Scottish Sanitary Survey Project

Sanitary Survey Report
Dornoch Firth
HS 054, HS 464, HS 465
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Report Distribution – Dornoch Firth

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

Table of Contents

1. General Description

Dornoch Firth is a tidal estuary located on the east coast of northern Scotland between Easter Ross and Sutherland districts. It extends over 25km in length and nearly 6km in width at its widest point. Dornoch Firth receives water from several rivers at its head, including the Carron, Oykel, Cassley and Shin. Two further rivers, the Evelix and Tain, discharge into the main body of the firth, which is bisected by the Dornoch Firth Bridge. There are a number of towns and villages located along the firth, the largest of which are Dornoch and Tain, both located on the outer part of the Firth. There are no harbours or marinas, and recreational use of the firth is limited primarily to areas around the sands on north shore. The entrance to the firth lies within a military bombing range.

The Dornoch Firth production area for common mussels covers over 14 km sq of the outer estuary, east of the Dornoch Firth bridge. Fast track and standard applications were submitted to the Food Standards Agency in Scotland for extension to the south and west of the existing classified area in October 2008.

This survey is being undertaken in response to the applications to extend the production area. This report specifically addresses the area east of the Dornoch Firth Bridge, a shown in Figure 1.1. The area west of the bridge (Dornoch Firth: Meikle Ferry) is addressed in a separate survey report.

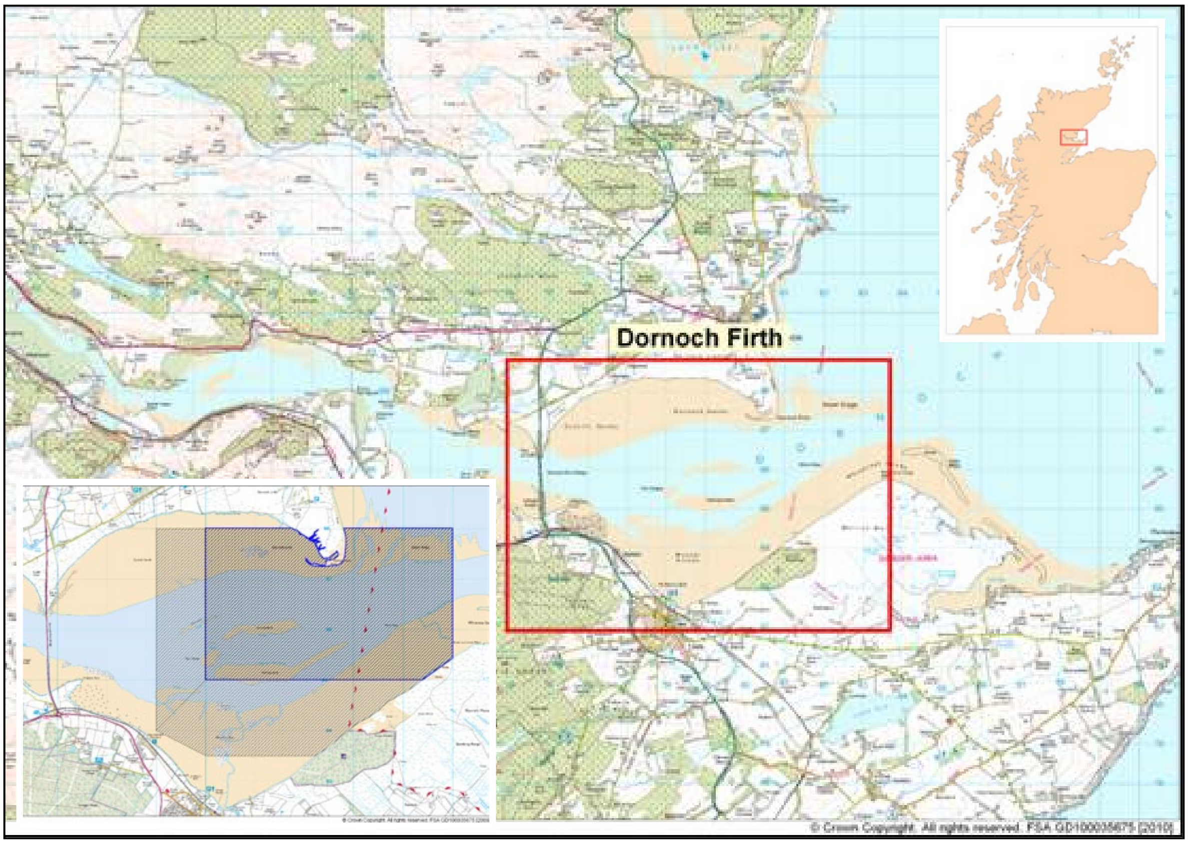

Figure 1.1 Location of survey area

2. Fishery

The fishery at Dornoch Firth is a wild mussel (*Mytilus* sp.) harvesting area that forms part of the Common Good of the Royal Burgh of Tain, and is managed by the Highland Council through their mussel fishery management company, Highland Fresh Mussels Ltd. It is one of the few areas in Scotland where the commercial gathering of wild mussels is allowed. The classified production area is summarised in Table 2.1 below.

Table 2.1 Dornoch Firth mussel areas

Production Area	Site	SIN	Species	RMP
Dornoch Firth	Dornoch Firth	HS 054 239 08	Common mussel	NH 800 865
Dornoch Firth	Tain	HS 054 240 08	Common mussel	
Dornoch Mussels 1	Mussel Scalps	HS 464 872 08	Common mussel	Not defined
Dornoch Mussels 2	Tain Scalps	HS 465 873 08	Common mussel	Not defined

The Dornoch Firth production area is described as the area bounded by lines drawn between NH 7800 8800 and NH 7976 8800 and between NH 8079 8800 and NH 8300 8800 and between NH 8300 8800 and NH 8300 8543 and between NH 8239 8500 and NH 7800 8500 and between NH 7800 8500 and NH 7800 8800 extending to MHWS.

A representative monitoring point (RMP) has been established at NH 800 865.

Two applications were submitted to FSAS for extension of the production area to the south and west, as shown in Figure 2.1. The area to the south named Mussel Scalps is defined as the area bounded by lines drawn between points NH 7700 8400, NH 7800 8500, NH 8236 8500, NH 8022 8350, NH 7800 8350, extending to MHWS. The area to the west, Tain Scalps, is described as the area bounded by lines drawn between points at NH 7700 8400, NH 7800 8500, NH 7800 8800 and NH 7700 8800. The proposed western extension will not cover all of the identified mussel bed at the north western side of the main channel.

Wild mussels are primarily dredged during high tide from shallow beds throughout the outer part of Dornoch Firth. Dredging is undertaken according to demand and may occur at any time of year. Hand gathering may be undertaken on a limited basis on arrangement with Scottish Natural Heritage, and is primarily used when the dredging boat is out of service.

Mussels are landed in 1 tonne bulk bags at the shore base at Meikle Ferry on the end of the Ness of Portnaculter, to the west of the Dornoch Firth Bridge. A depuration facility is located at the shore base. This is owned and operated by Frank Mohan and Sons, Ltd who purchase mussels from Highland Fresh Mussels for depuration. Mussels may also be exported directly to France, in which case the purchaser undertakes cleaning and/or depuration at the destination.

A map showing locations of known beds was provided by James Bromham from Highland Council and these have been represented in Figure 2.1, together with the production area boundaries.

There is no clear distinction between sites within the Dornoch Firth production area, and the westernmost beds overlap with the new production areas. The majority of the classified area and extension lies partly within the Dornoch Firth Shellfish Growing Water, which has been monitored by SEPA since 1981. The northeastern corner of the production area falls outwith the designated shellfish growing water. The eastern third of the Dornoch Firth production area falls within a danger area associated with the Royal Air Force bombing range at Morrich More, and so dredging of the beds in this area will be constrained by activity on the range.

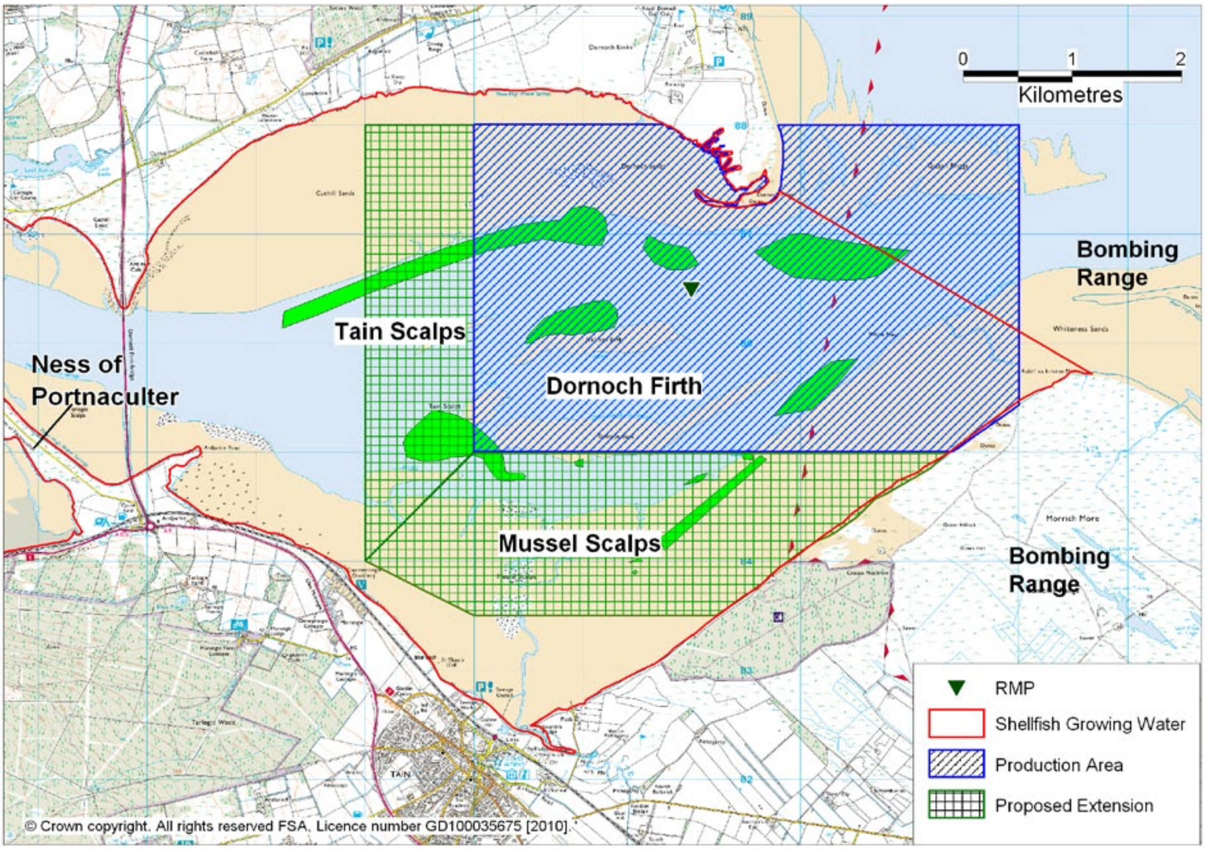

Figure 2.1 Outer Dornoch Firth mussel fishery

3. Human Population

The figure below shows information on population within the census output areas in the vicinity of Dornoch Firth. The data was obtained from the General Register Office for Scotland and is based on the 2001 census returns.

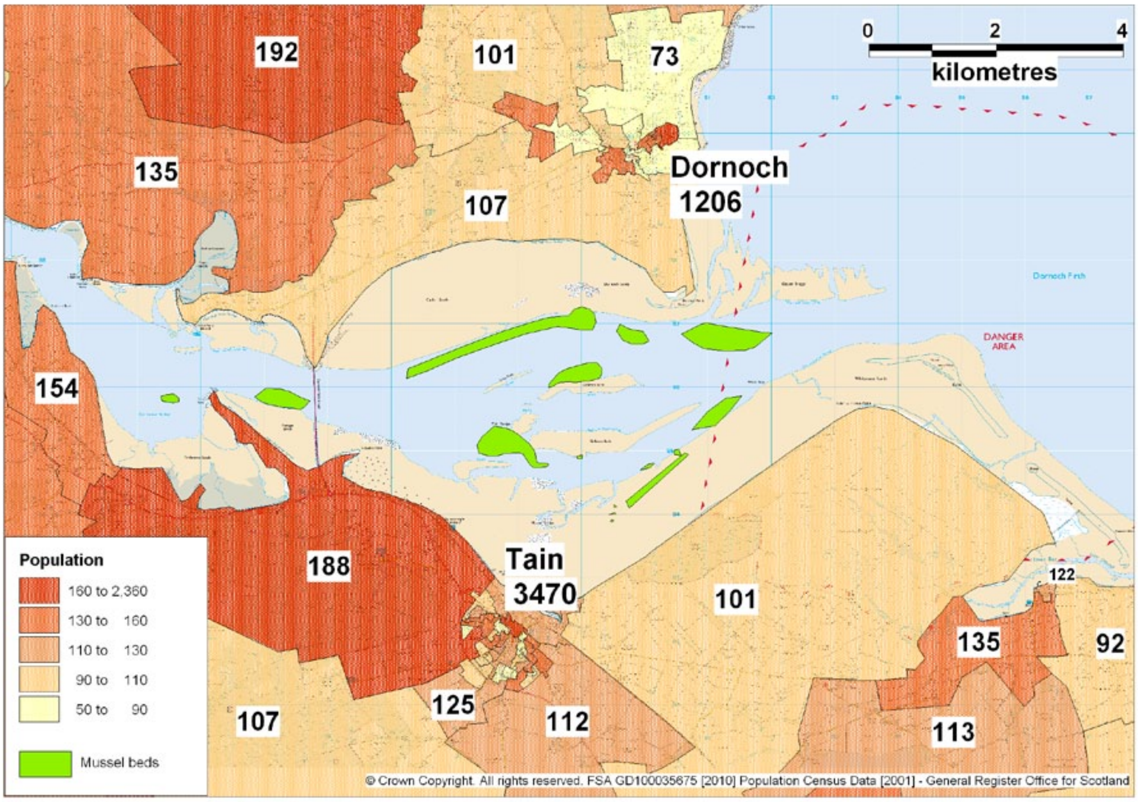

Figure 3.1 Population map for Dornoch Firth

Human population in the vicinity of Dornoch Firth is concentrated around two centres, with roughly two thirds of the local population. Population outside the towns is more dispersed with some small developments located along roads and the remainder rural.

The town of Tain lies south of the fishery. The thirty-one census output areas at Tain have a combined population of 3470. The smaller town of Dornoch is north of the fishery. The ten census output areas at Dornoch have a combined population of 1206. Upstream from the area shown above are the villages of Edderton, Ardgay and Bonar Bridge. The combined population of these areas is roughly 800.

The area has a highly seasonal population, with tourist attractions drawing visitors to the area from spring to autumn. Golf courses in the area draw visitors primarily in summer and but also outside the summer season. The parts of the shoreline that are sandy, such as around Tain, are popular with water sports enthusiasts and walkers. It is expected that the area population will be significantly higher during the tourist season of April - October.

Impacts from human population in the vicinity of the fishery are likely to be highest on the southern side of the firth, near the town of Tain.

4. Sewage Discharges

Scottish Water identified community septic tanks (ST) and other sewage discharges for the area surrounding Dornoch Firth. These are detailed in Table 4.1. Discharges are shown mapped in Figure 4.1, along with the mussel bed locations. A short list of acronyms follows at the end of this section.

Table 4.1 Discharges identified by Scottish Water

NGR	**Discharge Name**	**Discharge Type**	**Level of Treatment**	**Consented flow (DWF) m^3/d**	**Consent design pop**	**Predict spill frequency**
NH 7158 8533	Edderton ST	Continuous	septic tank	70	300	n/a
NH 7957 8821	Dornoch STW	Continuous	secondary plus u/v disinfection	1213	6779	n/a
NH 7957 8821	Dornoch STW CSO	Intermittent	settlement	1213	6779	53
NH 7994 8922	Dornoch WWPS Storm Tank	Intermittent	settlement	1213	6779	26
NH 7994 8922	Dornoch WWPS CSO	Intermittent	6mm screening	1213	6779	29
NH 7784 8282	Tain STW	Continuous	secondary plus u/v disinfection	1153	5000	n/a
NH 7835 8245	Tain Links WWPS CSO/EO	Intermittent	6mm screening	not given	not given	not known
NH 7780 8280	Tain WWTW CSO	Intermittent	Not known	1153	5000	not known
NH 786 823	Tain Golf Course WWPS EO	Intermittent	Not known	Not known	300	not known

n/a – not applicable

Limited microbiological data were provided by Scottish Water for final effluent at Dornoch and Tain STWs. Faecal coliform results were available for 11 and 9 samples respectively, taken between April 2007 and November 2008. In both cases, results were highest in 2007 (max 1200000 at Tain). This occurred prior to the upgrade to treatment installed in February 2008. No results greater than 4500 cfu/100 ml occurred in the 2008 sample data. However, it should be noted that there were significant gaps in the sampling data.

All three continuous discharges were observed during the shoreline survey in August 2009. The final effluent from the Tain STW discharged across the shoreline and so was accessible. A sample taken from this discharge contained 56000 *E. coli*/100ml, with a calculated loading based on consented DWF of 6.5 x 10^{11} *E. coli*/day. Both the final effluent from the Dornoch STW and discharge from the Dornoch storm tank enter Black Burn upstream of the shoreline. The end of a discharge pipe was seen during the shoreline survey, and a sample was taken from an accessible part of the Burn closer to the shore. This sample contained 27000 *E. coli*/100 ml. Although this sample would have included bacteria from both sewage and environmental sources, the measured flow of the burn was relatively low at the time (1620 m^3/day, Section 13). It is not known what proportion of that was attributable to the sewage discharge as opposed to background flow, however results of this magnitude have only been found within this project in watercourses substantially impacted by human sewage. The concentration of faecal indicator bacteria found in these samples was higher than would be expected for UV disinfected final effluent, which would normally be expected to contain fewer than 500 FIB/100 ml (Appendix 7). It is possible that the storm tank was discharging at the time, thereby contributing to elevated *E. coli* levels in the burn. The Edderton ST was reported to discharge to the firth west of the Dornoch Firth bridge. Although not displayed in Figure 4.1, discharges from this tank may affect water quality over the shellfish beds east of the bridge. The flow at Edderton could not be directly sampled as the end of the pipe was not accessible at the time of survey. Although the discharge volume from Edderton is much smaller than that from Tain or Dornoch STWs, the treatment level is lower therefore it may contribute higher loadings of faecal contaminants to the western side of the fishery. Loading calculations based on average *E. coli* content of primary treated effluent (Appendix 7) indicate that a loading of 5.0×10^{12} *E. coli*/day may be entering the firth from the Edderton discharge.

Spill frequencies reported for the Dornoch CSOs ranged from 26 to 53 per year. Spills from any of the CSOs or EOs would be screened only and therefore would contain substantially higher loadings of faecal indicator bacteria, such as *E. coli*, than the STW final effluents.

The Scottish Environment Protection Agency (SEPA) provided information on discharge consents issued in the vicinity of the production area and these are listed in Table 4.2 below.

Table 4.2 Discharges identified by SEPA

No.	Ref No.	NGR of discharge	Discharge Type	Level of Treatment	Consent/ design PE	Discharges to
1	CAR/R/1017582	NH 7449 8420	Treated sewage effluent	Septic tank	50	Fuaran na Slainthe
2	CAR/R/1008973	NH 7478 8953	Domestic	Package sewage treatment plant	6	Clashmore Burn
3	WPC/N/60892	NH 7724 8491	Treated sewage effluent	Septic tank	Not stated	Dornoch Firth
4	CAR/R/1015018	NH 7952 8011	Domestic	Septic tank	5	Aldie Water
5	CAR/R/1014146	NH 8161 8185	Domestic	Septic tank	5	Unnamed tributary of Fendom Burn
6	CAR/R/1013371	NH 7089 8587	Domestic	Septic tank	5	Land
7	CAR/R/1013485	NH 7094 8592	Domestic	Septic tank	5	Land
8	CAR/R/1009318	NH 7140 9050	Domestic	Septic tank	5	Land
9	CAR/R/1018972	NH 7320 8583	Domestic	Septic tank	8	Land via soakaway
10	CAR/R/1013456	NH 7375 8989	Domestic	Septic tank	6	Land
11	CAR/R/1011330	NH 7447 9204	Domestic	Septic tank	5	Land
12	CAR/R/1010623	NH 7449 9279	Domestic	Septic tank	5	Land
13	CAR/R/1018421	NH 7570 9139	Domestic	Septic tank	5	Land
14	CAR/R/1010516	NH 7625 8324	Domestic	Septic tank	5	Land

No.	Ref No.	NGR of discharge	Discharge Type	Level of Treatment	Consent/ design PE	Discharges to
15	CAR/R/1017914	NH 7639 8330	Domestic	Septic tank	5	Land via soakaway
16	CAR/R/1009383	NH 7675 9144	Domestic	Septic tank	6	Land
17	CAR/R/1010216	NH 7692 9397	Domestic	Septic tank	5	Land
18	CAR/R/1018568	NH 7718 9543	Domestic	Septic tank	10	Land via soakaway
19	CAR/R/1009384	NH 7882 9520	Domestic	Septic tank	5	Land
20	CAR/R/1009386	NH 7895 9519	Domestic	Septic tank	12	Land
21	CAR/R/1010752	NH 7897 9130	Domestic	Septic tank	5	Land
22	CAR/R/1017773	NH 7904 9093	Domestic	Septic tank	5	Land via soakaway
23	CAR/R/1018085	NH 7911 9430	Domestic	Septic tank	5	Land via soakaway
24	CAR/R/1009385	NH 7914 9512	Domestic	Septic tank	5	Land
25	CAR/R/1017778	NH 7932 9095	Domestic	Septic tank	26	Land via soakaway
26	CAR/R/1017774	NH 7936 9098	Domestic	Septic tank	20	Land via soakaway
27	CAR/R/1013326	NH 7945 9431	Domestic	Septic tank	5	Land
28	CAR/R/1009380	NH 7989 9012	Domestic	Septic tank	6	Land
29	CAR/R/1015032	NH 8165 8090	Domestic	Septic tank	10	Land
30	CAR/R/1009168	NH 8190 8137	Domestic	Septic tank	5	Land
31	CAR/R/1014074	NH 8204 8181	Domestic	Package sewage treatment plant	5	Land
32	CAR/R/1017917	NH 8318 8093	Domestic	Septic tank	5	Land via soakaway

Most of the listed consents discharge to land and are sufficiently distant from shore to be unlikely to impact water quality in the vicinity of the fishery. None of the consents provided by SEPA related to the Scottish Water discharges listed in Table 4.1, so it was not possible to cross reference them. Five of the consents discharge to water, of which two (discharging to Fendom Burn and Aldie Water) are less likely to impact water quality at the fishery due to their small size and the location of the watercourses. A septic tank at the Glenmorangie Distillery (No. 3 in Table 4.1) discharges directly to Dornoch Firth, though the volume was not specified on the discharge permit. During the shoreline survey, it was not possible to access the shoreline below the distillery to confirm presence of the discharge pipe or assess the flow. The distillery has a large visitor's centre and receives coach parties, therefore it is likely to have a significant daily flow. As the map in Figure 4.1 shows, this discharge lies within 150 m of the nearest identified mussel bed and therefore it would be expected to have a significant impact on microbiological water quality in the vicinity.

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

Table 4.3 Potential or actual discharges/septic tanks observed

No.	Date	NGR	Observation
1	05/08/2009	NH 78230 82596	Rock groin, plastic cover over pipe at end
2	05/08/2009	NH 78358 82437	Storm overflow outlet, trickling round side of cover
3	05/08/2009	NH 77898 82762	Tain WWTW
4	05/08/2009	NH 77849 82814	WWTW outfall, mild sewage odour
5	05/08/2009	NH 77846 82815	Sewage discharge
6	06/08/2009	NH 74662 84262	Septic tank for campground, 25 static homes with as many visitor pitches, tent pitches, toilet block, chemical toilet disposal
7	06/08/2009	NH 74917 84451	Septic tank for inn/pub
8	06/08/2009	NH 73192 85892	Discharge from mussel sorting shed, 2 60mm pipes, sal 22 ppt
9	06/08/2009	NH 73174 85890	Supply hoses for depuration trailer. Orange pvc pipe- broken into segments and not flowing
10	06/08/2009	NH 73171 85888	Ceramic septic pipe, discharge end just below high tide line no flow nor clear evidence of recent use
11	06/08/2009	NH 73406 85661	Houses, all on septic tanks with soakaways according to homeowner
12	06/08/2009	NH 71304 84939	Edderton septic tank. Access overgrown with vegetation
13	06/08/2009	NH 71488 85097	Iron discharge pipe for septic tank. Stream runs alongside, filtering through shingle and sand
14	07/08/2009	NH 79764 88259	Dornoch WWTW, appr 30m outside entrance
15	10/08/2009	NH 79566 88091	Black Burn, Dornoch WWTW discharge visible upstream, sewage odour, water appears dirty
16	10/08/2009	NH 79870 89230	Storm tank, Dornoch
17	10/08/2009	NH 78658 82265	Open drainage ditch with pipe through bank to river
18	10/08/2009	NH 78635 82310	Small concrete pipe extending into river, mostly underwater
19	10/08/2009	NH 78228 82385	Tain Links WWPS
20	10/08/2009	NH 78114 89123	Drumduran ST and SEPA monitoring point

Sewage infrastructure related to the main sewage treatment works at Tain and Dornoch was observed during the shoreline survey. Due to access restrictions it was not possible to directly view all of the shoreline, however a small number of other discharges as noted in Table 4.3 were observed where the shoreline was accessible.

Two septic tanks were found at the base of the Ness of Portnaculter. One of these, number 6 in Table 4.3, corresponds with SEPA discharge consent number CAR/R/1017582. The septic tank serves a caravan site with 25 static pitches and as many mobile pitches, plus an area for tents. This discharge drains to a small watercourse adjacent to the tank and has a consented PE of 50. A second tank was located outside a public house and inn near the campsite. Further septic tanks were found where houses had been developed at the end of Ness of Portnaculter. A local resident reported that these discharged to soakaway and no pipes were observed. However, there was little land available to accommodate soakaway systems and so if not functioning efficiently these could contribute to local contamination levels along the Ness and potentially to the western fringes of the mussel beds.

A community septic tank was observed adjacent to the road west of Dornoch near Davochfin. No discharge pipe was observed and it wasn't clear whether this discharged to soakaway or to a watercourse, as no watercourse appeared to pass close to the tank. However, as this is relatively remote from the shoreline it is considered to pose less of a risk of contamination to the fishery than the discharge at Dornoch.

The mussel beds along the northern side of the fishery are likely to be subject to contamination from the Dornoch STW, CSOs and storm tank discharges. The mussel beds in the southern part of the fishery are likely to be affected by contamination coming from both the Glenmorangie Distillery and Tain STW discharges (particularly any CSOs or EOs), with the distillery discharge having the greatest day to day effect as it lies closer to the mussel beds.

Acronyms

CSO	Combined Sewer Overflow
DWF	Dry Weather Flow
EO	Emergency Overflow
ST	Septic Tank
STW	Sewage Treatment Works
PE	Population Equivalent
WWTW	Wastewater Treatment Works
WWPS	Wastewater Pumping Station

Post survey note: Subsequent to circulation of the draft of this report, Scottish Water provided feedback to say that problems with the UV treatment at the Tain STW have since been rectified. It should be noted that the findings of the Anderson report are used primarily in this instance as an indication of where the maximum impact from these discharges could be expected. While the impact from sewage that has received effective UV treatment would be expected to be low, storm water or other overflows would result in untreated sewage discharging into the firth. These would be expected to occur after heavy rainfall, and expected spill frequencies at Dornoch range from 26 to 53 per year. The impact of these would be dependent upon the timing and duration of spills, however at an average of 1 spill per week predicted it would be expected that these could have a signficant effect on water quality at the mussel beds.

Scottish Water have also identified that an upgraded WWTW with UV disinfection was commissioned at Edderton subsequent to this survey. Therefore, final effluent quality from the new Edderton works is likely to be significantly cleaner under normal operational conditions than the loading estimated above.

While sewerage improvements in Dornoch Firth are designed to ensure the area achieves the guideline standard for Bathing Waters (100 FC/ 100 ml), the standard does not relate directly to standards of water quality anticipated to meet classification guidelines from a food safety standpoint.

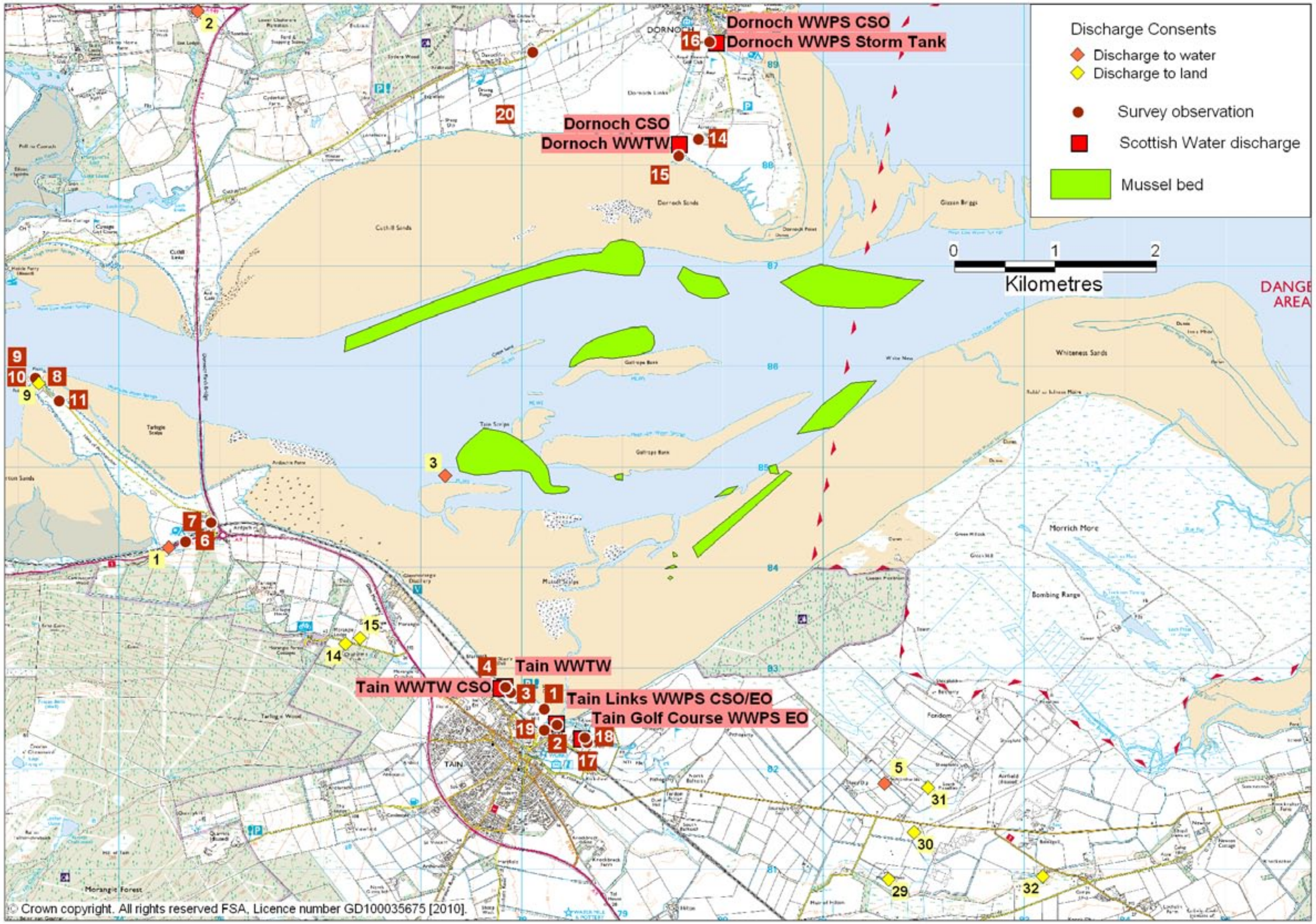

Figure 4.1 Map of discharges for Dornoch Firth

5. Geology and Soils

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

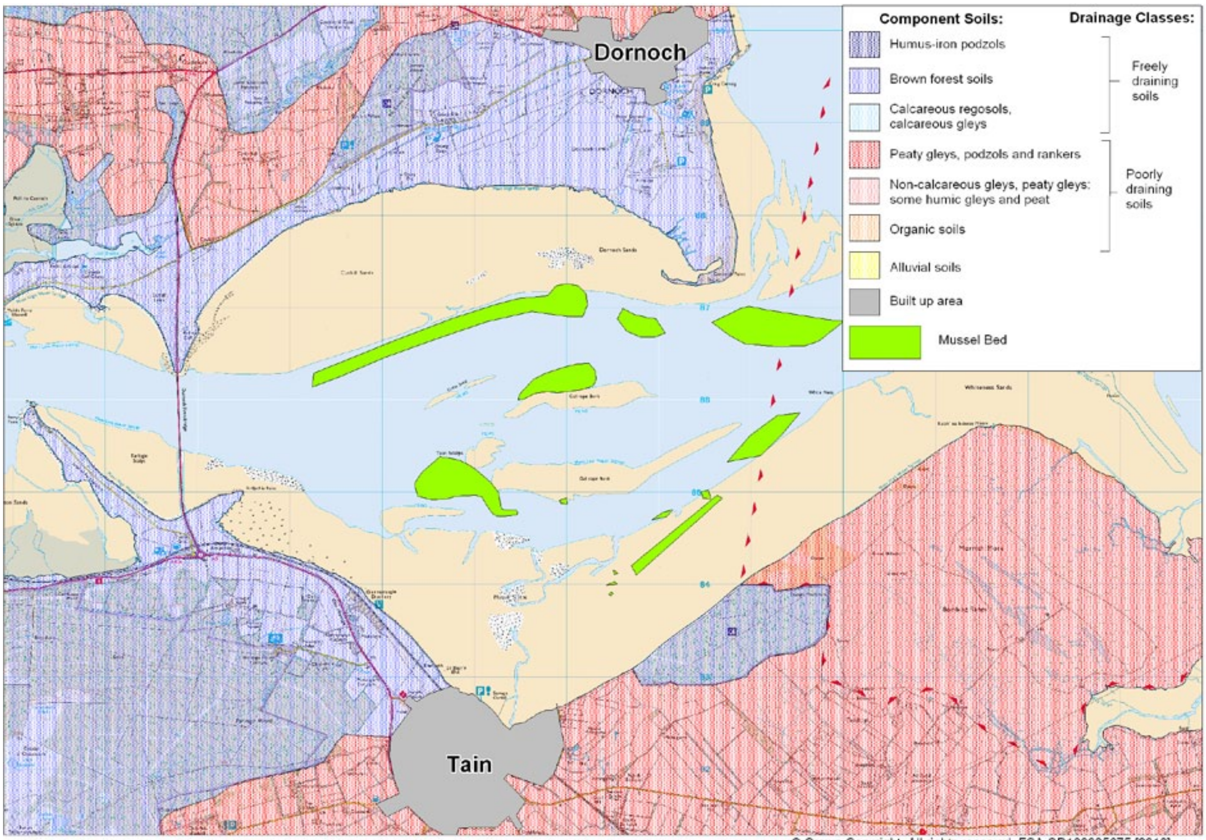

Figure 5.1 Component soils and drainage classes for Dornoch Firth

Two types of component soils are present in the area: peaty gleys, podzols and rankers and brown forest soils. The brown forest soils are found along the northern and southwestern shores of the outer firth as well as in a patch east of Tain and are freely draining. Therefore, in these areas the potential for runoff is reduced. The peaty gleys, podzols and rankers are poorly draining; and found in a strip north of Dornoch and also along most of the southeastern shore including much of the area around Tain.

The areas with the highest potential for runoff are the built up areas of Dornoch and Tain, where hard surfaces such as roads and other paving are impervious to rainfall.

Overall, the potential for contaminated runoff attributable to soil permeability is higher along the southern side of the fishery from Tain eastward.

6. Land Cover

Land Cover 2000 data was acquired for the area and is shown in Figure 6.1 below:

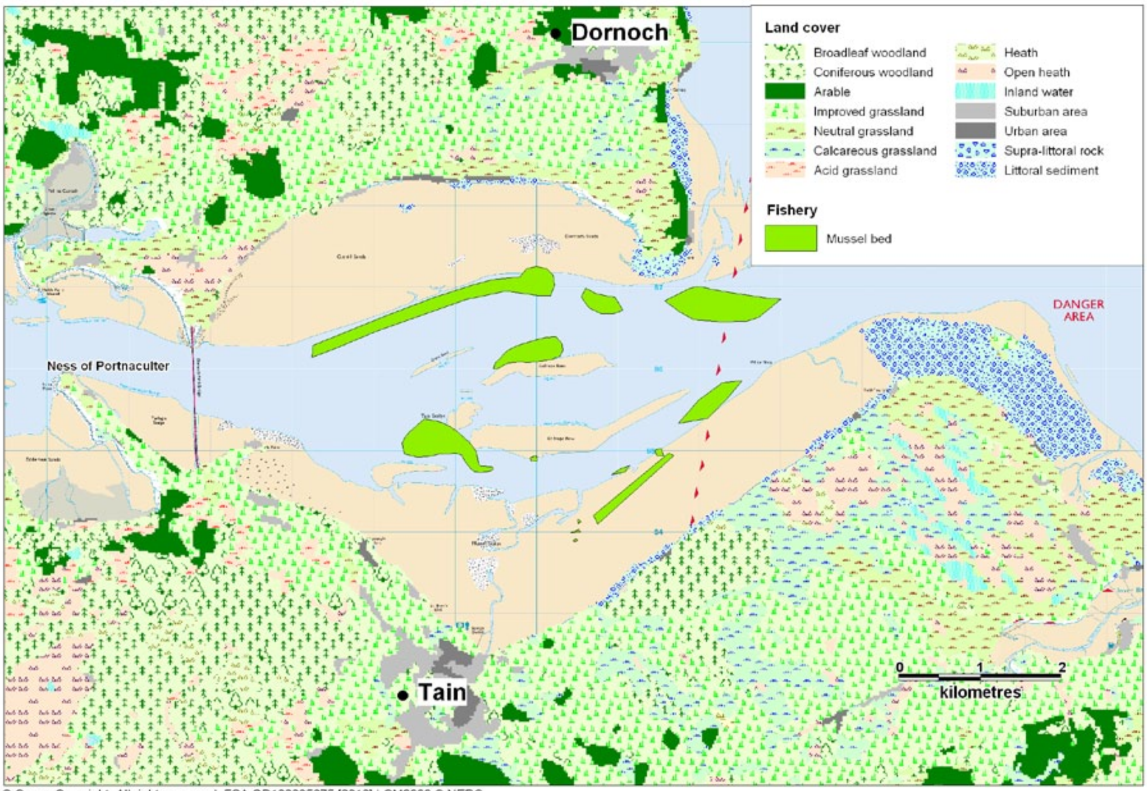

Figure 6.1 LCM2000 class land cover data for Dornoch Firth

Landcover in the area is varied. On the southern shore an area of improved grassland extends from 1.5 km east of Tain west to the Ness of Portnaculter and inland to south of Tain, where it becomes interspersed with arable fields. Further to the east and west of Tain are large tracts of coniferous and mixed woodland and beyond these more natural grassland and heath. Suburban and urban areas are clustered around Tain, but also present in smaller areas along the shoreline between Tain and the Dornoch Firth bridge. Further arable areas are located around the base of the Ness of Portnaculter, south of the bridge.

On the northern shoreline, large tracts of improved grassland and arable fields are located near to the shoreline, with urban and suburban areas noted at Dornoch and a few small areas inland. The urban area noted on the shoreline may actually related to a suburban developed area located along Sutherland Road through Davochfin to the southwest of Dornoch. There is no urban development directly along the northern shoreline of the firth.

The faecal coliform contribution would be expected to be highest from developed areas (approx 1.2 – 2.8x10^{9} cfu km^{-2} hr^{-1}) located around Dornoch and Tain. Intermediate contributions are expected from the improved grassland (approximately 8.3x10^{8} cfu km^{-2} hr^{-1}) which is located along part of both shores. Lower contributions are expected 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, though this effect is highest, at more than 100-fold, for the improved grassland.

7. Farm Animals

Agricultural activities can present a significant risk of faecal contamination to waterways through runoff from grazings, areas of hardstanding, and fields to which slurry has been applied but also from direct deposition to the shoreline and freshwater courses by livestock.

Agricultural census data to parish level was requested from the Rural Environment, Research and Analysis Directorate (RERAD) for the parishes of Creich, Dornoch, Edderton, and Tain. These parishes encompass a land area of 1890.2 km^2. Reported livestock populations for the parishes in 2008 are listed in Table 7.1. RERAD withheld data for reasons of confidentiality where the small number of holdings reporting would have made it possible to discern individual farm data. Any entries which relate to less than five holdings, or where two or fewer holdings account for 85% or more of the information, are replaced with an asterisk.

Table 7.1 Livestock numbers surrounding Dornoch Firth 2008

	Edderton		**Tain**		**Creich**		**Dornoch**	
	Holdings	Numbers	Holdings	Numbers	Holdings	Numbers	Holdings	Numbers
Pigs	0	0	*	*	*	*	*	*
Poultry	5	145	6	186	21	749	18	254
Cattle	15	868	17	2,712	33	1,167	23	1,427
Sheep	18	5294	14	10,834	37	9,249	38	12,628
Horses and ponies	8	34	9	72	15	47	14	62

* Data withheld for reasons of confidentiality

There appears to be large numbers of sheep in all the parishes, however due to the large areas, this data does not provide information on the livestock numbers immediately surrounding Dornoch Firth. The only significant source of local information was therefore the shoreline survey (see Appendix), which only relates to the time of the site visit on 5-10 August 2009. The spatial distribution of animals observed and noted during the shoreline survey is illustrated in Figure 7.1. This information should be treated with caution, as it applies only to the survey dates and is dependent upon the point of view of the observer (some animals may have been obscured from view by the terrain).

The area around the fishery is predominantly agricultural with large numbers of grazing stock observed during the survey. The number of cattle and sheep in the area is in the thousands. Animals are kept fenced from the shoreline as the intertidal mud is soft, and therefore hazardous to walk. Many of the surrounding fields are also sown for crop harvesting.

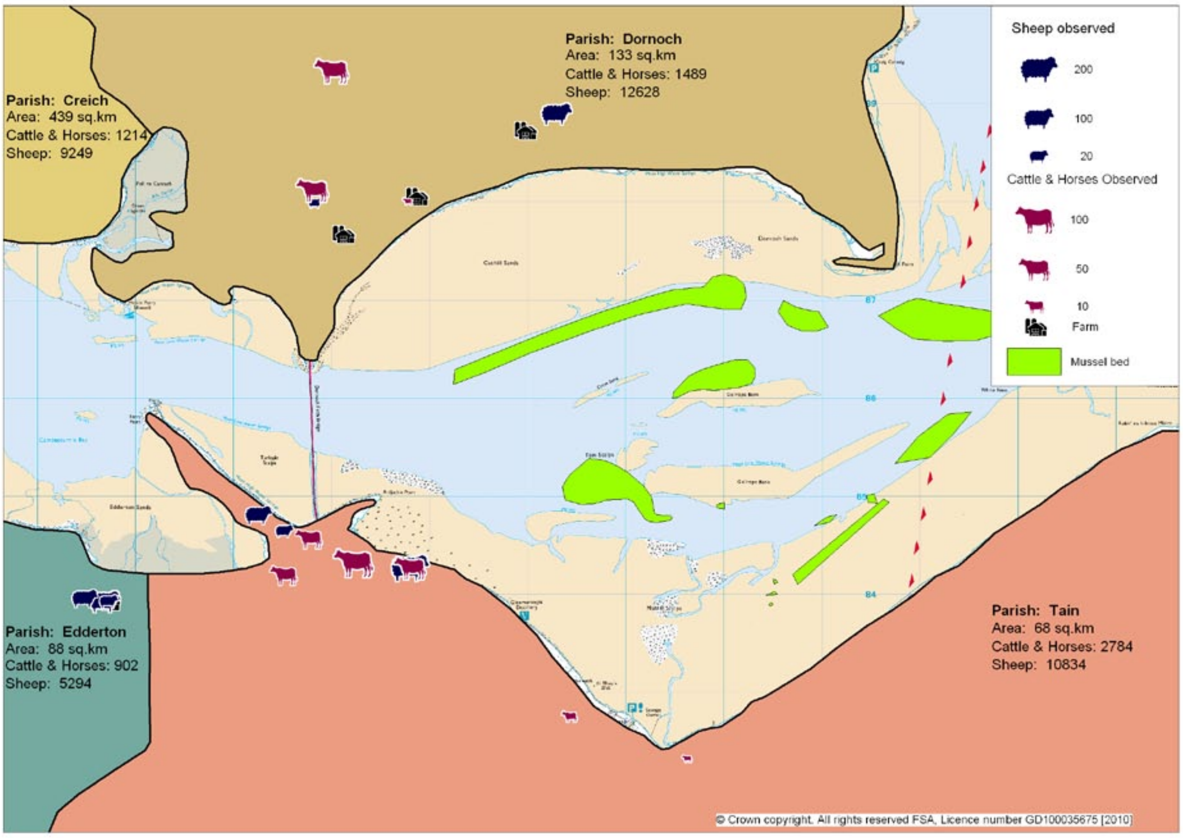

Figure 7.1 Map of agricultural parishes and livestock observations

8. Wildlife

General information related to potential risks to water quality by contamination from wildlife sources can be found in Appendix 4. A number of the wildlife species present or likely to be present at Dornoch Firth could potentially affect water quality around the fishery.

Seals

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*). Scotland hosts significant populations of both species.

Dornoch Firth & Morrich More Special Area of Conservation, which covers 8700 ha stretching from the outer firth to Bonar Bridge and was designated in part for its population of common seals. Both species have been recorded in Dornoch Firth, however the common seal is present and most regularly breeds in the area. Haulout sites are recorded on the sandbanks on either side of the entrance to the firth. Populations are reported by Scottish Natural Heritage to have declined in recent years, with 130 and 160 counted during a 2008 census of hauled-out animals in Dornoch Firth. It is estimated that this is likely to represent approximately 60% of the total population in the area. The general location of the haulout areas and recorded sightings of seals can be found in Figure 8.1. The locations of the haulout sites are adjacent to the mussel beds in the outer part of the firth and it is likely that seals will contribute to background levels of faecal contamination at the fishery.

Whales/Dolphins

The Moray Firth Special Area of Conservation (SAC) was designated in part for its population of bottlenose dolphins (*Tursiops truncatus*), which numbers in the low hundreds. This population is known to frequent the inner firth near the mouth of Cromarty Firth, which lies south of Dornoch Firth. These animals may pass close to or enter Dornoch Firth from time to time but they are not known to frequent the area. Therefore, they are not considered to be a significant potential source of faecal bacteria in the waters overlying the mussel fishery at Dornoch Firth.

Birds

Seabirds were the subject of a detailed census carried out in the summer of 1999 (Mitchell *et al.*, 2004). Records for the area around Dornoch Firth are shown in Table 8.1. Where counts were of sites/nests/territories occupied by breeding pairs, the actual number of birds present in the area will be higher.

Table 8.1 Counts of breeding seabirds within 5 km of the site

Common name	Species	Count	Method	Individual /pair
Herring gull	*Laras argentatus*	17	Occupied nests	Pairs
Common gull	*Larus canus*	22	Occupied nests	Pairs

Seabirds were recorded to have been breeding at two locations within a 5km radius of the mussel beds. Both locations had nesting gulls. These species are likely to be present in the area for much of the year so the number breeding is likely to underrepresent the total number present in the firth.

Large numbers of waders and wildfowl utilize the area during the winter, with some species also breeding in the area during the summer. Roosts are noted around Dornoch Point and at points along the shore westward and in Tain Bay. The maximum estimated numbers of birds in these areas approaches 20000 (Swann, 2007). Any impact on the microbiological water quality at the mussel fishery is likely to be most acute during the winter months and potentially at those beds closest to the roosting sites. It should be noted that these birds will feed throughout the intertidal areas and are susceptible to disturbance so their impact will most likely be widely spread.

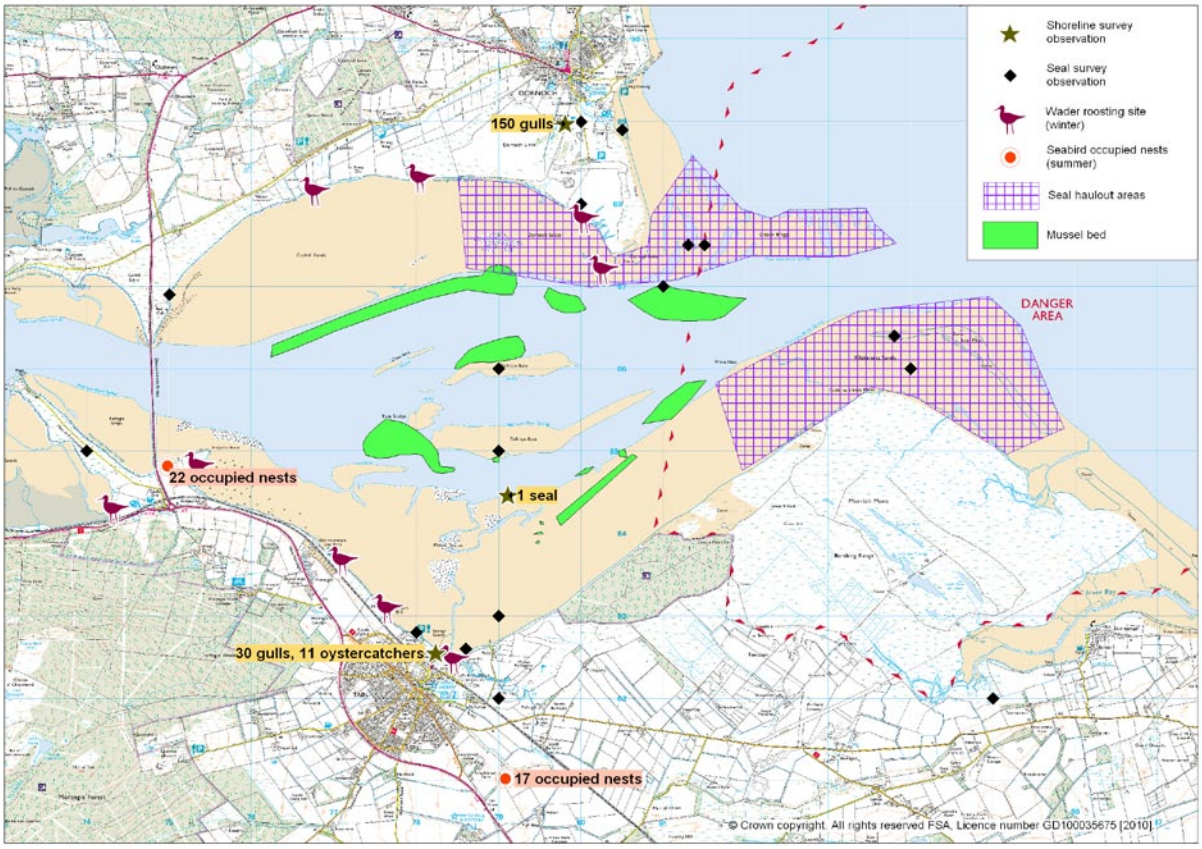

Figure 8.1 Wildlife observations at Dornoch Firth

Otters

The Dornoch Firth & Morrich More SAC is listed for otters and reports a 'good' population of them with suitable habitat in both the Rivers Oykel and Evelix so it is expected that they are present in the area. No otters were seen during the shoreline survey, but this is not unusual as these animals are not easily observed. The typical population densities of coastal otters are low and their impacts on the shellfishery are expected to be very minor.

Deer

Red, roe and Sika deer are all reportedly present in the area, potentially in high densities. However, no specific information was available on counts. Therefore, deer can be presumed to be present and their faeces to be present in rivers and streams discharging into the firth. Deer would tend to be present in the area year-round, though seasonal variations in their movements and density are not known. In the absence of further specific information, the spatial impact to the fishery will be presumed to be evenly distributed.

Summary

In summary, the main wildlife species potentially impacting on the production areas are likely to be seals and waterbirds, the latter of which are only present in large numbers between October and April. The largest impacts are expected at the northeastern shellfish beds where they lie closest to both seal haulout and wader roosting areas.

9. Meteorological data

The nearest weather station for which uninterrupted rainfall records for 2003-2008 are available is located at Tain Range, approximately 2.3 km to the south-east of the fishery. The nearest weather station for which wind data is available is Kinloss, approximately 33 km to the south-east of the fishery. While overall wind patterns may be broadly similar at the fishery and at Kinloss, local topography is likely result in some differences and conditions at any given instant may differ due to the distance between them. This section aims to describe the local rain and wind patterns and how they may affect the bacterial quality of shellfish within Dornoch Firth.

Rainfall and wind data were supplied to Cefas/FSAS by the Meteorological Office under licence. Unless otherwise identified, the content of this section (e.g. graphs) is based on further analysis of this data undertaken by Cefas.

9.1 Rainfall

High rainfall and storm events are commonly associated with increased faecal contamination of coastal waters through surface water run-off from land where livestock or other animals are present, and through sewer and waste water treatment plant overflows (e.g. Mallin et al, 2001; Lee & Morgan, 2003). Figures 9.1 and 9.2 present box and whisker plots summarising the distribution of individual daily rainfall values by year and by month. The grey box represents the middle 50% of the observations, with the median represented by a line within the box. The whiskers extend to the largest or smallest observations up to 1.5 times the box height above or below the box. Individual observations falling outside the box and whiskers are represented by the symbol *.

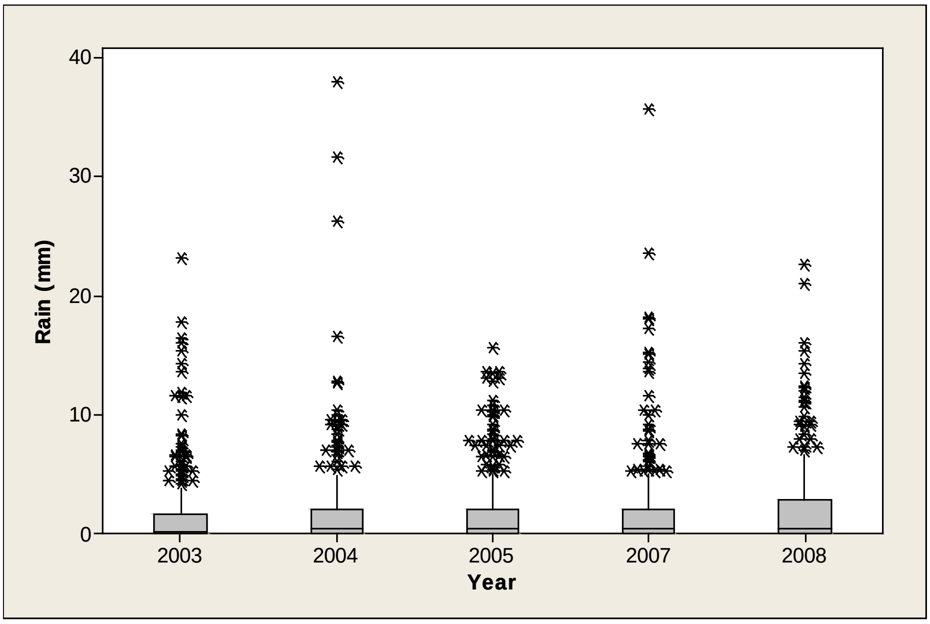

Figure 9.1 Box plot of daily rainfall values by year at Tain Range, 2003-2008

Figure 9.1 shows that rainfall patterns were broadly similar between the years presented here, with 75% of days having rainfall of less than 3 mm and the median rainfall being 1mm or less. Days with rainfall greater than 20 mm occurred in all years but 2005, and there did not appear to be any trend or pattern in these between the years presented.

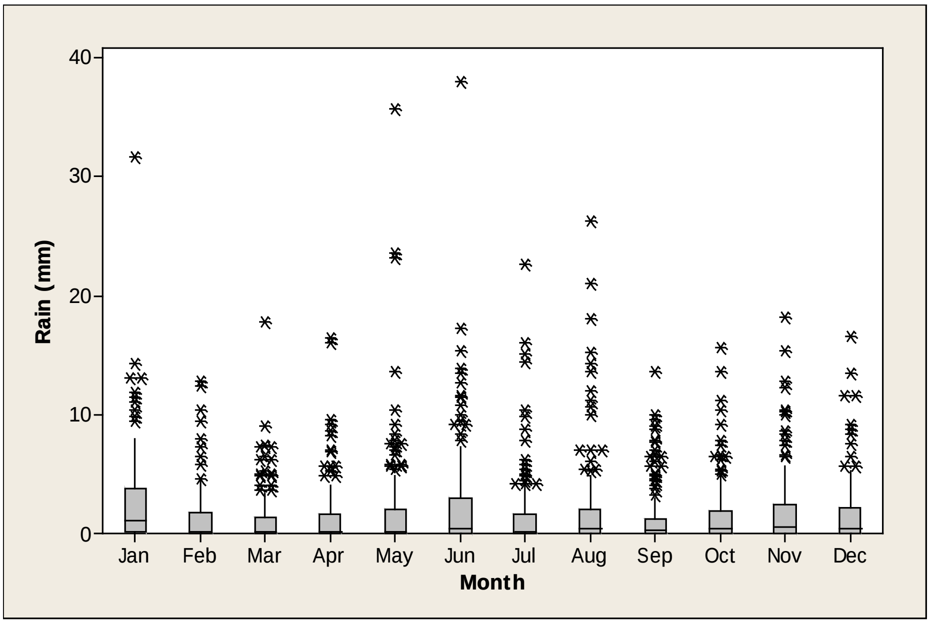

Figure 9.2 Box plot of daily rainfall values by month at Tain Range, 2003-2008

There does not appear to be a particularly strong seasonal pattern in rainfall at Tain Range. January and June were the wettest months and March and September the driest. High rainfall days (>20 mm) occurred in January and from May to August in this dataset. For the period considered here (2003-2008), 63% of days experienced rainfall less than 1 mm, and only 3% of days experienced rainfall of 10 mm or more.

9.2 Wind

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

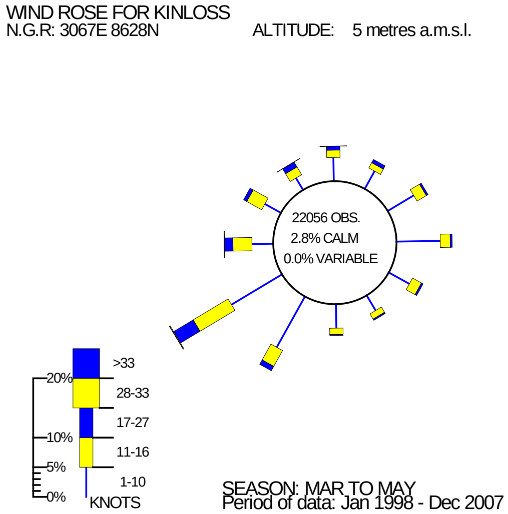

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Figure 9.3 Wind rose for Kinloss (March to May)

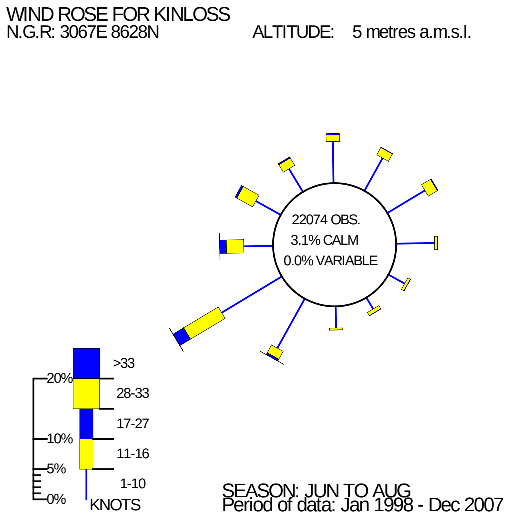

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Figure 9.4 Wind rose for Kinloss (June to August)

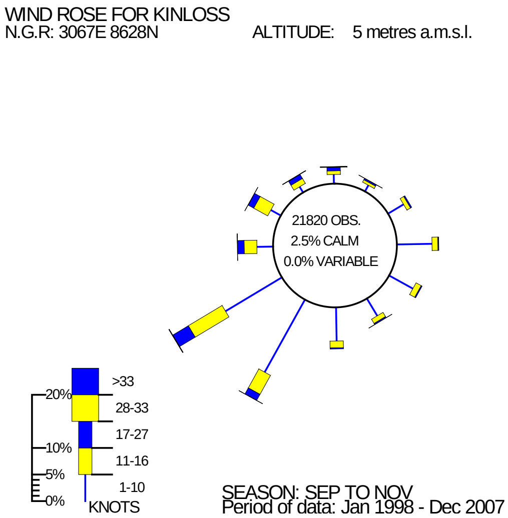

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Figure 9.5 Wind rose for Kinloss (September to November)

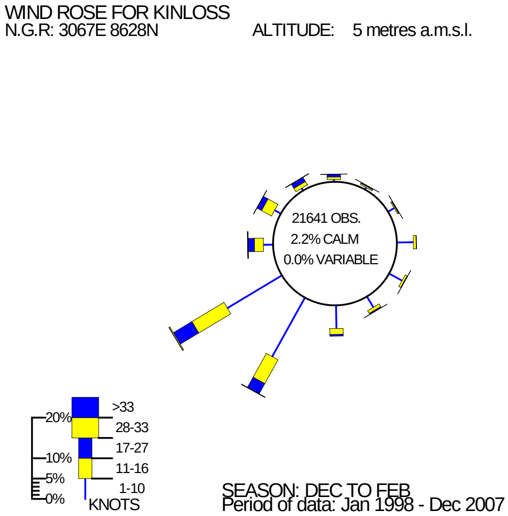

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Figure 9.6 Wind rose for Kinloss (December to February)

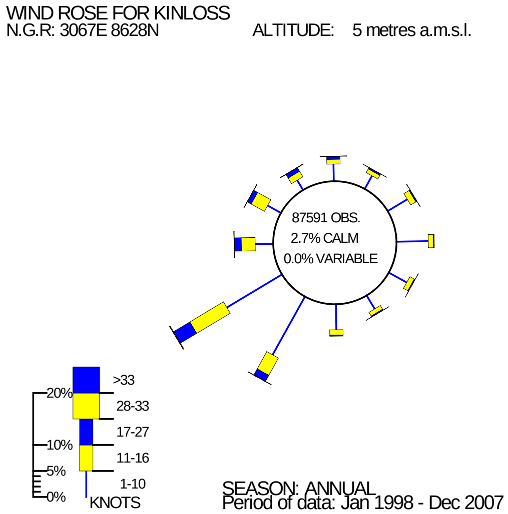

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Figure 9.7 Wind rose for Kinloss (Annual)

Wind direction is strongly skewed towards the south west at Kinloss, and there is a relatively low frequency of gales here compared to more exposed places such as Shetland. Winds are lightest during the summer months, and there is a higher frequency of winds from the north and east during spring and summer. The very skewed patterns of wind direction may be influenced by local topography. The station is located within the airfield at Kinloss, which is situated on low lying coastal land to the south of the Moray Firth and east of Findhorn Bay, but its exact sitting in relation to minor topographical features is not known.

Dornoch Firth has an east-west aspect and the surrounding land is generally low lying, although there is a hill rising to 300 m just to the west of Tain. The outer firth is broad and strong winds from any direction could affect the state of the bay over the mussel beds. 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. These surface water currents create return currents which may travel along the bottom or sides of the water body depending on bathymetry. Strong winds will increase the circulation of water and hence dilution of contamination from point sources within the sound.

10. Current and historical classification status

Dornoch Firth has been classified for common mussels since 2001. The classification history is presented in Table 10.1.

Table 10.1 Classification history, Dornoch Firth

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	a	a	a	a	a	a	a	a	a	a	a	a
2002	B	B	B	B	A	A	A	A	A	A	A	B
2003	A	A	A	A	A	A	A	B	A	A	A	A
2004	B	A	A	A	A	A	A	A	A	A	A	A
2005	B	A	A	A	A	B	B	B	B	B	B	B
2006	B	B	B	B	B	B	B	B	B	B	B	B
2007	B	B	B	B	B	B	B	B	B	B	B	B
2008	B	B	B	A	A	B	B	B	B	B	B	B
2009	B	A	A	A	A	A	A	B	B	B	A	A
2010	A	A	A	A	A	A	A	B	B	B	B	B
2011	B	A	A									

Note: Lower case denotes provisional classification

Table 10.2 Classification history, Dornoch Mussels 1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010				b	b	b	b	b	b	b	b	b
2011	b	b	b									

Note: Lower case denotes provisional classification

Table 10.3 Classification history, Dornoch Mussels 2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010				b	b	b	b	b	b	b	b	b
2011	b	b	b									

Note: Lower case denotes provisional classification

The Dornoch Firth production area received a provisional A classification in 2001. Since then it has held seasonal A/B classifications, with the timing of varying considerably from year to year, aside from in 2006 and 2007, when it was classified B all year.

The Dornoch Mussels 1 and Dornoch Mussels 2 production areas have both received provisional class B classification in 2010/11.

11. Historical *E. coli* data

11.1 Validation of historical data

All shellfish samples taken Dornoch Firth from the beginning of 2002 up to the 29th September 2009 were extracted from the database and validated according to the criteria described in the standard protocol for validation of historical *E. coli* data.

Three razor samples had no reported grid reference and so were not used in the analysis. One mussel sample with a reported sampling location within the Dornoch Firth, but to the west of the A9 road bridge was not used in the analysis. Five mussel samples which had reported sampling locations on land between 2 and 13 km from the existing production area were not used in the analysis. Four carpet clam samples which had reported sampling locations which fell outside of the Dornoch Firth, in the Moray Firth were also excluded from the analysis.

One mussel sample was reported as being received by the laboratory before it was collected, so this sample was excluded from the analysis.

Four samples had the result reported as <20, and were assigned a nominal value of 10, for statistical assessment and graphical presentation, and one sample had a reported result of >18000, and this was assigned a nominal value of 36000 for these purposes.

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

11.2 Summary of microbiological results

Approximately half of samples were taken from the nominal RMP and the remainder from 41 different locations. Therefore, data are presented for the nominal RMP and all other sampling locations combined in Table 11.1. Samples were reported as originating from three separate production areas: Dornoch Firth, Dornoch Mussels 1, and Dornoch Mussels 2. However, when the location of these samples was plotted by production area (Figure 11.1) there was no clear relationship with discrete geographical areas. The exception to this was Dornoch Mussels 1, which did seem to be clustered around one discrete mussel bed, albeit together with samples from other production areas. Therefore, for this section of the report all results will be analysed together as if they had originated from the same production area.

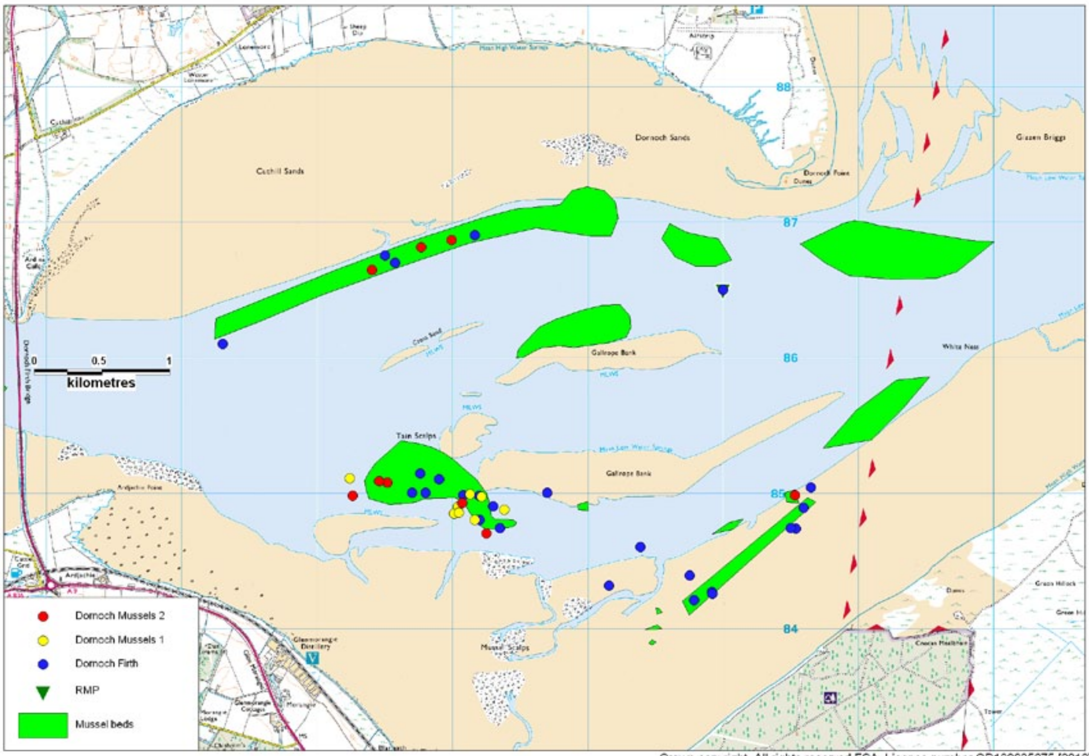

Figure 11.1 Reported sampling location by reported production area

Table 11.1 Summary of historical sampling and results

Sampling Summary		
Production area	Dornoch Firth/Dornoch Mussels 1/Dornoch Mussels 2	Dornoch Firth
Site	Dornoch Firth/Mussel Scalps/ Tain Scalps	Dornoch Firth
Species	Common mussels	Common mussels
SIN	HS-054-239-08/HS-464-872-08/ HS-465-873-08	HS-054-239-08
Location	41 locations	NH 800 865
Total no of samples	43	46
No. 2002		7
No. 2003		10
No. 2004		9
No. 2005		8
No. 2006		10
No. 2007	7	2
No. 2008	13	
No. 2009	23	
Results Summary		
Minimum	20	<20
Maximum	9100	>18000
Median	160	110
Geometric mean	230	110
90 percentile	1260	430
95 percentile	3280	690
No. exceeding 230/100g	18 (42%)	13 (28%)
No. exceeding 1000/100g	7 (16%)	2 (4%)
No. exceeding 4600/100g	1 (2%)	1(2%)
No. exceeding 18000/100g	0	1(2%)

11.3 Overall geographical pattern of results

Figure 11.2 presents a map showing *E. coli* result by reported sampling location. All but 3 locations were only sampled on one occasion. The RMP (NH 800 865) was sampled on 46 occasions, and NH 77992 86869 and NH 78214 84972 were sampled on two occasions. From 2002 to mid 2007, all samples were reported against the RMP, although it is quite likely that they were taken from a variety of locations within the area. For this reason, only the individual results at locations other than the RMP have been considered in the geographic analysis.

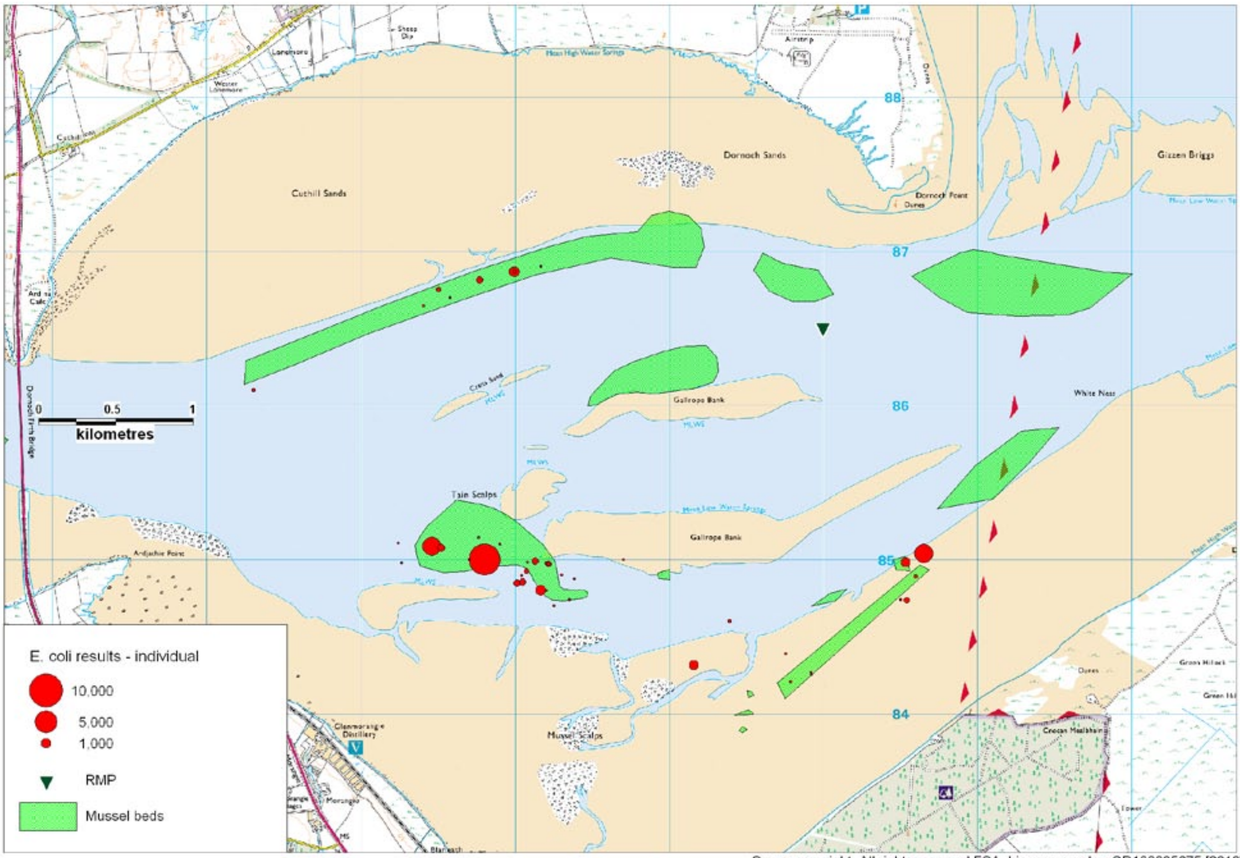

Figure 11.2 Map of individual results

Figure 11.2 shows a trend toward higher results in the south west mussel bed, although this area was most intensively sampled and so a greater range of results could arise from that cause alone.

The three production areas listed in Table 11.1 were all sampled on the same day on 6 occasions. When these samples were plotted by location, they did not align to discrete geographical areas so no comparison of results for these 6 occasions was made.

11.4 Overall temporal pattern of results

Figure 11.3 presents a scatter plot of individual results against date for Dornoch Firth. The points are fitted with trend lines calculated using two different techniques. These trend lines help to highlight any apparent underlying trends or cycles.

One of the trend lines joins the values representing the geometric mean of the previous 5 samples, the current sample and the following 6 samples and is referred to as a rolling geometric mean (black line). The other is a loess line (blue line), which stands for 'locally weighted regression scatter plot smoothing'. At each point in the data set an estimated value is fit to a subset of the data, using weighted least squares. The loess line approach gives more weight to points near to the x-value where the estimate is being made and less weight to points further away. In terms of the monitoring data, this means that any point on the loess line will be influenced more by the data close to it (in time) and less by the data further away.

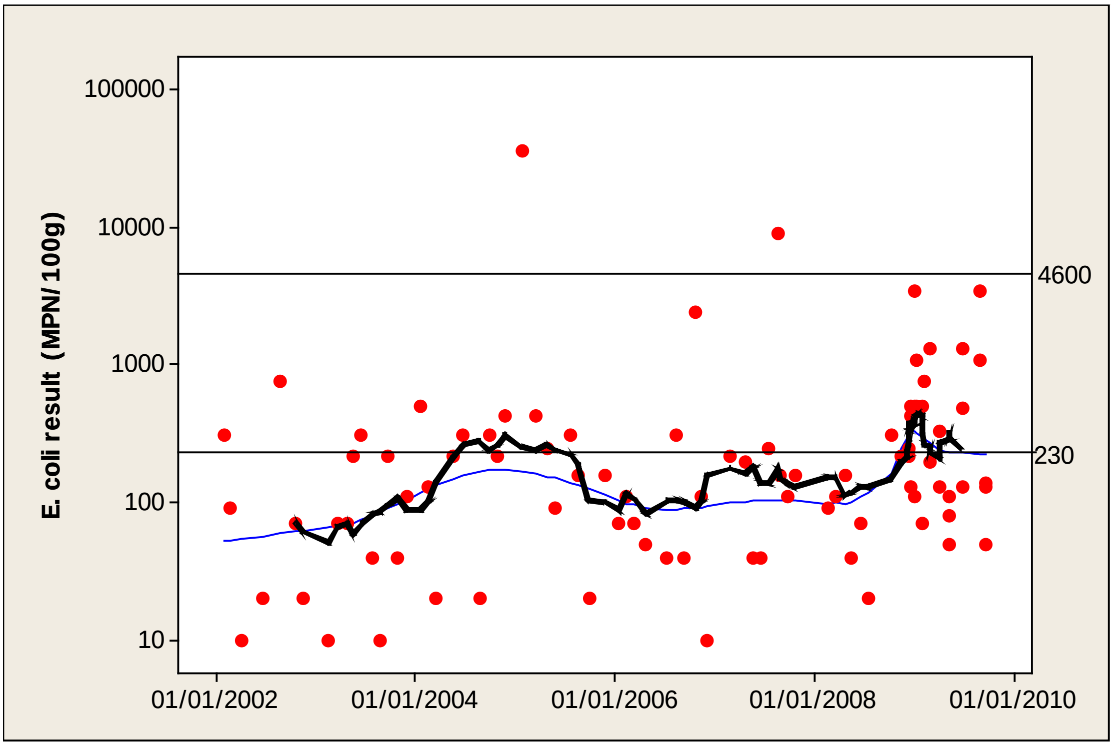

Figure 11.3 Scatterplot of *E. coli* results by date with rolling geometric mean (black line) and loess line (blue line)

Figure 11.3 suggests an overall deterioration in results through the sampling history, with a marked decline (represented by an increase in *E. coli* result) in 2009. Since 2007, no results of <20 *E.coli* MPN/100 g have been obtained and a greater proportion of the results has exceeded 230 *E.coli* MPN/100 g. The cluster of higher results in 2009 were geographically dispersed and therefore not directly indicative of any particular source.

11.5 Seasonal pattern of results

Season dictates not only weather patterns and water temperature, but livestock numbers and movements, presence of wild animals and patterns of human occupation. All of these can affect levels of microbial contamination, and cause seasonal patterns in results. Figure 11.4 presents a boxplot of *E. coli* result by month.

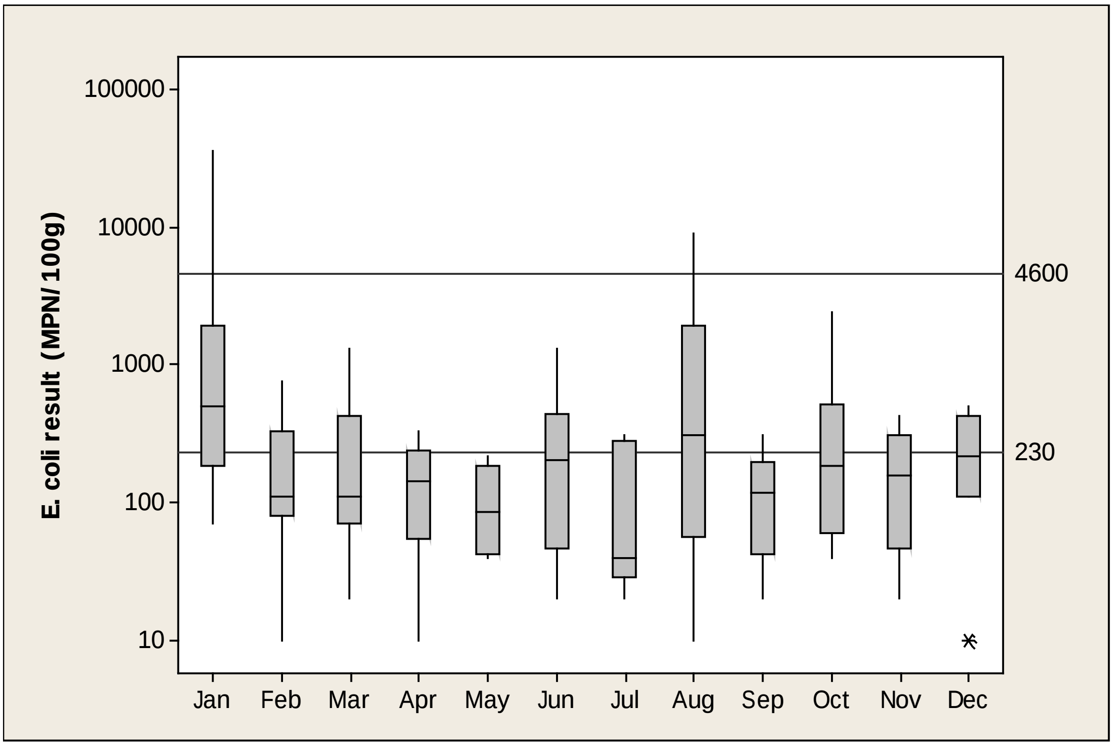

Figure 11.4 Boxplot of results by month

Higher results occurred during January and August, although there does not appear to be any overall pattern in *E. coli* levels by month.

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

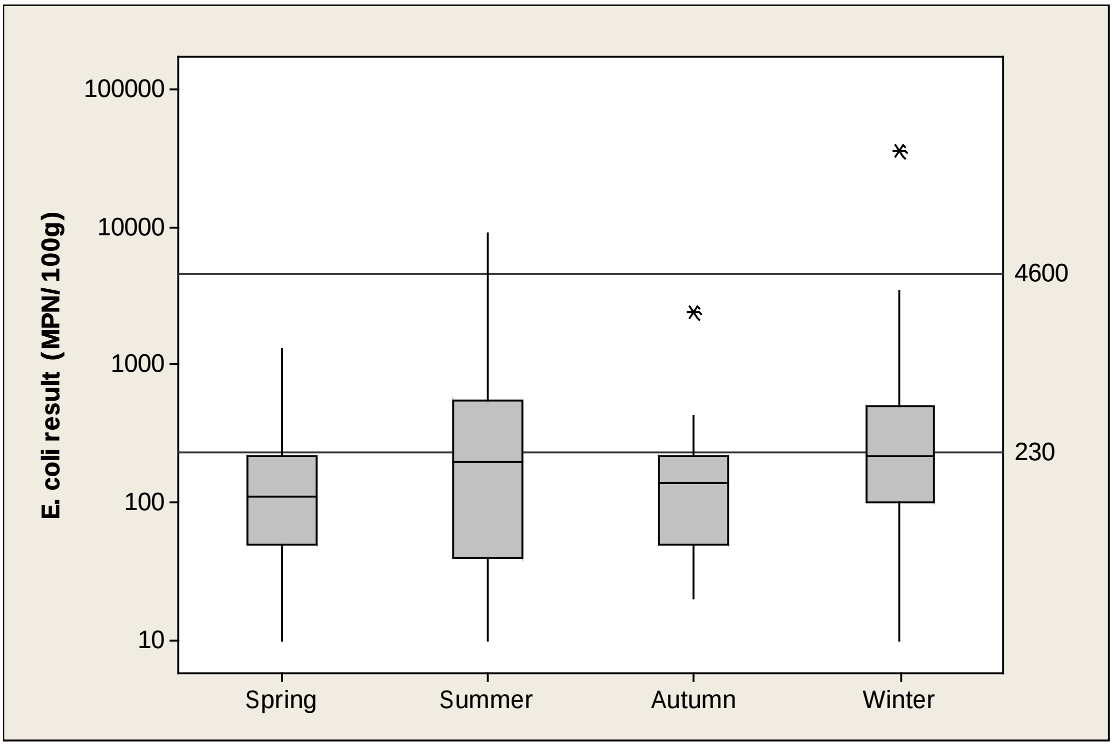

Figure 11.5 Boxplot of result by season

However, no significant difference was found between results by season (One-way ANOVA, p=0.229, Appendix 6). Highest results occurred in summer and winter, consistent with the monthly observations in Figure 11.4.

11.6 Analysis of results against environmental factors

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

11.6.1 Analysis of results by recent rainfall

The nearest weather station is at Tain Range, approximately 2.3 km to the south-east of the fishery. Rainfall data was purchased from the Meteorological Office for the period 1/1/2003 to 31/12/2008 (total daily rainfall in mm). As the effects of heavy rain may take differing amounts of time to be reflected in shellfish sample results in different systems, the relationships between rainfall in the previous 2 and 7 days and sample results was investigated and are presented below.

Two-day antecedent rainfall

Figure 11.6 presents a scatterplot of *E. coli* results against rainfall. A spearman's Rank correlation was carried out between results and rainfall.

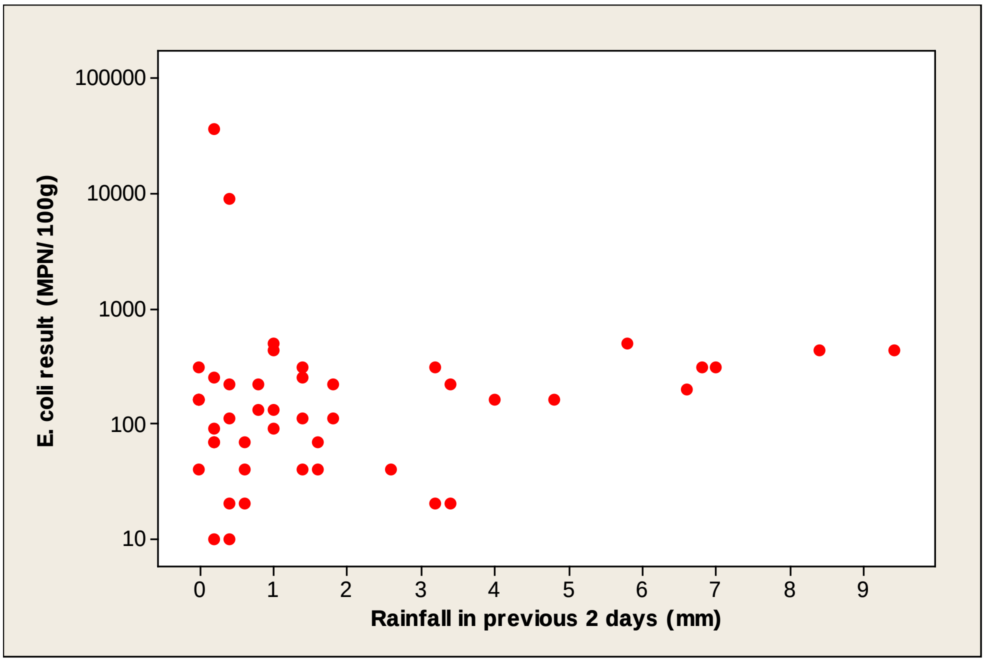

Figure 11.6 Scatterplot of result against rainfall in previous 2 days

No correlation was found between *E. coli* result and rainfall in the previous 2 days (Spearman's rank correlation=0.226, p=0.131, Appendix 6), although it is apparent from Figure 11.6 that no low results (<100 MPN/100 g) occurred when over 4 mm of rain had fallen. Two exceptionally high results occurred following rainfall of less than 0.5mm in the previous two days. These results may have been due to contamination sources that are independent of rainfall. When the data were evaluated excluding those two points, a statistically significant correlation between the remaining results and rainfall was found (Spearman's rank correlation = 0.323, p=0.032, Appendix 6).

Seven-day antecedent rainfall

Figure 11.7 presents a scatterplot of *E. coli* results against rainfall and again a Spearman's rank correlation was carried out between results and rainfall.

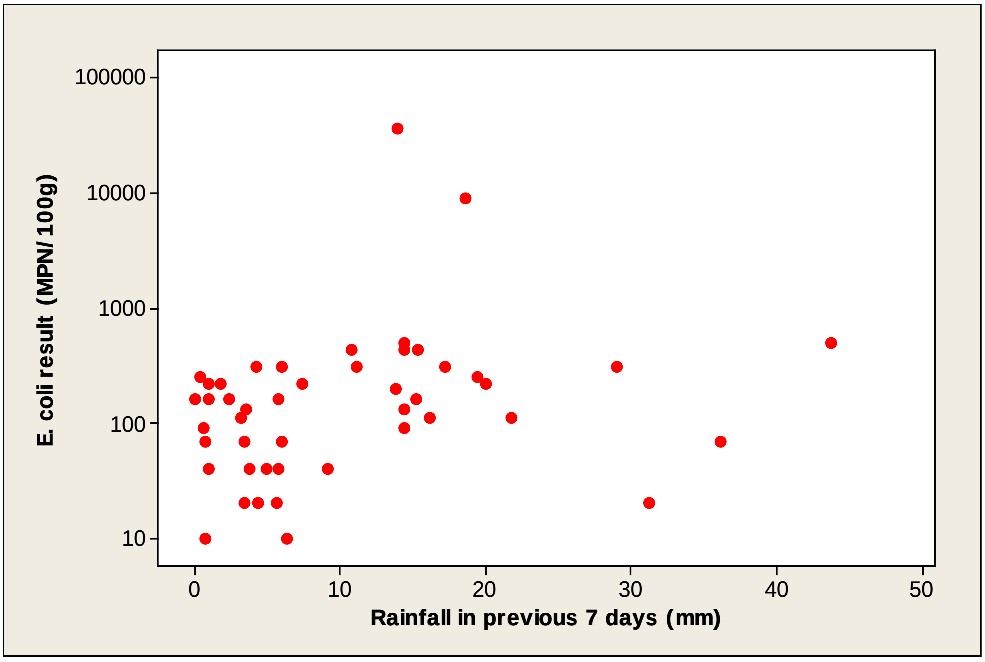

Figure 11.7 Scatterplot of result against rainfall in previous 7 days

A weak positive correlation was found between *E. coli* result and rainfall in the previous 7 days (Spearman's rank correlation= 0.344, p=0.019, Appendix 6), although low results did occur at rainfall over 30 mm. Here, the two exceptionally high results were found to occur within a week of moderate rainfall.

11.6.2 Analysis of results by tidal height and state

Spring/Neap Cycles

When the larger (spring) tides occur every two weeks, circulation of water and particle transport distances will increase, and more of the shoreline will be covered at high water, potentially washing more faecal contamination from livestock into the loch. Figure 11.8 presents a polar plot of $\log_{10}$ *E. coli* results on the lunar spring/neap tidal cycle. Full/new moons occur at 0º, and half moons occur at 180º. The largest (spring) tides occur about 2 days after the full/new moon, or at about 45º, then decrease to the smallest (neap tides) at about 225º, then increase back to spring tides. Results of under 230 *E. coli* MPN/100 g are plotted in green, those between 230 and 1000 *E. coli* MPN/100 g are plotted in yellow, and those over 1000 *E. coli* MPN/100 g are plotted in red. It should be noted that local meteorological conditions such as wind strength and direction can influence the height of tides and this is not taken into account.

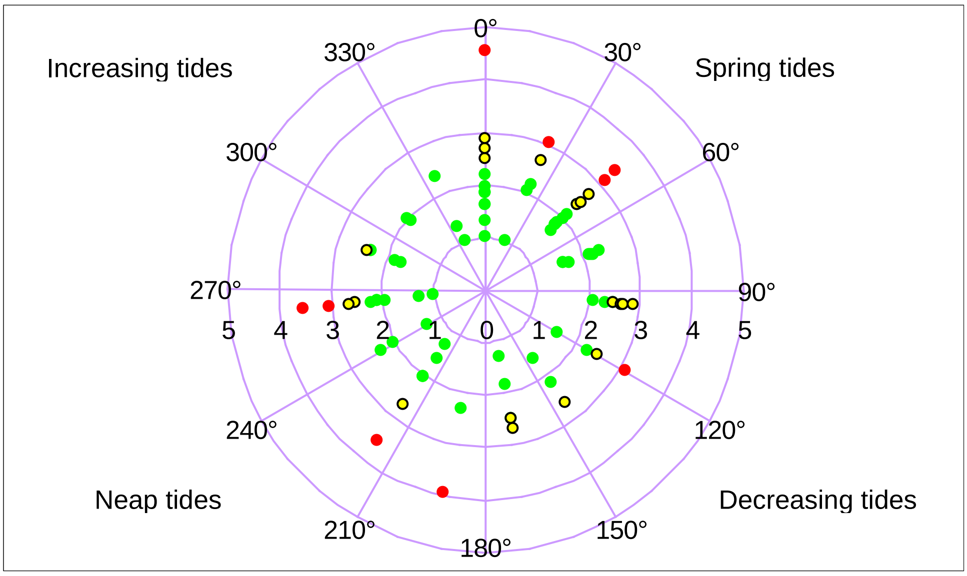

Figure 11.8 Polar plot of $\log_{10}$ *E. coli* results on the spring/neap tidal cycle

No correlation was found between *E. coli* results and the spring/neap cycle (circular-linear correlation, r=0.150, p=0.145, Appendix 6), and no pattern is apparent in Figure 11.8.

High/Low Cycles

Direction and strength of flow around the production areas will change according to tidal state on the (twice daily) high/low cycle, and, depending on the location of sources of contamination, this may result in marked changes in water quality in the vicinity of the beds during this cycle. As *E. coli* levels in some shellfish species can respond within a few hours or less to changes in *E. coli* levels in water, tidal state at time of sampling (hours post high water) was compared with *E. coli* results. Figure 11.9 presents a polar plot of $\log_{10}$ *E. coli* results on the lunar high/low tidal cycle. High water is located at 0º, and low water is located at 180º. Again, results of under 230 *E. coli* MPN/100 g are plotted in green, those between 230 and 1000 *E. coli* MPN/100 g are plotted in yellow, and those over 1000 *E. coli* MPN/100 g are plotted in red.

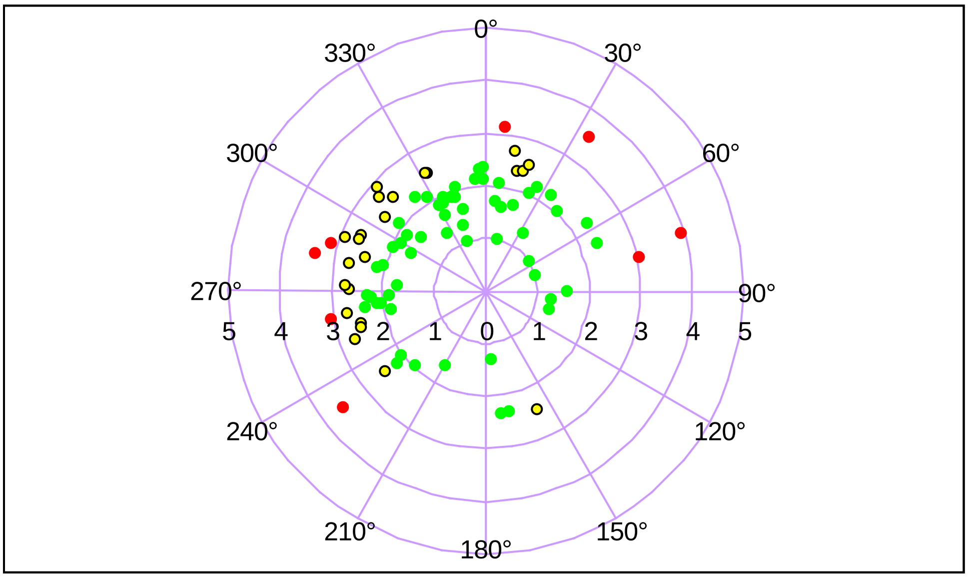

Figure 11.9 Polar plot of log-10 *E. coli* results on the high/low tidal cycle

A very weak correlation was found between *E. coli* results and the high/low tidal cycle (circular-linear correlation, r=0.190, p=0.044, Appendix 6) suggesting that levels of *E. coli* are non random with respect to the high/low cycle. Higher results tended to be seen from the first part of the rising tide to the first part of the falling tide, although sampling effort was biased toward high tide, with some parts of the fishery only accessible during high tide.

11.6.3 Analysis of results by water temperature

Water temperature is likely to affect the survival time of bacteria in seawater (Burkhardt *et al*, 2000) and the feeding and elimination rates of shellfish and therefore may be an important predictor of *E. coli* levels in shellfish flesh. It is of course closely related to season, and so any correlation between temperatures and *E. coli* levels in shellfish flesh may not be directly attributable to temperature, but to other factors such as seasonal differences in livestock grazing patterns. Figure 11.10 presents a scatterplot of *E. coli* results against water temperature.

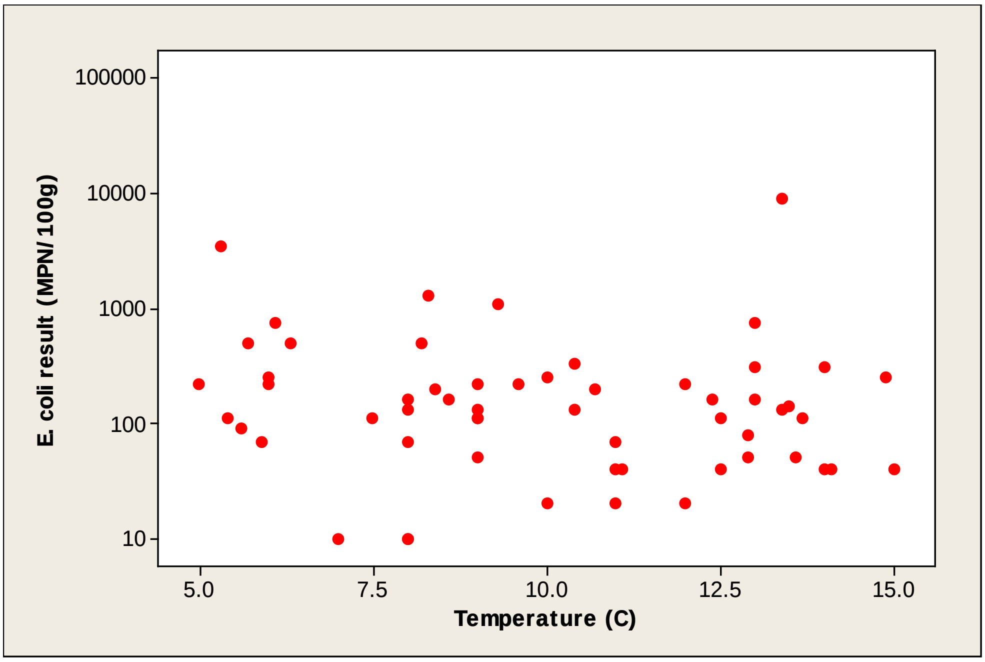

Figure 11.10 Scatterplot of result by water temperature

The coefficient of determination indicates that there was no relationship between the *E. coli* result and water temperature (Adjusted R-sq=0.0%, p=0.331, Appendix 6)

11.6.4 Analysis of results by wind direction

Wind speed and direction are likely to change water circulation patterns within the production area. However, the nearest wind station for which records were available was Kinloss, approximately 33 km to the south-east of the fishery. Given the differences in local topography and distance between the two it is likely that the overall patterns of wind direction differ, and that the wind strength and direction may differ significantly at any given time. Therefore it was not considered appropriate to compare *E. coli* results at Dornoch Firth with wind readings taken at Kinloss.

11.6.5 Analysis of results by salinity

Salinity will give a direct measure of freshwater influence, and hence freshwater borne contamination at the site. Figure 11.11 presents a scatter plots of *E. coli* result against salinity. Most of the salinities recorded ranged between 25 and 35 ppt. The highest *E. coli* result occurred at a recorded salinity of 15ppt, which was the only salinity recorded below 24 ppt. Results greater than 1000 *E. coli* MPN/100 g occurred at recorded salinities of up to 36 ppt.

The coefficient of determination indicates that there was no relationship between the *E. coli* result and salinity for mussels (Adjusted R-sq=1.8%, p=0.191, Appendix 6), although the highest result occurred at the only salinity recorded as less than 24 ppt.

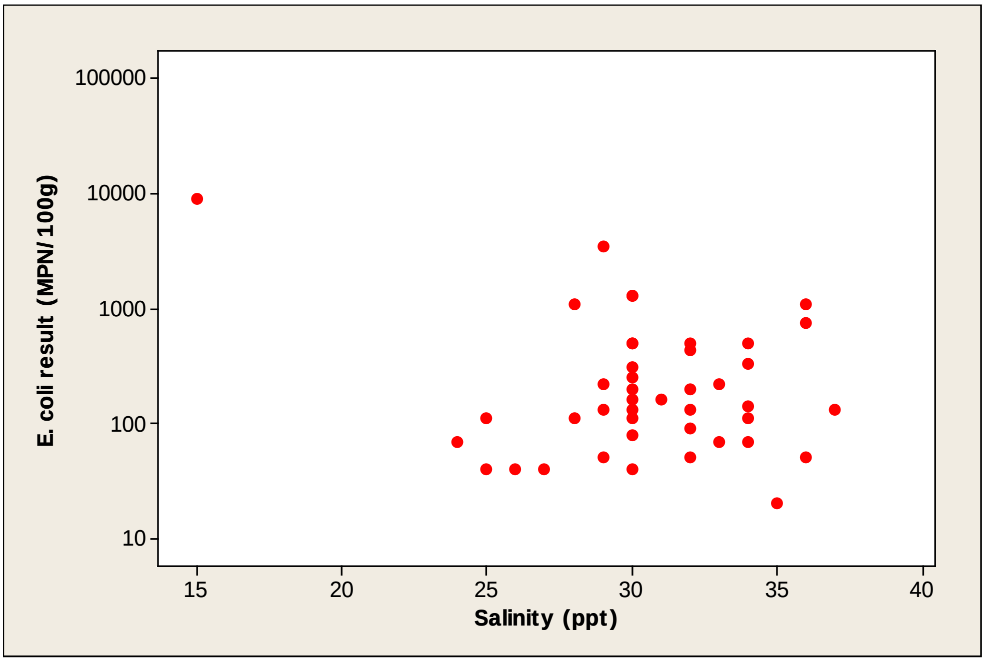

Figure 11.11 Scatterplot of result by salinity

11.7 Evaluation of results over 1000 *E. coli* MPN/100g

A total of 9 samples gave a result of over 1000 *E. coli* MPN/100g, and these are listed in Table 11.2.

Table 11.2 Historic *E. coli* sampling results over 1000 *E. coli* MPN/100g

Collection date	*E. coli* (MPN/100g)	Location	2 day rainfall (mm)	7 day rainfall (mm)	Water Temp (ºC)	Salinity (ppt)	Tidal state (high/low)	Tidal state (spring/neap)
25/01/2005	>18000	NH800865	0.2	14	*	*	Ebb	Spring
24/10/2006	2400	NH800865	*	*	*	*	High	Spring
21/08/2007	9100	NH778850	0.4	18.6	13.4	15	Flood	Neap
05/01/2009	3500	NH 80648 85041	*	*	5.3	29	Flood	Neap
12/01/2009	1100	NH 80531 84983	*	*	9.3	36	Flood	Spring
02/03/2009	1300	NH 78166 84803	*	*	8.3	30	Flood	Decreasing to neap
24/06/2009	1300	NH 77992 86869	*	*	*	30	Flood	Spring
31/08/2009	1100	NH 79156 84316	*	*	*	28	Ebb	Neap
31/08/2009	3500	NH 77459 85086	*	*	*	*	High	Neap

* Data unavailable

These results arose in January (3), March (1), June (1), August (3) and November (1). Six of these 9 results arose in 2009, although the highest result arose in 2005. Rainfall data was only available for two of these results, and these did not occur following particularly heavy rainfall. They occurred at a range of salinities, with one result occurring at the lowest salinity recorded (15 ppt). They occurred under a range of tidal conditions, although five of 9 occurred on a flooding tide, and none occurred at low water or when tide size was increasing towards spring tides.

The geographic distribution of all but the first two samples is shown in Figure 11.12. The first two samples were reported against the nominal RMP, and as the actual location from which they were taken is not clear they have been excluded from this analysis. The majority of these samples (6) were taken from along the southern side of the fishery, with only one sample from the northern side. Of the samples on the southern side of the fishery, half came from the bed on the southwestern side of the channel.

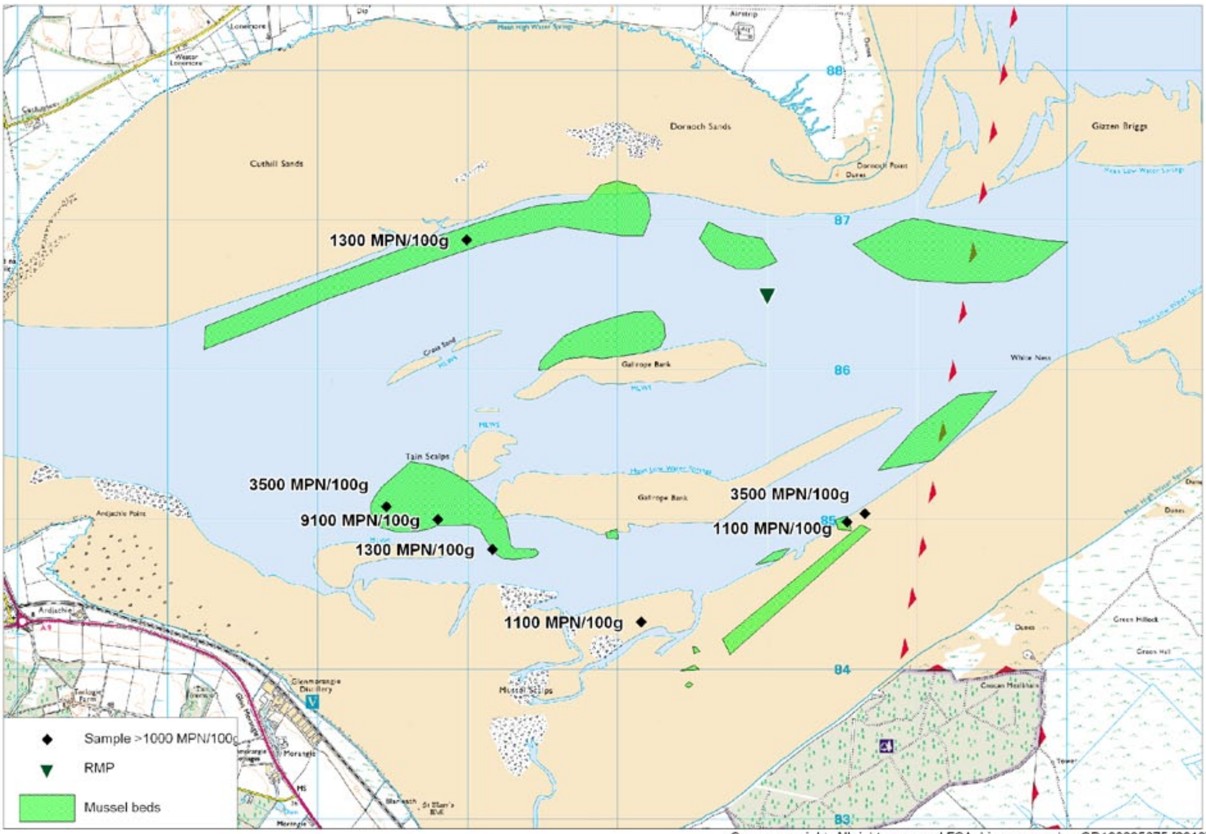

Figure 11.12 Map of results over 1000 *E. coli* MPN/100g

11.8 Summary and conclusions

Reported sampling locations did not align to the three discrete production areas sampled, so all samples were considered together in this analysis. A thematic map of results by sampling location showed a trend toward higher results in the south west mussel bed, although this area was most intensively sampled and so this may have biased the outcome.

An overall deterioration in results is apparent since 2002, and this mainly occurred during 2009. There was no significant difference in results by season, and no relationship between results and water temperature.

A positive correlation was found between *E. coli* results and rainfall in the previous 7 days, but not for rainfall in the previous 2 days except when the two highest results were omitted. No relationship was found between *E. coli* results and salinity, although the highest result for data was available occurred at the lowest recorded salinity, indicating it may have been related to fresh water influx to the area.

No correlation was found between *E. coli* result and tidal state on the spring/neap tidal cycle. A very weak correlation was found between *E. coli* result and tidal state on the high/low cycle suggesting levels of contamination were non random with respect to this cycle.

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.

The highest results originated from the southern side of the fishery, and particularly from the bed on the southwestern side of the channel.

11.9 Sampling frequency

When a production area has held the same (non-seasonal) classification for 3 years, and the geometric mean of the results falls within a certain range it is recommended that the sampling frequency be decreased from monthly to bimonthly. This is not appropriate this production area as it has held seasonal classifications in the last three years.

12. Other Designated Waters Data

Shellfish Growing Waters

The area considered in this report coincides in part with a shellfish growing water which was designated in 1998. The growing water encompasses a larger area than the production area covered by this report. The extent of the growing water is shown on Figure 12.1.

The monitoring requires the following testing:

- Quarterly for salinity, dissolved oxygen, pH, temperature, visible oil
- Twice yearly for metals in water
- Annually for metals and organohalogens in mussels
- Quarterly for faecal coliforms in mussels

There are 3 designated monitoring points within the growing water indicated on the map.

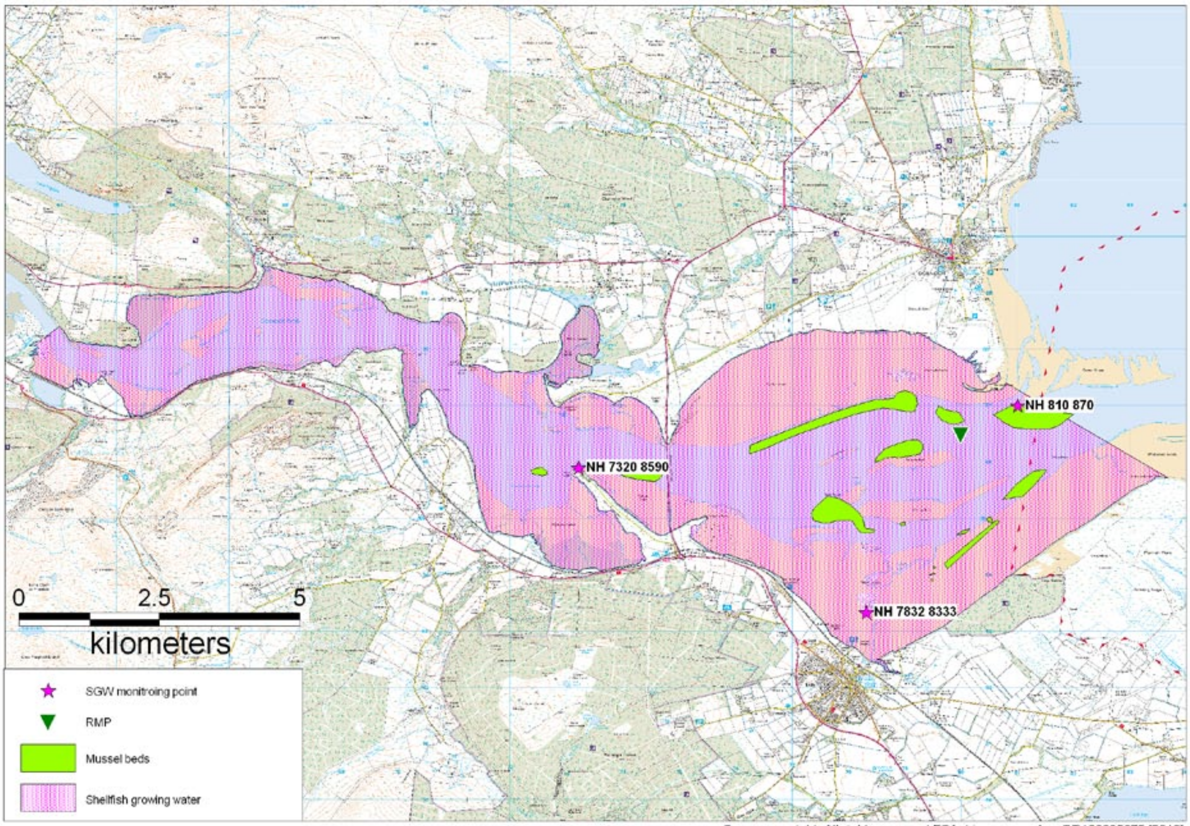

Figure 12.1 Shellfish growing waters and monitoring points

Three locations were sampled, one within the current production area (NH 810 870), one in the intertidal zone just off Tain (NH 7832 8333), and one at the Ferry Pier, to the west of the A9 road bridge (NH 7320 8590). The latter point is most relevant to the area considered in the separate Dornoch Firth: Meikle Ferry report.

On average results were highest in quarter 3, and lowest in quarter 1, but these differences were not statistically significant (one way ANOVA, p=0.360, Appendix 6).

Table 12.1 SEPA Faecal coliform results (faecal coliforms/100g) for shore mussels gathered from Dornoch Firth.

	Site	**Dornoch Firth**	**Dornoch Firth**	**Dornoch Firth Mussels @ Ferry Point Pier**
	OS Grid Ref.	NH 810 870	NH 7832 8333	NH 7320 8590
2000	Q1			
	Q2	40		
	Q3	250		
	Q4			
2001	Q1			
	Q2	40		
	Q3			
	Q4	110		
2002	Q1	250		
	Q2	50		
	Q3	250		
	Q4	40		
2003	Q1	<20*		
	Q2			
	Q3			9100
	Q4			220
2004	Q1		310	
	Q2		5400	
	Q3		9100	
	Q4			<20*
2005	Q1			40
	Q2			750
	Q3			70
	Q4			750
2006	Q1		40	
	Q2		40	
	Q3		90	
	Q4		5400	
2007	Q1		90	
	Q2			
	Q3			
	Q4			
Geometric mean		72	425	227

* Assigned a nominal value of 36000 for the calculation of the geometric mean.

No samples were taken from more than one site at the same time, so it is not possible to determine whether the differences in geometric mean were due to sampling location or variation with time. Maximum results were higher at the two more recently sampled sites and are indicative of the occurrence of high levels of faecal contamination at these sites at times.

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. However, the results confirm the outcome of shellfish hygiene testing, that mussels in the area are subject on occasion to moderately high levels on faecal contamination.

Bathing Waters

The beach east of Dornoch was identified as a bathing water under the EC Bathing Water Directive (76/160/EEC) in 1999. This area stretches from Dornoch Point northward for over 4.6 km along the coast east of the town of Dornoch as shown in Figure 12.2. The identified monitoring point for this area is NH 8190 9175, also shown in Figure 12.2, which lies approximately 1.5 km north of the identified bathing water.

Figure 12.2 Designated bathing water and monitoring point

This area has met the EC guideline standard of <100 faecal coliforms/100 ml since 1999. Microbiological results for 2007, as reported by SEPA in the 2008 bathing water report for Dornoch, were at or below 10 FC/100 ml. As a result of the historically good monitoring results at this beach, it has qualified for reduced sampling and is now only sampled 5 times per season. Given the location of the designated water outside the firth, the distance of the sampling point from the fishery, and the limited scope of annual sampling, these results are not considered representative of conditions at the fishery.

13. Rivers and streams

There are several river gauging stations on rivers or burns in the vicinity of Dornoch Firth. Six of these were on watercourses that were identified as discharging along the coastline of the firth and thus potentially relevant to the Dornoch Firth assessment (see Figure 13.1). One of these, Aldie Water at Glen Aldie, was located on a watercourse that eventually discharges into the outer firth – Aldie Water is a major tributary of the River Tain (see below). However, this gauging station appears to be have been discontinued and SEPA indicated that daily flow data was not available for this location. The other five gauging stations are located on watercourses that discharge into the inner firth and will be considered in detail in the Dornoch Firth: Meikle Ferry sanitary survey report, although reference to the outcome of the assessment of those stations will be considered in the conclusions at the end of this section.

The rivers and streams listed in Table 13.1 and shown in Figure 13.2 were measured and sampled during the shoreline survey of the outer firth. Other rivers and streams were measured and sampled in the inner firth above the bridge. The results of the latter are presented and analysed in the Dornoch Firth: Meikle Ferry sanitary survey report. There was no rainfall on the days of the survey during which the watercourses were measured and sampled.

Table 13.1 River and stream loadings for outer Dornoch Firth

No	Grid Reference	Width (m)	Depth (m)	Flow (m/s)	Flow in m^3/day	*E. coli* (cfu/ 100ml)	Loading (*E. coli* per day)
1	NH 78558 82416	39	0.51	0.28	$4.8x10^5$	360	$1.7x10^{12}$
2	NH 79566 88091	3	0.05	0.125	1620	27000	$8.1x10^8$

Watercourse 1 is the River Tain and this flows into the outer Dornoch Firth near the town of Tain. At low tide, the effective mouths of the river are close to some of the mussel beds on the southern side of the firth. Given the high loading of $1.7x10^{12}$ *E. coli* per day, it is likely that this will have an effect on the microbiological quality of the mussels at those locations. Watercourse number 2 is Black Burn, on the north-eastern side of the outer firth, and which flows from south of Dornoch. On the day of the survey, the calculated loading from Black Burn was relatively low and it would not be expected to impact significantly on the microbiological quality of the mussel beds on that side of the outer firth. Loadings from both watercourses would be expected to increase significantly following rainfall.

Other river and streams further up the firth were considered in the Dornoch Firth: Meikle Ferry sanitary survey report. It is likely that those watercourses would significantly impact on the quality of the mussel beds in the outer firth during the ebbing tide. The effect would be greatest at the western end of the mussel beds.

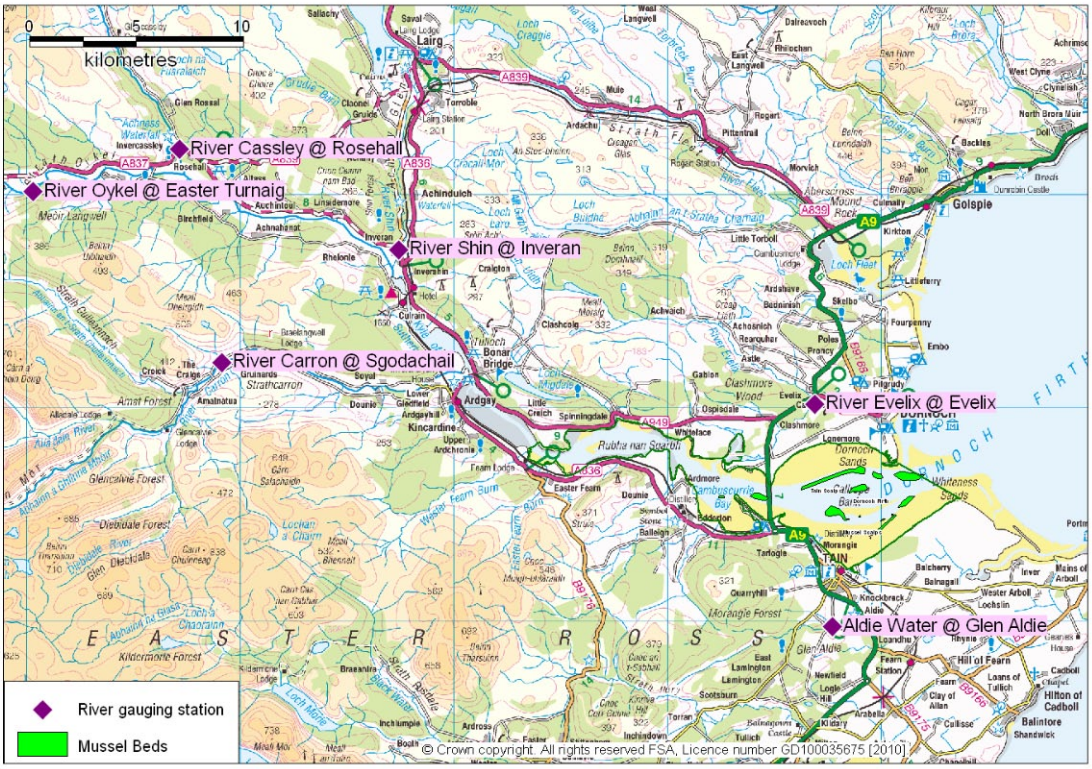

Figure 13.1 River gauging stations potentially relevant to the Dornoch Firth assessment

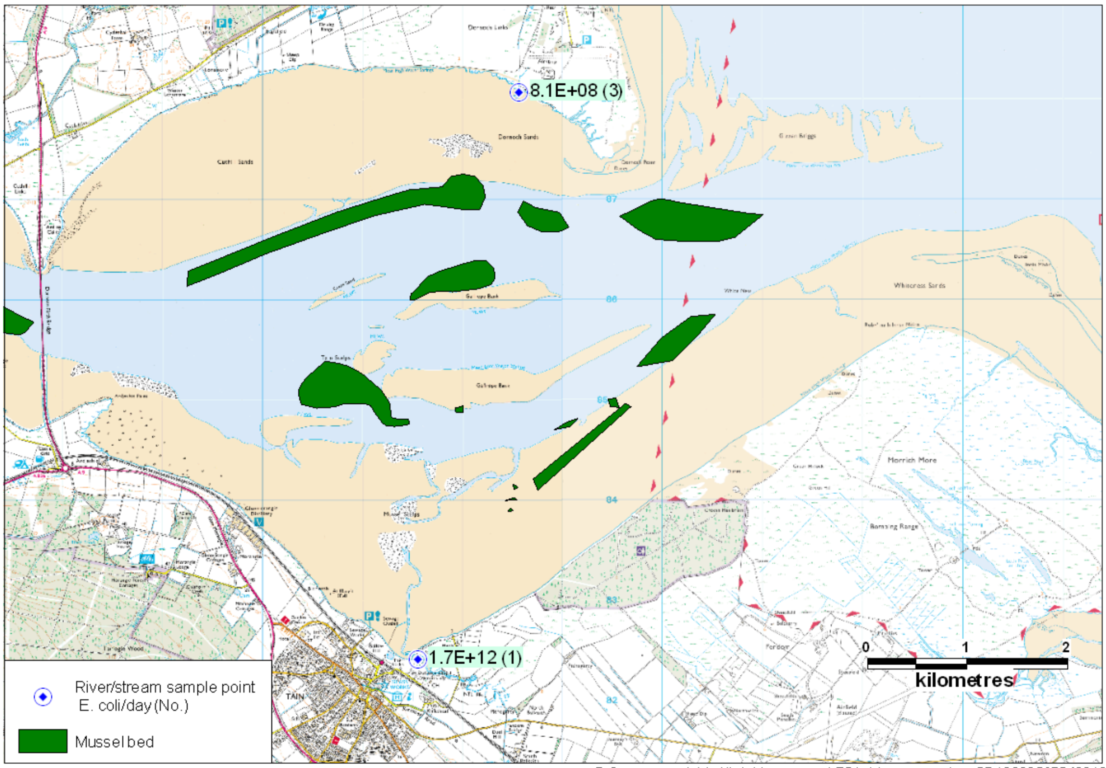

Figure 13.2 Rivers and streams sampled and measured in the outer Dornoch Firth during the shoreline survey

14. Bathymetry and Hydrodynamics

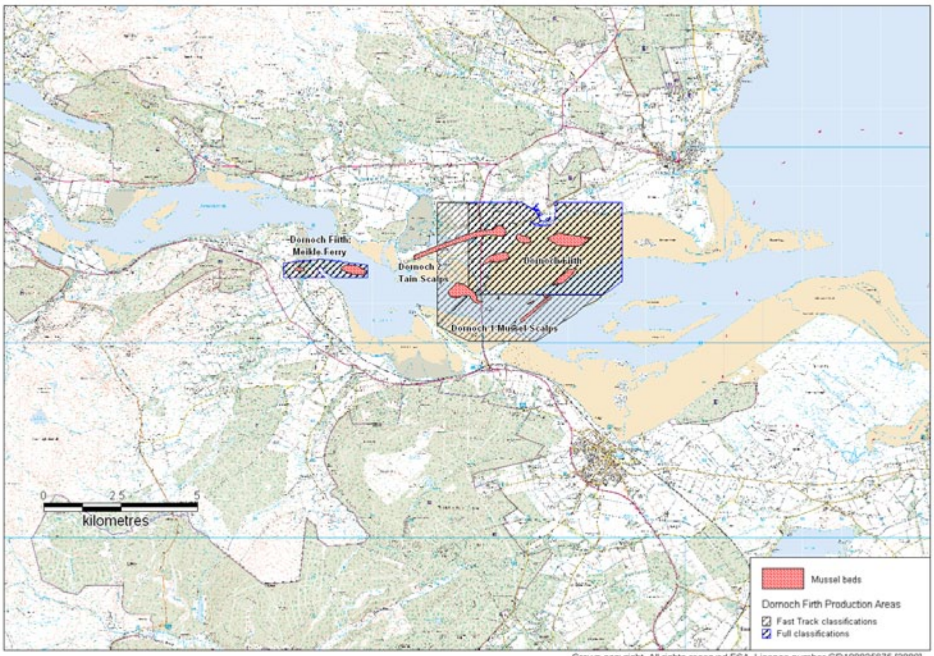

Figure 14.1 OS map of Dornoch Firth

Figure 14.2 Bathymetry of Dornoch Firth

Currents in coastal waters and estuaries are driven by a combination of tide, wind and freshwater inputs. This section aims to make a simple assessment of water movements around the area. Figure 13.1 shows the OS map of Dornoch Firth and Figure 13.2 shows the bathymetry of the firth. The Hydrographic Office charts, and derived Seazone vector data, only give bathymetric information for the firth to approximately 1.5 km above Dornoch Firth bridge.

Dornoch Firth is an estuary. It runs from west to east. At the western end it joins the Kyle of Sutherland. At the eastern end it enters the northern North Sea. In the vicinity of the mussel beds, it varies between approximately 1 and 6 km in width. It is generally shallow with depths less than 10 m, except at the mouth. There are extensive tidal mud and sand flats. These occur mainly at the shore but some are located in the channel towards the mouth of the firth.

The figures show that the mussel beds are located towards the mouth of the firth and stretch from the edges of the intertidal areas to approximately the 5 m mark. For completeness, the mussel beds and production area at Meikle Ferry are also shown – these are the subject of a separate report.

14.1 Tidal Curve and Description

The two tidal curves illustrated in Figure 13.3 are for Meikle Ferry within Dornoch Firth. The tidal curves have been output from UKHO TotalTide. The first is for seven days beginning 00.00 BST on 05/08/09 and the second is for seven days beginning 00.00 BST on 14/08/09. This two-week period covers the date of the shoreline survey. Together they show the predicted tidal heights over high/low water for a full neap/spring tidal cycle.

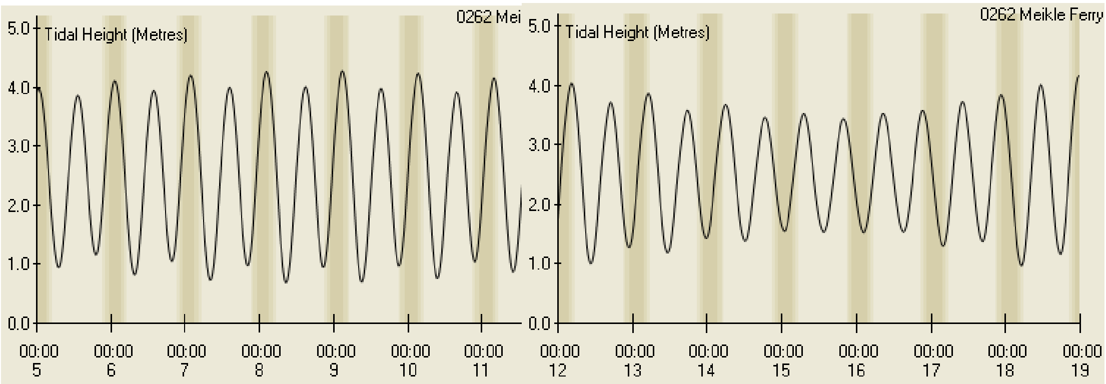

Figure 14.3 Tidal curves at Meikle Ferry

The following is the summary description for Meikle Ferry from TotalTide:
0262 Meikle Ferry is a Secondary Non-Harmonic port. The tide type is Semi-Diurnal.

HAT	5.0 m
MHWS	4.4 m
MHWN	3.4 m
MLWN	1.5 m
MLWS	0.6 m

The tidal range at spring tide is therefore approximately 3.8 m and at neap tide 1.9 m.

14.2 Currents

Tidal stream information was available for three stations on the south side of the extreme outer part of Dornoch Firth (above Portmahomack).

The locations of these stations, together with the tidal streams for peak fllod and ebb tide, are presented in Figures 13.4 and 13.5, and their tidal diamonds are presented in Tables 13.1, 13.2 and 13.3.

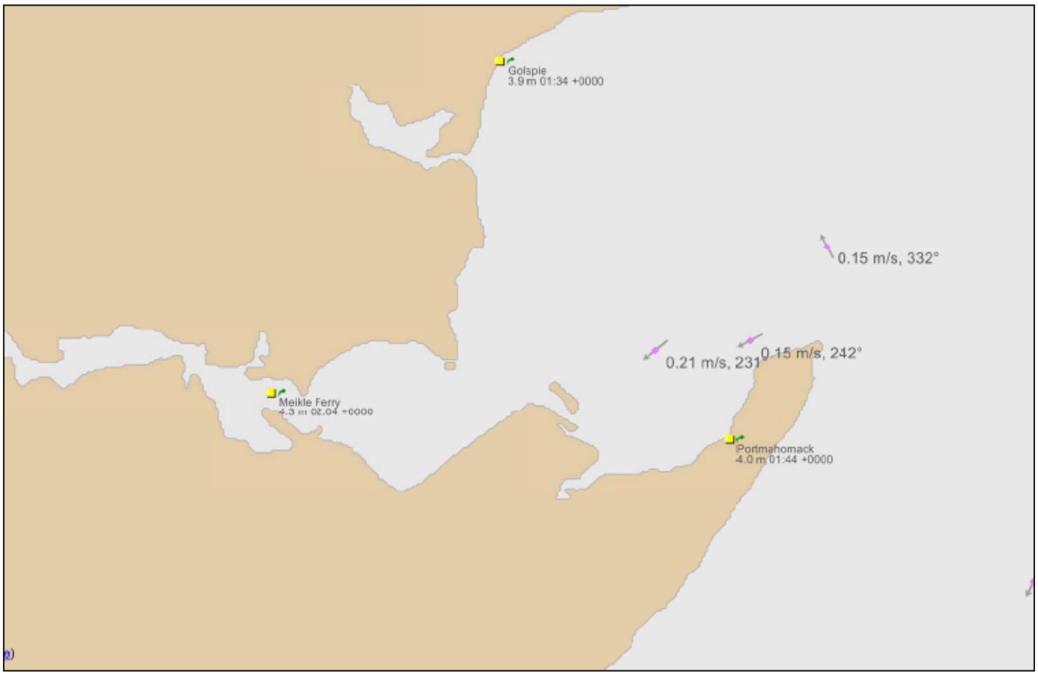

Figure 14.4 Spring flood tide in the outer Dornoch Firth

The tidal streams tend to flow along the coast outside of the firth and up and down the firth within the mouth, although the complex shape of the firth means that the flow is not necessarily in a straight easterly or westerly direction. Due to constrictions in the vicinity of Dornoch Firth Bridge and Meikle Ferry, the currents there tend to be approximately double those elsewhere in the firth.

Figure 14.5 Spring ebb tide at the outer Dornoch Firth

Scottish Water commissioned a hydrographic study of the area, which was undertaken in November-December 2005 (Anderson Marine Surveys, 2005). The final report of this study was provided to Cefas by Scottish Water. The survey included a bathymetric study and tracer dispersion analysis from the sewage discharges at Tain, Dornoch and Edderton. The study indicated that current speeds were higher around Dornoch Point and along the northern shore of the outer part of the firth, where single tidal excursions were reported to be greater than the length of the study area, which was the firth from the narrows northwest of Edderton to the east of Dornoch, encompassing the entire outer part of the firth. Bathymetric survey data confirmed the presence of a deeper channel along the northern side of the firth. The maximum current speed recorded during the survey was 1.159 m/s at a point in the channel roughly midway between Dornoch Point and the bridge. Currents were also measured in the intertidal areas, but this data was not provided. However, it was noted in the report that intertidal current speeds were higher than those found in the channel.

Slower current speeds were found along the southern side of the firth near Tain and and south of Dornoch Point. Tracer dispersion studies indicated that although effluents from the STWs at Dornoch and Tain would tend to affect areas to the east more than to the west, evidence of these discharges was found west of the bridge, in Edderton Bay.

Table 14.1 Tidal streams for station SN026D (57°51.88'N 3°52.88'W) (Totaltide)

Time	Direction	Spring rate (m/s)	Neap rate (m/s)
-06h	213°	0.15	0.10
-05h	222°	0.21	0.10
-04h	230°	0.21	0.10
-03h	239°	0.21	0.10
-02h	254°	0.10	0.05
-01h	343°	0.05	0.05
HW	023°	0.15	0.10
+01h	036°	0.26	0.15
+02h	055°	0.26	0.15
+03h	074°	0.21	0.10
+04h	086°	0.05	0.05
+05h	155°	0.05	0.00
+06h	210°	0.15	0.10

Table 14.2 Tidal streams for station SN026C (57°52.08'N 3°49.18'W) (Totaltide)

Time	Direction	Spring rate (m/s)	Neap rate (m/s)
-06h	213°	0.15	0.10
-05h	232°	0.15	0.10
-04h	242°	0.15	0.10
-03h	247°	0.10	0.05
-02h	253°	0.05	0.05
-01h	025°	0.05	0.00
HW	040°	0.15	0.05
+01h	040°	0.21	0.10
+02h	048°	0.21	0.10
+03h	058°	0.15	0.10
+04h	078°	0.10	0.05
+05h	138°	0.05	0.05
+06h	204°	0.15	0.10

Table 14.3 Tidal streams for station SN026A (57°54.08'N 3°46.18'W) (Totaltide)

Time	Direction	Spring rate (m/s)	Neap Rate (m/s)
-06h	240°	0.10	0.05
-05h	300°	0.10	0.05
-04h	328°	0.15	0.10
-03h	022°	0.15	0.10
-02h	064°	0.26	0.15
-01h	085°	0.26	0.15
HW	102°	0.26	0.15
+01h	113°	0.21	0.10
+02h	184°	0.10	0.05
+03h	258°	0.21	0.10
+04h	264°	0.31	0.21
+05h	246°	0.26	0.15
+06h	237°	0.15	0.10

The study indicated that faecal indicator concentrations were highest in the intertidal area around Tain and at the southern end of Edderton Bay, where slower current speeds did not disperse the effluent as much. The discharge at Dornoch was found to affect areas to the east and west, with highest impacts around Dornoch Point and along the shore to the north of the point.

Increases in faecal coliform concentrations of between 0 and 1 log cfu/100 ml are predicted for areas near the shore around Dornoch Point and approximately 500m north of the outfall at Tain. Increases of between 2 and 2.4 log are predicted for the sea immediately off the outfall at Tain, tailing off rapidly with distance from shore. These estimates only apply to the increase above background levels of contamination attributable to the STWs, and do not take account of other sources of faecal contamination such as livestock.

A study evaluating the equivalence between faecal indicator concentrations found in water and shellfish found that for common mussels, found that the geometric mean *E. coli* concentration of 0.9 per 100 ml corresponded with 95% compliance with Class A in shellfish (≤230 per 100 g). For Class B compliance (90%), the corresponding geometric mean *E. coli* concentration in seawater was 50.0 (EU Scientific Veterinary Committee Working Group of Faecal Coliforms in Shellfish, 1996). Therefore, the increase of 2 to 2.4 log predicted for the waters near Tain would be sufficient to cause water quality in this area to fall below levels consistent with Class B compliance.

Post survey note: Scottish Water noted that the Anderson study predated upgrades to UV disinfection at Tain and Dornoch STWs.

14.3 Conclusions

Tidal currents in the mouth of the firth are relative weak at a maximum of 0.26 m/s (approximately 0.5 knots) on spring tides. Greater current speeds have been recorded within the firth, with a maximum speed of 1.159 m/s recorded at a point in the channel roughly midway between Dornoch Point and the bridge. The topography means that easterly or westerly winds will have the greatest effect on currents. Depending on the direction, these may enhance or reduce the tidal currents.

The general flow will be along the shores of the firth, the direction depending on whether the current is flooding or ebbing. However, the complex shape of the shoreline, and the presence of drying areas in the middle of the firth, will modify this simple assumption.

Most of the mussel beds lie below mean low water springs and thus will be potentially exposed to contamination at all states of tide.

Discharges from the Tain, Dornoch and Edderton sewage discharges and CSOs will impact the fishery to differing extents, with the Tain and Dornoch discharges most likely to impact waters in the south end of the bay at Tain and along the shore North and West of Dornoch Point.

Discharges from the Glenmorangie septic tank are likely to be carried eastward over the adjacent mussel bed by flow within the river channel on the outgoing tide. Tidal currents are likely to be somewhat weak in this area, possibly reducing the transport distance from this source. However, given its proximity to the mussel bed it constitutes a significant source of faecal contaminants particularly to the mussel bed east of the discharge.

15. Shoreline Survey Overview

A physical survey of the shoreline at Dornoch Firth was carried out between 5-10 August 2009. This followed a period of hot, dry weather.

The fishery was confirmed to be subtidal common mussel beds. Harvesting was undertaken by dredging, which is done to demand. Sampling of the beds was undertaken during harvesting operations. A depuration facility had been set up at the shorebase west of the Dornoch Firth bridge, and this was in the process of obtaining required approvals for use.

The discharges from sewage treatments works at both Dornoch and Tain were observed. The Tain discharge is carried via a concrete duct to the shoreline above MHWS. A sample taken from the effluent contained 5.6×10^4 *E. coli* cfu/100 ml, which was consistent with treated sewage effluent. The discharge from the sewage treatment works at Dornoch drains via a pipe into Black Burn and then via the burn into the firth. On the day of survey, the flow in the burn appeared dirty and had a foul odour. A water sample taken from the burn at the shoreline contained 2.7×10^4 *E. coli* cfu/100 ml. While the proportion of flow (and hence contamination) attributable to the burn as opposed to the STW oufall is not known, the flow observed on the day was low (1620 m^3/day), possibly due to the dry weather, and not substantially higher overall than the consented maximum DWF at the sewage works (1213 m^3/day). The shoreline survey was undertaken during peak tourist season in the area and domestic demand would have been high at that time.

The area around the firth was observed to be largely agricultural outside the towns of Dornoch and Tain. Large numbers of livestock are present in the area, with 263 cattle and 306 sheep directly counted along the shore of the outer firth. Substantially more sheep and cattle were observed further west of the Dornoch Firth bridge along the upper parts of the firth. Animals are kept fenced from the shoreline.

Arable fields were also observed in the area, as well as plantation woods east and west of Tain and to the north and west of Dornoch.

Golf courses lined much of the northern shore of the firth, stretching from Dornoch to west of the Dornoch Firth bridge. Further golf courses were found along the south shore at Tain. Few boats were observed during the survey. The boat used to dredge the mussel beds is kept at the end of the Ness of Portnaculter and a small number of dingies were seen at Meikle Ferry. The sandy areas around Dornoch were used by kite surfers and walkers, however most of the rest of the shoreline was not suited to recreational use. Only two watercourses were observed to be flowing into the outer firth at the time of survey. The river Tain discharges to the firth east of the town and appeared to have a small pipe discharging to it upstream of the pedestrian bridge. A water sample taken from near the mouth of the river contained 360 *E. coli* /100 ml and had a salinity of 29.1 ppt, while one taken further upstream contained 100 *E. coli*/100 ml.

The easternmost extent of the firth lies within an active bombing range, which included part of the identified mussel beds. This was in active use at the time of survey, which precluded sampling from this part of the fishery.

Large numbers of gulls were observed, with the largest single flock seen on a golf course. The area was suitable habitat for wading birds, though only small numbers of oystercatchers were observed at the time of survey. One seal was seen in the water near the southern end of the fishery.

Three seawater samples were taken from over the mussel beds and these were found to be largely free of faecal contamination. Mussel samples collected on during the survey all were found to contain relatively low levels of faecal contamination with *E. coli* concentrations ranging from 20-90 MPN/100 g flesh and intravalvular fluid. None of the mussel samples came from the bed nearest the distillery outfall.

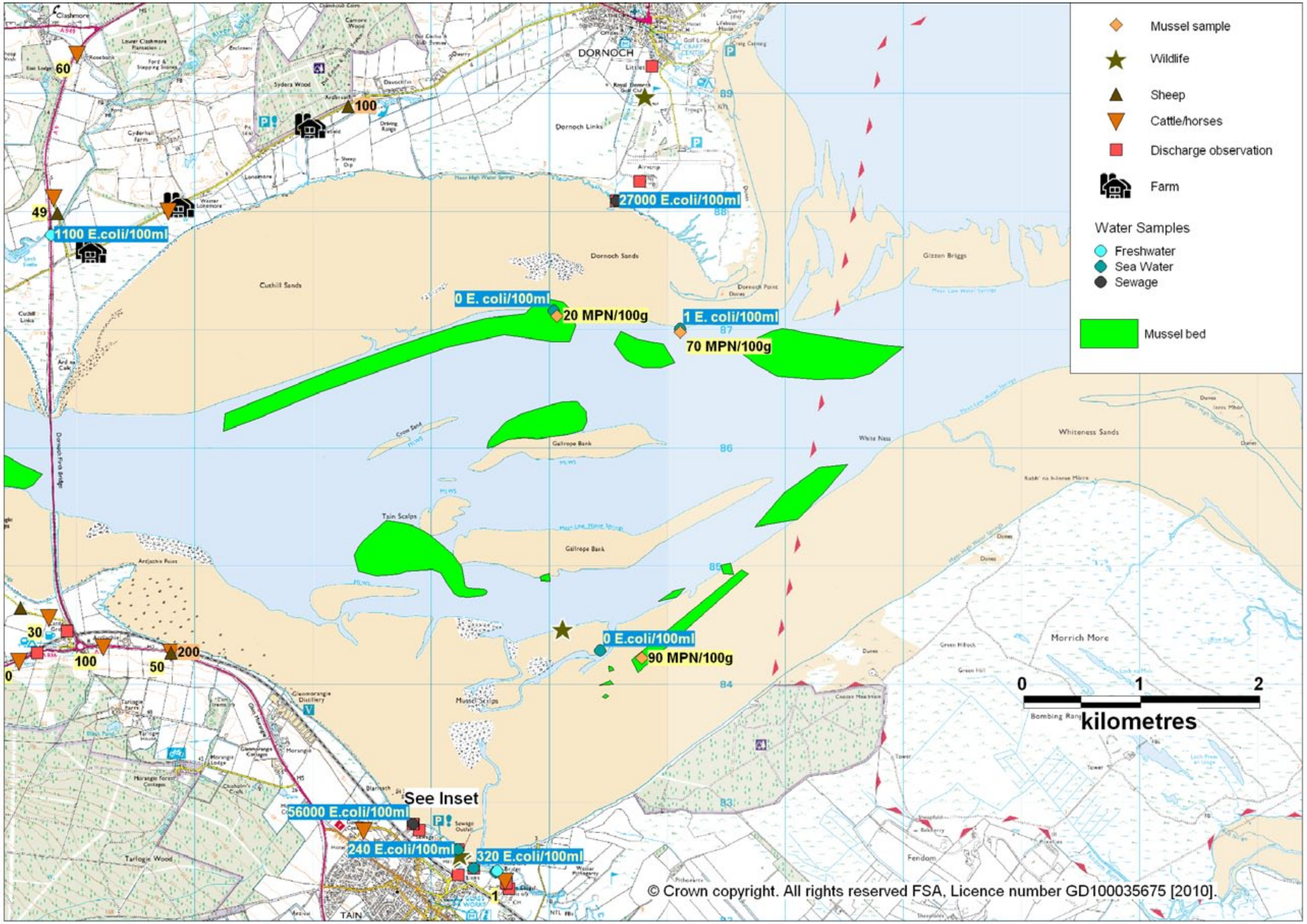

Figure 15.1 Summary of shoreline survey findings for Dornoch Firth

16. Overall Assessment

Human sewage impacts

Human sewage discharges to the fishery are predominantly from sewage treatment works at Tain and Dornoch and the septic tank at the Glenmorangie Distillery. A further sewage treatment works is located at Eddington, further up the estuary to the west of the fishery. While discharges located further upstream may also contribute to faecal contamination levels at the fishery, these are likely to be significantly diluted by the time they reach the mussel beds. The Tain and Dornoch discharges receive secondary treatment and UV disinfection, and were found at the time of shoreline survey to have *E. coli* concentrations that were consistent with secondary treated sewage. It is not known how often spills occur from the CSO's associated with these works, however any spills of untreated sewage would be expected to significantly impair water quality at the fishery. The Glenmorangie septic tank discharge, though much smaller than those from Tain and Dornoch, is not as highly treated and also discharges directly into the firth less than 150 m from a known mussel bed. This is likely to represent the area of highest risk in terms of faecal contamination of the shellfish.

A hydrodynamic survey conducted on behalf of Scottish Water found little impact from sewage discharges from Dornoch, and this tended to be confined to a small area south of where Black Burn meets the firth and west of the Dornoch Firth bridge, at the base of the Ness of Portnaculter. Discharges from the Tain sewage works affected a much broader area, including east of Dornoch Point and west of the Ness of Portnaculter. Most acutely affected was the area nearest the discharge, just south of the fishery. As an application has been submitted to extend the fishery southwards, this is pertinent to consideration of how far south the production area boundary should extend. The Edderton discharge was found to impact mostly to the west of the bridge and was substantially diluted before reaching the fishery. This study looked at impacts from the main discharges only and not discharges from the CSOs. Since the Anderson study was undertaken, Scottish Water have installed tertiary treatment systems to these STWs and therefore effluent quality is expected to have improved since the study date of 2005.

Few other septic pipes were found in the area, with most properties being connected to the mains sewerage. Two septic tanks located near the south end of the bridge would impact Edderton Bay, which lies outside the area covered by this survey. A further septic tank observed at Drumduran, however it was relatively far inland and no specific discharge was observed.

Sewage discharges (particularly untreated or incompletely treated discharges) from Tain are more likely to affect the beds along the south side of the channel and particularly the area around Mussel scalps. Discharges from Dornoch are most likely to impact the beds along the north side of the channel nearest the outlet of Black Burn. Untreated sewage spills from the CSOs in the area would be expected to compromise water quality at the fishery.

Agricultural impacts

A significant amount of agricultural activity is present along both the north and south sides of the fishery, as well as along rivers upstream of the firth. Livestock were observed in very large numbers, though they were not allowed direct access to the shore and few watercourses were observed draining pastures. Arable fields located inland from the shoreline would be expected to receive slurry application, though the amount and seasonality of its application is not known. The hydrodynamic study found that the predicted contribution from the sewage discharges only accounted for a small proportion of the overall faecal indicator bacteria found in water samples tested. The implication is that a substantial proportion of the faecal contamination in Dornoch Firth comes from agricultural activities.

Wildlife impacts

The area hosts a significant year-round population of seals, which use haulout sites around Dornoch Point very near to an identified bed. Therefore, seals may contribute to background levels of faecal contamination in the vicinity of the fishery, and particularly along it's northern and eastern boundaries.

Dornoch Firth hosts very large populations of wading birds and wildfowl, with in excess of 20000 birds likely to be present during the winter. Identified roosts are located along the shore west of Dornoch and also along the southern shore east of the bridge. Impacts from this source will be seasonal, with peak bird numbers occurring in the autumn and winter months.

Deer are likely to be present in large numbers throughout the area, though no detailed information was available on population sizes or ranges. They will be presumed to be evenly distributed around the area, and they are likely to be a significant contributor to diffuse faecal contamination found in the rivers and burns discharging into the firth.

Seasonal variation

There are several significant seasonal variations in potential sources of faecal contamination to the firth.

1. People: tourism to the area is significant with the largest numbers appearing during the school holidays. The tourist 'season' in the area runs generally from April to the end of September, with peak numbers expected during the traditional summer holiday months of July and August.

2. Agriculture: livestock numbers increase and decrease seasonally, with young borne in late spring and then sold on during Autumn. The extent of this variation is not known as these data were either not captured or not available. Application of slurry is likely to vary throughout the year, though actual

variation and rates of application for farms in the Dornoch Firth area are not known.

3. Wildlife: shore birds are present in substantial numbers during the autumn and winter months and would lead to an increase in contamination from these animals during this time. Seals are present year-round.

Rivers and streams

The River Tain flows into the outer Dornoch Firth close to some of the mussel beds on the southern side of the firth. Given the high loading of 1.7×10^{12} *E. coli* per day, it is likely that this will have a significant effect on the microbiological quality of the mussels at those locations.

Other river and streams further up the firth were considered in the Dornoch Firth: Meikle Ferry sanitary survey report. It is likely that those watercourses would significantly impact on the quality of the mussel beds in the outer firth during the ebbing tide. The effect would be greatest at the western end of the mussel beds.

All the rivers discharging into the firth will carry faecal contamination from diffuse sources, including livestock and wildlife, as well as upland septic tank discharges.

Meteorology, hydrography, and movement of contaminants

Most of the firth is intertidal and shallow, with a channel that runs along the northern side of the outer bay before it narrows at the Dornoch Firth Bridge. Most of the water movement in the area is driven by tidal flows.

Results from a hydrographic study of the area undertaken by Anderson Marine Surveys on behalf of Scottish Water indicated that currents within the firth are significantly stronger than those reported by UKHO for tidal diamonds outside the firth. Contamination from the discharges to Black Burn was found to sweep along the north side of the channel through the firth and around Dornoch Point, which would affect the northern mussel beds most. Contamination from the Tain sewage treatment works was found to accumulate in the southern end of the bay near the town of Tain and did not disperse as widely as that from Dornoch. Discharges from Edderton, to the west, were found to have relatively little impact in water samples collected from areas east of the bridge.

Pollution from diffuse sources is most likely to be carried to the fisheries via rivers and streams, but also from direct runoff from land. Discharges carried down the main flow through the firth are most likely to impact the beds closest to the channel. Contamination levels may also be higher near the shoreline, where direct runoff from land and smaller streams may carry animal waste from the surrounding fields to the sea.

Temporal and geographical patterns of sampling results

As the southern part of the fishery was more intensively sampled than the northern part and not all identified beds have been sampled, it is difficult to draw firm conclusions relating to spatial variation in levels of contamination across the fishery. Of the areas most intensively sampled, most locations were sampled only once so any variation in results is as likely to be due to time as location. However, highest results did appear to occur most frequently along the southern side of the fishery, and particularly at the southwestern bed nearest the distillery discharge. There has been a deterioration in monitoring results since 2007, with a marked decline in 2009.

17. Recommendations

Production Area

It is recommended that the mussel beds to the east of the bridge be consolidated into a single production area. As significant sources of faecal contamination have been identified to the north and south of the fishery, it is recommended that areas around Tain and Dornoch Point be excluded from the production area boundaries. Also excluded are areas near identified bird roosts and the seal haulouts at Gizzen Biggs.

Recommended boundaries are illustrated in Figure 17.1 and described as the area bounded by lines drawn between NH 8024 8350 to NH 7864 8400 to NH 7700 8400 to NH 7550 8500 to NH 7700 8800 to NH 8100 8700 to NH 8239 8500 extending to MHWS.

RMP

As the production area has been expanded compared to that represented by the current monitoring point, it is recommended that the RMP be relocated to reflect the area of highest risk of faecal contamination. Therefore, it is recommended that the RMP be relocated to NH 7752 8495, which lies on the identified mussel bed near to the septic tank discharge from the distillery.

Sampling Tolerance

As the fishery is dredged, a sampling tolerance of 250 m is recommended. This tolerance area is illustrated in Figure 17.1.

Frequency

The established production area has held seasonal classifications, therefore it is recommended that monthly monitoring be continued until such time that the area can be considered for reduced monitoring based on stability of classification.

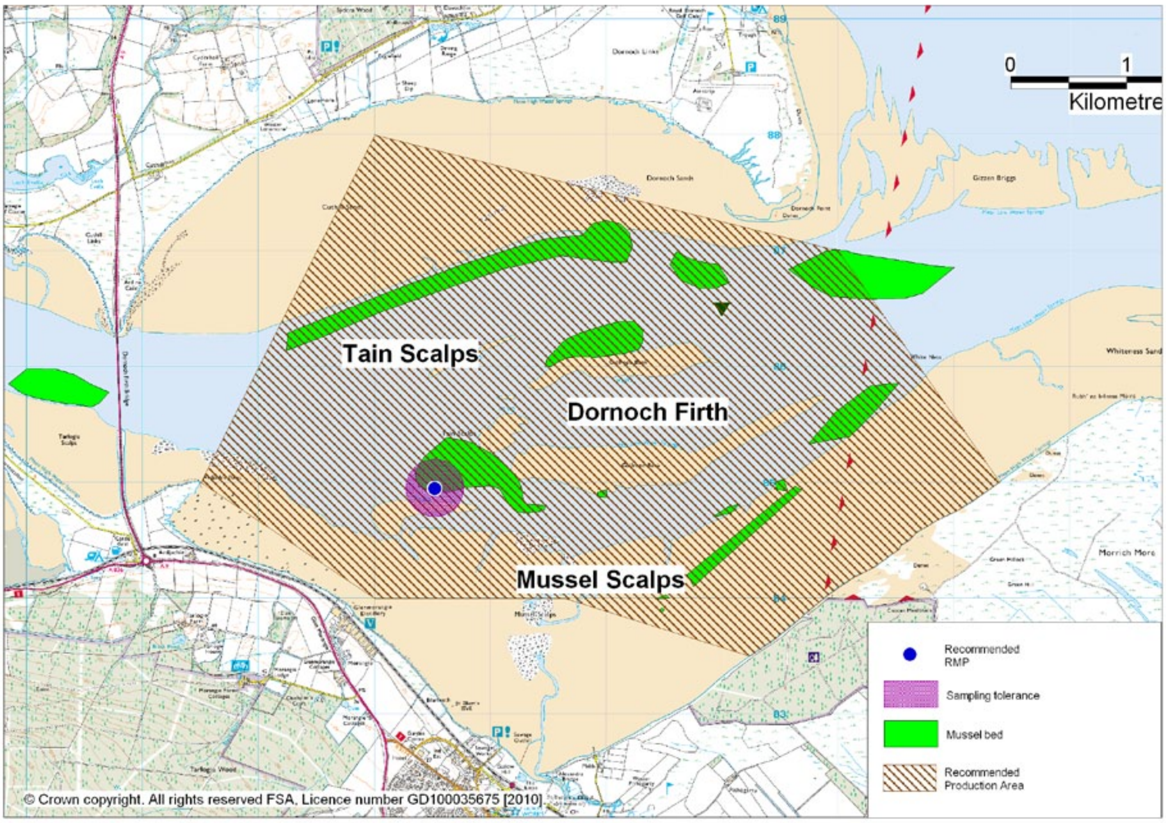

Figure 17.1 Map of recommendations for Dornoch Firth

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19. List of Figures and Tables

Figures

Tables

Appendices

1. **Sampling Plan**
2. **Table of Proposed Boundaries and RMPs**
3. **Geology and Soils Information**
4. **General Information on Wildlife Impacts**
5. **Tables of Typical Faecal Bacteria Concentrations**
6. **Statistical Data**
7. **Hydrographic Methods**
8. **Shoreline Survey Report**

Sampling Plan for Dornoch Firth

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
Dornoch Firth	Dornoch Firth	HS 054	Common mussels	Dredged	NH 7752 8495	277520	884950	250	NA	Dredge	Monthly	Highland Council Sutherland	Anne Grant	Anne Grant

Table of Proposed Boundaries and RMPs

Production Area	Species	SIN	Existing Boundary	Existing RMP	New Boundary	New RMP	Comments
Dornoch Firth	Common mussels	HS 054 239 HS 054 240	Area bounded by lines drawn between NH 7800 8800 and NH 7976 8800 and between NH 8079 8800 and NH 8300 8800 and between NH 8300 8800 and NH 8300 8543 and between NH 8239 8500 and NH 7800 8500 and between NH 7800 8500 and NH 7800 8800 extending to MHWS	NH 800 865	Area bounded by lines drawn between NH 8024 8350 to NH 7864 8400 to NH 7700 8400 to NH 7550 8500 to NH 7700 8800 to NH 8100 8700 to NH 8239 8500 extending to MHWS	NH 7752 8495	Boundaries amended to incorporate identified fishery and exclude areas most impacted by sewage discharges. Areas incorporated into a single production area with one RMP. RMP adjusted reflect impact of Glenmorangie discharge.
Dornoch Mussels 1	Common mussels	HS 464 872	Area bounded by lines drawn between points NH 7700 8400, NH 7800 8500, NH 8236 8500, NH 8022 8350, NH 7800 8350, extending to MHWS.	n/a			
Dornoch Mussels 2	Common Mussels	HS 465 873	Area bounded by lines drawn between points at NH 7700 8400, NH 7800 8500, NH 7800 8800 and NH 7700 8800.	n/a			

Geology and Soils Information

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

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

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

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

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

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

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

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

These component soils were classed broadly into two groups based on whether they are freely or poorly draining. Drainage classes were created based on information obtained from the both the Macaulay Institute website and personal communication with Dr. Alan Lilly. GIS map layers were created for each class with poorly draining classes shaded red, pink or orange and freely draining classes coloured blue or grey. These maps were then used to assess the spatial variation in soil permeability across a survey area and it's potential impact on runoff.

Glossary of Soil Terminology

Calcareous: Containing free calcium carbonate.

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

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

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

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

References

Macaulay Institute. http://www.macaulay.ac.uk/explorescotland. Accessed September 2007.

General Information on Wildlife Impacts

Pinnipeds

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

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

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

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

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

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

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

Cetaceans

As mammals, whales and dolphins would be expected to have resident populations of *E. coli* and other faecal indicator bacteria in the gut. Little is known about the concentration of indicator bacteria in whale or dolphin faeces, in large part because the animals are widely dispersed and sample collection difficult.

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

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

Birds

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

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

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

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

Deer

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

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

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

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

Other

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

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

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Tables of Typical Faecal Bacteria Concentrations

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

Source: Kay, D. et al (2008) Faecal indicator organism concentrations in sewage and treated

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}		

effluents. *Water Research* 42, 442-454.

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

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

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

Statistical data

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

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

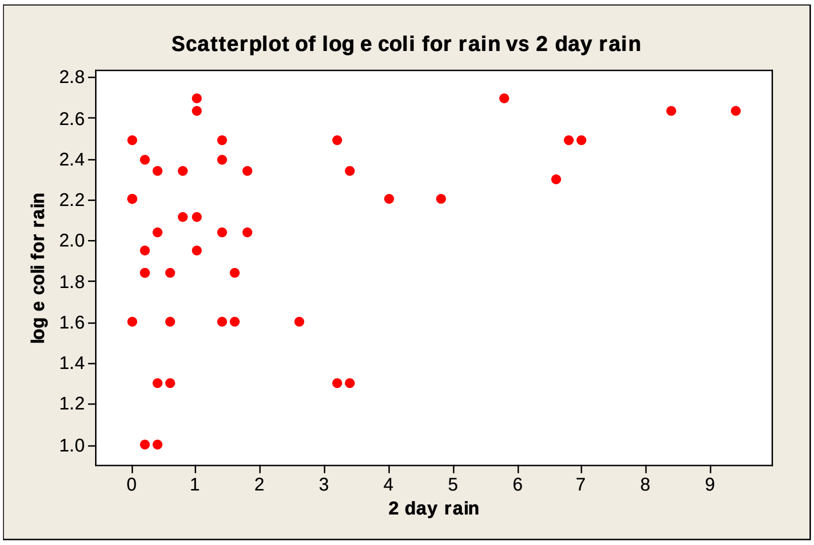
```
Source  DF      SS     MS     F      P
Season   3   1.771  0.590  1.47  0.229
Error   85  34.135  0.402
Total   88  35.905

S = 0.6337   R-Sq = 4.93%   R-Sq(adj) = 1.58%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ---------+---------+---------+---------+
1      23  2.0281  0.4570  (---------*----------)
2      22  2.2574  0.7720           (---------*----------)
3      19  2.1118  0.4963    (----------*-----------)
4      25  2.3868  0.7243              (---------*----------)
                           ---------+---------+---------+---------+
                                 2.00      2.25      2.50      2.75
Pooled StDev = 0.6337
```

Section 11.6.1 Spearmans rank correlation for *E. coli* result and 2 day rainfall

```
Pearson correlation of ranked 2 day rain and ranked e coli for rain = 0.226
P-Value = 0.131
```

Correlations: ranked 2 day rain, ranked e coli for rain – 2 highest values omitted

```
Pearson correlation of ranked 2 day rain and ranked e coli for rain = 0.323
P-Value = 0.032
```

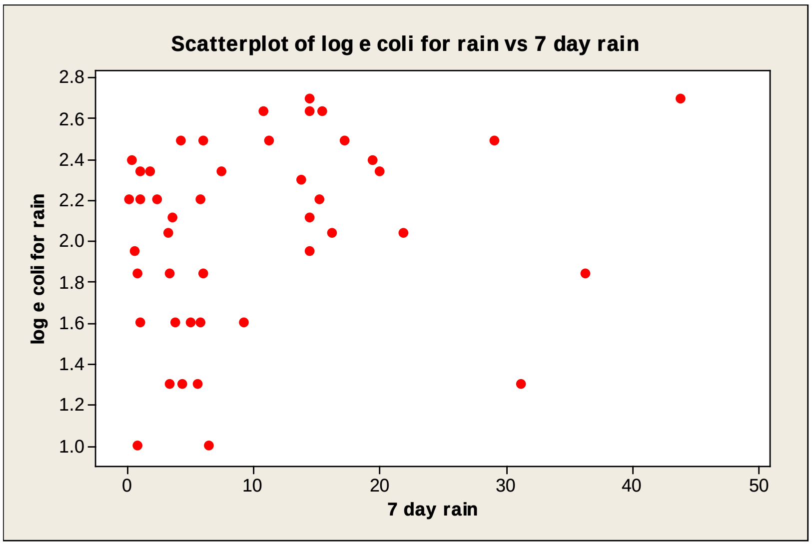


Section 11.6.1 Spearmans rank correlation for *E. coli* result and 7 day rainfall

```
Pearson correlation of ranked 7 day rain and ranked e coli for rain = 0.344
P-Value = 0.019
```

Correlations: ranked 7 day rain, ranked e coli for rain – 2 highest values omitted

```
Pearson correlation of ranked 7 day rain and ranked e coli for rain = 0.307
P-Value = 0.043
```



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

CIRCULAR-LINEAR CORRELATION
Analysis begun: 20 November 2009 09:21:19

Variables (& observations)	r	p
Angles & Linear (89)	0.15	0.145

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

CIRCULAR-LINEAR CORRELATION
Analysis begun: 20 November 2009 09:35:21

Variables (& observations)	r	p
Angles & Linear (89)	0.19	0.044

Section 11.6.3 Regression analysis – *E. coli* result vs water temperature

```
The regression equation is
log e coli for temperature = 2.39 - 0.0261 temperature


Predictor         Coef   SE Coef      T      P
Constant        2.3872    0.2773   8.61  0.000
temperature   -0.02609   0.02662  -0.98  0.331


S = 0.577361   R-Sq = 1.7%   R-Sq(adj) = 0.0%


Analysis of Variance

Source          DF       SS      MS     F      P
Regression       1   0.3201  0.3201  0.96  0.331
Residual Error  55  18.3340  0.3333
Total           56  18.6541
```

Unusual Observations

Obs	temperature	log e coli for temperature	Fit	SE Fit	Residual	St Resid
1	8.0	1.0000	2.1785	0.0933	-1.1785	-2.07R
5	7.0	1.0000	2.2046	0.1108	-1.2046	-2.13R
21	8.0	1.0000	2.1785	0.0933	-1.1785	-2.07R
27	13.4	3.9590	2.0377	0.1183	1.9214	3.40R
40	5.3	3.5441	2.2490	0.1469	1.2951	2.32R

R denotes an observation with a large standardized residual.

Section 11.6.5 Regression analysis – *E. coli* result vs salinity

The regression equation is
log e coli for salinity = 3.18 - 0.0292 salinity

Predictor	Coef	SE Coef	T	P
Constant	3.1754	0.6770	4.69	0.000
salinity	-0.02922	0.02200	-1.33	0.191

S = 0.556791   R-Sq = 4.1%   R-Sq(adj) = 1.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.5470	0.5470	1.76	0.191
Residual Error	41	12.7106	0.3100		
Total	42	13.2577			

Unusual Observations

Obs	salinity	log e coli for salinity	Fit	SE Fit	Residual	St Resid
7	15.0	3.9590	2.7371	0.3521	1.2219	2.83RX
22	29.0	3.5441	2.3281	0.0914	1.2160	2.21R

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

Section 12 One way ANOVA comparison of shellfish growing waters results by quarter

Analysis of Variance for log coli

Source	DF	SS	MS	F	P
quarter	3	2.539	0.846	1.13	0.360
Error	20	14.938	0.747		
Total	23	17.478			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level      N      Mean     StDev  -----+---------+---------+---------+-
Q1         6    1.8413    0.5599   (---------*----------)
Q2         6    2.1854    0.9084        (---------*----------)
Q3         6    2.7522    0.9616                (---------*----------)
Q4         6    2.2656    0.9614         (---------*----------)
                                  -----+---------+---------+---------+-
Pooled StDev =  0.8642               1.40      2.10      2.80      3.50
```

Hydrographic Methods

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

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

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

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

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

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

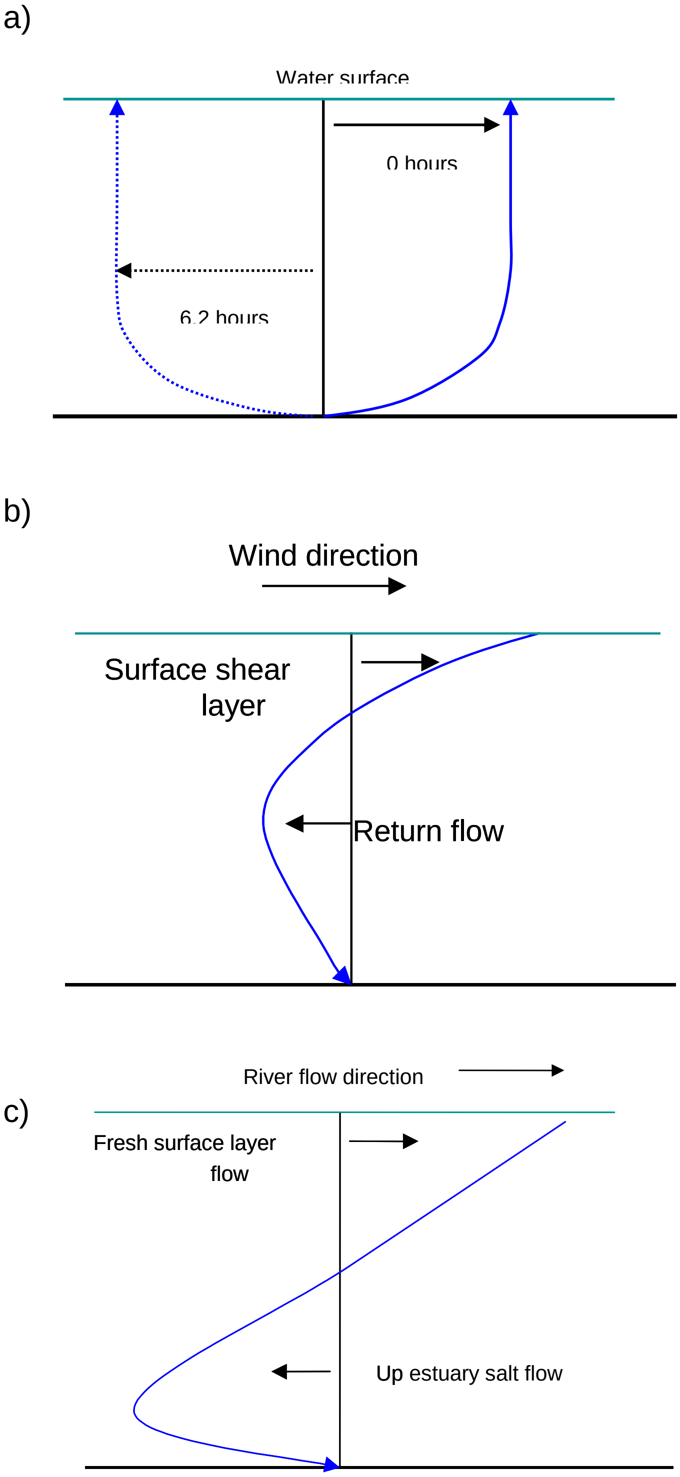


Figure 1. Typical vertical profiles for water currents. The black vertical line indicates zero velocity so portions of the profile to the left and right indicate flow moving in opposite directions. a) Peak tidal flow profiles. Profiles are shown 6.2 hours apart as the main tidal current reverses direction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

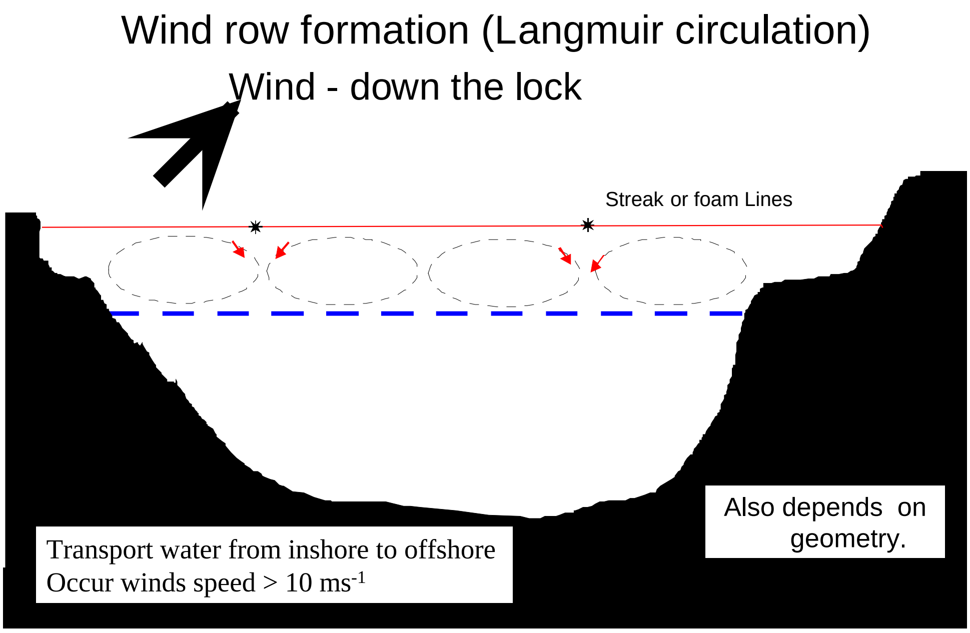


Figure 2. Schematic of wind driven 'wind row' currents. The dotted blue line indicates the depth of the surface fresh(er) water layer usually found in sea lochs.

Non-modelling Assessment

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

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

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

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

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

References

Edwards, A. and F. Sharples. (1986) Scottish sea lochs: a catalogue. Scottish Marine Biological Association, Oban. 250pp.

Glossary

The following technical terms may appear in the hydrographic assessment.

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

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

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

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

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

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

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

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

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

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

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

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

Shoreline Survey Report

Dornoch Firth

HS 054, HS 464
&
HS 465

Scottish Sanitary Survey Project Cefas

Shoreline Survey Report

Production Area	Site	SIN	Species
Dornoch Firth	Dornoch Firth	HS 054 239 08	Common mussel
	Tain	HS 054 240 08	Common mussel
	Tain Scalps	HS 465 873 08	Common mussel
	Mussel Scalps	HS 464 872 08	Common mussel

Harvester: Highland Fresh Mussels C/o the Highland Council
Local Authority: Highland Council
Status: New/Existing
Date Surveyed: 5-10 August 2009
Surveyed by: M. Price-Hayward, A. Grant
Existing RMP: NH 800 865
Area Surveyed: Upper Dornoch Firth

Weather observations
Weather during the survey period was predominantly warm, dry and windy. Temperatures to 20C, Winds S to SSW F2-5.

Site Observations

Fishery
Wild mussels are dredged during high tide from shallow beds throughout the outer part of Dornoch Firth. Dredging is undertaken according to demand and may occur at any time of year. At the time of survey, a depuration facility was installed at the shore base on the end of Ness of Portnaculter, to the west of the Dornoch Firth Bridge. This is owned and operated by Frank Mohan and Sons, Ltd who purchase mussels from Highland Fresh Mussels for depuration. The depuration facility had been inspected but had not yet received approval at the time of survey.

Sewage/Faecal Sources

There are two large towns adjacent to the production area, Dornoch on the north shore and Tain on the south shore, both of which have mains sewerage and wastewater treatment works (WWTW) with discharges to the Firth.

Tain WWTW lies on the western side of the town and near the southernmost extent of the bay with discharge to the shoreline above MHWS. The discharge itself lies approximately 2km south of the nearest identified mussel bed, with intertidal mud lying between the two.

Two additional discharge pipes were observed on the shoreline at Tain (Figure 1, Nos. 9 & 15). These appeared to be active, though it is not known what they discharge. A seawater sample taken from point 9 contained 240 *E. coli*/100 ml and one from point 15 contained 320 *E.coli*/100 ml.

The river Tain discharges to Dornoch Firth at the east end of Tain, and a water sample collected here contained 360 *E.coli*/100ml. The river runs through agricultural land stocked with cattle and sheep.

On the north side of the bay, Drumduran septic tank was found east of Davochfin (Figure 1, No. 38). No discharge was identified. Further east, the Dornoch WWTW was located south of town, between the airstrip and the shoreline. The discharge was not directly observed, as the land here was marshy. However, at Black Burn below the sewage treatment works, the water looked and smelled foul and a water sample (Table 2. No. 10) contained 27000 *E. coli*/100 ml, confirming septic discharge via this watercourse. A storm tank was found closer to town, though it was not possible to determine whether this discharged via the WWTW.

Cattle and sheep in the overall area number in the thousands. A total of 263 cattle and 306 sheep were directly counted around the outer firth as part of this survey, though an additional 284 cattle and over 1400 sheep were observed further west along the upper parts of the firth. Animals are kept fenced from the shoreline as the intertidal muds are soft and hazardous. There were also arable fields onto which slurry could be spread. The sampling officer reported that slurry tanks were present in the area, though none were directly observed during the survey. No slurry spreading was observed during the survey.

Seasonal Population

The area has a highly seasonal population, with tourist attractions drawing visitors to the area from spring to autumn. Golf courses in the area draw large numbers of visitors primarily in summer and smaller numbers outside the summer season. The parts of the shoreline that are sandy, such as around Tain, are popular with water sports enthusiasts and walkers.

Boats/Shipping

Few boats were observed during the survey. The boat used for dredging mussels is kept at the end of the Ness of Portnaculter. A handful of small open boats and dingies were present near Meikle Ferry. The majority of the firth is very shallow and only navigable at high tide. There are no shipping facilities within the firth.

Land Use

The area around the fishery is predominantly agricultural with large numbers of grazing stock observed during the survey. Some fields were sown to crop and some were grazed. There are large areas of plantation to the east of Tain and also to the north and west of Dornoch, which are actively forested.

Golf courses line much of the northern shore of the firth, stretching from Dornoch in the east to Meikle Ferry North, west of the Dornoch Firth bridge. On the south shore, there are golf courses at Tain.

The easternmost extent of the firth lies within a bombing range, including land beginning 3km east of Tain. Part of the identified mussel beds lie within this bombing range, which was active at the time of survey. Consequently, it was not possible to sample from these beds at the time.

Wildlife/Birds

Large numbers of gulls were observed during the survey, with the largest flock seen on a golf course (approx 150 birds). One seal was also observed during the survey. The area is suitable habitat for wading birds and geese, both of which would be expect to be more numerous here during the autumn and winter months.

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 voe or loch.

Other

The shoreline around Dornoch Firth was found to be muddy and inaccessible. There is a local mud rescue team who are called out to retrieve livestock and the occasional walker from the muds here, which are known to be treacherous. Livestock are generally fenced away from the immediate shoreline to prevent this happening. As a result, recreation within the firth is mainly limited to the northern coast around Dornoch. For more information on the upper part of Dornoch Firth, please refer to the shoreline survey report for Dornoch Firth: Meikle Ferry. Due to limitations of access, it was not possible to walk much of the shoreline around the firth and so there may have been additional discharges not noted in this report.

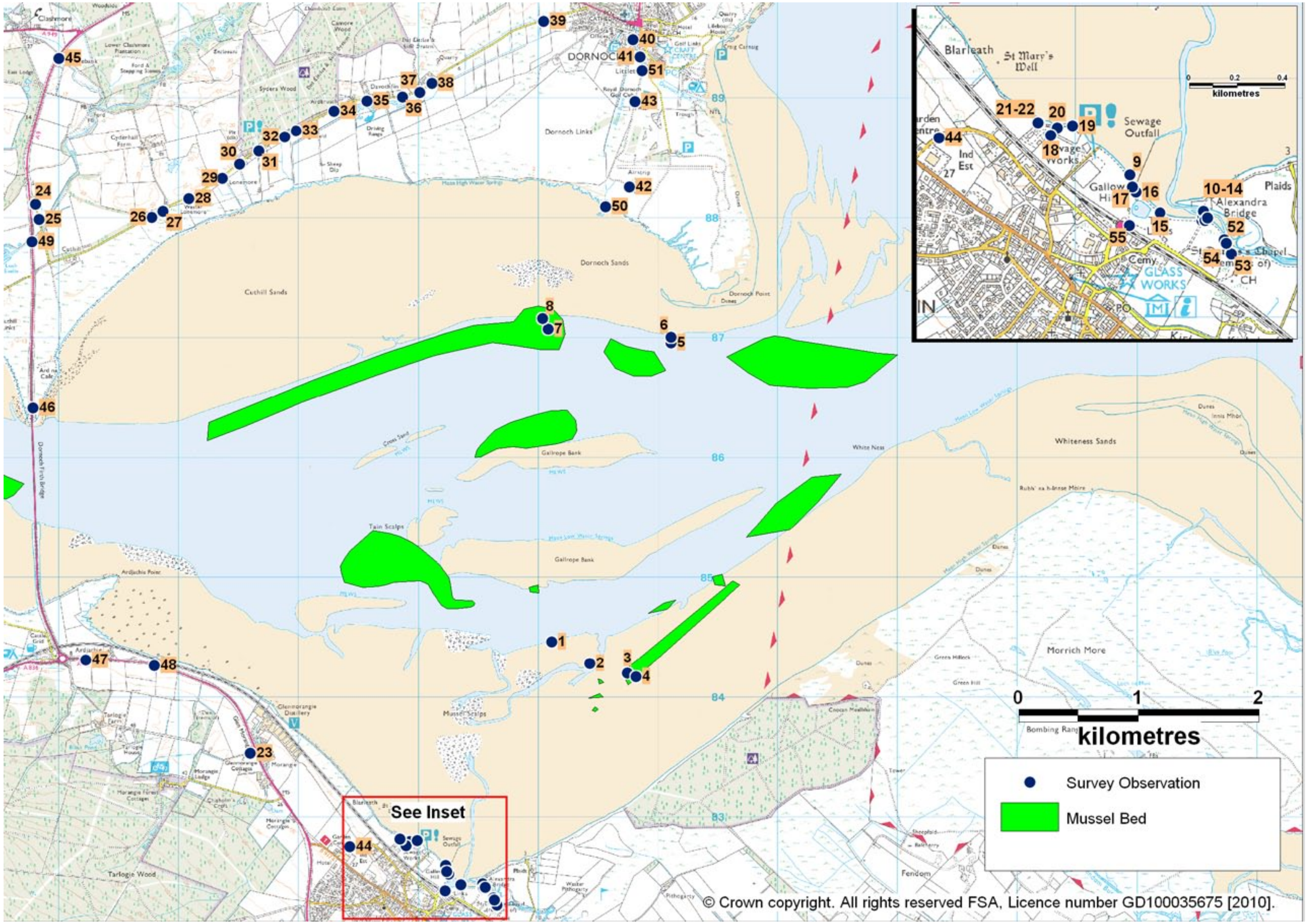


Figure 1. Map of Shoreline Observations

Table 1. Shoreline Observations

Obs No	Date	Time	Grid Ref	Easting	Northing	Assoc. Photo-graph	Observation
1	05/08/2009	10:31:08	NH 79114 84462	279114	884462		1 seal
2	05/08/2009	10:34:14	NH 79432 84280	279432	884280		Water sample 1
3	05/08/2009	10:39:48	NH 79747 84202	279747	884202		Dredge down
4	05/08/2009	10:41:20	NH 79817 84171	279817	884171		Dredge up, mussel sample 1
5	05/08/2009	11:12:26	NH 80110 86958	280110	886958		Dredge down
6	05/08/2009	11:13:54	NH 80108 87005	280108	887005		Dredge up, mussel sample 2, water sample 2
7	05/08/2009	11:22:07	NH 79085 87069	279085	887069		Dredge down
8	05/08/2009	11:23:23	NH 79039 87159	279039	887159		Dredge up,mussel sample 3, water sample 3
9	05/08/2009	13:54:11	NH 78230 82596	278230	882596		Rock groin, plastic cover over pipe at end. Water sample 6. Photograph
10	05/08/2009	14:07:25	NH 78533 82405	278533	882405		River bank
11	05/08/2009	14:08:50	NH 78537 82424	278537	882424		Midpoint of footbridge over river, water below appears >1m depth
12	05/08/2009	14:11:04	NH 78540 82443	278540	882443		River bank
13	05/08/2009	14:15:19	NH 78546 82406	278546	882406		Two water samples taken at river bank; water sample 7 - 180ml pot, water sample 8 - 30 ml pot. Salinity 28ppt at this point, Depthat bank 22 cm, flow 0.02m/s
14	05/08/2009	14:39:12	NH 78558 82416	278558	882416		Further upstream, nearer centre of river, depth 51cm flow 0.28m/s. Centre of channel too deep to wade
15	05/08/2009	14:51:42	NH 78358 82437	278358	882437		Storm overflow outlet, trickling round side of cover. Water sample 9 (seawater)
16	05/08/2009	14:55:41	NH 78256 82524	278256	882524		4 oystercatchers in grass field
17	05/08/2009	14:57:10	NH 78241 82546	278241	882546		30 gulls, 7 oystercatchers on mud flats
18	05/08/2009	15:21:39	NH 77898 82762	277898	882762		Tain WWTW
19	05/08/2009	15:33:33	NH 77989 82802	277989	882802		Unusual line of rocks, mud too soft to reach end
20	05/08/2009	15:36:39	NH 77927 82794	277927	882794		Area of bright green algae on shore adjacent WWTW
21	05/08/2009	15:39:21	NH 77849 82814	277849	882814		STW outfall, flowing. Mild sewage odour
22	05/08/2009	15:45:12	NH 77846 82815	277846	882815		Water sample 10, sewage discharge
23	06/08/2009	08:55:32	NH 76595 83532	276595	883532		Farm field
24	07/08/2009	10:44:19	NH 74805 88115	274805	888115		Cattle, 49
25	07/08/2009	10:44:38	NH 74836 87986	274836	887986		Rams, 6
26	07/08/2009	10:46:59	NH 75776 88002	275776	888002		Horse, 1
27	07/08/2009	10:47:11	NH 75871 88054	275871	888054		Farm entrance
28	07/08/2009	10:47:37	NH 76086 88160	276086	888160		House

Obs No	Date	Time	Grid Ref	Easting	Northing	Assoc. Photo-graph	Observation
29	07/08/2009	10:48:12	NH 76364 88329	276364	888329		House
30	07/08/2009	10:48:36	NH 76507 88447	276507	888447		4 houses
31	07/08/2009	10:48:58	NH 76670 88557	276670	888557		4 houses
32	07/08/2009	10:49:20	NH 76885 88675	276885	888675		House
33	07/08/2009	10:49:28	NH 76979 88725	276979	888725		Farm buildings
34	07/08/2009	10:49:56	NH 77296 88891	277296	888891		Sheep near shore, 100
35	07/08/2009	10:50:21	NH 77571 88976	277571	888976		6 houses
36	07/08/2009	10:51:25	NH 77869 89007	277869	889007		House
37	07/08/2009	10:51:36	NH 78011 89048	278011	889048		5 houses
38	07/08/2009	10:52:14	NH 78114 89123	278114	889123	Figure 4	Drumduran ST, SEPA monitoring point
39	07/08/2009	10:54:54	NH 79047 89638	279047	889638		New housing development
40	07/08/2009	10:57:02	NH 79794 89486	279794	889486		Slaughterhouse
41	07/08/2009	10:57:29	NH 79852 89344	279852	889344		Scottish Water Depot
42	07/08/2009	11:00:13	NH 79764 88259	279764	888259	Figure 5	Dornoch WWTW, appr 30m outside entrance
43	07/08/2009	11:04:55	NH 79811 88972	279811	888972		Gulls, 150 on golf course
44	07/08/2009	11:51:32	NH 77429 82753	277429	882753		Cattle, 4
45	07/08/2009	14:47:28	NH 75000 89328	275000	889328		Cattle, 60
46	07/08/2009	14:53:58	NH 74784 86411	274784	886411		Bridge, photo facing south side of firth, plantation pine opposite
47	07/08/2009	14:58:31	NH 75223 84310	275223	884310	Figure 6	Cattle, 100 in three fields
48	07/08/2009	15:03:47	NH 75799 84264	275799	884264	Figure 7	Cattle, 50. Sheep, 200
49	10/08/2009	11:59:25	NH 74779 87803	274779	887803		Stream, 10.4 m wide. Pt 1, 31 cm deep, 0.102 m/s. Pt 2, 30 cm deep, 0.086 m/s. Water sample 24
50	10/08/2009	12:43:09	NH 79566 88091	279566	888091		Black Burn, below Dornoch STW discharge. Sewage odour, water appears dirty. Est 3m wide, depth 5cm. Flow 0.125 m/s Water sample 25
51	10/08/2009	14:01:57	NH 79870 89230	279870	889230		Storm tank, Dornoch
52	10/08/2009	15:17:38	NH 78627 82324	278627	882324		Horse manure
53	10/08/2009	15:22:34	NH 78658 82265	278658	882265		Open drainage ditch with pipe through bank to river
54	10/08/2009	15:24:03	NH 78635 82310	278635	882310		Small concrete pipe extending into river. River tidal at this point, pipe mostly underwater
55	10/08/2009	15:31:48	NH 78228 82385	278228	882385		Tain Links WWPS

Photographs referenced in the table can be found attached as Figures 4-7.

Sampling

Water and shellfish samples were collected at sites marked on the map. Where indicated in Table 1, salinity was recorded in the field using a refractometer. Samples were transferred to coolboxes and shipped on the day collected to Glasgow Scientific Services for *E. coli* analysis. Bacteriology results follow in Tables 2 and 3.

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

Table 2. Water Sample Results

No.	Date	Sample	Grid Ref	Type	*E. coli* (cfu/100 ml)	Salinity (g/L)
1	05/08/2009	DFSW01	NH 79432 84280	Sea Water	0	32.7
2	05/08/2009	DFSW02	NH 80108 87005	Sea Water	1	33.4
3	05/08/2009	DFSW03	NH 79039 87159	Sea Water	0	34.2
4	05/08/2009	DFSW06	NH 78230 82596	Sea Water	240	30.0
5	05/08/2009	DFSW07	NH 78546 82406	Sea Water	360	29.1
6	05/08/2009	DFFW08	NH 78558 82416	Freshwater	100	
7	05/08/2009	DFSW09	NH 78358 82437	Sea Water	320	21.8
8	05/08/2009	DFFW10	NH 77846 82815	Sewage	56000	
9	10/08/2009	DF24	NH 74779 87803	Freshwater	1100	
10	10/08/2009	DF25	NH 79566 88091	Sewage	27000	

Table 3. Shellfish Sample Results

No.	Date	Sample	Grid Ref	Type	*E. coli* (MPN/ 100g)
1	05/08/2009	DFMussels1	NH 79783 84217	Mussel	90
2	05/08/2009	DFMussels2	NH 80109 86981	Mussel	70
3	05/08/2009	DFMussels3	NH 79062 87116	Mussel	20
4	05/08/2009	DFMussel4	NH 73733 85970	Mussel	20

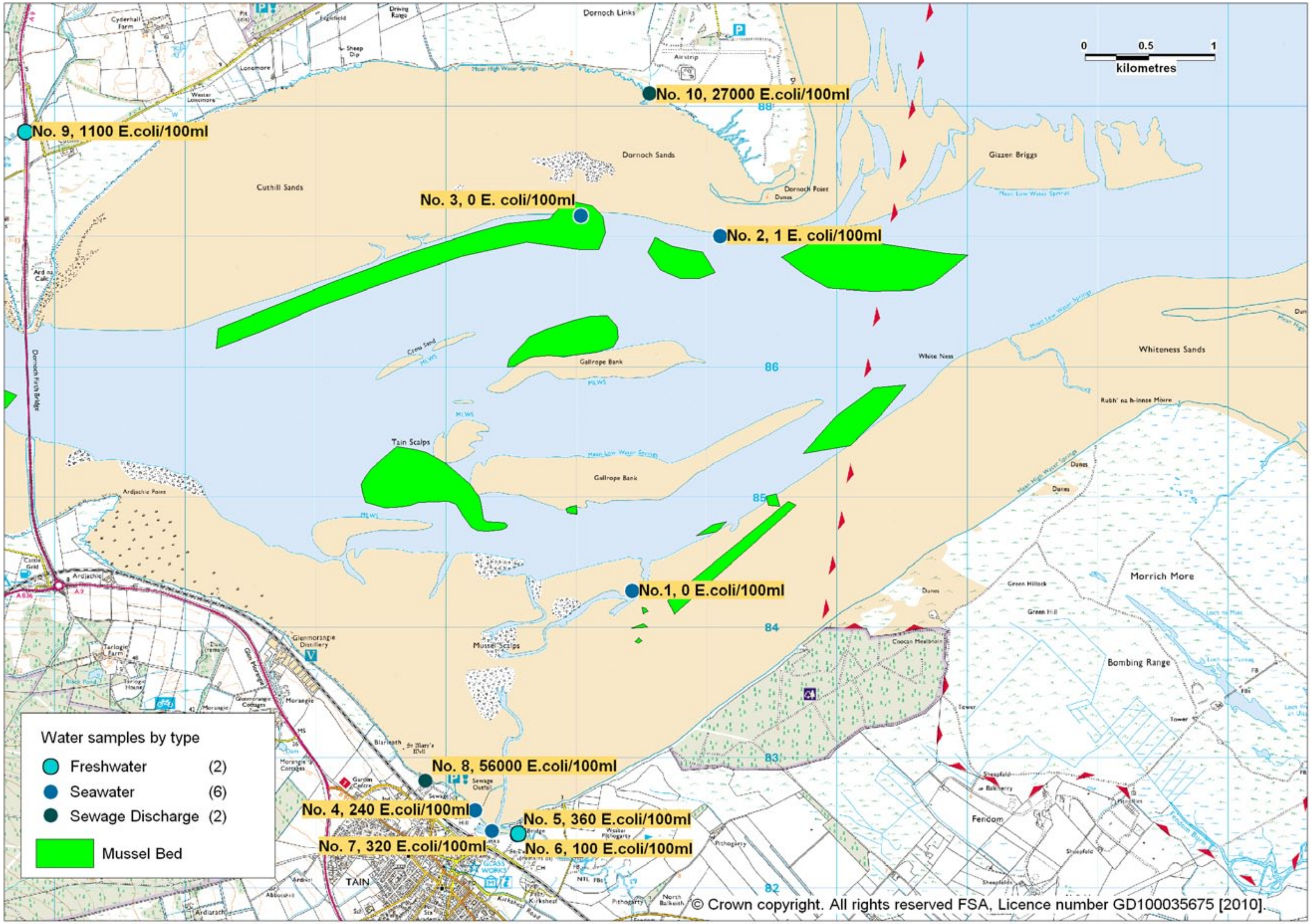


Figure 2. Water sample results map

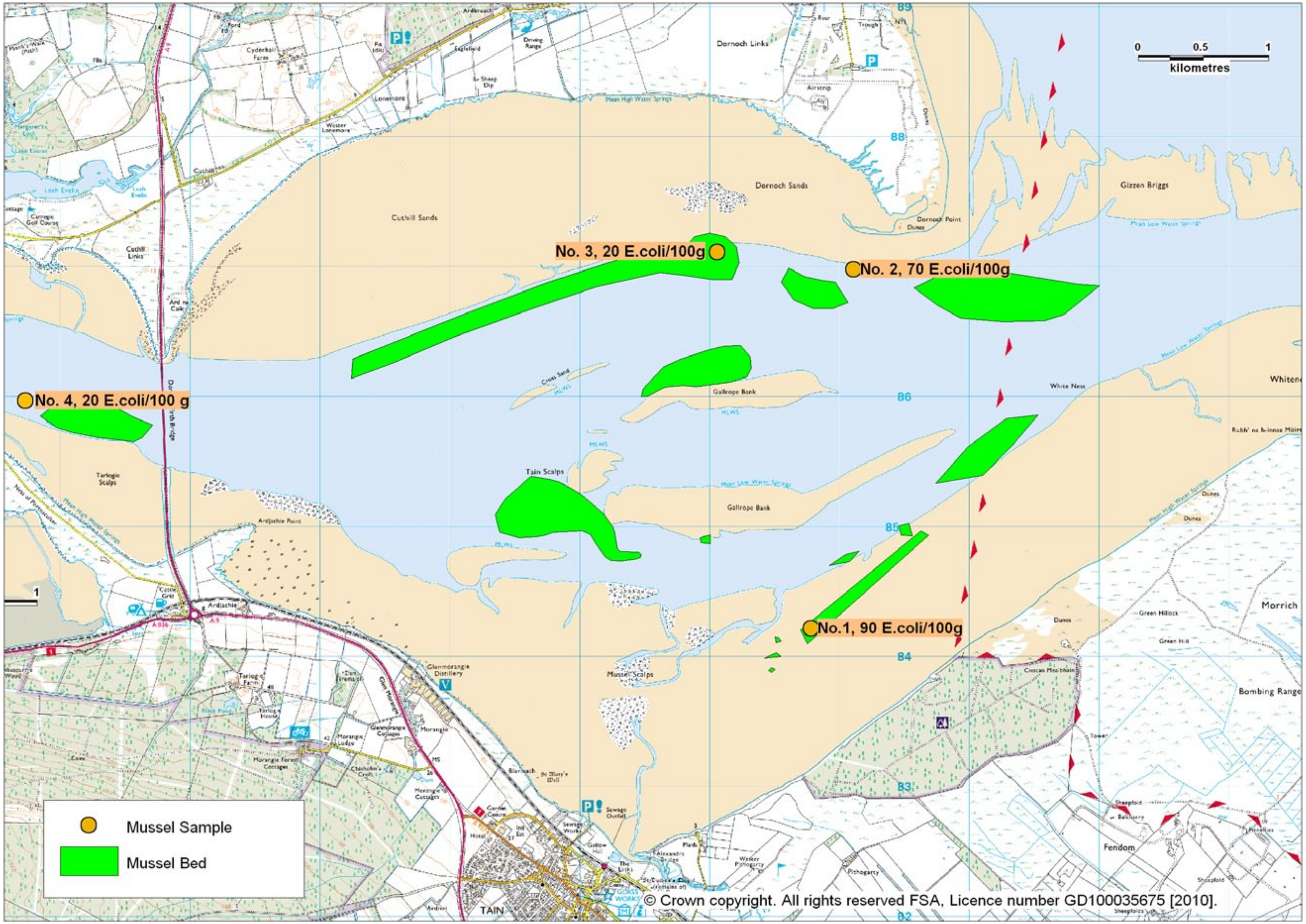


Figure 3. Shellfish sample results map

Photographs

Figure 4. Drumduran septic tank

Figure 5. Dornoch WWTW

Figure 5. Cattle near shoreline west of Tain

Figure 6. Cattle in fields south of shore, plantation woods beyond