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EC Regulation 854/2004

CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES

SANITARY SURVEY REPORT

Exe Estuary

December 2013

Food Standards Agency

Cover photo: Exe estuary, Exmouth

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Statement of use

This report provides a sanitary survey relevant to bivalve mollusc beds within the Exe estuary, as required under EC Regulation 854/2004 which lays down specific rules for official controls on products of animal origin intended for human consumption. It provides an appropriate hygiene classification zoning and monitoring plan based on the best available information with detailed supporting evidence. The Centre for Environment, Fisheries & Aquaculture Science (Cefas) undertook this work on behalf of the Food Standards Agency (FSA).

Revision history

Version	Details	Prepared by	Approved by	Approval date
1	Draft for internal consultation	Alastair Cook	Fiona Vogt	03/10/2013
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3	Final	F. Vogt/S. Kershaw	Simon Kershaw	02/01/2014

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Consultee	Date of consultation	Date of response
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Cefas, 2013. Sanitary survey of the Exe estuary. Cefas report on behalf of the Food Standards Agency, to demonstrate compliance with the requirements for classification of bivalve mollusc production areas in England and Wales under EC regulation No. 854/2004.

Contents

1. Introduction

1.1. Legislative Requirement

Filter feeding, bivalve molluscan shellfish (e.g. mussels, clams, oysters) retain and accumulate a variety of microorganisms from their natural environments. Since filter feeding promotes retention and accumulation of these microorganisms, the microbiological safety of bivalves for human consumption depends heavily on the quality of the waters from which they are taken.

When consumed raw or lightly cooked, bivalves contaminated with pathogenic microorganisms may cause infectious diseases (e.g. Norovirus-associated gastroenteritis, Hepatitis A and Salmonellosis) in humans. Infectious disease outbreaks are more likely to occur in coastal areas, where bivalve mollusc production areas (BMPAs) are impacted by sources of microbiological contamination of human and/or animal origin.

In England and Wales, fish and shellfish constitute the fourth most reported food item causing infectious disease outbreaks in humans after poultry, red meat and desserts (Hughes *et al.*, 2007).

The risk of contamination of bivalve molluscs with pathogens is assessed through the microbiological monitoring of bivalves. This assessment results in the classification of BMPAs, which determines the level of treatment (e.g. purification, relaying, cooking) required before human consumption of bivalves (Lee and Younger, 2002).

Under EC Regulation 854/2004 laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption, sanitary surveys of BMPAs and their associated hydrological catchments and coastal waters are required in order to establish the appropriate representative monitoring points (RMPs) for the monitoring programme.

The Centre for Environment, Fisheries & Aquaculture Science (Cefas) is performing sanitary surveys for new BMPAs in England and Wales, on behalf of the Food Standards Agency (FSA). The purposes of the sanitary surveys are to demonstrate compliance with the requirements stated in Annex II (Chapter II paragraph 6) of EC Regulation 854/2004, whereby 'if the competent authority decides in principle to classify a production or relay area it must:

a) make an inventory of the sources of pollution of human or animal origin likely to be a source of contamination for the production area;

b) examine the quantities of organic pollutants which are released during the different periods of the year, according to the seasonal variations of both human and animal populations in the catchment area, rainfall readings, waste-water treatment, etc.;

c) determine the characteristics of the circulation of pollutants by virtue of current patterns, bathymetry and the tidal cycle in the production area; and

d) establish a sampling programme of bivalve molluscs in the production area which is based on the examination of established data, and with a number of samples, a geographical distribution of the sampling points and a sampling frequency which must ensure that the results of the analysis are as representative as possible for the area considered.'

EC Regulation 854/2004 also specifies the use of *Escherichia coli* as an indicator of microbiological contamination in bivalves. This bacterium is present in animal and human faeces in large numbers and is therefore indicative of contamination of faecal origin.

In addition to better targeting the location of RMPs and frequency of sampling for microbiological monitoring, it is believed that the sanitary survey may serve to help to target future water quality improvements and improve analysis of their effects on shellfish hygiene. Improved monitoring should lead to improved detection of pollution events and identification of the likely sources of pollution. Remedial action may then be possible either through funding of improvements in point sources of contamination or as a result of changes in land management practices.

This report documents the information relevant to undertake a sanitary survey for mussels, Pacific and native oysters and *Tapes* spp[1] within the Exe estuary. The area was prioritised for survey in 2013-14 by a shellfish hygiene risk ranking exercise of existing classified areas.

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[1] The clam species *Tapes decussatus*, *T. philippinarum* and *V. pullastra* have similar morphologies (see Rayment, 2007) and their differentiation for commercial purposes has been proved to be difficult. In the sanitary survey of Shelly Bank in the Exe (Cefas, 2008) it was reported that no conclusive information existed regarding differentiation of *Tapes* spp. and *Venerupis* spp. It was therefore decided that in accordance with Article 23 of the Principle of Priority of the International Code of Zoological Nomenclature (ICZN, 1999), the name *Tapes* sp. should be used. It is therefore recommended that these bivalves should be classified by using the common generic name.

1.2. Area description

The Exe estuary is situated on the south west coast of England, towards the western end of Lyme Bay (Figure 1.1) in the English Channel. It covers an area of approximately 18 km² of which 60% is intertidal (Futurecoast, 2002).

Figure 1.1 Location of the Exe estuary

The Exe features a variety of habitats including a considerable area of shallow intertidal flats, saltmarsh and eel grass which attract a variety of wildlife; including significant numbers of internationally and nationally important species of overwintering birds. Consequently the estuary is protected under several national and international conservation designations including Special Site of Scientific Interest (SSSI), Ramsar site, a Special Protection Area (SPA)., National Nature Reserve (NNR), Special Area of Conservation (SAC) and a Local Nature Reserve (LNR). Recreational boating is popular within the Exe including yachting, dinghy sailing, kayaking and windsurfing. It supports a major mussel fishery, some oyster culture, and some naturally occurring stocks of clams and cockles.

1.3. Catchment

Figure 1.2 illustrates land cover within the Exe estuary catchment, which covers approximately 1,500 km².

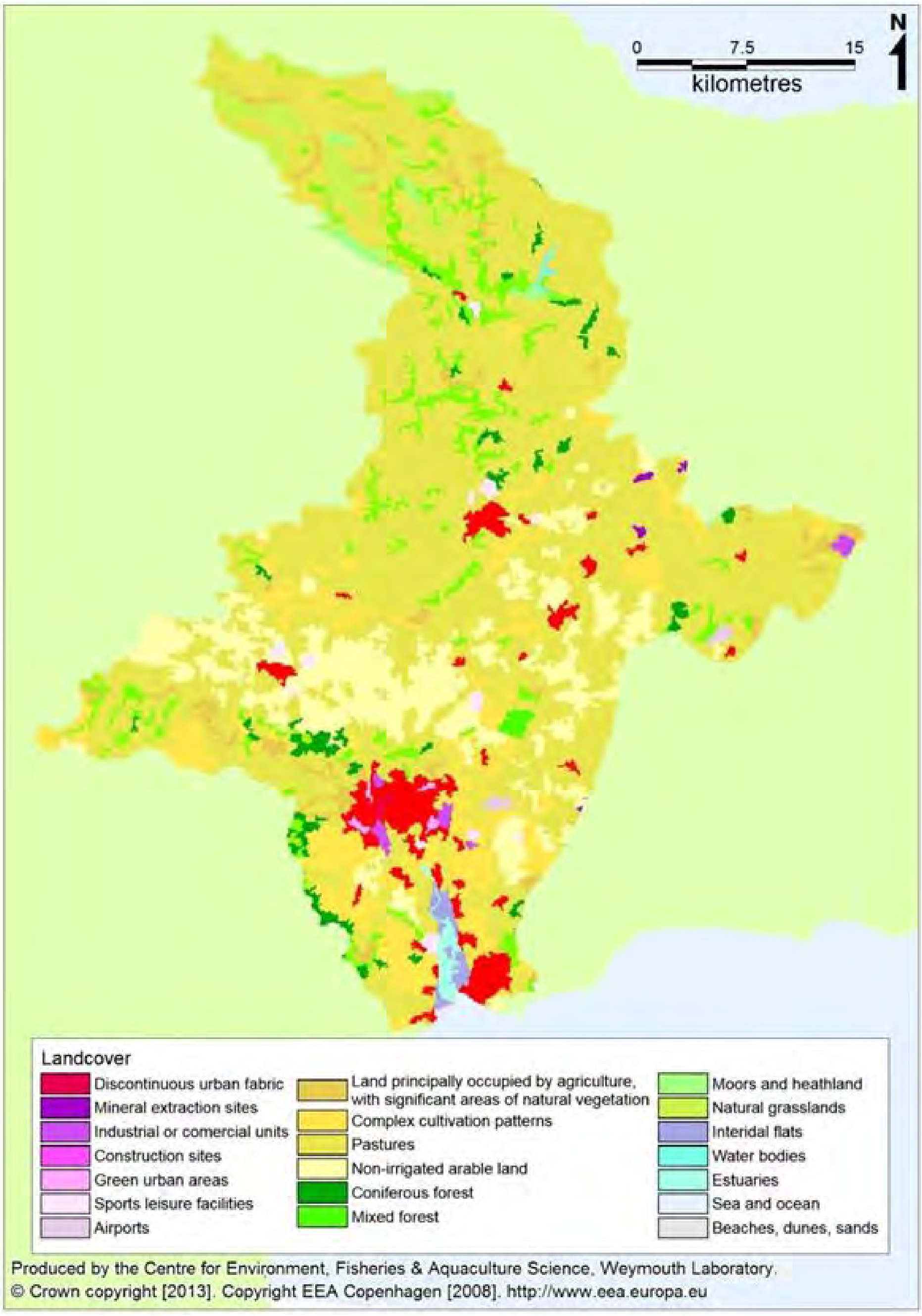

Figure 1.2 Landcover in the Exe catchment area

The catchment is predominantly rural in character, comprising of pasture and cultivated land, with packets of woodland, moors and heathland. The uppermost 10% of the catchment falls within the Exmoor National Park. Urbanised areas are mainly concentrated around the estuary, including the main towns of Exeter and Exmouth, and several villages. There are also a few towns and villages further inland.

Different land cover types will generate differing levels of contamination in surface runoff. Highest faecal coliform contribution arises from developed areas, with intermediate contributions from the improved pastures and lower contributions from the other land types (Kay *et al*. 2008a). The contributions from all land cover types would be expected to increase significantly after marked rainfall events, particularly for improved grassland, the contribution from which increases up to 100 fold.

The geology within the catchment is variable. Exmoor National Park in the upper reaches of the catchment is underlain predominantly with relatively impermeable siltstones, shale and sandstones and the lower catchment is predominantly a combination of mudstones, sandstones and breccias (Environment Agency, 2009).

2. Recommendations

2.1. Mussels

It is proposed that the mussel fishery should be divided into the following three zones:

Exe approaches

This zone contains naturally occurring mussel beds which are the subject of a dredge fishery. The main contaminating influence is likely to be the ebb plume from the estuary, which may be of greater influence towards its western end. The Littleham Brook and two CSOs discharge towards the eastern end of this zone, one of which is unmonitored and the other of which spilled for <1% of the time in recent years. Microbiological monitoring results suggest that there is little difference in levels of *E. coli* across this zone, but that background levels of contamination (rather than peak levels) are slightly higher at the western end. It is therefore recommended that the existing dredged RMP at Beacon Point is retained.

Dawlish Warren to Starcross

This zone contains mainly mussels ongrown from relayed seed, which are harvested via dredge. Up estuary sources (catchment runoff) are likely to be a significant influence in this zone, although microbiological flesh monitoring results did not find any evidence of a strong gradient of increasing contamination towards the head of the estuary. Sources direct to this zone include the Shutterton Brook, the Cockwood Harbour stream, and the Staplake Brook. Shutterton Brook and Cockwood Harbour stream both receive intermittent discharges, of which the most significant (monitored) asset is the Cockwood Harbour PS, in the lower reaches of the Cockwood stream, which has spilled for 3.3% of the time in recent years. Shutterton Brook and Cockwood Harbour stream each receive effluent from a small sewage treatment works. Moorings are present throughout this zone. On balance, it is recommended that a new RMP be located where the Cockwood Harbour drainage channel cuts across the intertidal. Sampling may be by dredge or by hand.

Starcross to Powderham

This zone contains mussels ongrown from relayed seed, which are harvested by dredge. It will extend the classified area up to Starcross Marina, and classification of this extended area will be required in the future as the harvester intends to lay mussels up potentially as far as the northern boundary of this zone. Up estuary sources (catchment runoff) are likely to be a significant influence in this zone, although microbiological flesh monitoring results did not find any evidence of a strong gradient of increasing contamination towards the head of the estuary. The main source discharging direct to this zone is the River Kenn, which receives effluent from two sewage works. It is therefore recommended that a new RMP is located adjacent to the path the River Kenn has cut across the intertidal. Sampling may be by dredge or by hand.

Sampling requirements

It is recognised that the RMP locations given in Table 3.1 may require some slight adjustments due to the uncertainties over the exact extent of mussel coverage, to ensure they coincide with stocks and follow the principles identified in these recommendations. Any adjustments should be communicated by the LEA to the classification team at Cefas.

Sampling should be on a monthly basis to maintain a full year round classification. Samples should be of mussels of a harvestable size. RMP tolerances, once locations are agreed, should be 10m for handpicked samples and 100m for dredged samples. If bagged mussels are used they should be allowed to equilibrate *in situ* for at least two weeks prior to sampling.

2.2. Pacific oysters

Currently, there are two Pacific oyster trestle sites remaining within the estuary, one off Cockwood, and a larger site by Dawlish Warren. They are temporarily declassified at present, but may require classification in the future. One zone is proposed to cover the two sites, as monitoring results from the two blocks of trestles have yielded almost identical results. The drainage channel from the Shutterton Brook is the source most likely to create a hotspot within the trestle areas due to the proximity of its drainage channel to the eastern end of the trestles by Dawlish Warren. It is therefore recommended that the RMP be located on the very eastern extremity of this block of trestles.

Sampling should be on a monthly basis for a full year round classification. Samples should be of Pacific oysters of a harvestable size. RMP tolerances, once locations are agreed, should be 10m for handpicked samples.

2.3. Native oysters

There are plans to establish a native oyster culture site in the Starcross to Powderham area, with a pilot study planned to start later this year. Commercial scale production is still some years off, however. Up estuary sources (catchment runoff) are likely to be a significant influence in this zone, although microbiological flesh monitoring results did not find any evidence of a strong gradient of increasing contamination towards the head of the estuary. The main source discharging direct to this zone is the River Kenn, which receives effluent from two sewage works. It is therefore recommended that the RMP be located adjacent to the path the River Kenn has cut across the intertidal.

Sampling should be on a monthly basis, although the months of May and June, the first two months of the closed season, may be omitted as long as all other months are successfully sampled. Samples should be of native oysters of a harvestable size. RMP tolerances, once locations are agreed, should be 10m for handpicked samples.

2.4. *Tapes* spp.

There are plans to establish a palourde culture site in the Starcross area, and there are some wild stocks already present in the area. Hatchery seed has yet to be laid however, and wild stocks are sparse. Up estuary sources (catchment runoff) are likely to be a significant influence in this zone, although microbiological flesh monitoring results did not find any evidence of a strong gradient of increasing contamination towards the head of the estuary. Sources of contamination direct to this area include the Staplake Brook and two intermittent discharges by the jetty at Starcross, one of which is unmonitored and the other of which spilled for <1% of the time in recent years. It is therefore recommended that the RMP be located immediately adjacent to the path that the Shutterton Brook cuts across this intertidal.

Sampling should be on a monthly basis. Samples should be of palourdes (*Tapes* spp.) of a harvestable size, and should be collected by hand. RMP tolerances, once locations are agreed, may need to be 100m to ensure that sufficient stock for sampling can be regularly found.

2.5. Cockles

The cockle bed on cockle sands is currently declassified as there is no commercial interest in it at present. Up estuary sources (catchment runoff) are likely to be a significant influence in this zone, although microbiological flesh monitoring results did not find any evidence of a strong gradient of increasing contamination towards the head of the estuary. The Withycombe Brook and three intermittent sewage outfalls, one of which is unmonitored and two of which spilled for <1% of the time discharge direct to this zone. Of these the Withycombe Brook will usually be the most significant contaminating influence. The drainage channels carrying all these sources converge in the middle of this cockle bed, and it is recommended that the RMP be located at this confluence.

Sampling should be on a monthly basis. Samples should be of cockles of a harvestable size, and should be collected by hand. RMP tolerances, once locations are agreed, may need to be 100 m to ensure that sufficient stock for sampling can be regularly found.

3. Sampling Plan

3.1. General Information

Location Reference

Production Area	Exe
Cefas Main Site Reference	M026
Ordnance survey 1:25,000 map	Explorer 110
Admiralty Chart	2290

Shellfishery

Species/culture	Mussels	Wild/cultured
	Pacific oysters	Cultured
	Palourdes (*Tapes* spp.)	Wild/cultured
	Native oysters	Cultured
	Cockles	Wild
Seasonality of harvest	Closed season for native oysters only is from May to August inclusive	

Local Enforcement Authority

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3.2. Requirement for Review

The Guide to Good Practice for the Microbiological Monitoring of Bivalve Mollusc Harvesting Areas (EU Working Group on the Microbiological Monitoring of Bivalve

Mollusc Harvesting Areas, 2010) indicates that sanitary assessments should be fully reviewed every 6 years, so this assessment is due a formal review in 2019. The assessment may require review in the interim should any significant changes in sources of contamination come to light, such as the upgrading or relocation of any major discharges.

Table 3.1 Number and location of representative monitoring points (RMPs) and frequency of sampling for classification zones

Classification zone	RMP	RMP name	NGR	Latitude & Longitude (WGS84)	Species	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Comments
Exe approaches	B26AT	Beacon Point	SX 9969 8050	50º 36.93'N 03º 25.15'W	Mussels	Wild	Dredge	Dredge	100m	Monthly	Existing RMP and zone
Dawlish to Starcross	TBA*	Cockwood Harbour	SX 9794 8072	50º 37.03'N 03º 26.64'W	Mussels	Wild	Dredge	Dredge/hand	100m/10m	Monthly	
Starcross to Powderham	TBA*	River Kenn	SX 9763 8313	50º 38.33'N 03º 26.94'W	Mussels	Wild	Dredge	Dredge/hand	100m/10m	Monthly	
Cookwood and Dawlish	TBA*	Creek (east end)	SX 9866 8000	50º 36.65'N 03º 26.02'W	Pacific oysters	Trestle culture	Hand	Hand	10m	Monthly (if required)	Temporarily declassified. May require reclassification at harvester request.
Starcross to Powderham	TBA*	River Kenn	SX 9763 8313	50º 38.33'N 03º 26.94'W	Native oysters	Trestle culture	Hand	Hand	10m	Monthly (except May and June)	Pilot trials to start here later in 2013. Harvester to advise LEA when tackle and stock are present for sampling.

Classification zone	RMP	RMP name	NGR	Latitude & Longitude (WGS84)	Species	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Comments
Starcross	TBA*	Staplake Brook	SX 9786 8112	50º 37.25'N 03º 26.71'W	Palourdes (*Tapes* spp.)	Wild, possibly bed culture in the future	Hand	Hand	100m	Monthly	Very little stock to sample at present and no commercial harvesting. No seed will be laid for at least a year. LEA may wish to consider whether classification sampling is worthwhile use of resources at present.
Cockle Sand	TBA*	Kings Lake	SX 9927 8194	50º 37.71'N 03º 25.53'W	Cockles	Wild	Hand or dredge	Hand	100m	Monthly	Currently declassified due to lack of commercial interest. LEA may need to reclassify on harvester request at some point. Old Kings Lake RMP moved slightly so it is centred on the drainage channel confluence.

**RMP codes will be generated once the report has been agreed and finalised.*

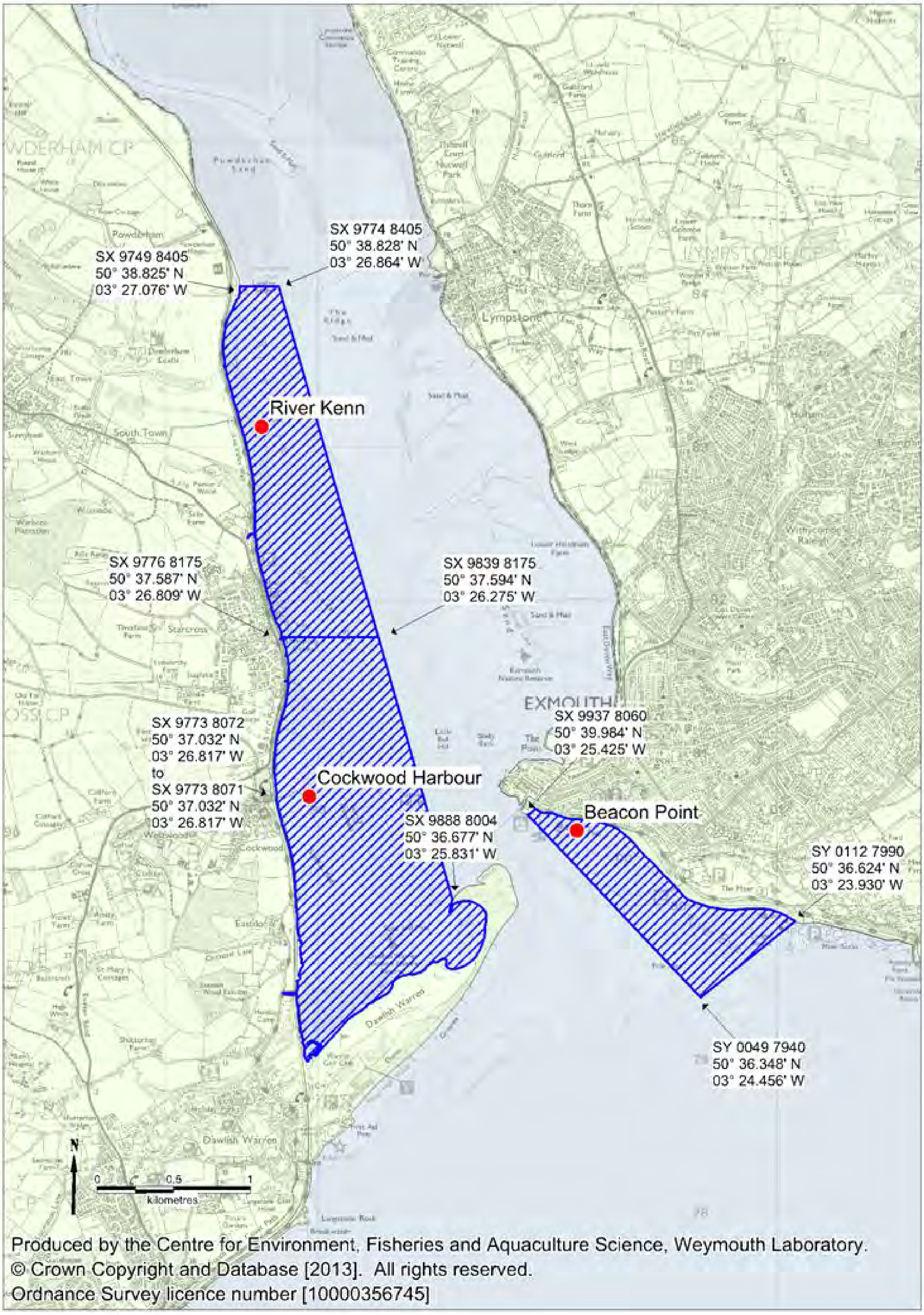

Figure 3.1: Recommended zoning and monitoring arrangements (mussels)

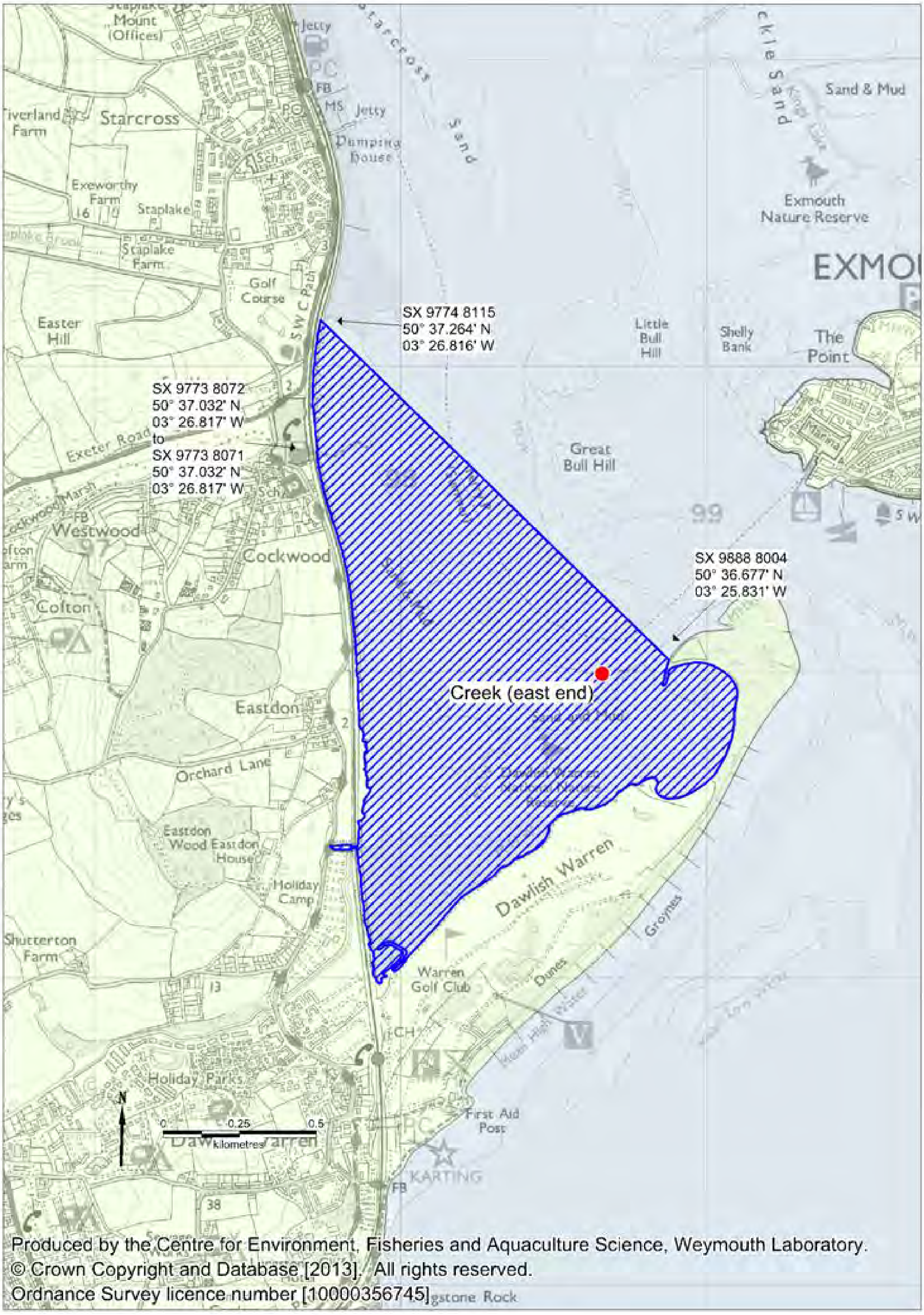

Figure 3.2: Recommended zoning and monitoring arrangements (Pacific oysters)

Figure 3.3: Recommended zoning and monitoring arrangements (native oysters)

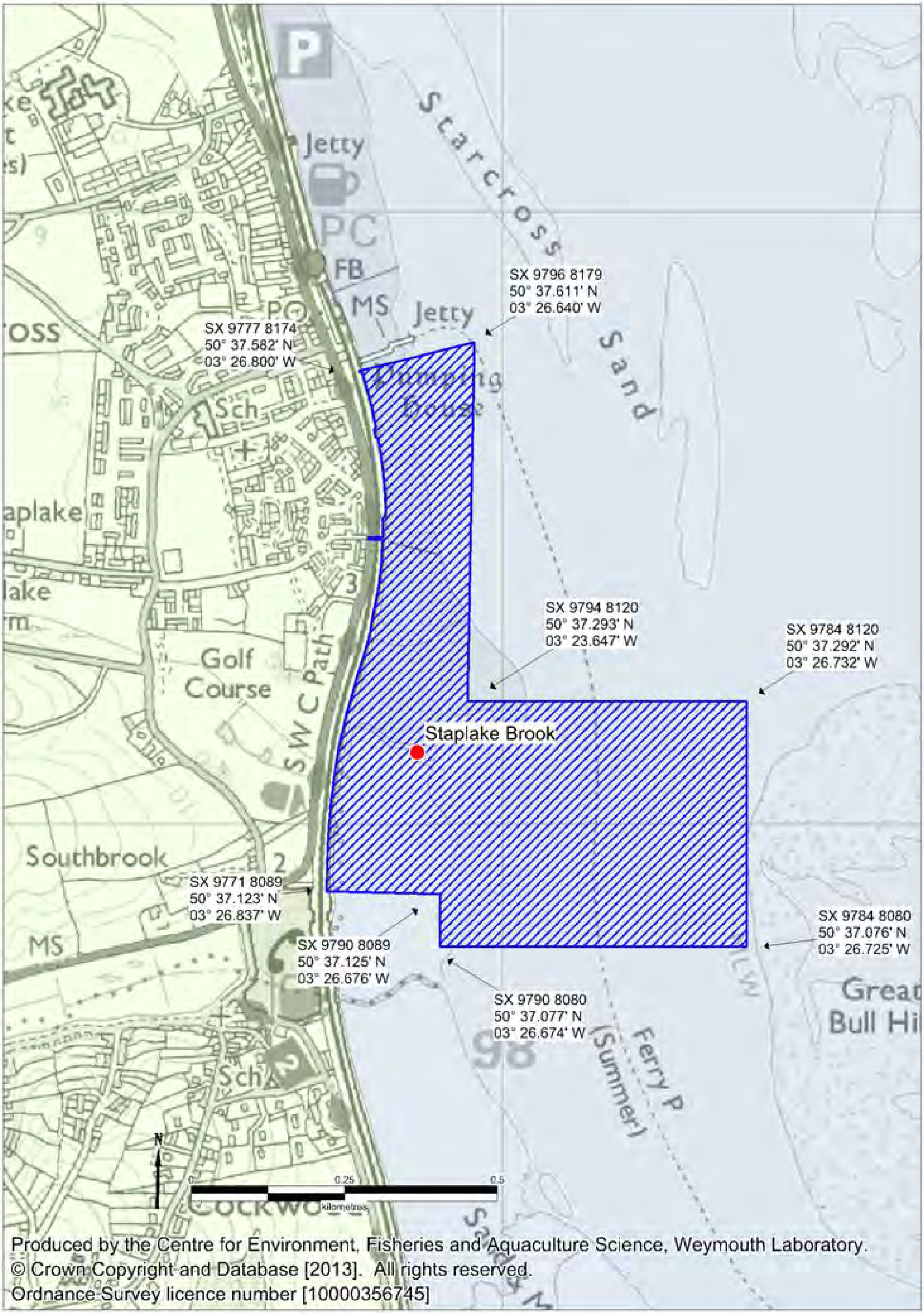

Figure 3.4: Recommended zoning and monitoring arrangements (*Tapes* spp.)

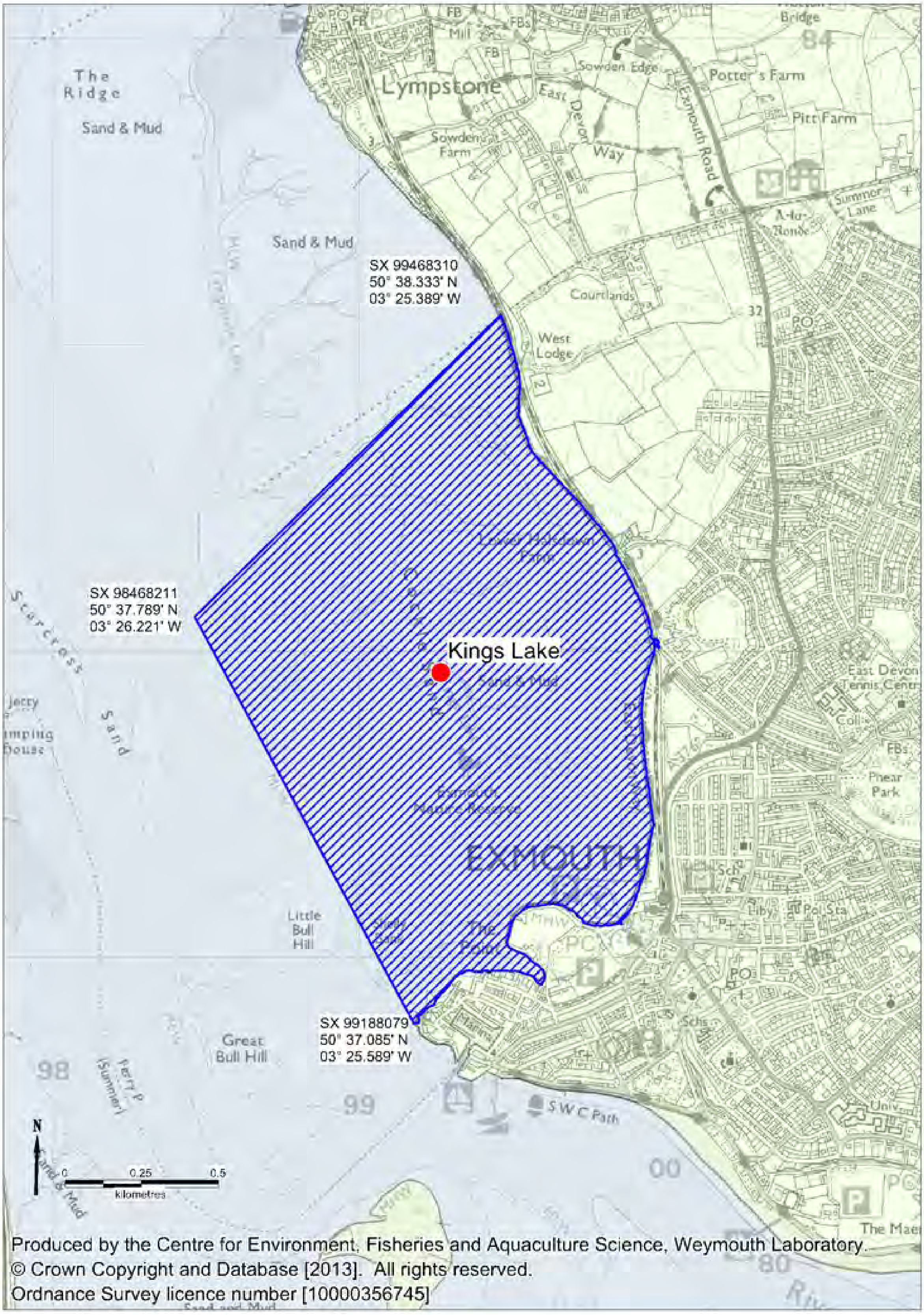

Figure 3.5: Recommended zoning and monitoring arrangements (cockles)

4. Shellfisheries

4.1. Species, location and extent

Exmouth Mussels operate the main shellfishery in the estuary. They ongrow seed mussels in a leased area in the lower intertidal and subtidal area adjacent to the west shore, between Cockwood and Powderham. Seed stocks are generally sourced from the estuary approaches. Naturally occurring market sized mussels may also be harvested direct from the main (eastern) approach channel out as far as Maer Rocks. Naturally occurring mussels are also present in various places inside the estuary. The Bull Hill bank for example can support dense natural settlements of mussels, and patches of mussels are present at Sowden End. The exact location of the seed and naturally occurring market mussels varies from year to year. The distribution of mussels within the ongrowing area also varies significantly as batches of mussels are laid and later harvested. Formerly mussels were harvested from Sowden End, but this practice no longer occurs.

Pacific oysters are also cultured in the estuary by River Exe Shellfish Farms. There are trestles holding stock on the edge of the main subtidal channel, just north of Dawlish Warren, and a second Pacific oyster culture site on the lower intertidal just north of Cockwood. These are not currently in active production and have been temporarily declassified. Formerly some Pacific oysters were cultured at Sowden End, although this site has now been abandoned.

There are significant cockle stocks on the Cockle Sand, which were until recently classified for harvest. Classification sampling ceased in 2012 due to a lack of commercial activity. Hand gathering for personal consumption continues on a regular basis, and was observed during the shoreline survey.

There are some naturally occurring native clams. There are plans to harvest these commercially in the Starcross area. Natural stocks here are sparse, and the intent is to stock the area with hatchery produced seed. Given that seed are yet to be laid here, it will be a few years before commercial volumes may be produced. Some limited culture of Manila clams used to occur at Sowden End, but this site is no longer in operation. An application to dredge Manila clams (and some other clam species) from Shelly Bank prompted a previous sanitary survey of the Exe (Cefas, 2008) but hygiene sampling results from this bed were consistent with a C classification, so these plans were abandoned.

A request to classify the intertidal area on the west bank between Starcross and Powderham for the harvest of native oyster has recently been received. Trestles and stock have yet to be placed on site.

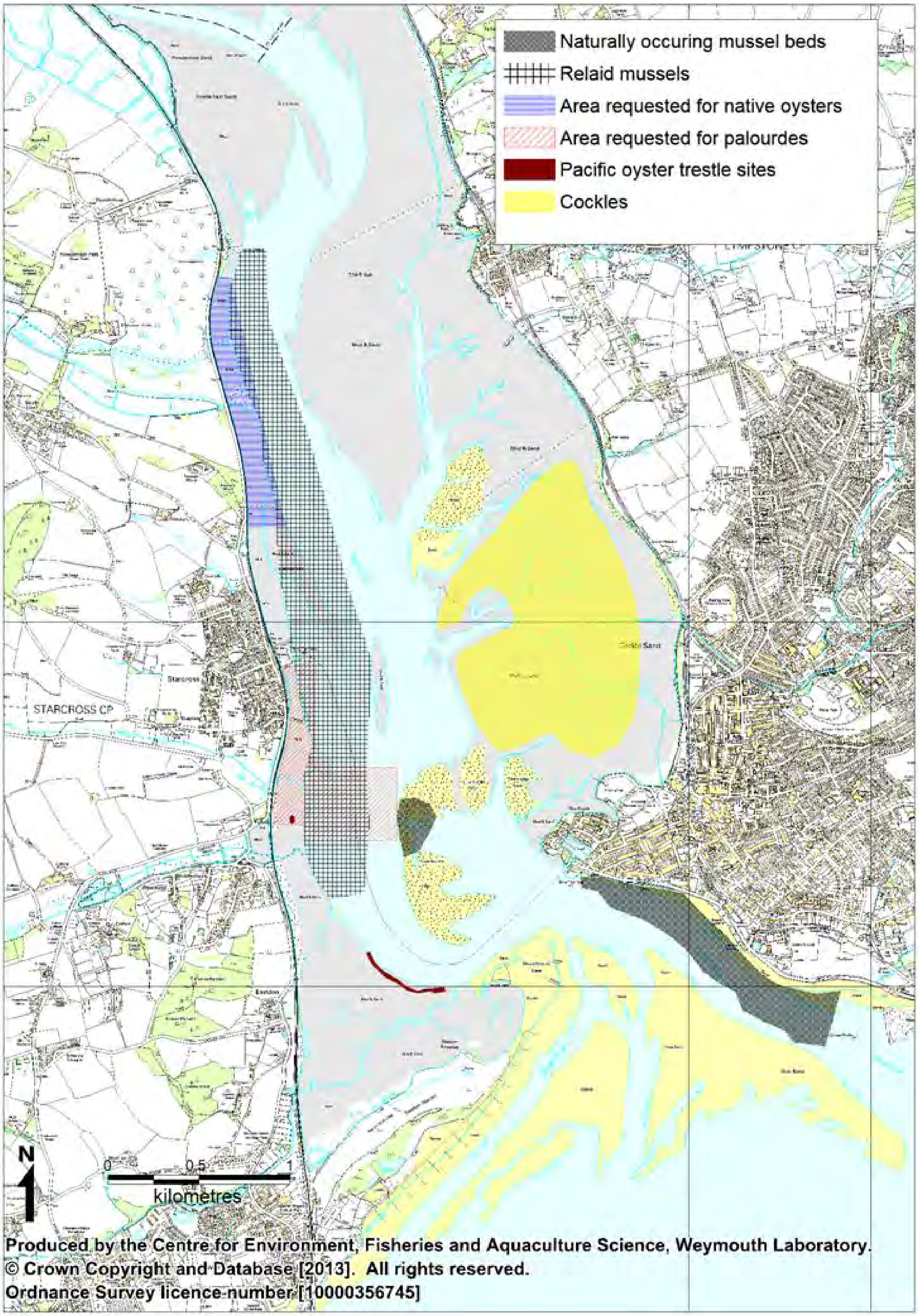

Figure 4.1: Active and proposed shellfish interests in the Exe estuary

4.2. Growing Methods and Harvesting Techniques

Mussels are ongrown on the sea bed within the estuary, and may also be harvested directly from the estuary approaches. The source of seed for ongrowing is usually from ephemeral seed mussel beds located around the mouth of the estuary. A specially adapted relaying boat is used to maintain their viability during the process and deliver them evenly to the ongrowing areas. Harvest is via an hydraulic elevator, which uses water jets to dislodge the mussels from the seabed onto a conveyor. The conveyor is kept just above the seabed to avoid causing any damage. Ongrowing of seed mussel to harvest takes around 2 years.

Pacific oysters are grown from seed in mesh bags on trestles, and are harvested by hand. They take between 2 and 3 years to reach a market size. The intention is to use similar methods for native oyster culture at the site just south of Powderham, although this species is slightly slower growing and may take a year or two longer to reach market size. Before a commercial scale fishery can be developed, pilot trials to investigate growth and survival will have to be undertaken. A source of adult stock for these trials has been found, but a source of seed for larger scale production has yet to be identified. It is uncertain how well the oysters will survive and grow here given the variable salinity.

Cockles are naturally occurring, and may be harvested by hand or using the Exmouth Mussels elevator dredge.

Palourdes occur naturally in small numbers. The intention at the Starcross site is to lay hatchery seed in the substrate to be harvested when they attain market size. No seed has been laid as yet.

4.3. Seasonality of Harvest, Conservation Controls and Development Potential

Mussels may be harvested at any time of the year, although they are in poorer (post-spawning) condition in the late spring and early summer so most harvesting activity takes place from September to March. A minimum landing size of 2” (50.8mm) applies within the district. Although traditional dredging is not allowed within the estuary, the elevator dredge is permitted as it is considered much less damaging to the substrate and benthic communities. Collection of seed from the public areas requires permission from the Devon and Severn IFCA, whereas relaying and ongrowing on private grounds does not require any licence. From 2009 to 2011 between 150 and 175 tonnes of mussels were harvested annually (MacAlister Elliot and Partners Ltd, 2012). There is considerable potential to increase the volumes harvested annually, and Exmouth Mussels have an ambition to increase this to around 2500 tonnes.

The Pacific oyster culture fishery is not subject to any fishery management controls, and has operated on a year round basis. It is possible that during July and August the quality of the oysters is lower post spawning, as has been observed in the nearby Dart (Cefas, 2011). Currently the fishery is not active and is temporarily declassified. No information on historic production volumes was available, and the future for this fishery is uncertain.

The only conservation control applying to cockles is a minimum size of ¾" (19.1mm). There are no limits to the amount of cockles which can be taken for personal consumption within the district, at present, although it is likely that the IFCA may impose bag limits on non-commercial gathering at some point to help prevent overexploitation.

A closed season (May to August) and minimum size of 2 ¼" (57mm) applies to native oysters in the district. No closed season or minimum sizes apply to either Palourdes or Manila clams. As the culture fisheries for both palourdes and native oysters are at a very early stage in their development and trials on a significant scale have yet to start, their prospects for success are uncertain. An estimated annual production of up to 20 tonnes was indicated on the classification application form for the native oyster area.

4.4. Hygiene Classification

Table 4.1 lists all classifications within the Exe estuary from 2004 onwards.

Table 4.1: Classification history for the Exe, 2004 onwards

Bed name	Species	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Powderham	P. oyster	B	A	A	A	B	-	-	-	-	-
Pool	P. oyster	B	B-LT	A	A	B	B	B-LT	B-LT	B-LT	-
Pool	Mussel	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Creek	P. oyster	B	B-LT	A	A	A	B	B-LT	B-LT	B-LT	B-LT
Mussels south	Mussel	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Sowden End	Mussel	B	B	B	B	B	B	C	-	-	-
Sowden End	P. oyster	-	B	B	B	B	B	C	-	-	-
Sowden End	Manila clam	-	-	-	B	B	-	C	-	-	-
Exmouth (Beacon)	Mussel	B	B	B	B	B	B	-	B	B	B
Kings Lake	Cockle	-	B	B	B	B	B	B-LT	B-LT	B-LT	-

LT denotes long term classification

The vast majority of classifications issued have been B. An A classification was awarded from 2006 to 2008 for Pacific oysters at Pool. At Sowden End all classifications were downgraded to C during 2010, which effectively ended the fishery here. During 2013, all Pacific oysters were temporarily declassified and sampling frequency has been reduced to quarterly to maintain this status. Sampling of cockles at Kings Lake ceased in 2012 so this bed is now declassified. The area classified for mussels does not extend up the estuary as far as the leased grounds. Although the area classified for mussels covers the areas currently harvested from, seed may be laid in the near future up as far as the Starcross Yacht Club, at the northern end of the ongrowing area shown in Figure 4.1 (Exmouth Mussels, pers. comm.) so the classified area will need extending.

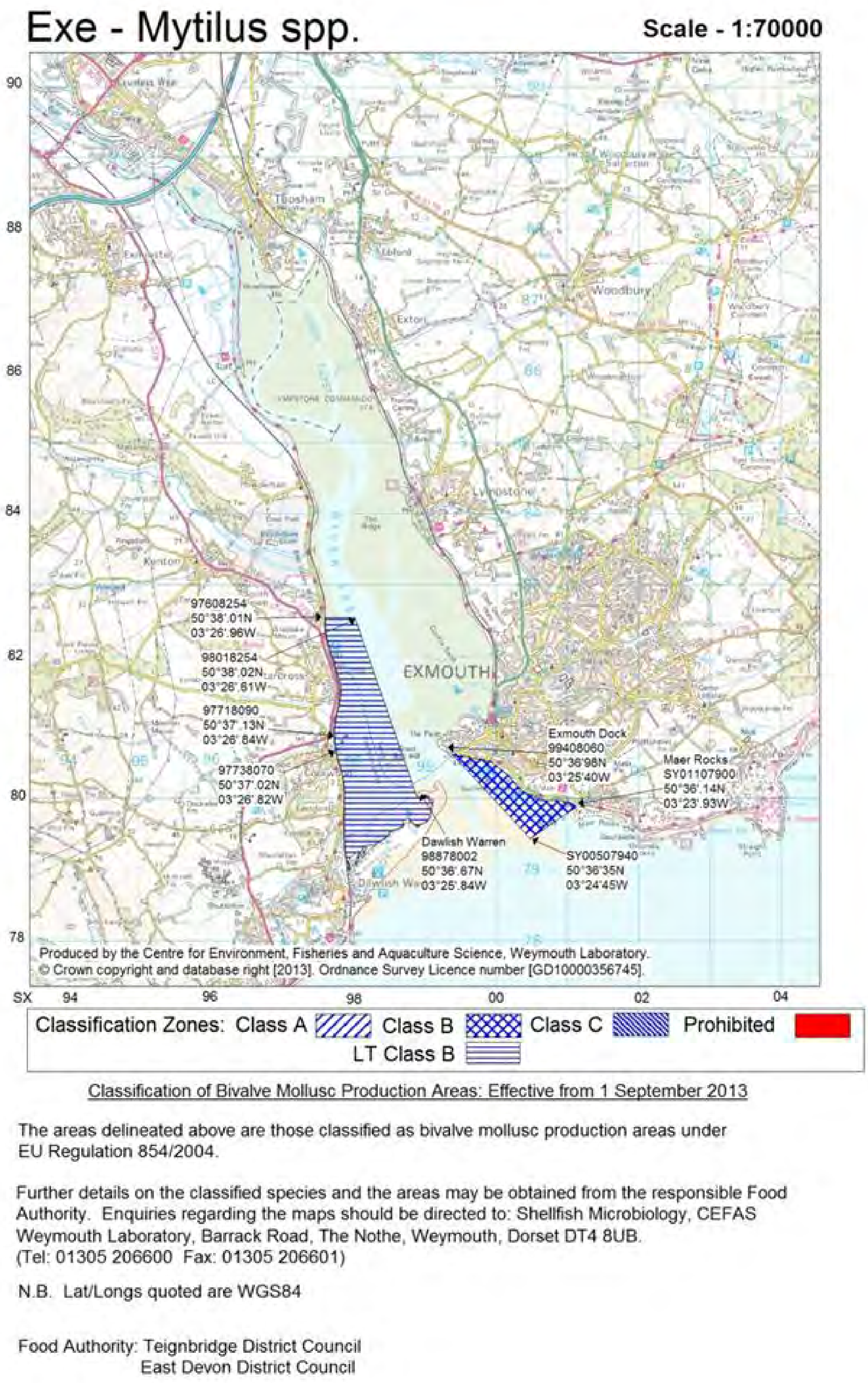

Figure 4.2: Current mussel classifications

5. Overall Assessment

5.1. Aim

This section presents an overall assessment of sources of contamination, their likely impacts, and patterns in levels of contamination observed in water and shellfish samples taken in the area under various programmes, summarised from supporting information in the previous sections and the Appendices. Its main purpose is to inform the sampling plan for the microbiological monitoring and classification of the bivalve mollusc beds in this geographical area.

5.2. Shellfisheries

The main fishery in the Exe is a mussel fishery, which relays seed taken from around the estuary mouth along the west shore of the estuary where it is ongrown. Wild stocks are also harvested from the estuary approach channel, to the south of Exmouth. The fishery is already relatively large, and there are ambitions to increase annual production significantly in the future. The area currently classified will require extension in the next year or two up as far as the Starcross Yacht Club, as seed is likely to be laid to the north of the currently classified area. Although mussels are not generally harvested during the late spring whilst they are recovering from spawning, there is no formal closed season so continued year round classification is required.

No other species are currently classified, but there are existing shellfish resources which may require reclassification at some point, as well as two new fisheries in an early stage of their development. The area where mussels, Pacific oysters and Manila clams were formerly cultured at Sowden End was abandoned after it received a downgrade to a C classification, and it is not anticipated that it will be reinstated as a culture site in the future.

Farmed Pacific oysters have been classified for harvest in the estuary until recently. Although they are currently temporarily declassified, trestles remain at two sites, both of which have some stock on. A sampling plan for these is needed as it is likely they will resume commercial production at some point. As these may be harvested at any time of the year, any classification should be on a year round basis.

There is a cockle bed on Cockle Sand, which has been exploited on a commercial basis in the recent past, but is now only subject to casual gathering. A sampling plan is provided for this should commercial interest be renewed. No closed season applies to cockles in the district, so any cockle classification would need to be on a year round basis.

A new fishery for Palourdes in the Starcross area is currently at an early stage in its development. Whilst there are some limited naturally occurring stocks of this species here, numbers are limited to such an extent that collecting sufficient for a sample can be time consuming. It is planned that hatchery seed will be laid within the area identified by the harvester, but none has been laid as yet. The fishery is therefore unlikely to be in commercial production for several years. No closed season applies to this species, so any classification would need to be on a year round basis.

Finally, a new native oyster culture site is planned on the west shore between Starcross and Powderham, where hatchery seed is to be cultured on trestles. Tackle and stock for pilot trials to assess survival and growth are anticipated to be in place later in 2013. A closed season (May to August) applies to native oysters in the district, so the classification does not need to cover these months.

In some areas in England and Wales, it has been considered acceptable to classify one species on the basis of monitoring results from another where classifications for both are required within the same geographic area. This approach will reduce laboratory costs, but must be suitably protective of public health whilst not resulting in an unfairly poor classification. Younger & Reese (2011) identified that mussels may be a suitable surrogate species for Pacific oysters, although mussels can accumulate *E. coli* to about twice the level of that found in oysters. Mussels are more tolerant of lower salinities (Laing and Spencer, 2006), and so are likely to feed and hence accumulate *E. coli* at lower salinities. Salinity is highly variable within the estuary, so the use of mussels as a surrogate for Pacific oysters may result in an unfairly poor classification in Pacific oysters and so is not considered appropriate here. Historically, palourdes and Manila clams have been classified separately although they are now both categorised together as *Tapes* spp, and are referred to as such in the sampling plan.

5.3. Pollution Sources

Freshwater Inputs

All rivers and streams carry some contamination from land runoff and so will require consideration in this assessment. Their impacts will be greatest where they enter the estuary, and within or immediately adjacent to any drainage channels they follow across the intertidal area.

The Exe estuary has a hydrological catchment of 1,500 km². The principle land use is pasture, with some arable land and a few urban areas, and the underlying geology is generally impermeable. The main river is the Exe, which is a large spate river draining to the head of the estuary with a mean discharge of around 25 m^3/sec. The River Clyst also drains to the head of the estuary, but its mean daily flow is only around 1.3m^3/sec. Overall, about 90% of the catchment is drained by watercourses that enter the estuary at its head, several km up-estuary from the shellfisheries. Given its large catchment and high discharge volume, the River Exe is likely to account for a large proportion of the fluxes of indicator bacteria into the estuary. The influence of freshwater borne contamination is likely to be highest towards the up-estuary ends of the shellfish beds, so a general principle of locating RMPs at the up-estuary end of classification zones should be applied.

Superimposed on this there may be more localised 'hotspots' associated with smaller freshwater inputs discharging in close proximity to the shellfish beds which should also be considered in the sampling plan. The smaller watercourses entering the estuary in the vicinity of the fisheries range from small surface water outfalls to minor rivers and will be of more localised significance but may cause hotspots of contamination where they enter the estuary. Any drainage channels they follow across the intertidal areas are likely to contain relatively high concentrations of indicator bacteria at lower states of the tide. Most of the significant freshwater inputs in the vicinity of the shellfisheries were sampled and measured during the shoreline survey, allowing spot estimates of the bacterial loading they were delivering at the time to be made. Information on watercourses draining in close proximity to the fisheries is summarised as follows:

- The River Kenn is the largest of these in terms of volumes discharged by a considerable margin. It drains to the west shore within the native oyster site and the upper reaches of the mussel ongrowing area, and was delivering a bacterial loading of 1.17×10^{12} *E. coli*/day at the time of survey.
- The Staplake Brook is a small watercourse discharging at Starcross, which was delivering a bacterial loading of 9.55×10^{9} *E. coli*/day at the time of survey.
- Another small watercourse discharges just south of the Staplake Brook, through the harbour at Cockwood. This was not sampled or measured.
- The Shutterton Brook discharges just north of Dawlish Warren, and its drainage channel cuts across the intertidal just south of the main block of oyster trestles. It was delivering a bacterial loading of 7.16×10^{10} *E. coli*/day at the time of survey.
- Wootton Brook discharges at Lympstone, and although it is small in terms of volumes discharged, it was carrying high concentrations of *E. coli* at the time of survey (41,000 cfu/100ml) and so its bacterial loading was high (1.31×10^{12} *E. coli*/day). Its drainage channel cuts across the intertidal off Lympstone and feeds into a subtidal channel (Lympstone Lake).
- A small stream at West Lodge was delivering a bacterial loading of 3.25×10^{9} *E. coli*/day at the time of survey.
- The Withycombe Brook discharges by the sports ground in Exmouth, and follows a drainage channel across the cockle bed at cockle sands. It was delivering a bacterial loading of 2.30×10^{11} *E. coli*/day at the time of survey.

- The Littleham Brook discharges to the beach at Exmouth, via a piped outfall at Maer Rock which was covered by the tide at the time this area was surveyed and so could not be accessed.

Flow gauging records from fixed stations on the Exe, two significant Exe tributaries (Culm and Creedy), and the Clyst indicate a strong seasonality in discharge rates, with higher average flows during the colder months of the year. Whether these higher average winter flows actually carry higher average bacterial loadings is uncertain. High flow events are likely to be associated with higher bacterial loadings, particularly as river levels rise when heavy rain occurs following a dry period (the 'first flush'). As the Exe is a spate river, which will respond quite rapidly to rainfall, the bacterial loadings it delivers are likely to fluctuate greatly in response to rainfall.

Human Population

Total resident population within the Exe estuary catchment was about 377,000 at the time of the last census (2011). The main population centre is Exeter (population of ~118,000) which is located at the head of the estuary. Other large population centres include Exmouth, on the east shore of the outer estuary, and Tiverton, on the banks of the river Exe some distance inland. The wider catchment is predominantly rural and more sparsely populated.

The South Devon coast is a popular tourist destination in the summer months due to its beaches, attractive countryside and seaside towns. Both Dawlish Warren and Exmouth are seaside resorts. Significant influxes of holidaymakers are therefore anticipated at these times. Tourists will therefore increase the population in these areas in the summer months, and sewage works here will receive increased volumes of effluent. However, much of Exeter's student population (~18,000) will be absent during the summer and other holiday periods which may result in sewage works serving Exeter receiving lower volumes of effluent at these times.

Sewage Discharges

The inland areas of the Exe catchment are served by a series of generally small sewage works, most of which discharge to watercourses draining to the head of the estuary via the rivers Exe and Clyst. Exeter is served by a large sewage works at Countess Wear, which discharges to the very upper reaches of the estuary. The total consented dry weather flow for these works is over 69,000 m^3/day. Over half of this is from the Exeter (Countess Wear) STW, which provides UV treatment. Final effluent testing results indicate this treatment is highly effective, and the estimated average bacterial loading this works generates is effectively negligible ($3.5x10^9$ faecal coliforms/day). Most of the other works discharging to the Exe, Clyst and tributaries thereof provide secondary treatment and so are likely to generate considerably higher bacterial loadings than the Exeter (Countess Wear) STW despite their smaller sizes. It is likely that there is significant bacterial die-off during transit through the watercourses to the estuary, particularly for the more distant sewage works.

The River Kenn receives sewage from two sewage works with a combined consented dry weather flow of just over 2000 m^3 /day. The larger of these (Kenton & Starcross STW) provides UV treatment. Again, final effluent testing indicates that the UV treatment is effective, and the average loading generated by this works is negligible ($9.1x10^8$ faecal coliforms/day). The smaller works (Kenn & Kenford STW) only provides secondary treatment and so is likely to generate a much larger average bacterial loading (estimated at $8.6x10^{11}$ faecal coliforms/day).

Exmouth and Dawlish are served by two relatively large sewage works, both of which provide UV treatment and discharge to Lyme Bay just outside the estuary. Exmouth STW discharges via a subtidal outfall off Straight Point, about 4.5km to the east of the estuary mouth. It generates an estimated average bacterial loading of $3.3x10^{10}$ faecal coliforms/day, which is minor and unlikely to be of significance to any fisheries within the estuary or its approaches. Dawlish STW also discharges via a subtidal outfall, about 4.5km to the west of the estuary mouth, and generates an estimated average bacterial loading of $3.4x10^{10}$ faecal coliforms/day. As such, it is also unlikely to be off any significance to fisheries in the estuary or its approaches.

Occasionally, concentrations of faecal coliforms of up to two orders of magnitude higher than the average were recorded in the final effluent from all the UV treated works. Therefore, the loading generated by this works may increase significantly from time to time. Also, it should be noted that UV disinfection is less effective at eliminating viruses than bacteria and so the effluent may present a greater health risk than bacteriological testing would suggest.

In addition to the continuous sewage discharges, there are a large number of intermittent water company discharges associated with the sewerage networks. The main clusters are found in urban areas such as Exeter and Exmouth. Of the 50 intermittent discharges within 2km of the estuary, only 15 have spill event monitoring. For those without event monitoring it is difficult to assess their potential impacts aside from noting their location and potential to spill untreated sewage. Of those with spill monitoring, all but two spilled for less than 1% of the time in recent years, so capturing the impacts of a spill from these during a years' worth of monthly monitoring is unlikely. The assets which spilled most frequently were Cockwood PSEO, which discharges to the foreshore at Cockwood and was active for 3.3% of the time, and the overflow at Exeter (Countess Wear) STW, which spilled for 1.9% of the time. The former may be of some significance given its close proximity to some shellfish resources.

Intermittent discharges create issues in management of shellfish hygiene however infrequently they spill. Their impacts' are not usually captured during a year's worth of monthly monitoring from which the classification is derived as they only operate occasionally. Thus when they do have a significant spill, heavily contaminated shellfish may be harvested under a better classification than the levels of *E. coli* within them may merit. A reactive system alerting relevant parties to spill events in real time may therefore convey better public health protection.

Although most properties in the vicinity of the estuary are connected to mains sewage, there are a number of private discharges from properties that are not. Where specified, these are generally treated by small treatment works such as package plants. The majority of these are small, serving one or a small number of properties. Most of these within 2km of the estuary lie on the eastern shore. Wooton Brook and Exton Brook both receive several private discharges, and this will contribute to the bacterial load carried by these watercourses. The Commando Training Centre sewage plant provides secondary treatment for a maximum flow of 375m^3/day discharges to Exton Brook and is by far the most significant of these in terms of volumes discharged and the bacterial loading it will generate. Neither the Exton Brook nor the Wooton Brook discharge to the estuary near any commercially active shellfish beds. Also of possible significance is a hotel which discharges up to 12 m^3/day of septic tank effluent direct to the estuary on the west bank about 2km north of Powderham.

Agriculture

The majority of land within the Exe catchment is used for agriculture. Most is pastures, although there are extensive areas in the lower catchment where crops are cultivated. A total of 125,045 cattle and 302,595 sheep were recorded within the catchment area in the 2010 agricultural census, so significant and widespread impacts from grazing animals are anticipated. Environment Agency bathing waters investigations using a DNA tracing technique suggest the majority of faecal indicator bacteria are of ruminant origin at Exmouth Town Beach. This will probably apply to the estuary as well. Faecal matter from grazing livestock is either deposited directly on pastures, or collected from livestock sheds if animals are housed indoors during the colder months and then applied to agricultural lands as a fertilizer. Significant numbers of poultry and some pigs are also farmed in the catchment. Manure from pigs and poultry is typically stored and applied tactically to nearby farmland.

The vast majority of the agricultural land lies within parts of the catchment drained by watercourses discharging to the estuary upstream of the fishery, so higher impacts towards the up-estuary ends of the shellfisheries are generally anticipated on this basis. Almost all significant watercourses will be affected to some extent. Therefore, in general RMPs should be situated at the up-estuary ends of shellfish beds, or at points where significant watercourses enter the estuary. No livestock were recorded on pastures adjacent to the estuary during the shoreline survey, although the fields behind the shoreline were obscured from the surveyors view throughout much of the survey.

The primary mechanism for mobilisation of faecal matter from agricultural land is via land runoff, so fluxes of livestock related contamination into the estuary will be highly rainfall dependent. Rainfall and river flows are generally higher during the winter months, although high rainfall events may occur at any time of the year. Peak concentrations of faecal indicator bacteria in watercourses are likely to arise when heavy rain follows a significant dry period (the ‘first flush’). Numbers of sheep and cattle will increase significantly in the spring, with the birth of lambs and calves, and decrease in the autumn when animals are sent to market. The seasonal pattern in application of manures and slurries to agricultural land is uncertain. Cattle may be housed indoors during the winter, so applications of slurry collected from such operations is likely to be spread in the late winter and spring, depending on the storage capacities of each farm.

Boats

The discharge of sewage from boats is potentially a significant source of bacterial contamination of shellfisheries within the Exe estuary. There is a substantial amount of boat traffic within the estuary, which hosts a Marina at Exmouth, several sailing clubs, and around 1,800 moorings which are mainly spread throughout the subtidal areas of the outer estuary. There are no sewage pump-out facilities available at the Marina. The majority of vessels using the estuary are pleasure craft such as yachts and cabin cruisers, with a small fishing and charter fleet also based in the estuary. There are no commercial ports within the Exe.

It is likely that the larger of the private vessels (yachts, cabin cruisers, fishing vessels) which have onboard toilets make overboard discharges from time to time. This may occur whilst boats are in passage, and it is quite likely that any boats in overnight occupation on the moorings will make a discharge at some point during their stay. It is less likely that vessels in occupation in the marina will make overboard discharges as access to on shore facilities is much easier. On this basis, the outer estuary and approach channels may be most at risk. Peak pleasure craft activity will occur in the summer, so highest impacts are anticipated at this time. Most pleasure craft are removed from the estuary and put into storage from November to April. However, it is difficult to be more specific without any firm information about the locations, timings and volumes of such discharges. Therefore, whilst inputs from boats may be a contaminating influence, it will have no material bearing on the sampling plan.

Wildlife

The Exe estuary encompasses a variety of habitats including intertidal mudflats, saltmarsh, and eelgrass beds. These features attract significant populations of birds and other wildlife. The most significant wildlife aggregation in terms of shellfish hygiene is likely to be overwintering waterbirds (waders and wildfowl). An average total count of 19,000 waterbirds was reported over five winters up to 2010/11 for the Exe.

Geese and ducks will mainly frequent the saltmarsh in the upper estuary, where their faeces will be carried into coastal waters via runoff into tidal creeks or through tidal inundation. Any contamination from such birds will therefore mainly arrive at the estuary upstream of the fisheries. Waders, such as dunlin and oystercatchers forage upon shellfish and so will forage (and defecate) directly on any shellfish beds on the intertidal. RMPs located in the intertidal rather than subtidal areas may therefore better capture contamination from foraging waders. At high tide large numbers of birds are reported to aggregate at Dawlish Warren, Bowling Green Marsh and Exminster Marshes, so these areas may be subject to higher levels of diffuse contamination of avian origin.

Whilst a small proportion of these waterbirds may remain in the area during the summer, most will migrate away to breed. Gulls breed in the area during the summer months (86 pairs in 2001) most of which were recorded nesting around the lower estuary. Again, their impacts are considered diffuse away from their nesting sites, and so will not influence the sampling plans.

A few otters are present, but only in low numbers. Also, it is possible that the occasional seal enters the estuary, although there are no major seal colonies in the vicinity. Neither of these mammals will be an influence on the sampling plan due to their low numbers and wide ranging habits. No other wildlife species which may have a bearing on the sampling plan have been identified.

Domestic animals

Dog walking takes place on beaches/intertidal and paths adjacent to the shoreline of the survey area and could represent a potential source of diffuse contamination to the near shore zone. The intensity of dog walking is likely to be higher closer to the more urban areas. As a diffuse source, this will have little influence on the location of RMPs.

Summary of Pollution Sources

An overview of sources of pollution likely to affect the levels of microbiological contamination to the shellfish beds is shown in Table 5.1 and Figure 5.1.

Table 5.1: Qualitative assessment of seasonality of important sources of contamination.

Pollution source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agricultural runoff												
Urban runoff												
Continuous sewage discharges												
Intermittent sewage discharges												
Birds												
Boats												

Red - high risk; orange - moderate risk; yellow - lower risk.

Figure 5.1: Summary of main contaminating influences

5.4. Hydrography

The Exe estuary is a narrow, funnel shaped estuary of about 15km in length, and from 1-2km in width, becoming much narrower towards the tidal limit at Exeter. A major river drains to its head. It covers an area of about 18km², of which 59% is intertidal. It is characterised by extensive sand and mudflats bisected by a subtidal river channel. The main river channel runs close to the west shore through the lower reaches of the estuary and becomes more meandering in the middle to upper reaches. It also becomes progressively narrower and shallower in the upper reaches, where it is generally less than 1m deep relative to chart datum. Where watercourses drain to the lower and middle reaches of the estuary, they have cut drainage channels across the intertidal area, which generally run perpendicular to the shore. The estuary mouth is constrained by a sandbar protruding from the west shore and an urbanised spit on the east shore, and the accelerated tidal flows through this constriction have scored the channel to a depth of 13m. Large ebb and flood deltas have formed either side of the mouth. Most of the perimeter of the estuary is protected by railway embankments on both the east and west shore, with sea walls protecting urban areas such as Exmouth and Lympstone. The estuary is flanked by strips of saltmarsh in some places but these are not particularly extensive. Its relatively shallow nature and the high proportion of which is intertidal will promote exchange of water, but limit the dilution potential away from the main channel.

The average tidal range at Exmouth Dock is 3.8m on spring tides and 1.5m on neap tides. The large tidal range will drive extensive water movements in the area, and will be the main driver of water circulation. The tidal curve is asymmetrical, with a shorter duration and faster moving ebb tide. The relatively large tidal range drives extensive water movements within the estuary. The strongest tidal currents of up to 1.7 m/s (and possibly more) arise in the estuary mouth. Within the main body of the estuary, peak current velocities decrease to between 0.5 and 1m/s in the main channels, which would translate to a tidal excursion in the very approximate order of 6-12km on spring tides. Current velocities on neap tides are around half that experienced on spring tides. Therefore, on the larger tides particles released at Exeter at high water may travel as far as Cockwood, but on neap tides they may not even reach Powderham before the tide reverses.

Within the English Channel, tides flood in an easterly direction and ebb in a westerly direction. Tidal stream atlases indicate that large scale eddies do not form within Lyme Bay. Therefore, contamination from sources discharging to the shore to the west of the estuary (Dawlish Warren STW and some intermittent discharges) may be carried in on the flood tide, but sources to the east (Exmouth STW, Littleham Brook and several intermittent discharges) will be carried past the estuary mouth rather than into it as the tide ebbs. Within the estuary, the tide floods up the main channels, moving up intertidal creeks and spreading out across the flats, with the reverse occurring on the ebb.

Tidal streams flood up the estuary in a westerly direction, following the main channels, and spreading out across intertidal areas, where current velocities will be considerably lower, with the reverse essentially occurring on the ebb. Consequently, shoreline sources of contamination will primarily impact up and downstream of their locations along the bank to which they discharge. Around low tide contamination from shoreline sources such as streams will be carried through drainage channels where the dilution potential is low, until reaching the main deeper channels. During the flood tide more water passes through the channel running past Exmouth and north of Bull Hill Bank, whereas on the ebb more water passes through the channel to the south of Bull Hill Bank. Shellfish towards the west bank of the outer estuary may therefore be more exposed to the ebb tide, which is likely to carry higher levels of contamination than the flood tide.

Superimposed on tidal circulation are the effects of wind and freshwater inputs. The vast majority of land runoff enters the estuary at its head. Density effects are reported to modify circulation at times, particularly in the upper estuary and during times of high freshwater input. Neap tides may also accentuate density effects as both tidal current velocities (and hence the extent of turbulent mixing) and the volume of tidal exchange will be lower. When such effects occur, they will result in a shear between surface and bottom currents, with less dense freshwater moving in a net seaward direction at the surface, and a net movement of more saline water up-estuary lower in the water column.

The salinity profile of the estuary gives a useful indication of the spatial pattern of impacts from contamination carried into the estuary by land runoff. Decreased salinity was strongly correlated with higher levels of faecal coliforms at the shellfish waters monitoring point off Cockwood, for example. Salinity will fluctuate significantly at any given location in response to tidal states and river flows. Unsurprisingly, salinity measurements show that the degree of freshwater influence increases greatly towards the head of the estuary. At the estuary mouth, salinity is generally approaching that of full strength seawater, although lower salinities were occasionally recorded. A lower average salinity was recorded at Exmouth Beach than at Dawlish Warren, suggesting the ebb plume influence is more marked to the east of the mouth. At the shellfish waters monitoring point off Cockwood, the average salinity is only around 25ppt. Salinity in the upper reaches of the estuary are considerably lower, and in the narrow section towards the tidal limit the channel is filled almost entirely with freshwater. A series of salinity measurements taken in August 1987 indicate a fairly steep salinity gradient in the upper estuary, which becomes more gentle in the outer estuary and continues through to the mouth. It is therefore concluded that there is likely to be a quite pronounced gradient of runoff borne contamination across the fishery, and RMPs set at the upstream end of the shellfishery will be most effective at capturing contamination from this source. Due to density effects, this may be more acute in the upper layer of the water column than on the estuary bed, where the shellfish are located, although intertidal and to a lesser extent subtidal shellfish will be exposed to lower salinity water towards low tide.

Strong winds can modify surface currents. The prevailing wind direction is from the south west, and the strongest winds tend to blow from this direction. The spits at the mouth will afford some shelter from wave action generated in the open sea, and the surrounding topography will tend to funnel winds up and down the estuary. The prevailing winds will tend to push surface water up the estuary, which will in turn create return currents at depth or along any sheltered margins. Exact effects are dependent on the wind speed and direction as well as state of the tide and other environmental variables so a great number of scenarios may arise. Where strong winds blow across a sufficient distance of water they may create wave action, and where these waves break contamination held in intertidal sediments may be resuspended, although given the enclosed nature of the estuary strong wave action is not anticipated. Energetic wave action will occur from time to time in the estuary approaches where there are some mussel resources.

5.5. Summary of Existing Microbiological Data

The Exe estuary has been subject to considerable microbiological monitoring over recent years, deriving from Bathing Waters and Shellfish Waters monitoring programmes as well as shellfish flesh monitoring for hygiene classification purposes. Figure 5.2 shows the locations of the monitoring points referred to in this assessment. The last major sewage treatment upgrades occurred in 2002, so data from 2003 onwards is considered in this assessment.

Figure 5.2: Microbiological sampling sites

Bathing Waters

Two sites were sampled under the Bathing Waters monitoring programme, where around 20 water samples were taken each bathing season (May-September) and enumerated for faecal coliforms. Both lie outside of the estuary, either side of its mouth. The average result at Exmouth Beach was significantly higher than at Dawlish Warren Beach (geometric means of 11.6 and 5.9 faecal coliforms/100ml respectively). Results exceeding 1000 faecal coliforms/100ml were recorded occasionally at both. Since 2003 results have been fairly stable, although a slight peak is apparent at Exmouth Beach in 2009, and both sites appear to have improved slightly since this time. A significant correlation between tidal state across the high/low tidal cycle and faecal coliform concentration was found at Exmouth Beach only. Here results were higher on average during the flood tide, which was unexpected as it was anticipated that the ebb plume from the estuary would be an influence. Significant correlations between tidal state across the spring/neap cycle and faecal coliform concentrations were found at both bathing waters sites, although the correlation was weak for Dawlish Warren. When this data was plotted, a slight tendency for higher results on neap tides could be seen at Exmouth Beach, but no particular pattern was apparent for Dawlish Warren. At both bathing water sites, significant correlations between rainfall up to a week before sampling and faecal coliform concentrations were detected consistently. The correlations were stronger at Exmouth Beach than at Dawlish Warren, suggesting the former is more influenced by rainfall dependent sources such as land runoff.

Shellfish waters

Under the shellfish waters monitoring programme two sites (Cockwood and Outer Exe) were sampled for faecal coliforms in water on a quarterly basis. Monitoring only commenced at Outer Exe in 2011, and only 10 sample results were available for this location, whereas the monitoring history at Cockwood dates back to before 2003 with 51 samples taken since. Average faecal coliform concentrations were significantly higher at Cockwood than at Outer Exe (geometric means of 122 and 19.5 faecal coliforms/100ml respectively), which is to be expected as the former is within an enclosed estuary whilst the latter lies just outside the estuary mouth. Faecal coliform levels at Cockwood increased between 2003 and 2007, then decreased and have remained stable since 2010. Sampling at Outer Exe has not been taking place for long enough to show any temporal patterns in faecal coliform levels. Seasonal variation was found at Cockwood, where faecal coliform concentrations were significantly higher in the autumn and winter than during the spring and summer. A similar pattern was seen at Outer Exe, although the effect was not statistically significant due to the relatively low numbers of sample results available. A significant influence of tide was found at Cockwood across the high/low tidal cycle, but not across the spring/neap cycle. Here, faecal coliform levels tended to increase during the ebb tide, were highest on average around low water, and decreased as the tide flooded suggesting up-estuary sources are an influence. At Cockwood, significant correlations between rainfall up to a week before sampling and faecal coliform concentrations were consistently detected indicating that rainfall dependent sources such as land runoff are a significant influence. A strong positive correlation between faecal coliform concentrations and salinity was also found here, further reinforcing the conclusion that land runoff is a major influence within the estuary. The effects of tide, rainfall, and salinity were investigated for Outer Exe due to the low sample numbers.

Shellfish Hygiene classification monitoring

Under the shellfish hygiene classification monitoring programme there have been 15 RMPs active since 2003, of which six are mussel RMPs, five are Pacific oyster RMPs, two are for Manila clams, one is for cockles and one is for Palourdes.

Across the six mussel RMPs, results were significantly higher on average at Sowden End, Beacon Point and Maer Rock No. 11 Buoy compared to Pool and Mussel South. The reasons for this are uncertain, particularly the higher results obtained in the two RMPs in the estuary approaches relative to the RMPs on the west shore of the main body of the estuary. It would seem that there are either higher levels of contamination to the east side of the main channel, or that more local sources are responsible for the observed spatial variation. Also, the sampling method and the water depth may be an influence as the two RMPs in the approaches are subtidal and sample by dredge, whereas the Pool and Mussel South are intertidal and sampled by hand. A comparison of paired (same day) samples was possible for five mussel RMP pairings, where sampling had been undertaken on the same day on 20 or more occasions. Results at all site pairings (Sowden End vs Sowden End Site 2, Beacon Point and Maer Rock No. 11 Buoy; Mussel South vs Pool; and Beacon Point vs Maer Rock No. 11 Buoy) were strongly correlated on a sample by sample basis, suggesting they are all under similar contaminating influences. Paired sample results were very similar at the two RMPs in the approaches, although the mean result of these samples only was slightly higher at Beacon Point, where there were fewer low results. This suggests that the western end of this zone is subject to slightly higher background levels of contamination, presumably due to increased influence of the estuary plume.

Across the five Pacific oyster RMPs, Sowden End and Creek Oyster Barge had significantly higher levels of *E. coli* than all of the other Pacific oyster RMPs. The higher results at Sowden End may possibly be explained by local sources here, but the marked difference between Creek and Creek Oyster Barge is perhaps surprising given they are within 125m of each other. The Creek Oyster Barge RMP is located just off from where the drainage channel from the Shutterton Brook meets the main estuary channel, whereas the Creek RMP is over 100m from this drainage channel. Also, it is assumed that the oyster barge was a floating installation and samples from

Creek are taken from trestles on the sea bed. A combination of location relative to the drainage channel, and density effects may offer an explanation for this difference. There are other possible explanations such as birds aggregating on the raft, but none have a particularly firm basis. Comparison of paired (same day) samples showed significant correlations between Powderham vs Pool and Creek vs Pool. Correlations between Creek Oyster Barge vs Pool and Creek Oyster Barge vs Creek were not significant, suggesting that Creek Oyster Barge may be influenced by different sources than Pool and Creek. Paired sample results at Pool and Creek were almost identical in terms of geometric mean result, although the 4600 MPN/100g threshold was only exceeded at Pool. This suggests that the two trestle sites may not need separate monitoring, and that there would be a slight preference to sample at the Pool trestle site to cover the two.

Although results for Manila clams were higher in terms of average and peak result at Shelly Bank compared to Sowden End, no significant difference was found in *E. coli* levels between the two. The data is not however directly comparable as they were sampled throughout different periods. Cockles and Palourdes have only one RMP each so a geographic assessment of levels of *E. coli* in these species was not possible.

Since 2003, no consistent overall temporal patterns were found across the whole area. In some cases (Pacific oysters at Pool and Creek, and cockles at Kings Lake) there appears to have been a slight peak in results around 2009, and levels of *E. coli* in mussels at Pool and Mussel South appear to have increased gradually since 2008. Significant seasonal patterns in results were only observed for Pacific oysters at Creek Oyster Barge, where results were significantly higher during the autumn than the summer.

A significant influence of the high/low tidal cycle was detected for mussels at Pool and Maer Rock No. 11 Buoy, and for Pacific oysters at Sowden End, Creek, and Creek Oyster Barge. These correlations were generally quite weak and strong patterns were not always seen when the data was plotted. At the Pool mussel RMP, higher results tended to occur just after low water, although sampling effort was strongly targeted towards this time. At Maer Rock No. 11 Buoy, the few low results that occurred tended to be around high tide, and *E. coli* levels were higher on average just after low water. A vague tendency for higher results to occur around low tide was seen at the three Pacific oyster RMPs, although sampling was targeted towards this time. A significant influence of the spring/neap tidal cycle was detected in mussels at Sowden End, Sowden End Site 2, and Beacon Point, and in Pacific oysters at Sowden End, Pool, Creek and Creek Oyster Barge. These correlations were generally quite weak, and when the data was plotted all of them showed a vague tendency for higher levels of *E. coli* as the tide size increased from neaps to springs.

Rainfall events rapidly increased contamination in most mussel sites and the Kings Lake cockle RMP. However, rainfall did not have a significant effect on contamination at Pacific oyster RMPs. At Powderham, the farthest up-estuary site, increased rainfall actually appears to be tentatively associated with lower *E. coli* results. This is probably due to the greater tolerance of mussels (and possibly cockles) to changes in salinity. Lowered salinity due to rainfall is likely to reduce feeding of the oysters, therefore decreasing their uptake of contaminants.

Appendices

Appendix I. Human Population

Figure I.1 shows the population densities in the census areas that lie fully or partially within the Exe catchment. These data were derived from the 2011 census.

Figure I.1: Population densities in the Exe catchment area

The total population in the catchment is approximately 377,000, and increased by 6.6% between the 2001 and 2011 censuses. Much of the catchment is rural, with the uppermost reaches of the Exe running through the Exmoor national park. Population densities in these areas are low, ranging from 10 to 100 people per km². Exeter, the most populated area, has a total of 118,000 residents, or approximately 31% of the population of the catchment. Other large population centres include Tiverton and Exmouth. All three of these settlements lie on the banks of the River Exe or its estuary and so are likely to contribute contamination to the fisheries either via the river, or in the case of Exmouth, through being directly adjacent to the fisheries.

In addition to the resident population, many tourists visit the area. Dawlish Warren on the south-west of the estuary is thought to receive 800,000 visitors per year (Page and Connell, 2006). Exmouth, on the south-eastern shore of the estuary is also a significant seaside resort. Tourists will therefore increase the population in these areas in the summer months, and sewage works here will receive increased volumes of effluent. However, much of Exeter's student population (just under 18,000) will be absent during the summer and other holiday periods which may result in sewage works serving Exeter receiving lower volumes of effluent at these times.

Appendix II. Sources and Variation of Microbiological Pollution: Sewage Discharges

Details of all water company owned sewage treatment works in the hydrological catchment and two discharging to nearby coastal waters were taken from the most recent update of the Environment Agency national permit database (March 2013). These are mapped in Figure II.1, and details are presented in Table II.1

Due to its largely rural nature, the Exe catchment is served by a series of generally small sewage works, most of which discharge to watercourses draining to the head of the estuary via the rivers Exe and Clyst. The total consented dry weather flow for these works is over 69,000 m^3/day. Over half of this is from the Exeter (Countess Wear) STW, which provides UV treatment. Most others provide secondary treatment. It is likely that there is significant bacterial die-off during transit through the watercourses to the estuary, particularly for the more distant sewage works.

Also of significance, the River Kenn receives sewage from two sewage works with a combined consented dry weather flow of just over 2000 m^3/day. The larger of these (Kenton & Starcross STW) provides UV treatment. There are also two relatively large sewage discharges to Lyme Bay, just outside the estuary mouth (Exmouth and Dawlish STWs) both of which provide UV treatment.

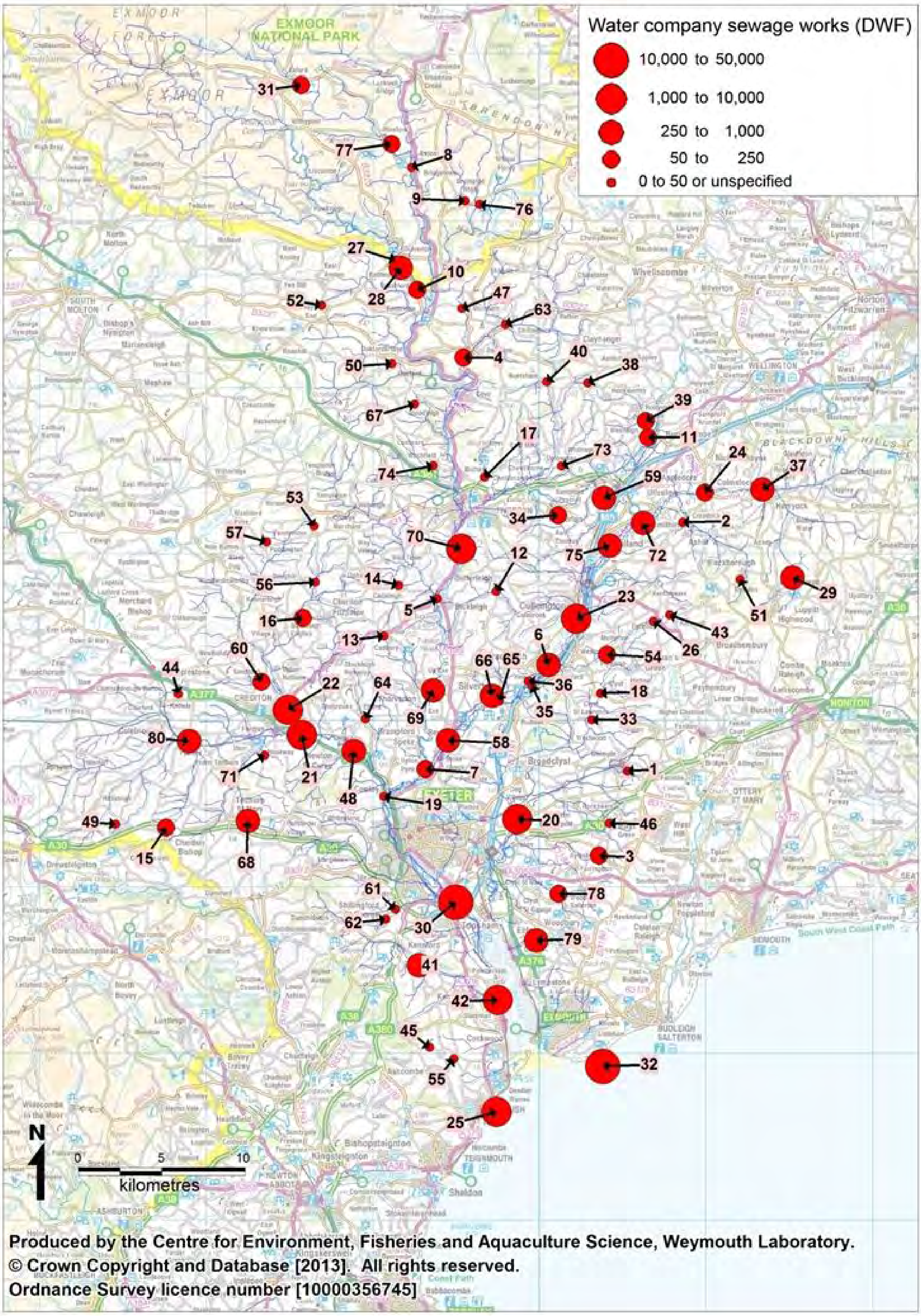

Figure II.1: Continuous water company sewage discharges to the Exe catchment and nearby coastal waters

Table II.1: Details of continuous water company sewage works

No.	Name	NGR	Treatment	Dry weather flow (m^3/day)	Estimated bacterial loading (cfu/day)	Receiving environment
1	Aller Grove STW	SY0529096950	Secondary	9	$3.0x10^{10}$*	R. Clyst trib.
2	Ashill STW	ST0860011900	Unspecified	Unspecified		Ashill stream
3	Aylesbeare STW	SY0358091860	Secondary	103	$3.4x10^{11}$*	Aylesbeare Brook
4	Bampton STW	SS9542021810	Unspecified	230		Batherm
5	Bickleigh STW	SS9385007300	Unspecified	Unspecified		R. Exe trib.
6	Bradninch STW	ST0055003330	Primary settlement	404	$4.0x10^{12}$*	R. Culm
7	Brampford Speke STW	SX9314097070	Secondary	104.54	$3.4x10^{11}$*	R. Exe
8	Bridgetown STW	SS9230033230	Secondary	Unspecified		R. Exe
9	Brompton Regis STW	SS9553031200	Unspecified	Unspecified		Pulham River
10	Brushford STW	SS9266025860	Secondary	124	$4.1x10^{11}$*	R. Barle
11	Burlescombe & Westleigh STW	ST0653016980	Secondary	155	$5.1x10^{11}$*	R. Lynher
12	Butterleigh STW	SS9740007750	Unspecified	Unspecified		Burn River
13	Cadbury Cross STW	SS9065005050	Unspecified	Unspecified		Thorverton Stream
14	Cadeleigh STW	SS9153008120	Unspecified	Unspecified		Unnamed watercourse
15	Cheriton Bishop STW	SX7757093550	Secondary	144	$4.8x10^{11}$*	Ford Brook
16	Cheriton Fitzpaine STW	SS8578006140	Secondary	115	$3.8x10^{11}$*	Holly Water trib.
17	Chettiscombe Village STW	SS9670014610	Secondary	13.5	$4.5x10^{10}$*	Town Leat
18	Clyst Hydon STW	ST0367001620	Secondary	7.13	$2.4x10^{10}$*	R. Clyst
19	Cowley Bridge STW	SX9064095420	Unspecified	Unspecified		R. Exe trib.
20	Cranbrook STW	SX9866094050	Membrane filtration	2810		R. Clyst
21	Crediton STW (outlet 1)	SX8572099120	Phosphate stripping	4100		R. Yeo/R. Creedy
22	Crediton STW (outlet 2)	SS8487700621				
23	Cullompton STW	ST0220006100	Secondary	2955	$9.8x10^{12}$*	R. Culm
24	Culmstock STW	ST0992013680	Secondary	118	$3.9x10^{11}$*	R. Culm
25	Dawlish STW	SX9742076470	UV disinfection	4856	$3.4x10^{10}$**	Lyme Bay
26	Dulford STW	ST0685005950	Unspecified	Unspecified		R. Weaver trib.
27	Dulverton (Recreation) ST	SS9133027640	Septic tank	Unspecified		R. Barle
28	Dulverton STW	SS9167027180	Secondary	468	$1.5x10^{12}$*	R. Barle

No.	Name	NGR	Treatment	Dry weather flow (m^3/day)	Estimated bacterial loading (cfu/day)	Receiving environment
29	Dunkeswell STW	ST1519008580	Secondary	314	$1.0x10^{12}$*	R. Madford
30	Exeter (Countess Wear) STW	SX9497089050	UV disinfection	40486	$3.5x10^{9}$**	Exe estuary
31	Exford STW	SS8567038160	Secondary	120	$4.0x10^{11}$*	R. Exe
32	Exmouth STW	SY0379079190	UV disinfection	11825	$3.3x10^{10}$**	Lyme Bay
33	Foretown STW	ST0315000010	Secondary	4.8	$1.6x10^{10}$*	R. Clyst trib.
34	Halberton STW	ST0113012320	Secondary	208	$6.9x10^{11}$*	Halberton Stream trib.
35	Hele (Whiteways) STW	SS9955002050	Unspecified	Unspecified		R. Culm
36	Hele Village STW	SS9935002350	Unspecified	Unspecified		R. Culm
37	Hemyock STW	ST1339013880	Secondary	446	$1.5x10^{12}$*	R. Culm
38	Hockworthy STW	ST0290020270	Secondary	Unspecified		R. Lowman trib.
39	Holcombe Rogus STW	ST0639017990	Secondary	119	$3.9x10^{11}$*	R. Lynher
40	Huntsham STW	ST0045020350	Unspecified	Unspecified		R. Lowman
41	Kenn & Kennford STW	SX9276085270	Secondary	262	$8.6x10^{11}$*	R. Kenn
42	Kenton & Starcross STW	SX9748283180	UV disinfection	1750	$9.1x10^{8}$*	Exe estuary
43	Kerswell STW	ST0782006330	Secondary	Unspecified		R. Weaver
44	Knowle STW	SS7831001590	Unspecified	Unspecified		R. Troney trib.
45	Mamhead STW	SX9340080350	Unspecified	Unspecified		R. Exe trib.
46	Marsh Green STW	SY0419093810	Reedbed	28		Ford Stream
47	Morebath STW	SS9535024770	Unspecified	Unspecified		R. Batherm trib.
48	Newton St Cyres STW	SX8885098140	Secondary	300	$9.9x10^{11}$*	R. Creedy
49	North Bovey STW	SX7452093750	Unspecified	Unspecified		R. Bovey
50	Oakford STW	SS9113021420	Unspecified	Unspecified		Iron Mill Stream trib.
51	Oakleigh STW	ST1205208469	Package plant	5 (max)	$1.7x10^{10}$*	Soakaway
52	Oldway End STW	SS8690024950	Unspecified	Unspecified		Brockney Brook trib.
53	Pennymoor STW	SS8646011670	Secondary	34	$1.1x10^{11}$*	Binneford Water trib.
54	Plymtree STW	ST0406003960	Secondary	96.8	$3.2x10^{11}$*	R. Weaver
55	Port Road Parkside STW	SX9485079650	Secondary	3.6	$1.2x10^{10}$*	Shutterton Brook trib.
56	Poughill STW	SS8653008290	Package plant	Unspecified		Holy Water
57	Puddington STW	SS8360010730	Unspecified	Unspecified		R. Creedy
58	Rewe & Stock Cannon STW	SX9450098800	Secondary	429	$1.4x10^{12}$*	R. Culm

No.	Name	NGR	Treatment	Dry weather flow (m^3/day)	Estimated bacterial loading (cfu/day)	Receiving environment
59	Sampford Peverell STW	ST0386813361	Secondary	296	$9.8x10^{11}$*	Spratford Stream
60	Sandford STW	SS8330002300	Secondary	118	$3.9x10^{11}$*	R. Creedy trib.
61	Shillingford Abbot STW	SX9135088650	Unspecified	Unspecified		Matford Brook
62	Shillingford St George STW	SX9075088050	Secondary	37	$1.2x10^{11}$*	Matford Brook trib.
63	Shillingford STW	SS9794023780	Unspecified	Unspecified		R. Bartherm
64	Shute STW	SS8954000080	Secondary	12.3	$4.1x10^{10}$*	R. Creedy trib.
65	Silverton Mill STW	SS9757001160	Secondary	36	$1.2x10^{11}$*	R. Culm
66	Silverton STW	SS9715001480	Secondary	563.64	$1.9x10^{12}$*	Unnamed stream
67	Stoodleigh STW	SS9250019000	Unspecified	Unspecified		Stoodleigh Stream
68	Tedburn St Mary STW	SX8248093950	Secondary	383	$1.3x10^{12}$*	Lilly Brook
69	Thorverton STW	SS9360001800	Secondary	309	$1.0x10^{12}$*	R. Exe
70	Tiverton STW	SS9530010300	Secondary	6900	$2.3x10^{13}$*	R. Exe
71	Trobridge Court STW	SX8348697904	Package plant	4.3 (max)	$1.4x10^{10}$*	Soakaway
72	Uffculme STW	ST0622011860	Secondary	564	$1.9x10^{12}$*	R. Culm
73	Uplowman STW	ST0132015270	Secondary	42	$1.4x10^{11}$*	Uplowman Stream
74	Washfied STE	SS9360015300	Unspecified	Unspecified		Washfield Stream
75	Willand STW	ST0422010500	Secondary	613	$2.0x10^{12}$*	R. Culm trib.
76	Wimblehall Reservoir ST	SS9640031000	Septic tank	6.3	$6.3x10^{10}$*	Soakaway
77	Winsford STW	SS9110034630	Secondary	84	$2.8x10^{11}$*	R. Exe
78	Woodbury Salterton STW	SY0115089580	Secondary	201	$6.6x10^{11}$*	Crindle Brook
79	Woodbury STW	SX9979086780	Secondary	408	$1.3x10^{12}$*	Polly Brook
80	Yeoford STW	SX7894098740	Secondary	493	$1.6x10^{12}$*	R. Yeo

*Faecal coliforms (cfu/day) based on geometric base flow averages from a range of UK STWs providing secondary treatment (Table II.2).
** *E. coli* (cfu/day) based on geometric mean final effluent testing data (Table II.3).
Data from the Environment Agency

Table II.2: Summary of reference faecal coliform levels (cfu/100ml) for different sewage treatment levels under different flow conditions.

Treatment Level	Flow			
	Base-flow		High-flow	
	n	Geometric mean	n	Geometric mean
Storm overflow (53)	-	-	200	7.2×10^6
Primary (12)	127	1.0×10^7	14	4.6×10^6
Secondary (67)	864	3.3×10^5	184	5.0×10^5
Tertiary (UV) (8)	108	2.8×10^2	6	3.6×10^2

Data from Kay et al. (2008b).
n - number of samples.
Figures in brackets indicate the number of STWs sampled.

Table II.3: Summary statistics for final effluent testing data from the UV treated works, January 2007 to March 2011

Sewage works	No.	Geometric mean result (cfu/100ml)	Minimum	Maximum
Dawlish STW	94	693.9	7	76,000
Exeter (Countess Wear) STW	95	8.7	0	1,200
Exmouth STW	95	282.5	1	82,000
Kenton & Starcross STW	93	51.8	0	3,100

Data from the Environment Agency

Bacteriological testing results for the final effluent indicate that disinfection is generally effective, particularly for Exeter (Countess Wear) STW. Only Dawlish STW had a higher average concentration of faecal coliforms in its effluent than the average reported by Kay *et al* (2008b). The estimated (average) bacterial loading they generate is therefore very small, although the maximum recorded concentrations of faecal coliforms were over two orders of magnitude higher than the average. It must be noted that UV disinfection is less effective at eliminating viruses than bacteria (e.g. Tree et al, 1997).

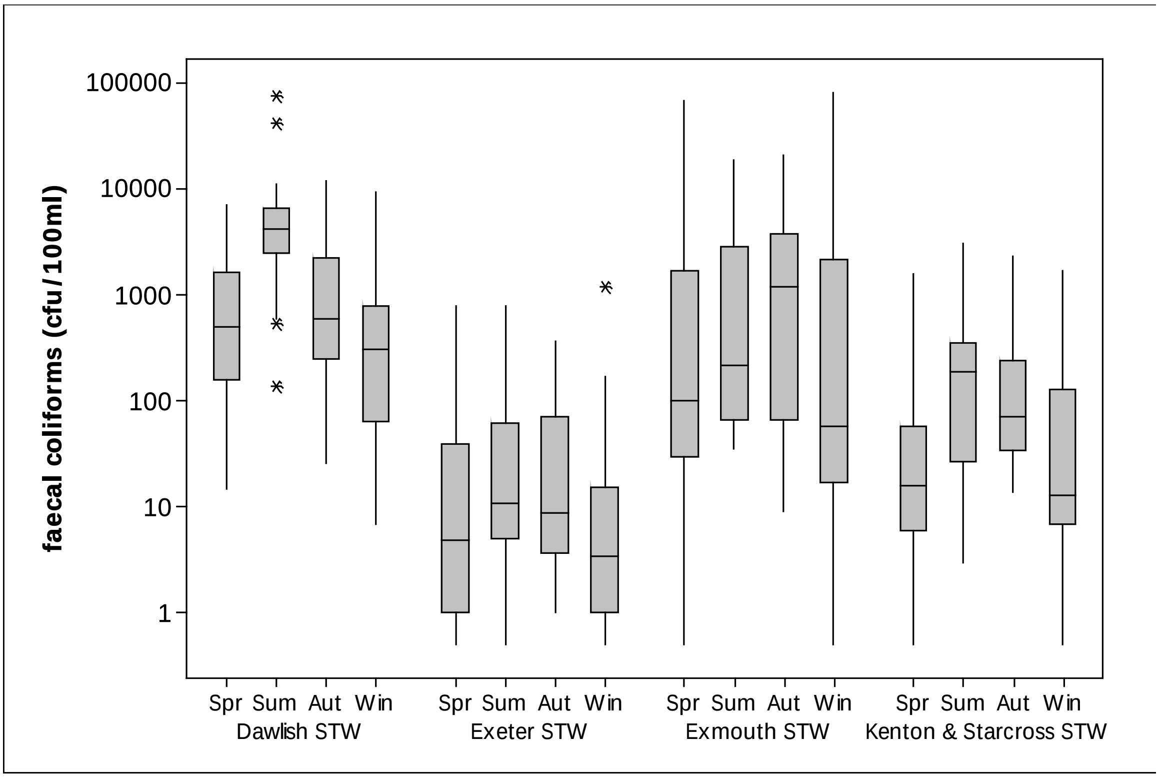

Figure II.2: Boxplot of faecal coliform concentrations in STW final effluent by season.
Data from the Environment Agency.

Some seasonality in final effluent faecal coliform concentrations was observed at all the UV treated works, with higher average results in the summer and autumn. This pattern was most marked at Dawlish STW.

In addition to the continuous sewage discharges, there are numerous intermittent discharges associated with the sewerage networks. The locations of these, and of private discharges within 2km of the Exe estuary are shown in Figure II.3.

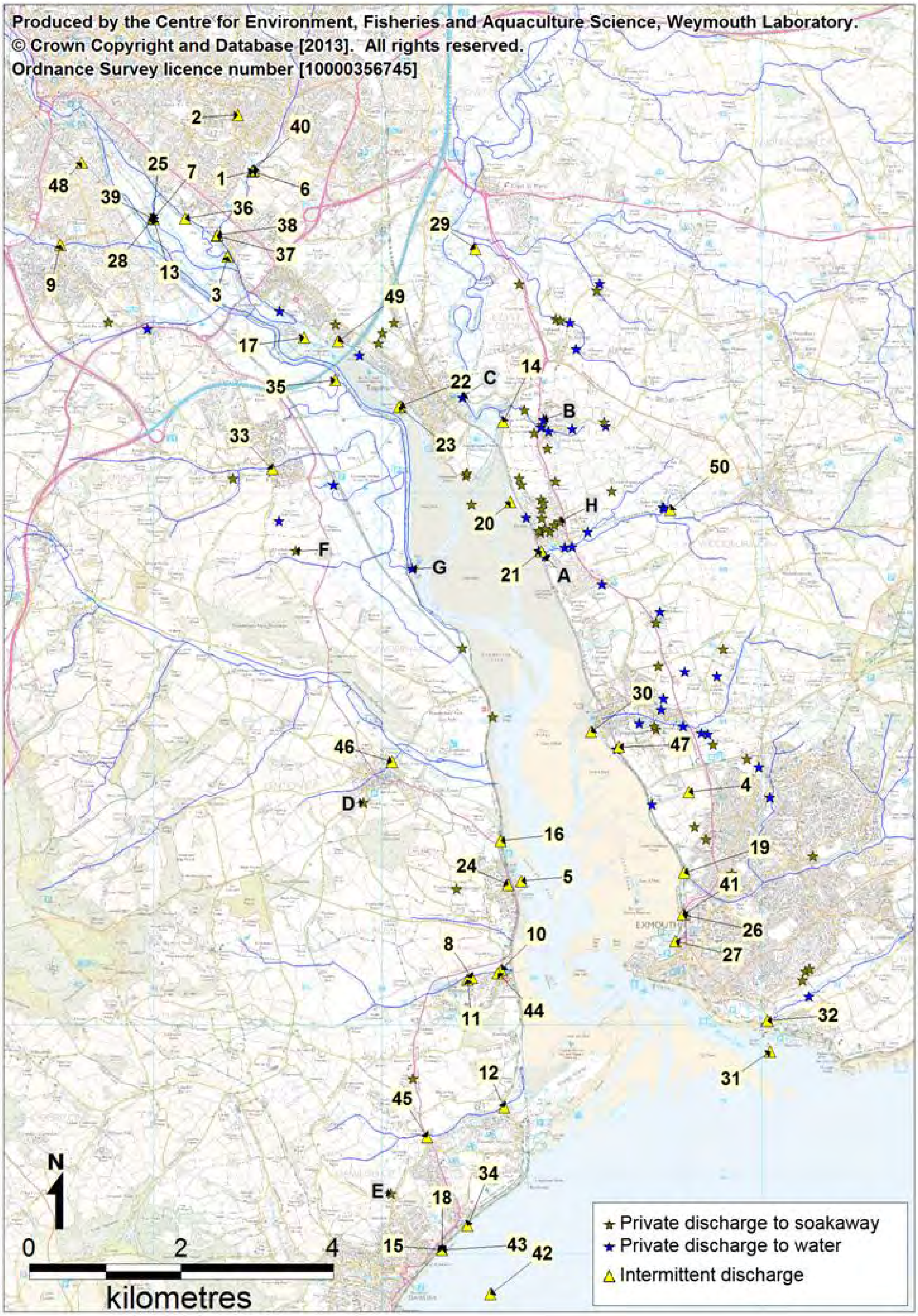

Figure II.3: Intermittent and private discharges within 2km of the estuary

Table II.4: Details of intermittent discharges within 2km of the Exe estuary

No.	Name (permit database)	Permit No.	NGR	Receiving water
1	2 Dryden Rd CSO	201910	SX9429991244	River Exe
2	21 Wonford ST CSO	201909	SX9410491977	River Exe
3	30 Mill Rd PSCSO/EO	201628	SX9397090122	River Exe
4	Ash Grove CSO	200127/CS/01	SY0003083070	Unnamed watercourse
5	Bonhay Rd CSO	202625	SX9783081900	Exe estuary
6	Burnthouse Lane CSO	202223	SX9429091240	Northbrooks
7	Church Rd (Jct Cecil Rd) CSO	201915	SX9299090613	River Exe
8	Church Rd CSO	201933	SX9718280629	Cofton Stream
9	Church Rd CSO	202628	SX9176390267	Alphin Brook
10	Cockwood PSEO	202629	SX9756680731	Cofton Stream
11	Cofton PSCSO/EO	202627	SX9711880605	Cofton Stream
12	Dawlish Warren Rd PS	202631	SX9760678925 & SX9760478924	Shutterton Brook
13	Dunsford Rd CSO	201932	SX9299090613	River Exe
14	Ebford PS	202365	SX9759087940	River Clyst
15	Elm Grove CSO	200825	SX9679077050	Lyme Bay
16	Exeleigh PSEO	201557	SX9756082430	River Exe
17	Exeter (Countess Wear) STW	202475	SX9479089240 & SX9497089050	Exe estuary
18	Exeter Rd CSO	200826	SX9679077050	Lyme Bay
19	Exeter Rd CSO Exmouth	200128/CS/01	SX9997082010	Withycombe Brook
20	Exton North PS	203229	SX9769086890	Exe estuary
21	Exton South PS	203230	SX9810086240	Exe estuary
22	Ferry Rd PSCSO/EO	201634	SX9624088142	River Exe
23	Follet Rd CSO	201636	SX9622088140	River Exe
24	Generals Lane PS	202633	SX9766081850	Unnamed watercourse
25	Guys Hylton PS	200242/PE/01	SX9298090620	Exe estuary
26	Hartopp Rd CSO	200122/CS/01	SX9996081460	Exe estuary
27	Imperial Rd Tank CSO	200123/CS/01	SX9986081110	Exe estuary
28	John Stoker School	201931	SX9299090613	River Exe

29	Langaton Lane CSO	201852	SX9723090220	Pin Brook
30	Lympstone Foreshore PSCSO/EO	202179	SX9874983863	Exe estuary
31	Maer PS & Tank CSO	200126/PC/01	SY0111079660	Lyme Bay
32	Maer Rd CSO Exmouth	200125/CS/01	SY0107080060	Littleham Brook
33	Main Road CSO	201779	SX9455687319	Bray Brook
34	Marina PSEO	201576	SX9712277366	Lyme Bay
35	Milbury Lane PS	201580	SX9538088490 & SX9483087960	White Gulf Dyke
36	Mill Race CSO	201896	SX9341090620	River Exe
37	Northbrook Golf Course Lower CSO	201897	SX9382090390	River Exe
38	Northbrook Golf Course Upper CSO	201914	SX9382890396	River Exe
39	Opp 125 Okehampton Rd CSO	201903	SX9298990614	River Exe
40	Parkland Drive PSCSO/EO	201632	SX9430391243	Unnamed Watercourse
41	Phaer Park PSEO/CSO	200124/PC/01	SX9996081460	Exe estuary
42	Sandy Lane PS	200898	SX9742076470	Lyme Bay
43	Sea Lawns Outfall CSO Dawlish	200828	SX9679077050	Lyme Bay
44	Ship Inn CSO	202630	SX9752580690	Cofton Stream
45	Shutterton Brook PS	202632	SX9658978535	Shutterton Brook
46	Slittercombe Lane PSCSO/EO	202626	SX9613083470	River Kenn
47	Sowden Lane PS	201329	SX9912083670	Unnamed watercourse
48	Tan Lane PSCSO/EO	201629	SX9204591353	River Exe
49	Topsham (Newport) PSEO	201631	SX9541688998	River Exe
50	Woodbury STW	202848	SX9979086780	Polly Brook

Data from the Environment Agency

For those without event monitoring it is difficult to assess their potential impacts aside from noting their location and potential to spill untreated sewage. For those with event monitoring some spill summary statistics covering the period January 2008 to March 2012 are shown in Table II.5

Table II.5: Summary of spill records from monitored intermittent discharges (number of events, duration of events (hrs) and percentage time active)

		Spring			Summer			Autumn			Winter			Total		
No.	Name	N	Hrs	%	N	Hrs	%	N	Hrs	%	N	Hrs	%	N	Hrs	%
4	Ash Grove CSO	1	0.1	<0.1%	1	0.6	<0.1%	4	5.8	0.1%	1	2.8	<0.1%	7	9.2	<0.1%
5	Bonhay Rd CSO	3	7.7	0.1%	1	7.3	0.1%	9	21.1	0.2%	14	90.1	0.9%	27	126.2	0.3%
9	Church Rd CSO	20	14.5	0.2%	11	13.3	0.2%	15	13.0	0.1%	9	2.8	<0.1%	55	43.6	0.1%
10	Cockwood PSEO	20	238.1	2.5%	37	444.4	5.0%	40	129.4	1.5%	43	428.7	4.2%	140	1240.5	3.3%
11	Cofton PSCSO/EO	2	18.9	0.2%	2	6.4	0.1%	5	7.5	0.1%	4	13.2	0.1%	13	46.0	0.1%
12	Dawlish Warren Rd PS	35	20.0	0.2%	24	30.2	0.3%	26	52.9	0.6%	63	61.3	0.6%	148	164.3	0.4%
17	Exeter (Countess Wear) STW	31	89.9	0.9%	32	92.7	1.0%	45	156.2	1.8%	59	382.4	3.8%	167	721.2	1.9%
19	Exeter Rd CSO Exmouth	2	0.8	<0.1%	6	2.2	<0.1%	5	6.2	0.1%	6	10.1	0.1%	19	19.2	0.1%
26	Hartopp Rd CSO	1	3.3	<0.1%	6	14.5	0.2%	1	0.7	<0.1%	0	-	-	8	18.5	<0.1%
27	Imperial Rd Tank CSO	0	-	-	0	-	-	2	12.8	0.1%	0	-	-	2	12.8	<0.1%
32	Maer Rd CSO Exmouth	0	-	-	2	10.2	0.1%	14	134.0	1.5%	12	148.4	1.5%	28	292.5	0.8%
41	Phaer Park PSEO/CSO	1	1.5	<0.1%	4	40.8	0.5%	3	54.8	0.6%	0	-	-	8	97.1	0.3%
44	Ship Inn CSO	4	9.2	0.1%	7	5.1	0.1%	11	4.8	0.1%	5	1.4	0.0%	27	20.6	0.1%
45	Shutterton Brook PS	2	0.7	<0.1%	2	3.8	<0.1%	2	3.1	<0.1%	0	-	-	6	7.6	<0.1%
46	Slittercombe Lane PSCSO/EO	4	3.2	<0.1%	1	6.8	0.1%	1	1.1	<0.1%	2	4.7	0.0%	8	15.7	<0.1%

Data from the Environment Agency

All but two of the monitored intermittent discharges spilled for less than 1% of the time, and generally considerably less. The overflow at the Exeter (Countess Wear) STW spilled for 1.9% of the period considered, mainly during the winter. The impacts of this will be felt via the main riverine input. The Cockwood PSEO spilled for 3.3% of the period. This will be the most significant monitored outfall in terms of impacts on shellfisheries as not only did it spill the most, but it discharges to a stream which in turn discharges in very close proximity to some shellfish resources.

Although the vast majority of the survey area is served by water company sewerage infrastructure, there are also some private discharges in the area. Where specified, these are generally treated by small treatment works such as package plants. The majority of these are small, serving one or a small number of properties. Most of these within 2km of the estuary lie on the eastern shore. Details of the larger private discharges (>5m^3/day maximum permitted flow) are presented in Table II.6.

Table II.6: Details of private sewage discharges of over 5m^3/day

Ref.	Property served	Location	Treatment type	Max. daily flow (m^3/day)	Receiving environment
A	Commando training centre	SX9814086180	Biological filtration	375	Exton Brook
B	Ebford House Hotel	SX9812087970	Unspecified	5	Ebford Brook trib.
C	Fisher Bridge Mill	SX9705088270	Package plant	5.6	River Clyst
D	Oakdene Court	SX9575082930	Unspecified	5	Soakaway
E	Gatehouse Farm cottages	SX9611577787	Package plant	12	Soakaway
F	The Barns (Crablake Farm)	SX9486086250	Septic tank	5	Soakaway
G	The Turf Hotel	SX9639386013	Septic tanks	12	Exe estuary
H	Warren House	SX9834086630	Package plant	5	Soakaway

Data from the Environment Agency.

Those discharging to soakaway should be of no significance, assuming they are functioning properly. Wooton Brook and Exton Brook both receive several private discharges, and this will contribute to the bacterial load carried by these watercourses. The Commando training centre sewage plant, which provides secondary treatment and discharges to Exton Brook is by far the most significant of these in terms of volumes discharged and the bacterial loading it will generate. Neither the Exton Brook or the Wooton Brook discharge to the estuary near any commercial shellfish beds. The Turf Hotel discharges direct to the estuary on the west bank about 2km upstream of the shellfisheries.

Appendix III. Sources and Variation of Microbiological Pollution: Agriculture

The majority of land within the Exe catchment is used for agriculture. Of this, most is pasture, although there is a belt of arable land just north of Exeter, and much of the farmland adjacent to the estuary is also in crop production (Figure 1.2). Table III.1 presents livestock numbers and densities for the catchments draining to the estuary. This data was provided by Defra and is based on the 2010 census. Geographic assignment of animal counts in this dataset is based on the allocation of a single point to each farm, whereas in reality an individual farm may span the catchment boundary. Nevertheless, the data should give a reasonable indication of numbers of livestock within the catchment.

Table III.1 Livestock numbers and densities in the Exe catchment

Cattle		Sheep		Pigs		Poultry	
No.	Density (no/km^2)	No.	Density (no/km^2)	No.	Density (no/km^2)	No.	Density (no/km^2)
125,045	85	302,595	205	39,597	27	3,315,432	2242

Data from Defra

The concentration of faecal coliforms excreted in the faeces of animal and humans and corresponding loads per day are summarised in Table III.2.

Table III.2: Levels of faecal coliforms and corresponding loads excreted in the faeces of warm-blooded animals.

Farm Animal	Faecal coliforms (No. g^{-1} wet weight)	Excretion rate (g day^{-1} wet weight)	Faecal coliform load (No. day^{-1})
Chicken	1,300,000	182	2.3×10^8
Pig	3,300,000	2,700	8.9×10^8
Human	13,000,000	150	1.9×10^9
Cow	230,000	23,600	5.4×10^9
Sheep	16,000,000	1,130	1.8×10^{10}

Data from Geldreich (1978) and Ashbolt et al. (2001).

There are significant numbers of grazing animals within the catchment area. Diffuse inputs associated with grazing livestock are therefore anticipated via direct deposition on pastures. Slurry is also collected from livestock sheds when cattle are housed indoors and subsequently applied to fields as fertilizer. Pigs and poultry are also present in significant numbers. Manure from pig and poultry operations is typically collected, stored and spread on nearby farm land (Defra, 2009). Sewage sludge may also be used as fertilizer, but no information on local practices was available at the time of writing.

The primary mechanism for mobilisation of faecal matter deposited or spread on farmland to coastal waters is via land runoff, so fluxes of livestock related contamination into the estuary will be highly rainfall dependent. Peak concentrations of faecal indicator bacteria in watercourses are likely to arise when heavy rain follows a significant dry period (the ‘first flush’). It is likely that most, if not all of the main watercourses will be impacted to some extent by agriculture. Runoff from the majority of the catchment area enters the estuary upstream of the fisheries. Higher impacts may therefore be anticipated towards the up-estuary ends of the shellfish beds on this basis, although there are some significant streams feeding into the lower estuary which will also carry some agricultural contamination. No livestock were recorded on pastures adjacent to the estuary during the shoreline survey, although the fields behind the shoreline were obscured from the surveyors view throughout much of the survey.

There is likely to be seasonality in levels of contamination originating from livestock. Numbers of sheep and cattle will increase significantly in the spring, with the birth of lambs and calves, and decrease in the autumn when animals are sent to market. During winter, cattle may be transferred from pastures to indoor sheds, and at these times slurry will be collected and stored for later application to fields. Timing of these applications is uncertain, although farms without large storage capacities are likely to spread during the winter and spring. Poultry/pig manure and sewage sludge may be spread at any time of the year. Therefore peak levels of contamination from sheep and cattle may arise following high rainfall events in the summer, particularly if these have been preceded by a dry period which would allow a build up of faecal material on pastures, or on a more localised basis if wet weather follows a slurry application which is more likely in winter or spring.

Appendix IV. Sources and Variation of Microbiological Pollution: Boats

The discharge of sewage from boats is potentially a significant source of bacterial contamination of shellfisheries within the Exe estuary. There is substantial boat traffic within the Exe, consisting mainly of recreational craft. Figure IV.1 presents an overview of boating activity derived from the shoreline survey, satellite images and various internet sources.

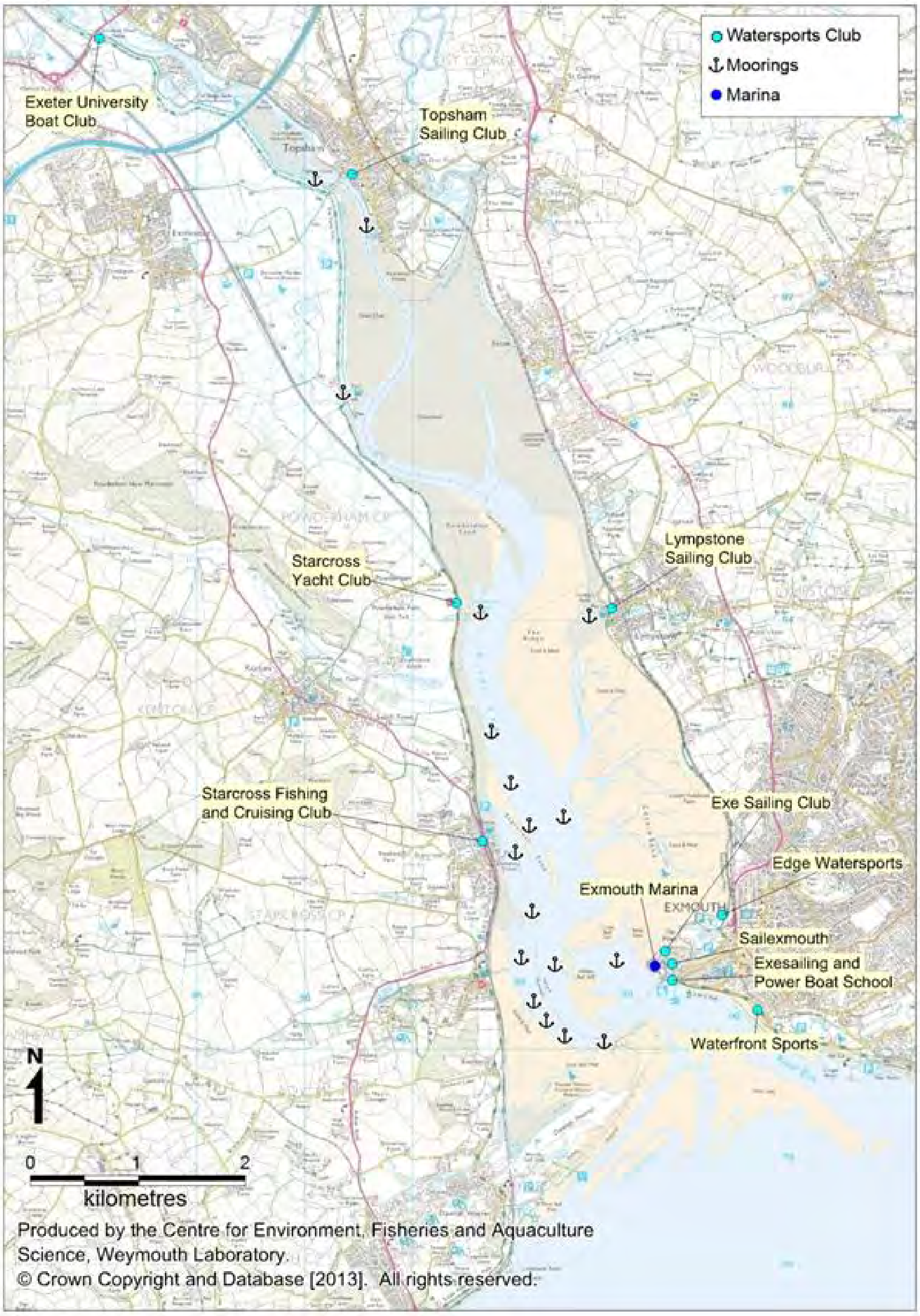

Figure IV.1: Boating activity within the Exe Estuary

Recreational boating is popular within the estuary; there are approximately 1,800 moorings which are predominantly located in the lower estuary (Exe Estuary Management Partnership, 2012). Between 80-90% of boats moored in the Exe will be in the water between April until October/November (Liley et. al, 2011) at which point they are removed for overwintering. The Exmouth Marina, at the mouth of the estuary holds 200 berths (Exmouth Marina, 2013) and no sewage pump out facilities are available here.

There are several sailing and watersports centres surrounding the Exe which offer a range of watersports including sailing, motor boating, kite surfing, windsurfing, water skiing, rowing and kayaking. These smaller recreational boats are not large enough to contain onboard toilet facilities however, and are therefore unlikely to make overboard discharges. There is a small fishing fleet of around 10 vessels that operate out of the Exe estuary, and several charter boats can be hired for both fishing and cruising (Liley et.al, 2011). A small passenger ferry also runs daily between Exmouth and Starcross. There are no commercial ports within the Exe.

Private vessels such as yachts, motor cruisers and fishing vessels of a sufficient size are likely to make overboard discharges from time to time. This may either occur when the boats are moored or at anchor, particularly if they are in overnight occupation, or while they are navigating through the relative calm of the estuary. The areas that are at highest risk from microbiological pollution therefore include the mooring areas for larger private vessels (in the lower estuary) and the main navigation routes through the estuary. Peak pleasure craft activity is anticipated during the summer, so associated impacts are likely to follow this seasonal pattern. It is difficult to be more specific about the potential impacts from boats and how they may affect the sampling plan without any firm information about the locations, timings and volumes of such discharges.

Appendix V. Sources and Variation of Microbiological Pollution: Wildlife

The Exe estuary features a variety of estuarine habitats, of which approximately 60% are intertidal mudflats (Futurecoast, 2002). It also contains saltmarsh, eel grass, reed beds and sand dunes (Exe Estuary Management Partnership, 2012). These habitats attract significant populations of birds and other wildlife. Consequently the entire estuary has been designated as a Special Site of Scientific Interest (SSSI), Ramsar site and a Special Protection Area (SPA). Dawlish Warren spit on the western edge of the mouth has been designated as a National Nature Reserve (NNR), Special Area of Conservation (SAC) and a Local Nature Reserve (LNR). There is also a small LNR at Exmouth.

The most significant wildlife aggregation in terms of shellfish hygiene is likely to be overwintering waterbirds (waders and wildfowl). Studies in the UK have found significant concentrations of microbiological contaminants (thermophilic Campylobacter, salmonellae, faecal coliforms and faecal streptococci) from intertidal sediment samples supporting large communities of birds (Obiri-Danso and Jones, 2000). The estuary supports internationally and nationally important species of waterbird including Dark-bellied brent geese, Pied avocet, Grey plover, Dunlin, Black-tailed godwit and Slavonian grebe (Natural England, 2012). An average total count of 19,000 waterbirds (wildfowl and waders) was reported over five winters up to 2010/11 for the Exe (Holt *et al*, 2012). A study undertaken by Austin et.al, 2008 revealed that at low tide avocet and Dunlin frequented the northern reaches of the estuary in particular on the mudflats of Powderham Sand and north of Lympstone whereas the little egret was distributed more widely throughout the estuary. At high tide large numbers of birds tend to aggregate at Dawlish Warren, Bowling Green Marsh and Exminster Marshes (Liley et al, 2011).

Geese and ducks will mainly frequent the grassland and saltmarsh, where their faeces will be carried into coastal waters via runoff into tidal creeks or through tidal inundation. Therefore RMPs within or near to the drainage channels from saltmarsh areas will be best located to capture contamination from this source. Waders, such as dunlin and oystercatchers forage upon shellfish and so will forage (and defecate) directly on any shellfish beds on the intertidal. They may tend to aggregate in certain areas holding the highest densities of bivalves of their preferred size and species, but this will probably vary from year to year. Contamination via direct deposition may be patchy, with some shellfish containing high levels of *E. coli* while others a short distance away are unaffected. At high tide waders are likely to frequent the saltmarsh and the perimeter of the estuary. Due to the diffuse and spatially unpredictable nature of contamination from wading birds it is difficult to select specific RMP locations to best capture this, although they may well be a significant influence during the winter months.

Birds such as gulls and terns and relatively small numbers of waders remain in the area to breed in the summer, but the majority migrate elsewhere outside of the winter months. Bird numbers and potential impacts on the hygiene status of the fisheries are therefore much lower during the summer. The JNCC Seabird 2000 census recorded a total of 86 pairs of herring gulls and Great Black-backed gulls primarily within the lower estuary (Mitchell et al, 2004). Seabirds are likely to forage widely throughout the area so inputs could be considered as diffuse, but are likely to be most concentrated in the immediate vicinity of the nest sites. Their faeces will be carried into coastal waters via runoff from their nesting sites or via direct deposition to the adjacent intertidal.

Otters have been sighted around the Exe estuary, but exact numbers are not known (Devon Mammal Group, 2012) and are likely to be small. Otters generally tend to favour the more secluded areas with access to watercourses. However, given their likely wide distribution and small numbers they have no material bearing on the sampling plan.

There are no major seal colonies in the vicinity of the Exe estuary, with the closest significant colony in the Solent (SCOS, 2012). Whilst they may occasionally visit the estuary, they will not be a significant source of contamination to the shellfishery. No other wildlife species which may have a bearing on the sampling plan have been identified.

Appendix VI. Meteorological Data: Rainfall

The Exminster House weather station, by the head of the Exe estuary, received an average of 801 mm per year between 2003 and 2011. Figure VI.1 presents a boxplot of daily rainfall records by month at this rainfall gauge.

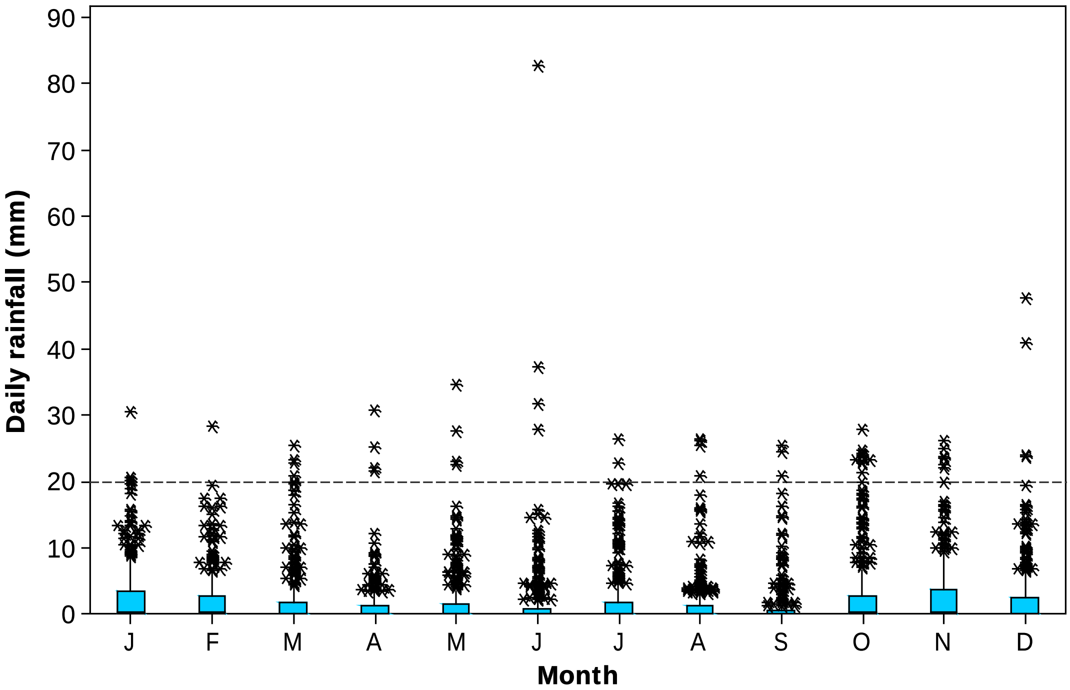

Figure VI.1: Boxplot of daily rainfall totals at Exminster House, January 2003 to December 2011.
Data from the Environment Agency

Rainfall records from here, which is representative of conditions in the vicinity of the shellfish beds indicate relatively low seasonal variation in average rainfall. Rainfall was lowest on average in September and highest on average in October and November. Daily totals of over 20mm were recorded on 1.6% of days and 51% of days were dry. Further inland, in the upper catchment where elevations are higher, the average annual rainfall increases progressively to the extent that rainfalls on Exmoor are about double that experienced at Exminster (NERC, 2013).

Rainfall may lead to the discharge of raw or partially treated sewage from combined sewer overflows (CSO) and other intermittent discharges as well as runoff from faecally contaminated land (Younger *et al*., 2003). Representative monitoring points located in parts of shellfish beds closest to rainfall dependent discharges and freshwater inputs will reflect the combined effect of rainfall on the contribution of individual pollution sources. Relationships between levels of *E. coli* and faecal coliforms in shellfish and water samples and recent rainfall are investigated in detail in Appendix XI and Appendix XII.

Appendix VII. Meteorological Data: Wind

South-west England is one of the more exposed areas of the UK, with wind speeds on average only greater in western Scotland. The strongest winds are associated with the passage of deep depressions close to or across the British Isles. The frequency and strength of depressions is greatest in the winter half of the year and this is when mean speeds and gusts are strongest. (Met Office, 2012).

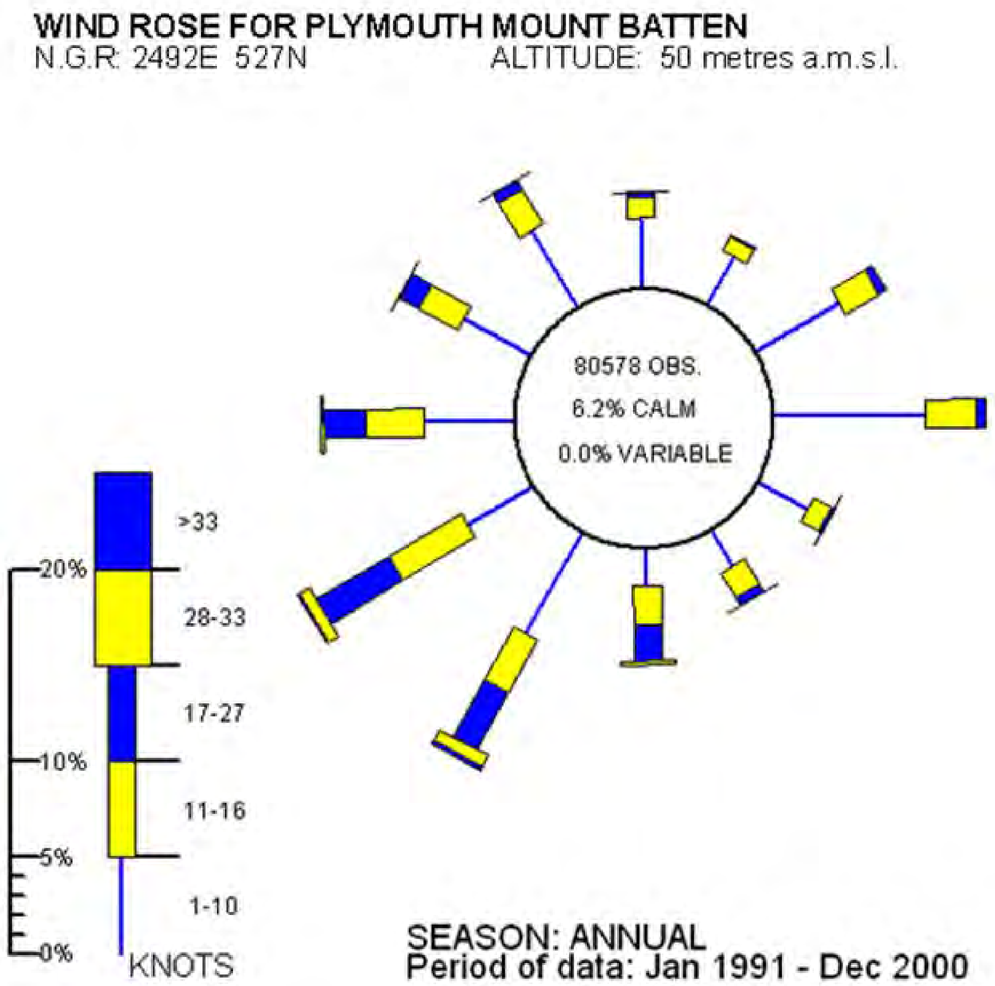

Figure VII.1: Wind Rose for Plymouth, Mount Batten.
Produced by the Meteorological Office. Contains public sector information licensed under the Open Government Licence v1.0

The wind rose illustrates the typical frequency of speed and direction throughout a year and confirms a prevailing south westerly wind. The Exe has a narrow mouth that faces south east into Lyme Bay which is constricted by spits and sheltered by the western side of Lyme Bay (Langston *et al*, 2003). The land surrounding the estuary generally consists of low hills, which will offer some shelter from the prevailing winds. The topography will tend to funnel winds up or down the estuary.

Appendix VIII. Hydrometric Data: Freshwater Inputs

The Exe estuary has a hydrological catchment of 1,500 km² (Environment Agency, 2009) within which the principle land cover is pasture, with some cultivated land and built up areas. Around 90% of the catchment is drained by watercourses that enter the estuary around its head, principally the Exe and its tributaries, and also the River Clyst. There are several smaller but nevertheless potentially significant watercourses draining to the shore of the estuary at various locations. The largest of these by a considerable margin is the River Kenn. The majority of land runoff therefore enters the estuary upstream of the fisheries, so an underlying gradient of decreasing runoff related levels of indicator bacteria is anticipated from the head of the estuary down to the mouth. The smaller watercourses entering the estuary in the vicinity of the fisheries range from small surface water outfalls to minor rivers and will be of more localised significance but may cause hotspots of contamination where they enter the estuary.

The geology within the catchment is variable, but generally of low permeability. Exmoor National Park in the upper reaches of the catchment is underlain predominantly with siltstones, shale and sandstones, and the lower catchment is predominantly a combination of mudstones, sandstones and breccias (Environment Agency, 2009). The low permeability will result in a rapid response to rainfall, particularly in the upper reaches of the catchment. The river Exe has significant floodplains bordering its lower reaches which will buffer flows to some extend during flood events.

Figure VIII.1: Freshwater inputs to the Exe estuary

There are fixed flow gauging stations on the Exe, the Creedy, the Culm and the Clyst. Table VIII.1 presents summary statistics from these stations.

Table VIII.1 Summary flow statistics for four gauging stations on the river Exe and tributaries

Watercourse	Station Name	Catchment Area (Km²)	Mean Annual Rainfall 1961-1990 (mm)	Mean Flow (m^3s^{-1})	Q95[1] (m^3s^{-1})	Q10[2] (m^3s^{-1})
Exe	Thorverton	600.9	1248	15.956	2.180	36.600
Culm	Woodmill	226.1	971	3.788	1.070	7.866
Creedy	Cowley	261.6	910	3.416	0.312	8.226
Clyst	Withy Bridge	-	-	0.691	0.060	1.560

[1]Q95 is the flow that is exceeded 95% of the time (i.e. low flow). [2]Q10 is the flow that is exceeded 10% of the time (i.e. high flow).

Data from Centre for Ecology and Hydrology and Environment Agency

As these are located some distance from the tidal limits the actual volumes of runoff delivered to the estuary will be higher than that measured at the gauging stations. Sherwin and Torres (2001) report mean daily flows of 25.5m^3/sec for the Exe (downstream of where the Culm and Creedy join it) and 1.27m^3/sec for the Clyst. They also report a mean daily flow of 0.52m^3/sec for the River Kenn, indicating that this watercourse is of a significant size. Boxplots showing mean daily flow records by month for individual fixed gauging stations are presented in Figure VIII.2 to Figure VIII.5.

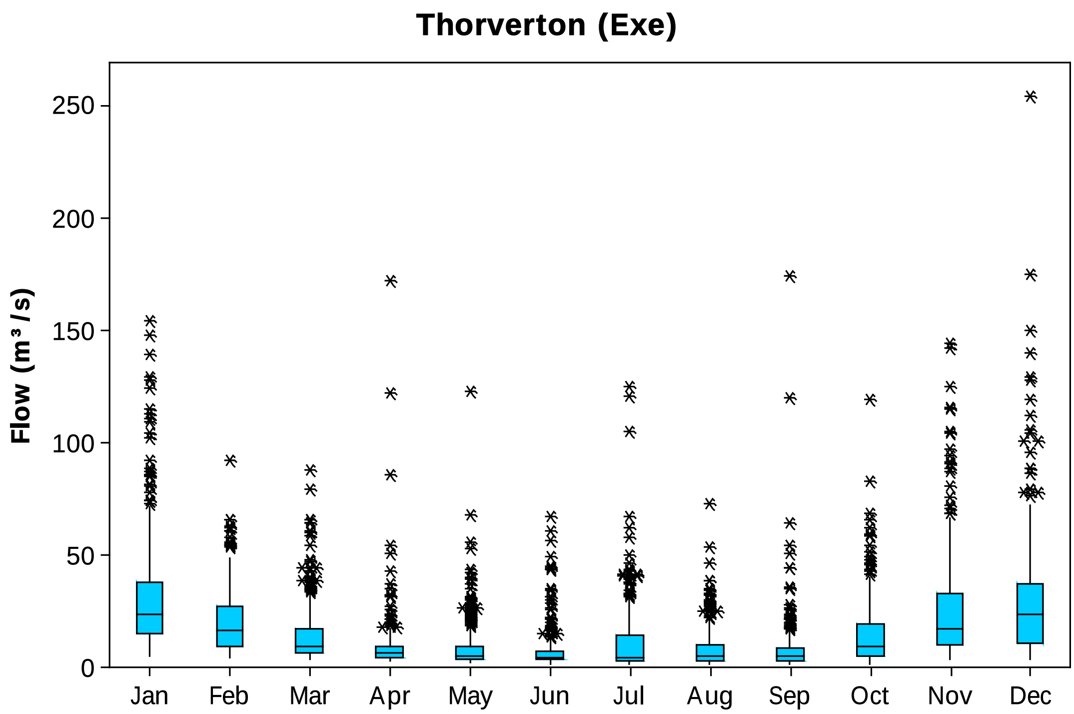

Figure VIII.2: Boxplots of mean daily flow records from the Thorverton gauging station on the Exe (2003 - 2013)

Data from the Environment Agency

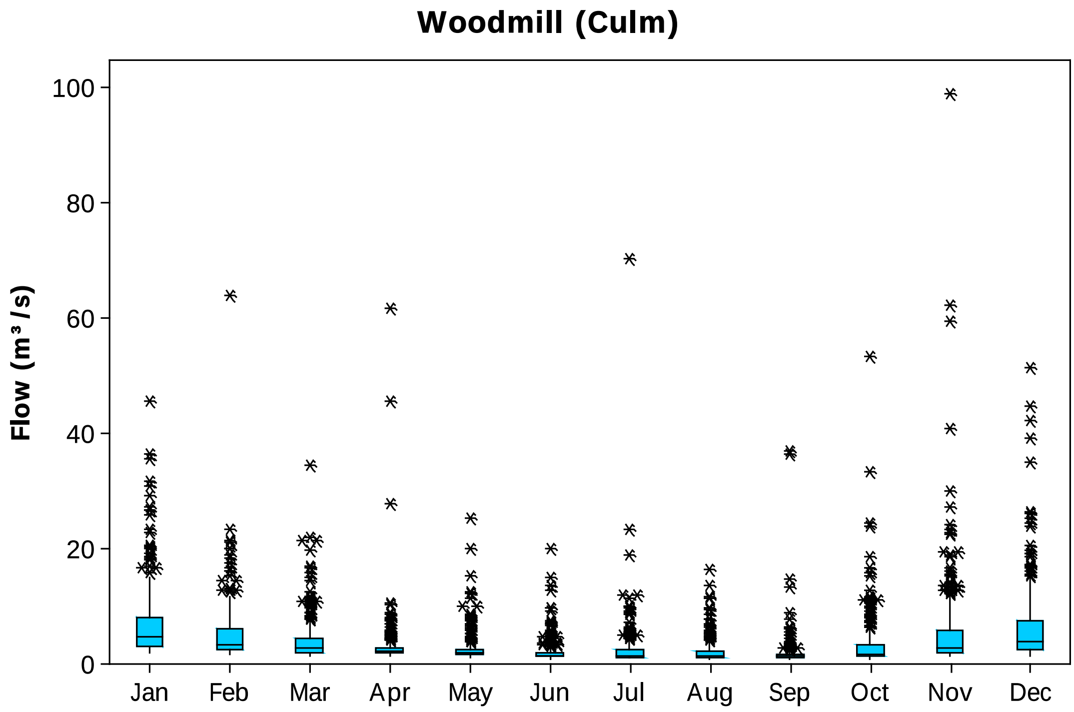

Figure VIII.3: Boxplots of mean daily flow records from the Woodmill gauging station on the Culm (2003 - 2013)

Data from the Environment Agency

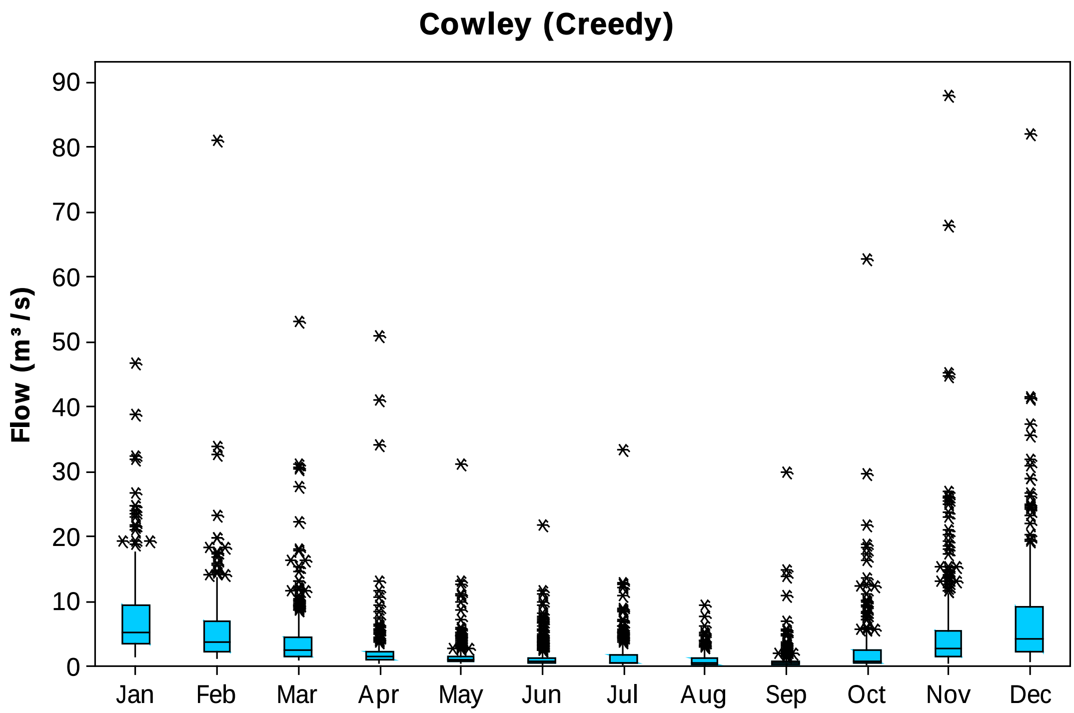

Figure VIII.4: Boxplots of mean daily flow records from the Cowley gauging station on the Creedy (2003 - 2013)

Data from the Environment Agency

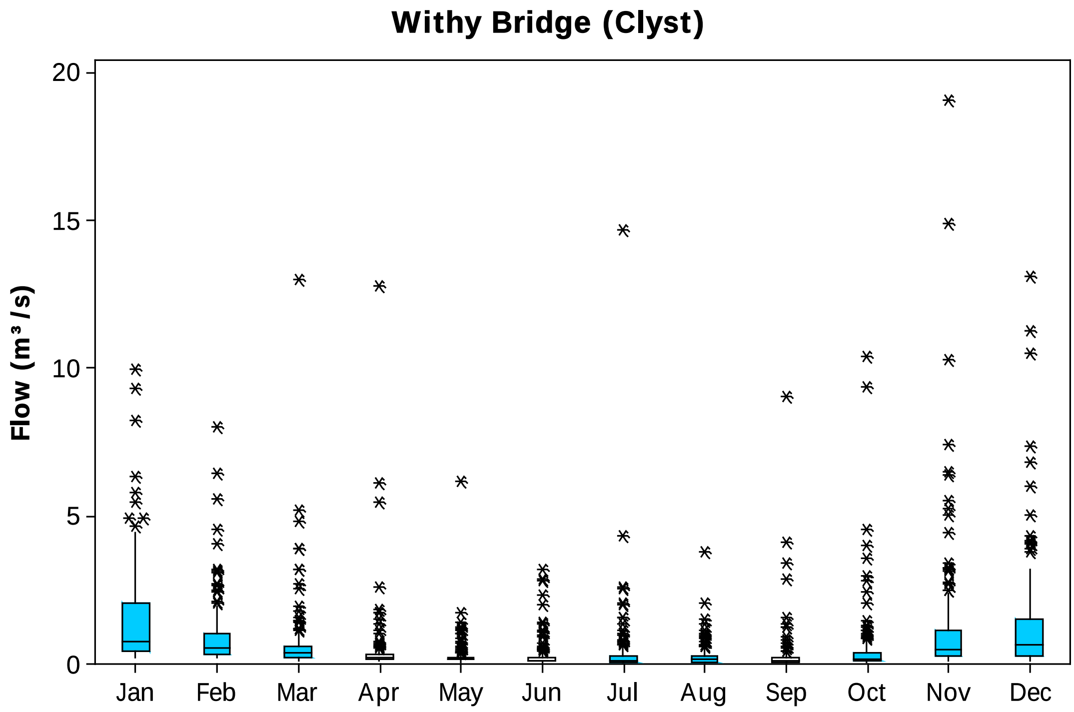

Figure VIII.5: Boxplots of mean daily flow records from the Withy Bridge gauging station on the Clyst (2008 - 2013)
Data from the Environment Agency

There is a strong seasonal pattern at all four river gauges, with higher average flows during the colder months of the year. High flow events have however been recorded during most months of the year. The seasonal pattern of flows is not entirely dependent on rainfall as during the colder months there is less evaporation and transpiration, leading to a higher water table. This in turn leads to a greater level of runoff immediately after rainfall. Increased levels of runoff are likely to result in an increase in the amount of microorganisms carried into coastal waters. Additionally, higher runoff will decrease residence time in rivers, allowing contamination from more distant sources to have an increased impact during high flow events.

During the shoreline survey, which was conducted under dry conditions, watercourses which could be safely accessed were sampled for *E. coli* and spot flow measurements were made, allowing an estimate of the *E. coli* loading each was delivering at the time to be made. The results are presented in Table VIII.2 and Figure VIII.6

Table VIII.2 *E. coli* sample results, measured discharge and calculated *E. coli* Loadings

Name	Flow (m^3/s)	*E. coli* concentration (CFU/100 ml)	*E. coli* loading (CFU/day)
Shutterton Brook	0.06	1300	7.16×10^{10}
Staplake Brook	0.02	550	9.55×10^{9}
River Kenn	2.22	610	1.17×10^{12}
Withycombe Brook	0.07	4000	2.30×10^{11}
Stream at West Lodge	0.004	900	3.25×10^{9}
Wootton Brook	0.04	41000	1.31×10^{12}

Figure VIII.6: Measured stream loadings from the shoreline survey

The largest watercourse discharging in the immediate vicinity of the shellfisheries in terms of volumes was the River Kenn, by a considerable margin. The Wootton Brook carried high levels of *E. coli*, and so also delivered a relatively large bacterial loading to the estuary. The Withycombe discharges to the shore adjacent to cockle sands. Just to the south of Staplake Brook, a stream discharges to the Cockwood Harbour which was not sampled or measured as the survey path did not cross it. Finally, the Littleham Brook discharges to the Beach at Exmouth, via a piped outfall at Maer Rock. This outfall pipe was covered by the tide at the time this area was surveyed and so could not be accessed. All these watercourses are likely to produce localised hotspots of contamination, particularly within any drainage channels they follow across the intertidal, where relatively high concentrations of indicator bacteria may arise at lower states of the tide.

Appendix IX. Hydrography

IX.1. Bathymetry

The Exe estuary is a narrow funnel shaped estuary of about 15 km in length from its mouth to its tidal limit (Langston *et al*, 2003) which covers an area of around 18km^2. A large sand spit and sand dunes of Dawlish Warren protruding from the west bank constricts the mouth to about 350m in width. The spit on the eastern side of the estuary has now been built upon. The estuary has a narrow approach channel, and large ebb and flood tide deltas. The relatively narrow mouth will accelerate tidal flows through it and has been scoured to a depth of 13m below chart datum, the deepest point in the estuary. Inside the mouth the estuary widens to up to 1-2km, and its main body is characterised by extensive intertidal areas bisected by a subtidal river channel. Its relatively shallow nature and the high proportion of its area which is intertidal (59%) will promote exchange of water, but limit the dilution potential away from the main channel. The main river channel runs close to the west shore through the lower reaches of the estuary and becomes more meandering in the middle to upper reaches It also becomes progressively narrower and shallower in the upper reaches, where it is generally less than 1m deep relative to chart datum.. A secondary channel carrying the River Clyst splits from the main channel in the middle reaches. Other smaller watercourses have also cut drainage channels across the intertidal in various locations, and these generally run perpendicular to the main river channel. The upper reaches narrow at Topsham and at its tidal limit it consists only of a narrow river channel. Intertidal sediments are generally sandy with gravel and shell in the outer reaches, becoming muddier towards the head (Futurecoast, 2002).

Most of the perimeter of the estuary is protected by railway embankments on both the east and west shore, with sea walls protecting urban areas such as Exmouth and Lympstone. The estuary is flanked by strips of saltmarsh in some places but these are not particularly extensive. The approach channel to Exmouth Docks is maintained by dredging (Futurecoast, 2002).

Figure IX.1: Bathymetry of the Exe estuary

IX.2. Tides and Currents

Currents in coastal waters are predominantly driven by a combination of tide, wind and freshwater inputs. The Exe estuary is macro-tidal and expresses a semi diurnal cycle with an average tidal range on spring tides of 3.8m at Exmouth Dock (Table IX.1).

Table IX.1: Tide Levels and ranges within the Exe estuary

	Height above chart datum (m)				Range (m)	
Port	**MHWS**	**MHWN**	**MLWN**	**MLWS**	**Spring**	**Neap**
Exmouth Approaches	4.60	3.40	1.70	0.50	4.10	1.70
Exmouth Dock	4.00	2.80	1.30	0.20	3.80	1.50
Starcross	4.10	2.90	1.40	0.70	3.40	1.50
Topsham	4.80	-	2.80	-	-	-

Data from the Proudman Oceanographic Laboratory

Within the English Channel, tides flood in an easterly direction and ebb in a westerly direction. Tidal stream atlases do not indicate the presence of large scale eddies within Lyme Bay. Therefore, contamination from sources discharging to the shore to the west of the estuary may be carried in on the flood tide, but sources to the east will be carried past the estuary mouth rather than into the estuary as the tide ebbs. Table IX.2 presents the direction and rate of tidal streams at a station within the approach channel (Figure IX.2) at hourly intervals before and after high water.

Table IX.2: Tidal Stream Predictions for Exmouth Approaches

Time before /after high water	Direction (°)	Rate (m/s)	
		Spring	**Neap**
HW-6	133	1.0	0.5
HW-5	303	0.5	0.2
HW-4	303	1.0	0.5
HW-3	303	1.0	0.5
HW-2	304	1.3	0.6
HW-1	315	1.3	0.6
HW	313	0.9	0.4
HW+1	-	0.0	0.0
HW+2	116	0.4	0.2
HW+3	120	1.1	0.5
HW+4	128	1.6	0.7
HW+5	132	1.7	0.8
HW+6	131	1.3	0.6
Excursion Km (flood)		21.5	9.6
Excursion Km (ebb)		25.7	11.7

Data from Admiralty Chart 2290

The tidal diamond shows a clear bi-directional pattern of tidal streams, with water moving up the channel on the flood, and back down on the ebb. Currents here are very strong, peaking at 1.7m/s during the later stages of the ebb. There is some tidal asymmetry, with a shorter duration, faster flowing ebb tide. The tidal excursion (the distance water travels during the course of a flood or ebb tide) based on this diamond is in the order of 20-25km on spring tides and just under half that on neap tides. However, the constricted channel at the mouth and approaches will experience the fastest tidal streams, so these will be significant overestimates.

Sherwin and Torres (2001) reported the results of fixed current meter deployments undertaken during spring tides. Peak flood and ebb vectors are presented in Figure IX.2.

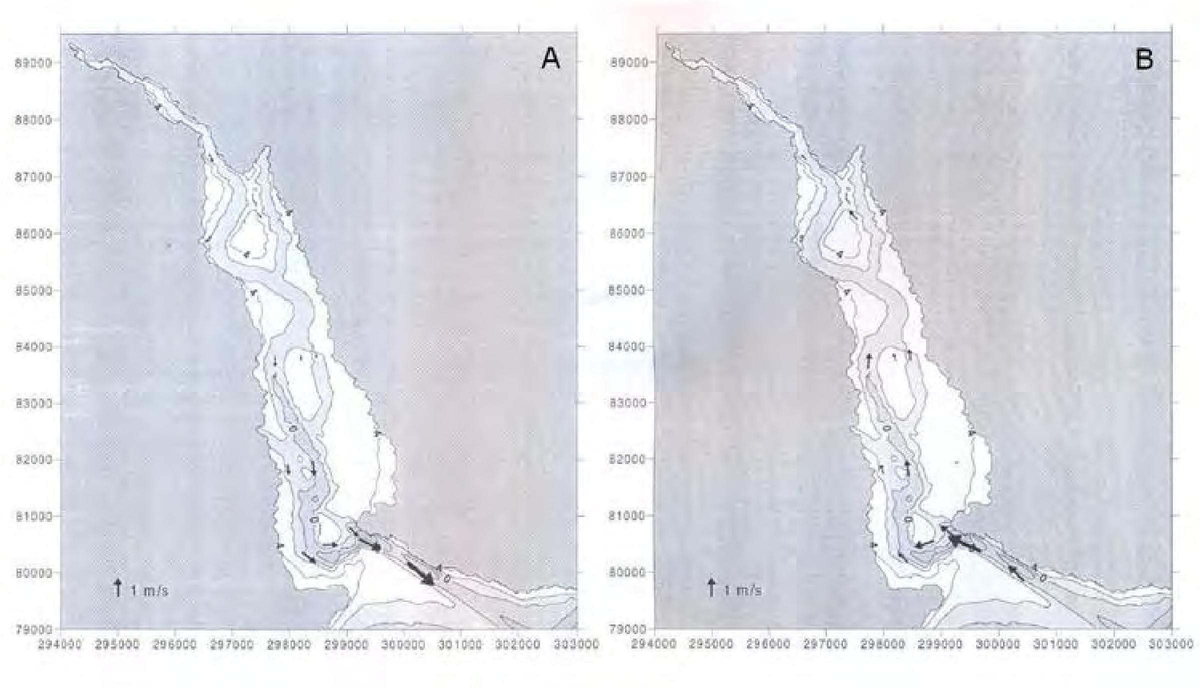

Figure IX.2: Maximum ebb and flood tide currents in the Exe Estuary.
Currents measured on several spring tides in August 1987.
Reproduced from Sherwin and Torres (2001) under permission of the first author.

Figure IX.2 indicates that currents become progressively slower towards the head of the estuary and over the intertidal areas away from the main channels. It also gives the impression that during the flood tide more water passes through the channel running past Exmounth and north of Bull Hill Bank, whereas on the ebb more water passes through the channel to the south of Bull Hill Bank. Such an effect is not apparent further up the estuary. The peak current velocities recorded in the main body of the estuary (between 0.5 and 1m/s) would translate to a tidal excursion in the very approximate order of 6-12km, and around half that on neap tides. Contamination released at the head of the estuary will therefore not be carried to the mouth of the estuary during the course of a single ebb tide. On the larger tides, particles released at Exeter at high water may travel as far as Cockwood, but on neap tides they may not even reach Powderham before the tide reverses.

Advection of pollutants by tidal currents is likely to be the main mode of contaminant transport in the Exe estuary. The flood tide will convey relatively clean water originating from the English Channel into the estuary, whereas the ebb tide will carry contamination from shoreline sources out through the estuary. During the flood, the principal tidal stream flows up the main channel(s). As water levels rise, water will spread out across the intertidal. Exact circulation patterns are likely to be complex and current velocities are lower in these shallower areas. The reverse will occur on the ebb tide. Consequently, shoreline sources of contamination will primarily impact up and downstream of their locations along the bank to which they discharge. Around low tide contamination from shoreline sources such as streams will be carried through drainage channels where the dilution potential is low, until reaching the main deeper channels.

In addition to tidally driven currents, are the effects of freshwater inputs and wind. The flow ratio (freshwater input:tidal exchange) is reported as 0.047 (average) and 0.741 (maximum) suggesting that it is partially mixed at low flows but an ebb plume is likely when river discharge is high (Futurecoast, 2002). Sherwin and Torres (2001) report stratification in the upper and middle reaches of the estuary during neap tides. Density effects may result in a shear between surface and bottom currents, with less dense freshwater moving in a net seaward direction at the surface, and a net movement of more saline water up-estuary lower in the water column. Such effects are likely to be minor relative to tidal circulation. Where stratification does occur, freshwater borne contamination will tend to remain entrained near the surface, keeping it separate from the benthic shellfish beds, at higher states of the tide at least.

As land runoff typically contains higher levels of faecal indicator bacteria than seawater, salinity may be used a useful indicator of levels of freshwater borne contamination. An overall gradient of decreasing salinity towards the head is typical within estuaries such as the Exe, and the associated geographic variation in levels of *E. coli* are often key considerations when developing shellfish hygiene sampling plans. Box plots of near surface salinity measurements are presented in Figure IX.3 (sampling locations in Figure IX.1).

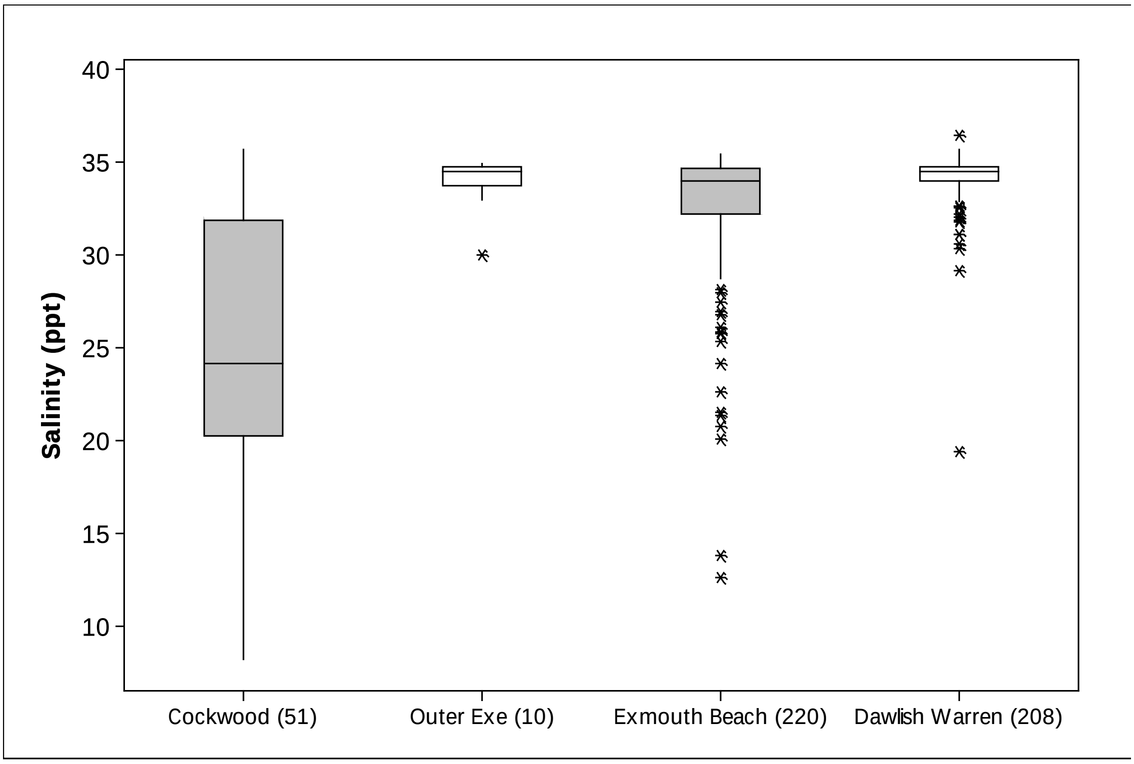

Figure IX.3: Boxplot of near surface salinity measurements, 2003 to 2013 (number of measurements in brackets)
Data from the Environment Agency

Salinities at the three outer sites were generally that of full strength seawater, with occasional signs of higher freshwater influence. Of the two sites sampled on more than 200 occasions more lower salinities were recorded at Exmouth Beach than at Dawlish Warren, suggesting that the plume from the estuary has more of an influence to the east. At the one site within the main body of the estuary (Cockwood), a large variation in the salinity was observed, where it ranged from less than 10ppt to just over 35ppt. Significant temporal variations in salinity, associated with tidal state and river discharges are therefore anticipated throughout the main body of the estuary. A series of salinity measurements taken in August 1987 and reported in Sherwin and Torres (2001) indicate a fairly steep salinity gradient in the upper estuary, which becomes more gentle in the outer estuary but continues through to the mouth. These measurements confirm that there is likely to be an underlying gradient of increasing levels of runoff associated contamination towards the head of the estuary.

Strong winds will 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^{-1}) would drive a surface water current of about 1 knot or 0.5 m s^{-1}. These currents in turn drive return currents which may travel lower in the water column or along sheltered margins. The estuary is largely sheltered from the prevailing south westerly winds, which would tend to push surface water in a north easterly direction. Exact effects are dependent on the wind speed and direction as well as state of the tide and other environmental variables so a great number of scenarios may arise. Where strong winds blow across a sufficient distance of water they may create wave action, and where these waves break contamination held in intertidal sediments may be resuspended. The east shore may be slightly more vulnerable to such effects, but given the enclosed nature of the estuary strong wave action is not generally anticipated.

Appendix X. Microbiological Data: Seawater

X.1. Bathing waters

There are two bathing waters around the Exe Estuary designated under the Directive 76/160/EEC (Council of the European Communities, 1975). Due to changes in the analyses of bathing water quality by the Environment Agency from 2012, only data produced up to the end of 2011 were used in these analyses.

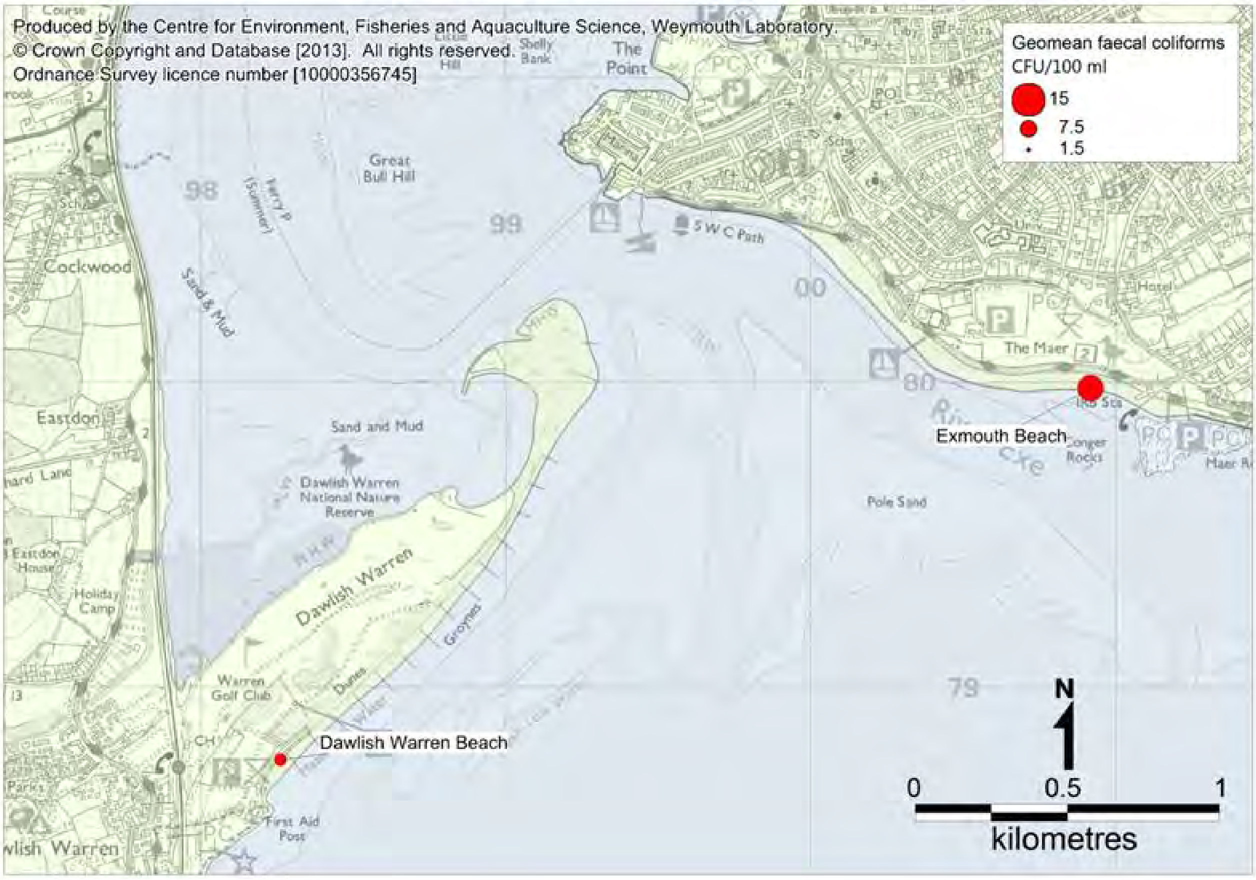

Figure X.1: Location of designated bathing waters monitoring points in the Exe Estuary

Around twenty water samples were taken from each of the bathing waters sites during each bathing season, which runs from the 15th May to the 30th September. Faecal coliforms were enumerated in all these samples. Summary statistics of all results by bathing water are presented in Table X.1, and Figure X.2 presents box plots of these data.

Table X.1: Summary statistics for bathing waters faecal coliforms results, 2003-2011 (cfu/100ml).

Site	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 100	% over 1,000
Dawlish Warren Beach	186	01/05/2003	20/09/2011	5.6	<2	3000	4.8	1.1
Exmouth Beach	193	14/04/2003	19/09/2011	11.6	<2	4000	17.1	3.6

Data from the Environment Agency

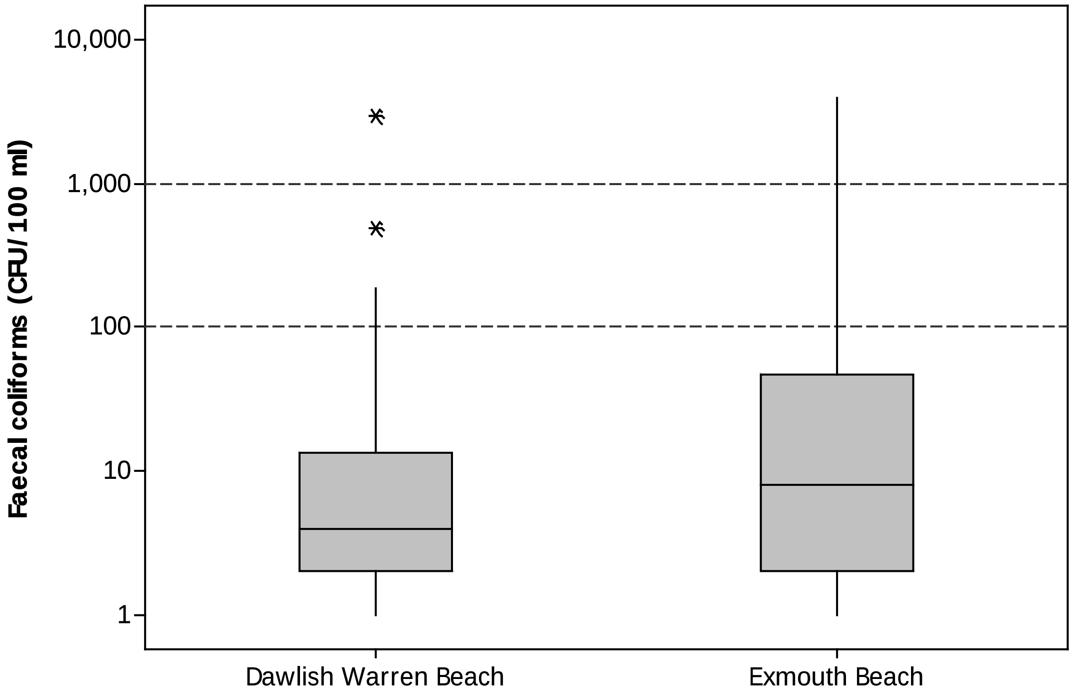

Figure X.2: Box-and-whisker plots of all faecal coliforms results by site
Data from the Environment Agency

Both sites had results exceeding 1,000 faecal coliforms/100 ml, but Exmouth Beach had more than Dawlish Warren Beach. A two sample T-test showed that Exmouth Beach had significantly higher results overall than Dawlish Warren Beach ($p < 0.001$).

Overall temporal pattern in results

The overall variation in faecal coliform levels found at bathing water sites is shown in Figure X.1

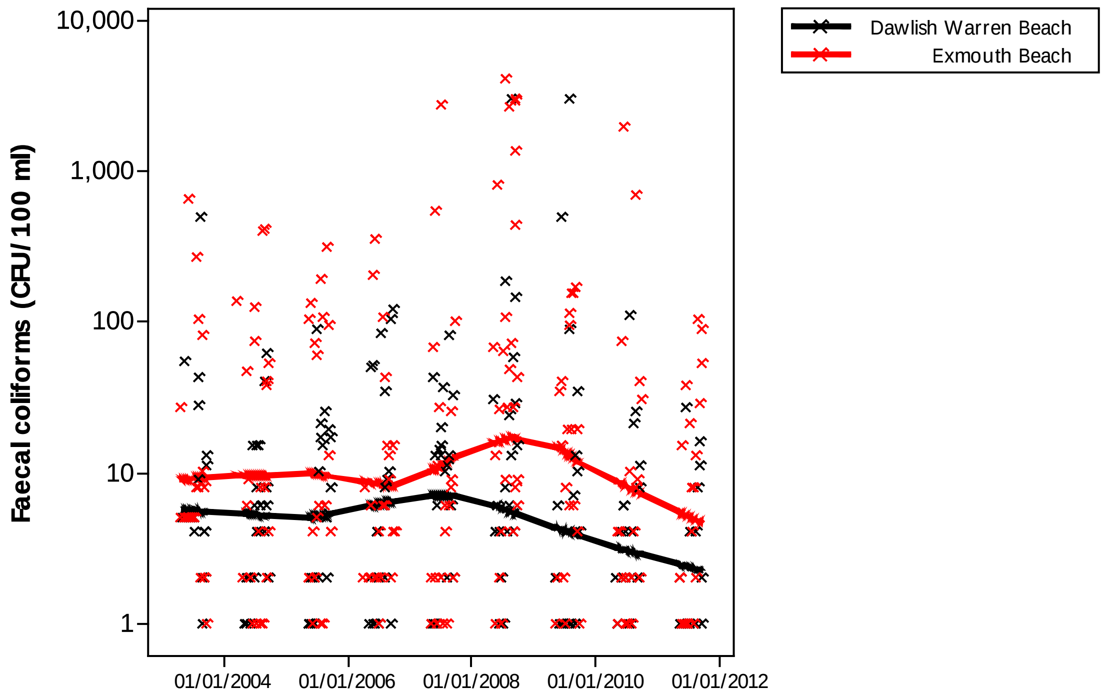

Figure X.3 Scatterplot of faecal coliform results for bathing waters in the Exe Estuary overlaid with loess lines.
Data from the Environment Agency

Faecal coliform levels have remained fairly stable since 2003. However there was a slight peak at Exmouth Beach around 2009, and a slight improvement at both sites since this time.

Influence of tides

To investigate the effects of tidal state on faecal coliform results, circular-linear correlations were carried out against both the high/low and spring/neap tidal cycles for each of these bathing waters sampling points. Correlation coefficients are presented in Table X.2, with statistically significant correlations highlighted in yellow.

Table X.2: Circular linear correlation coefficients (r) and associated p values for faecal coliform results against the high low and spring/neap tidal cycles

	High/low tides		Spring/neap tides	
Site Name	**r**	**p**	**r**	**p**
Dawlish Warren Beach	0.102	0.149	0.138	0.031
Exmouth Beach	0.279	<0.001	0.216	<0.001

Data from the Environment Agency

Figure X.4 presents a polar plot of $\log_{10}$ faecal coliform results against tidal states on the high/low cycle for the correlations indicating a statistically significant effect. High water at Exmouth is at 0° and low water is at 180°. Results of 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1000 are plotted in yellow, and those exceeding 1000 are plotted in red.

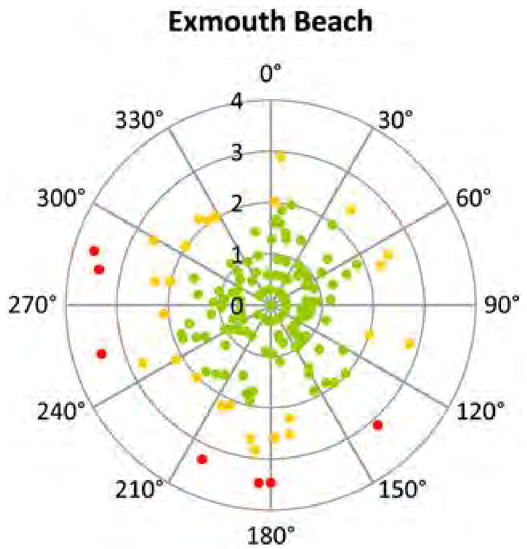

Figure X.4: Polar plots of $\log_{10}$ faecal coliforms against tidal state on the high/low tidal cycle for bathing waters monitoring points with significant correlations
Data from the Environment Agency

At Exmouth Beach, higher results tended to occur in the flood tide.

Figure X.5 presents polar plots of faecal coliform results against the lunar spring/neap cycle, where a statistically significant correlation was found. 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 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1000 are plotted in yellow, and those exceeding 1000 are plotted in red.

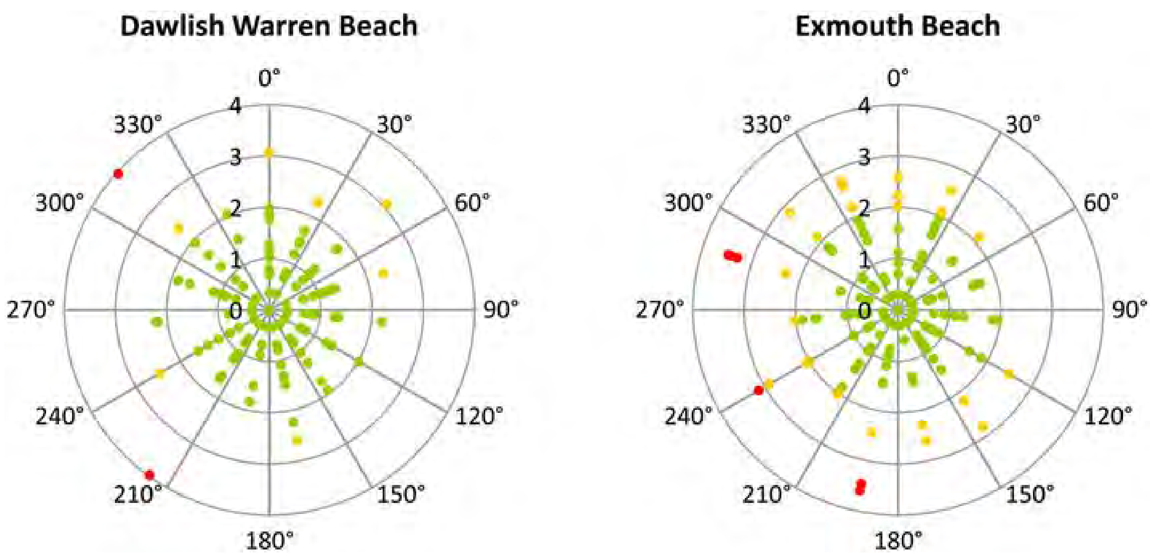

Figure X.5: Polar plots of log10 faecal coliforms against tidal state on the spring/neap tidal cycle for bathing waters monitoring points with significant correlations
Data from the Environment Agency

At Exmouth Beach, a slight tendency for higher results on neap tides can be seen, but no particular pattern was apparent for Dawlish Warren, where the correlation was much weaker.

Influence of Rainfall

To investigate the effects of rainfall on levels of contamination at the bathing waters sites Spearman's rank correlations were carried out between rainfall recorded at the Exminster House weather station (Appendix VI for details) over various periods running up to sample collection and faecal coliforms results. These are presented in Table X.3 and statistically significant correlations ($p<0.05$) are highlighted in yellow.

Table X.3: Spearmans Rank correlation coefficients for faecal coliforms results against recent rainfall

	Site	Dawlish Warren Beach	Exmouth Beach
	n	186	193
24 hour periods prior to sampling	1 day	0.127	0.274
	2 days	0.251	0.438
	3 days	0.208	0.312
	4 days	0.186	0.242
	5 days	0.182	0.215
	6 days	0.190	0.239
	7 days	-0.017	0.148
Total prior to sampling over	2 days	0.208	0.443
	3 days	0.240	0.486
	4 days	0.250	0.474
	5 days	0.249	0.438
	6 days	0.245	0.437
	7 days	0.206	0.428

Data from the Environment Agency

At both bathing water sites, faecal coliform levels rapidly increase after rainfall, and remain higher for several days. However, this is more pronounced at Exmouth Beach, where the correlations coefficients between rainfall and faecal coliform levels are higher than at Dawlish Warren Beach.

X.2. Shellfish Waters

There are two shellfish waters sites designated under Directive 2006/113/EC (European Communities, 2006) in the Exe Estuary. Figure X.6 shows the location of these sites. Table X.4 presents summary statistics for bacteriological monitoring results and Figure X.7 presents a boxplot of faecal coliforms levels from the monitoring points.

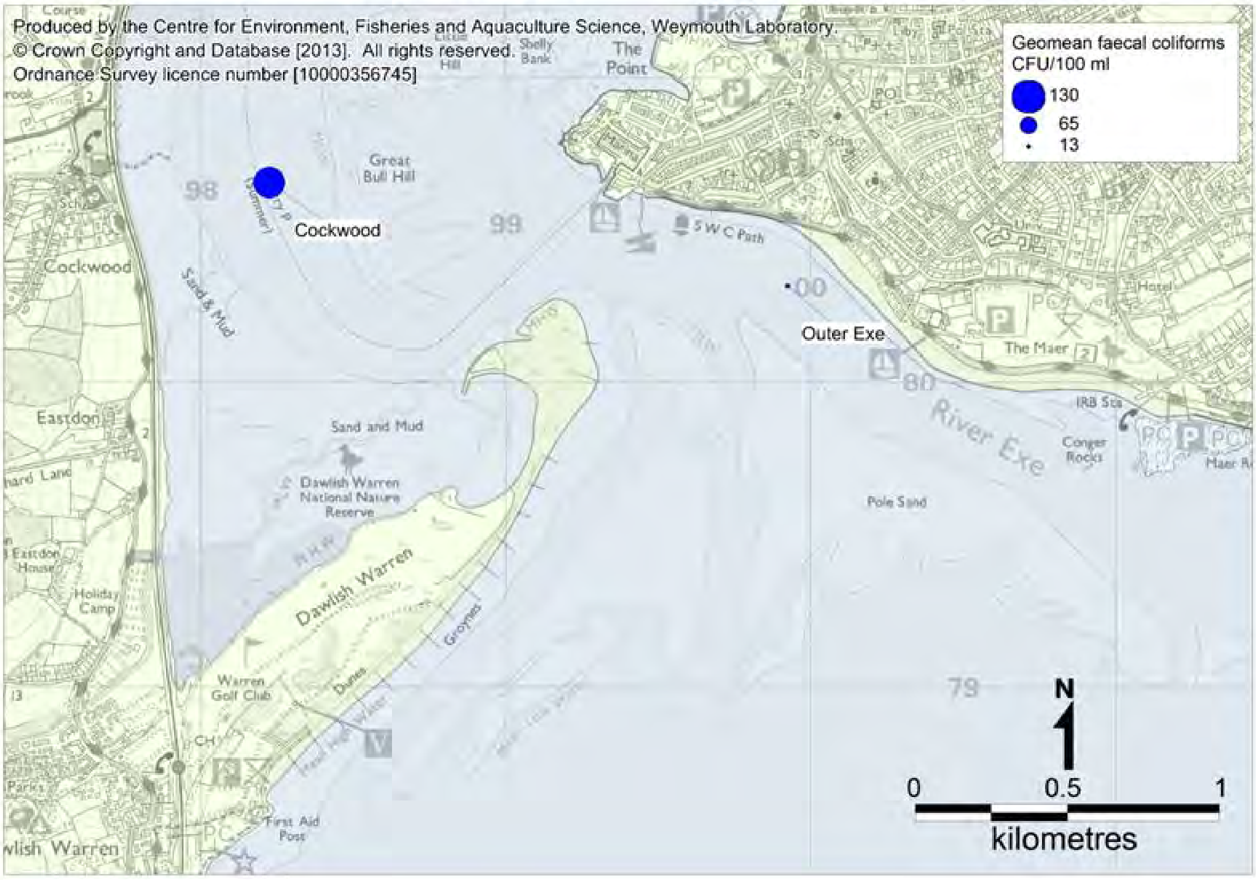

Figure X.6: Location of shellfish waters sampling points in the Exe Estuary

Table X.4: Summary statistics for shellfish waters faecal coliform results, 2003 to 2013 (cfu/100ml).

Site	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 100	% over 1,000
Cockwood	51	17/04/2003	18/04/2013	122.0	<2	16200	52.9	19.6
Outer Exe	10	24/01/2011	18/04/2013	19.5	<2	392	20.0	0.0

Data from the Environment Agency

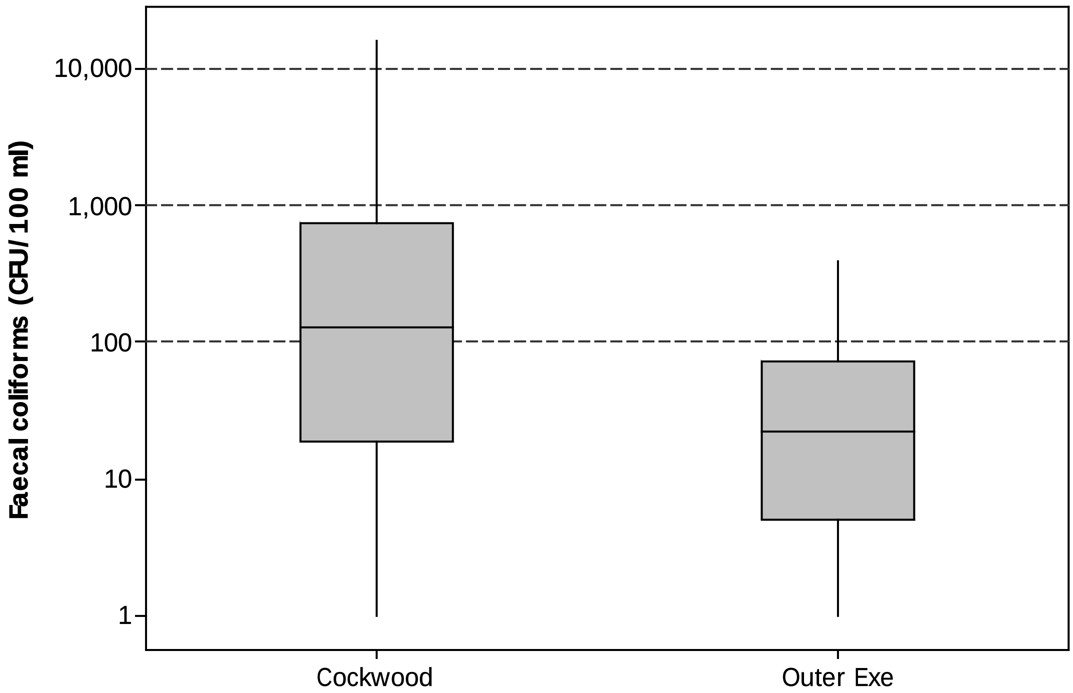

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Figure X.7: Box-and-whisker plots of all faecal coliforms results
Data from the Environment Agency

Faecal coliform levels only reached greater than 1,000 CFU/100 ml at Cockwood. There was also one occasion when levels exceed 10,000 CFU/100 ml. A two sample T test revealed that faecal coliforms were significantly higher at Cockwood than at Outer Exe (p = 0.014).

Overall temporal pattern in results

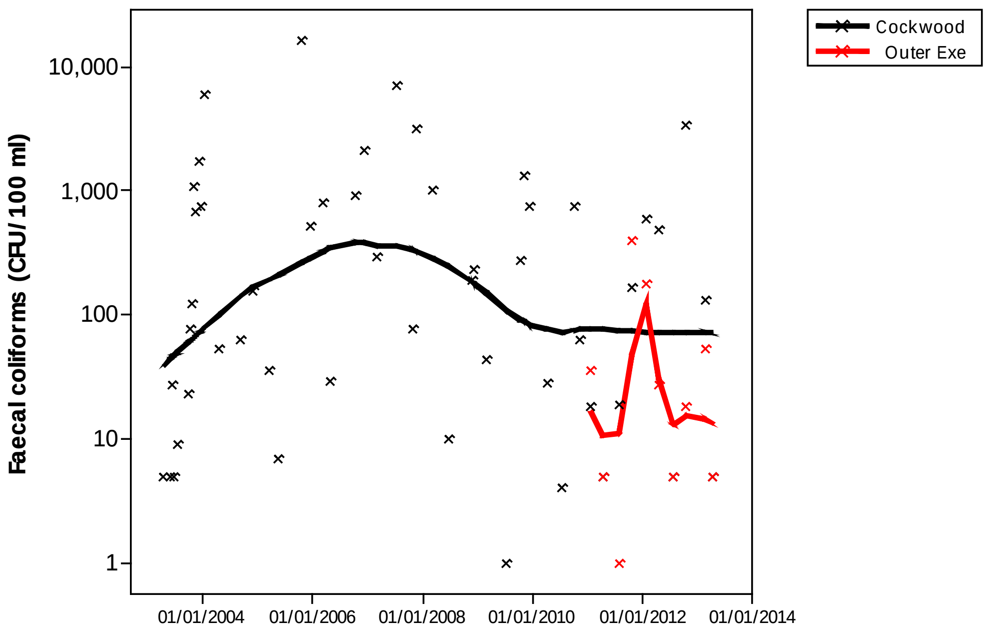

Figure X.8: Scatterplot of faecal coliform results by date, overlaid with loess lines
Data from the Environment Agency

Figure XI.8 shows that faecal coliform levels at Cockwood increased between 2003 and 2007. They then decreased and have remained stable since 2010. Sampling at Outer Exe has not been taking place for long enough to show any temporal patterns in faecal coliform levels.

Seasonal patterns of results

Comparisons (One-way ANOVA) of faecal coliform levels revealed that there was a significant difference between seasons ($p < 0.001$) at Cockwood. Post ANOVA Tukey tests showed that faecal coliforms were significantly higher in the autumn and winter at Cockwood than during the spring and summer. A one-way ANOVA to compare faecal coliform levels at Exe outer did not reveal any significant differences between seasons ($p = 0.058$). However very few samples have been taken at Outer Exe, and Figure X.9 shows that similarly to Cockwood, there is likely to be increased levels of faecal coliforms in autumn and winter compared with spring and summer.

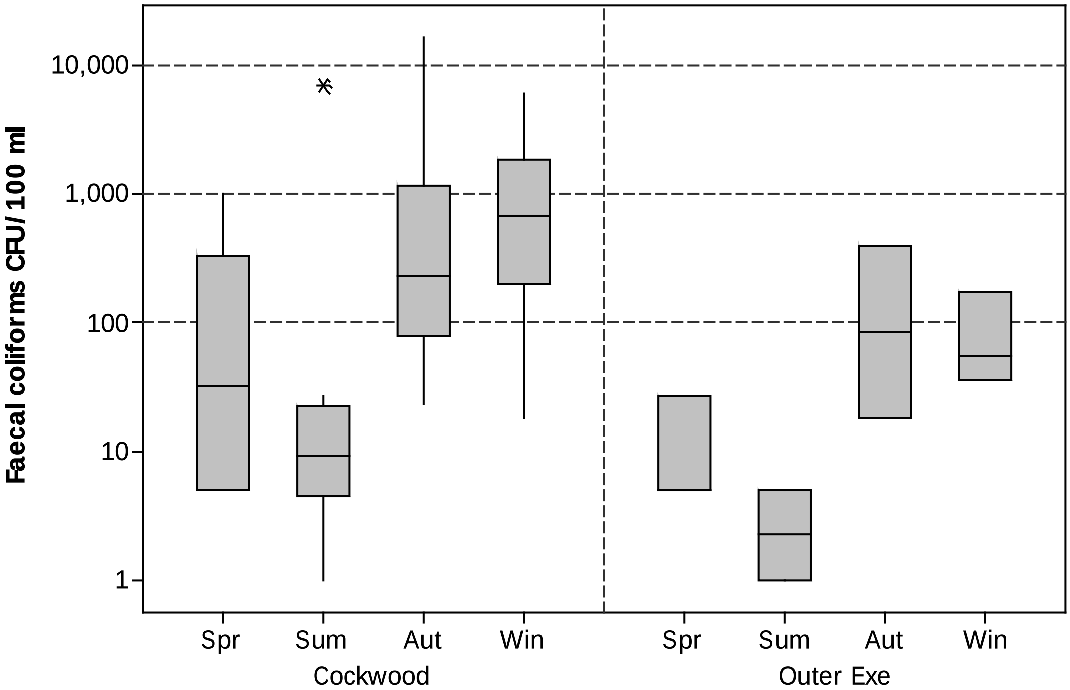

Figure X.9: Boxplot of faecal coliform results by site and season
Data from the Environment Agency

Influence of tide

To investigate the effects of tidal state on faecal coliform results, circular-linear correlations were carried out against the high/low and spring/neap tidal cycles. The results of these correlations are summarised in

Table X.5, and significant correlations are highlighted in yellow. These tests were not performed on the Outer Exe data due to the low numbers of samples at this site.

Table X.5: Circular linear correlation coefficients (r) and associated p values for faecal coliform results against the high/low and spring/neap tidal cycles

	High/low tides		Spring/neap tides	
Site	r	p	r	p
Cockwood	0.453	<0.001	0.240	0.062

Data from the Environment Agency

Figure X.10 presents a polar plot of log^{10} faecal coliform results against tidal states on the high/low cycle for the correlations indicating a statistically significant effect. High water at Exmouth is at 0° and low water is at 180°. Results of 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1000 are plotted in yellow, and those exceeding 1000 are plotted in red.

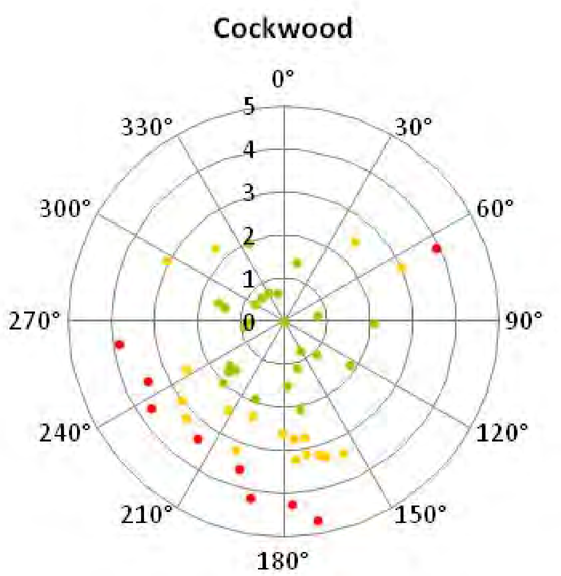

Figure X.10: Polar plots of log10 faecal coliforms against tidal state on the high/low tidal cycle for shellfish waters monitoring points with significant correlations
Data from the Environment Agency

Faecal coliform levels at Cockwood tended to increase during the ebb tide, were highest on average around low water, and decreased as the tide flooded.

Influence of rainfall

To investigate the effects of rainfall on levels of contamination at the water quality monitoring sites Spearman's rank correlations were carried out between rainfall recorded at the Exminster House weather station (Appendix VI for details) over various periods running up to sample collection and faecal coliform results. These are presented in Table X.6 and statistically significant correlations ($p<0.05$) are highlighted in yellow. These tests were not performed on the Outer Exe data due to the low numbers of samples at this site

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Table X.6: Spearmans Rank correlation coefficients for faecal coliform results against recent rainfall

	Site	Cockwood
	n	47
24 hour periods prior to sampling	1 day	0.314
	2 days	0.314
	3 days	0.492
	4 days	0.313
	5 days	0.142
	6 days	0.339
	7 days	0.244
Total prior to sampling over	2 days	0.328
	3 days	0.405
	4 days	0.420
	5 days	0.395
	6 days	0.478
	7 days	0.499

Data from the Environment Agency

Faecal coliform levels were rapidly increased by rainfall events at Cockwood and continued to have an effect for several days.

Influence of salinity

Pearson's correlations were run to determine the effect of salinity on faecal coliforms at Cockwood (too few samples were taken at Outer Exe for reliable comparison). Figure X.11 shows a scatterplot of faecal coliforms against salinity and the results of Pearson's correlations between the two.

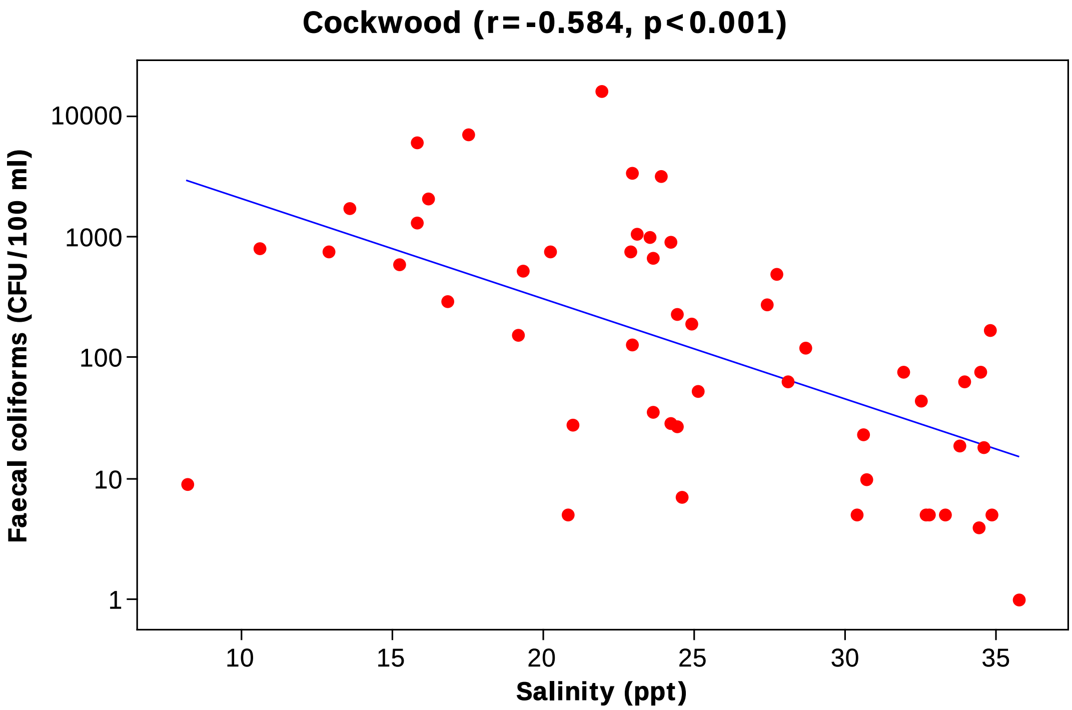

Figure X.11: Scatterplot of salinity against faecal coliform results
Data from the Environment Agency

A strong negative correlation between salinity and faecal coliform levels was observed. Considering the large range of salinities that were recorded, this suggests that land runoff is a significant contaminating influence.

Appendix XI. Microbiological Data: Shellfish Flesh

There are 15 RMPs in the Exe estuary that have been sampled since 2003. One is for cockles, two are for Manila clams, six are for mussels, five are for Pacific oysters and one is for palourdes. The geometric mean results of shellfish flesh monitoring from 2003 to 2013 at these RMPs are presented in Figure XI.1 and summary statistics are presented in Table XI.1 and Figure XI.2 to Figure XI.5. Palourdes were not sampled on 10 or more occasions and so will not be considered further.

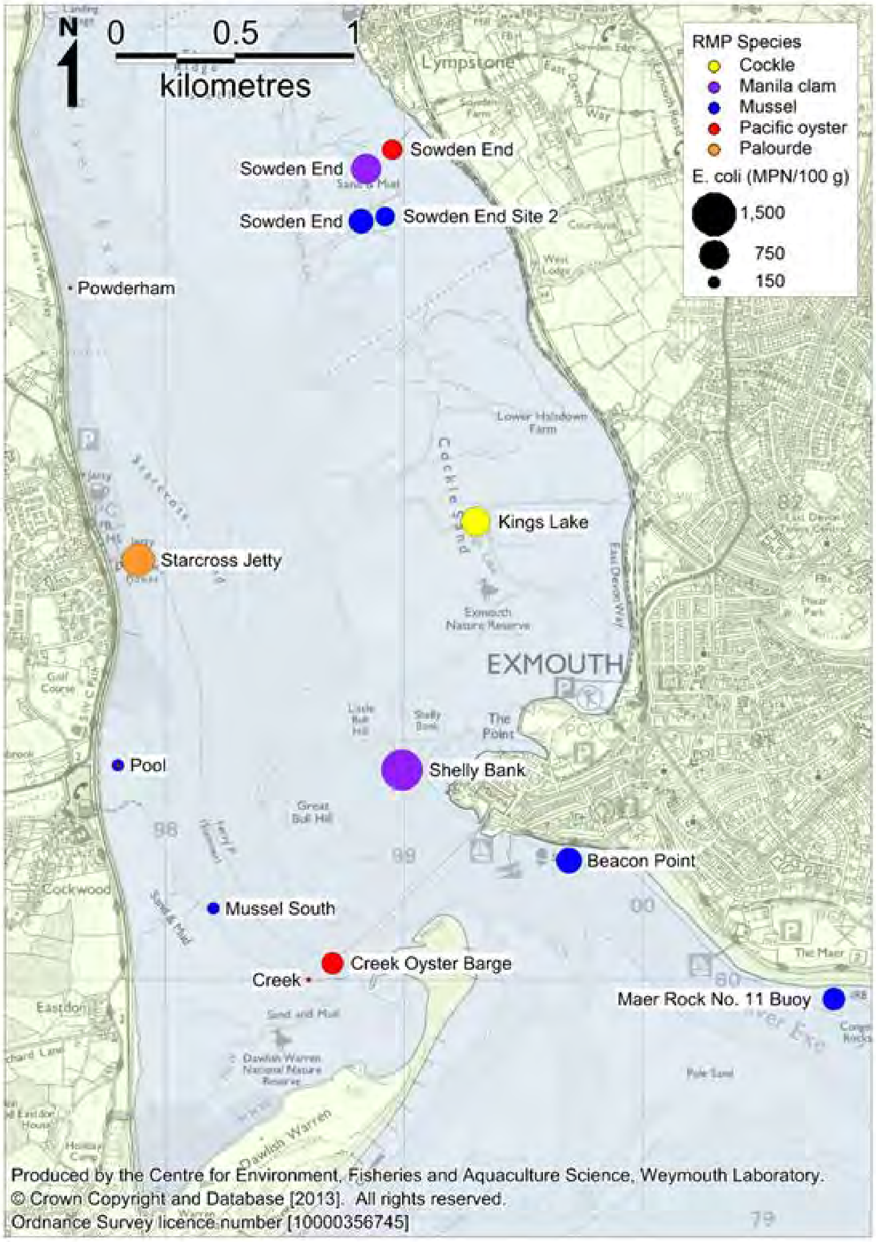

Figure XI.1: Bivalve RMPs active since 2003.

Table XI.1: Summary statistics of *E. coli* results (MPN/100 g) sampled from 2003 onwards

Site	Species	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 230	% over 4,600	% over 46,000
Kings Lake	Cockle	104	02/06/2004	09/07/2012	718.6	20	350000	76.9	9.6	1.9
Sowden End	Manila clam	30	04/09/2006	07/05/2008	757.8	<20	9100	80.0	10.0	0.0
Shelly Bank	Manila clam	41	21/04/2008	09/07/2012	1323.0	<20	92000	87.8	26.8	2.4
Sowden End	Mussel	124	05/02/2003	07/06/2010	548.2	<20	54000	72.6	10.5	0.8
Sowden End Site 2	Mussel	30	05/02/2003	18/09/2003	344.8	20	5400	63.3	3.3	0.0
Pool	Mussel	121	16/01/2003	18/06/2013	148.1	<20	9200	40.5	4.1	0.0
Mussel South	Mussel	129	16/01/2003	18/06/2013	155.4	<20	16000	44.2	3.9	0.0
Beacon Point	Mussel	120	18/09/2003	21/05/2013	596.7	<20	>18000	71.7	13.3	0.0
Maer Rock No. 11 Buoy	Mussel	38	18/09/2003	09/10/2006	471.5	<20	9100	68.4	7.9	0.0
Sowden End	Pacific oyster	80	14/06/2004	07/06/2010	385.0	<20	24000	63.8	10.0	0.0
Powderham	Pacific oyster	63	03/03/2003	26/03/2008	21.1	<20	790	6.3	0.0	0.0
Pool	Pacific oyster	120	16/01/2003	25/06/2013	33.3	<20	16000	18.3	1.7	0.0
Creek	Pacific oyster	122	16/01/2003	25/06/2013	31.7	<20	3500	18.0	0.0	0.0
Creek Oyster Barge	Pacific oyster	55	31/10/2005	11/10/2010	450.1	20	16000	76.4	5.5	0.0
Starcross Jetty	Palourde	4	22/05/2013	03/07/2013	923.9	80	>18000	75.0	25.0	0.0

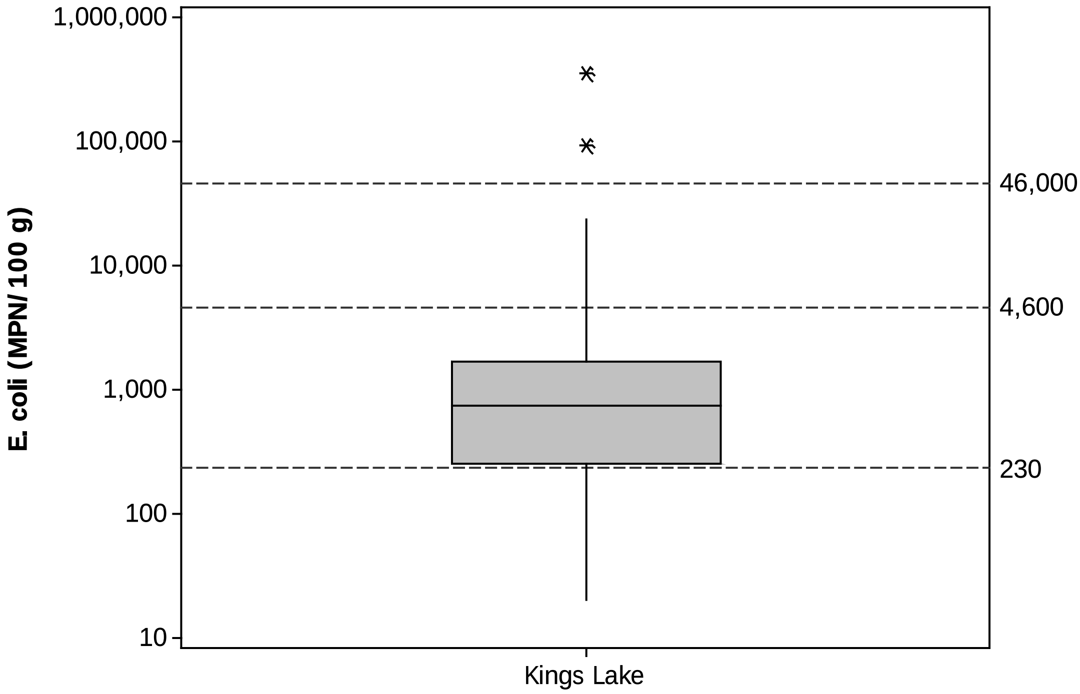

Figure XI.2: Boxplots of *E. coli* results from cockle RMPs from 2003 onwards.

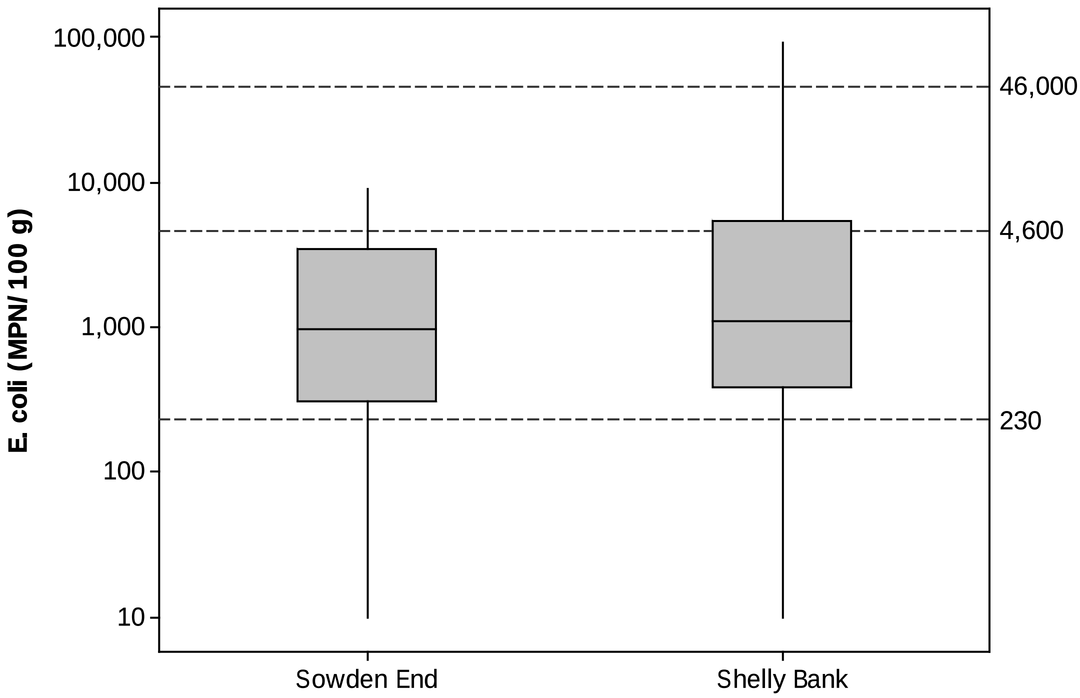

Figure XI.3: Boxplots of *E. coli* results from Manila clam RMPs from 2003 onwards.

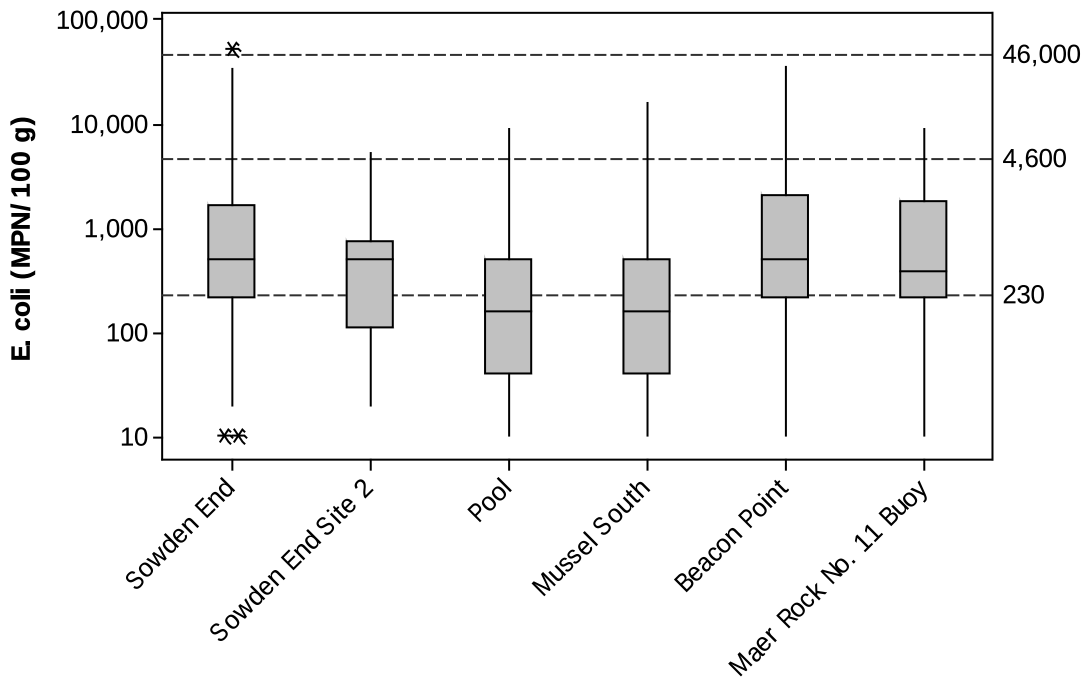

Figure XI.4: Boxplots of *E. coli* results from mussel RMPs from 2003 onwards.

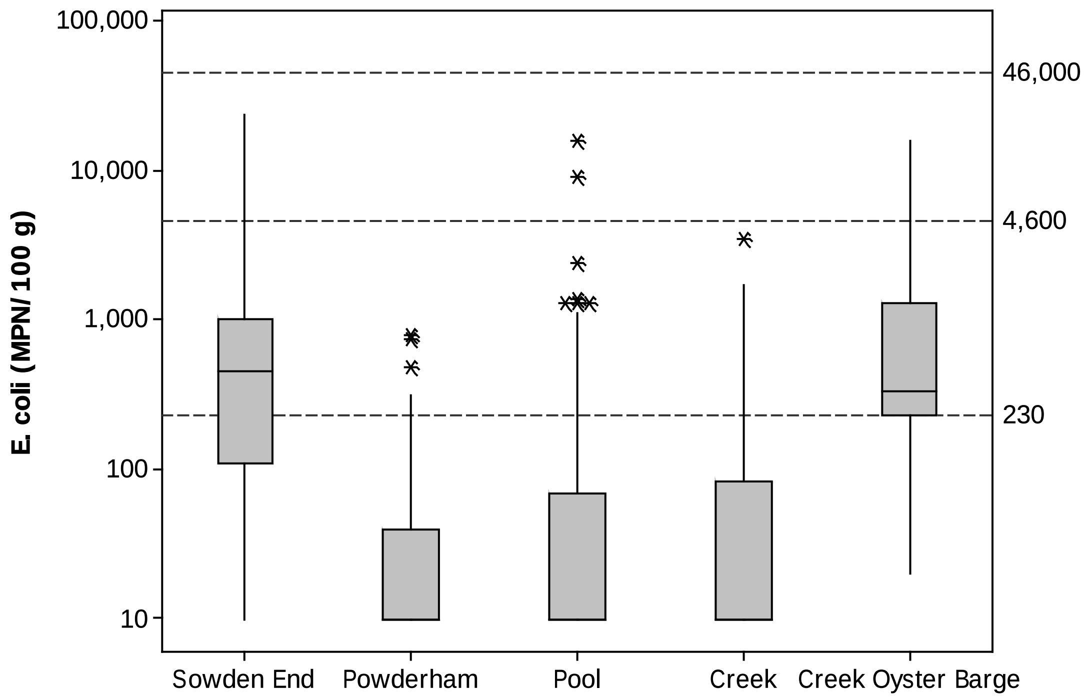

Figure XI.5: Boxplots of *E. coli* results from Pacific oyster RMPs from 2003 onwards.

E. coli levels exceeded 230 MPN/100 g at all sites and exceeded 4,600 MPN/100 g in 10% or more samples at five sites (including Starcross Jetty palourdes).

Statistical comparisons of Manila clam RMPs (Two sample T-tests) revealed that there were no significant differences between the two RMPs (p = 0.207).

Statistical comparisons of mussel RMPs (One-way ANOVA) revealed that there was a significant variation between sites ($p < 0.001$). Post ANOVA Tukey tests showed that Sowden End, Beacon Point and Maer Rock No. 11 Buoy had significantly higher *E. coli* levels than Pool and Mussel South. Pool and Mussel South are both located towards the western shore of the estuary, while Sowden End, Beacon Point and Maer Rock No. 11 Buoy are located towards the eastern shore.

Comparisons of Pacific oysters (One-way ANOVA) also revealed that there was a significant variation between sites ($p < 0.001$). Post ANOVA Tukey tests showed that Sowden End and Creek Oyster Barge had significantly higher levels of *E. coli* than all of the other Pacific oyster RMPs.

To further explore geographical variation in *E. coli* levels, Pearson's correlations were run to compare *E. coli* levels between individual pairs of sites which were sampled on the same day and therefore under similar environmental conditions on 20 or more occasions. The two Manila clam RMPs did not share 20 sampling days and so no comparison was run.

For mussels, five correlations were possible (Sowden End vs Sowden End Site 2, Beacon Point and Maer Rock No. 11 Buoy; Mussel South vs Pool; and Beacon Point vs Maer Rock No. 11 Buoy). All of these correlations were statistically significant ($p < 0.05$), indicating that these sites are affected by similar sources.

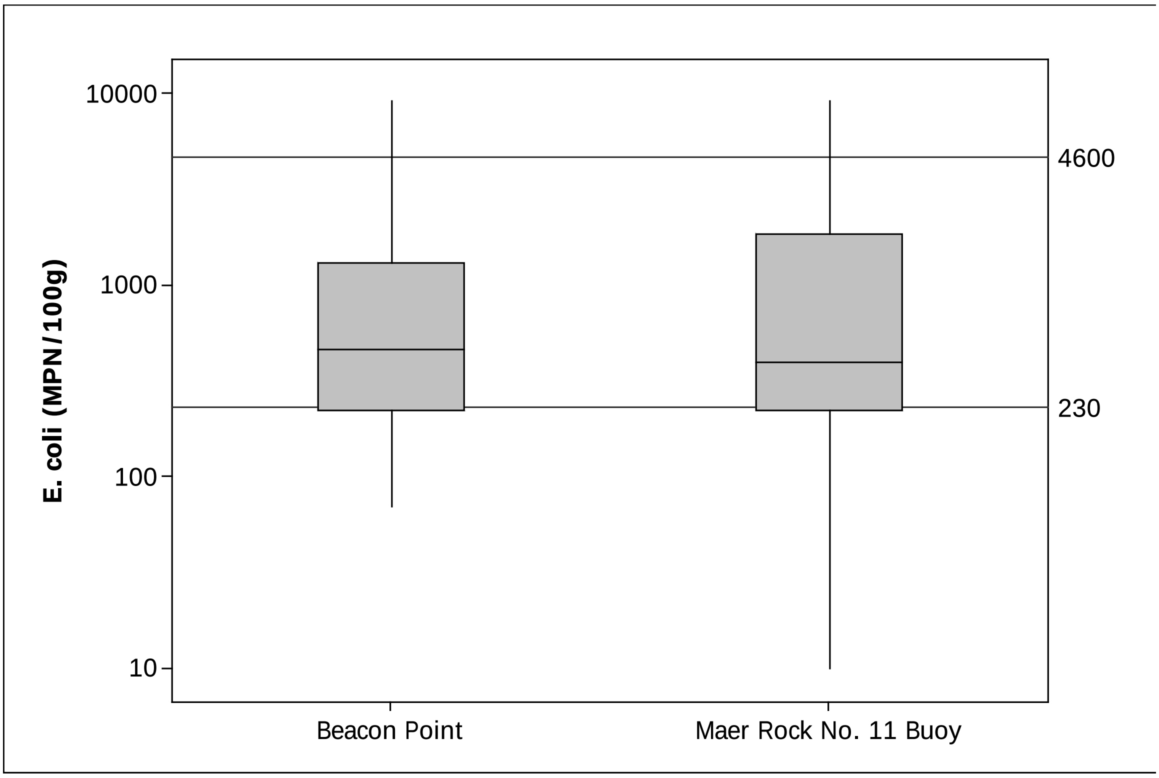

Figure XI.6: Result of paired (same day) sampled from the two mussel RMPs in the estuary approaches

When only the paired data was considered for the two sites in the approach channel (Beacon Point and Maer Rock No. 11 buoy), the former had a slightly higher geometric mean result, although the difference was not statistically significant (Paired T-test, p=0714). The boxplots (Figure XI.6) show that the peak result was the same at both, but fewer very low results were recorded at Beacon Point, suggesting that there is a marginal preference for monitoring at the western end of this zone for best public health protection.

Comparisons between Pacific oyster RMPs showed significant correlations ($p < 0.05$) between Powderham vs Pool and Creek vs Pool. Correlations between Creek Oyster Barge vs Pool and Creek were not significant, suggesting that Creek Oyster Barge may be influenced by different sources than Pool and Creek. This is somewhat surprising given the close proximity of Creek Oyster Barge to Creek. Paired sample results at Pool and Creek were almost identical in terms of geometric mean result, although the 4600 MPN/100g threshold was only exceeded at Pool.

XI.1. Overall temporal pattern in results

Figure XI.7 shows that over all, levels of *E. coli* in cockles remained about the same from 2003 to 2012. However, there was a slight increase in *E. coli* levels between 2008 and 2010.

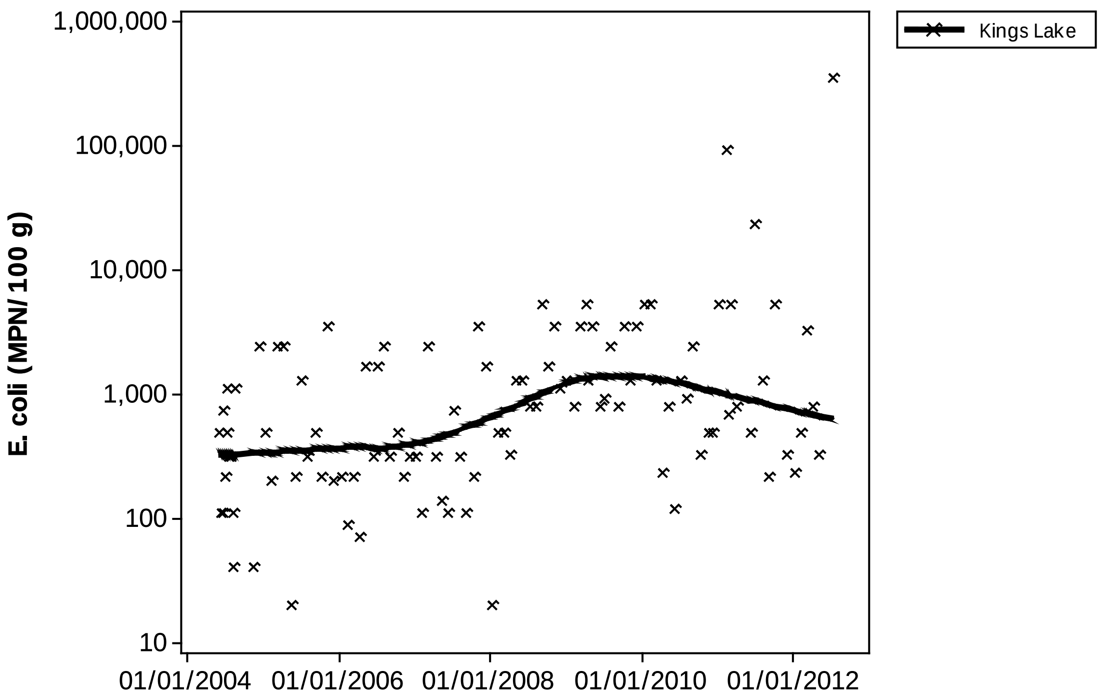

Figure XI.7: Scatterplot of *E. coli* results in cockles by RMP and date, overlaid with loess lines

Figure XI.8 shows that *E. coli* levels in Manila clams were quite variable. Samples were not collected for a long enough period at either of the sites to make any firm conclusions on temporal patterns in Manila clams.

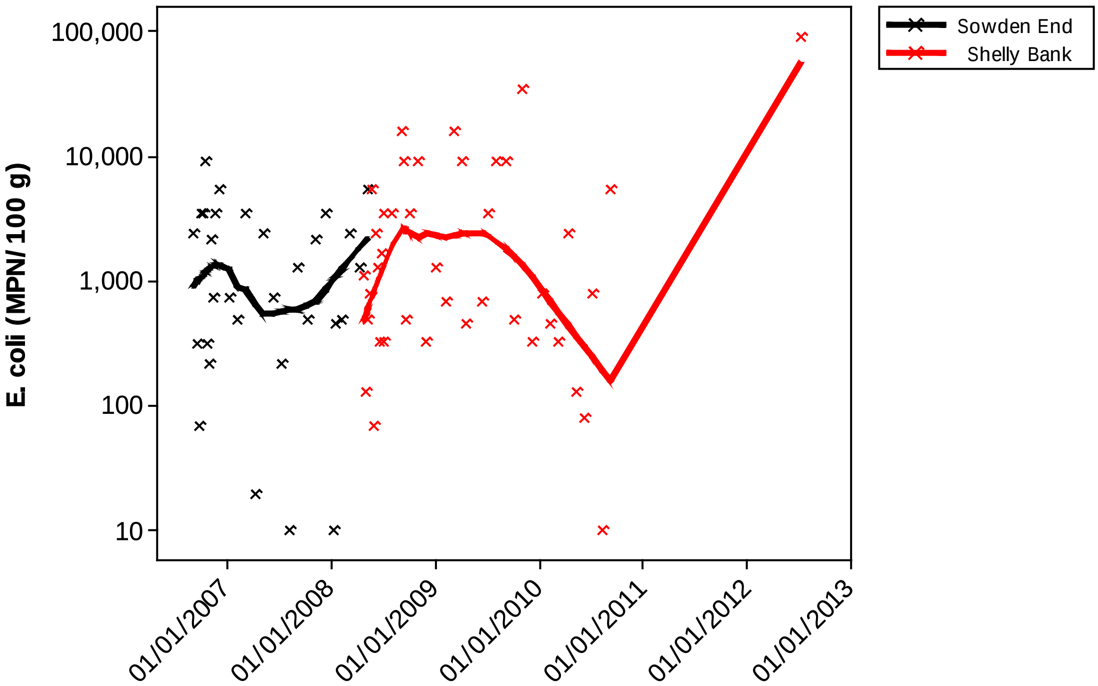

Figure XI.8: Scatterplot of *E. coli* results in Manila clams by RMP and date, overlaid with loess lines

Figure XI.9 shows that *E. coli* levels in mussels have remained relatively constant at Beacon point, while there has been an increase in *E. coli* levels at Mussel South and Pool so that both of these sites now have similar *E. coli* levels to Beacon Point.

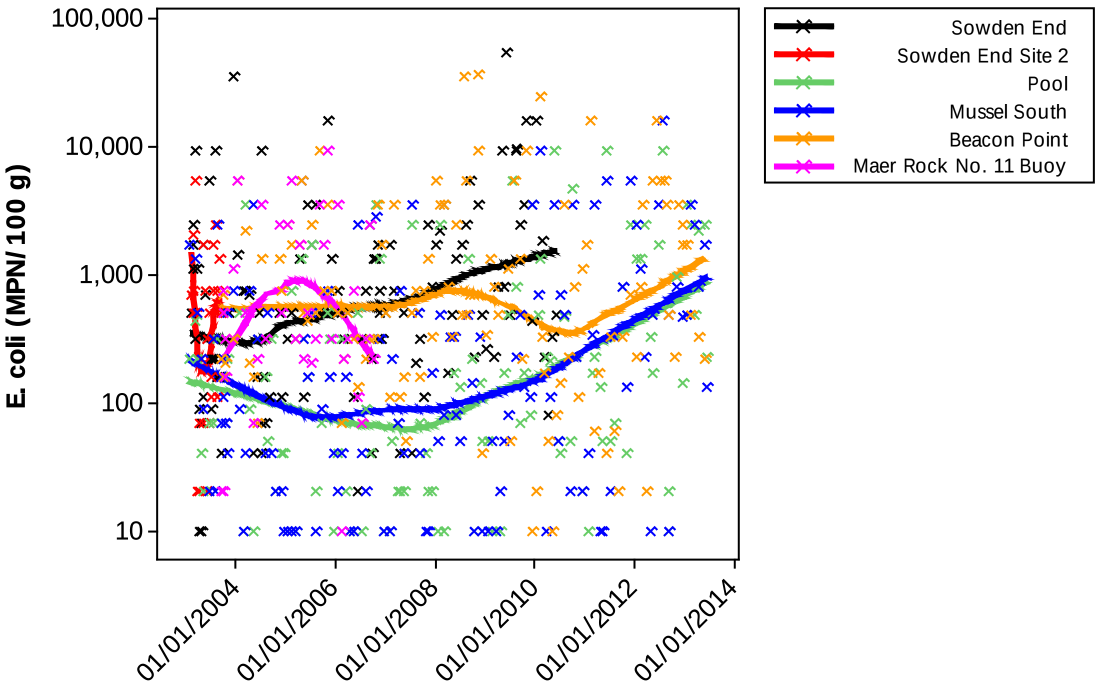

Figure XI.9: Scatterplot of *E. coli* results in mussels by RMP and date, overlaid with loess lines

Figure XI.10 shows that *E. coli* levels in Pacific oysters have always been relatively high at Sowden End and Creek Oyster Barge. *E. coli* levels at Powderham fell between 2003 and

2005 and remained low until sampling stopped in 2008. At Pool and Creek, *E. coli* levels have fluctuated on an approximate three year cycle.

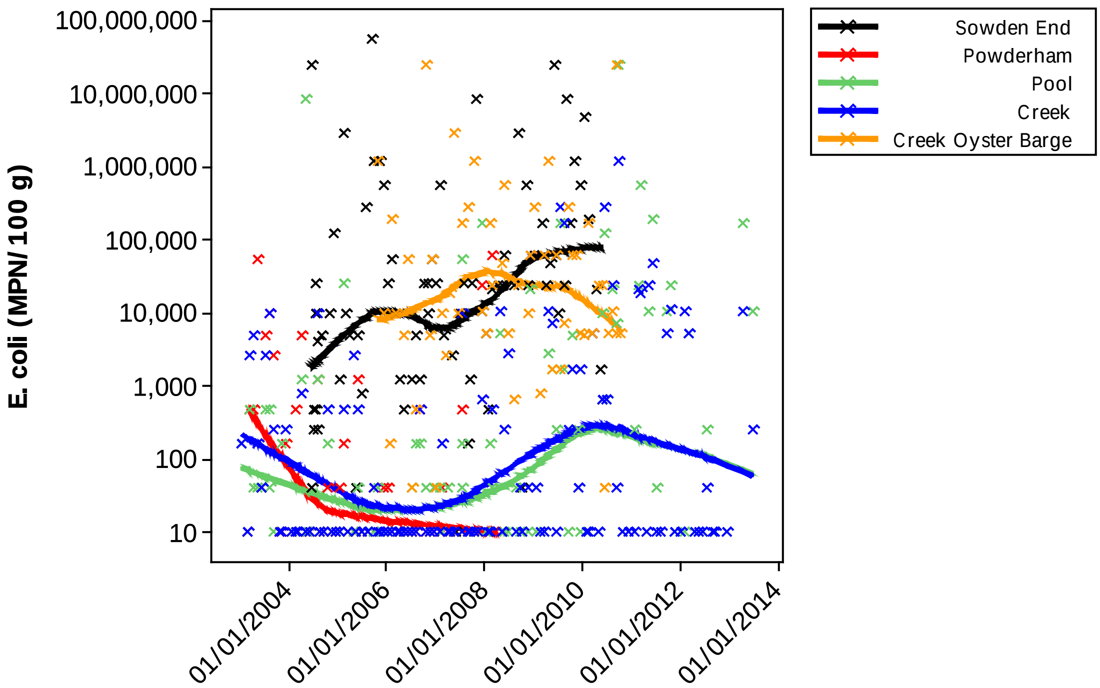

Figure XI.10: Scatterplot of *E. coli* results in Pacific oysters by RMP and date, overlaid with loess lines

XI.2. Seasonal patterns of results

The seasonal patterns of results from 2003 onwards were investigated by RMP. One-way ANOVA tests showed that significant seasonal variation was only seen in Sowden End and Creek Oyster Barge Pacific oysters ($p = 0.025$ and 0.038 respectively). Post ANOVA Tukey tests revealed no significant pairwise differences between seasons at Sowden End, but did show that *E. coli* levels were greater during the autumn than summer at Creek Oyster Barge. See Figure XI.11 to Figure XI.14.

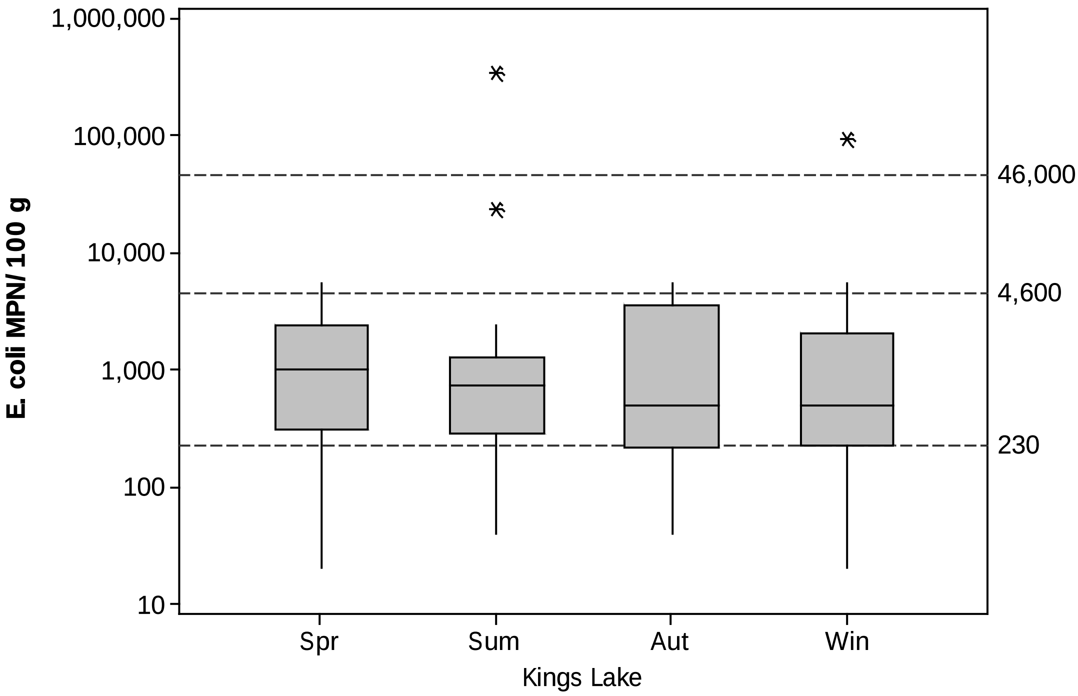

Figure XI.11: Boxplot of *E. coli* results in cockles by RMP and season

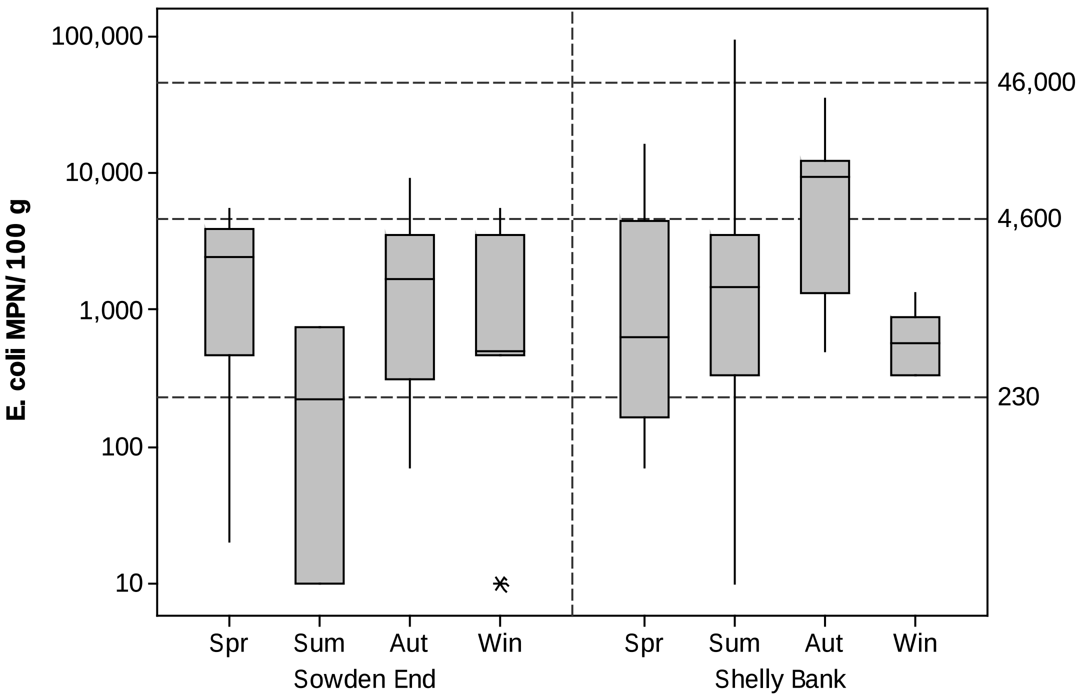

Figure XI.12: Boxplot of *E. coli* results in Manila clams by RMP and season

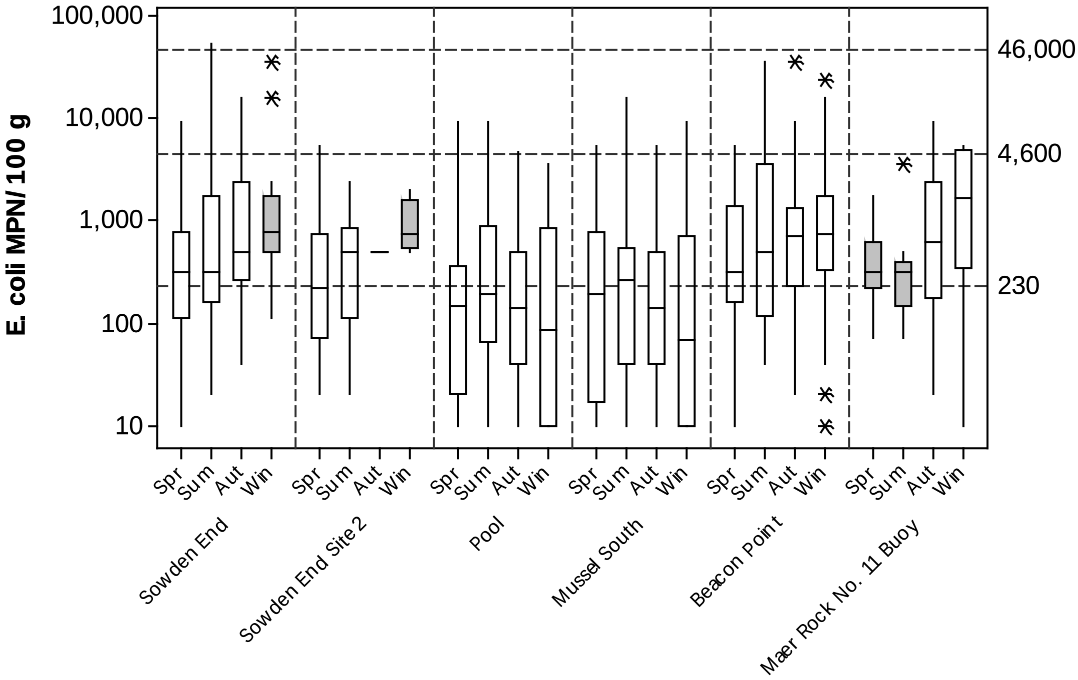

Figure XI.13 Boxplot of *E. coli* results in mussels by RMP and season

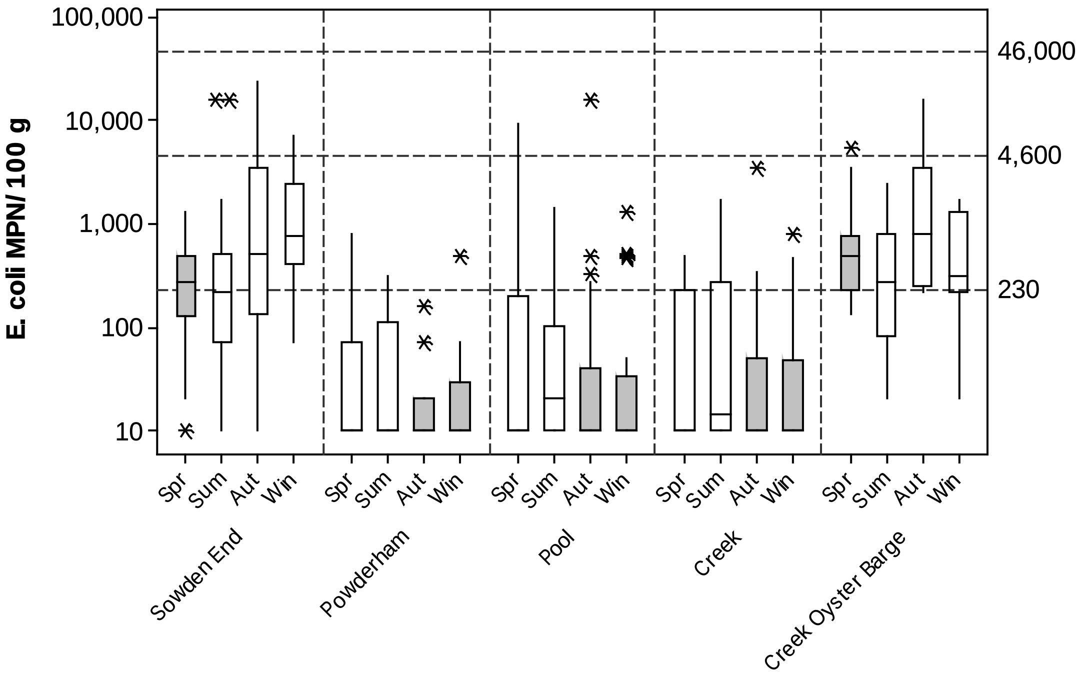

Figure XI.14: Boxplot of *E. coli* results in Pacific oysters by RMP and season

XI.3. Influence of tide

To investigate the effects of tidal state on *E. coli* results, circular-linear correlations were carried out against the high/low and spring/neap tidal cycles for each RMP with 30 or more samples. The results of these correlations are summarised in Table XI.2, with significant results highlighted in yellow.

Figure XI.15 and Figure XI.16 present polar plots of $\log_{10}$ *E. coli* results against tidal states on the high/low cycle for the correlations indicating a statistically significant effect. High water at Exmouth is at 0° and low water is at 180°. Results of 230 *E. coli* MPN/100g or less are plotted in green, those from 231 to 4,600 are plotted in yellow, and those exceeding 4,600 are plotted in red.

Table XI.2: Circular linear correlation coefficients (r) and associated p values for *E. coli* results against the high/low and spring/neap tidal cycles

		High/low tides		Spring/neap tides	
Site Name	**Species**	**r**	**p**	**r**	**p**
Kings Lake	Cockle	0.037	0.868	0.159	0.079
Sowden End	Manila clam	0.273	0.133	0.235	0.223
Shelly Bank	Manila clam	0.148	0.435	0.155	0.400
Sowden End	Mussel	0.150	0.065	0.234	0.001
Sowden End Site 2	Mussel	0.117	0.689	0.462	0.003
Pool	Mussel	0.196	0.011	0.085	0.429
Mussel South	Mussel	0.096	0.310	0.133	0.106
Beacon Point	Mussel	0.131	0.135	0.165	0.041
Maer Rock No. 11 Buoy	Mussel	0.421	0.002	0.225	0.169
Sowden End	Pacific oyster	0.224	0.021	0.203	0.042
Powderham	Pacific oyster	0.147	0.275	0.159	0.218
Pool	Pacific oyster	0.127	0.152	0.176	0.027
Creek	Pacific oyster	0.193	0.012	0.233	0.002
Creek Oyster Barge	Pacific oyster	0.281	0.017	0.321	0.005

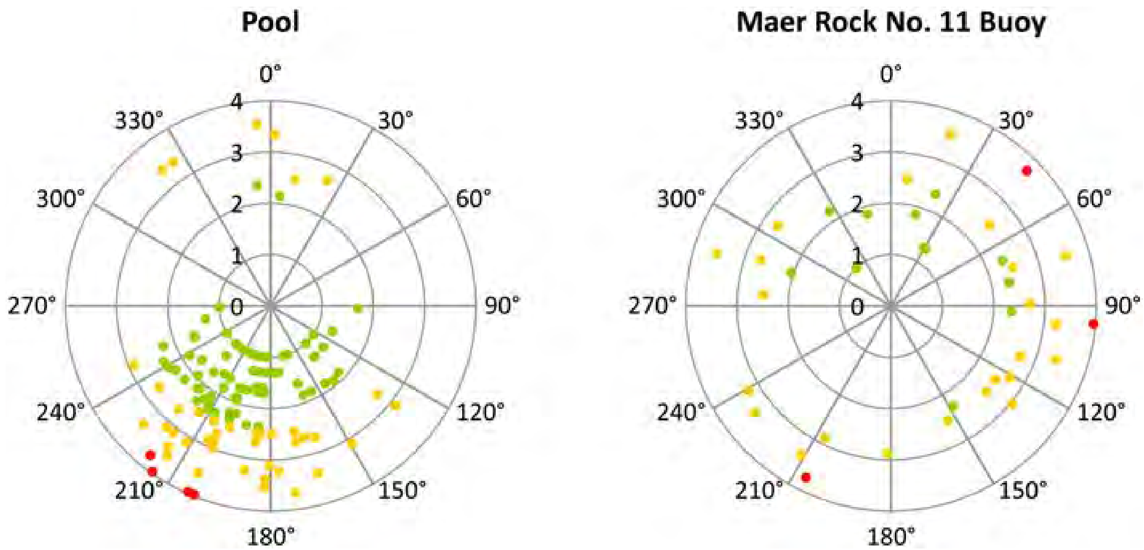

Figure XI.15: Polar plots of $\log_{10}$ *E. coli* results (MPN/100g) against tidal state on the high/low tidal cycle for mussel sampling points with significant correlations

At the Pool mussel RMP, higher results tended to occur just after low water, although sampling effort was strongly targeted towards this time. At Maer Rock No. 11 Buoy, the few low results that occurred tended to be around high tide, and *E. coli* levels were higher on average just after low water.

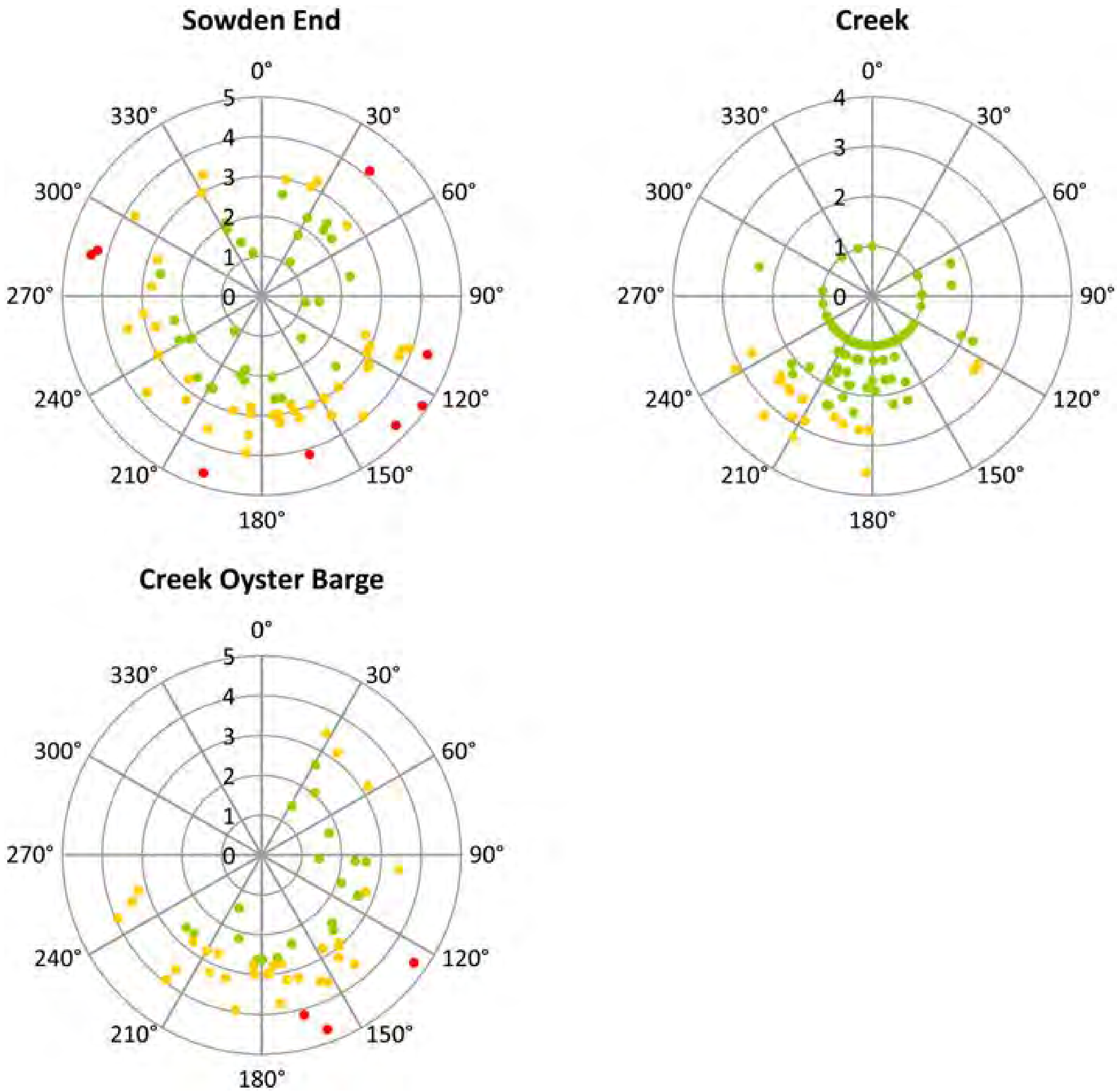

Figure XI.16: Polar plots of log10 *E. coli* results (MPN/100g) against tidal state on the high/low tidal cycle for Pacific oyster sampling points with significant correlations

As with mussel RMPs, higher results tended to occur around low tide in the Pacific oyster RMPs although sampling was targeted towards this time.

Figure XI.17 and Figure XI.18 present polar plots of $\log_{10}$ *E. coli* results against the spring/neap tidal cycle for those RMPs that showed a significant correlation. Full/new moons occur at 0º, and half moons occur at 180º, and 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 230 *E. coli* MPN/100g less are plotted in green, those from 231 to 4,600 are plotted in yellow, and those exceeding 4600 are plotted in red.

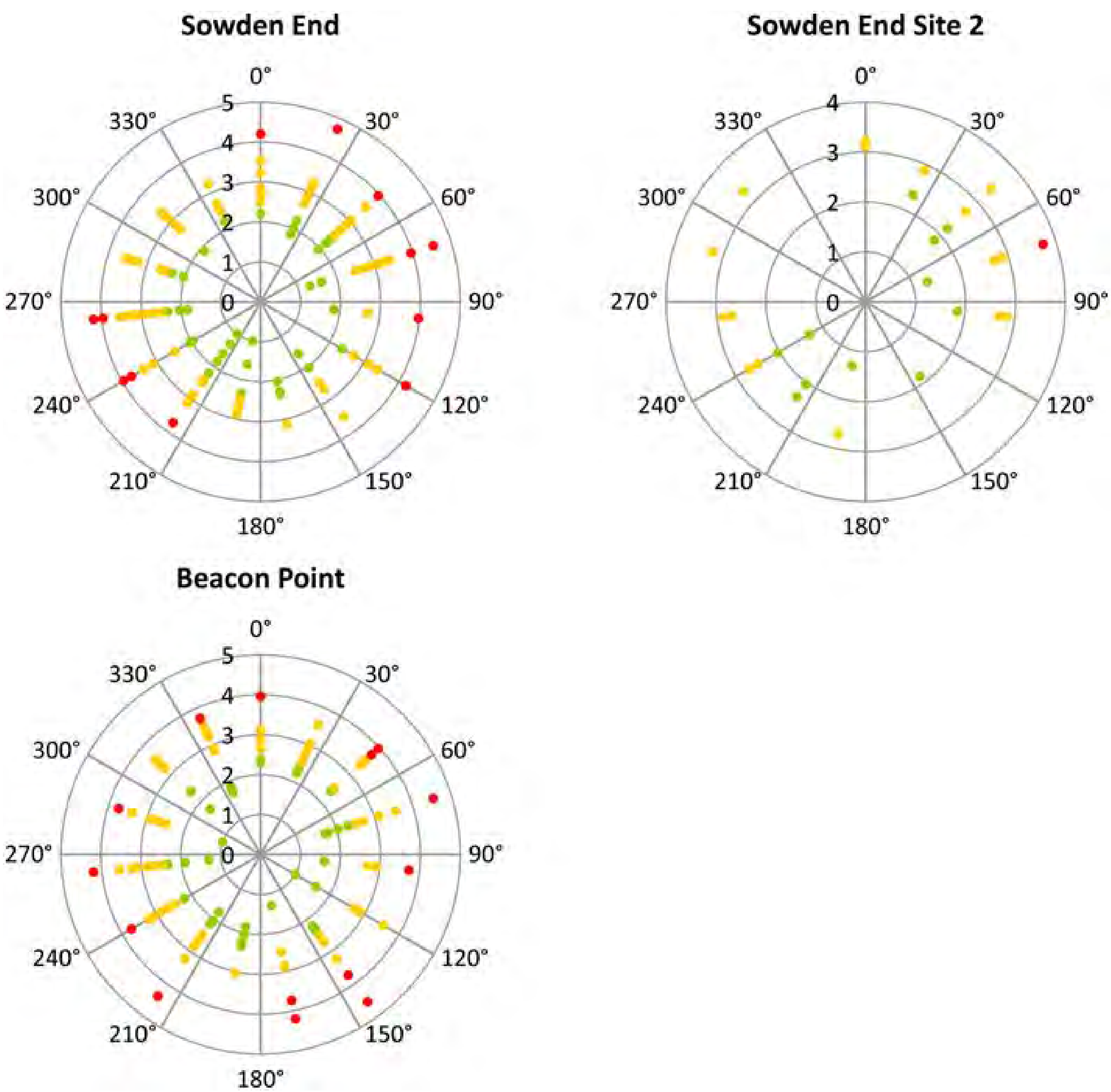

Figure XI.17: Polar plots of log_{10} *E. coli* results (MPN/100g) against tidal state on the spring/neap tidal cycle for mussel sampling points with significant correlations

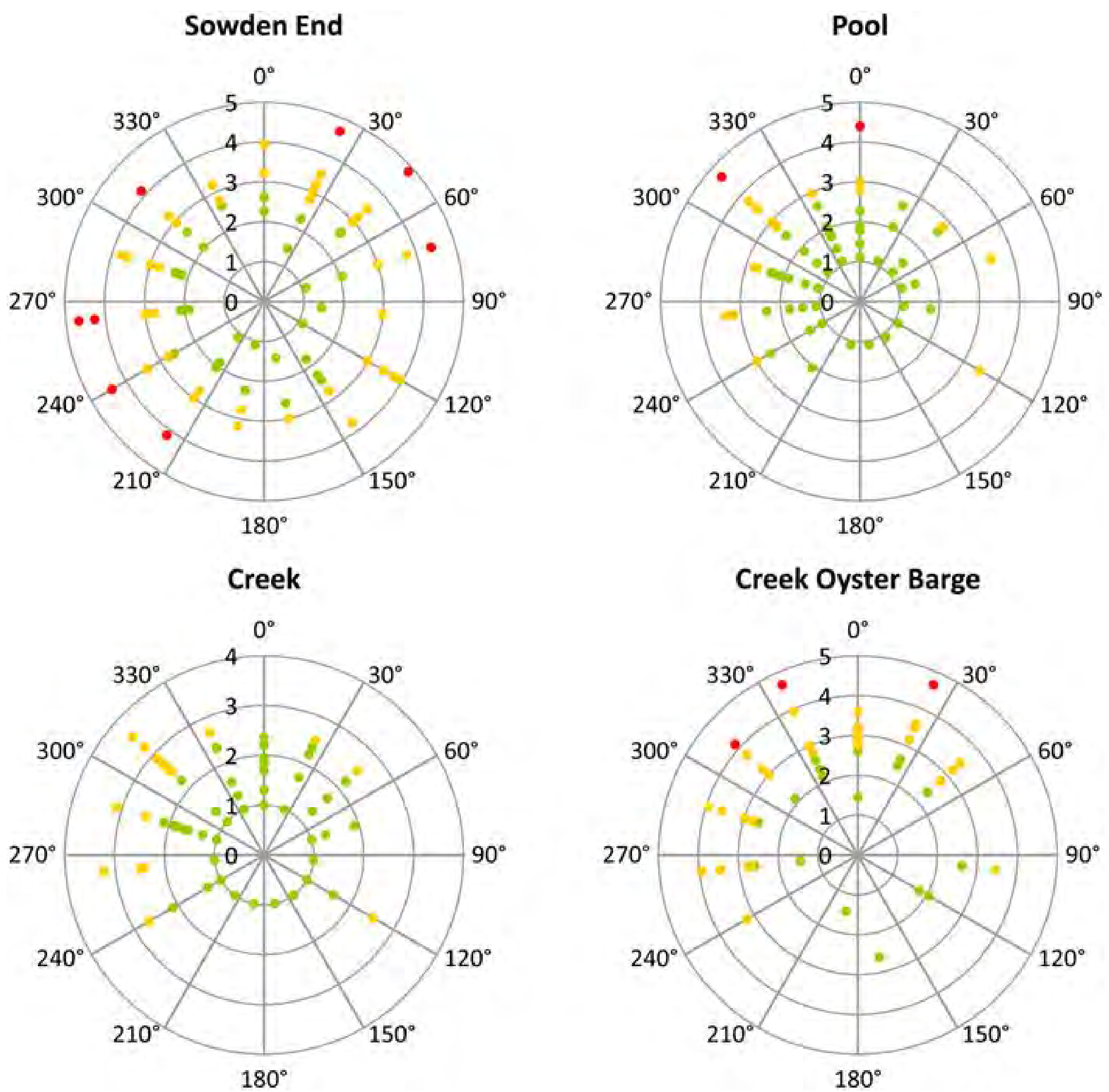

Figure XI.18: Polar plots of log10 *E. coli* results (MPN/100g) against tidal state on the spring/neap tidal cycle for Pacific oyster sampling points with significant correlations

ll of the RMPs (both mussel and Pacific oyster) which had significant correlations with the spring/neap tidal cycle tended to have higher *E. coli* levels as tide size increased towards spring tides.

XI.4. Influence of rainfall

To investigate the effects of rainfall on levels of contamination within shellfish samples, Spearman's rank correlations were carried out between *E. coli* results and rainfall recorded at the Exminster weather station (Appendix VI for details) over various periods running up to sample collection. These are presented in Table XI.3, and statistically significant correlations ($p<0.05$) are highlighted in yellow.

Table XI.3: Spearman's Rank correlations between rainfall recorded at Exminster and shellfish hygiene *E. coli* results from the Exe

			24 hour periods prior to sampling							Total prior to sampling over					
Site	**Species**	**n**	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**
Kings Lake	Cockle	103	0.209	0.128	0.127	0.168	0.198	0.112	0.119	0.204	0.212	0.231	0.245	0.259	0.242
Sowden End	Manila clam	30	-0.045	-0.101	0.102	0.074	0.251	-0.108	0.216	-0.030	0.068	0.054	0.085	0.068	0.137
Shelly Bank	Manila clam	40	0.102	0.130	0.304	0.249	0.220	0.275	0.145	0.147	0.237	0.258	0.286	0.415	0.442
Sowden End	Mussel	124	0.300	0.192	0.220	0.396	0.117	0.194	0.143	0.275	0.307	0.337	0.341	0.394	0.397
Sowden End Site 2	Mussel	30	0.458	0.377	0.260	0.422	0.171	0.346	0.259	0.458	0.456	0.445	0.485	0.491	0.461
Pool	Mussel	110	0.185	0.016	0.131	0.223	0.151	0.041	0.111	0.125	0.172	0.201	0.196	0.216	0.250
Mussel South	Mussel	118	0.057	0.050	0.134	0.225	0.113	0.028	0.202	0.075	0.152	0.182	0.172	0.195	0.255
Beacon Point	Mussel	108	0.240	0.299	0.292	0.404	0.304	0.347	0.317	0.287	0.326	0.387	0.389	0.416	0.446
Maer Rock No. 11 Buoy	Mussel	38	-0.031	0.399	0.365	0.388	0.239	0.303	0.159	0.225	0.328	0.338	0.378	0.386	0.361
Sowden End	Pacific oyster	80	0.030	0.032	0.111	0.090	-0.016	0.063	-0.045	0.023	0.102	0.102	0.080	0.125	0.113
Powderham	Pacific oyster	63	-0.078	-0.021	0.162	-0.120	-0.209	-0.148	-0.132	-0.083	-0.014	-0.063	-0.149	-0.142	-0.158
Pool	Pacific oyster	114	0.051	0.025	0.126	0.003	-0.112	0.055	-0.033	0.050	0.075	0.059	0.009	0.036	-0.004
Creek	Pacific oyster	116	0.006	0.044	0.141	-0.034	-0.083	-0.021	-0.100	0.021	0.035	0.019	-0.011	-0.004	-0.047
Creek Oyster Barge	Pacific oyster	55	0.149	0.086	0.074	0.114	-0.092	0.082	-0.107	0.148	0.148	0.141	0.078	0.112	0.082

Rainfall events rapidly increased contamination in most mussel sites and the Kings Lake cockle RMP. However, rainfall did not have a significant effect on contamination at Pacific oyster RMPs. At Powderham, the farthest up-estuary site, increased rainfall actually appears to be tentatively associated with lower *E. coli* results. This is probably due to the greater tolerance of mussels (and possibly cockles) to changes in salinity. Lowered salinity due to rainfall is likely to reduce feeding of the oysters, therefore decreasing their uptake of contaminants.

Appendix XII. Shoreline Survey Report

Date (time)
2nd July 2013 (08:50 – 12:15)
3rd July 2013 (08:30 – 13:00)

Cefas officers
David Walker (both dates)
Alastair Cook (3rd July only)

Local Enforcement Authority Officer
Gavin Fearby, Teignbridge DC (2nd July only)

Area Surveyed
Southern half of Exe estuary. From Dawlish Warren to Powderham on western shore, and from Exmouth to Lympstone on eastern shore (Figure XII.1).

Weather
2nd July, clear, 15°C, wind 6.5 km/h 0°
3rd July, clear, 18°C, wind 1 km/h 188°

Tides
Admiralty TotalTide predictions for Exmouth (50°36'N 3°23'W). All times in this report are BST.

02/07/2013		
	Time	Height
High	01:08 13:37	3.4 m 3.3 m
Low	06:37 19:07	1.5 m 1.6 m

03/07/2013		
	Time	Height
High	02:10 14:41	3.4 m 3.4 m
Low	07:40 20:13	1.5 m 1.5 m

XII.1. Objectives

The shoreline survey aims to obtain samples of freshwater inputs to the area for bacteriological testing; confirm the location of previously identified sources of potential contamination; locate other potential sources of contamination that were previously unknown and find out more information about the fishery. A full list of recorded observations is presented in Table XII.1 and the locations of these observations are mapped in Figure XII.1. Photographs are presented in Figure XII.3 to Figure XII.25. The shoreline survey was carried out over several visits. Every effort was made to ensure the entire shoreline was surveyed, although there were some short stretches where the shoreline was privately owned and could not be accessed.

XII.2. Description of Fishery

There are currently classifications for Pacific oysters and mussels in the Exe estuary. However, recent applications for both palourdes and native oysters have been made. There are no palourdes in the interim RMP assigned for palourdes (nearby observation 10) and initial samples for palourde classification have been taken within a 150 m radius of observation 8, as this is the only area where there is a high enough density to allow sampling. Nevertheless, it takes a very long time to acquire enough specimens from this site for a sample, indicating that there is unlikely to be a high enough density for a viable fishery.

Additionally, sample collection for the Mussel South RMP (SX 982 803), occurs approximately 240 m to the north-north west of the RMP due to low stock densities at the RMP site. The actual sampling location is very close to the edge of the tolerance for this RMP.

Dead shells of cockles and mussels were observed throughout the estuary and dead shells of palourdes were observed on the western shore.

XII.3. Sources of contamination

Sewage discharges

The Kenton and Starcross STW is the only water company STW that discharges into the estuary within the survey area. This STW discharges with the River Kenn at observation 13. A sample was taken here that had an *E. coli* concentration of 610 CFU/100 ml, which equates to approximately 1.2×10^{12} CFU per day (Sample D07).

There are several intermittent discharges into the estuary and the locations of the Ship Inn CSO, Cockwood PSEO, Bonhay Road CSO, Imperial Road CSO, Hartopp road CSO, Exeter Road CSO, Ash grove CSO, Sowden Lane CSO and Lympstone Foreshore CSO were confirmed.

Freshwater inputs

Three water courses were observed, including Shutterton Brook (observation 3), the River Kenn (observation 13) and Wooton Brook (observation 38). All of these inputs were sampled and were found to contribute approximately 2.6×10^{12} *E. coli* CFU per day combined. However, Wooton Brook had particularly high concentrations of *E. coli* at 41,000 CFU/100 ml, indicating that it is contaminated with a significant sewage source. There are no water company assets registered as discharging into Wooton Brook however a private sewage treatment works and a poultry farm both have registered discharged upstream.

Boats and Shipping

Recreational boats were seen moored throughout the estuary in both the channels and the intertidal areas.

Wildlife

Some scattered flocks of birds were seen throughout the harbour.

Other

On 2nd July much of the seawater along the shoreline was observed to contain black suspended sediment. This was likely to be churned up deeper anoxic layers of the estuary bed. According the Gavin Fearby from Teignbridge DC, this occurred during recent work that was undertaken on an upstream bridge.

Seawater samples taken across the estuary had approximately 1 log higher *E. coli* on 2nd July on the western shore than on 3rd July on the eastern shore where no black sediment was observed. This difference in E. coli levels may be explained by the resuspension of *E. coli* in sediment. However, due to the low tidal state on 3rd July no samples were taken on the eastern shore that corresponded properly with those on the western shore. Therefore it cannot be concluded that the higher *E. coli* levels were caused by resuspension.

Figure XII.1: Locations of shoreline observations (see Table XII.1 for details)

Table XII.1: Details of Shoreline Observations

No.	NGR	Date	Time	Photo	Description
1	SX 98842 79364	02/07/2013	09:03		Groyne 9, no dogs beyond this point
2	SX 98730 79943	02/07/2013	09:15		Seawater sample (sample D01)
3	SX 97865 79443	02/07/2013	09:54	Figure XII.3	Stream (Shutterton Brook) - Outfall for Dawlish Warren PS (sample D02)
4	SX 97858 80097	02/07/2013	10:04	Figure XII.4	Drainage from under railway
5	SX 97735 80723	02/07/2013	10:19	Figure XII.5	Harbour entrance - Outfall for Ship Inn CSO and Cockwood PSEO (sample D03)
6	SX 97795 80906	02/07/2013	10:25	Figure XII.6	Bagged mussels
7	SX 97792 80939	02/07/2013	10:27		Dead shell (Palourdes, cockles, mussels)
8	SX 97761 81040	02/07/2013	10:29		~150 m radius for actual palourde collection
9	SX 97750 81110	02/07/2013	10:42		Drainage from golf club (sample D04)
10	SX 97792 81703	02/07/2013	10:42		Seawater sample. No shellfish visible (rocky substrate) (sample D05)
11	SX 97730 81870	02/07/2013	10:51	Figure XII.7	Bonhay Road CSO outfall
12	SX 97628 82253	02/07/2013	10:52	Figure XII.8	Pipe, not flowing (sample D06)
13	SX 97489 83184	02/07/2013	11:21	Figure XII.9	River Kenn flowing through sluices (sample D07)
14	SX 97375 83514	02/07/2013	11:28		Drainage ditch from Powderham Castle grounds (sample D08)
15	SX 97508 84037	02/07/2013	11:42		Seawater sample (sample D09)
16	SX 99529 80603	03/07/2013	08:47		Seawater sample (sample E01)
17	SX 99354 80642	03/07/2013	08:53	Figure XII.10	Mussel nets on land (out back of Exmouth mussels)
18	SX 99481 80959	03/07/2013	09:04		Patio drainage
19	SX 99550 80946	03/07/2013	09:06		Drainage from workshop
20	SX 99593 80936	03/07/2013	09:07	Figure XII.11	Pile of mussel dead shell
21	SX 99609 80945	03/07/2013	09:09	Figure XII.12	Surface water outfall, not flowing
22	SX 99858 81119	03/07/2013	09:20	Figure XII.13	Imperial Road CSO, not flowing
23	SX 99906 81075	03/07/2013	09:21		Imperial Road pumping station
24	SX 99942 81066	03/07/2013	09:23		Enclosure for 22
25	SX 99959 81470	03/07/2013	09:29	Figure XII.14	Hartopp road CSO, not flowing, black and anoxic (sample E02)
26	SX 99969 82034	03/07/2013	09:42	Figure XII.15	Storm drain (sample E03)
27	SX 99965 82042	03/07/2013	09:50	Figure XII.16	Drain, possibly Exeter Road CSO, not flowing. Algae indicates high nutrients
28	SX 99965 82042	03/07/2013	09:50	Figure XII.17	Just downstrean of 27. Sanitary waste, possible sewage fungus
29	SX 99617 82574	03/07/2013	10:02	Figure XII.18	Cone covered with barnacles at site of registered private discharge
30	SX 99520 82756	03/07/2013	10:06	Figure XII.19	Possible old trestle posts ~100 m NW
31	SX 99519 82912	03/07/2013	10:10	Figure XII.20	Ash grove CSO outfall (sample E04)
32	SX 99464 83067	03/07/2013	10:17	Figure XII.21	Pipe
33	SX 99324 83318	03/07/2013	10:22		Crab tiles
34	SX 99061 83594	03/07/2013	10:29	Figure XII.22 & Figure XII.23	Sowden Lane CSO, pipe fractured so not discharging in proper location. Not flowing. Old bags of oysters, possibly abandoned
35	SX 99154 83679	03/07/2013	10:39		Pumping station for 34
36	SX 98786 83919	03/07/2013	10:47	Figure XII.24	Lympstone Foreshore CSO
37	SX 98836 84062	03/07/2013	10:51		Pumping station for 36

No.	NGR	Date	Time	Photo	Description
38	SX 98842 84115	03/07/2013	10:53	Figure XII.25	Wooton Brook (sample E05)
39	SY 00281 80171	04/07/2013	11:35		Seawater sample (sample E06)

Table XII.2: Water sample *E. coli* results, spot flow gauging results and estimated stream loadings

Sample	Observation number	Water type	Flow (m^3/s)	*E. coli* concentration (CFU/100 ml)	*E. coli* loading (CFU/day)
D01	2	Sea water		10	
D02	3	Fresh water	0.06372	1300	$7.16x10^{10}$
D03	5	Sea water		30	
D04	9	Fresh water	0.0201	550	$9.55x10^{9}$
D05	10	Sea water		1600	
D06	12	Sea water		840	
D07	13	Fresh water	2.216667	610	$1.17x10^{12}$
D08	14	Fresh water		160	
D09	15	Sea water		200	
E01	16	Sea water		20	
E02	25	Fresh water		30	
E03	26	Fresh water	0.066623	4000	$2.30x10^{11}$
E04	31	Fresh water	0.004176	900	$3.25x10^{9}$
E05	38	Fresh water	0.03696	41000	$1.31x10^{12}$
E06	39	Sea water		10	

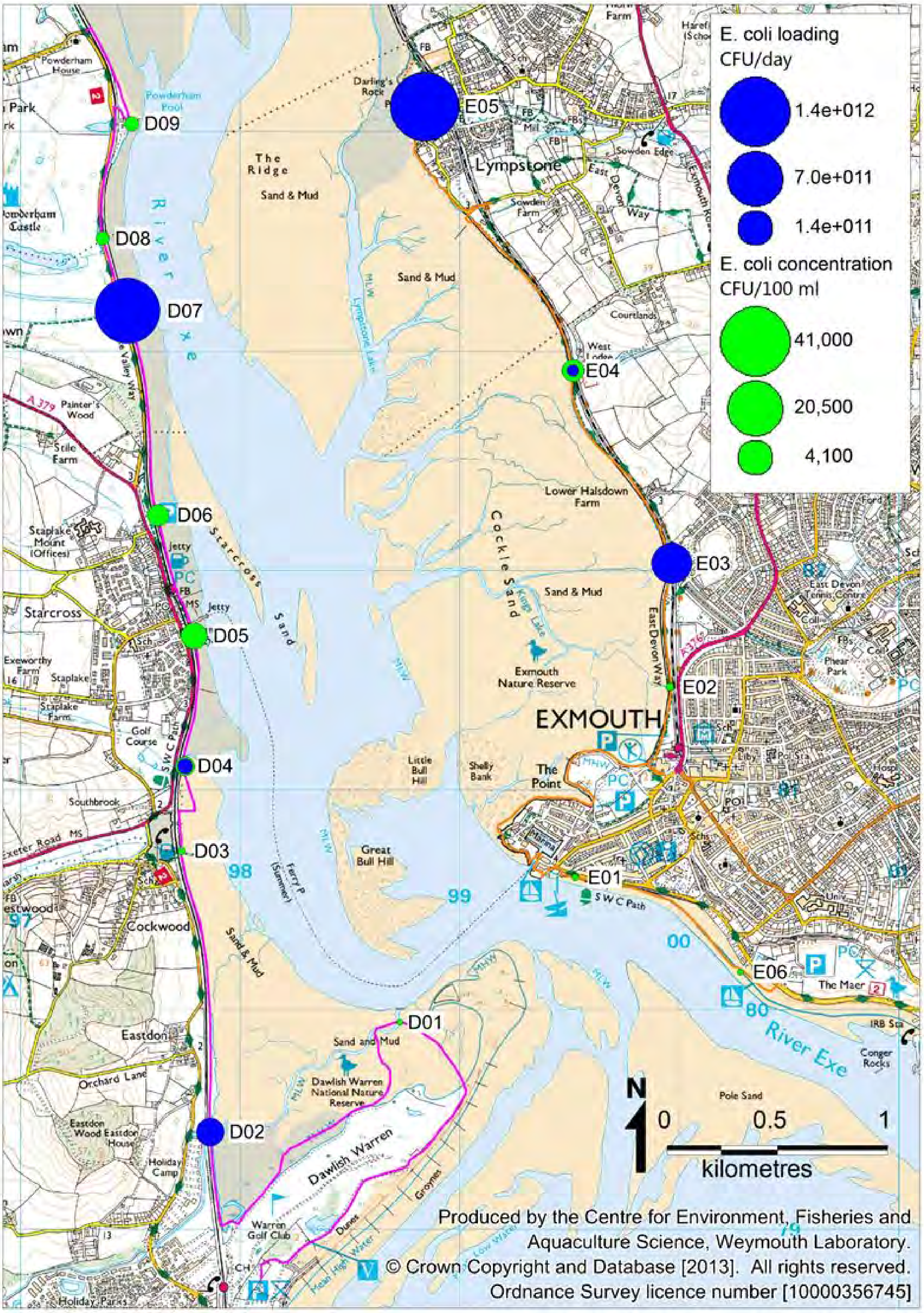

Figure XII.2: Water sample results

Figure XII.3

Figure XII.4

Figure XII.5

Figure XII.6

Figure XII.7

Figure XII.8

Figure XII.9

Figure XII.10

Figure XII.11

Figure XII.12

Figure XII.13

Figure XII.14


Figure XII.15


Figure XII.16

Figure XII.17

Figure XII.18

Figure XII.19

Figure XII.20

Figure XII.21

Figure XII.22


Figure XII.23


Figure XII.24

Figure XII.25

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List of Abbreviations

AONB	Area of Outstanding Natural Beauty
BMPA	Bivalve Mollusc Production Area
CD	Chart Datum
Cefas	Centre for Environment Fisheries & Aquaculture Science
CFU	Colony Forming Units
CSO	Combined Sewer Overflow
CZ	Classification Zone
Defra	Department for Environment, Food and Rural Affairs
DWF	Dry Weather Flow
EA	Environment Agency
E. coli	Escherichia coli
EC	European Community
EEC	European Economic Community
EO	Emergency Overflow
FIL	Fluid and Intravalvular Liquid
FSA	Food Standards Agency
GM	Geometric Mean
IFCA	Inshore Fisheries and Conservation Authority
ISO	International Organization for Standardization
km	Kilometre
LEA (LFA)	Local Enforcement Authority formerly Local Food Authority
M	Million
m	Metres
ml	Millilitres
mm	Millimetres
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MPN	Most Probable Number
NM	Nautical Miles
NRA	National Rivers Authority
NWSFC	North Western Sea Fisheries Committee
OSGB36	Ordnance Survey Great Britain 1936
mtDNA	Mitochondrial DNA
PS	Pumping Station
RMP	Representative Monitoring Point
SAC	Special Area of Conservation
SHS	Cefas Shellfish Hygiene System, integrated database and mapping application
SSSI	Site of Special Scientific Interest
STW	Sewage Treatment Works
UV	Ultraviolet
WGS84	World Geodetic System 1984

Glossary

Bathing Water	Element of surface water used for bathing by a large number of people. Bathing waters may be classed as either EC designated or non-designated OR those waters specified in section 104 of the Water Resources Act, 1991.
Bivalve mollusc	Any marine or freshwater mollusc of the class Pelecypoda (formerly Bivalvia or Lamellibranchia), having a laterally compressed body, a shell consisting of two hinged valves, and gills for respiration. The group includes clams, cockles, oysters and mussels.
Classification of bivalve mollusc production or relaying areas	Official monitoring programme to determine the microbiological contamination in classified production and relaying areas according to the requirements of Annex II, Chapter II of EC Regulation 854/2004.
Coliform	Gram negative, facultatively anaerobic rod-shaped bacteria which ferment lactose to produce acid and gas at 37°C. Members of this group normally inhabit the intestine of warm-blooded animals but may also be found in the environment (e.g. on plant material and soil).
Combined Sewer Overflow	A system for allowing the discharge of sewage (usually dilute crude) from a sewer system following heavy rainfall. This diverts high flows away from the sewers or treatment works further down the sewerage system.
Discharge	Flow of effluent into the environment.
Dry Weather Flow (DWF)	The average daily flow to the treatment works during seven consecutive days without rain following seven days during which rainfall did not exceed 0.25 mm on any one day (excludes public or local holidays). With a significant industrial input the dry weather flow is based on the flows during five working days if production is limited to that period.
Ebb tide	The falling tide, immediately following the period of high water and preceding the flood tide.
EC Directive	Community legislation as set out in Article 189 of the Treaty of Rome. Directives are binding but set out only the results to be achieved leaving the methods of implementation to Member States, although a Directive will specify a date by which formal implementation is required.
EC Regulation	Body of European Union law involved in the regulation of state support to commercial industries, and of certain industry sectors and public services.
Emergency Overflow	A system for allowing the discharge of sewage (usually crude) from a sewer system or sewage treatment works in the case of equipment failure.
Escherichia coli (E. coli)	A species of bacterium that is a member of the faecal coliform group (see below). It is more specifically associated with the intestines of warm-blooded animals and birds than other members of the faecal coliform group.
E. coli O157	E. coli O157 is one of hundreds of strains of the bacterium Escherichia coli. Although most strains are harmless, this strain produces a powerful toxin that can cause severe illness. The strain O157:H7 has been found in the intestines of healthy cattle, deer, goats and sheep.
Equilibrate	To bring to or be in equilibrium/balance. In the context used in this report: a time period which allows sufficient time for the species of filter feeding bivalve mollusc being sampled to reach an equilibrium between the amount of faecal indicator bacteria in the overlying water and the amount ingested/accumulated by the shellfish. This necessarily assumes consistent level of bacteria in the water whereas in practise the level will vary.
Faecal coliforms	A group of bacteria found in faeces and used as a parameter in the Hygiene Regulations, Shellfish and Bathing Water Directives, E. coli is the most common example of faecal coliform. Coliforms (see above) which can produce their characteristic reactions (e.g. production of acid from lactose) at 44°C as well as 37°C. Usually, but not exclusively, associated with the

	intestines of warm-blooded animals and birds.
Flood tide	The rising tide, immediately following the period of low water and preceding the ebb tide.
Flow ratio	Ratio of the volume of freshwater entering into an estuary during the tidal cycle to the volume of water flowing up the estuary through a given cross section during the flood tide.
Geometric mean	The geometric mean of a series of N numbers is the Nth root of the product of those numbers. It is more usually calculated by obtaining the mean of the logarithms of the numbers and then taking the anti-log of that mean. It is often used to describe the typical values of skewed data such as those following a log-normal distribution.
Hydrodynamics	Scientific discipline concerned with the mechanical properties of liquids.
Hydrography	The study, surveying, and mapping of the oceans, seas, and rivers.
Lowess	Locally Weighted Scatterplot Smoothing, more descriptively known as locally weighted polynomial regression. At each point of a given dataset, a low-degree polynomial is fitted to a subset of the data, with explanatory variable values near the point whose response is being estimated. The polynomial is fitted using weighted least squares, giving more weight to points near the point whose response is being estimated and less weight to points further away. The value of the regression function for the point is then obtained by evaluating the local polynomial using the explanatory variable values for that data point. The LOWESS fit is complete after regression function values have been computed for each of the n data points. LOWESS fit enhances the visual information on a scatterplot.
Telemetry	A means of collecting information by unmanned monitoring stations (often rainfall or river flows) using a computer that is connected to the public telephone system.
Secondary Treatment	Treatment to applied to breakdown and reduce the amount of solids by helping bacteria and other microorganisms consume the organic material in the sewage or further treatment of settled sewage, generally by biological oxidation.
Sewage	Sewage can be defined as liquid, of whatever quality that is or has been in a sewer. It consists of waterborne waste from domestic, trade and industrial sources together with rainfall from subsoil and surface water.
Sewage Treatment Works (STW)	Facility for treating the waste water from predominantly domestic and trade premises.
Sewer	A pipe for the transport of sewage.
Sewerage	A system of connected sewers, often incorporating inter-stage pumping stations and overflows.
Storm Water	Rainfall which runs off roofs, roads, gulleys, etc. In some areas, storm water is collected and discharged to separate sewers, whilst in combined sewers it forms a diluted sewage.
Waste water	Any waste water but see also “sewage”.

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