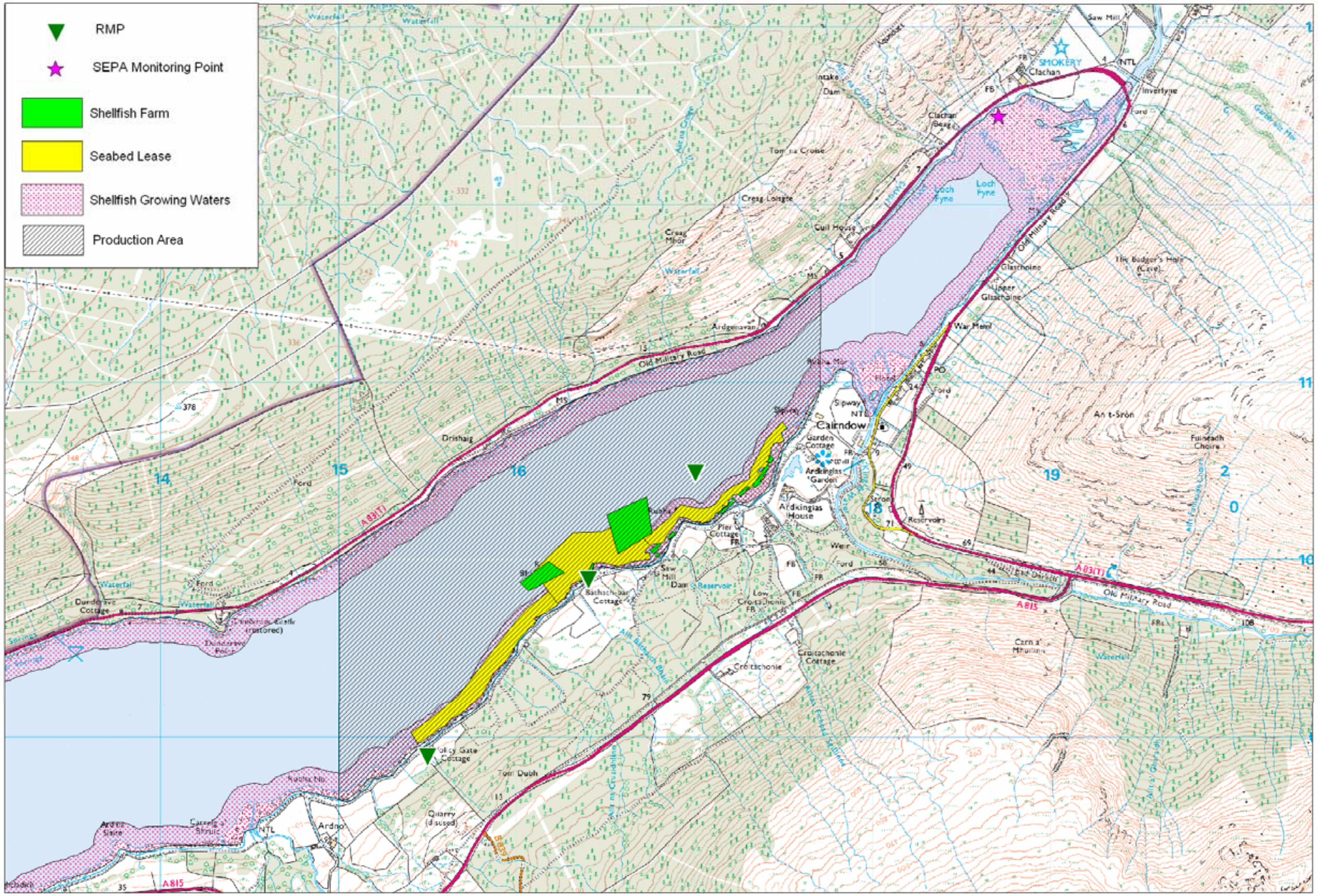

Figure 12.1 Map showing part of the designated shellfish growing water and the Loch Fyne Head SEPA monitoring point

Table 12.1 SEPA Faecal coliform results (faecal coliforms/100g) for non-commercial shellfish gathered from Loch Fyne Head.

	Site	Loch Fyne inner/Head
	OS Grid Ref.	NN 164 099/ NN 18699 12499
	Q3	2200
1999	Q4	2400
	Q1	70
	Q2	40
	Q3	220
2000	Q4	5400
	Q1	430
	Q2	20
	Q3	<20*
2001	Q4	500
	Q1	220
	Q2	20
	Q3	220
2002	Q4	310
	Q1	20
	Q2	-
	Q3	600
2003	Q4	220
	Q1	40
	Q2	70
	Q3	500
2004	Q4	750
	Q1	40
	Q2	500
	Q3	750
2005	Q4	70
	Q1	20
	Q2	3500
	Q3	-
2006	Q4	3100

* Assigned a nominal value of 10 for the purpose of calculating the geometric mean

The samples are reported as originating from either the designated monitoring point at the head of the loch, or from NN 164099, which is the RMP for Loch Fyne: Ardkinglas: The Shore. It is not possible to determine from which site each individual sample was collected.

The geometric mean result of all SEPA shore mussel samples was 152 faecal coliforms / 100g. Results ranged from 3 to 5400 faecal coliforms/100g. There was a significant difference in results between the quarters (One-way ANOVA, p=0.039, Appendix 4). A post ANOVA test (Tukeys comparison, Appendix 4) indicated that results for quarter 4 were significantly higher than results for quarter 1, and there were no other significant differences between the quarters. This differs from the results of the classification testing for *E. coli* where the highest results were seen in summer and autumn.

Levels of faecal coliforms are usually closely correlated to levels of *E. coli* often at a ratio of approximately 1:1. The ratio depends on a number of factors, such as environmental conditions and the source of contamination and as a consequence the results presented in Table 12.1 are not directly comparable with other shellfish testing results presented in this report. The geometric mean level of contamination in shore mussels taken as part of the SEPA monitoring point is almost double the overall geometric mean of the rope mussel samples tested for *E. coli* (82.9 mpn/100g) presented in Table 11.1.

Results for the physical and chemical parameters monitored by SEPA are not presented in this report.

13 Hydrographic assessment.

This site was chosen for a full hydrodynamic modelling using the Hydrotrack model described in the Hydrography Methods Document. This document can be consulted for background information on the model and the methods applied.

13.1 Physical Characteristics

Primary data comes from the Sea Loch Catalogue (SLC) produced by the SMBA. The loch is 61 km long with a maximum depth of 185 m. Average depth at low water is 16.8 m. There are two sills within the Loch. Loch Fyne ranks first as the deepest, longest and having the largest water volume of all the sea lochs in the catalogue.

Tides

Spring tidal range is given as 3.1 m, with the area at high and low water being 183.7 km^2 and 175.7 km^2 respectively. The low water volume of the loch is 9746 M m^3. Measured tidal currents in the upper basin were in the range of 5-10 cm s^{-1} with significant contributions from the diurnal as well as the dominant semi-diurnal tidal constituents (Gillibrand 2002). Currents speeds across the two sills were 37 and 13 cm s^{-1}.

Wind driven flows

Wind statistics measured at Glasgow: Bishopton on (Figure 13.1) were judged to be representative of the wind speed and directions experienced at Loch Fyne. The annual average shows the prevailing wind direction is from the west. Winds from an easterly direction are also important. This is presumable due to the east-west aspect of the Clyde valley in which the wind station is located. Loch Fyne is also located in a valley with an east-west aspect.

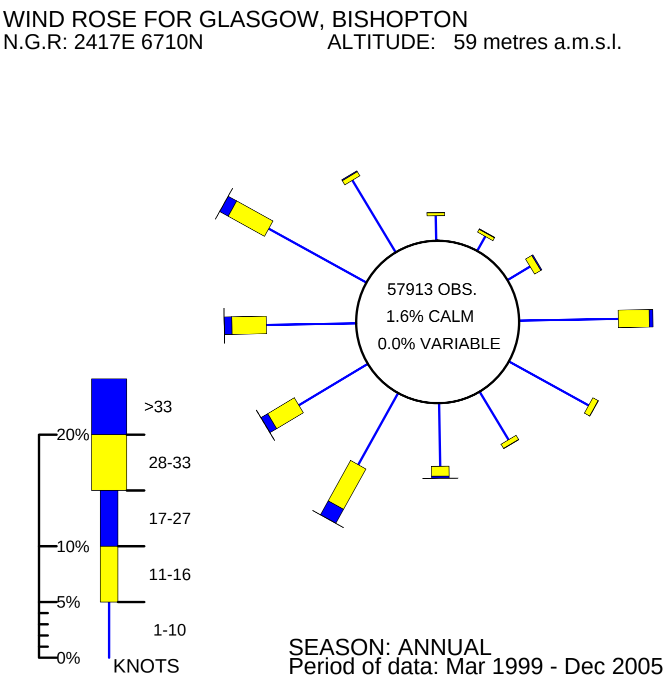

Figure 13.1 Annual wind rose for Glasgow: Bishopton.

Density driven flows

Over the entire loch, freshwater inputs are estimated to be small compared to tidal inputs. The sea loch catalogue gives the volume ratio of runoff to tidal exchange as 1:204; which is relatively low. However at the head of the loch near Cairndow, freshwater inputs come from both the River Fyne, Kinglass water, and from a number of small streams. Measurements reported in Gillibrand (2002) and measured during the shoreline survey show significant freshwater stratification at the head of the loch and in the upper basin in general. This will give rise to a seaward flowing, less dense surface layer which is likely to be quite important for transporting material in the upper reaches of the loch.

13.2 Related studies

Loch Fyne has been the subject of a number of studies mainly in connection with fish farming. A fairly detailed field and modelling study is reported in Gillibrand (2001, 2002). Fixed current meters were deployed, and salinity and temperature profiles were collected. Modelling used a depth resolving but width averaged model 2D model. The main emphasis was on calculating long term water renewal rates in connection with fish farm inputs rather than calculating short terms particle paths as here.

13.3 Model study

Set-up

The area covered by the model is shown in Figure 13.2 and represents approximately the top 10 km of the landward end of the loch. This is in the top end of the upper basin that is beyond the second sill. The resolution of the model (the grid spacing) was 100 m and variations in currents down to this lengthscale can be represented. A single semi-diurnal (12.4 hour period) tidal flow was applied of a magnitude to reproduce the observed spring tidal range of approximately 3.1 m, as given in the Scottish Sea Loch Catalogue and Gillibrand (2002).

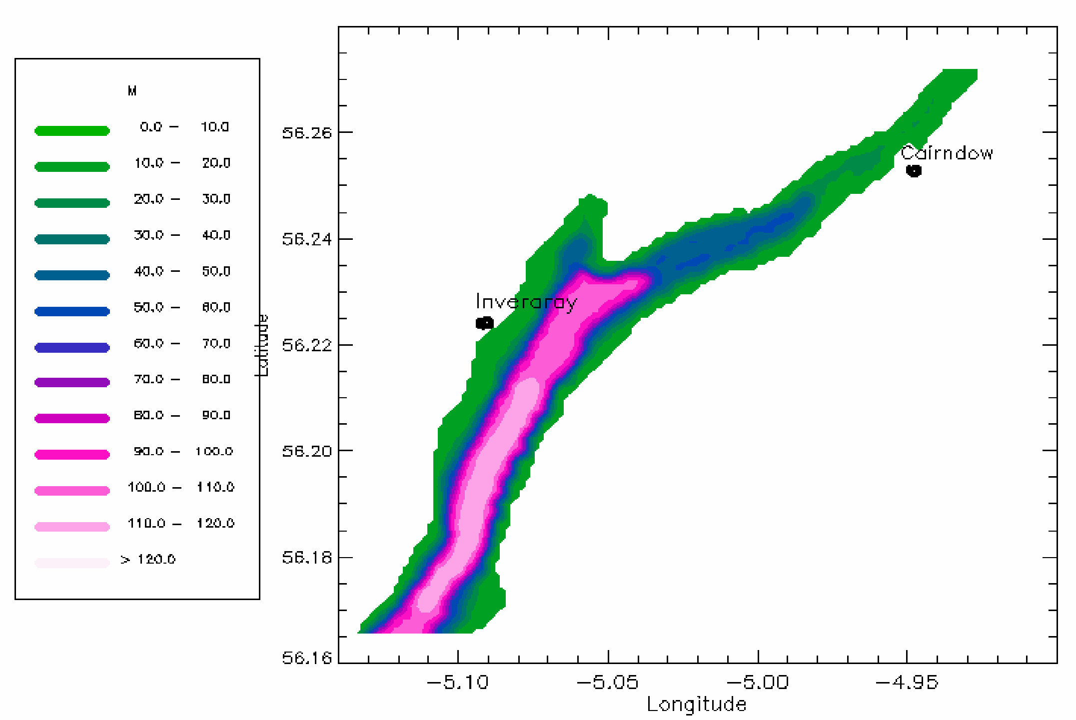

Figure 13.2 Model domain with depths (m).
With permission SeaZone Ltd.

Water inputs from two rivers in the region were included. These were the Rivers Fyne and Kinglass, both near the head of the loch in the vicinity of Cairndow. River inputs were based on width, depth and velocity measurements reported in the Shoreline survey. Because the model grid size is greater than the river widths, input flow speeds were adjusted to reproduce the flow rates reported in the survey. Starting points were adjusted slightly in some cases to ensure particle paths remained in the water. River inputs are likely to be highly variable and a scaling factor of 1.5 was applied to the observed flow rate to account for inputs that may be at the higher end of the annual range.

In addition to the tidal and river forcing, the model response to constant winds blowing from the north, south, east and west directions at a speed of 5 m s^{-1} (gentle to moderate breeze) was calculated. The effect of the surrounding topography is likely to cause alignment of winds along the axis of the loch and so south-westerly and north-easterly winds were also simulated[1]. In each wind scenario, winds were applied for 48 hours so that a constant (equilibrium) current pattern was attained. Particles were released into the combined tidal and equilibrium wind generated currents from locations identified as potential sources by the shoreline survey. The paths of these particles were then followed for 48 hours.

Limitations of using a depth integrated model are discussed in the hydrography methods document (Appendix 5). These concern the inability of the model to describe vertical structure within the water column and will effect the modelling of wind and density driven flows in particular. In this application, particularly in the vicinity of Cairndow, this limitation may be rather important. Measurements reported in Gillibrand (2002), and confirmed by the shoreline survey (Appendix 1, Table 4), clearly indicate that the freshwater inputs form a less dense surface layer several metres thick in the upper basin of the Loch. The present model, although including river sources, assumes such inputs are mixed through the entire water depth and will not resolve the surface layer. Since this surface layer is likely to carry the majority of bacterial load, the present model results may not give a good indication of the movement of contaminants.

Results

Modelled tidal currents were found to be weak in the upper basin of Loch Fyne covered by the model. Typical current speeds from the model were 5 cm s^{-1} or less. This is consistent with values of 5-6 cm s^{-1} for the main (M2) tidal constituent measured in the middle of the upper basin and reported in Gillibrand (2002). The location of this measurement is not within the present model domain, so it was not possible to compare directly with the present model. Tidal residual flow was predicted to be very weak and generally of the order of a few mm s^{-1}.

Shoreline surveys indicate potentially significant point sources of contamination within the upper reaches of Loch Fyne associated with the settlements of Inveraray and Cairndow. Some of the main sources of contamination in the vicinity of the production area at Cairndow were included: the River Fyne, Kinglass and ‘stream 6’ (see section 14 for further details). Simulations assumed these locations, together with a source at Inveraray, as starting points for particle tracking.

Tidal currents alone lead to small net transport distances (Figure 13.3). Nevertheless, material released from stream 6 on the ebb tide was predicted to impact the production area. The addition of wind-generated flows was found to have a large affect on water movement near Inveraray (Figure 13.4) and a more limited but still significant affect at the far end of the loch near Cairndow (Figure 13.5). At Cairndow wind generated flows may be constrained by the narrow width. For runs with imposed wind, the state of the tide at which particles were released (particles released 6.2 hours apart) had little effect, consistent with the relatively weak tidal influence.

[1] Although these can in theory be deduced from combining the results from the other wind directions.

The particle paths for the wind driven runs can be explained by reference to the underlying water circulation patterns in each case (figure 13.6, 13.7). Visual inspection confirms that particles move in a way consistent with these patterns. However, it should be emphasised these flows are set up as a consequence of persistent winds from a given direction. At any particular time winds will vary dynamically and so the results shown correspond to an idealised situation. They are nevertheless indicative of the response that might be expected.

Runs with and without river inputs (not shown) suggested relatively minor modifications to the results by including river inputs. These were based on flow rates observed during the shoreline survey that may not be representative of conditions more generally. Also, the model results only represent the depth averaged effect of river inputs. As discussed above the freshwater inputs in reality are confined to a surface layer. It is difficult to know how this will modify the results. From general principles it might be expected that flows from the River Fyne at the head of the Loch will tend to move along the northern shore away from the production area. Nevertheless it seems likely that these flows, moving in a general seawards direction could carry material from the rivers through the production area.

Considering the results overall, some useful conclusions can be reached. It seems unlikely that inputs from Inveraray will affect the production area near Cairndow. Inputs from the rivers Fyne and Kinglass appear to be less likely to cause contamination than might be expected as the wind generated current patterns tend to produce circular gyre patterns that trap particles away from the production area. However, it is important to note these patterns are the results of the persistent winds applied in the model. Under specific dynamic wind conditions an impact from the river Fyne and Kinglass sources is almost certainly possible. Clearly the source within the production area (stream 6) is capable of impacting the area under northerly winds for example.

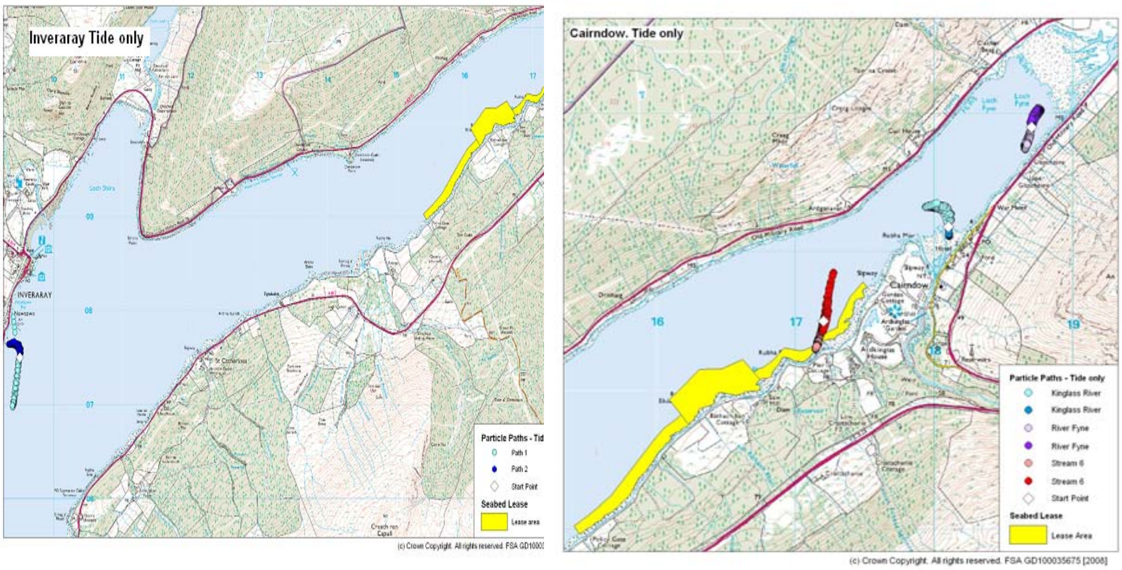

Figure 13.3 Tidal particle paths from sources identified in the shoreline survey for Inveraray and Cairndow.

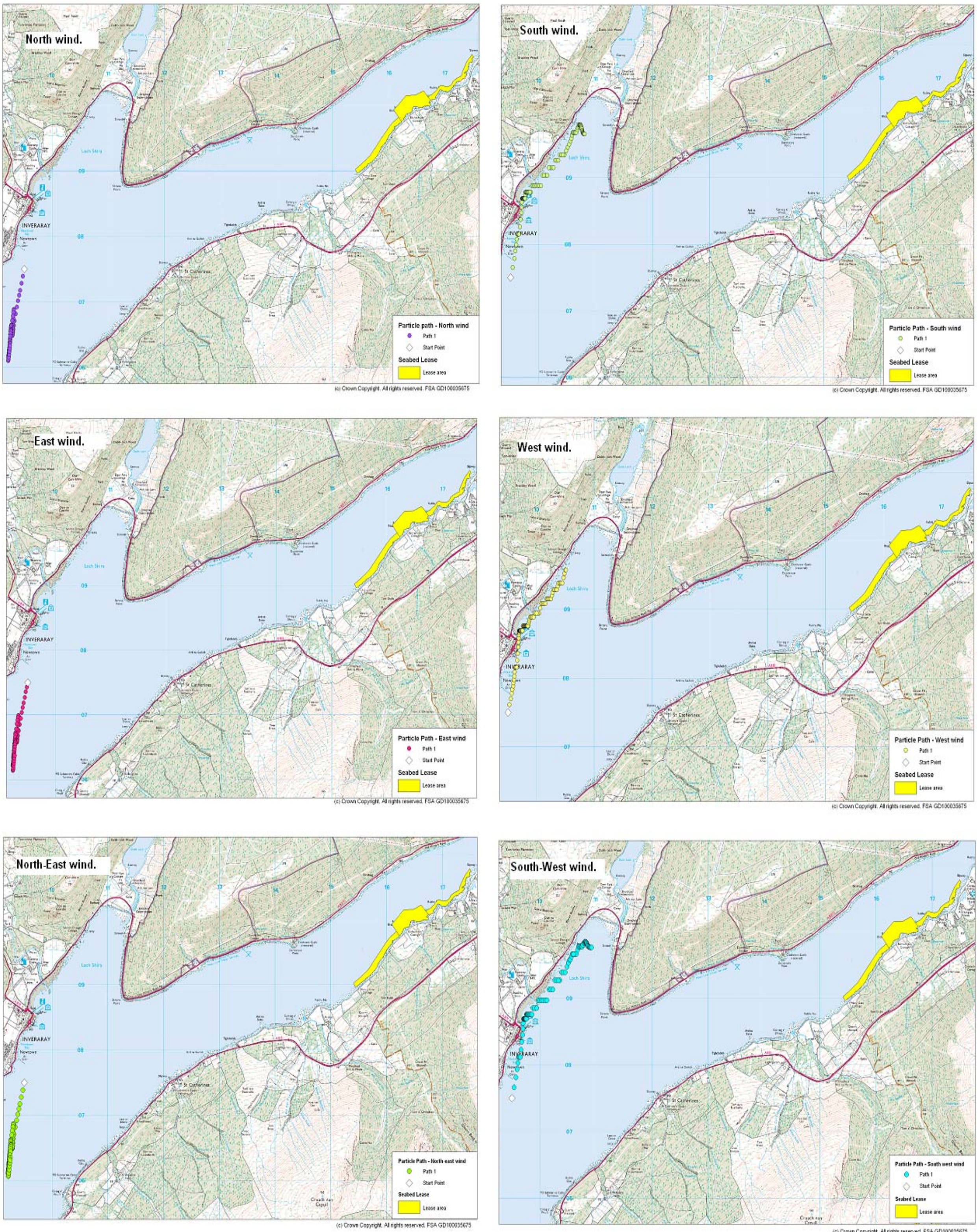

Figure 13.4 Inveraray, wind + tide particle paths from sources identified in the shoreline survey .
The white diamond shows the start location.

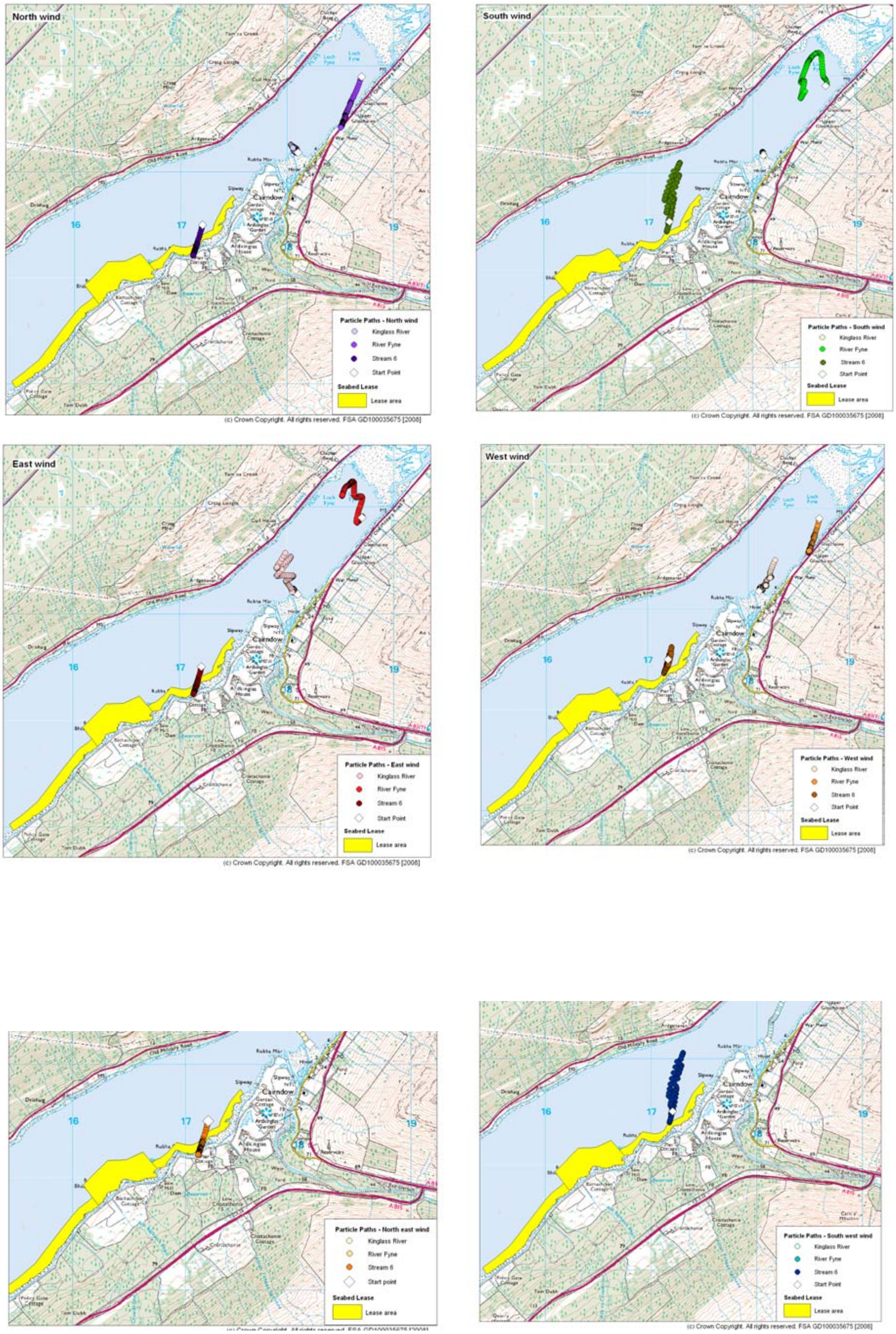

Figure 13.5 Cairndow, wind + tide particle paths from sources identified in the shoreline survey. The white diamond shows the start location.

Transport distances due to tides are very small (less than 500 m for Inveraray and significantly less for Cairndow) so that after 48 hours particles are still within the vicinity of the release point. Wind generated currents and freshwater inputs have an important influence.

At Inveraray, imposed north and east (and north-easterly) winds move particles along the shore in the south-westerly direction. South and west (and south-easterly) winds move particles along the shore in a north-easterly direction toward loch Shira. In general it seems unlikely that contamination from Inveraray would impact the shellfish area along the southern shore to the southwest of Cairndow.

In the vicinity of Cairndow, south and westerly winds tend to move particles toward the head of the loch and away from the production area. North and easterly winds tend to move material down the loch but the patterns of wind generated flows tend to keep the material confined to the top end of the loch. Inputs from ‘Stream 6’ within the production area are predicted to cause impacts under north or easterly winds.

The present model simulations cannot describe the surface layer associated with freshwater inputs. It seems likely that these flows, moving in a general seawards direction could carry material from the rivers through the production area.

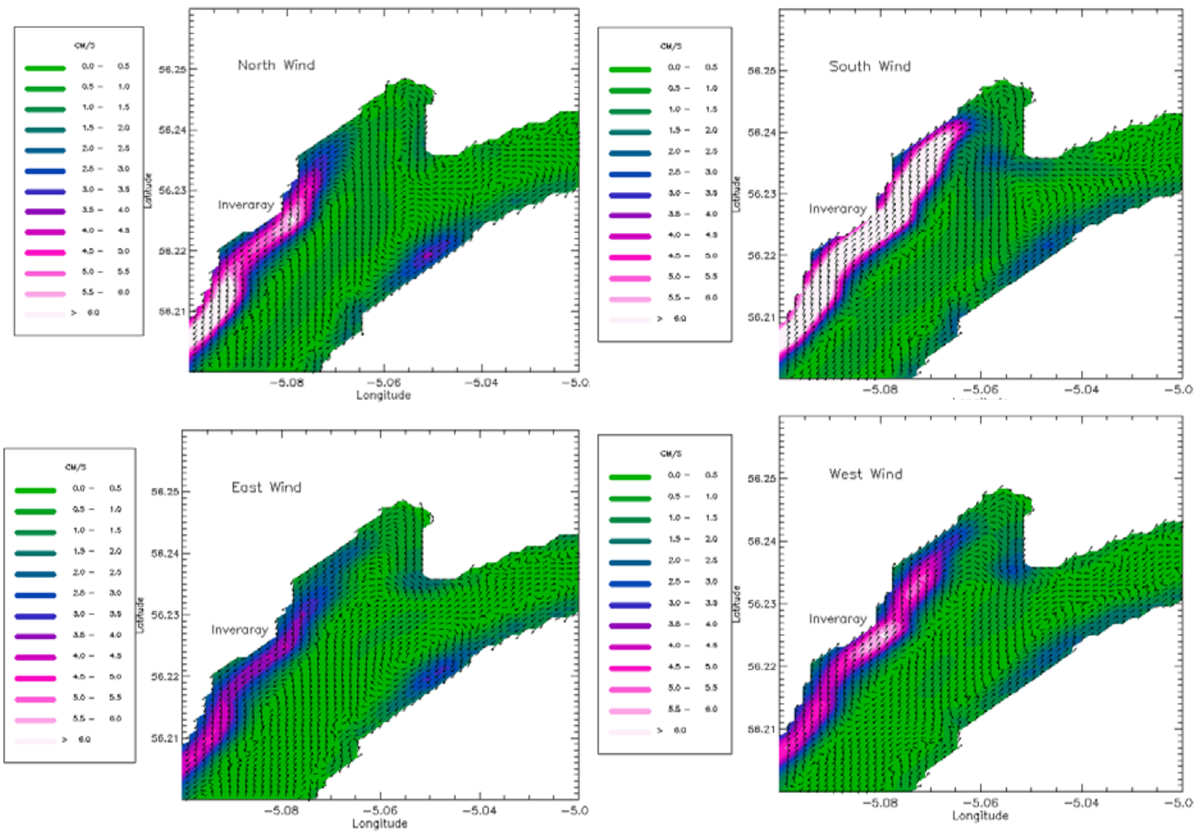

Figure 13.6 Wind driven residual currents near Inveraray.
Colour distribution indicates residual current speed and arrows give the direction.
Arrows plotted at every model grid point.

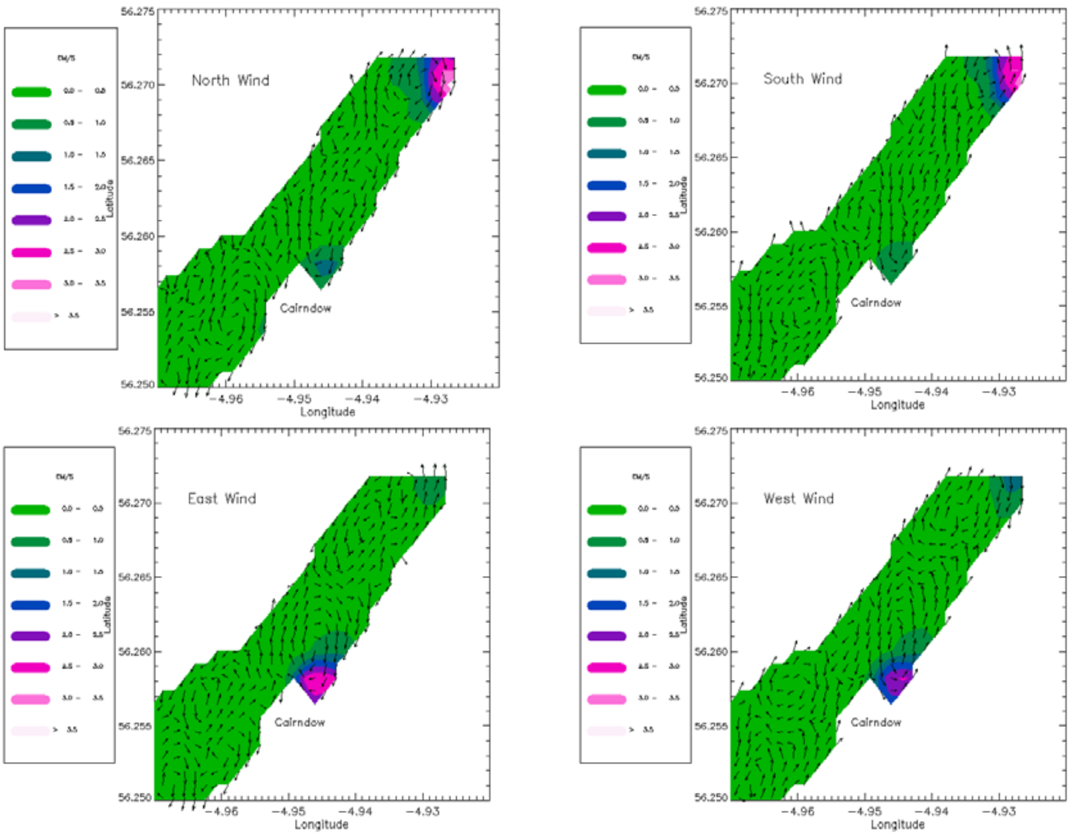

Figure 13.7 Wind and freshwater driven residual currents near Cairndow. Colour distribution indicates residual current speed and arrows give the direction. Arrows plotted at every model grid point.

14. River Flow

There are no river gauging stations on rivers or burns feeding into Loch Fyne Ardkinglas.

The following burns were measured and sampled during the shoreline survey. These represented the largest freshwater inputs into Loch Fyne Ardkinglas.

Table 14.1 River flows and loadings – Loch Fyne Ardkinglas

No.	NGR	Description	Width (m)	Depth (m)	Measured flow (m/s)	E. coli (cfu/100ml)	Discharge (m^3/day)	Loading (*E. coli*/day)
1	NN 18896 12633	Stream	1.3	0.07	0.19	>100000*	1525	1.8E+12
2	NN 09837 09042	River Aray	41.7	0.17	0.58	100	359469	3.6E+11
3	NN 17371 10347	Stream 6***	2.2	0.12	0.45	3000	10264	3.1E+11
4	NN 11405 10083	River Shira	17.8	0.25	0.70	100	269136	2.7E+11
5	NN 18004 10730	Kinglas Water***	22	0.3	0.18	200	102643	2.1E+11
6	NN 15179 08716	Stream	1	0.07	1.10	1300	6653	8.6E+10
7	NN 16323 09811	Stream	1.5	0.08	0.56	1000	5806	5.8E+10
8	NN 19435 12643	River Fyne***	32.3	0.3	0.13	<100*	108838	5.4E+10
9	NN 14515 08520	Stream	4.5	0.45	0.31	100	54238	5.4E+10
10	NN 14894 08647	Stream	1.5	0.09	0.37	1000	4316	4.3E+10
11	NN 16034 09535	Stream	0.75	0.15	0.55	700	5346	3.7E+10
12	NN 17248 10304	Stream	4	0.15	0.63	100	32659	3.3E+10
13	NN 16843 10018	Stream	2	0.15	0.71	100	18403	1.8E+10
14	NN 13893 08341	Stream	1.1	0.03	0.38	700	1083	7.6E+09
15	NN 12969 07947	Stream	0.8	0.11	0.32	200	2433	4.9E+09
16	NN 13063 07985	Stream	0.9	0.03	0.63	300	1470	4.4E+09
17	NN 16871 11175	Stream	0.85	0.05	1.15	<100*	4223	2.1E+09
18	NN 16730 09972	Stream	0.3	0.15	0.14	300	544	1.6E+09
19	NN 15363 08825	Stream	0.6	0.04	0.37	200	767	1.5E+09
20	NN 15471 08913	Stream	0.4	0.1	0.19	200	657	1.3E+09
21	NN 14790 09885	Stream	0.3	0.05	0.75	100	972	9.7E+08
22	NN 15431 10307	Stream	1.1	0.2	0.10	<100*	1901	9.5E+08
23	NN 14125 08369	Stream	0.1	0.06	0.48	300	249	7.5E+08
24	NN 09446 08229	Stream	1.66	0.01	1.04	<100*	1492	7.5E+08
25	NN 16038 10737	Stream	0.27	0.06	0.44	100	616	6.2E+08
26	NN 16301 10874	Stream	0.6	0.1	0.22	<100*	1140	5.7E+08
27	NN 16746 09961	Stream	0.55	0.06	0.37	<100*	1055	5.3E+08
28	NN 12982 07954	Stream	1.3	0.01	0.12	300	135	4.0E+08
29	NN 16035 10731	Stream	0.22	0.25	0.17	<100*	808	4.0E+08
30	NN 15546 10413	Stream	0.55	0.05	0.27	<100*	642	3.2E+08
31	NN 15651 10523	Stream	0.25	0.015	1.12	<100*	363	1.8E+08
32	NN 15171 10129	Stream	0.8	0.05	0.10	<100*	346	1.7E+08

* Assigned a nominal value of 50 for the calculation of loading
** Assigned a nominal value of 120000 for the calculation of loading
*** Particle paths of these streams are modelled in Section 13

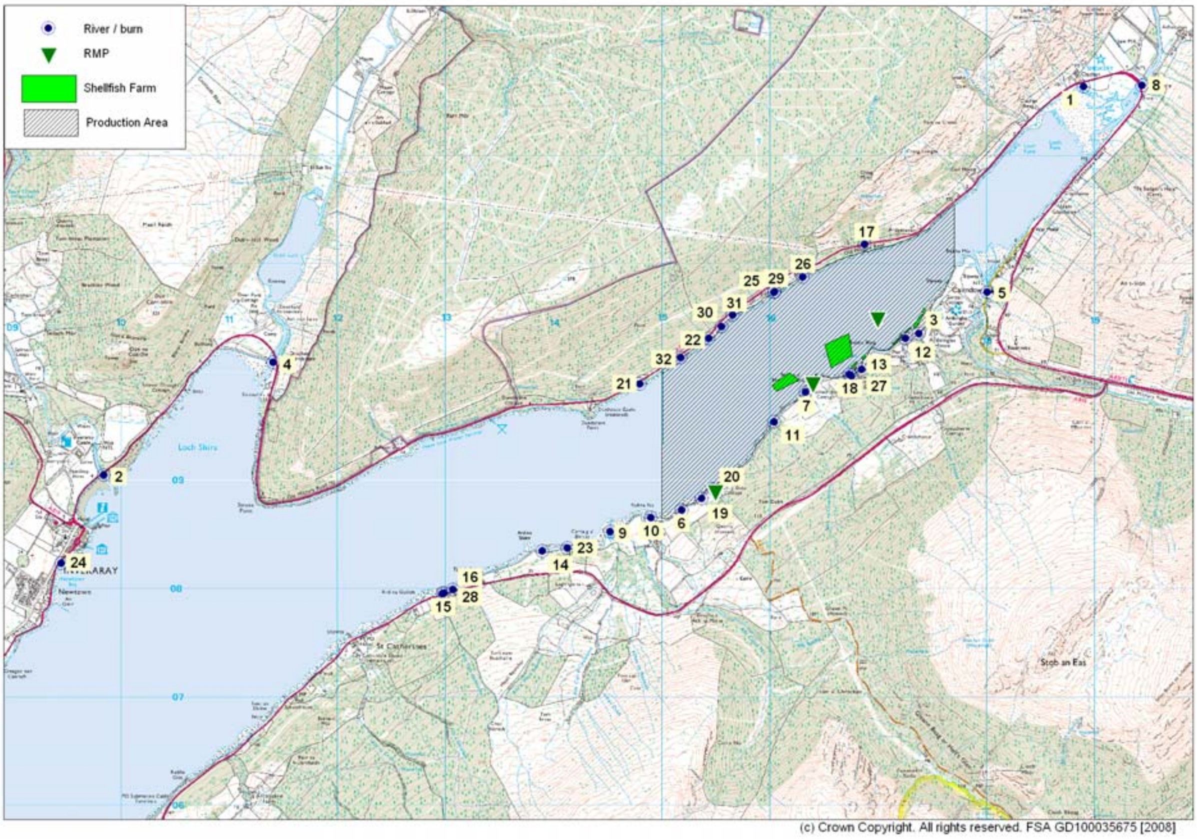

Figure 14.1 Map of significant streams and loadings

The cumulative effect of these watercourses will significantly increase *E. coli* levels in upper Loch Fyne, although no attempt to quantify the magnitude of this effect has been made. Given the overall net seaward flow of the surface layer, watercourses discharging from the south shore into and just to the east of the production area are likely to have the greatest effect on the shellfishery. The most significant of these would be ‘stream 6’ and Kinglas Water.

15. Shoreline Survey Overview

The sanitary survey at Loch Fyne: Ardkinglas was carried out on request of the FSAS following an outbreak of viral gastroenteritis associated with oysters originating from the production area in the summer of 2007.

The shoreline survey was conducted on the 10th to 12th October 2007.

The fishery consists of two main areas of mussel lines, and twelve blocks of oyster trestles stretching across the three sites named in the classification document. There are also holding tanks at the depuration plant where oysters bought in by the company are held prior to depuration. These are filled from the loch without any disinfection of the intake or discharge water.

Scottish water septic tank discharges are located at Cairndow and Inverary. There are also a number of private discharges in the area, including the outfall from the Depuration plant and the Panfish processing plant which discharge directly into the production area on the south shore. A private discharge from the top end of the loch yielded the highest concentration, and loading, of *E.coli* of all inputs sampled during the shoreline survey.

The area has significant tourist trade, mainly centred on Inverary, although there is a hotel in Cairndow and caravan parks at St Catherines and Dalchenna, and a number of seasonally occupied properties. In addition, the Loch Fyne complex draws large numbers of visitors, so the summer population will be significantly higher in some parts of the upper loch.

Land surrounding the production area was largely wooded, with some areas of grassland. Few livestock were seen around the shoreline of the loch apart from several sheep grazing on the southwest and northeast corners of the production area. Few wild animals and birds were seen.

Seawater samples taken from the loch gave *E. coli* results ranging from 4 to 2500 cfu/100 ml, indicating high levels of contamination in some samples. Samples taken offshore near the mussel lines were generally cleaner than those taken from the shore. Aside from this, no clear spatial pattern could be identified.

A high proportion of the many watercourses discharging into the production area were sampled, but none was particularly contaminated at the time of sampling. The one exception to this was a stream at the head of the loch, into which the Loch Fyne complex septic tank is believed to discharge. Some watercourses were relatively large, and the cumulative effects of all these watercourses are likely to be significant.

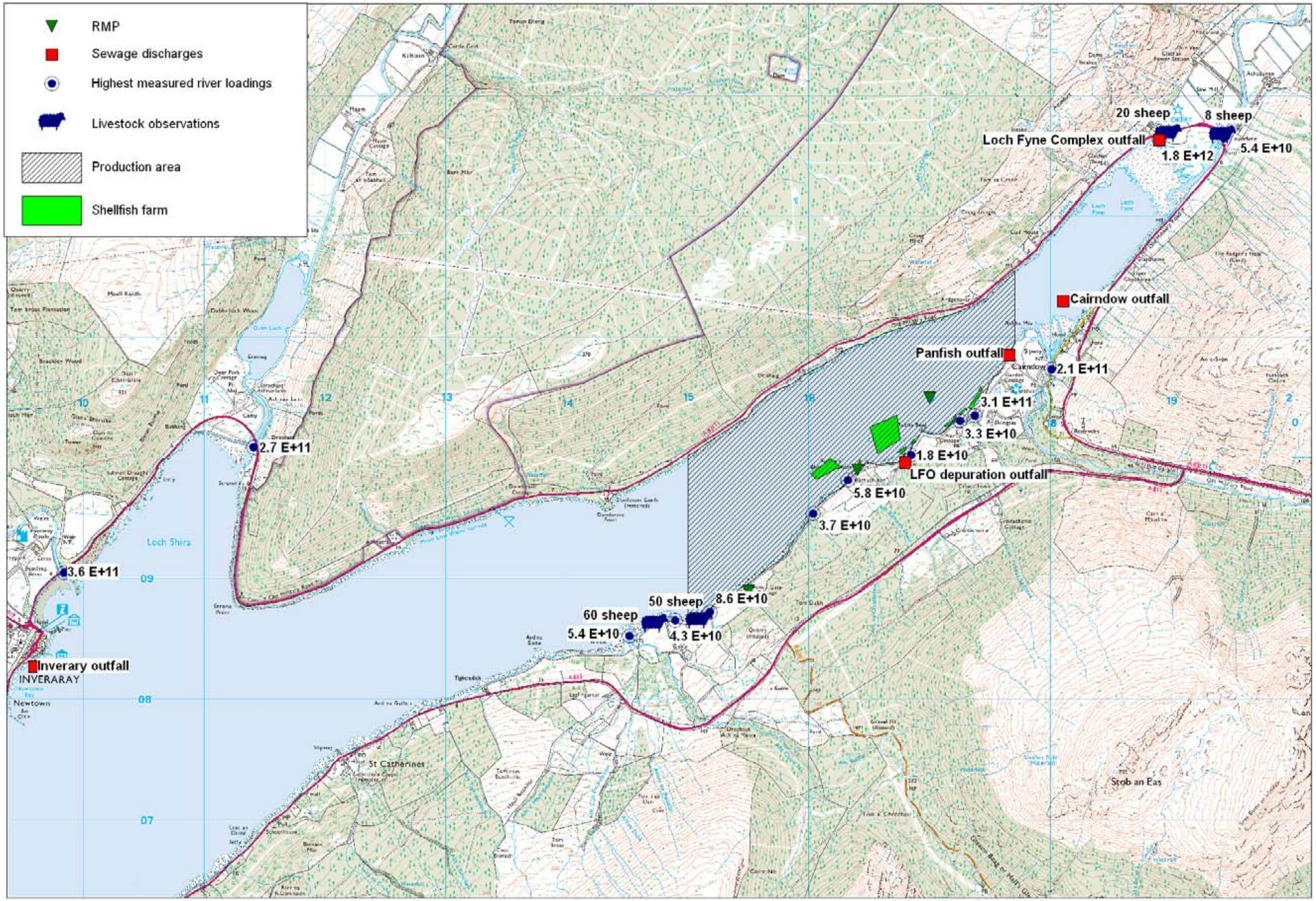

Figure 15.1 Significant findings from the shoreline survey

16. Overall Assessment

Human sewage inpacts

The closest major sewage input is at Cairndow, on the southern shore approximately 0.5 km to the east of the production area boundaries. This discharge has a population equivalent of 34. There are also private inputs direct to the southern shore of the loch at the eastern end of the production area (Panfish plant, approximately 50 employees) and approximately in the centre of the production area (LFO depuration plant, less than 10 employees). Given their location, these are likely to affect the fishery the most, and it would be expected that the eastern end of the production area would be most heavily affected.

Further afield, there is one private discharge on the north shore of the production area. At the head of the loch there is a private discharge from the Loch Fyne complex. Over 5 km to the west of the western boundary of the production area is a major sewage discharge from the settlement of Inverary (population equivalent of 721). These discharges are unlikely to significantly impact the fishery given their location and predicted patterns of movement of contaminants around the loch.

No sanitary debris was seen on the shoreline survey.

It is possible that there are sporadic minor inputs from limited boat traffic.

Agricultural impacts

There is little reported in the way of arable agriculture in the vicinity of the loch. However, there were two areas where livestock were grazing, which may provide a significant source of contamination to the loch. The highest concentration was on the south shore, around the western boundary of the production area where approximately 110 sheep were grazing on pasture adjacent to the shoreline. Inputs from these would have the greatest effect on the western end of the production area. Of less significance, 28 sheep were seen at the head of the loch.

Wildlife impacts

Potential wildlife impacting on the shellfishery include wildfowl, deer, seals, dolphins and otters, but impacts from these animals are likely to be minor and difficult to predict temporally and geographically.

Seasonal variation

The area has a significant tourist trade and this is centred on Inverary. There is also a hotel in Cairndow, caravan parks at St Catherines and Dalchenna, as well as a number of seasonally occupied properties. The Loch Fyne complex also attracts a large number of visitors. There are a small number of moorings which may be used by pleasure craft in the summer. The summer population will therefore be significantly higher in some parts of the upper loch.

Seasonal variations in livestock population are expected with an increase in numbers with the birth of lambs and calves in the spring. The weather is colder, wetter and windier in the autumn and winter months. A significant seasonal pattern was found in historic monitoring results, with higher *E. coli* levels in both species of shellfish in the summer and autumn months.

Rivers and streams

River and stream inputs to upper Loch Fyne are numerous, contributing loadings between 1.7×10^8 and 1.8×10^{12} *E. coli* per day. The cumulative effect of these watercourses will significantly increase *E. coli* levels in the upper loch. Watercourse discharging from the south shore into and just to the east of the production area are likely to have the greatest effect on the shellfishery. The most significant of these were 'stream 6' and Kinglas Water.

Meteorology, hydrology, and movement of contaminants

Tidal currents in the upper loch are weak, leading to small net transport distances. Modelling predicts that only sources very close to the production sites, but not sources from Cairndow or further afield, will impact on the fishery due to tidal currents alone. Analysis of historic *E. coli* monitoring results indicates that results are on average higher when tides are larger, indicating that, for the points sampled, increased tidal flow increases the impact of contaminant sources on the shellfishery. Therefore, it may be suggested that some important contamination sources are close enough to have an impact on spring tides, but far enough away to have less of an impact on neap tides. This effect was statistically significant for oysters (cultured in the intertidal zone), but not significant for mussels, which are cultured further offshore.

The prevailing wind direction is from the west at the Glasgow weather station, and also from the west but with a more uniform overall distribution at the Tiree weather station. The local topography is likely to funnel south westerly and northeasterly winds up and down the loch respectively, and provide some shelter from winds from other directions. Modelling indicates that winds are likely to significantly change particle paths. At Inverary, northeasterly winds would move particles along the shore in a southwesterly direction away from the production area. Southwesterly winds would move particles along the shore in a north easterly direction, but it is unlikely that they would be transported far enough to have an impact on the shellfishery on the southern shore. At Cairndow, southwesterly winds would move particles away from the production area and towards the head of the loch. Northeasterly winds would tend to move particles down the loch, but the modelled pattern of wind-generated flows would tend to keep material confined to the top end of the loch. Analysis of historic *E. coli* monitoring results found no correlation between mean wind direction in the previous 7 days and *E. coli* result.

The ratio of runoff volume to tidal exchange in the loch as a whole is relatively low (1:204), but is likely to be higher when the upper loch is considered alone. In the upper loch, there is significant freshwater stratification which will give rise to a seaward flowing, less dense surface layer which is likely to be quite important for transporting materials. This has not been considered in the model discussed in the previous two paragraphs, and would superimpose a net seaward flow of contamination onto it, therefore increasing the potential importance of sources around Cairndow. This effect is likely to be stronger during the autumn and winter months when rainfall is higher. Stratification would be likely to result in higher levels of contamination at the top of the mussel lines than at the bottom.

No relationship between historic *E. coli* monitoring results and recent rainfall was found for either shellfish species. This suggests that the more important sources of microbial contamination affecting this production area are independent of rainfall, such as continuous septic discharges, rather than runoff from pasture.

It must be stressed that the *E. coli* results will be a combination of many factors, including the loadings of contaminants for various sources entering the loch, the way that these are transported within the loch due to tide and wind, and the rates of uptake and depuration by the shellfish themselves. The amount of historical data was too limited to undertake an analysis of the interaction of factors.

Temporal and geographical patterns of sampling results

In terms of overall temporal trends, historic monitoring results indicate a slight improvement in average *E. coli* results was apparent for mussels, but a slight overall deterioration in average *E. coli* results for oysters, but with more high results in recent years for both species. A very high *E. coli* result was obtained for an oyster sample taken from here just before the viral gastroenteritis outbreak potentially associated with this production area in summer 2007, although it is not possible to evaluate the cause of this on the available information. A comparable high result was not observed in mussel samples taken around the same time.

A significant seasonal pattern was found in historic monitoring results, with higher *E. coli* levels in both species of shellfish in the summer and autumn months. A weak positive relationship between temperature and *E. coli* result was also found. These two relationships are in agreement with each other, and suggest increased uptake of bacterial contamination by shellfish at higher water temperatures, and/or increased levels of bacterial contamination entering the loch during the warmer months.

As discussed already in this section, no relationship between wind direction or recent rainfall and historic *E. coli* monitoring results was found, but a significant positive relationship between tide size and *E. coli* result was found for oysters.

No geographical trends were found in historic *E. coli* monitoring results for either species, although it must be noted that the accuracy of reported sampling locations prior to the commencement of the OC sampling programme in 2007 cannot be verified. *E. coli* results in oysters taken during the shoreline survey suggest contamination is higher at the north eastern end of the trestles, and lower at the south western end. A similar spatial pattern in norovirus (genogroup II) contamination levels was apparent in January and February 2008 when high levels were present in the oysters (see below). This suggests an important source of (human) contamination enters the loch at, or to the north east of the points sampled, possibly from Cairndow and/or the Panfish plant. No clear spatial trend was seen in mussels sampled during the shoreline survey, either in terms of location or depth sampled. The sample yielding the highest result was taken from the surface near the southeastern corner of the eastern block of mussels. Contamination is likely to be greater near the surface due to stratification, and closer inshore nearer sources of contamination on the south shore.

Seawater samples taken as part of the shoreline survey show relatively high levels of contamination in the upper loch, with no obvious geographical pattern. Results of sampling undertaken as part of the shoreline survey are specific to the conditions on the date of sampling, and care should be exercised in drawing broader conclusions from this data.

Results of Norovirus testing

Norovirus contamination was seen throughout the period over which the monitoring reviewed in this report was undertaken (July 2007 to March 2008). Genogroup I was not detected between 31/07/07 and 11/10/07 and was generally at lower levels (as determined by the PCR units) than Genogroup II. Genogroup II norovirus was detected in most samples with the levels being markedly higher from January to March 2008. During the latter period, levels of Genogroup II were highest at the eastern end of the oyster area and lowest at the western end.. The limited data available to date would therefore indicate that oysters harvested from towards the western end of the lease would tend to have the lower relative concentration of Norovirus Genogroup II than those harvested from the eastern end and therefore, by extrapolation, would be assumed to pose a lower relative risk to consumers. The present state of knowledge regarding the interpretation of the real-time PCR data for Norovirus does not allow for a determination of absolute risk associated with such contamination. This conclusion would need to re-examined when a significant amount of additional data has become available.

17. Recommendations

The production area boundaries for both species are given as the area bounded by lines drawn between NN 1500 1002 and NN 1500 0865 and between NN 1770 1155 and NN 1770 1095. Adjacent Crown Estates leases within this area cover a continuous 2.7 km of shoreline, much of which is utilised for oyster culture. There is some evidence for higher levels of contamination in oysters towards the eastern end of the production area, but this appears to be a gradual change along the whole of the shoreline.

Exclusion zones around the discharges from the Panfish plant and the Depuration plant could be considered, but viral contamination was found at all locations sampled. Without further information on the variation in risk of illness with increase in PCR units, it is not possible to determine whether removing these parts of the production area from use would reduce the risk to consumers. Also, the sanitary content of these two discharges is not fully known, but are believed to be of a similar size (Panfish) and smaller than (LFO depuration) that of the Scottish Water discharge at Cairndow. Improvements to or relocation of these discharges, and the discharge at Cairndow would reduce risks to consumers, but it is beyond the scope of this report to suggest such actions. In conclusion, it is recommended that the existing western boundary be retained, but the eastern boundary should be moved approximately 220 m east, to prevent expansion of the fishery towards the Panfish and Cairndow discharges. There is potential to decrease risk via operational changes on the part of the harvester.

The recommended production area for both species is the area bounded by lines drawn between NN 1500 1002 and NN 1500 0865 and between NN 1748 1057 and NN 1748 1135.

There are currently 3 RMPs set for this production area. These are named after the three Crown Estates leases, and each one applies to both species. There is poor agreement between the locations of the RMPs, the Crown Estates leases, and the location of the shellfish farms. As a consequence it is appropriate to reset the RMPs to one location for each species, and these locations should coincide with where the shellfish are grown, and where contamination is likely to be the highest.

As identified above, oysters are grown along much of a 2.7 km stretch of shoreline. Available evidence suggests that contamination of oysters is higher towards the eastern end of the production area, so the RMP for oysters should be located at NN 1741 1054 to reflect this. No sampling depth is applicable. It is recommended that a dedicated sampling bag be placed in this location from which mature stock, which have been placed inside this bag for a minimum of two weeks should be sampled.

Mussels are cultured in two blocks approximately in the middle of the production area, about 100 m offshore. Although there is little direct evidence to support this, contamination is likely to be greater near the surface due to stratification, and closer inshore at the eastern extremity nearer sources of contamination on the south shore. It is therefore recommended that the RMP be set at NN 1674 1015 to reflect this. Sampling depth is recommended to be 1 metre.

Due to the seasonal changes in levels of contamination, the high volume of the operation, and the potential association with outbreaks of illness, it is recommended that monthly sampling be maintained for this production area.

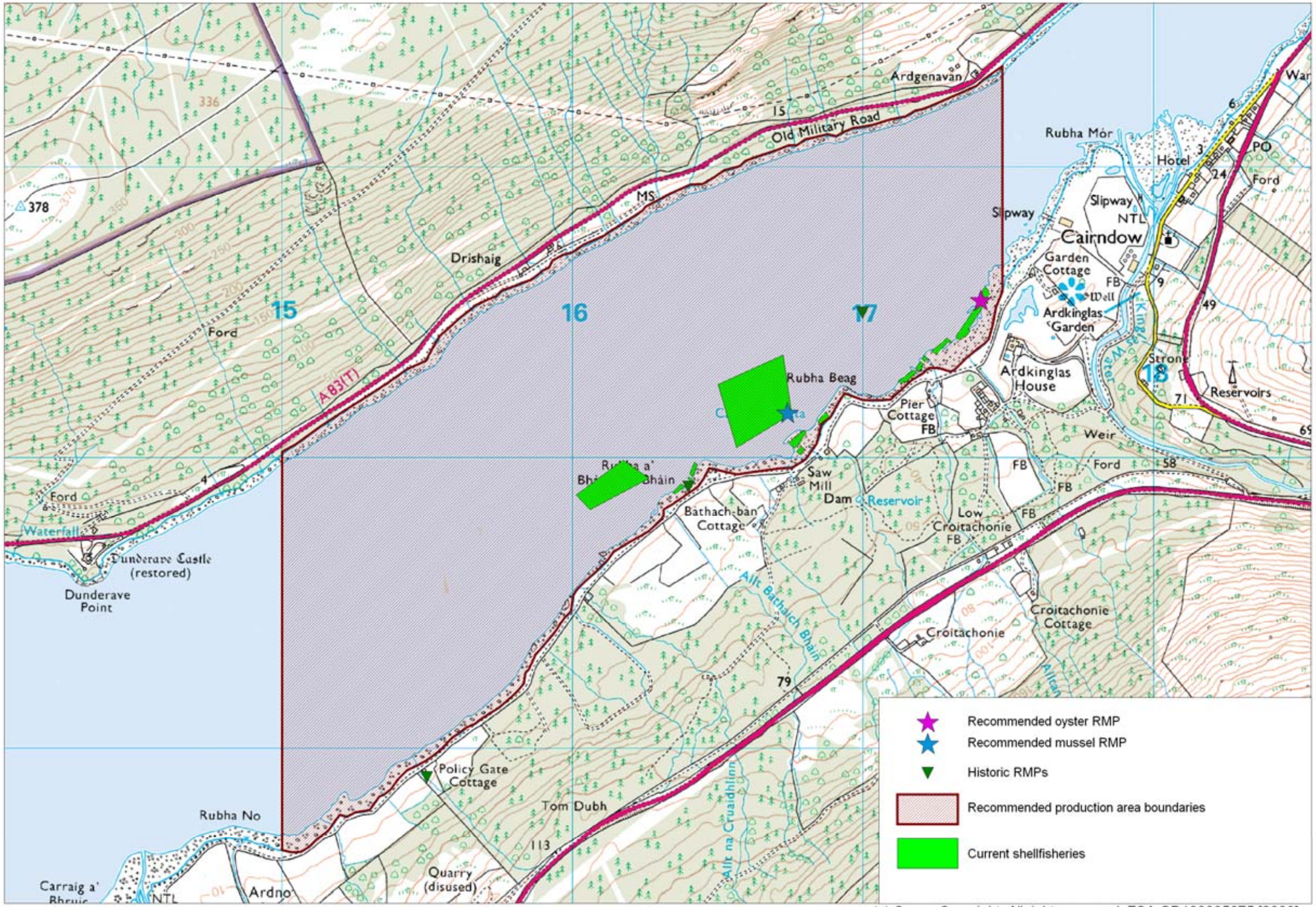

Figure 17.1 Map of recommendations

18. References

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5. Hydrographic methods
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Sampling plan - Loch Fyne Ardkinglas

PRODUCTION AREA	SITE NAME	SIN	SPECIES	TYPE OF FISHERY	NGR OF RMP	EAST	NORTH	TOLERANCE (M)	DEPTH (M)	METHOD OF SAMPLING	FREQ OF SAMPLING	LOCAL AUTHORITY	AUTHORISED SAMPLER(S)	LOCAL AUTHORITY LIAISON OFFICER
Loch Fyne: Ardkinglas	The Shore, The Point, Policy Gates	AB 147 036 AB 147 035 AB 147 034	Pacific oyster	Trestle	NN 1741 1054	217410	710540	10	na	Hand	Monthly	Argyll & Bute Council	Christine McLachlan, William MacQuarrie, Ewan McDougall, Donald Campbell	Christine McLachlan
Loch Fyne: Ardkinglas	The Shore, The Point, Policy Gates	AB 147 036 AB 147 035 AB 147 034	Common mussel	Rope	NN 1674 1015	216740	710150	10	1	Hand	Monthly	Argyll & Bute Council	Christine McLachlan, William MacQuarrie, Ewan McDougall, Donald Campbell,	Christine McLachlan

Comparative Table of Boundaries and RMPs – Loch Fyne: Ardkinglas

Production Area	Species	SIN	Existing Boundary	Existing RMP	New Boundary	New RMP	Comments
Loch Fyne Ardkinglas	Common Mussels	AB 147 036 08	Area bounded by lines drawn between NN 1500 1002 and NN 1500 0865 and between NN 1770 1155 and NN 1770 1095.	NN 155 089 NN 170 105 NN 164 099	Area bounded by lines drawn between NN 1500 1002 and NN 1500 0865 and between NN 1748 1057 and NN 1748 1135.	All common mussel sites NN 1674 1015	It is recommended that the existing western boundary be retained, but the eastern boundary should be moved approximately 220 m east, to prevent expansion of the fishery towards two discharges. RMPs are set to one location for each species to coincide with location of shellfish beds and where contamination is highest.
	Common Mussels	AB 147 035 08					
	Common Mussels	AB 147 034 08					
	Pacific Oysters	AB 147 036 13				All Pacific oyster sites NN 1741 1054	
	Pacific Oysters	AB 147 035 13					
	Pacific Oysters	AB 147 034 13					

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 and catchment export coefficients in the UK. Water Research (under editorial consideration).

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

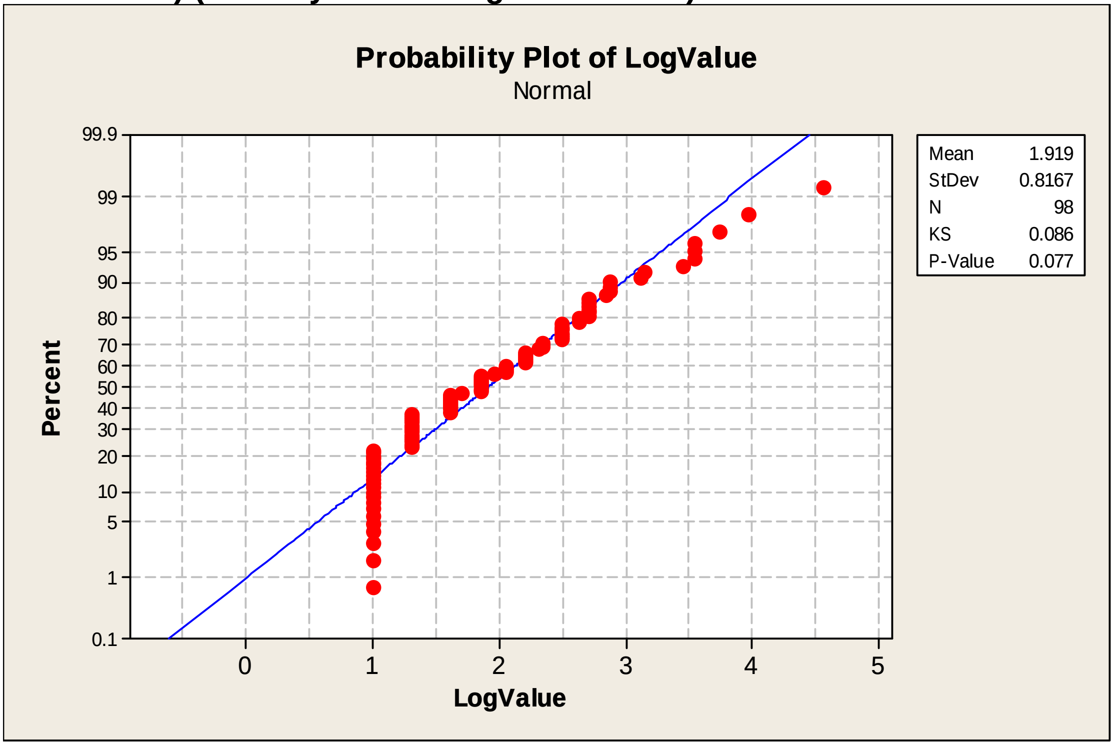
Animal	Faecal coliforms (FC) number	Excretion (g/day)	FC Load (numbers /day)
Chicken	1,300,000	182	2.3×10^8
Cow	230,000	23,600	5.4×10^9
Duck	33,000,000	336	1.1×10^{10}
Horse	12,600	20,000	2.5×10^8
Pig	3,300,000	2,700	8.9×10^8
Sheep	16,000,000	1,130	1.8×10^{10}
Turkey	290,000	448	1.3×10^8
Human	13,000,000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

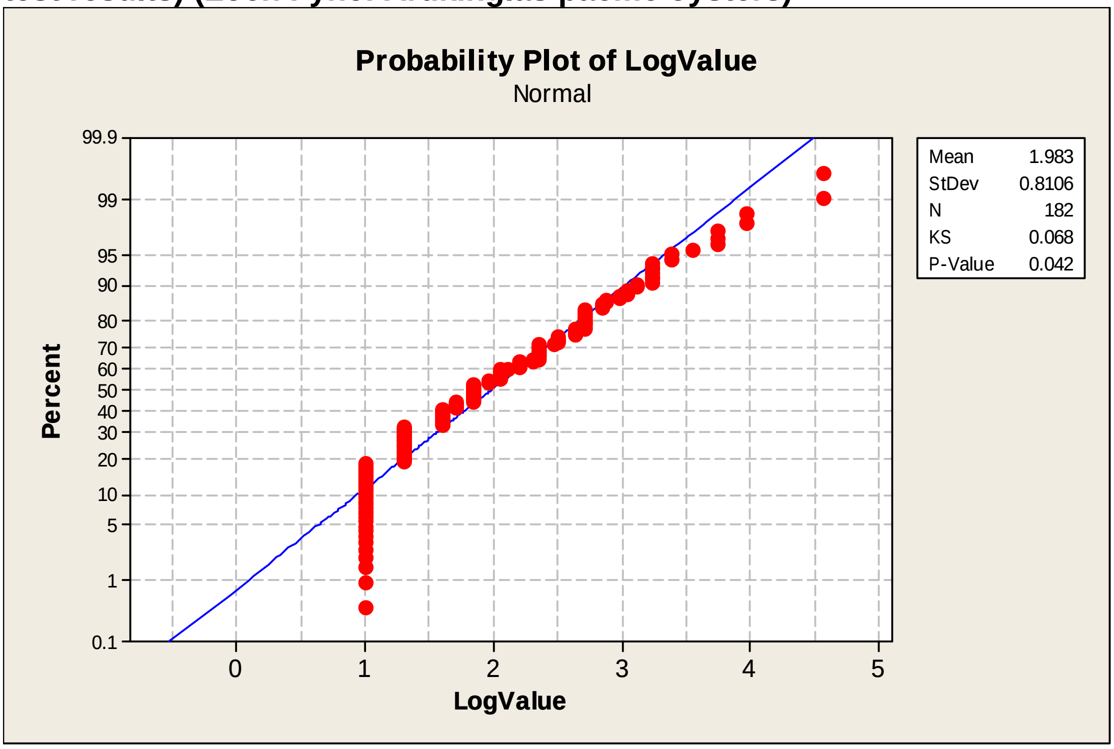
Statistical data

All analyses were undertaken using log transformed results as this gives a more normal distribution.

Distribution of results on log scale (with Kolmogorov-Smirnov normality test results) (Loch Fyne: Ardkinglas mussels)



Distribution of results on log scale (with Kolmogorov-Smirnov normality test results) (Loch Fyne: Ardkinglas pacific oysters)



ANOVA comparison of log result (mussels) by sampling location

```
Source   DF      SS     MS     F      P
GridRef   6   8.013  1.335  2.14  0.056
Error    91  56.686  0.623
Total    97  64.699

S = 0.7893   R-Sq = 12.38%   R-Sq(adj) = 6.61%


                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level      N    Mean   StDev  --------+---------+---------+---------+-
NN155089   3  1.1003  0.1738  (------*-------)
NN162098   2  1.5207  0.7364   (---------*--------)
NN164099  12  1.8177  0.8360          (---*---)
NN166101   1  2.6990       *        (------------*-------------)
NN166102   7  1.6506  0.3151        (----*----)
NN170105  70  1.9461  0.8292              (*-)
NN170107   3  3.1297  0.4228                  (------*-------)
                              --------+---------+---------+---------+-
                                    1.2       2.4       3.6       4.8

Pooled StDev = 0.7893
```

ANOVA comparison of log result (pacific oysters) by sampling location

```
Source    DF       SS     MS     F      P
GridRef    3    1.594  0.531  0.81  0.492
Error    178  117.344  0.659
Total    181  118.938

S = 0.8119   R-Sq = 1.34%   R-Sq(adj) = 0.00%


                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level      N    Mean   StDev  ------+---------+---------+---------+---
NN155089  64  1.9238  0.8314              (-*-)
NN162098  60  2.1162  0.8282                (-*-)
NN164099  57  1.9098  0.7714              (-*-)
NN170105   1  1.9542       *  (---------------*---------------)
                              ------+---------+---------+---------+---
                                  1.0       2.0       3.0       4.0

Pooled StDev = 0.8119
```

ANOVA comparison of log result (mussels) by season, with Tukeys comparison

```
Source  DF      SS     MS     F      P
Season   3  12.787  4.262  7.72  0.000
Error   94  51.912  0.552
Total   97  64.699

S = 0.7431   R-Sq = 19.76%   R-Sq(adj) = 17.20%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ---------+---------+---------+---------+
1      26  1.5133  0.4934  (------*------)
2      24  2.3310  0.9153                     (------*-------)
3      25  2.2232  0.8642                  (-------*------)
4      23  1.6155  0.6266    (------*-------)
```

```
                           ---------+---------+---------+---------+
                                  1.60      2.00      2.40      2.80

Pooled StDev = 0.7431


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

Individual confidence level = 98.96%


Season = 1 subtracted from:

Season    Lower  Center   Upper  --------+---------+---------+---------+-
2        0.2674  0.8178  1.3681                      (-------*-------)
3        0.1653  0.7099  1.2545                    (-------*-------)
4       -0.4544  0.1022  0.6587            (------*-------)
                                 --------+---------+---------+---------+-
                                     -0.70      0.00      0.70      1.40


Season = 2 subtracted from:

Season    Lower   Center    Upper  --------+---------+---------+---------+-
3       -0.6635  -0.1079   0.4478           (------*-------)
4       -1.2829  -0.7156  -0.1482  (-------*-------)
                                   --------+---------+---------+---------+-
                                       -0.70      0.00      0.70      1.40


Season = 3 subtracted from:

Season    Lower   Center    Upper  --------+---------+---------+---------+-
4       -1.1695  -0.6077  -0.0460   (-------*-------)
                                   --------+---------+---------+---------+-
                                       -0.70      0.00      0.70      1.40
```

ANOVA comparison of log result (pacific oysters) by season, with Tukeys comparison

```
Source   DF       SS      MS      F      P
Season    3   32.243  10.748  22.07  0.000
Error   178   86.695   0.487
Total   181  118.938

S = 0.6979   R-Sq = 27.11%   R-Sq(adj) = 25.88%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ---+---------+---------+---------+------
1      45  1.4913  0.4541  (-----*----)
2      52  2.3860  0.8641                          (----*-----)
3      38  2.4300  0.8940                          (-----*------)
4      47  1.6465  0.4656      (-----*-----)
                           ---+---------+---------+---------+------
                            1.40      1.75      2.10      2.45

Pooled StDev = 0.6979


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

Individual confidence level = 98.98%
```

```
Season = 1 subtracted from:

Season    Lower  Center   Upper  -------+---------+---------+---------+--
2        0.5260  0.8948  1.2635                         (----*----)
3        0.5397  0.9387  1.3378                         (----*-----)
4       -0.2225  0.1552  0.5329              (----*-----)
                                 -------+---------+---------+---------+--
                                     -0.70      0.00      0.70      1.40


Season = 2 subtracted from:

Season    Lower   Center    Upper  -------+---------+---------+---------+--
3       -0.3425   0.0440   0.4305            (-----*----)
4       -1.1040  -0.7395  -0.3750   (----*-----)
                                   -------+---------+---------+---------+--
                                       -0.70      0.00      0.70      1.40


Season = 3 subtracted from:

Season    Lower   Center    Upper  -------+---------+---------+---------+--
4       -1.1786  -0.7835  -0.3884  (-----*----)
                                   -------+---------+---------+---------+--
                                       -0.70      0.00      0.70      1.40
```

Regression analysis, log result against previous 2 days rainfall, mussels

```
The regression equation is
LogValue mussel 2 day = 1.86 - 0.0058 rain 2 days mussel


Predictor               Coef  SE Coef      T      P
Constant              1.8650   0.1753  10.64  0.000
rain 2 days mussel  -0.00577  0.01252  -0.46  0.647


S = 0.847339   R-Sq = 0.5%   R-Sq(adj) = 0.0%


Analysis of Variance

Source          DF       SS      MS     F      P
Regression       1   0.1525  0.1525  0.21  0.647
Residual Error  43  30.8733  0.7180
Total           44  31.0258


Unusual Observations

     rain 2  LogValue
       days  mussel 2
Obs  mussel       day    Fit  SE Fit  Residual  St Resid
 16     5.0     3.959  1.836   0.139     2.123      2.54R
 29     0.0     4.556  1.865   0.175     2.691      3.25R
 37    15.5     3.544  1.776   0.146     1.769      2.12R

R denotes an observation with a large standardized residual.
```

Regression analysis, log result against previous 2 days rainfall, oysters

```
The regression equation is
LogValue 2 day oyst = 2.06 - 0.0135 rain 2 days oyst
```

```
Predictor               Coef   SE Coef      T      P
Constant              2.0642    0.1233  16.73  0.000
rain 2 days oyst   -0.013534  0.008330  -1.62  0.108


S = 0.832131   R-Sq = 3.1%   R-Sq(adj) = 1.9%


Analysis of Variance

Source          DF       SS      MS     F      P
Regression       1   1.8282  1.8282  2.64  0.108
Residual Error  82  56.7802  0.6924
Total           83  58.6084


Unusual Observations

     rain 2
       days  LogValue 2
Obs    oyst    day oyst     Fit  SE Fit  Residual  St Resid
 20    58.3      1.0000  1.2751  0.4122   -0.2751     -0.38 X
 55     0.0      3.7324  2.0642  0.1233    1.6682      2.03R
 56     0.0      3.9590  2.0642  0.1233    1.8949      2.30R
 76    15.5      3.5441  1.8544  0.1016    1.6897      2.05R
 81    16.6      4.5563  1.8395  0.1060    2.7168      3.29R
 82     0.8      3.7324  2.0534  0.1189    1.6790      2.04R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.
```

ANOVA comparison of log result by rain in previous 2 days quartile (mussels)

```
Source          DF      SS     MS     F      P
2 DAY Q mussel   3   0.055  0.018  0.02  0.995
Error           41  30.970  0.755
Total           44  31.026

S = 0.8691   R-Sq = 0.18%   R-Sq(adj) = 0.00%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  -------+---------+---------+---------+--
Q1     10  1.8224  1.1688     (---------------*---------------)
Q2     15  1.8189  0.8094        (------------*------------)
Q3     11  1.8392  0.8413      (---------------*--------------)
Q4      9  1.7405  0.5508  (----------------*---------------)
                           -------+---------+---------+---------+--
                               1.40      1.75      2.10      2.45

Pooled StDev = 0.8691
```

ANOVA comparison of log result by rain in previous 2 days quartile (oysters)

```
Source        DF      SS     MS     F      P
2 DAY Q oyst   3   3.257  1.086  1.57  0.203
Error         80  55.351  0.692
Total         83  58.608

S = 0.8318   R-Sq = 5.56%   R-Sq(adj) = 2.02%
```

```
                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ------+---------+---------+---------+---
Q1     15  1.7450  1.0237      (-----------*-----------)
Q2     31  2.0943  0.7197                   (--------*-------)
Q3     23  2.0391  0.9349                (---------*---------)
Q4     15  1.6000  0.6497  (-----------*-----------)
                           ------+---------+---------+---------+---
                               1.40      1.75      2.10      2.45

Pooled StDev = 0.8318
```

Regression analysis, log result against previous 7 days rainfall, mussels

```
The regression equation is
LogValue mussel 7 day = 1.65 + 0.00165 rain 7 days mussel


Predictor               Coef   SE Coef     T      P
Constant              1.6523    0.1672  9.88  0.000
rain 7 days mussel  0.001652  0.002646  0.62  0.536


S = 0.741200   R-Sq = 0.9%   R-Sq(adj) = 0.0%


Analysis of Variance

Source          DF       SS      MS     F      P
Regression       1   0.2141  0.2141  0.39  0.536
Residual Error  41  22.5245  0.5494
Total           42  22.7386


Unusual Observations

     rain 7  LogValue
       days  mussel 7
Obs  mussel       day    Fit  SE Fit  Residual  St Resid
 15      30     3.959  1.703   0.121     2.256      3.09R
 21     250     2.041  2.066   0.550    -0.024     -0.05 X
 35      51     3.544  1.736   0.114     1.808      2.47R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.
```

Regression analysis, log result against previous 7 days rainfall, oysters

```
The regression equation is
LogValue 7 day oyst = 2.08 - 0.00403 rain 7 days oyst


Predictor              Coef   SE Coef      T      P
Constant             2.0762    0.1481  14.02  0.000
rain 7 days oyst  -0.004029  0.002550  -1.58  0.118


S = 0.774416   R-Sq = 3.1%   R-Sq(adj) = 1.9%


Analysis of Variance

Source          DF       SS      MS     F      P
Regression       1   1.4975  1.4975  2.50  0.118
Residual Error  77  46.1785  0.5997
Total           78  47.6760
```

```
Unusual Observations

     rain 7
       days  LogValue 7
Obs    oyst    day oyst     Fit  SE Fit  Residual  St Resid
 31      58      3.3802  1.8413  0.0918    1.5389      2.00R
 40     250      1.3010  1.0682  0.5255    0.2329      0.41 X
 71      51      3.5441  1.8712  0.0877    1.6729      2.17R
 76      35      4.5563  1.9356  0.0924    2.6207      3.41R
 77      23      3.7324  1.9824  0.1060    1.7500      2.28R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.
```

ANOVA comparison of log result by rain in previous 7 days quartile (mussels)

```
Source           DF      SS     MS     F      P
7 DAY Q mussel    3   2.378  0.793  1.52  0.225
Error            39  20.360  0.522
Total            42  22.739

S = 0.7225   R-Sq = 10.46%   R-Sq(adj) = 3.57%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  --------+---------+---------+---------+-
Q1      9  1.3722  0.3282  (-----------*-----------)
Q2      9  1.9959  1.0368                 (-----------*-----------)
Q3     15  1.8844  0.7564                 (--------*---------)
Q4     10  1.5775  0.5667        (----------*-----------)
                           --------+---------+---------+---------+-
                                1.20      1.60      2.00      2.40

Pooled StDev = 0.7225
```

ANOVA comparison of log result by rain in previous 7 days quartile (oysters)

```
Source         DF      SS     MS     F      P
7 DAY Q oyst    3   3.338  1.113  1.88  0.140
Error          75  44.338  0.591
Total          78  47.676

S = 0.7689   R-Sq = 7.00%   R-Sq(adj) = 3.28%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev   -+---------+---------+---------+--------
Q1     10  2.1272  0.9999               (-----------*-----------)
Q2     18  1.8704  0.7150            (--------*--------)
Q3     33  2.0148  0.8080                  (-----*------)
Q4     18  1.5360  0.5819   (--------*--------)
                            -+---------+---------+---------+--------
                           1.20      1.60      2.00      2.40

Pooled StDev = 0.7689
```

ANOVA comparison of log result by tide size (mussels)

```
Source      DF      SS     MS     F      P
Tide size    2   1.358  0.679  1.02  0.365
Error       95  63.340  0.667
Total       97  64.699

S = 0.8165   R-Sq = 2.10%   R-Sq(adj) = 0.04%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level    N    Mean   StDev   -+---------+---------+---------+--------
Large   53  2.0020  0.8695                          (-----*------)
Medium  37  1.8721  0.7454                     (------*-------)
Small    8  1.5814  0.7579   (---------------*----------------)
                             -+---------+---------+---------+--------
                            1.05      1.40      1.75      2.10

Pooled StDev = 0.8165
```

ANOVA comparison of log result by tide size (oysters) with Tukeys comparison

```
Source       DF       SS     MS     F      P
tide size     2    9.636  4.818  7.89  0.001
Error       179  109.302  0.611
Total       181  118.938

S = 0.7814   R-Sq = 8.10%   R-Sq(adj) = 7.08%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level    N    Mean   StDev  -------+---------+---------+---------+--
Large   88  2.2208  0.8582                             (----*-----)
Medium  83  1.7624  0.6754            (-----*----)
Small   11  1.7453  0.8846  (--------------*---------------)
                            -------+---------+---------+---------+--
                                 1.50      1.80      2.10      2.40

Pooled StDev = 0.7814


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

Individual confidence level = 98.07%


tide size = Large subtracted from:

tide size    Lower   Center    Upper
Medium     -0.7408  -0.4584  -0.1760
Small      -1.0657  -0.4755   0.1147

tide size    -+---------+---------+---------+--------
Medium             (-----*----)
Small        (----------*-----------)
             -+---------+---------+---------+--------
           -1.00     -0.50      0.00      0.50


tide size = Medium subtracted from:

tide size    Lower   Center   Upper    -+---------+---------+---------+-----
---
Small      -0.6092  -0.0171  0.5751             (-----------*-----------)
```

```
                                       -+---------+---------+---------+-----
---
                                     -1.00     -0.50      0.00      0.50
```

Regression analysis, log result against water temperature, mussels

```
The regression equation is
Logresult for temp = 0.882 + 0.103 temp


Predictor     Coef  SE Coef     T      P
Constant    0.8818   0.3404  2.59  0.012
temp       0.10325  0.03063  3.37  0.001


S = 0.778358   R-Sq = 14.1%   R-Sq(adj) = 12.9%


Analysis of Variance

Source          DF       SS      MS      F      P
Regression       1   6.8823  6.8823  11.36  0.001
Residual Error  69  41.8030  0.6058
Total           70  48.6854


Unusual Observations

           Logresult
Obs  temp   for temp     Fit  SE Fit  Residual  St Resid
  1  10.0     3.5441  1.9143  0.0948    1.6298      2.11R
 54  16.4     1.0000  2.5751  0.1977   -1.5751     -2.09R
 55  16.0     4.5563  2.5338  0.1869    2.0225      2.68R
 56   2.0     2.4914  1.0883  0.2819    1.4030      1.93 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.
```

Regression analysis, log result against water temperature, oysters

```
The regression equation is
Log result for temperature = 0.762 + 0.123 WaterTemp


Predictor     Coef  SE Coef     T      P
Constant    0.7617   0.1903  4.00  0.000
WaterTemp  0.12318  0.01740  7.08  0.000


S = 0.707058   R-Sq = 27.4%   R-Sq(adj) = 26.8%


Analysis of Variance

Source           DF      SS      MS      F      P
Regression        1  25.061  25.061  50.13  0.000
Residual Error  133  66.491   0.500
Total           134  91.551


Unusual Observations

                 Log result
                        for
Obs  WaterTemp  temperature     Fit  SE Fit  Residual  St Resid
  1        1.5       1.3010  0.9465  0.1658    0.3546      0.52 X
```

```
  2        2.0       1.3010  1.0080  0.1578    0.2930      0.43 X
 23       15.5       1.0000  2.6709  0.1081   -1.6709     -2.39R
 47       13.0       4.5563  2.3630  0.0762    2.1933      3.12R
125       12.0       3.7324  2.2398  0.0672    1.4926      2.12R
131       16.0       4.5563  2.7325  0.1154    1.8238      2.61R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.
```

Circular-Linear correlation, wind direction and log result, mussels

CIRCULAR-LINEAR CORRELATION
Lock Fyne Ardkinglas mussels
Analysis begun: 21 February 2008 16:44:10

Variables (& observations)	r	p
Angles & Linear (38)	0.114	0.633

Circular-Linear correlation, wind direction and log result, oysters

CIRCULAR-LINEAR CORRELATION
Loch Fyne Ardkinglas oysters
Analysis begun: 21 February 2008 16:45:41

Variables (& observations)	r	p
Linear & Angles (77)	0.176	0.1

ANOVA comparison of log result (SEPA monitoring data) by quarter with Tukeys comparison

```
Source   DF      SS     MS     F      P
Quarter   3   4.798  1.599  3.27  0.039
Error    24  11.740  0.489
Total    27  16.538

S = 0.6994   R-Sq = 29.01%   R-Sq(adj) = 20.14%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  ---------+---------+---------+---------+
Q1     7  1.8039  0.5111  (--------*--------)
Q2     6  2.0487  0.8964     (---------*---------)
Q3     7  2.4828  0.7377             (--------*--------)
Q4     8  2.8571  0.6426                    (--------*-------)
                          ---------+---------+---------+---------+
                                1.80      2.40      3.00      3.60

Pooled StDev = 0.6994


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

Individual confidence level = 98.90%


Quarter = Q1 subtracted from:

Quarter    Lower  Center   Upper  ---------+---------+---------+---------+
Q2       -0.8282  0.2448  1.3179            (---------*----------)
Q3       -0.3521  0.6789  1.7099                (----------*---------)
```

```
Q4        0.0550  1.0532  2.0515                    (---------*---------)
                                    ---------+---------+---------+---------+
                                          -1.0       0.0       1.0       2.0


Quarter = Q2 subtracted from:

Quarter    Lower  Center   Upper  ---------+---------+---------+---------+
Q3       -0.6390  0.4341  1.5071             (---------*----------)
Q4       -0.2333  0.8084  1.8501                 (---------*----------)
                                  ---------+---------+---------+---------+
                                        -1.0       0.0       1.0       2.0


Quarter = Q3 subtracted from:

Quarter    Lower  Center   Upper  ---------+---------+---------+---------+
Q4       -0.6239  0.3743  1.3726             (---------*---------)
```

Hydrographic methods

1.0 Introduction
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. This document collects together information common to all hydrographic assessments avoiding the repetition of information in each individual report.

The hydrography at most sites will be assessed on the basis of bathymetry and tidal flow software only and is not discussed in any detail in this document. 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 focus on this more detailed hydrographic assessment and describes the common methodology applied to all sites.

The regulations require an appreciation of the hydrography and currents within a region classified for shellfish production.

2.0 Background processes
This section gives an overview of the hydrographic processes relevant to sanitary surveys.

Movement in the estuarine and coastal waters is generally driven by one of three mechanisms: 1) Tides, 2) Winds, 3) Density differences. Unless tidal flows are weak they usually dominate over the short term (~12 hours) and move material over the length of the tidal excursion. The tidal residual flow acts over longer time scales to give a net direction of transport. 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.

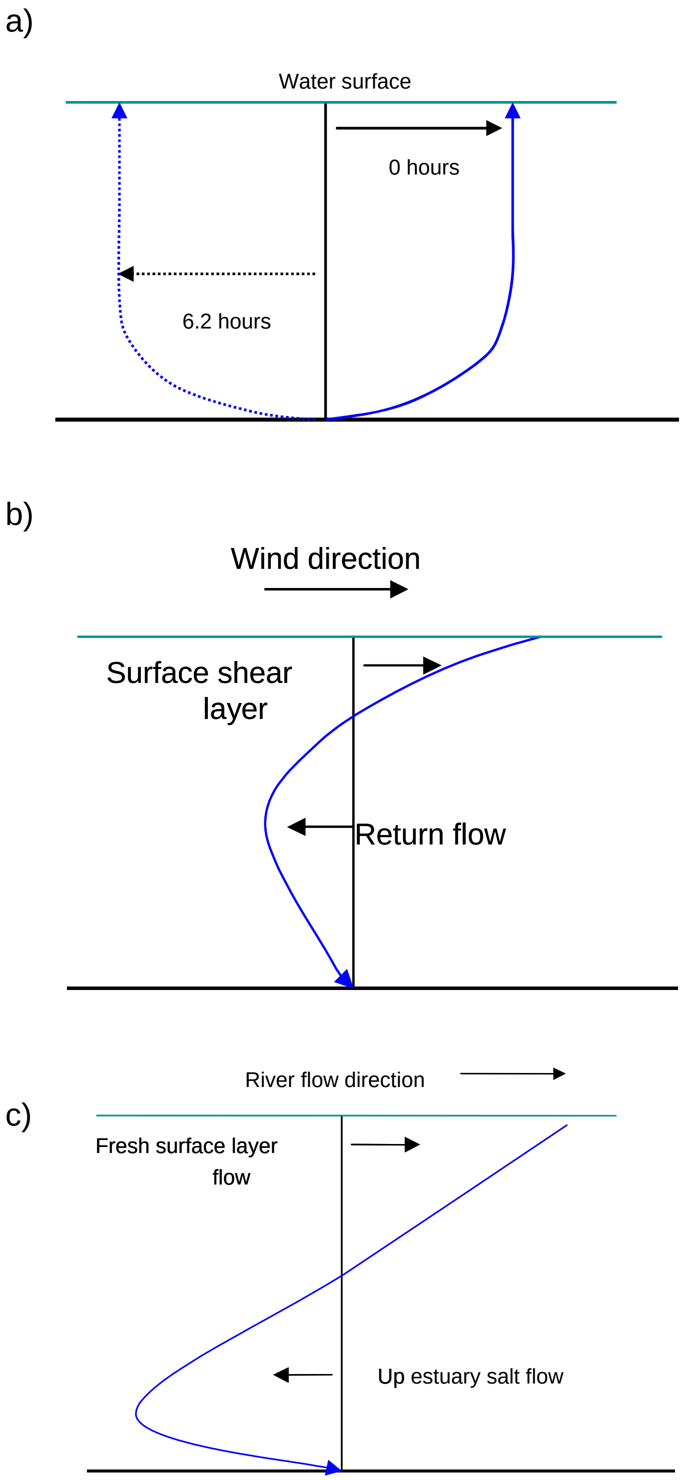


Figure 1. Typical vertical profiles for water currents. The black vertical line indicates zero velocity so portions of the profile to the left and right indicate flow moving in opposite directions. a) Peak tidal flow profiles. Profiles are shown 6.2 hours apart as the main tidal current reverses direction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

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.

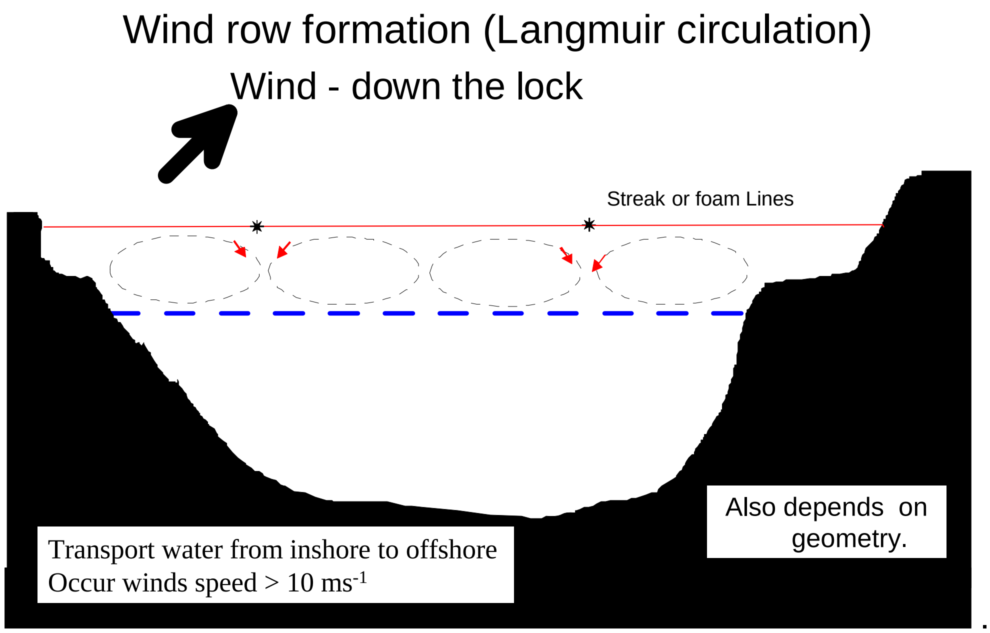


Figure 2: Schematic of wind driven ‘wind row’ currents. The dotted blue line indicates the depth of the surface fresh(er) water layer usually found in sea lochs.

3.0 Basic Assessment

This will be applied to most sites and consists of a description of bathymetry and the tidal regime obtained from admiralty charts and tidal diamonds and is not described in detail here.

4.0 More Detailed Assessment

This is applied at the request of the regulator (FSAS) when particular circumstances apply. Typically this will be at sites where production areas regular fail or where unusual results have been reported.

4.1 Modelling approach

The Hydrotrack computer model is used. This is able to simulate depth averaged tidal currents and give some indication of wind driven currents. Model output from the model is analysed to provide information on:

- Particle paths due to tides and winds.
- Residual current patterns due to tide and winds.

Tidal forcing is a simple sinusoidal current applied at the model boundary. Where possible the assumption is made that the change in tidal phase across the boundary is negligible. Basic checking of the model is limited to the available data. In most cases this is limited to reproducing the observed tidal range. If tidal diamond or current meter observations are available, model results are checked against these.

Model calculations are carried out for five cases: tides only and tides plus winds from north, south east and west directions. The resulting winds patterns are for winds blowing constantly for 48 hours so that a steady current pattern is produced. In reality of course winds are highly variable. For each of these cases the results over the last two tidal periods are analysed to provide tidal phase and amplitude and the residual current. The paths of particles moving with the water and starting from known sources of contamination are calculated using the analysed currents. For point sources very near the shore, model release points may be moved slightly offshore out to ensure particles are caught by the prevailing current and not trapped at the release point.

For a given water body, the strength of the applied wind is chosen to ensure wind driven currents are large relative to the tidal currents so that particle paths clearly show the wind driven movement.

Although Hydrotrack calculates currents over the spatial area of a water body, it cannot calculate the vertical profile of currents. Although adequate for tidal flows this has limitations for wind and density driven systems characteristic of many sea lochs. Therefore the modelling approach is more usefully applied to tidally dominated systems or shallow regions where vertical structure may be less significant.

4.2 Non-modelling approach

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'.
7. Estimates of flow speed combined with T_{90} will give a 'region of influence'.
8. The ratio of river run-off to tidal prism gives an indication of the importance of density effects.

Many Scottish shell fish 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.

For the more detailed assessment of sea loch regions, the "Sea Loch catalogue" 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 area 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.

Dilution calculations in regions with steep and variable bathymetry typical of sea lochs are extremely difficult. The following methods are applied.

For class A and B classifications, correlation with data (European Commission 1996) suggest the following water concentration need to be achieved:

Class A: 1 bacterium per 100 ml = 10^4 m^{-3}
Class B: 100 bacterium per 100 ml = 10^6 m^{-3}

4.2.1 Integrated inputs

Given *E. coli* loadings and estimates of water body volume and flushing time, the E. coli concentration averaged over the entire water body can be estimated from

$$C = S T_f / V$$

C = number *e-coli* m^{-3}
S = Sum of all loadings (number of *e-coli* per day)
T_f = Flushing time (days)
V = Water body volume (m^3)

This can then be compared with the Class A and B requirements.

4.2.2 Individual inputs

For a source with a loading M *E. coli* per second, discharging into water flowing at speed u (ms^{-1}), the number of *E. coli* per meter in the flow direction is given by M/u (*E. coli* m^{-1}). To achieve a target concentration of T, the cross sectional area that the material needs to be mixed over is given by

$$A = M/(u T)$$

Assuming an average depth for the water body this can be converted to a distance offshore. A subjective judgement can then made as to whether this is likely to occur over the relevant time scales (< 3 days). That is, will the required dilution occur quickly enough that only localised impacts would be expected? For sea lochs the assumption is made that away from the sills, mixing is likely to be quite weak.

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 of terms

The following technical terms 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 nearshore 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

Loch Fyne: Ardkinglas
AB 147

Scottish Sanitary Survey Project

Cefas

Shoreline Survey Report

Prod. area:	Loch Fyne: Ardkinglas
Site name:	The Shore; The Point; Policy Gates
Species:	Pacific oysters; Common mussels
Harvester:	Loch Fyne Oyster Company
Local Authority:	Argyll and Bute Council
Status:	Mussels: 2007 = A - April & May B - June to December 2008 = A - January to March P. oysters 2007 = A - April & May, December B - June to November 2008 = A - January to March
Date Surveyed:	10/10 – 12/10/2007
Surveyed by:	Ron Lee (Cefas); Michelle Price-Hayward (Cefas); Andy MacLeod (Argyll & Bute Council)
Existing RMP:	The Point (AB 147 035 08); Policy Gates (AB 147 034 13)
Area Surveyed:	See map in Figure 1

Weather observations

10/11/07: Bright cloud, light breeze
11/11/07: Cloudy but mainly dry, occasional showers, heavy early morning prior to start
12/11/07: Cloudy but dry

Site Observations

<u>Fishery</u>

There are two main areas of mussel lines, termed by the company the West and East banks. These do not correspond directly to any of the three named sites in the production area. The dropper lines are 10 m in length. Rotation of the mussels is undertaken separately within each area. Harvesting is undertaken during the period from October to March/April.

Twelve relatively discrete sets of Pacific oyster trestles were identified along the southern bank of the loch, stretching across the three sites named in the classification document. The site was closed for oyster harvesting at the time of the shoreline survey due to Norovirus incidents that had occurred in July. Otherwise, harvesting would take place year-round. The size of oysters varied markedly between some of the sets of trestles, with some sets only containing juvenile stock.

Holding tanks within the depuration plant complex on the south shore are filled from the loch without any disinfection of the intake water. They effectively constitute an extension of the production area. All batches of oysters bought in by the company are held in those tanks prior to depuration and therefore are at risk from any microbiological contamination (including viral) from the production area. The water from the tanks discharges into the vicinity of some of the active trestles and this constitutes a potential source of contamination of those shellfish.

<u>Sewage/Faecal Sources</u>

Permitted Scottish Water discharges in the vicinity of the production area are shown below in Table 1.

Table 1. Consented Scottish Water discharges[1]

Discharge Name	NGR	Discharge Type	Level of Treatment	Consented flow (DWF) m3/d	Consented/ design PE	Predicted spill frequency
Inverarary	NN 0961 0794	Continuous		633	721	
Inveraray Satellite PS No1, CSO & EO	NN 0954 0827	Intermittent	Screened overflow	83	101	
Inveraray Transfer PS No1, CSO & EO	NN 0987 0844	Intermittent	Screened overflow	278	320	
Inveraray Transfer PS No2, CSO & EO	NN 0961 0794	Intermittent	Screened overflow	633	721	
Cairndow	NR 118 113	Continuous	Septic Tank	12.2	34	none
Argyll Caravan Park						
St Catherines						

[1]Data from Scottish Water

Table 2 shows the permitted non-Scottish Water discharges in the vicinity of the production area.

Table 2. Permitted non-Scottish Water discharges[1]

Reference number	NGR	Sewage type	Population Equivalent	Applicant name
CAR/R/1013856	NN 1224 0753	Domestic	5	New house in field adjacent to St Catherines caravan park
CAR/R/1014576	NN 1667 0988	Domestic	6	New house on land north of Arleigh, Cairndow
CAR/R/1017707	NN 1925 1328	Domestic	5	Clachan power station, Cairndow, Inveraray

[1]Data from SEPA

In addition, there is a septic tank outfall near the Loch Fyne Restaurant complex near the head of the loch which serves the restaurant, processing plant and other enterprises on the site. A large number of properties will be on private septic tanks.

Information was received from SEPA at a meeting during the shoreline survey activities. This indicated that problems with the continuous and intermittent outfalls at Inverarary would be addressed by ongoing resewerage work. A new sewage works was planned for Cairndow to incorporate the whole community in the public system. The private outfall at the Loch Fyne Restaurant complex was also due for upgrading.

Seasonal Population

The area has a significant tourist trade and this is centred on Inverarary although there is a hotel in Cairndow, caravan parks at St Catherines and Dalchenna and individual seasonally occupied properties. In addition, the Loch Fyne restaurant complex attracts a large number of visitors, including coach parties. The summer population will therefore be significantly higher in some parts of the upper loch.

Boats/Shipping

There is a small harbour at Inverarary. Apart from this, the main boating activity seen in the upper loch was associated with the Loch Fyne shellfishery. There was some evidence (e.g. mooring buoys) that seasonal boating activity may occur.

Land Use

The land around the loch in the vicinity of the production area was largely wooded, with deciduous trees prevailing. There were large areas of coniferous plantation woods on the upper slopes in some areas and these appeared to be subject to logging activity. There are some relatively small areas of grassland grazed by sheep, mainly at the head of the loch and around Inveraray. Inverarary is the largest community in the vicinity with Cairndow being the second largest. There are several isolated properties on the shoreline. The principal commercial activities are the Panfish processing plant and Loch Fyne Depuration plant on the south side of the loch and the Loch Fyne processing plant/restaurant complex on the north side.

Wildlife/Birds

Very few wild birds and animals were observed during the shoreline survey. With the latter, the thick woodland and bushes directly adjacent to the shoreline in many places would have prevented direct observation. Deer tracks were seen on the shore itself in one location.

General Observations

Outside Inveraray and Cairndow, there are a number of dwellings near the shore. Part of Cairndow, as well as these individual dwellings, are not currently on a mains sewerage system and will therefore have individual septic tanks. There has historically been no requirement in Scotland to register these individual systems and so little record is available regarding their age, type, size or location. Three are referred to above in Table 2.

Evidence of discharge pipes from individual septic tanks was seen for a small number of properties.

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 loch.

Specific observations taken on site are listed in Table 3 and are mapped in Figures 1 to 4.

Sampling

Water samples were collected at sites illustrated on the maps in Figures 5 to 7 and shellfish samples were collected at the sites illustrated on the map in Figure 8. Samples were transferred to cool boxes after collection and transported to the laboratory where they were analysed for *E. coli* content. Samples of oysters were also sent to the Cefas Weymouth laboratory for norovirus testing.

Salinity and temperature profiles were recorded at a number of positions in the vicinity of the mussel lines. Readings were taken using a portable salinity meter with a 5 metre cable and were taken at 3 depths at each location: 1 m, 3 m and 5 m. The results are shown in Table 4.

Samples of seawater were also tested for salinity by the laboratory using a salinity meter under more controlled conditions. These results are more precise than the field measurements and are shown in Table 5, given in units of grams salt per litre of water. This is the same as ppt.

Microbiology results follow in Tables 5 and 6.

Acknowledgements

We would like to thank Argyll & Bute Council and the Loch Fyne Oyster (LFO) Company for their co-operation in the undertaking of this survey. In particular, we would like to thank Ian McKay, the LFO mussel farm manager and Andy McPherson, the LFO oyster farm manager.

Figure 1. Overview Map of Shoreline Observations

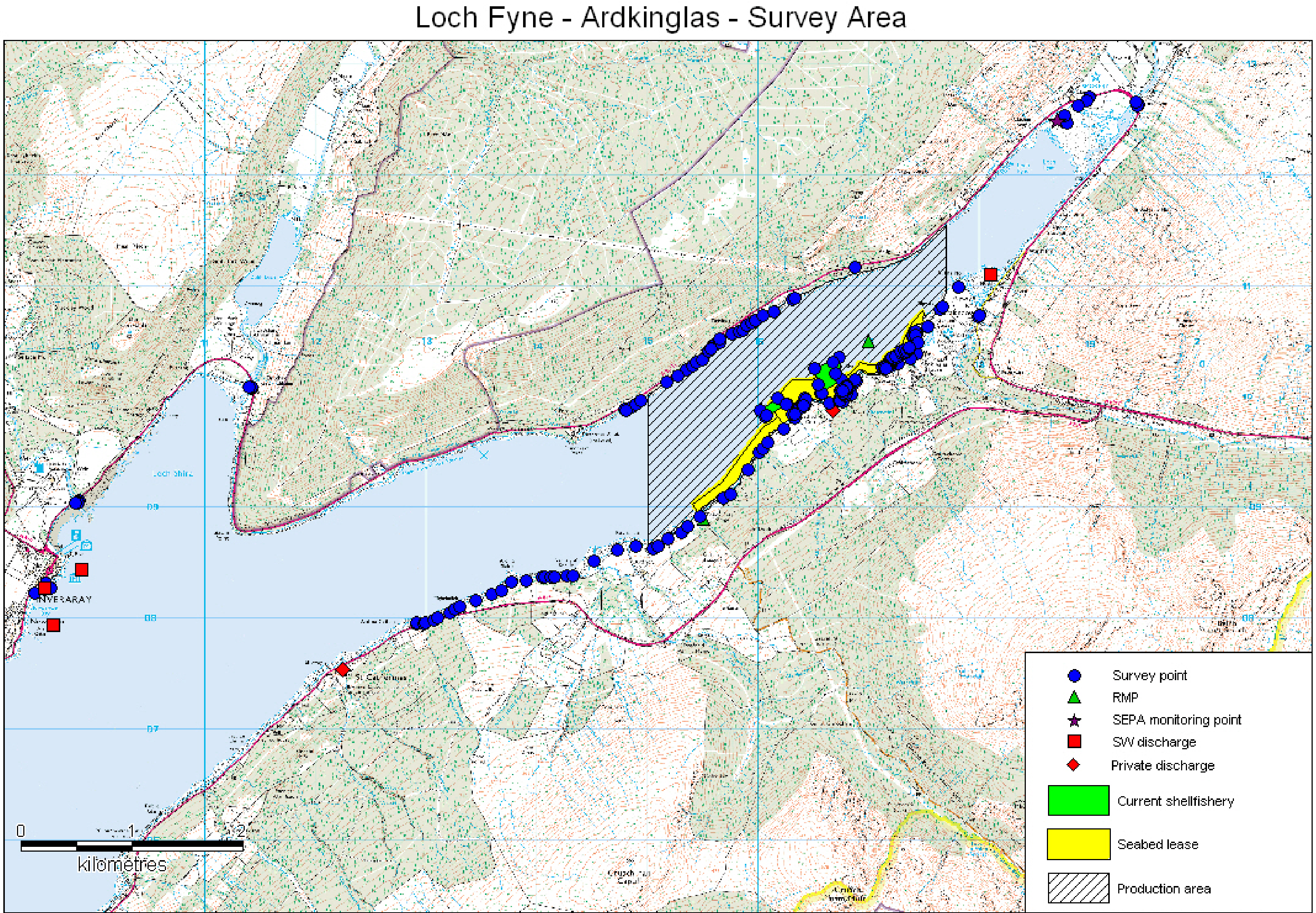


Figure 2. Map of Shoreline Observations – South Western End of Survey

Loch Fyne - Ardkinglas Survey - South Western End

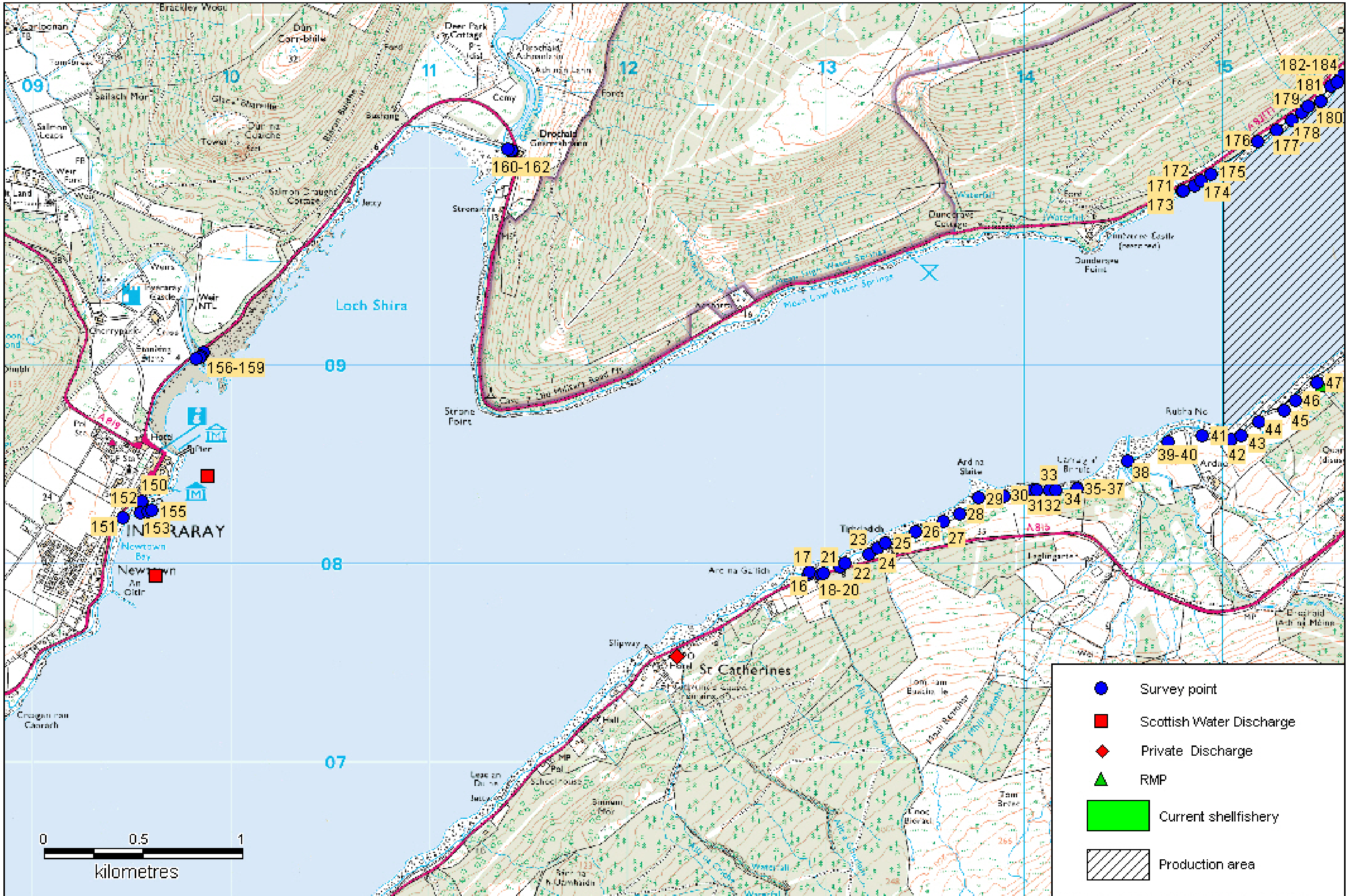


Figure 3. Map of Shoreline Observations – Middle Section of Survey

Loch Fyne - Ardkinglas Survey - Middle Section

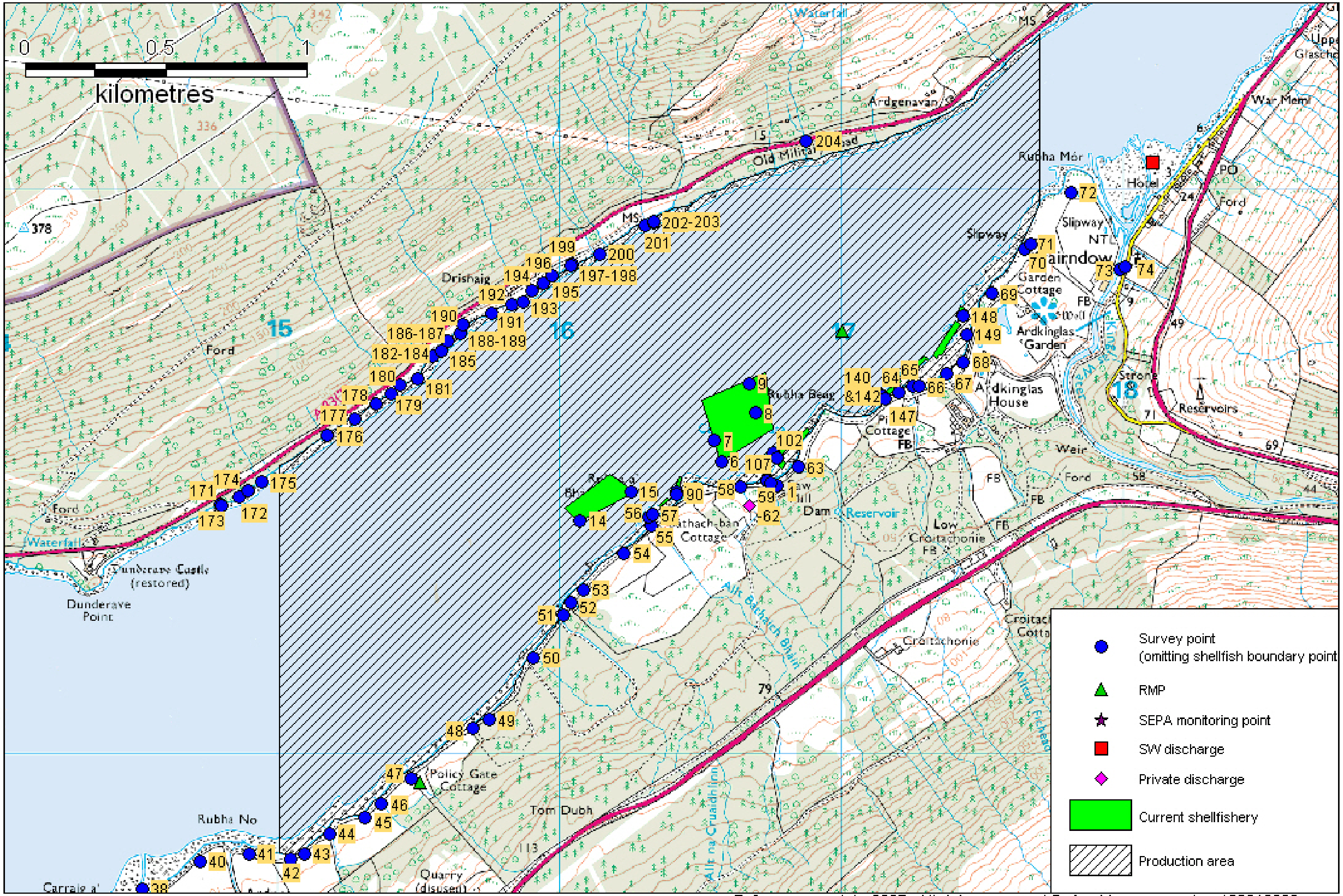


Figure 4. Map of Shoreline Observations – North Eastern End of Survey

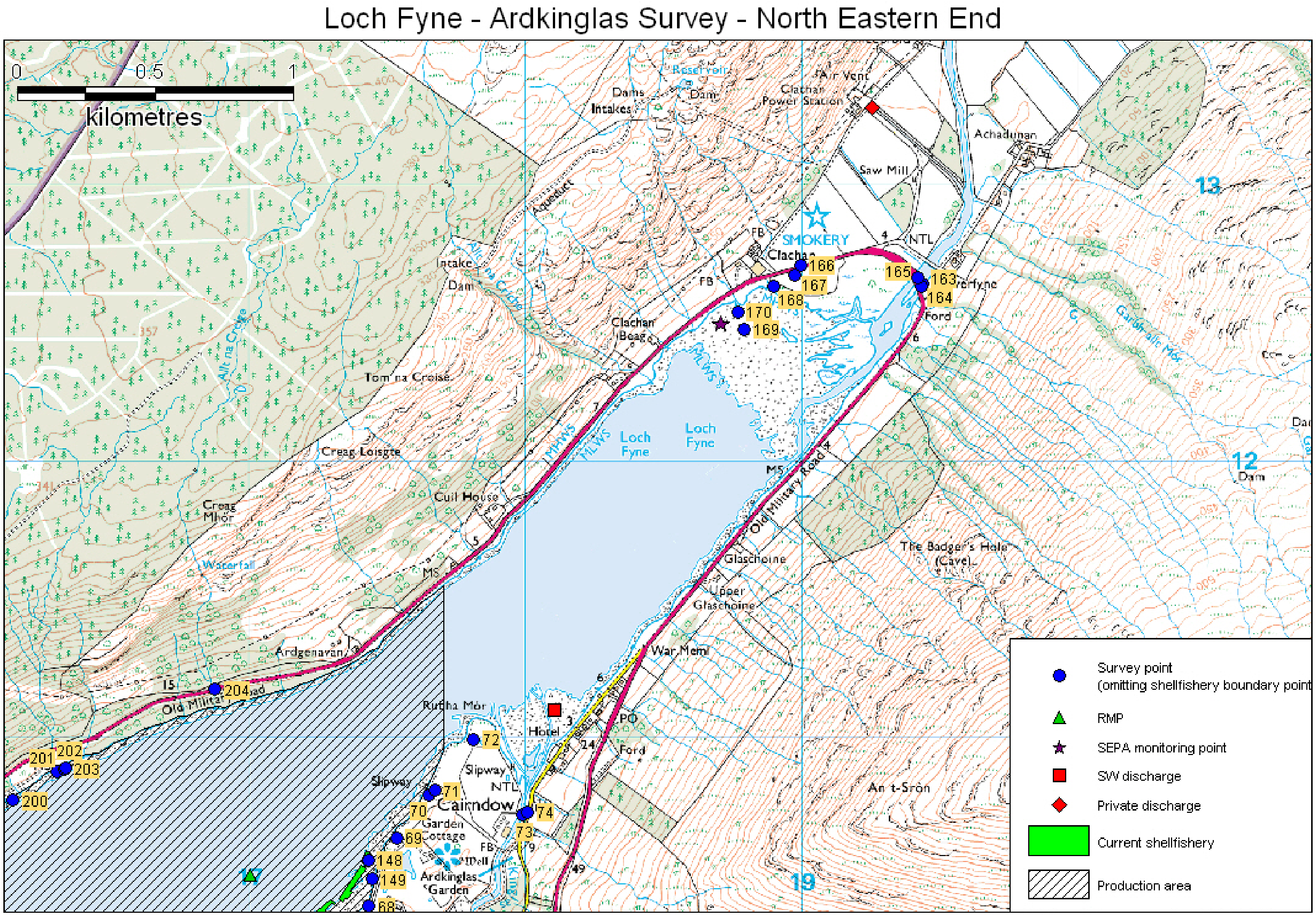


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Table 3. Shoreline Observations

No.	Date	Time	NGR	East	North	Associated photograph	Description
1	10/10/2007	13:59	NN 16766 09952	216766	709952	Figure 9	East block mussels: 5 photographs
2	10/10/2007	14:03	NN 16756 10151	216756	710151		SE corner mussel lines
3	10/10/2007	14:04	NN 16724 10354	216724	710354		NE corner mussel lines; approximately 30 gulls in vicinity of fishery
4	10/10/2007	14:05	NN 16502 10253	216502	710253		NW corner mussel lines
5	10/10/2007	14:06	NN 16566 10034	216566	710034		SW corner mussel lines
6	10/10/2007	14:07	NN 16571 10037	216571	710037		Spat line
7	10/10/2007	14:08	NN 16545 10111	216545	710111		Fyne 11 mussel sample; Fyne (sea)water sample 1; salinity profile (see Table 2)
8	10/10/2007	14:28	NN 16693 10209	216693	710209		Fyne 12, 13 & 14 mussel samples; Fyne (sea)water sample 2
9	10/10/2007	14:55	NN 16669 10312	216669	710312		Fyne 15 & 16 mussel samples; Fyne (sea) water sample 3; salinity profile (see Table 2)
10	10/10/2007	15:18	NN 16176 09992	216176	709992		West block mussels; NE corner; 1 heron, 4 cormorants on fishery
11	10/10/2007	15:19	NN 16263 09930	216263	709930		SE corner mussel lines
12	10/10/2007	15:20	NN 16062 09822	216062	709822		SW corner mussel lines
13	10/10/2007	15:20	NN 16013 09872	216013	709872		NW corner mussel lines
14	10/10/2007	15:24	NN 16067 09829	216067	709829		Fyne 17 mussel sample; Fyne (sea)water sample 4; salinity profile (see Table 2)
15	10/10/2007	15:39	NN 16251 09928	216251	709928		Fyne 18 mussel sample; Fyne (sea)water sample 5; salinity profile (see Table 2)
16	11/10/2007	07:52	NN 12906 07944	212906	707944		Two houses above road; woodland behind shore
17	11/10/2007	08:00	NN 12909 07958	212909	707958		Fyne (sea)water sample 6
18	11/10/2007	08:02	NN 12967 07948	212967	707948		Small stream; Fyne (fresh)water sample 7; 70 cm wide 15 cm deep 0.68 m/s
19	11/10/2007	08:05	NN 12969 07947	212969	707947		Small stream; Fyne (fresh)water sample 8; 80 cm wide 11 cm deep 0.32 m/s
20	11/10/2007	08:11	NN 12982 07954	212982	707954		Two very small streams combine; Fyne (fresh)water sample 21; 1.3 m wide 1 cm deep 0.12 m/s
21	11/10/2007	08:21	NN 13063 07985	213063	707985		Very small stream; Fyne (fresh)water sample 21; 90 cm wide 3 cm deep 0.63 m/s
22	11/10/2007	08:28	NN 13091 08002	213091	708002		Very small stream; not sampled
23	11/10/2007	08:30	NN 13209 08049	213209	708049		Very small stream; not sampled
24	11/10/2007	08:31	NN 13255 08076	213255	708076		Small stream; not sampled
25	11/10/2007	08:32	NN 13297 08106	213297	708106		Three dwellings above shore
26	11/10/2007	08:35	NN 13445 08161	213445	708161		Small stream; not sampled; 1 dwelling above shore

No.	Date	Time	NGR	East	North	Associated photograph	Description
27	11/10/2007	08:37	NN 13587 08211	213587	708211		Very small stream; not sampled
28	11/10/2007	08:38	NN 13672 08248	213672	708248		Very small stream; not sampled
29	11/10/2007	08:40	NN 13763 08331	213763	708331		Large dwelling above shore; mussel shells ++
30	11/10/2007	08:43	NN 13893 08341	213893	708341		Small stream with froth; Fyne (fresh)water sample 22; 1.1 m wide 3 cm deep 0.38 m/s
31	11/10/2007	08:54	NN 14043 08374	214043	708374		Small boat on shore
32	11/10/2007	08:55	NN 14059 08375	214059	708375		Very small stream; not sampled
33	11/10/2007	08:57	NN 14125 08369	214125	708369		Small stream from pipe, some froth; Fyne (fresh)water sample 23; 10 cm wide 6 cm deep 0.48 m/s
34	11/10/2007	09:01	NN 14155 08372	214155	708372		Land run-off; not sampled
35	11/10/2007	09:03	NN 14263 08379	214263	708379		No record made
36	11/10/2007	09:03	NN 14263 08379	214263	708379		Very small stream; not sampled; woodland above shore
37	11/10/2007	09:05	NN 14325 08379	214325	708379		Very small stream; not sampled
38	11/10/2007	09:10	NN 14515 08520	214515	708520	Figure 10	Large stream; Fyne (fresh)water sample 24; 4.5 m wide 45 cm deep 0.31 m/s
39	11/10/2007	09:20	NN 14719 08616	214719	708616		No record made
40	11/10/2007	09:21	NN 14720 08616	214720	708616	Figure 11	Approximately 60 sheep in field above shore
41	11/10/2007	09:27	NN 14894 08647	214894	708647	Figure 12	Stream; Fyne (fresh)water sample 25; 1.5 m wide 9cm deep 0.37 m/s
42	11/10/2007	09:33	NN 15041 08628	215041	708628		Land run-off; not sampled
43	11/10/2007	09:34	NN 15091 08645	215091	708645		Concrete slipway; approximately 42 sheep in field above shore; dwelling with 8 sheep in field to west
44	11/10/2007	09:37	NN 15179 08716	215179	708716		Small stream; Fyne (fresh)water sample 26; 1 m wide 7 cm deep; 1.1 m/s
45	11/10/2007	09:44	NN 15306 08774	215306	708774		Very small stream; not sampled
46	11/10/2007	09:46	NN 15363 08825	215363	708825		Small stream through pipe; Fyne (fresh)water sample 27; 60 cm wide 4 cm deep 0.37 m/s
47	11/10/2007	09:59	NN 15471 08913	215471	708913	Figure 13	Small stream with presumed 10 cm diameter septic tank outlet; Fyne (fresh(water) 28; 40 cm wide 10 cm deep 0.19 m/s
48	11/10/2007	10:11	NN 15686 09089	215686	709089		Very small stream; not sampled
49	11/10/2007	10:13	NN 15744 09121	215744	709121		Very small stream; not sampled; woodland above shore
50	11/10/2007	10:19	NN 15904 09340	215904	709340		Very small stream; not sampled
51	11/10/2007	10:24	NN 16010 09493	216010	709493		Very small stream; not sampled
52	11/10/2007	10:25	NN 16034 09535	216034	709535		Stream; Fyne (fresh)water sample 29; 75 cm wide 15 cm deep 0.55 m/s; wooded area above shore
53	11/10/2007	10:30	NN 16080 09583	216080	709583		Land run-off; not sampled; mussel barge offshore at w estern end of west mussel bank
54	11/10/2007	10:35	NN 16225 09712	216225	709712		Land run-off; not sampled; mussel barge offshore at western

No.	Date	Time	NGR	East	North	Associated photograph	Description
							end of west mussel bank; small boat on bank
55	11/10/2007	10:38	NN 16323 09811	216323	709811		Stream; Fyne (fresh)water sample 30; 1.5 m wide 8 cm deep 0.56 m/s
56	11/10/2007	10:42	NN 16310 09840	216310	709840		West end of disused oyster racks
57	11/10/2007	10:43	NN 16327 09847	216327	709847		Disused oyster racks in shallows and on shore
58	11/10/2007	10:56	NN 16640 09947	216640	709947		Disused oyster racks and other shellfish plant debris; Fyne (sea)water sample 31; mussel shells +
59	11/10/2007	11:03	NN 16730 09972	216730	709972	Figure 14	Small stream; Fyne (fresh)water sample 32; 30 cm wide; 15 cm deep 0.14 m/s; 3 houses above shore
60	11/10/2007	11:07	NN 16745 09961	216745	709961		Pipe from depuration plant - unable to reach end to sample
61	11/10/2007	11:08	NN 16732 09970	216732	709970		Fyne (sea)water sample 33
62	11/10/2007	11:08	NN 16746 09961	216746	709961		Small stream; Fyne (fresh)water 34; 55 cm wide 6 cm deep 0.37 m/s; motor boat off shore
63	11/10/2007	11:38	NN 16843 10018	216843	710018		Stream; Fyne (fresh)water 35; 2 m wide 15 cm deep 0.71 m/s; house above stream; more disused racks nearby
64	11/10/2007	11:55	NN 17201 10281	217201	710281		Disused pier; cottage above shore; disused racks
65	11/10/2007	11:56	NN 17248 10304	217248	710304	Figure 15	Stream; Fyne (fresh)water sample 36; 4 m wide 15 cm deep 0.63 m/s
66	11/10/2007	12:05	NN 17270 10304	217270	710304		Disused oyster racks; houses behind stream
67	11/10/2007	12:08	NN 17371 10347	217371	710347		Stream; Fyne (fresh)water sample 37; 2.2 m wide 12 cm deep 0.45 m/s
68	11/10/2007	12:15	NN 17429 10388	217429	710388		Ardkinglas House above shore
69	11/10/2007	12:20	NN 17530 10636	217530	710636		House above shore; Land run-off disappeared through shingle; mussel shells +++
70	11/10/2007	12:24	NN 17648 10789	217648	710789		Partly submerged pipe
71	11/10/2007	12:26	NN 17667 10808	217667	710808	Figure 16	Panfish processing plant; Salmon cages near shore for transporting/keeping live fish
72	11/10/2007	12:31	NN 17809 10993	217809	710993		Cairndow village behind shore; mussel shells +++
73	11/10/2007	12:45	NN 17985 10718	217985	710718	Figure 17	Kinglas Water East Bank 30 cm deep 0.18 m/s
74	11/10/2007	12:50	NN 18004 10730	218004	710730		Kinglas Water West Bank; Fyne (fresh)water sample 38
75	11/10/2007	18:29	NN 16346 09882	216346	709882		Corner westernmost active oyster trestles (1)
76	11/10/2007	18:29	NN 16409 09930	216409	709930		Seawater sample LF40
77	11/10/2007	18:30	NN 16353 09875	216353	709875	Figure 18	Corner oyster trestles (1)
78	11/10/2007	18:30	NN 16388 09901	216388	709901		Corner oyster trestles (1)
79	11/10/2007	18:31	NN 16374 09909	216374	709909		Corner oyster trestles (1)
80	11/10/2007	18:32	NN 16410 09917	216410	709917		Corner oyster trestles (2)
81	11/10/2007	18:33	NN 16398 09929	216398	709929		Corner oyster trestles (2)

No.	Date	Time	NGR	East	North	Associated photograph	Description
82	11/10/2007	18:33	NN 16411 09917	216411	709917		Corner oyster trestles (2)
83	11/10/2007	18:34	NN 16416 09921	216416	709921		Corner oyster trestles (2)
84	11/10/2007	18:34	NN 16402 09935	216402	709935		Corner oyster trestles (2)
85	11/10/2007	18:35	NN 16414 09935	216414	709935		Corner oyster trestles (3)
86	11/10/2007	18:36	NN 16404 09945	216404	709945		Corner oyster trestles (3)
87	11/10/2007	18:36	NN 16418 09939	216418	709939		Corner oyster trestles (3)
88	11/10/2007	18:37	NN 16429 09977	216429	709977		Corner oyster trestles (3)
89	11/10/2007	18:37	NN 16421 09985	216421	709985		Corner oyster trestles (3); Mussels +++ growing on seabed
90	11/10/2007	18:44	NN 16411 09921	216411	709921		Oyster sample, Loch Fyne 01
91	11/10/2007	18:44	NN 16786 10010	216786	710010		Corner oyster trestles (4)
92	11/10/2007	18:45	NN 16771 10021	216771	710021		Corner oyster trestles (4)
93	11/10/2007	18:45	NN 16788 10039	216788	710039		Corner oyster trestles (4)
94	11/10/2007	18:45	NN 16799 10031	216799	710031		Corner oyster trestles (4)
95	11/10/2007	18:46	NN 16764 10032	216764	710032		Corner oyster trestles (5)
96	11/10/2007	18:46	NN 16745 10051	216745	710051		Corner oyster trestles (5)
97	11/10/2007	18:47	NN 16791 10060	216791	710060		Corner oyster trestles (5)
98	11/10/2007	18:47	NN 16788 10066	216788	710066		Corner oyster trestles (5)
99	11/10/2007	18:48	NN 16806 10086	216806	710086		Corner oyster trestles (5)
100	11/10/2007	18:48	NN 16798 10095	216798	710095		Corner oyster trestles (5)
101	11/10/2007	18:48	NN 16791 10091	216791	710091		Corner oyster trestles (5) (north 2 m)
102	11/10/2007	18:53	NN 16755 10068	216755	710068		Freshwater sample LF 41
103	11/10/2007	18:54	NN 16855 10114	216855	710114		Corner oyster trestles (6)
104	11/10/2007	18:54	NN 16844 10126	216844	710126		Corner oyster trestles (6)
105	11/10/2007	18:55	NN 16885 10143	216885	710143		Corner oyster trestles (6)
106	11/10/2007	18:55	NN 16872 10157	216872	710157		Corner oyster trestles (6)
107	11/10/2007	18:57	NN 16765 10049	216765	710049		Oyster sample, Loch Fyne 02
108	11/10/2007	19:00	NN 17132 10255	217132	710255		Corner oyster trestles (7)
109	11/10/2007	19:01	NN 17123 10263	217123	710263		Corner oyster trestles (7)
110	11/10/2007	19:01	NN 17143 10263	217143	710263		Corner oyster trestles (7)
111	11/10/2007	19:01	NN 17147 10258	217147	710258		Corner oyster trestles (7)
112	11/10/2007	19:02	NN 17185 10294	217185	710294		Corner oyster trestles (7)
113	11/10/2007	19:02	NN 17176 10303	217176	710303		Corner oyster trestles (7)
114	11/10/2007	19:04	NN 17192 10298	217192	710298		Corner oyster trestles (8)
115	11/10/2007	19:04	NN 17182 10308	217182	710308		Corner oyster trestles (8)
116	11/10/2007	19:04	NN 17204 10309	217204	710309		Corner oyster trestles (8)
117	11/10/2007	19:05	NN 17201 10313	217201	710313		Corner oyster trestles (8)

No.	Date	Time	NGR	East	North	Associated photograph	Description
118	11/10/2007	19:05	NN 17210 10321	217210	710321		Corner oyster trestles (8)
119	11/10/2007	19:05	NN 17200 10331	217200	710331		Corner oyster trestles (8)
120	11/10/2007	19:06	NN 17213 10330	217213	710330		Corner oyster trestles (9)
121	11/10/2007	19:06	NN 17203 10341	217203	710341		Corner oyster trestles (9)
122	11/10/2007	19:06	NN 17223 10341	217223	710341		Corner oyster trestles (9)
123	11/10/2007	19:07	NN 17213 10353	217213	710353		Corner oyster trestles (9)
124	11/10/2007	19:08	NN 17253 10355	217253	710355		Corner oyster trestles (10)
125	11/10/2007	19:08	NN 17237 10367	217237	710367		Corner oyster trestles (10)
126	11/10/2007	19:09	NN 17293 10399	217293	710399		Corner oyster trestles (10)
127	11/10/2007	19:09	NN 17302 10394	217302	710394		Corner oyster trestles (10)
128	11/10/2007	19:10	NN 17308 10397	217308	710397		Corner oyster trestles (10)
129	11/10/2007	19:10	NN 17291 10413	217291	710413		Corner oyster trestles (10)
130	11/10/2007	19:11	NN 17334 10404	217334	710404		Corner oyster trestles (11)
131	11/10/2007	19:11	NN 17320 10417	217320	710417		Corner oyster trestles (11)
132	11/10/2007	19:12	NN 17344 10415	217344	710415		Corner oyster trestles (11)
133	11/10/2007	19:12	NN 17352 10416	217352	710416		Corner oyster trestles (11)
134	11/10/2007	19:12	NN 17370 10438	217370	710438		Corner oyster trestles (11)
135	11/10/2007	19:13	NN 17363 10442	217363	710442		Corner oyster trestles (11)
136	11/10/2007	19:14	NN 17418 10525	217418	710525		Corner oyster trestles (11)
137	11/10/2007	19:14	NN 17400 10535	217400	710535		Corner oyster trestles (11)
138	11/10/2007	19:15	NN 17423 10543	217423	710543		Corner oyster trestles (12)
139	11/10/2007	19:15	NN 17404 10557	217404	710557		Corner oyster trestles (12)
140	11/10/2007	19:16	NN 17139 10275	217139	710275		Seawater sample LF 42
141	11/10/2007	19:16	NN 17399 10552	217399	710552		Corner oyster trestles (12); and 136 plus 5 m out
142	11/10/2007	19:16	NN 17143 10270	217143	710270		Fyne (sea)water sample LF43
143	11/10/2007	19:17	NN 17437 10564	217437	710564		Corner oyster trestles (12)
144	11/10/2007	19:17	NN 17432 10571	217432	710571		Corner oyster trestles (12)
145	11/10/2007	19:18	NN 17435 10576	217435	710576		Corner oyster trestles (12)
146	11/10/2007	19:18	NN 17420 10589	217420	710589		Corner oyster trestles (12); and 140 plus 5 m out
147	11/10/2007	19:26	NN 17149 10259	217149	710259		Oyster sample Loch Fyne 03
148	11/10/2007	19:44	NN 17426 10554	217426	710554		Oyster sample Loch Fyne 04
149	11/10/2007	19:55	NN 17440 10487	217440	710487		Cage
150	12/10/2007	07:01	NN 09544 08313	209544	708313		Sewage pumping station
151	12/10/2007	07:12	NN 09446 08229	209446	708229		Culverted stream; Freshwater sample LF50; 1.66 m wide 1 cm deep 1.87 m in 1.8 secs; plus surface water outlets in sea wall
152	12/10/2007	07:21	NN 09535 08254	209535	708254		End of 150 mm iron pipe; no flow; mussel shells and occasional

No.	Date	Time	NGR	East	North	Associated photograph	Description
							cockle shell on shore
153	12/10/2007	07:24	NN 09571 08265	209571	708265		Approximately 350 mm diameter rubberised pipe through concrete outer; sealed off
154	12/10/2007	07:32	NN 09593 08271	209593	708271	Figure 19	500 mm concrete pipe with plastic sections; end about 8 m further out
155	12/10/2007	07:34	NN 09593 08269	209593	708269		Seawater sample LF51
156	12/10/2007	08:05	NN 09851 09064	209851	709064	Figure 20	River Aray - east end of eastern arch of bridge; width 18.6 m; depth 16 cm; flow 0.42 m/s; Freshwater sample LF52
157	12/10/2007	08:07	NN 09839 09050	209839	709050		River Aray - west end of eastern arch of bridge
158	12/10/2007	08:07	NN 09837 09042	209837	709042		River Aray - east end of western arch of bridge; width 23.1 m; depth 18 cm; flow 0.7 m/s
159	12/10/2007	08:09	NN 09815 09035	209815	709035		River Aray - west end of western arch of bridge
160	12/10/2007	08:32	NN 11411 10079	211411	710079		No record made
161	12/10/2007	08:32	NN 11405 10083	211405	710083	Figure 21	River Shira - bank at bridge; width 17.8 m; depth 25 cm; flow 0.42 m/s; Freshwater sample LF53
162	12/10/2007	08:33	NN 11389 10091	211389	710091		River Shira - bank at bridge
163	12/10/2007	08:57	NN 19435 12643	219435	712643		River Fyne, 30cm deep, flow 0.13 m/s, width 32.3 m, Freshwater sample LF54
164	12/10/2007	09:00	NN 19432 12634	219432	712634	Figure 22	River Fyne - bank at bridge
165	12/10/2007	09:01	NN 19418 12663	219418	712663		River Fyne - bank at bridge (8 sheep in field on hill above)
166	12/10/2007	09:07	NN 18992 12709	218992	712709		About 30 sheep in field approx 100m back from entrance to Loch Fyne Oysters
167	12/10/2007	09:08	NN 18973 12674	218973	712674		Roadside outside Loch Fyne Oyster Restaurant; large house next to complex; 20 sheep in field on south side of road; hills above - some woods but mainly grass/heather
168	12/10/2007	09:20	NN 18896 12633	218896	712633	Figures 23 & 24	Stream with presumed septic tank outlet from Loch Fyne complex; no sanitary waste; 1.3 m wide 7 cm deep 10.3 secs for 2 m; sewage fungus; Freshwater sample LF55
169	12/10/2007	09:29	NN 18790 12478	218790	712478		Seawater sample LF56
170	12/10/2007	09:32	NN 18765 12540	218765	712540		Very small stream; not sampled
171	12/10/2007	10:07:05	NN 14790 09885	214790	709885		Stream, Freshwater sample LF57, 30cm x 5cm flow 0.75, photo taken square culvert
172	12/10/2007	10:21:34	NN 14857 09910	214857	709910		Deer tracks on shore, possibly 2 animals
173	12/10/2007	10:27	NN 14795 09881	214795	709881		Start of survey section
174	12/10/2007	10:28:49	NN 14889 09934	214889	709934		Surface water runoff, dribble not sampled
175	12/10/2007	10:30:33	NN 14937 09964	214937	709964		Small stream not sampled
176	12/10/2007	10:36:19	NN 15171 10129	215171	710129		Stream, 80cm x 5 cm x 0.10m/s, Freshwater sample LF58
177	12/10/2007	10:40:50	NN 15270 10190	215270	710190		Stream, not sampled

No.	Date	Time	NGR	East	North	Associated photograph	Description
178	12/10/2007	10:43:33	NN 15345 10241	215345	710241		Small stream, trickle, not sampled
179	12/10/2007	10:45:11	NN 15399 10276	215399	710276		Asphalt tipped onto shoreline
180	12/10/2007	10:46:36	NN 15431 10307	215431	710307		Stream, 1.1m x 20cm x0.10 m/s, Freshwater sample LF59
181	12/10/2007	10:50	NN 15490 10332	215490	710332		Heavily wooded above; deciduous lower, coniferous upper
182	12/10/2007	10:53:06	NN 15543 10409	215543	710409		No record made
183	12/10/2007	10:53:33	NN 15543 10410	215543	710410		No record made
184	12/10/2007	10:55:05	NN 15546 10413	215546	710413		Stream, 55cm x 5 cm x 0.27m/s, Freshwater sample LF60
185	12/10/2007	10:58:56	NN 15575 10431	215575	710431		Seawater sample LF61
186	12/10/2007	11:00:28	NN 15596 10464	215596	710464		Stream, not sampled
187	12/10/2007	11:08	NN 15600 10463	215600	710463		Photographs taken across loch towards depuration plant
188	12/10/2007	11:09:38	NN 15643 10493	215643	710493		No record made
189	12/10/2007	11:10:04	NN 15643 10493	215643	710493		V.small stream not sampled
190	12/10/2007	11:12:39	NN 15651 10523	215651	710523		Stream, 25cm x 1.5cm x 1.12m/s, bright green algal growth at shoreline, Freshwater sample LF62
191	12/10/2007	11:20:40	NN 15755 10564	215755	710564		V.small stream not sampled
192	12/10/2007	11:23:04	NN 15825 10594	215825	710594		Surface water runoff over broad area, too shallow to sample
193	12/10/2007	11:26:52	NN 15865 10602	215865	710602		Bright green algal growth at shoreline behind house, Seawater sample LF63
194	12/10/2007	11:29:07	NN 15898 10644	215898	710644		Broad, v. shallow stream across shore, not sampled
195	12/10/2007	11:30:56	NN 15936 10670	215936	710670		Surface water runoff, not sampled
196	12/10/2007	11:32:21	NN 15969 10695	215969	710695		House on shoreline
197	12/10/2007	11:38:52	NN 16038 10737	216038	710737		Stream adjacent to house above, 27cmx6cmx0.44m/s, Freshwater sample LF64
198	12/10/2007	11:39:03	NN 16038 10737	216038	710737		Stream with some foam, 22cmx25cmx0.17m/s, see waypoint 140
199	12/10/2007	11:39:23	NN 16035 10731	216035	710731		Sample from above stream, Freshwater sample LF65
200	12/10/2007	11:42:27	NN 16140 10773	216140	710773		Stream not sampled
201	12/10/2007	11:45:44	NN 16301 10874	216301	710874		Stream, 60cmx10cmx0.22m/s, Freshwater sample LF66
202	12/10/2007	11:48	NN 16328 10886	216328	710886		End of survey section
203	12/10/2007	11:50:09	NN 16332 10888	216332	710888		Seawater sample LF67
204	12/10/2007	12:02:03	NN 16871 11175	216871	711175		Large stream, 85cmx5cmx1.15m/s, Freshwater sample LF68

Photographs referenced in the table can be found attached as Figures 9-24.

Table 4. Salinity profiles

Site	NGR	Depth (metres)	Salinity (ppt)	Temperature (ºC)
East Block mussels	NN 16545 10111	1	30.5	14.4
East Block mussels	NN 16545 10111	5	30.7	14.3
East Block mussels	NN 16545 10111	10	31.0	13.9
East Block mussels	NN 16693 10209	1	30.6	14.0
East Block mussels	NN 16693 10209	5	31.2	13.4
East Block mussels	NN 16693 10209	10	31.4	13.2
East Block mussels	NN 16669 10312	1	30.7	13.8
East Block mussels	NN 16669 10312	5	31.2	13.3
East Block mussels	NN 16669 10312	10	31.4	13.2
West Block mussels	NN 16067 09829	1	30.0	13.8
West Block mussels	NN 16067 09829	5	31.2	13.3
West Block mussels	NN 16067 09829	10	31.3	13.2
West Block mussels	NN 16251 09928	1	29.6	13.7
West Block mussels	NN 16251 09928	5	31.4	13.1
West Block mussels	NN 16251 09928	10	31.5	13.0

Table 5. Water Sample Results

No.	Date	Sample	Type	NGR	*E. coli* (cfu/100ml)	Salinity(g/L)
1	10/10/2007	Fyne 1	Sea Water	NN 16545 10111	40	13.5
2	10/10/2007	Fyne 2	Sea Water	NN 16693 10209	50	13.4
3	10/10/2007	Fyne 3	Sea Water	NN 16669 10312	40	15.7
4	10/10/2007	Fyne 4	Sea Water	NN 16067 09829	20	18.6
5	10/10/2007	Fyne 5	Sea Water	NN 16251 09928	30	13.9
6	10/10/2007	Fyne 6	Sea Water	NN 12909 07958	4	27.5
7	10/10/2007	Fyne 8	Fresh Water	NN 12968 07947	200	
8	10/10/2007	Fyne 9	Sea Water	NN 12982 07954	200	
9	11/10/2007	Fyne 21	Fresh Water	NN 13063 07985	300	
10	11/10/2007	Fyne 22	Fresh Water	NN 13893 08341	700	
11	11/10/2007	Fyne 23	Fresh Water	NN 14125 08369	300	
12	11/10/2007	Fyne 24	Fresh Water	NN 14515 08520	100	
13	11/10/2007	Fyne 25	Fresh Water	NN 14894 08647	1000	
14	11/10/2007	Fyne 26	Fresh Water	NN 15179 08716	1300	
15	11/10/2007	Fyne 27	Fresh Water	NN 15363 08825	200	
16	11/10/2007	Fyne 28	Fresh Water	NN 15471 08913	200	
17	11/10/2007	Fyne 29	Fresh Water	NN 16034 09535	700	
18	11/10/2007	Fyne 30	Fresh Water	NN 16323 09811	1000	
19	11/10/2007	Fyne 31	Sea Water	NN 16640 09947	80	23.5
20	11/10/2007	Fyne 32	Fresh Water	NN 16730 09972	300	
21	11/10/2007	Fyne 33	Sea Water	NN 16732 09970	23	23.8
22	11/10/2007	Fyne 34	Fresh Water	NN 16746 09961	<100	
23	11/10/2007	Fyne 35	Fresh Water	NN 16843 10018	100	
24	11/10/2007	Fyne 36	Fresh Water	NN 17248 10304	100	
25	11/10/2007	Fyne 37	Fresh Water	NN 17371 10347	3000	
26	11/10/2007	Fyne 38	Fresh Water	NN 18004 10730	200	
27	11/10/2007	LF40	Sea Water	NN 16409 09930	150	
28	11/10/2007	LF41	Sea Water	NN 16755 10068	700	
29	11/10/2007	LF42	Sea Water	NN 17139 10275	380	
30	11/10/2007	LF43	Sea Water	NN 17143 10270	2500	
31	12/10/2007	LF50	Fresh Water	NN 09446 08229	<100	
32	12/10/2007	LF51	Sea Water	NN 09593 08269	62	
33	12/10/2007	LF52	Fresh Water	NN 09851 09064	100	
34	12/10/2007	LF53	Fresh Water	NN 11405 10083	100	
35	12/10/2007	LF54	Fresh Water	NN 19435 12643	<100	
36	12/10/2007	LF55	Fresh Water	NN 18896 12633	>100000	
37	12/10/2007	LF56	Sea Water	NN 18790 12478	1100	
38	12/10/2007	LF57	Fresh Water	NN 14790 09885	100	
39	12/10/2007	LF58	Fresh Water	NN 15171 10129	<100	
40	12/10/2007	LF59	Fresh Water	NN 15431 10307	<100	
41	12/10/2007	LF60	Fresh Water	NN 15546 10413	<100	
42	12/10/2007	LF61	Sea Water	NN 15575 10431	340	
43	12/10/2007	LF62	Fresh Water	NN 15651 10523	<100	
44	12/10/2007	LF63	Sea Water	NN 15865 10602	380	
45	12/10/2007	LF64	Fresh Water	NN 16038 10737	100	
46	12/10/2007	LF65	Fresh Water	NN 16035 10731	<100	
47	12/10/2007	LF66	Fresh Water	NN 16301 10874	<100	
48	12/10/2007	LF67	Fresh Water	NN 16332 10888	1000	
49	12/10/2007	LF68	Fresh Water	NN 16871 11175	<100	

Table 6. Shellfish Sample Results

No.	Date	Sample	Type	NGR	*E. coli* (MPN/100g)	Depth (metres)	Norovirus Genogroup I	II
1	10/10/2007	Fyne 11	Mussels	NN 16545 10111	20	0 to 1	ND	ND
2	10/10/2007	Fyne 12	Mussels	NN 16693 10209	310	Surface	ND	ND
3	10/10/2007	Fyne 13	Mussels	NN 16693 10209	220	2	ND	ND
4	10/10/2007	Fyne 14	Mussels	NN 16693 10209	40	5	ND	ND
5	10/10/2007	Fyne 15	Mussels	NN 16669 10312	70	0.5	ND	ND
6	10/10/2007	Fyne 16	Mussels	NN 16669 10312	70	5	ND	ND
7	10/10/2007	Fyne 17	Mussels	NN 16067 09829	110	1	ND	ND
8	10/10/2007	Fyne 18	Mussels	NN 16251 09928	130	1	ND	ND
9	11/10/2007	OY1	Oysters	NN 16411 09921	110	N/A	Neg	Pos
10	11/10/2007	OY2	Oysters	NN 16765 10049	310	N/A	Neg	Pos
11	11/10/2007	OY3	Oysters	NN 17149 10259	1300	N/A	Neg	Pos
12	11/10/2007	OY4	Oysters	NN 17426 10554	ND	N/A	Neg	Pos

N/A = Not applicable ND = Not done

Fig. 5. Water sample results map – South Western end of survey

Loch Fyne - Ardkinglas Survey - South Western End - Water Samples

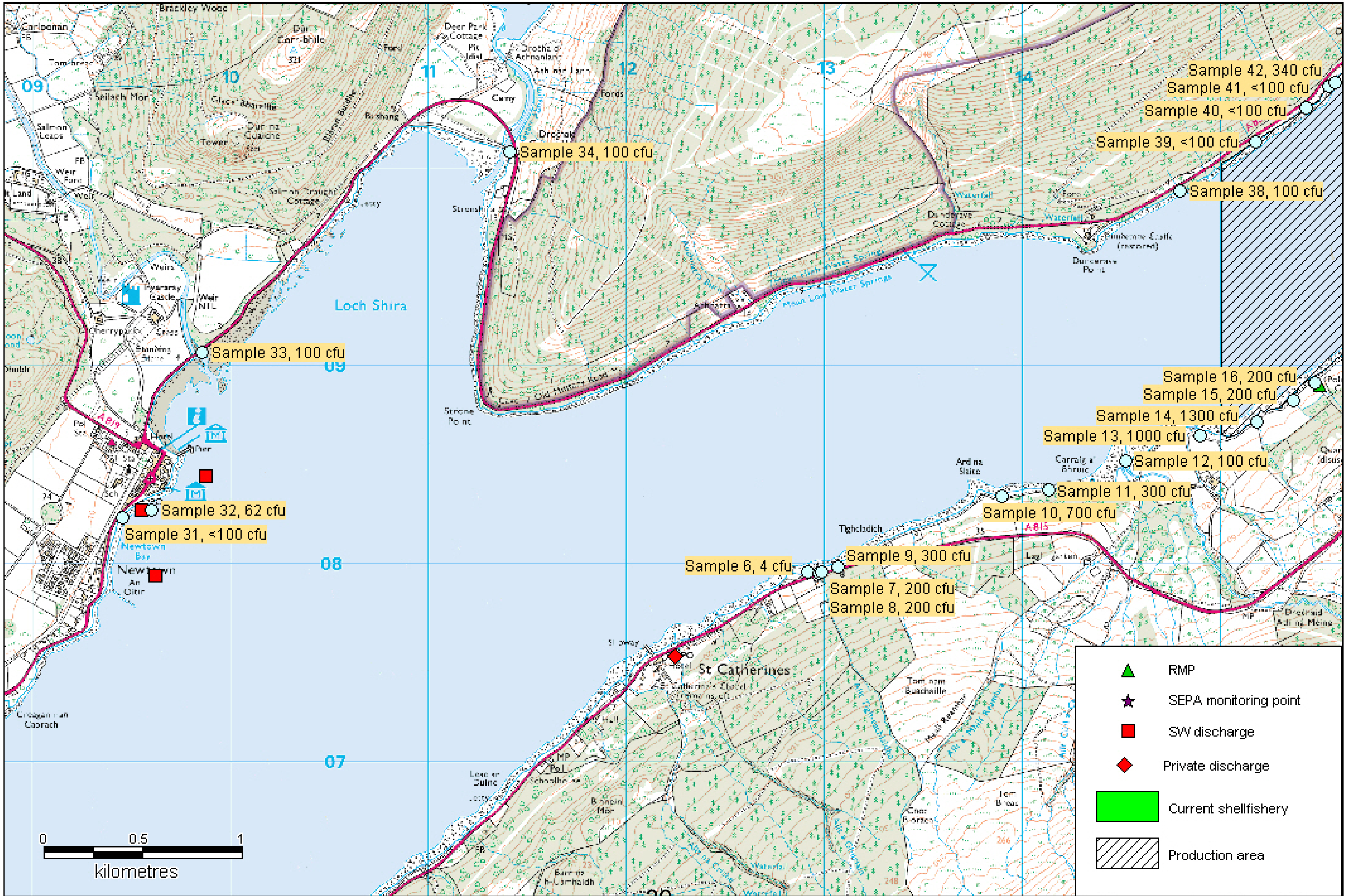


Fig. 6. Water sample results map – middle section of survey

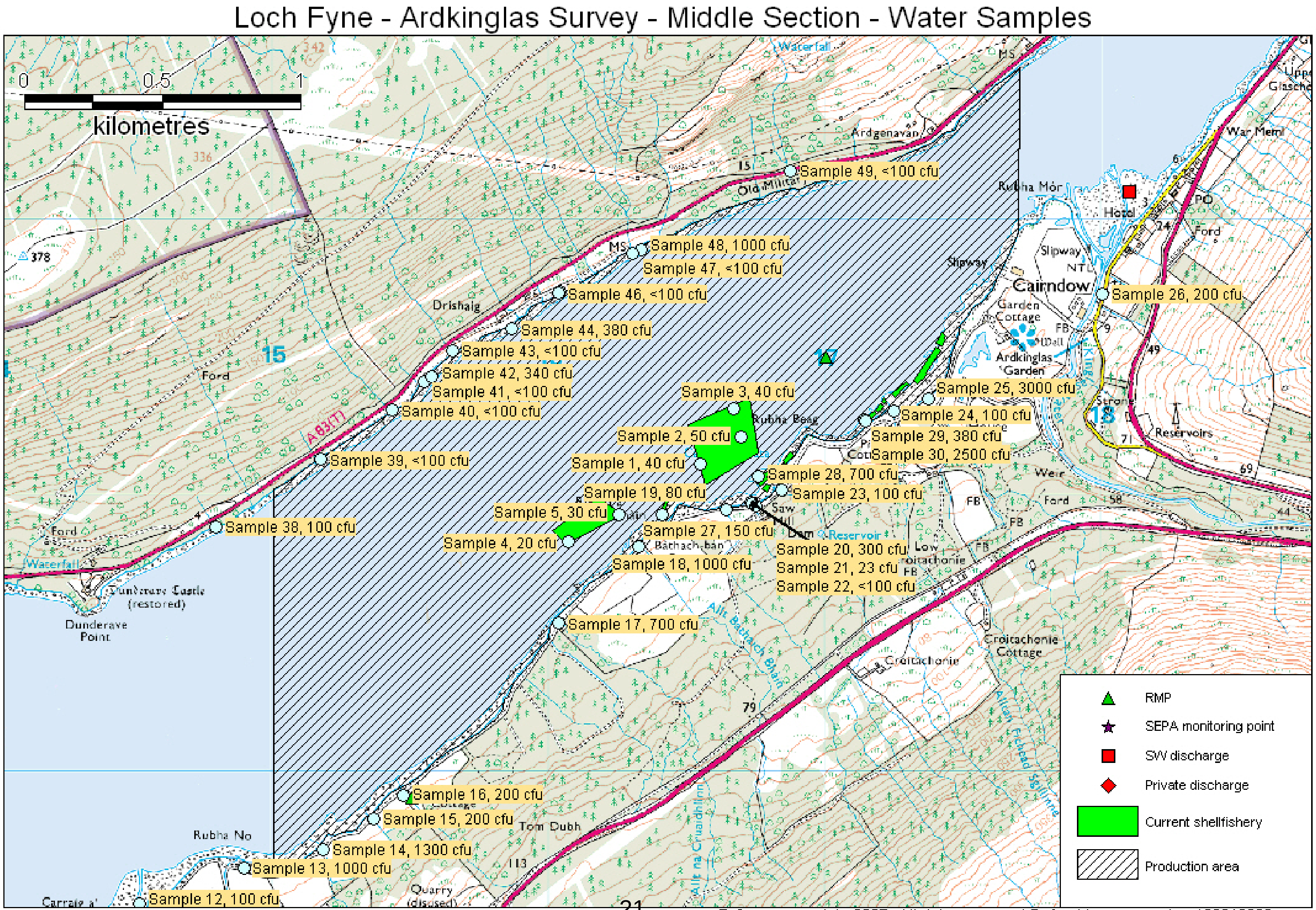


Fig. 7. Water sample results map – North Eastern end of survey

Loch Fyne - Ardkinglas Survey - North Eastern End - Water Samples

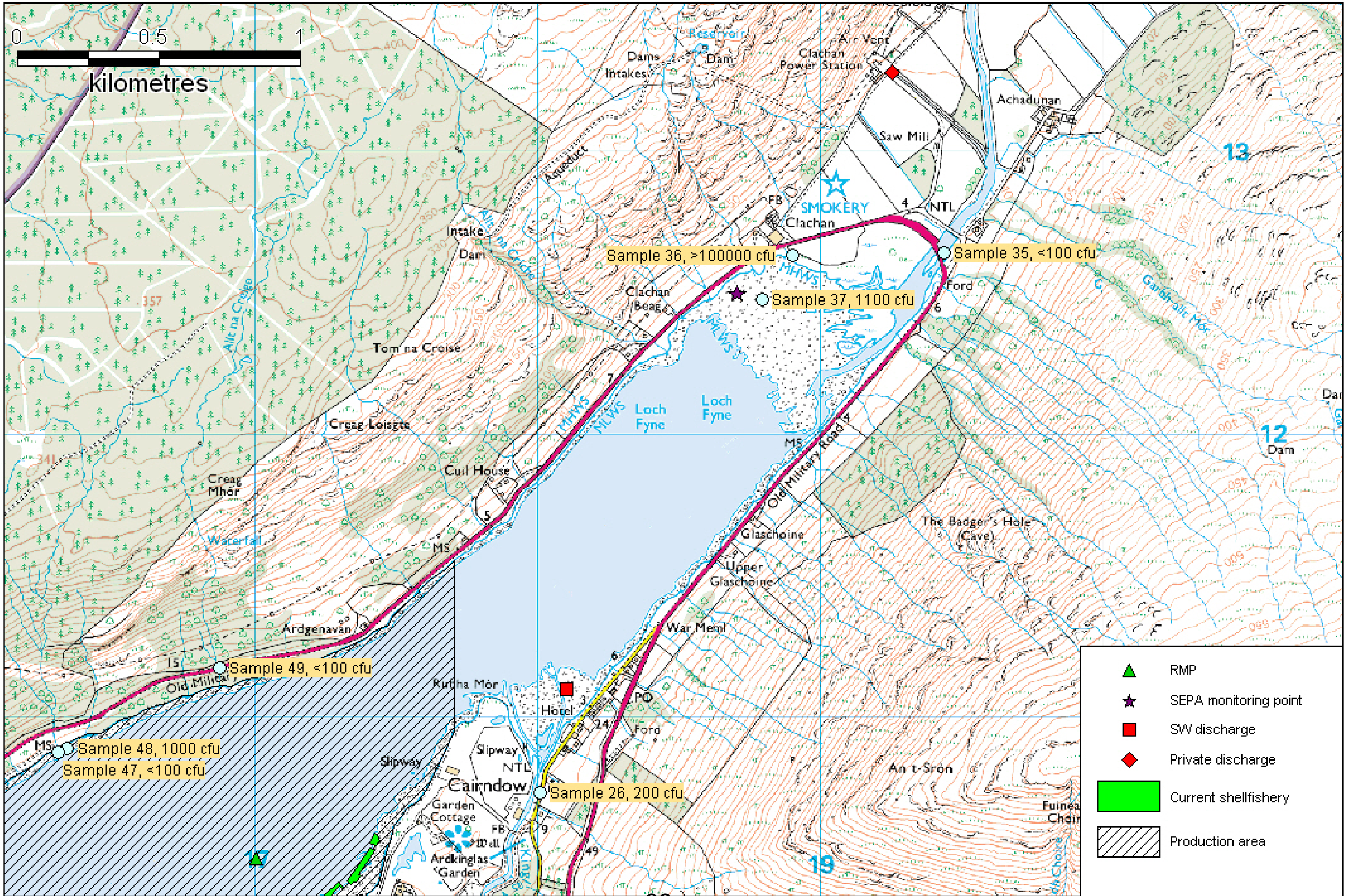
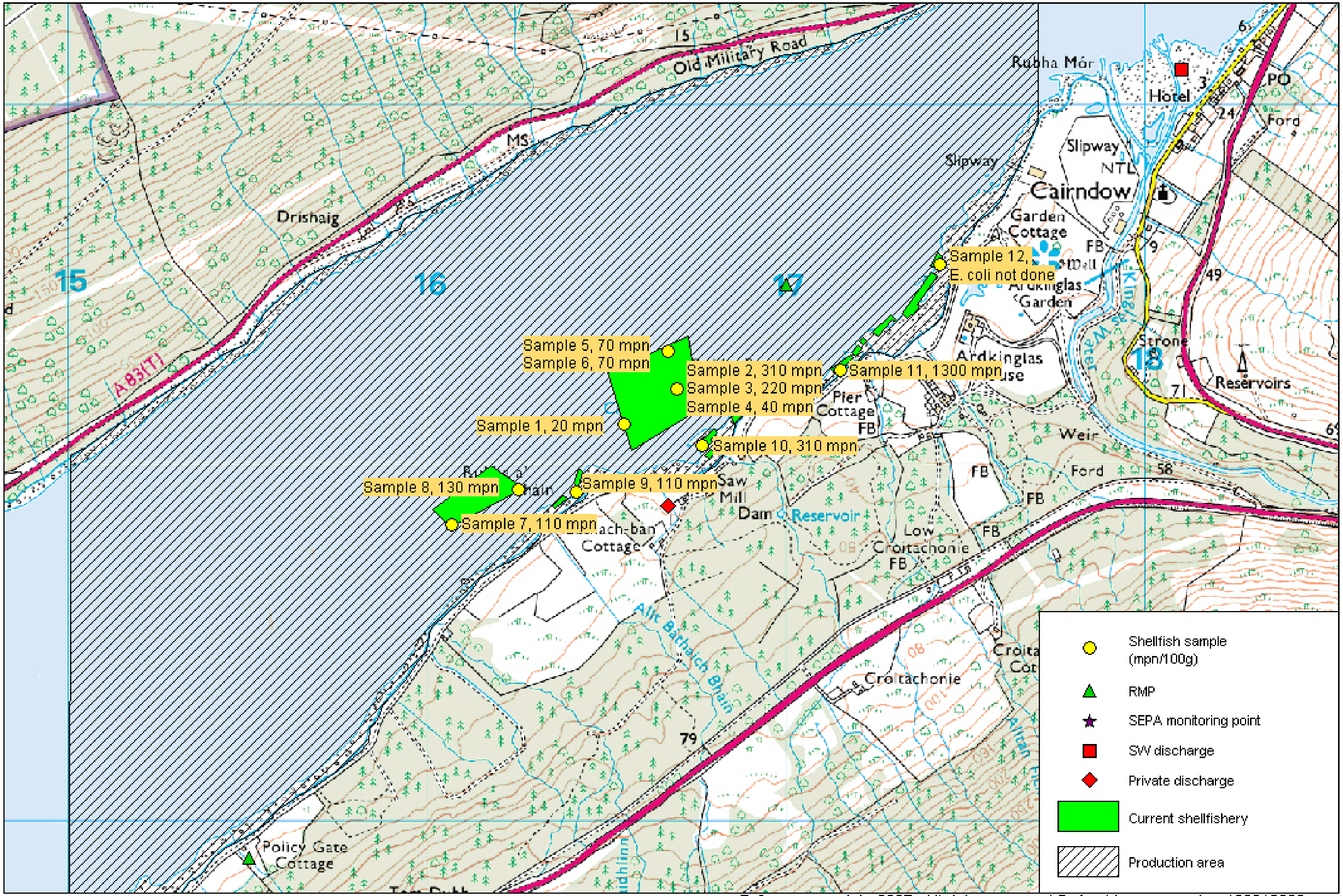


Figure 8 Shellfish sample results map

Loch Fyne - Ardkinglas Survey - Shellfish Samples



Photographs

Figure 9. East block mussels

Figure 10. Large stream

Figure 11. Sheep in field above shore

Figure 12. Stream

Figure 13. Presumed septic tank outlet

Figure 14. Stream, pipes and houses by depuration plant

Figure 15. Stream

Figure 16. Panfish plant

Figure 17. Kinglas Water

Figure 18. Oyster trestles at dusk (mussel lines in background)

Figure 19. Inverarary – outfall pipe at dawn

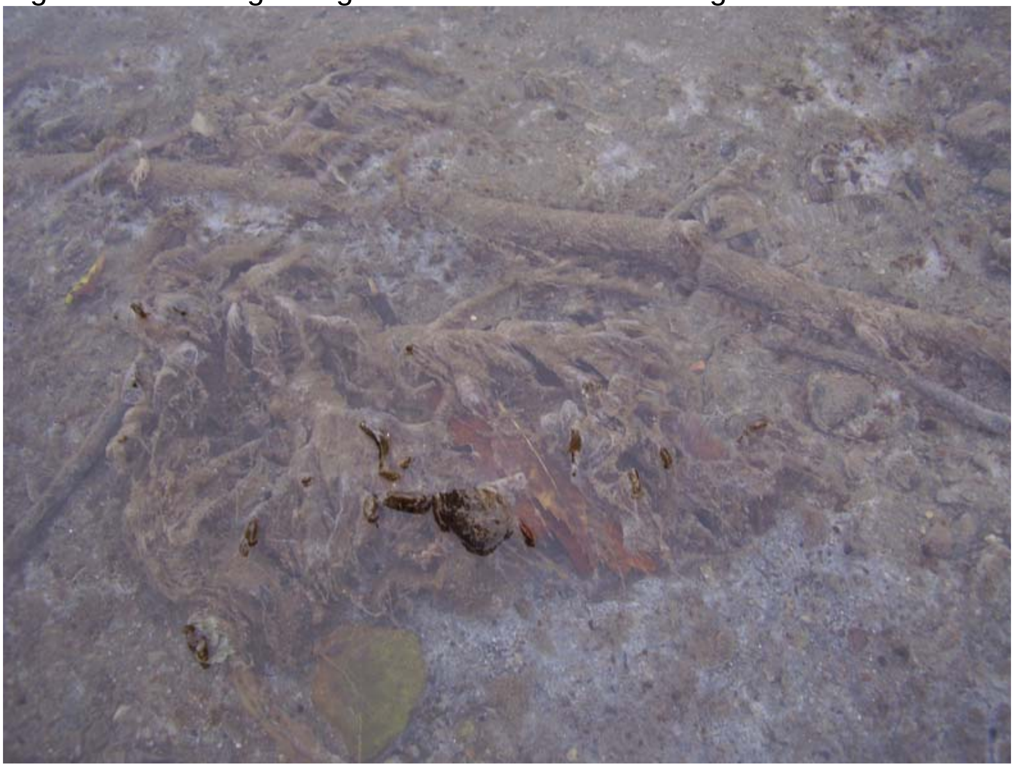
Figure 20. River Aray

Figure 21. River Shira

Figure 22. River Fyne

Figure 23. Stream with presumed septic tank outlet (hidden by tyre)

Figure 24. “Sewage fungus” in stream shown in Figure 23.



Norovirus Survey Report

Summary report on norovirus testing at Loch Fyne Ardkinglas
October 2007 to September 2008

Introduction

The Pacific oyster fishery at Loch Fyne Ardkinglas consists of 12 discrete sets of trestles stretching along approximately 1.3 km of the south shore of Loch Fyne, just to the west of the small settlement of Cairndow. In addition to the shellfish grown in the area, oysters are brought in from other production areas, held in holding tanks which are effectively an extension of the production area as non-disinfected water from the Loch is used in these tanks. They are then depurated and distributed. Relatively high volumes of oysters are produced and distributed from the area. The fishery has been classified as predominantly A class in recent years, with periods of B class during the summer and autumn.

During the summer of 2007, an outbreak of viral gastroenteritis involving 21 cases and approximately 100 people was reported to Cefas from a number of restaurants nationwide. The suspected cause of this outbreak was norovirus contamination in Pacific oysters (*Crassostrea gigas*) from the Loch Fyne Ardkinglas production area. As part of the response to this outbreak, the Food Standards Agency Scotland commissioned a sanity survey of the production area.

The sanitary survey identified the three most significant sources of human faecal contamination. These are listed in Table 1. A map of the fishery and these discharges is presented in Figure 1.

Table 1. Sources of human contamination to Ardkinglas production area

Name	Location	Description
Cairndow	NN 181 113	Scottish Water septic tank, population equivalent of 34, continuous discharge, outfall is approximately 130m offshore from the low water mark in a depth of 10-20m.
Panfish	NN 17654 10849	Fish processing plant septic tank, approximately 50 employees during normal working hours, outfall is believed to be just beyond the low water mark.
LFO depuration plant	NN 16795 09948	Depuration plant septic tank, less than 10 employees during normal working hours, outfall is believed to be just beyond the low water mark.

The outfalls for the Panfish septic tanks and the Loch Fyne Oysters depuration plant toilets discharge directly into the production area on the south shore where the shellfish are cultured. The Panfish plant has approximately 50 employees, and the depuration plant has less than 10. Both these establishments would only be in full use during working hours. Just to the east of the production area boundaries, a Scottish Water communal septic tank at Cairndow with a population equivalent of

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Cefas is an executive agency of Defra

34 discharges about 130 m out from the low water mark on the south shore. The rest of the population of the village are currently served by a number of private septic tanks.

As part of the sanitary survey of Loch Fyne: Ardkinglas, monthly samples were taken for norovirus testing from four locations within the production area over a 12 month period to investigate temporal and geographical trends in levels of norovirus contamination. This report aims to present and evaluate the results of this testing programme.

Methods

Pacific oyster samples were collected from four locations within the production area starting on the 11/10/2007 and continuing for 12 months. The sites, from the northeast to the southwest were named Ardkinglas Gardens, Pier Cottage, Saw Mill and Bathach-ban Cottage. On one occasion, only two of the four sites were sampled (December 2007). The locations of these sampling points are shown in Figure 1.

Samples were despatched immediately after collection under temperature controlled conditions to the Cefas Weymouth laboratory, where they were tested for Norovirus using a semi-quantitative real-time reverse transcription PCR technique as described in detail by Lowther *et al* (2008).

Results are presented in PCR units for norovirus genogroups I and II. PCR units are semi quantitative units, calculated from the C_t values (the time taken for fluorescence to exceed a user defined threshold). Where the result was reported as not detected, a nominal value of 0.48 PCR units, approximately 1/2 the limit of detection (L.O.D.), was assigned for the calculation of the geometric mean, and for all other statistical evaluations and graphical presentations using log-transformed data.

In addition to the samples collected for norovirus analysis, oyster samples were taken for *E. coli* analysis on all but the first three norovirus sampling dates as part of the routine classification sampling programme. Locations sampled are shown in Figure 1. On one occasion where the result was reported as <20 it was assigned a nominal value of 10 for graphical presentation and statistical analysis. All *E. coli* results are reported as mpn/100g.

All statistical evaluations and graphical presentations were produced using the Minitab 15 statistical software package.

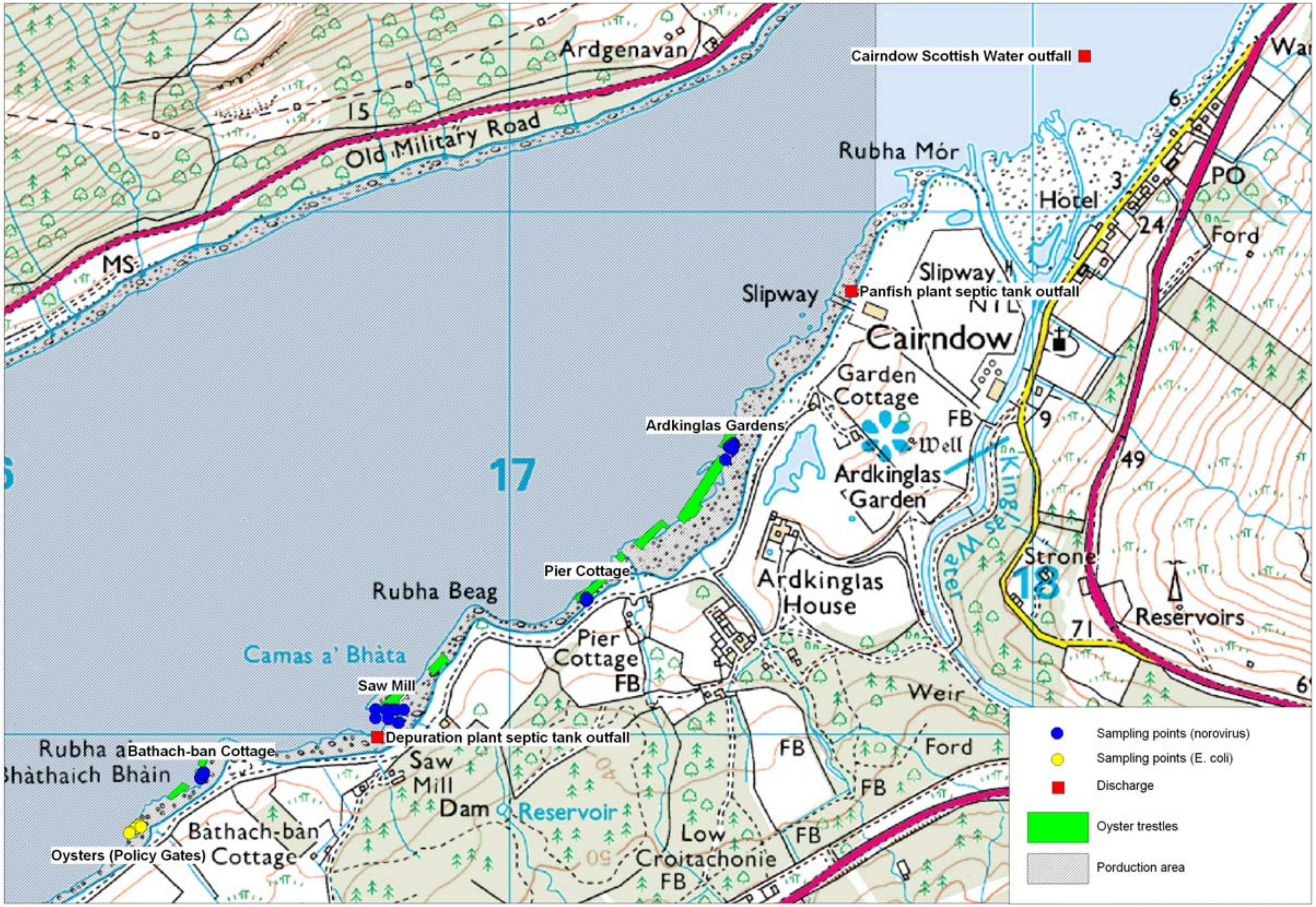

Figure 1. Map of the oyster fishery, sampling points and most significant discharges

Results

All testing results are presented in Table 2.

Table 2. All testing results in PCR units

	Norovirus Genogroup I				Norovirus Genogroup II			
	Ardkinglas	Pier Cottage	Saw Mill	Bathach-Ban	Ardkinglas	Pier Cottage	Saw Mill	Bathach-Ban
No. samples	11	12	12	11	11	12	12	11
Geometric mean result	2.4	1.9	3.2	3.3	28.0	17.5	8.2	4.7
Prevalence (%)	64%	42%	58%	64%	82%	83%	75%	55%
Results for 11/10/2007	ND	ND	ND	ND	18.5	9.1	25.2	7.3
Results for 20/11/2007	3.9	16.3	20.9	4.8	ND	8.8	ND	ND
Results for 04/12/2007	NS	1.9	8.7	NS	NS	ND	3.3	NS
Results for 15/01/2008	7.6	15.4	5.3	15.3	238.7	181.0	141.4	42.2
Results for 12/02/2008	15.4	15.3	21.1	8.2	465.0	308.1	254.9	98.6
Results for 11/03/2008	14.0	ND	4.4	9.7	176.0	26.6	24.6	102.5
Results for 08/04/2008	ND	ND	17.8	12.7	16.4	33.0	39.0	38.2
Results for 06/05/2008	ND	ND	ND	17.5	117.8	29.1	ND	ND
Results for 24/06/2008	ND	ND	ND	ND	ND	74.6	7.2	ND
Results for 08/07/2008	1.5	ND	ND	ND	70.1	45.5	15.0	7.6
Results for 04/08/2008	1.0	ND	ND	ND	36.9	ND	ND	ND
Results for 02/09/2008	28.0	38.7	25.8	7.6	20.0	9.5	2.8	ND

ND = not detected
NS = no sample

On every sampling occasion over the 12-month period at least one sample tested positive for at least one genogroup. Of the 46 samples submitted, 6 (13%) tested negative for both genogroups, 6 (13%) tested positive for genogroup I only, 14 (30%) tested positive for genogroup II only, and 20 (43%) tested positive for both genogroups. Genogroup II was more prevalent (74%) than genogroup I (57%), and was detected in at higher levels on average (geometric mean PCR units for GI was 9.6, and for GII was 36.3 for all positive testing samples).

Figure 2 presents a chart of geometric mean norovirus result for all sites sampled by genogroup and sampling date. Figures 3 and 4 present charts of norovirus result by site and sampling date for genogroups I and II respectively.

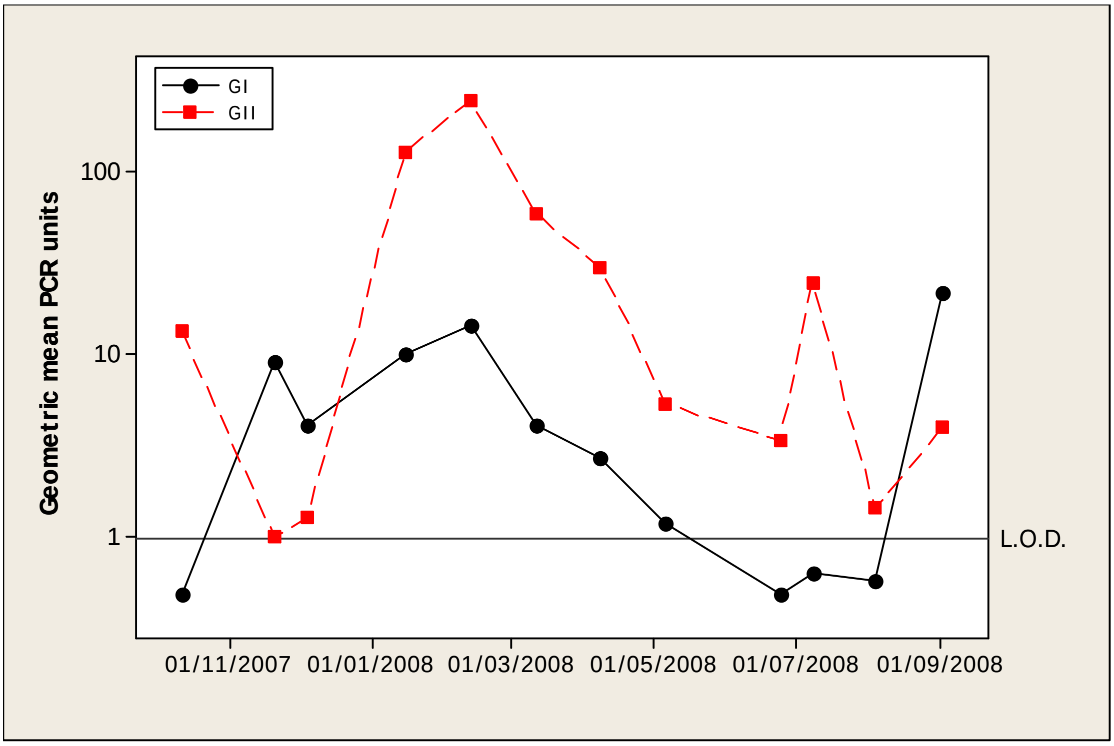

Figure 2. Geometric mean norovirus results by genogroup and date.

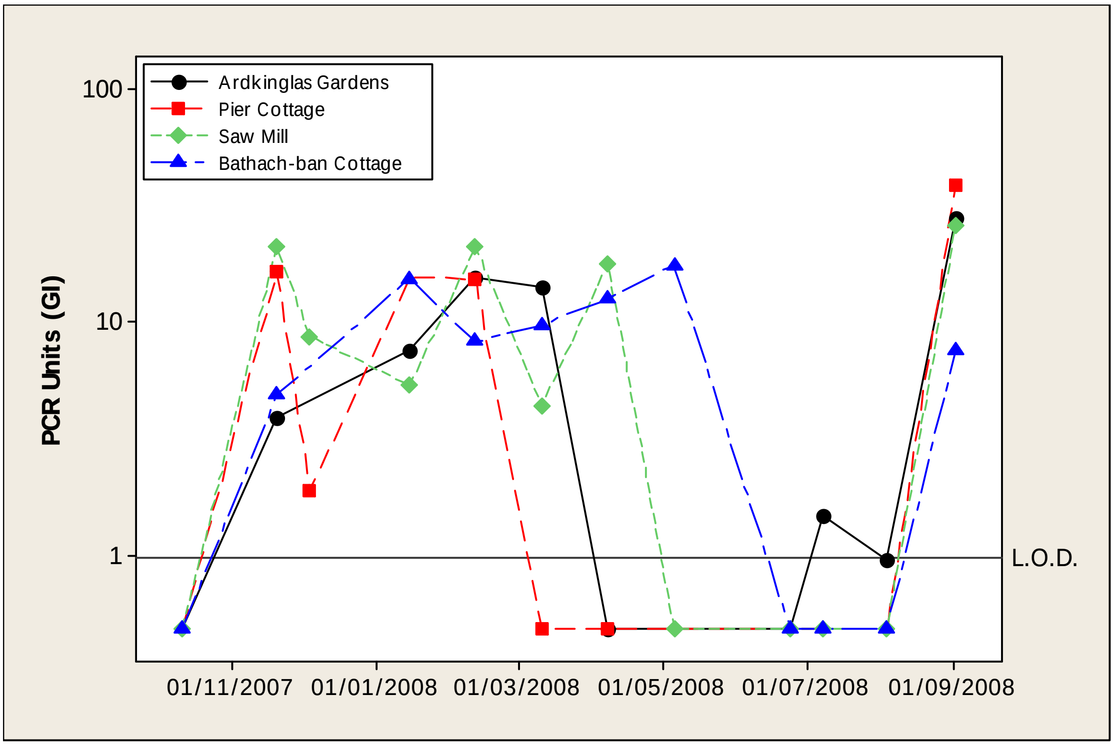

Figure 3. Norovirus genogroup I results by sampling location and date.

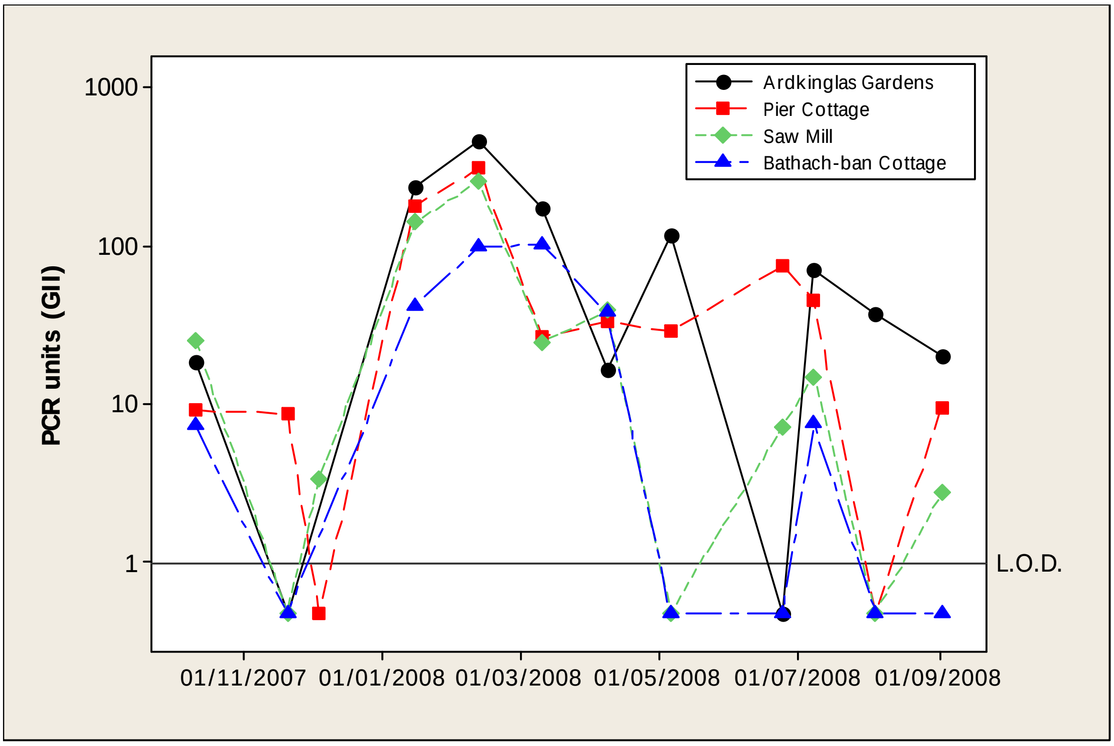

Figure 4. Norovirus genogroup II results by sampling location and date.

For genogroup I, highest mean result occurred in September 2008. Results were on average lower during the warmer months, and higher during the colder months.

For genogroup II, the highest mean result arose in February 2008, when a distinct peak in contamination was seen. A spatial pattern is apparent on the leading edge of the peak (January and February 2008) with results highest at the northeastern end of the site, and lowest at the southwestern end of the site.

Figure 5 presents a box plot of norovirus results by quarter for each genogroup (quarter 1 is January to March, quarter 2 is April to June, quarter 3 is July to September, quarter 4 is October to December).

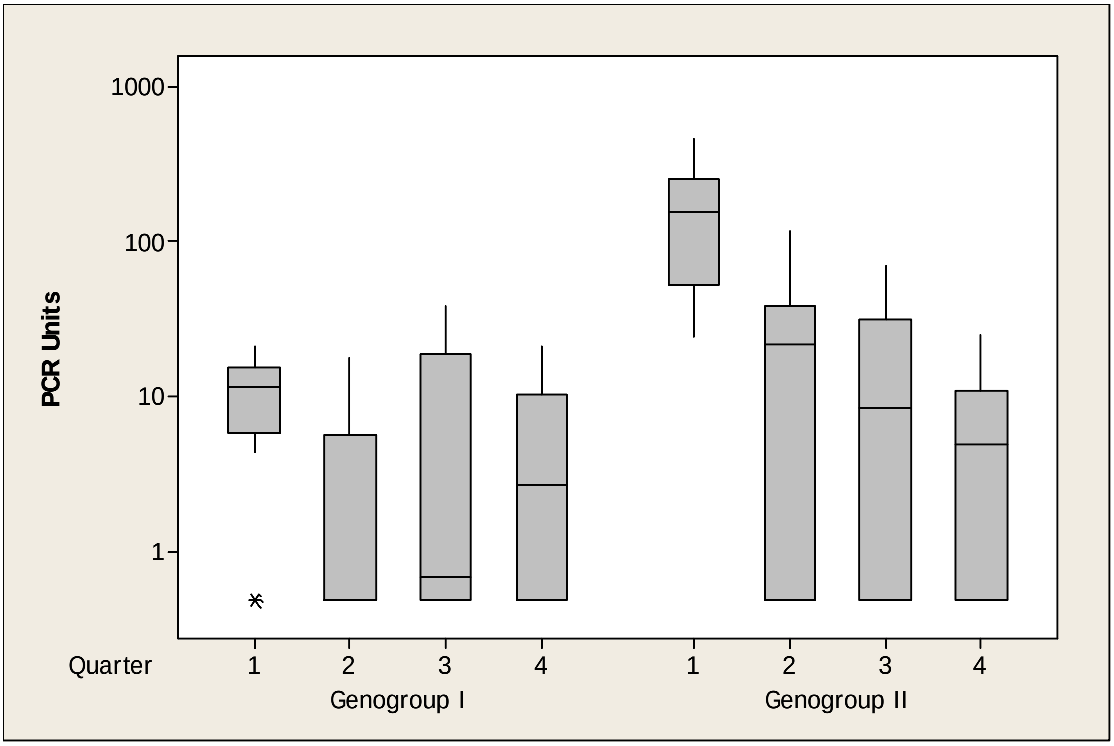

Figure 5. Box plot of norovirus results by Quarter and genotype.

For both genogroups I and II, mean results were highest during quarter 1. The differences between results for each quarter was significant for both genogroup I (one way ANOVA, p=0.020) and genogroup II (one way ANOVA, p=0.000, Appendix 1). Post ANOVA tests (Tukeys comparisons, Appendix 1) indicated that results were significantly higher for quarter 1 compared to quarter 2 for genogroup I, and for genogroup II results were significantly higher for quarter 1 compared to all other quarters.

Figure 6 presents a box plot of norovirus results by sampling location (from north east to south west) for each genogroup.

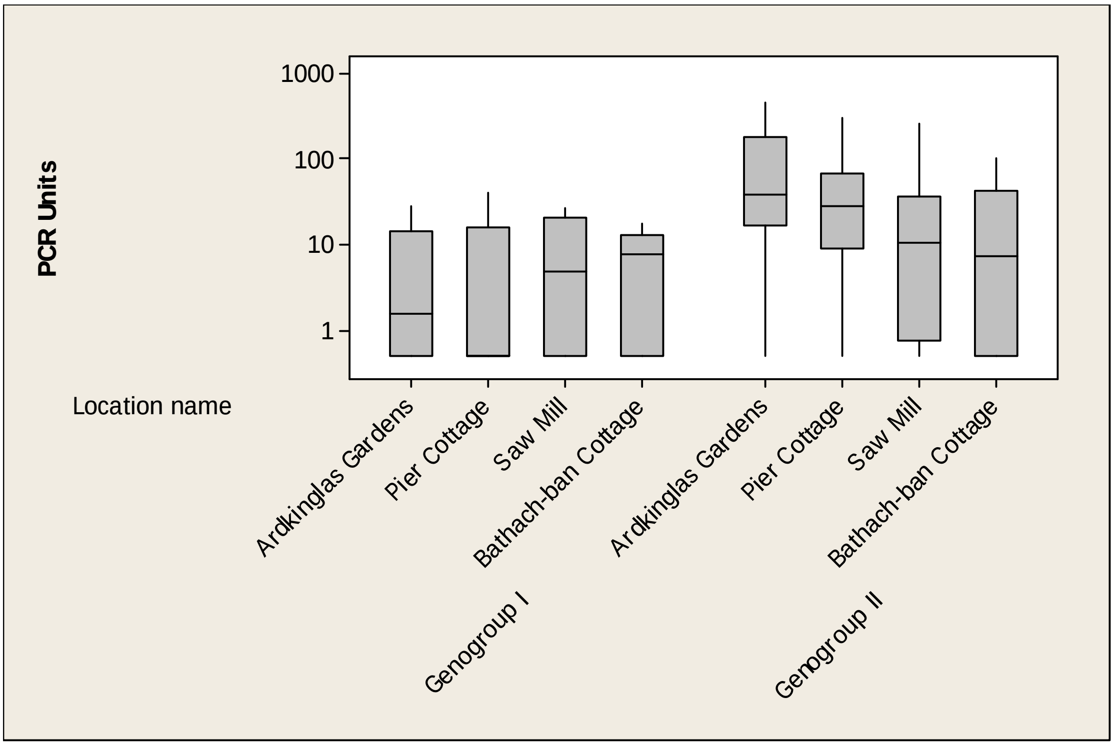

Figure 6. Box plot of norovirus results by sampling location and genotype.

No spatial pattern was apparent for genogroup I. An overall spatial pattern in contamination levels was apparent for Genogroup II, with results highest on average at the northeastern end of the shore at Ardkinglas, and lowest at the southwestern end of the shore.

A two-way analysis of variance of norovirus results was carried out using the factors sampling location and collection date for each genogroup. For genogroup I, a significant effect of collection date was found (p=0.000), but no effect of sampling location was found (p=0.475). For genogroup II significant effects were found for both collection date (p=0.000) and for sampling location (p=0.022). This confirms that the spatial pattern observed for genogroup II is statistically significant. A post ANOVA test (Tukeys comparison) indicated that the results for genogroup II were significantly higher at Ardkinglas Gardens than at Bathach-Ban Cottage. The full outputs from these tests are presented in Appendix 1.

Figure 7 presents a scatter plot of *E. coli* results for oysters, and mean norovirus result for both genogroups by date. Figure 8 presents scatter plots of mean norovirus results against shellfish results.

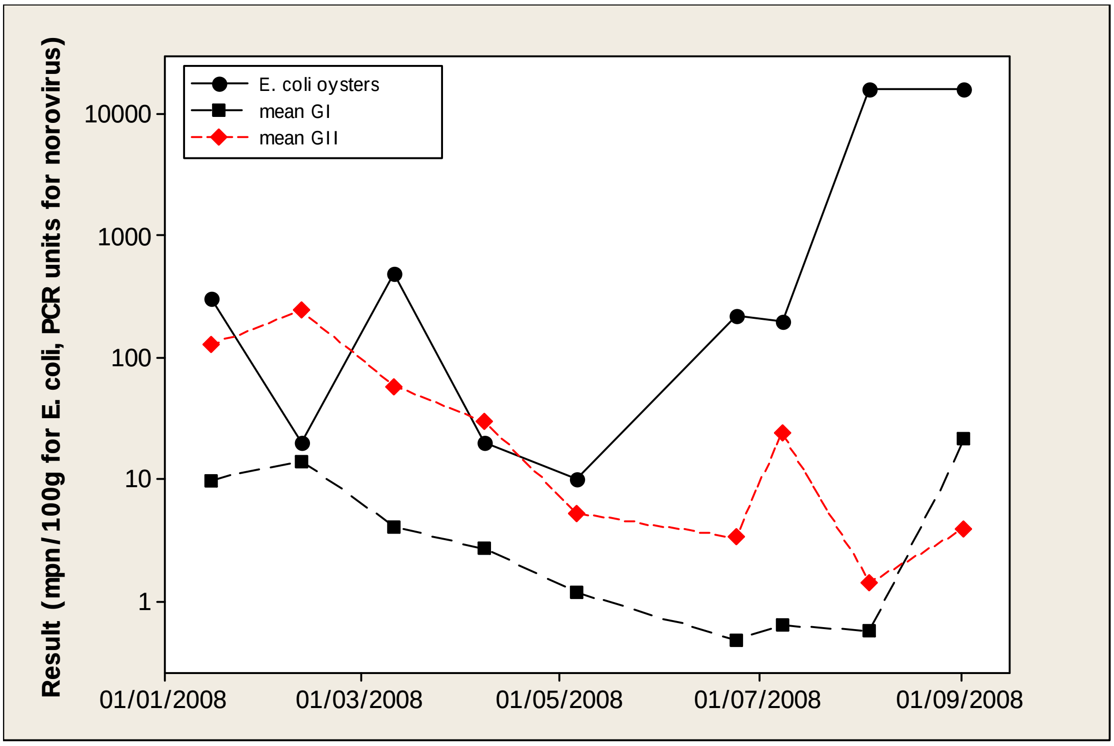

Figure 7. Time series plot of geometric mean norovirus results by genogroup *and E. coli* results

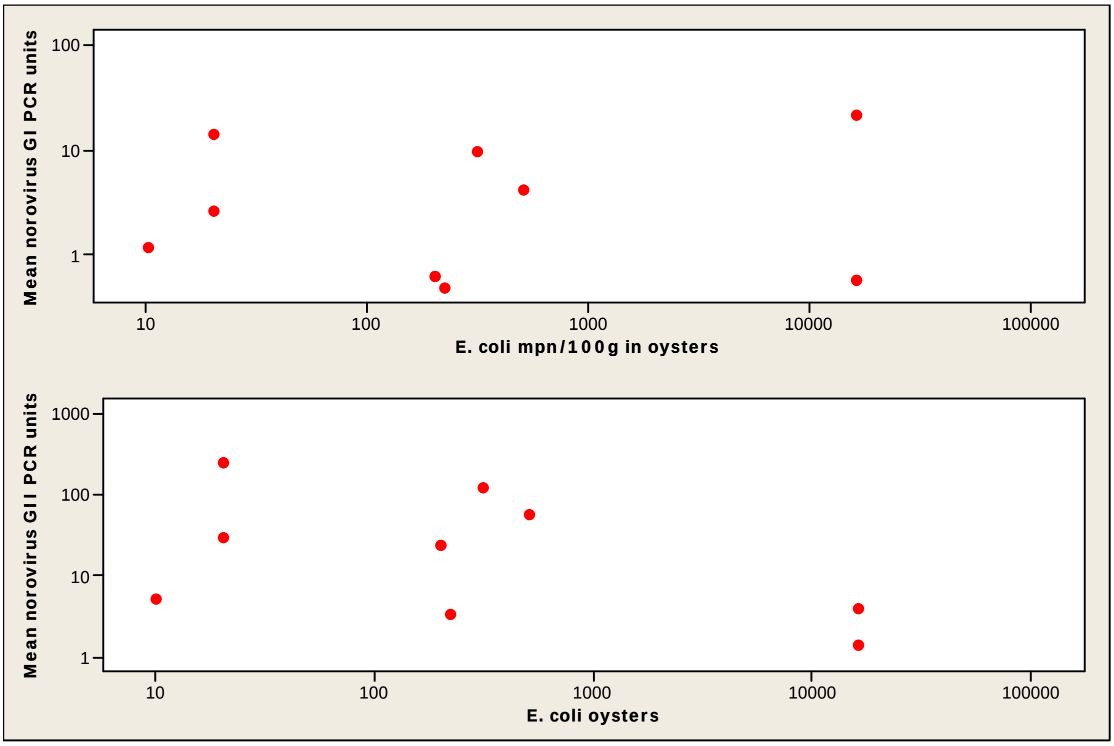

Figure 8. Scatter plots of mean norovirus results for each genogroup against *E. coli* results

No relationship between the levels of *E. coli* and norovirus are apparent in Figure 8. Coefficients of determination indicate that there was no relationship between levels of norovirus GI and *E. coli* (Adjusted R-sq=0.0%, p=0.887, Appendix 1) or norovirus GII and *E. coli* (Adjusted R-sq=14.7%, p=0.167, Appendix 1).

Conclusions

The levels and prevalence of contamination by genogroup I was lower than for genogroup II (geometric mean PCR units 2.7 and 11.6 respectively, prevalence 57% and 74% respectively). Significant temporal trends were found for both genogroups, with larger seasonal differences observed for genogroup II. Significant spatial trends were only found for genogroup II. Possible explanations for these facts include that levels of genogroup I in the local population may be lower, the two genogroups may originate from different sources, the two genogroups differ in their stability in the environment, and that there may be differences in the assay performance between genogroups.

The seasonal pattern has been noted in several studies. The level of norovirus infection in the human population is generally higher in the winter months and thus the virus will be present more consistently, and at higher concentrations, in sewage in winter. Viral clearance from the shellfish will also tend to be lower during the colder months, as their metabolism is slower. Virus particles will survive longer during the winter months as temperatures and levels of UV are lower and the water likely to be more turbid. Virus was found, albeit at lower levels and prevalence during the warmer months, indicating that sources are present throughout the year.

The spatial pattern observed for genogroup II suggests the source of the viral contamination enters the loch to the northeast of the points sampled. The closest possible source to the northeast is the Panfish plant septic tank overflow, which discharges close to the shore approximately 375 m away from the nearest sampling point at Ardkinglas gardens. Another possible source would be the Scottish Water Discharge at Cairndow, which discharges approximately 1000 m to the north east of the nearest sampling point at Ardkinglas Gardens into deeper water further offshore.

E. coli levels in oyster samples were unrelated to the level of both norovirus GI and GII levels in those samples. The poor predictive power of *E. coli* in individual samples in relation to norovirus is well documented.

Reference

Lowther, J.A., Henshilwood, K., Lees, D.N. (2008). Determination of norovirus contamination in oysters from two commercial harvesting areas over an extended period, using semi quantitative real-time reverse transcription PCR. Journal of food protection 71(7), 1427-1433.

One-way ANOVA: Log PCRU GI versus Quarter

```
Source   DF      SS     MS     F      P
Quarter   3   4.761  1.587  3.64  0.020
Error    42  18.299  0.436
Total    45  23.060

S = 0.6601   R-Sq = 20.65%   R-Sq(adj) = 14.98%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ------+---------+---------+---------+---
1      12  0.9208  0.4428                   (------*-------)
2      12  0.0607  0.6874  (------*-------)
3      12  0.2968  0.7954      (-------*-------)
4      10  0.3744  0.6656       (-------*--------)
                           ------+---------+---------+---------+---
                               0.00      0.50      1.00      1.50

Pooled StDev = 0.6601


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

Individual confidence level = 98.93%


Quarter = 1 subtracted from:

Quarter    Lower   Center    Upper  ---+---------+---------+---------+------
2        -1.5804  -0.8602  -0.1399  (----------*---------)
3        -1.3443  -0.6240   0.0963      (---------*---------)
4        -1.3019  -0.5465   0.2090      (----------*----------)
                                    ---+---------+---------+---------+------
                                    -1.40     -0.70      0.00      0.70


Quarter = 2 subtracted from:

Quarter    Lower  Center   Upper  ---+---------+---------+---------+------
3        -0.4841  0.2361  0.9564                  (---------*----------)
4        -0.4417  0.3137  1.0691                   (---------*----------)
                                  ---+---------+---------+---------+------
                                  -1.40     -0.70      0.00      0.70


Quarter = 3 subtracted from:

Quarter    Lower  Center   Upper  ---+---------+---------+---------+------
4        -0.6779  0.0776  0.8330               (----------*----------)
                                  ---+---------+---------+---------+------
                                  -1.40     -0.70      0.00      0.70
```

One-way ANOVA: Log PCR GII versus Quarter

```
Source   DF      SS     MS      F      P
Quarter   3  17.865  5.955  10.25  0.000
Error    42  24.399  0.581
Total    45  42.264

S = 0.7622   R-Sq = 42.27%   R-Sq(adj) = 38.15%


                           Individual 95% CIs For Mean Based on Pooled StDev
```

```
Level   N    Mean   StDev    +---------+---------+---------+---------
1      12  2.0867  0.4149                        (------*-----)
2      12  0.9078  0.9536         (-----*-----)
3      12  0.7140  0.8472      (-----*------)
4      10  0.4680  0.7157    (------*------)
                             +---------+---------+---------+---------
                           0.00      0.70      1.40      2.10

Pooled StDev = 0.7622


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

Individual confidence level = 98.93%


Quarter = 1 subtracted from:

Quarter    Lower   Center    Upper  -----+---------+---------+---------+----
2        -2.0106  -1.1789  -0.3472       (-------*--------)
3        -2.2044  -1.3727  -0.5410     (-------*--------)
4        -2.4910  -1.6187  -0.7465  (--------*--------)
                                    -----+---------+---------+---------+----
                                      -2.0      -1.0       0.0       1.0


Quarter = 2 subtracted from:

Quarter    Lower   Center   Upper  -----+---------+---------+---------+----
3        -1.0255  -0.1938  0.6379               (-------*-------)
4        -1.3122  -0.4399  0.4324            (--------*-------)
                                   -----+---------+---------+---------+----
                                     -2.0      -1.0       0.0       1.0


Quarter = 3 subtracted from:

Quarter    Lower   Center   Upper  -----+---------+---------+---------+----
4        -1.1183  -0.2461  0.6262              (--------*-------)
                                   -----+---------+---------+---------+----
                                     -2.0      -1.0       0.0       1.0
```

General Linear Model: Log PCRU GI versus Location name, Collection Date

```
Factor           Type   Levels  Values
Location name    fixed       4  Ardkinglas Gardens, Pier Cottage, Saw Mill,
                                Zathach-ban Cottage
Collection Date  fixed      12  11/10/2007, 20/11/2007, 04/12/2007, 15/01/2008,
                                12/02/2008, 11/03/2008, 08/04/2008, 06/05/2008,
                                24/06/2008, 08/07/2008, 04/08/2008, 02/09/2009


Analysis of Variance for Log PCRU GI, using Adjusted SS for Tests

Source           DF   Seq SS   Adj SS  Adj MS     F      P
Location name     3   0.4872   0.5177  0.1726  0.85  0.475
Collection Date  11  16.3096  16.3096  1.4827  7.34  0.000
Error            31   6.2635   6.2635  0.2020
Total            45  23.0603


S = 0.449498   R-Sq = 72.84%   R-Sq(adj) = 60.57%


Unusual Observations for Log PCRU GI
```

Obs	Log PCRU GI	Fit	SE Fit	Residual	St Resid	
20	-0.31876	0.45551	0.25204	-0.77426	-2.08	R
24	1.25022	0.50390	0.25204	0.74632	2.01	R
28	1.24393	0.18596	0.25355	1.05797	2.85	R

R denotes an observation with a large standardized residual.

Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Log PCRU GI
All Pairwise Comparisons among Levels of Location name
Location name = Ardkinglas Gardens subtracted from:

Location name	Lower	Center	Upper
Pier Cottage	-0.6422	-0.1272	0.3878
Saw Mill	-0.4090	0.1059	0.6209
Zathach-ban Cottage	-0.3755	0.1450	0.6654

```
Location name        ------+---------+---------+---------+
Pier Cottage         (------------*------------)
Saw Mill                   (------------*------------)
Zathach-ban Cottage         (------------*------------)
                     ------+---------+---------+---------+
                        -0.40      0.00      0.40      0.80
```

Location name = Pier Cottage subtracted from:

Location name	Lower	Center	Upper
Saw Mill	-0.2651	0.2332	0.7314
Zathach-ban Cottage	-0.2428	0.2722	0.7872

```
Location name        ------+---------+---------+---------+
Saw Mill                      (------------*-----------)
Zathach-ban Cottage            (------------*------------)
                     ------+---------+---------+---------+
                        -0.40      0.00      0.40      0.80
```

Location name = Saw Mill subtracted from:

Location name	Lower	Center	Upper
Zathach-ban Cottage	-0.4759	0.03903	0.5540

```
Location name        ------+---------+---------+---------+
Zathach-ban Cottage      (------------*------------)
                     ------+---------+---------+---------+
                        -0.40      0.00      0.40      0.80
```

Tukey Simultaneous Tests
Response Variable Log PCRU GI
All Pairwise Comparisons among Levels of Location name
Location name = Ardkinglas Gardens subtracted from:

Location name	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
Pier Cottage	-0.1272	0.1897	-0.6708	0.9073
Saw Mill	0.1059	0.1897	0.5585	0.9435
Zathach-ban Cottage	0.1450	0.1917	0.7563	0.8733

Location name = Pier Cottage subtracted from:

Location name	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
Saw Mill	0.2332	0.1835	1.271	0.5880
Zathach-ban Cottage	0.2722	0.1897	1.435	0.4878

Location name = Saw Mill subtracted from:

Location name	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
Zathach-ban Cottage	0.03903	0.1897	0.2058	0.9968

General Linear Model: Log PCR GII versus Location name, Collection Date

Factor	Type	Levels	Values
Location name	fixed	4	Ardkinglas Gardens, Pier Cottage, Saw Mill, Zathach-ban Cottage
Collection Date	fixed	12	11/10/2007, 20/11/2007, 04/12/2007, 15/01/2008, 12/02/2008, 11/03/2008, 08/04/2008, 06/05/2008, 24/06/2008, 08/07/2008, 04/08/2008, 02/09/2009

Analysis of Variance for Log PCR GII, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Location name	3	3.9850	4.1133	1.3711	3.70	0.022
Collection Date	11	26.7939	26.7939	2.4358	6.57	0.000
Error	31	11.4854	11.4854	0.3705		
Total	45	42.2643				

S = 0.608685   R-Sq = 72.82%   R-Sq(adj) = 60.55%

Unusual Observations for Log PCR GII

Obs	Log PCR GII	Fit	SE Fit	Residual	St Resid
26	2.07100	1.05808	0.34334	1.01292	2.02 R
30	-0.31876	0.85649	0.34334	-1.17525	-2.34 R
31	1.87251	0.74237	0.34129	1.13014	2.24 R
40	1.56660	0.48648	0.34334	1.08012	2.15 R

R denotes an observation with a large standardized residual.

Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Log PCR GII
All Pairwise Comparisons among Levels of Location name
Location name = Ardkinglas Gardens subtracted from:

Location name	Lower	Center	Upper
Pier Cottage	-0.811	-0.1141	0.58323
Saw Mill	-1.141	-0.4435	0.25388
Zathach-ban Cottage	-1.483	-0.7780	-0.07325

```
Location name        -----+---------+---------+---------+-
Pier Cottage                   (-----------*-----------)
Saw Mill                  (-----------*----------)
Zathach-ban Cottage  (-----------*-----------)
                     -----+---------+---------+---------+-
                       -1.20     -0.60      0.00      0.60
```

Location name = Pier Cottage subtracted from:

Location name	Lower	Center	Upper
Saw Mill	-1.004	-0.3294	0.34538
Zathach-ban Cottage	-1.361	-0.6639	0.03350

```
Location name        -----+---------+---------+---------+-
Saw Mill                     (-----------*----------)
```

```
Zathach-ban Cottage    (-----------*-----------)
                     -----+---------+---------+---------+-
                       -1.20     -0.60      0.00      0.60


Location name = Saw Mill  subtracted from:

Location name         Lower   Center   Upper
Zathach-ban Cottage  -1.032  -0.3345  0.3628

Location name        -----+---------+---------+---------+-
Zathach-ban Cottage          (----------*-----------)
                     -----+---------+---------+---------+-
                       -1.20     -0.60      0.00      0.60


Tukey Simultaneous Tests
Response Variable Log PCR GII
All Pairwise Comparisons among Levels of Location name
Location name = Ardkinglas Gardens  subtracted from:

                     Difference       SE of           Adjusted
Location name          of Means  Difference  T-Value   P-Value
Pier Cottage            -0.1141      0.2568   -0.444    0.9702
Saw Mill                -0.4435      0.2568   -1.727    0.3275
Zathach-ban Cottage     -0.7780      0.2595   -2.998    0.0260


Location name = Pier Cottage  subtracted from:

                     Difference       SE of           Adjusted
Location name          of Means  Difference  T-Value   P-Value
Saw Mill                -0.3294      0.2485   -1.325    0.5543
Zathach-ban Cottage     -0.6639      0.2568   -2.585    0.0665


Location name = Saw Mill  subtracted from:

                     Difference       SE of           Adjusted
Location name          of Means  Difference  T-Value   P-Value
Zathach-ban Cottage     -0.3345      0.2568   -1.302    0.5683
```

Regression Analysis: mean GI versus E. coli oysters

```
The regression equation is
mean GI = 0.353 + 0.030 E. coli oysters


Predictor           Coef  SE Coef     T      P
Constant          0.3531   0.5451  0.65  0.538
E. coli oysters   0.0301   0.2044  0.15  0.887


S = 0.677630   R-Sq = 0.3%   R-Sq(adj) = 0.0%


Analysis of Variance

Source          DF      SS      MS     F      P
Regression       1  0.0100  0.0100  0.02  0.887
Residual Error   7  3.2143  0.4592
Total            8  3.2242
```

Regression Analysis: mean GII versus E. coli oysters

```
The regression equation is
```

mean GII = 2.04 - 0.332 E. coli oysters

Predictor	Coef	SE Coef	T	P
Constant	2.0430	0.5754	3.55	0.009
E. coli oysters	-0.3324	0.2157	-1.54	0.167

S = 0.715197   R-Sq = 25.3%   R-Sq(adj) = 14.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.2142	1.2142	2.37	0.167
Residual Error	7	3.5805	0.5115		
Total	8	4.7948			