EC Regulation 854/2004

CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES

SANITARY SURVEY REPORT

Dart Estuary (Devon)

2009

Cover photo: Pacific oysters in bags on trestles at Higher Gurrow Point (foreground). Sandridge Boathouse and vessel used by the shellfish industry in the Dart Estuary (Background).

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STATEMENT OF USE: This report provides information from a study of the information available relevant to perform a sanitary survey of bivalve mollusc production areas in the Dart Estuary. Its primary purpose is to demonstrate compliance with the requirements for classification of bivalve mollusc production areas, laid down in EC Regulation 854/2004 laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption. The Centre for Environment, Fisheries & Aquaculture Science (Cefas) undertook this work on behalf of the Food Standards Agency (FSA).

DISSEMINATION: Food Standards Agency, South Hams District Council (Environmental Health), Devon Sea Fisheries Committee, Environment Agency.

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EXECUTIVE SUMMARY

Under EC Regulation 854/2004, there is a requirement for competent authorities intending to classify bivalve mollusc production and relaying areas (BMPAs) to undertake a number of tasks collectively known (in England and Wales) as 'sanitary surveys'. The main purpose of these surveys is to inform the sampling plans for the microbiological monitoring and classification of BMPAs.

This report documents the qualitative assessment made to the levels of microbiological contamination in Pacific oysters and mussels from the Dart Estuary, on the South Devon coast as a result of a sanitary survey undertaken by Cefas on behalf of the Food Standards Agency (FSA). The assessment is supported by published information for the Dart river catchment areas and information obtained from a shoreline survey performed in the estuary. The report also presents the recommended sampling plan for new and existing BMPAs in the estuary.

Significant correlations were found between daily and total river flows and *E. coli* levels in bivalves from most existing RMPs. Similarly, *E. coli* levels in bivalves from all RMPs showed a significant relationship with total rainfall for a period of, at least, three days before sampling. Both results indicate the positive effect of rainfall and river flow in determining the variation of the levels of microbiological contamination in bivalves from the Dart Estuary.

The main pollution sources likely to affect the levels of microbiological contamination to BMPAs are continuous sewage discharges at Totnes, Dittisham, Ashprington, Harbertonford and, to a lesser extent, Dartmouth STW and crude discharges in the South Town area of Dartmouth. A number of continuous and intermittent minor sewage discharges at Higher Dittisham, Stoke Gabriel, Tuckenhay and Totnes and diffuse agricultural runoff to the River Dart or its main tributaries (Harbourne, Hems and Wash) may contribute to elevated levels of contamination, particularly during heavy rainfall or storm periods.

Waste discharges from boats and bird faeces deposited directly onto the sandbanks are considered to potentially contribute to elevated levels of microbiological contamination in bivalve molluscs.

As a consequence of this assessment, new boundaries were defined for new and existing BMPAs and new locations of RMPs were established for the purposes of the sampling plan.

1 INTRODUCTION

The present report documents information relevant to undertake a sanitary survey of bivalve mollusc production areas (BMPAs) in the Dart Estuary (Devon). The sanitary survey was prompted by an application for microbiological monitoring and classification of Pacific oysters (*Crassostrea gigas*) at Blackness Point.

On 21 November 2008, the LEA informed Cefas that the industry no longer wishes to use the area at Blackness Point for cultivation operations but only for seed production. Information relating to the assessment of microbiological pollution sources on this area and recommendations for its monitoring have therefore been deleted from this report.

A desk based assessment of existing information has been undertaken and the results are presented in Sections 2 to 9. The results from a shoreline survey undertaken in the proposed BMPA and adjacent coastal area of the estuary are set out in the Appendix I.

In Section 10, the results of the desk study and shoreline survey are drawn together in an overall assessment of the potential sources of pollution likely to impact on the levels of microbiological contamination for BMPAs.

The sampling plan for microbiological monitoring, derived from the overall assessment, is set out in Appendix II. The sampling plan includes the location of representative monitoring points (RMPs) and required sampling frequency for Pacific oysters and mussels in new and existing BMPAs in the estuary.

1.1 Background

Filter feeding, bivalve molluscan shellfish (e.g. oysters, mussels) 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 (Bell, 2006).

When consumed raw or lightly cooked, bivalves contaminated with pathogenic microorganisms may cause infectious diseases (e.g. Norovirus-associated gastroenteritis, Hepatitis A, 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 microbiological 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 areas;

(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 regime 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 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. However, the standard test[1] used to enumerate *E. coli* does not differentiate between contamination of animal or human origins. For example, the enterohemorrhagic serotype *E. coli* O157 can be present in cattle faeces at concentrations of 10^6 CFU g^{-1} (1,000,000 Colony Forming Units per gram) (Omisakin *et al.*, 2003). The average flux of faecal coliforms from humans is approximately 2.14×10^9 CFU g^{-1} per day (Geldreich, 1966).

Both sewage discharges and agricultural inputs to river systems discharging to estuaries are thought to significantly impact on a number of coastal and estuarine BMPAs in England and Wales (Younger *et al.*, 2003). Another potentially significant source of contamination is waste discharged from boats (Sobsey *et al.*, 2003).

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[1] ISO TS 16649-3: Microbiology of food and animal feeding stuffs – Enumeration of β-Glucuronidase positive *Escherichia coli* – part 3: Most Probable Number (MPN) technique using 5-Bromo-4-Cloro-3-Indolyl-β-D-Glucuronide Acid. International Organization for Standardization, Geneva.

The outcomes of the sanitary survey should better target the location of RMPs and frequency of sampling for microbiological monitoring and improved monitoring should lead to improved detection of pollution events and identification of sources of pollution. Remedial action may then be possible either through funding of improvements in point sources of contamination or as a result of proactive changes in land management practices.

2 SITE DESCRIPTION

The Dart Estuary is situated in Devon, southwest coast of England (Figure 2.1).

Figure 2.1. Location of the Dart Estuary, Devon and its two river catchments.

The River Dart drains a catchment area of 470 km^2, from its headwaters on the slopes of Dartmoor National Park to where it enters the sea at Dartmouth (Figure 1.2) in Start Bay is approximately 45 km. The catchment includes upland moor, steep sided, wooded river valleys and low-lying, undulating land in the lower estuarine reaches. Well drained loams over limestone, sandstone or shale and loams over granite are the predominant soil types in upper and mid reaches of the catchment (Environment Agency, 2004).

The Dart catchment contains a wide range of habitats that support a remarkable diversity of plants and animals. There are various habitat conservation designations within the catchment, including 21 Sites of Special Scientific Interest (SSSI). The tidal area and surrounding valley downstream of Totnes is part of the South Devon Area of Outstanding Natural Beauty (AONB). Dartmoor and the South Dartmoor Woodlands are candidate Special Areas of Conservation (cSACs), to be designated under the EC Habitats Directive on the Conservation of Natural Habitats and wild fauna and flora. Other important designations include a Prime Biodiversity Area of the Dart valley above Buckfastleigh and the Environmentally Sensitive Area (ESA) of Dartmoor.

Figure 2.2. Aerial view of the Dart Estuary.
Reproduced under licence from ©Anquet Technology Ltd (2005).

The estuarine coastal area is predominantly formed by rocky shores bordered by woodland and agricultural land. Sandflats, mudflats and a few areas of saltmarsh dominate the intertidal area.

2.1 Human population and tourism activities

The Dart catchment is predominantly rural and sparsely populated. The major population centres are listed in Table 2.1.

Table 2.1. Population centres in the Dart river catchment.

Town	Resident population
Totnes	8,210
Dartmouth	5,678
Ashburton	4,243
Buckfastleigh	3,884
Stoke Gabriel	1,330
Dittisham	432

Data from Devon County Council (2008).

The distribution of resident human population in Census Area Wards totally or partially included within the Dart catchment area is shown in Figure 2.3. Resident population in coastal wards of the estuary ranges from 4,975 people in Totnes Town Ward to 1,952 people in East Dart. More populated wards in the eastern part of the estuary, such as Blatchcombe (11,495 people), Ashburton and Buckfastleigh (8,261 people), Churston-with-Galmpton (6,938 people) and Ambrook (5,727 people) are partially contained within the Dart catchment.

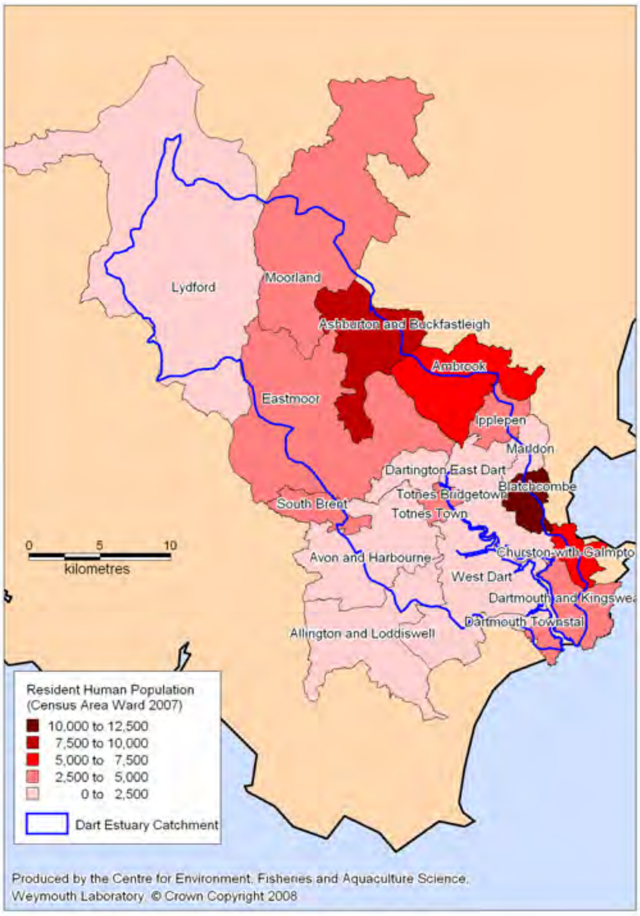


Figure 2.3. Human population in Census Area Wards in the Dart catchment area.
Data provided by the Devon County Council (2008) and based on data from the Office for National Statistics, Census Area Statistics (England and Wales). © Crown Copyright. Dart Estuary catchment boundary refers to Mean High Water. Census Area Ward boundaries refer to Mean Low Water.

Higher concentration of pollution sources of human origin would be expected in more populated wards. However, sewage effluents from these are not discharged to the estuary. Those considered to significantly impact on the levels of microbiological contamination in the estuary occur in Totnes and Dartmouth (see Section 7.1).

The low numbers of human population in wards in the upper Dart catchment contrast with significantly higher numbers of farmed cattle and sheep (see Sections 2.2 and 8.1) and therefore the overall potential microbiological load delivered from these areas of the catchment[2].

There is very little heavy industry within the catchment (Devon Wildlife Trust, 2004). The increase in human population in coastal areas of the Dart Estuary is mostly due to recreation and tourism activities. Tourism nowadays represents one of the most important industries in Devon. Approximately 15% of people in Dartmouth and 7.3% of people in Totnes parishes are employed in hotels and catering (Devon County Council, 2006, 2006a).

Tourism activities in the Dart catchment have long been associated with the countryside, yachting and boating. The number of visits to the main tourism attractions in the catchment reached more than 1.39 M people in 2002.
Tourism within the Dartmoor National Park is a major component of the local economy as a whole (Devon Wildlife Trust, 2004).

The estuary is also well known by its excellent conditions for water-based recreational activities (Devon Wildlife Trust, 2004). Of particular relevance are cruises along the river between Dartmouth and Totnes by the Dart Pleasure Craft Ltd (721,822 visitors) and the Woodlands Leisure Park at Dartmouth (400,000 visitors) undertaken on a year-round basis (South West Tourism *in* Devon Wildlife Trust, 2004).

Figure 2.4 shows an increase in the number of tourists to Dartmouth area from January to August and the popularity of summer months.

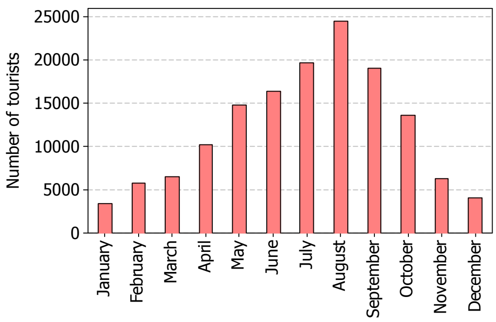


Figure 2.4. Monthly variation in numbers of tourists in Dartmouth. Figures indicate both overnight and day visitors.
Data from Dartmouth Tourist Information Centre (2008).

[2] Published literature quotes excreted thermotolerant coliforms in humans ranging between 10^5 and 4×10^8 coliforms per g, for an excretion rate of 150 g per day.) Whilst in cows the excretion of those microorganisms ranges between 2×10^5 and 7×10^7 coliforms per g, for an excretion rate of 23,600 g per day (see Pommepuy *et al.*, 2005). These figures indicate that contamination from cattle is potentially higher than contamination from human sources.

Increased human impact in summer months will increase the potential for higher levels of microbiological contamination in the estuary. This is likely to be one of the factors accounting for a significant increase in geometric means of *E. coli* detected in mussels from Flat Owers, Sandridge Boathouse and Waddeton in July (see Section 9.1.5).

2.2 Land use/cover and farm animals

In the upper reaches of the Dart catchment, Dartmoor comprises an area of granite outcrops and open moorland, drained by steep wooded valleys. The intermediate and lower areas of the catchment are dominated by agricultural land interspersed with significant areas of natural vegetation and grassland. Permanent grassland corresponds to approximately 35% of agricultural land (Defra 2008). There are urbanised areas containing some light industry at Totnes, Buckfastleigh and Dartmouth (Figure 2.5).

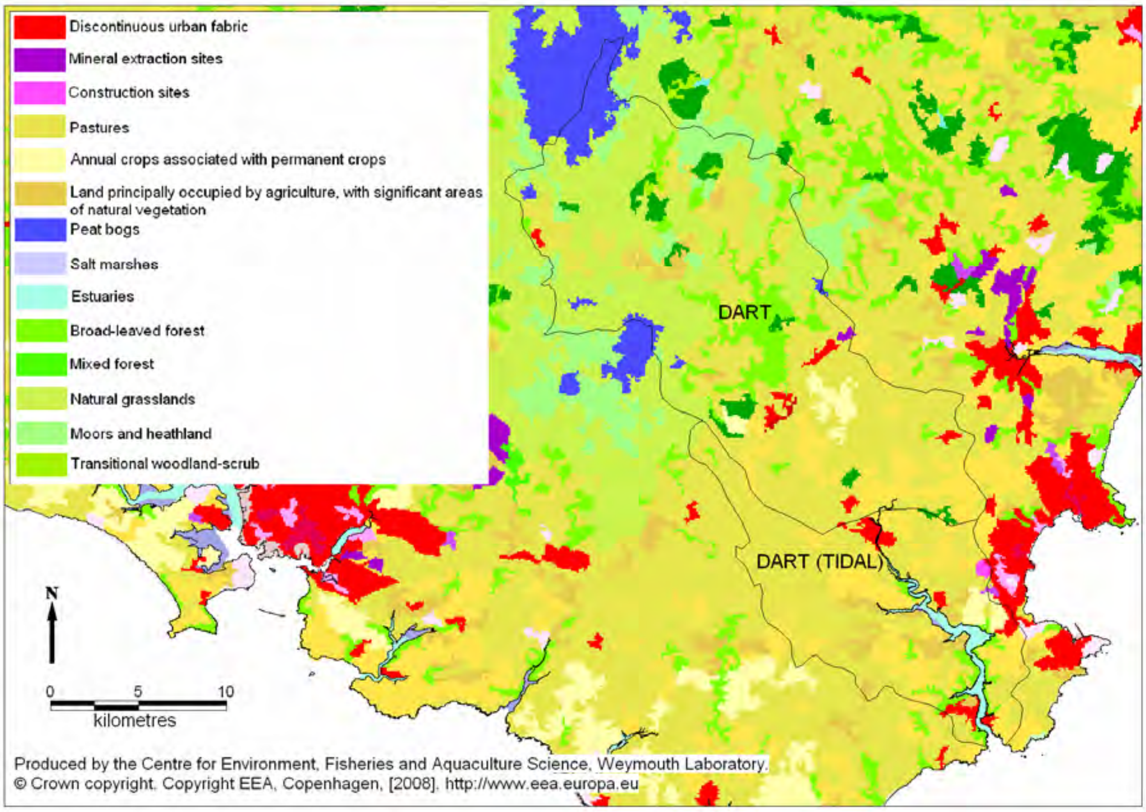


Figure 2.5. Land cover in the Dart catchment.

Extensive livestock production occurs both on moorland and grassland in the catchment. Approximately 56% of livestock are cattle and sheep (Table 2.2), which predominate in the upper Dart, whilst poultry predominate in lowland areas.

Table 2.2. Numbers of farmed animals in the Dart catchment.

Subcatchment	Cattle	Pigs	Sheep	Poultry
Dart (upper)	18,391	468	46,308	25,860
Dart (tidal)	12,752	3,702	27,548	52,791

Data from Defra June 2006 Agricultural Census.

These livestock production areas are potentially significant sources of microbiological contamination to the River Dart and its tributaries. The potential impact of these watercourses needs therefore to be considered in relation to the siting of RMPs for the microbiological monitoring programme. The effect of this in terms of the sampling plan is discussed in more detail in Section 8.1.

3 Shellfisheries

3.1 Species, location and extent

Harvesting of oysters and mussels for human consumption has a long tradition in the Dart Estuary. The cultivation of the Pacific oyster *Crassostrea gigas*, which is a non-native species in the UK, started in the 1960s in the Dart and is now well established in the estuary (Spencer *et al.*, 1994). Although the occurrence of natural spatfalls has been occasionally reported in the estuary, the cultivation is still dependent on the regular supply of juveniles (seed) from commercial hatcheries.

Natural spatfalls of mussels *Mytilus* spp. are also known to occur in the estuary. The production of this species is based on both natural stock and cultivation of seed dredged in South Devon [T. Robbins, Devon Sea Fisheries Committee (SFC), pers. com., 8 April 2008; Sarah Clark, Devon SFC, pers. com., 25 March 2008].

Cultivation operations have been established along the tidal waters of the intermediate estuary, at Sandridge Boathouse (total area = 0.007 km^2), Waddeton (total area = 0.02 km^2) and Flat Owers (total area = 0.01 km^2) (Figure 3.1).

The sanitary survey was prompted by an application for classification of a production area for Pacific oysters, covering an area of 0.008 km^2 at Blackness Point (as measured by Cefas following shoreline survey; see Appendix I).

Pacific oysters traditionally cultivated in bags at Sandridge Boathouse were transferred by the industry to Higher Gurrow Point (Figure 4). This was initially noted during the shoreline survey conducted on 23 January 2008 (see Appendix I), and later confirmed by the Local Enforcement Authority (LEA) to have occurred about 18 months previously (J. Kershaw, South Hams District Council, pers. com., 20 February 2008). The LEA also confirmed that sampling of Pacific oysters for the purposes of microbiological monitoring appears to have continued at Sandridge Boathouse.

The total area of the new bed at Higher Gurrow Point is approximately 0.006 km^2. This sanitary survey also documents information relevant to Higher Gurrow Point and the final sampling plan presented in the Appendix II of this report recommends the establishment of a new RMP and boundaries for a new production area at this site.

Bivalve mollusc cultivation sites within the estuary and the new area at Higher Gurrow Point are highlighted in Figure 3.1.

Existing production area and current classification status of *C. gigas* and *Mytilus* spp. in the Dart Estuary are shown in Figures 3.2 and 3.3.

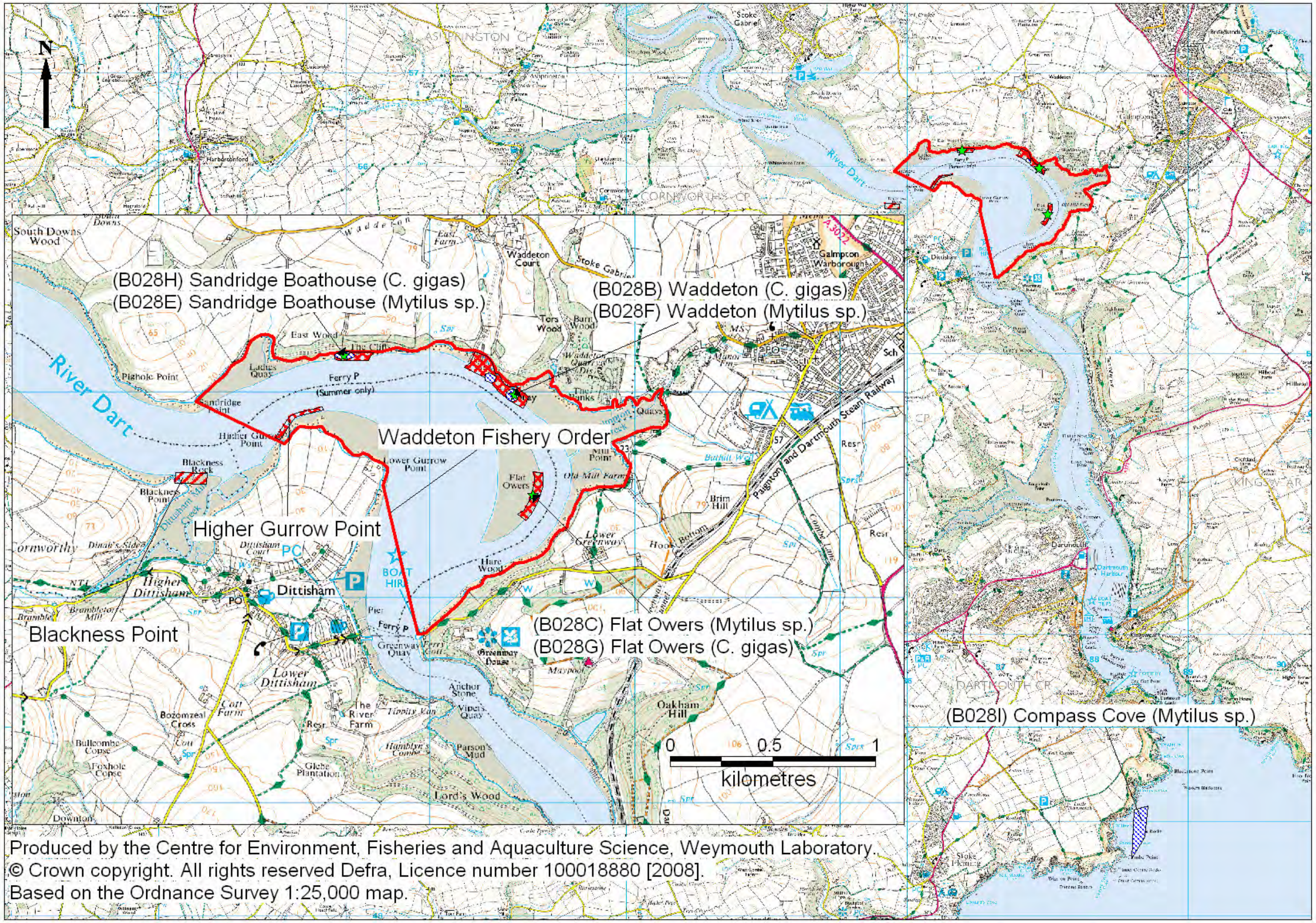
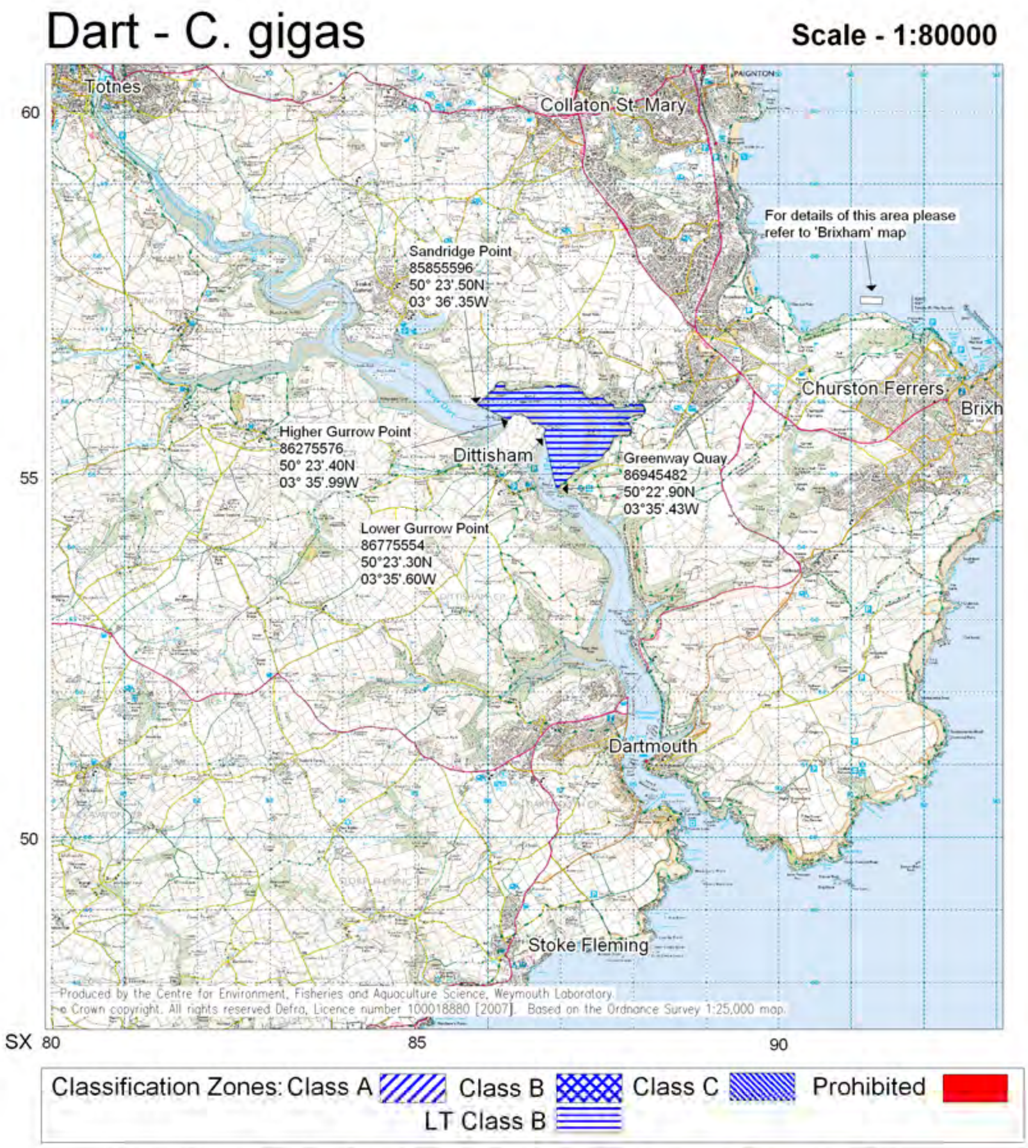


Figure 3.1. Bivalve mollusc cultivation sites and boundaries of Several Order in the Dart Estuary.



Classification of Bivalve Mollusc Production Areas: Effective from 1 September 2007

The areas delineated above are those classified as bivalve mollusc production areas under EU Regulation 854/2004.

Further details on the classified species and the areas may be obtained from the responsible Food Authority. Enquiries regarding the maps should be directed to: Shellfish Microbiology, CEFAS Weymouth Laboratory, Barrack Road, The Nothe, Weymouth, Dorset DT4 8UB.
(Tel: 01305 206600 Fax: 01305 206601)

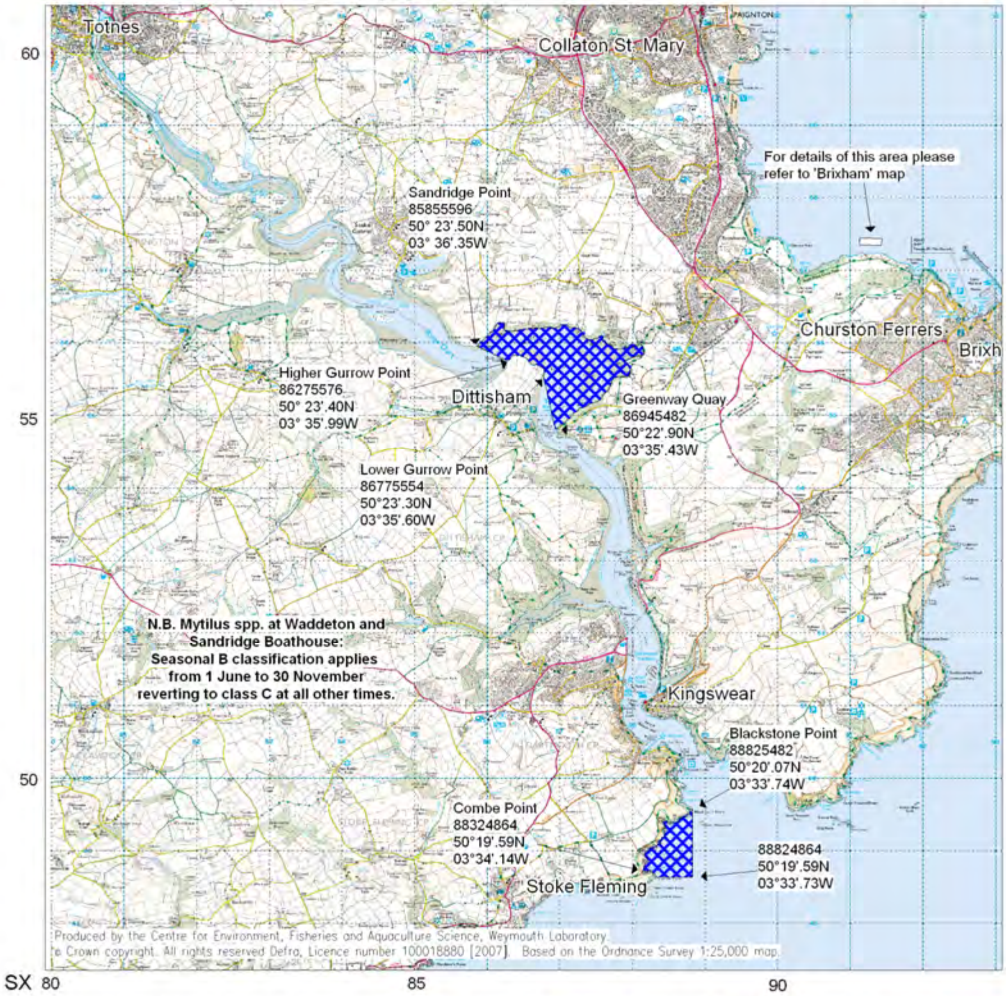
N.B. Lat/Longs quoted are OSGB 36
Separate map available for Mytilus spp. at Dart

Food Authority: South Hams District Council

Figure 3.2. Existing production area and current classification status of* C. gigas *in the Dart Estuary.

Dart - Mytilus spp.

Scale - 1:80000



Classification Zones: Class A, Class B, Class C, Prohibited, LT Class B

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N.B. Lat/Longs quoted are OSGB 36
Separate map available for C. gigas at Dart

Food Authority: South Hams District Council

Figure 3.3. Existing production areas and current classification status of **Mytilus** ***spp. in the Dart Estuary.***

Cefas has been informed by the Devon SFC that there is no harvesting of mussels at Flat Owers at the moment (T. Robbins, Devon SFC, pers. com., 8 April 2008). This bed is presently classified (Figure 3.3) and the results of microbiological monitoring are presented in this report on the basis that they provide information on the levels of contamination in close proximity with existing BMPAs. The new boundaries of the production area are presented in Section 9.2 as a result of the overall assessment of pollution sources on the microbiological contamination of BMPAs.

In 2005, a mussel production area of approximately 0.06 km^2 was established in Compass Cove (Figure 3.1). The production area, which was operated by Brixham Sea Farms Ltd, is no longer in operation due to limited growth of stock. The LEA officially confirmed this fact in April 2008 (Peter Wearden, South Hams District Council, pers. com., 9 April 2008).

3.2 Growing methods and harvesting techniques

Pacific oysters are grown in bags supported above the river-bed on trestles or on the foreshore in bags at Higher Gurrow Point, on the foreshore in bags and some directly on the foreshore at Waddeton and Flat Owers.

When grown in bags, juvenile oysters are placed in 9 mm mesh bags attached to longlines on the ground for ongrowing. When above 40 g, they are taken out of bags and spread directly on the river-bed to mature at 80 g harvestable size.

Mussels are grown on the river-bed. Pacific oysters and mussels are harvested by hand.

Figure 3.4. Pacific oysters in bags on trestles at Higher Gurrow Point with views to upper Dart (A) and The Cliffs (B).

3.3 Seasonality of harvest and conservation controls

The Waddeton Fishery Order 2001, which came into force on 27 April 2001, confers on the Devon SFC the right of regulating the fishery for bivalve molluscs (oysters, mussels, cockles and clams) in the Dart Estuary for a period of 25 years (Ministry of Agriculture, Fisheries and Food, 2001).

The harvesting of mussels and Pacific oysters in existing BMPAs in the Dart Estuary is undertaken year round.

There is higher demand for Pacific oysters on Christmas and Valentines Day (Sarah Clark, Devon SFC, pers. com., 18 March 2008).

3.4 Capacity of area and socio-economy

In 2005–2006, approximately four tonnes of juvenile Pacific oysters were laid in the production areas, resulting in 14.2 tonnes of adults harvested for marketing. Approximately nine tonnes of mussels were harvested during this year (Sarah Clark, Devon SFC, pers. com., 18 March 2008).

In 2006–2007, approximately six tonnes juvenile Pacific oysters were laid in the production areas, resulting in 17.6 tonnes of adults harvested. Approximately 10 tonnes of mussels were harvested during this year (Sarah Clark, Devon S FC, pers. com., 18 March 2008).

There are six fishermen working in the production of mussels and Pacific oysters in the Dart Estuary. MacAlister, Elliott & Partners Ltd (2003) reported that the industry has good relations with other users in the estuary and that, with adequate consultation, the activity could expand significantly without infringing other users' rights.

As part of the sanitary survey, the Devon SFC was consulted on a likely future expansion of the BMPA to Lower Gurrow Point. Cefas has been informed that there are no plans to expand the production area since the river-bed in the area is not adequate for cultivation of bivalve molluscs (T. Robbins, Devon SFC, pers. com., 10 April 2008).

4 Climate

As in most of the southwest UK, the climate in the Dart catchment is relatively mild. Teignmouth and Plymouth are two coastal Met Office stations in the vicinity of the Dart Estuary. Local independent weather stations include one at Stoke Gabriel, which has been operating since December 2006 and a new station at Froward Point established early in 2008 and operated by volunteers from the National Coastwatch Institution (Neil Millward, Stoke Gabriel Weather Station, pers. com., 25 March 2008). The location of these stations is shown in Figure 4.1.

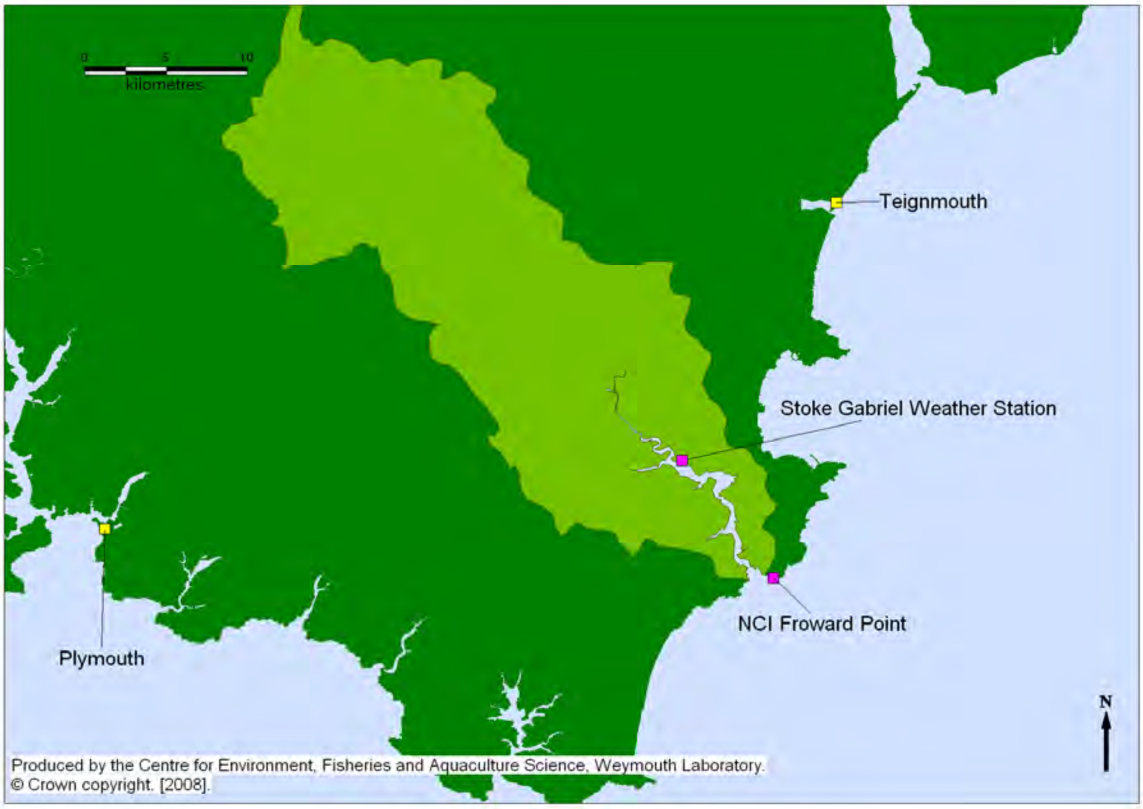


Figure 4.1. Location of meteorological stations considered in the present report.

It is generally accepted that filtration rates in bivalve molluscs increase with increasing temperature throughout the natural range of this parameter. Field studies have shown that this effect usually results in maximum concentrations of microbiological contaminants being detected in summer months (Šolić *et al.*, 1999).

Figure 4.2 shows that maximum air temperature in the Southwest UK generally increases from January to peak in July. The role of water temperature in driving the density gradient in the Dart Estuary is discussed in Section 6.4.

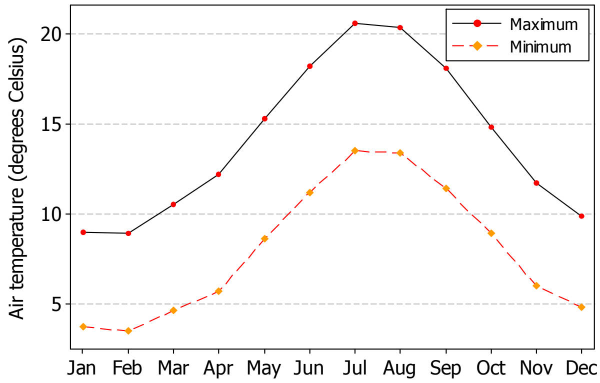


Figure 4.2. Monthly variation in air temperature in Teignmouth for the period 1971–2000.
Data from Met Office (2007).

The sunniest parts of the United Kingdom such as along the South coast of England, achieve annual average figures of around 1,750 h of sunshine. The dullest parts of England are the mountainous areas, with annual average totals of less than 1,000 h (Met Office, 2007b). The average annual sunshine duration recorded in most of the Dart (tidal) catchment ranges between 1,611 h and 1,806 h (Met Office, 2007).

Figure 4.3 shows monthly variation in hours of bright[3] sunshine in Teignmouth. More than 100 h of sunshine are usually recorded during the period April–September. July is usually the sunniest month of the year.

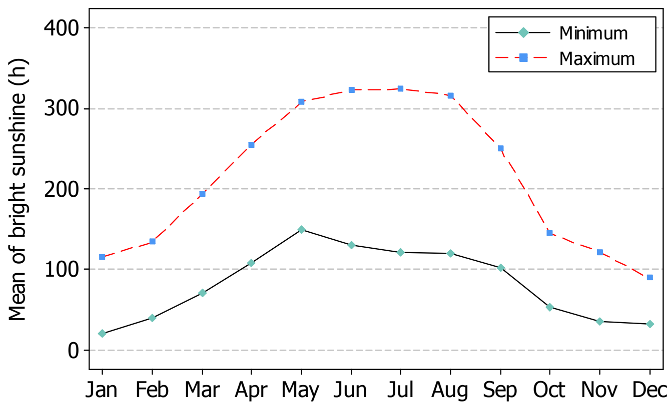


Figure 4.3. Monthly variation in hours of bright sunshine in Teignmouth for the period 1971-2000.
Data from Met Office (2007).

It is generally accepted that the most rapid die-off or low persistence of bacteria occurs in marine and freshwaters in coastal areas with high sunlight intensities. The deleterious effect of solar radiation on the levels of microbiological contamination is more pronounced in surface waters penetrated by ultraviolet radiation. Bags of Pacific oysters suspended supported above the river-bed on

[3] The threshold for the measurement of bright sunshine is a direct solar irradiance of 120 W m^2 (M. Perry, Met Office, pers. com., 28 April 2008).

trestles are usually more exposed to these conditions. By contrast, areas where mussels are cultivated tend to be deeper and therefore to be less affected by the effect of solar radiation. However, studies aiming to analyse the effect of this factor on the levels of microbiological contamination in specific surface waters are complex and beyond the scope of this assessment.

As for all the southwest England, the predominant and strongest winds in the Dart catchment are from a west or southwest direction. In general, the most severe gales across the region occur in autumn and winter, but these may occur at any season (Wheeler and Mayes, 1997). Figure 4.4 shows a typical wind rose in Devon.

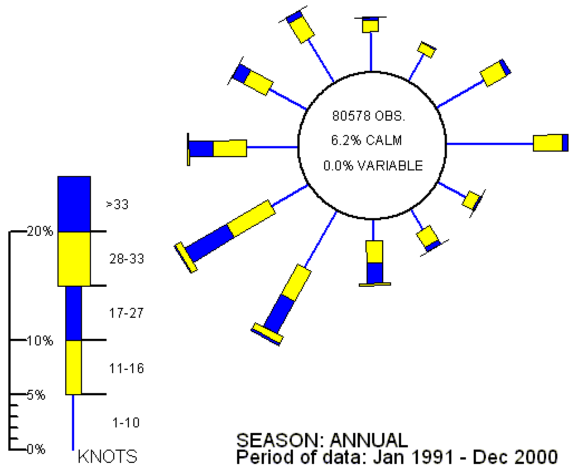


Figure 4.4. Wind direction and speed (knots) at Plymouth for a ten year period.
Data from Met Office (2007).

Given the relatively sheltered location of the estuary, wind driven currents are not expected to significantly influence water movements and hence circulation of contaminants within the estuary. However, strong wind conditions are expected to impinge effluent plumes upon the shore in the broader and shallower areas of the estuary (South West Water, 2002).

The approaches to the estuary are exposed to winds with an easterly component in them. Is it known that light silting occurs occasionally under easterly winds. Observations indicate that a layer of approximately 10 cm of sediment is accreted, which quickly disperses when prevailing southwest winds re-establishes themselves (T. Robbins, pers. com., 20 May 2008).

Resuspension of sediments is known to be an important factor accounting for significant increases of microbiological contamination in shallow coastal areas and particularly in partially mixed estuaries such as the Dart. *Escherichia coli*, viruses and other pathogenic microorganisms may survive for several days or even weeks in association with accreted fine sediments and silts (see Pommepuy *et al*., 2005 and references therein).

More localised data on wind speed and direction is needed to investigate the effect of this parameter on the levels of *E. coli* in bivalves.

5 Hydrology

5.1 Rainfall

The southwest of England is one of the wettest regions in the UK. The rainfall pattern varies greatly throughout the Dart catchment. The pattern is heavily influenced by the topography, which forces the moisture-laden air to precipitate high levels of rainfall throughout the upper reaches of the catchment.

The average annual totals range from over 2,000 mm in large parts of Dartmoor to approximately 1,000 mm in Dartmouth, although more than 2,500 mm may be recorded on Dartmoor in the wettest years. This compares to an average annual rainfall for England and Wales of approximately 1,250 mm (Perry, 2006). Close to the sea level, precipitation varies little and is typical of that recorded for other coastal areas in the southwest UK (Wheeler and Mayes, 1997).

Total daily rainfall data from three rain-gauges representative of the hydrometric network in the Dart catchment were analysed for the period January 2003–June 2007. The location of these gauges is given in Figure 5.1 and monthly variation in rainfall at each is shown in Figure 5.2.

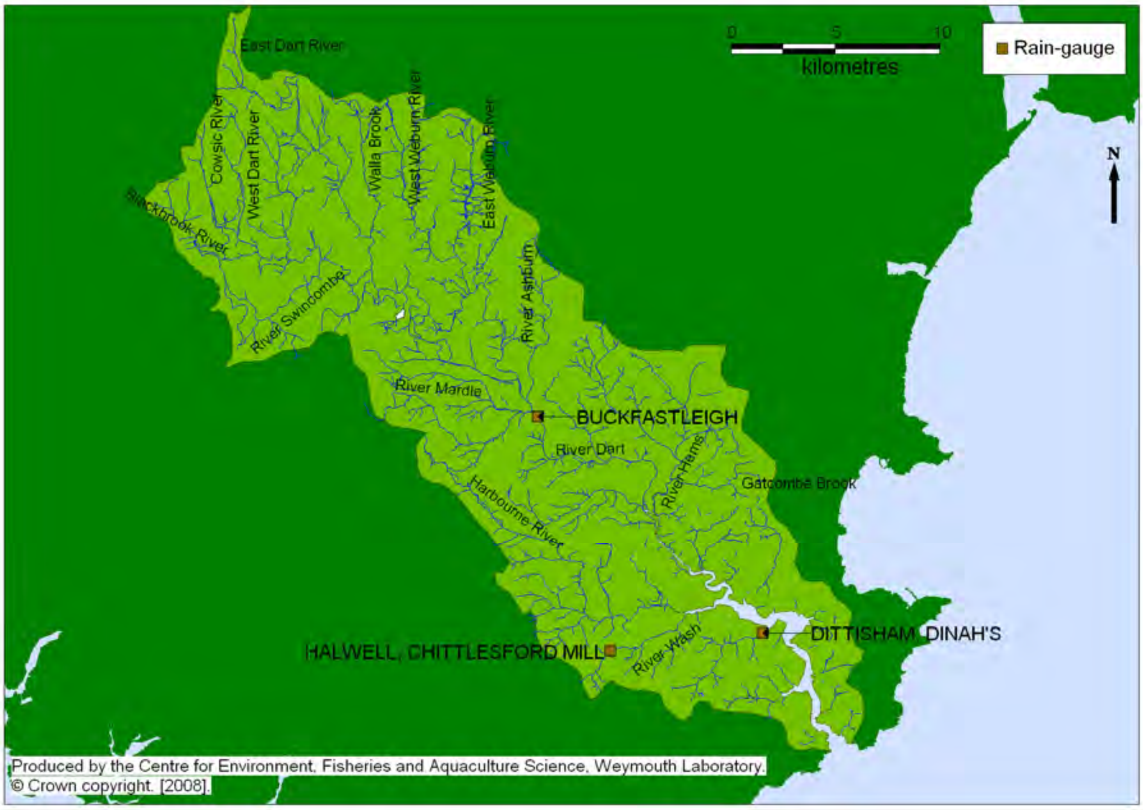


Figure 5.1. Rivers and rain-gauge stations in the Dart catchment.

Results evidence the decreasing gradient of rainfall between the upper and lower reaches of the catchment. The wettest month varies between October and January (Figure 5.2). An increase in the levels of microbiological contamination in bivalve molluscs from rainfall dependent discharges and runoff from agricultural land is therefore expected during the autumn-winter period.

An examination of the variation in the microbiological contamination of mussels and Pacific oysters with variation in rainfall is presented in Section 9.1.3.

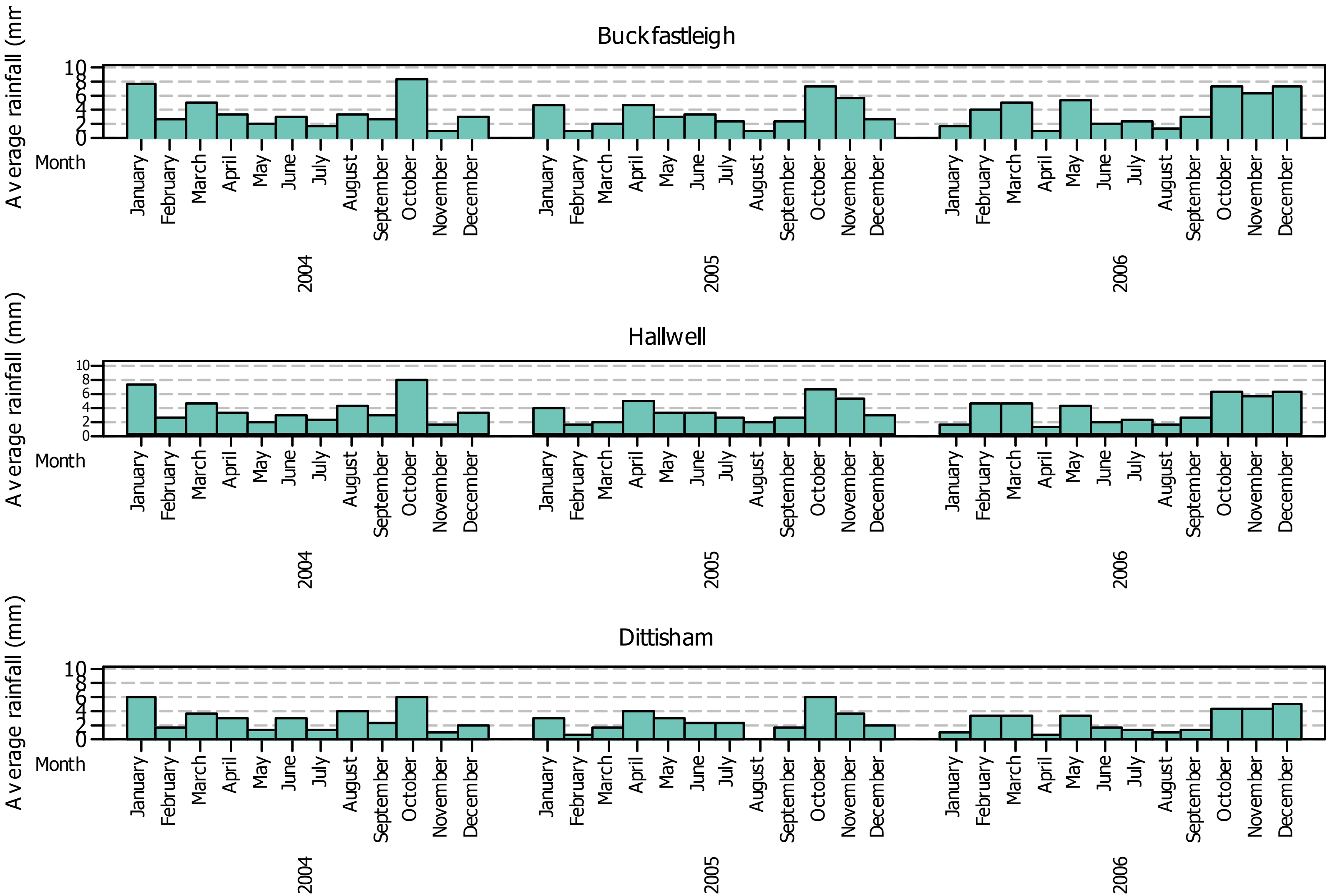


Figure 5.2. Monthly variation of rainfall (mm) in three gauging stations in the Dart catchment.
Data from the Environment Agency (2007).

5.2 River flow

The Dart catchment drains a total area of approximately 470 km^2. The East and West Dart rivers extend for approximately 44 km and 41 km, respectively from Dartmoor to the tidal limit just above the confluence with the River Hems. There are also a number of other small streams across the catchment (Figure 5.3).

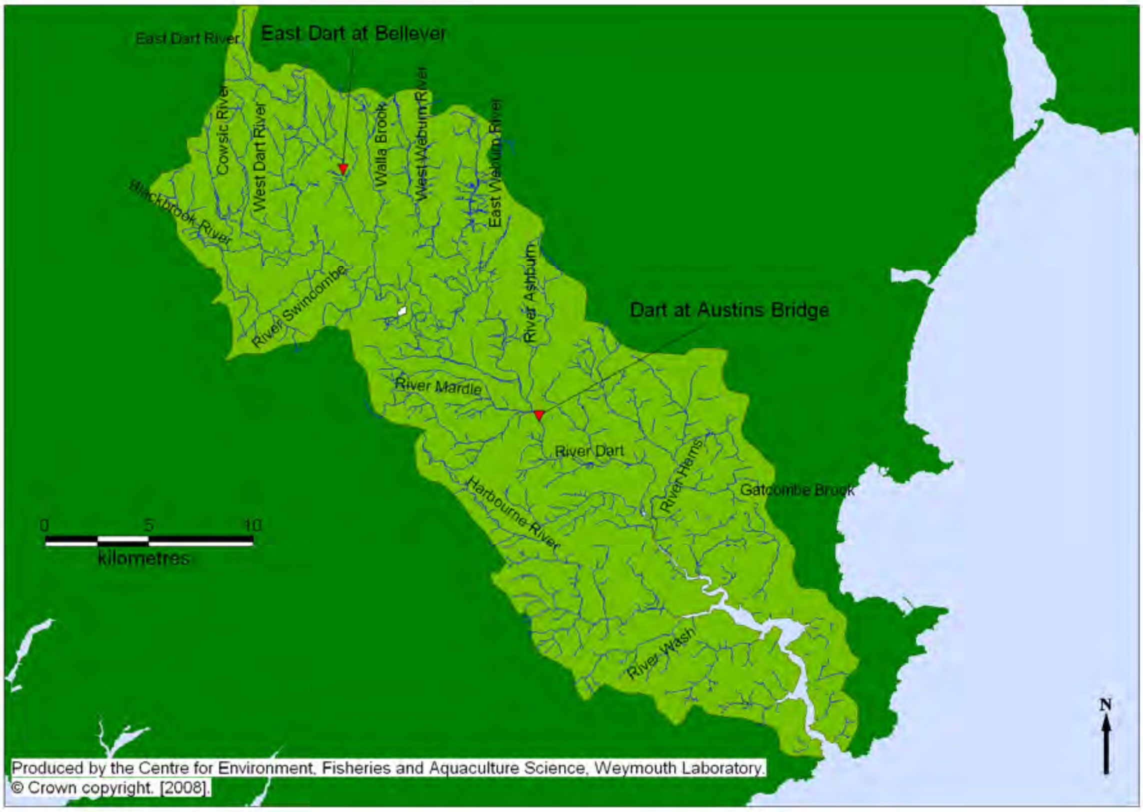


Figure 5.3. Rivers and river gauging stations in the Dart catchment.

River flows in the Dart catchment are measured through the hydrometric network operated by the Environment Agency (Environment Agency, 1997). Table 5.1 shows mean flows for the two gauging stations marked on Figure 5.3.

Table 5.1. Hydrological characteristics in the Dart.

	River gauging station*	
	Bellever	Austin's Bridge
Sub catchment area (km^2)	21.5	247.6
Level of station (m)	309.0	22.4
Maximum altitude (m)	604.0	604.0
Mean flow (m^3 s^{-1})	1.2	11.1
Q95 (95% exceedance) (m^3 s^{-1})	0.2	1.5
Q10 (10% exceedance) (m^3 s^{-1})	2.7	25.1

* data recorded during the period 1964–2006. Data from: the National River Flow Archive (2008) and Thomas & Murdoch (2005).

The rivers Blackbrook, Webburn, Walla Brook and Gatcombe (Dart catchment) are known to have a lower contribution (mean flows <0.5 m^3 s^{-1}; NERC, Environment Agency, SEPA and Rivers Agency, 2008; Thomas and Murdoch,

2005) to river flows than that from the River Dart measured at Bellever and Austin's Bridge gauging stations (Table 5.1).

Q95 and Q10 values represent the averaged flow that is exceeded for 95% and 10% of the time, respectively. The higher Q95 recorded at Austin's Bridge reflects the cumulative exceedances in all the upper Dart tributaries.

Water levels in rivers in the upper Dart catchment respond rapidly to rainfall resulting in relatively short times to peak typically less than 12 h and high water levels that fall quickly after rainfall has ceased. The hydrograph shown in Figure 5.4 exemplifies these conditions through the combination of daily river flows recorded at Austin's Bridge (maximum altitude = 22.4 m Ordnance Datum) with daily total rainfall recorded at Buckfastleigh rain-gauge station during the period 1 January–22 September 2000.

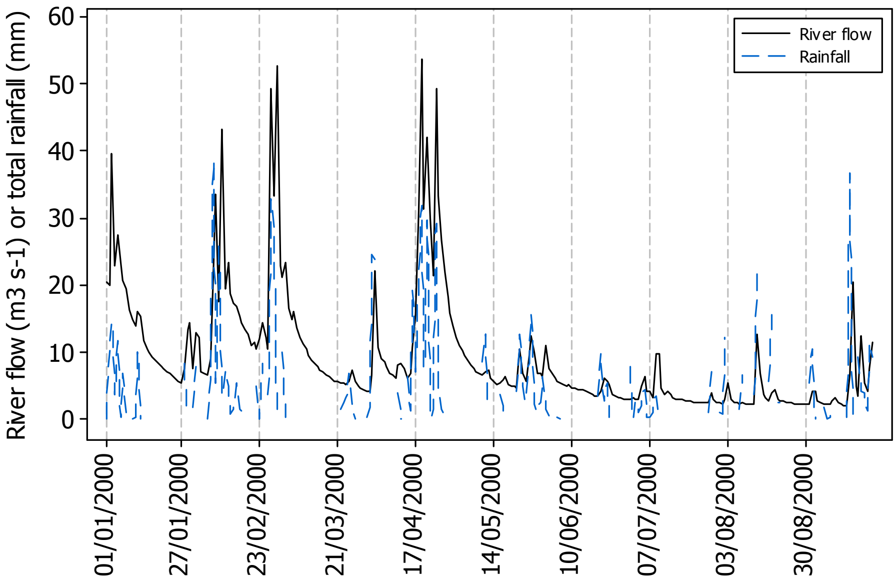


Figure 5.4. Hydrograph for the Dart at Austin's Bridge and daily total rainfall recorded at Buckfastleigh.

In the lower Dart catchment, flood peaks tend to be delayed as a result of the lower topography peaking approximately 12 to 24 h (Environment Agency, 2004).

Odling-Smee, Oberman Associates Ltd (2008) reported that sharp rainfall events in summer usually result in very little runoff and that winter floods tend to be more critical as a greater percentage of water runs off quickly with water saturation in soil. Therefore, consideration could be given by the LEA to sampling under these conditions in order to reflect the potential worst-case scenario of microbiological contamination, if this aspect of the recommendations of the *Good Practice Guide for Microbiological Monitoring of Bivalve Mollusc Harvesting Areas* (Cefas-CRL, 2007) is adopted in the UK at some time in the future.
An examination of the variation in the microbiological contamination of mussels and Pacific oysters with variation in river flows is presented in Section 8.1.4.

6 Hydrography and hydrodynamics

6.1 General

The estuary has been classified as a drowned river valley without spits (Type 3b Ria) (Futurecoast, 2002). The cross-sectional width of the Dart is approximately 400 m of the stretch between the mouth at Dartmouth to Blackness Point decreasing significantly to approximately 180 m at Stoke Gabriel and Ashprington.

6.2 Bathymetry

The mean depth of water in the lower reaches of the estuary at Dartmouth is less than 15 m relative to Chart Datum (CD) reaching 20 m at the elongated depression in the centre of the channel in the mouth of the estuary. The area between Higher Gurrow Point - Sandridge Point and Greenway Quay, which encompasses the BMPAs is shallow, with less than 5 m relative to CD (UK Hydrographic Office, 2000).

Due to its length and slowly flushed conditions, the Dart is able to accumulate large and increasing amounts of fine and, whenever available, coarse sediment (Futurecoast, 2002; Uncles *et al.*, 2002). Until early 1980s, the estuary was dredged for aggregates (Odling-Smee, 2005). Siltation and bank erosion in some areas prompted a study on the hydrography and hydrodynamics in the upper reaches of the estuary in order to establish a sustainable dredging policy and to recommend a policy for river-bed maintenance. The study concluded that, with adequate assessment and monitoring, the upper and middle sections of the channels could be dredged on a low rate basis in the future (Odling-Smee, Oberman Associates Ltd, 2008).

Significant changes in the levels of microbiological contamination may occur in the rivers during or after dredging operations (Mallin *et al.*, 2000). If data is available at some time in the future, the effect of dredging operations on the levels of microbiological contamination in the Dart Estuary should be evaluated at the next review of the sanitary survey.

6.3 Tides and tidal currents

The estuary has an asymmetrical macro tidal regime. The flooding spring tide typically has the duration of 6:30[5] and the ebb tide a duration of 5:40 (Thain *et al.*, 2004).

At Dartmouth, the mean spring tide range is 4.4 m and the mean neap tide range is 1.8 m (Table 6.1). The tidal length (mouth to limit of reversing tidal currents) is estimated to be 19 km and the estimated residence (flushing) time[6] is estimated to be approximately seven days (Uncles *et al.*, 2002).

[5] Figures referring to tide times are denoted as hours:minutes.
[6] The residence time is the ratio between the tidal volume and the freshwater input to the estuary.

Table 6.1. Tidal constants in the Dart Estuary.

	Height (metres*)		
	Dartmouth	Greenway Quay	Totnes
Mean Sea Level (MSL)	2.9	-	-
Highest Astronomical Tide (HAT)	5.3	-	-
Mean High Water Springs (MHWS)	4.9	4.9	3.5
Mean High Water Neaps (MHWN)	3.8	3.8	2.3
Mean Low Water Neaps (MLWN)	2.0	2.0	-
Mean Low Water Springs (MLWS)	0.6	0.6	-
Metres below Ordnance Datum Newlyn	2.62	2.62	1.20

** above Chart Datum.*
Data compiled from United Kingdom Hydrographic Office (2000, 2001).

The estuary is ebb dominant with a flow ratio suggesting that a freshwater plume may develop and emerge from the mouth of the estuary at ebb tides under maximum river discharges (Futurecoast, 2002; Thain *et al.*, 2004). Odling-Smee, Oberman Associates Ltd (2008) reported that when winter floods are coincident with neap tides, the water level tends to be above Ordnance Datum for a complete tidal cycle and this induces stronger ebb flows and, consequently, increases sediment transport out of the channels. Consideration could be given by the LEA to sampling when winter floods are coincident with neap tides in order to reflect the potential worst-case scenario of microbiological contamination, if this aspect of the recommendations of the *Good Practice Guide for Microbiological Monitoring of Bivalve Mollusc Harvesting Areas* (Cefas-CRL, 2007) is adopted in the UK at some time in the future.

The results of the effect of tidal stage (ebb vs. flood) on the levels of *E. coli* in bivalves at the time of sampling were investigated through a series of *t*-tests. Table 6.2 shows that *E. coli* levels in bivalves from all RMPs were not significantly higher for samples collected during the ebb stage than those collected during the flood stage.

Table 6.2. Results of t-tests to examine relationship between tidal stage at time of sampling and levels of* E. coli *in bivalve molluscs from the Dart Estuary.

	State of tide				
Bed name (RMP)	Ebb		Flood		
Species	GM	n	GM	n	*p*
Waddeton (B028B) *C. gigas*	197	21	340	36	0.478
Waddeton (B028F) *Mytilus* spp.	933	20	908	36	0.941
Sandridge Boathouse (B028E) *Mytilus* spp.	738	35	1,071	23	0.215
Sandridge Boathouse (B028H) *C. gigas*	291	30	218	24	0.243
Flat Owers (B028C) *Mytilus* spp.	734	23	659	30	0.387
Flat Owers (B028G) *C. gigas*	269	24	260	29	0.470

GM – geometric mean.
n – number of samples.
p - statistically significant (p<0.05).
t-tests performed after Log_{10}-transformed E. coli *levels. Less-than* E. coli *results were transformed to the half value. More-than* E. coli *results were transformed to double value.*
Data for period January 2003–November 2007.
Tidal predictions for Dartmouth from POLTIPS.3 (Proudman Oceanographic Laboratory).

It should be pointed out that most of the samples were collected within one hour of LW and therefore the analysis is biased by the lack of results representing the complete tidal amplitude (Figure 6.1). These results are therefore inconclusive regarding the likely effect of tidal stage on the levels of microbiological contamination in BMPAs.

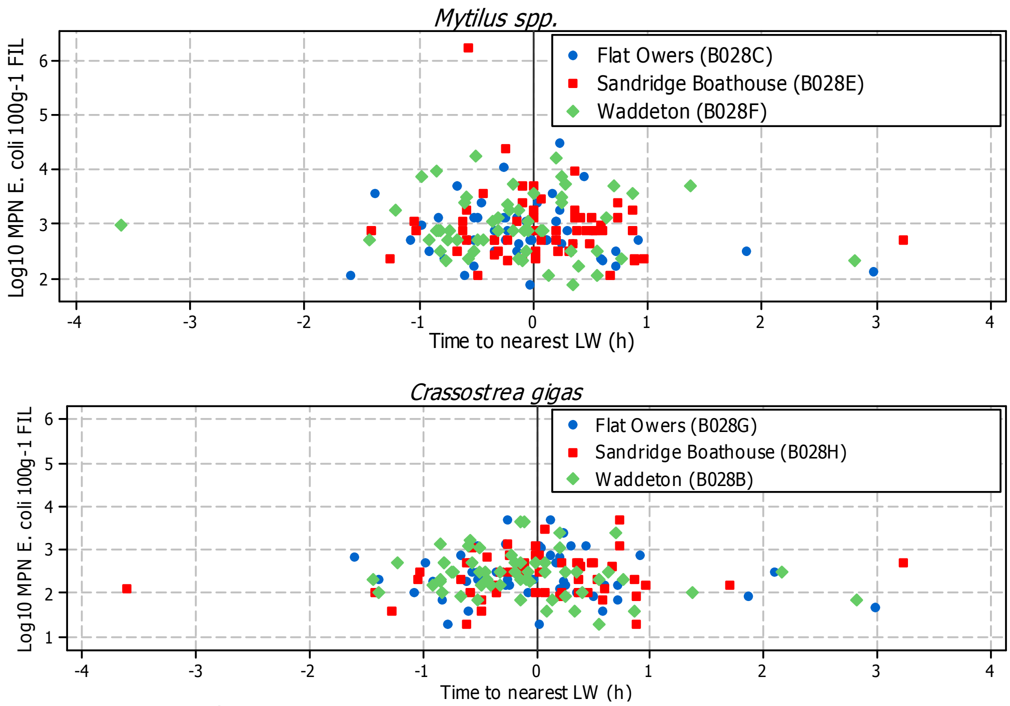


Figure 6.1. Scatterplot of **E. coli** ***levels in mussels and Pacific oysters from six monitoring points according to time to Low Water.***

Mean flow velocities on flood tides at the mouth of the estuary are 0.6 and 0.3 m s^{-1} during spring and neap tides respectively (Thain *et al.*, 2004). Odling-Smee, Oberman Associates Ltd (2008) reported maximum velocities up to 1 m s^{-1} at Hole in the Wall (cf. Figure 6.2) during a spring tide on 20 March 2003.

The pattern of circulation of pollutants at the mouth of the estuary results from the rectilinear flow within the main channel and the progressive offshore wave along the English Channel. The combination of these tend to result in a clockwise circulation of pollutants on the flood tide and an anticlockwise circulation on the ebb tide. This pattern is likely to aid the removal of the ebb tide plume from the western shoreline of the estuary to outside of the estuary (South West Water Ltd, 2002).

Overall, the clockwise pattern of circulation on the flood tide is likely to promote the transport of microbiological contamination from sources situated at the mouth of the estuary, which under strong tidal currents might affect the existing BMPAs.

The anticlockwise pattern of circulation on the ebb would promote the transport of contamination from sources situated close to existing BMPAs, particularly those along the western shoreline.

6.4 Density gradient

The Dart Estuary is partially mixed to almost well mixed. Partially mixing conditions in the estuary are prevalent during high river flow discharges (R. Thain, pers. com., 11 July 2008). During high tidal flow velocities, a degree of stratification is known to occur both on a tidal and seasonal basis, increasing markedly in autumn and winter (Priestley and Thain, 2005). The spring-neap transition determines pronounced variations in stratification, being these variations stronger during neap tides (Thain *et al.*, 2004). Consideration could be given by the LEA to sampling during neap tides in order to reflect the potential worst-case scenario of microbiological contamination, if this aspect of the recommendations of the *Good Practice Guide for Microbiological Monitoring of Bivalve Mollusc Harvesting Areas* (Cefas-CRL, 2007) is adopted in the UK at some time in the future.

The variations in the horizontal density gradient along the Dart are predominantly dominated by variations in salinity (Priestley, 1998). However, at some times of the year, water temperature is an important factor driving stratification in the estuary. This is particularly evident during early summer, when freshwater from the upper estuary is warmer and buoyant, or during mid-winter, when the inflowing seawater is comparatively colder and dense.

Variation in surface water temperature and salinity monitored in nine stations along the middle and upper reaches of the Dart estuary (Figure 6.2) are presented in Figure 6.3.

Figure 6.2. Sampling points of surface water for temperature and salinity profiles.

Figure 6.3 shows an increasing horizontal salinity gradient from 0 ppt at Totnes Weir to 23.6 ppt at The Anchor Stone during high river flow conditions. The highest difference in median salinity (4.7 ppt) was found between Totnes and Hole in the Wall. This area is within the tidal reach and indicates the limit of the influence of saline water in the estuary.

In general, the distribution of commercially exploited bivalve molluscs is favoured by salinities above 20 ppt (Laing & Spencer, 2006). There are no commercial beds in the river above Blackness Point (Figure 6.2) where salinities reduce below 20 ppt during high flow conditions (Figure 6.3). At lower salinities, filter-feeding activity is likely to cease along with the ingestion of microbiological contaminants. In these circumstances, sampling of bivalves at low water may not represent the worst-case conditions of microbiological contamination. For the purposes of the sampling plan, consideration could be given by the LEA to undertake sampling during high water at Higher Gurrow Point, where salinities are generally lower than those at Waddeton (Figure 6.3).

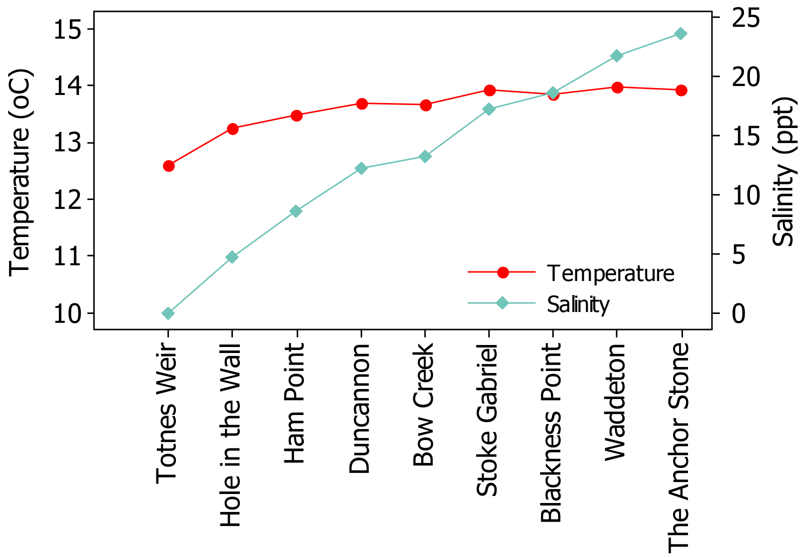


Figure 6.3. Surface median water temperature and salinity at nine locations along the Dart Estuary.
Measurements taken weekly and following rainfall events over a six-month period in 2000.
Permitted use by Allen (2001).

Data indicated low variation in water temperature (12.6–14°C) along the estuary. Vertical profiles of water temperature were recorded from 20 transects across the upper reaches of the estuary over a complete tidal cycle and during low river flows on 19 March 2003 (Figure 5.3). The maximum range (8.7–9.1°C) was recorded at High Water -1:50 (HW-1:50) and the lowest range (7.7–7.8°C) for the parameter was obtained at HW+6:17. The vertical profile shown in Figure 6.4 exemplifies the salinity gradient with depth in the absence of rainfall. The highest salinity range (13.8–23.7 psu) was obtained at HW +3:00.

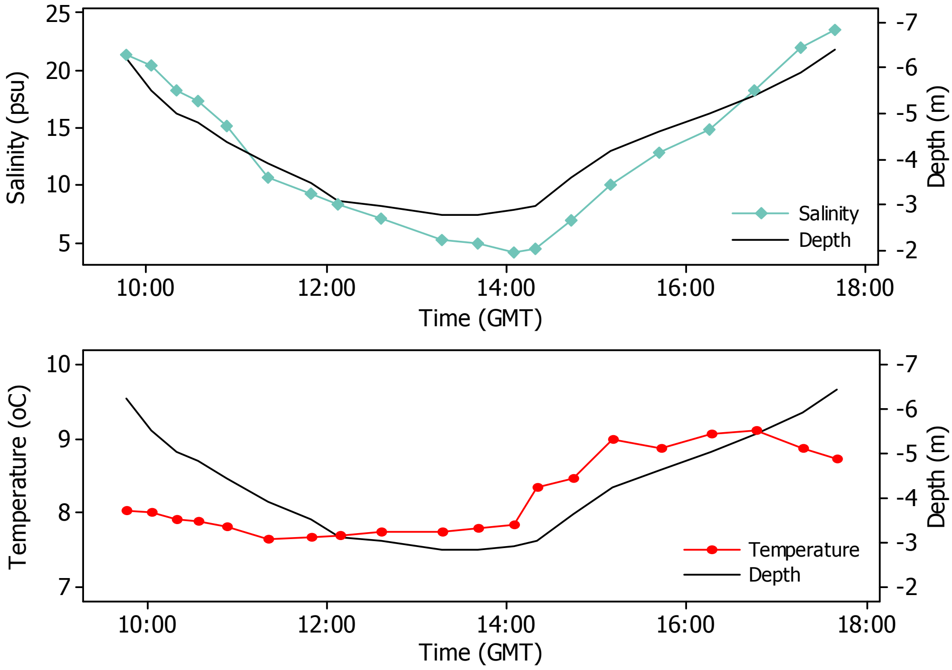


Figure 6.4. Water temperature and salinity profiles between Sandridge Point and Blackness Point, Dart Estuary.

The Devon Sea Fisheries Committee has recorded salinity values ranging between 10 psu and 32 psu (mean = 22.3) and water temperature between 5 ℃ and 20 ℃ (mean temperature = 13.5 ℃) in BMPAs in the estuary, as part of experiments on Pacific oyster cultivation methods undertaken by between 2001 and 2004.
The association between the temperature-salinity regime and *E. coli* levels in surface waters was analysed using the Ordinary Least Squares (Linear Regression). This method shows the covariation between the variables and can also be used to predict values of one variable based on knowledge of another variable (Helsel and Hirsch, 2002).

Regression coefficients varied between 0.3 and 0.5 in consecutive surveys undertaken in August and September 2000, indicating lack of a strong relationship between water temperature or salinity and *E. coli* levels. This indicates that water temperature is not adequate to predict the magnitude of microbiological contamination in bivalves.

A very characteristic transient V-shaped tidal intrusion front is formed near the mouth of the estuary during flooding spring tides (Figure 6.5). The tidal intrusion, which was observed progressing upstream during the shoreline survey (see Appendix I), is driven by the constriction at the mouth of the channel and a depression in the river bed just landward of the mouth (Thain *et al*., 2004). A marked and steeply inclined salinity gradient develops below the surface manifestation of the intrusion. Acoustic doppler current profiles and conductivity, temperature and depth studies have indicated that major lateral changes occur in the vertical structure of the water column over distances of less than 50 m in the Estuary (Priestley and Thain, 2003).

It has been hypothesized that tidal intrusion fronts may act as temporary barriers to the exchange of water masses and entrap fine particulate matter, acting like 'sieves' in the estuarine sediment transfer system to both land- and marine-derived sediments (Reeves and Duck, 2001). Under some circumstances, these processes are likely to promote retention of microbiological contaminants near their sources and contribute to temporary extreme levels of contamination in some areas of the estuary where those sources are present. Whenever possible, it is therefore recommended that sampling for the purposes of microbiological monitoring should be undertaken during spring tides since these are likely to produce the worst-case scenario of microbiological contamination.

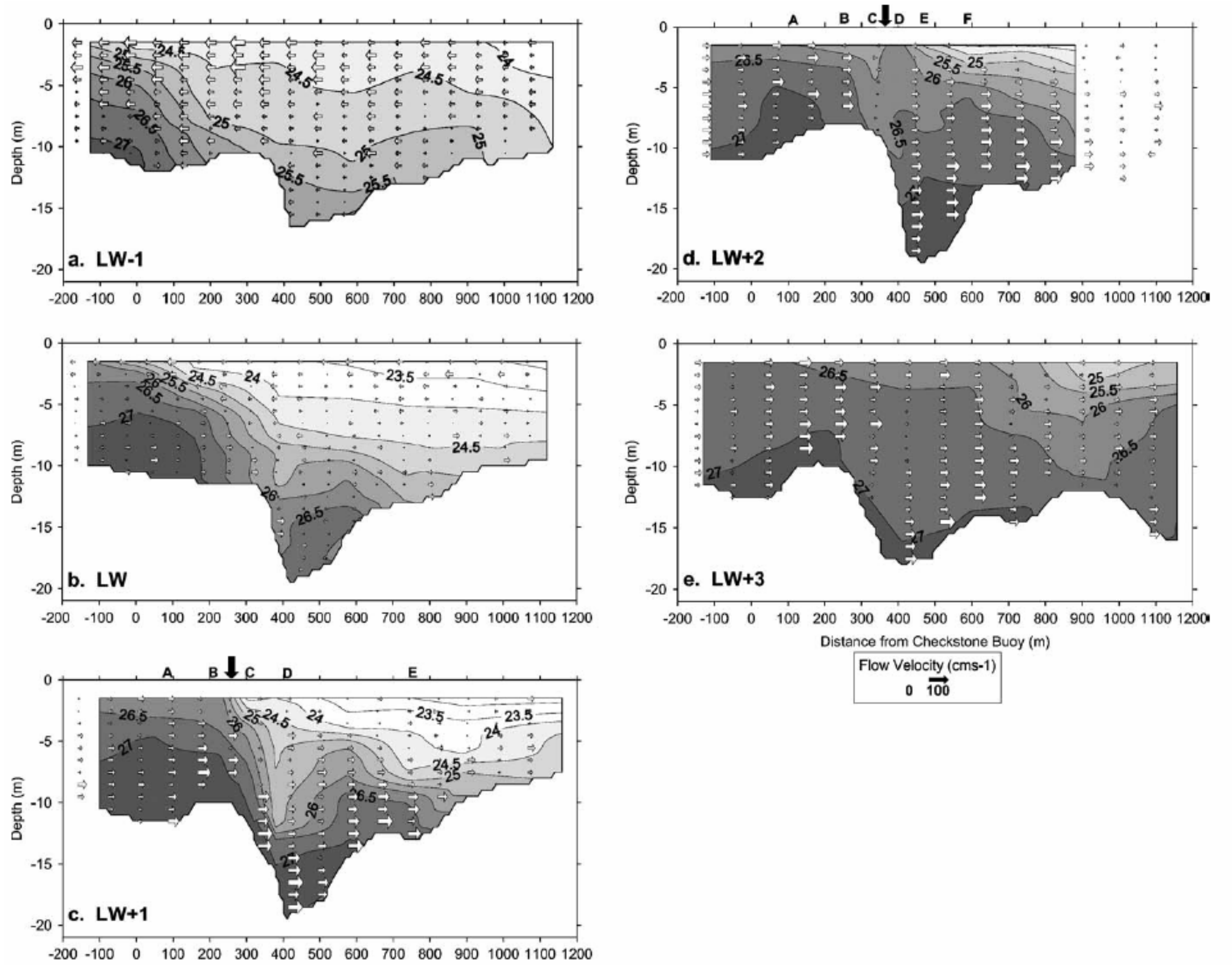


Figure 6.5. Hourly contours of density anomaly at spring tides from 1 h before low water (a) to 3 h after low water (e). From Checkstone Buoy to the lower ferry (1200 m distance), at the mouth of the estuary. Flow vectors overlayed. The constricted section of the mouth starts approximately 150 m from Checkstone Buoy, represented by letter B in (c) and (d). At LW+1, the visual manifestation of the front was between B and C. At LW+2, it was observed between C and D (see vertical arrows).
(a): relatively homogeneous water column, with predominant seaward flow.
(b): outflow in the surface layer, basal inflow current, with net inflow.
(c): well-mixed layer upstream of the mouth and a two layer regime downstream.
(d): downstream migration of the front.
(e): disappearance of the visual manifestation of the front.
Republished from Thain et al. *(2004) with permission by the author.*

7 Point sources of microbiological pollution

7.1 Sewage discharges

Sewage effluents in the Dart catchment are treated in a number of sewage treatment works (STW). Most of the larger STW are associated with urbanised areas in the upper, mid and lower catchment. The sewerage infrastructure is also served by numerous overflows, including combined sewer overflows (CSO), emergency overflows (EO) and overflows from sewage pumping stations (PS). Figure 7.1 shows the continuous and intermittent sewage discharges likely to be a source of microbiological contamination for the BMPAs.

There are a number of continuous minor discharges (not listed in the Environment Agency Pollution Reduction Plan; see Figure 7.1) in Stoke Gabriel, Dittisham and Galmpton areas likely to significantly impact on BMPAs.

Intermittent sewage discharges can deliver highly contaminated water to coastal areas resulting from the rapid flushing of stored contaminants during storm conditions and/or the overloading during periods of heavy rainfall (Lee *et al.*, 2003 and references therein). Contaminant microorganisms in these discharges can be rapidly accumulated by bivalves and be the cause for the deterioration in the microbiological quality of many BMPAs (Younger *et al.*, 2003).

Intermittent discharges at Galmpton and Dittisham areas identified in the Environment Agency Pollution Reduction Plan and others not identified in the plan are less than 3 km from bivalve beds and constitute the higher risk of contamination for bivalve molluscs.

Larger STW treat effluents to, at least, secondary treatment. A membrane bioreactor was installed in March 2003 at Dittisham STW. Results from the microbiological control undertaken in this STW between May 2003 and September 2006 present a geometric mean of faecal coliforms in effluent discharge of 2.9×10^{1}, with occasional periods of low efficacy reaching 3.9×10^{4}.

Ultraviolet (UV) disinfection was installed at the largest and some smaller works discharging into or close to BMPAs. The fluvial distance of these discharges to BMPAs is approximately 12 km (Table 7.1).

There are a number of untreated discharges in the South Town area of Dartmouth likely to impact on BMPAs. These are approximately 6 km from the new bed for Pacific oysters at Higher Gurrow Point (Table 7.2). Kay *et al*. (2008) documents reference concentrations of faecal coliforms in crude sewage discharges under low and high flow conditions of 1.7×10^{7} and 3.5×10^{6} (geometric means) respectively. As part of the water industry programme for the period 2005–2010, these sewage discharges are programmed by the Environment Agency to be transferred to Dartmouth STW for secondary treatment and UV disinfection by March 2009 (Environment Agency, 2007). The effect of these upgrades on the levels of microbiological contamination in BMPAs should be assessed at the next review of the sanitary survey.

Table 7.1. Significant continuous sewage discharges in the Dart Cachment.

Map Ref. ID	Continuous	Discharge[†] Type of treatment	DWF ($m^3 d^{-1}$)	Pop. eq.	Approximate (fluvial) distance from BMPA (km) Higher Gurrow Point	Sandridge Boathouse	Waddeton	Flat Owers
A	Totnes STW	T (UV)	3,967	n/a	10.4	10.8	11.5	12
B	Harbertonford STW	S (B)	n/a	n/a	11.2	11.6	12.3	12.8
C	Ashprington STW	S	98	450	5.4	5.8	6.5	7
D	Dittisham STW	MBR	66	296	1.4	1.2	1.2	0.9
E	Dartmouth & Kingswear STW	T (UV)	4,644	7,681[‡]	6.2	5.9	5.4	4.8
F	Castle House, South Town	U	4	n/a	6.1	5.9	5.7	5.3
G	Beacon Boathouse, South Town	U	1.5	n/a	6.2	6	5.8	5.4
H	Bight Boatyard, South Town	U	30	n/a	6.1	5.9	5.7	5.3
I	Beechcroft Cottage, South Town	U	4	n/a	6.1	5.9	5.7	5.3
J	Bell House, South Town	U	4	n/a	6.3	6.1	5.9	5.6
K	Deans Lodge, South Town	U	2	n/a	6.3	6.1	5.9	5.6
L	Grammercy, South Town	U	n/a	n/a	6.3	6.1	5.9	5.6
M	Ten Fathoms, South Town	U	1.5	n/a	6.3	6.1	5.9	5.6

† - only discharges into the Dart tidal waters or its main tributaries are listed.
‡ - population equivalent from Ofwat (2005).
Pop. eq. - population equivalent.
DWF - dry weather flow.
U - untreated.
S - secondary.
T - tertiary.
UV - ultra-violet disinfection.
B - biological treatment.
MBR - membrane bioreactor.
EO - emergency overflow.
SO - storm overflow.
n/a - not available.

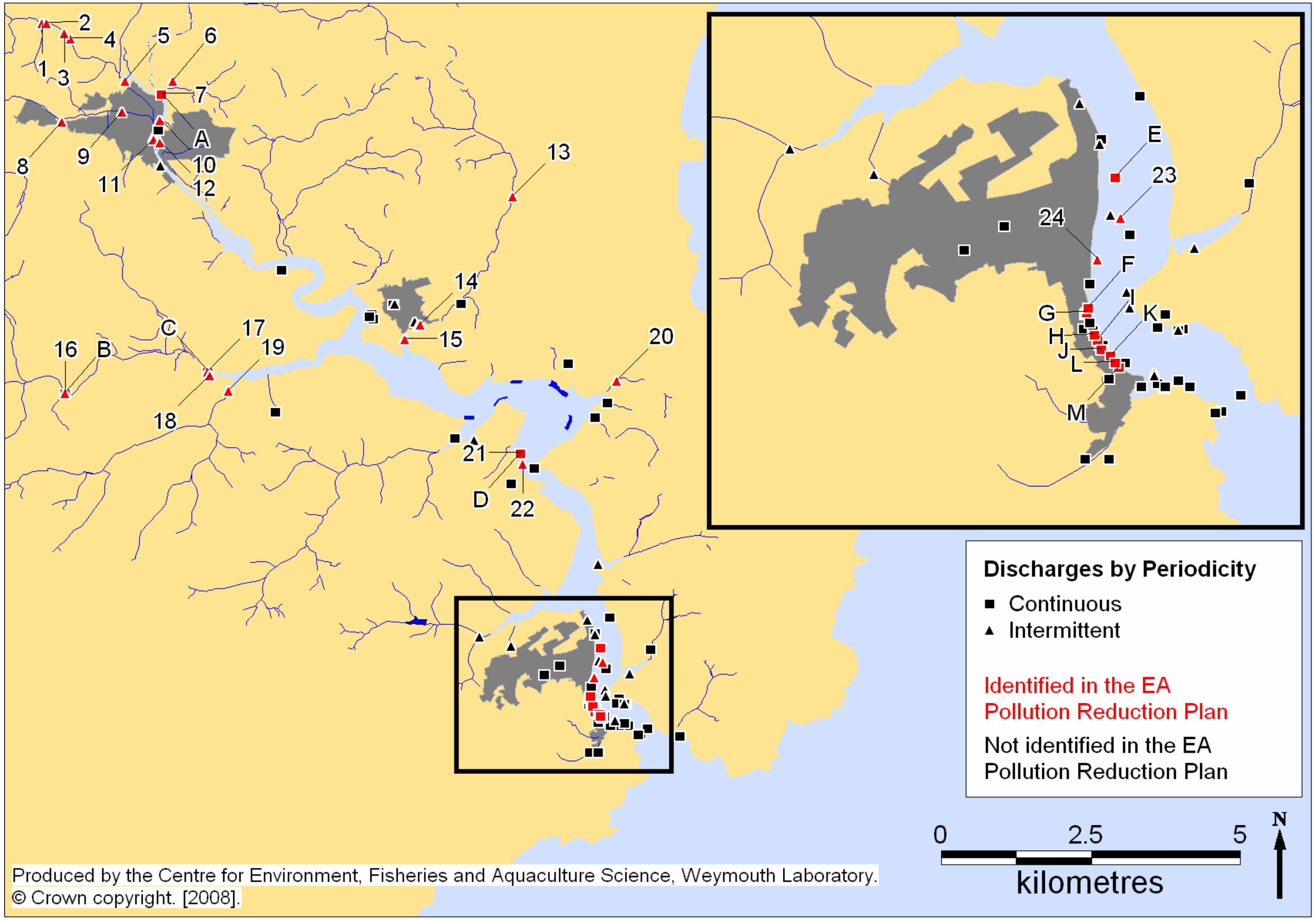


Figure 7.1. Sewage discharges with a potential or significantly potential impact on the levels of microbiological contamination for bivalve mollusc production areas in the Dart Estuary.
For details on discharges, refer to Table 7.1.

Table 7.2. Significant intermittent sewage discharges in the Dart cachment.

Map Ref. ID	Discharge[†] Intermittent	Type of treatment	Approximate (fluvial) distance from BMPA (km) Higher Gurrow Point	Sandridge Boathouse	Waddeton	Flat Owers
1	Dartington B CSO	SO	12.4	12.8	13.5	14
2	Dartington (Shinners Bridge) CSO	SO	12.4	12.8	13.5	14
3	Dartington Textile Mill CSO	SO	12	12.4	13.1	13.6
4	Dartington C CSO	SO	11.9	12.3	13	13.5
5	Swallowfields CSO	SO	11.1	11.5	12.2	12.6
6	Swallowfields SSO (Kevics)	SO	10.1	10.5	11.2	11.7
7	Totnes STW CSO	SO	9.8	10.2	10.9	11.4
8	Totnes (Quarry Close) (Follaton Road) CSO	SO	11	11.4	12.1	12.6
9	St Johns Terrace CSO	SO	10	10.4	11.1	11.6
10	Totnes Town PS CSO/EO	SO	10.2	10.6	11.3	11.8
11	Fore Street SO	SO	9.6	10	10.7	11.1
12	Streamer Quay CSO	SO	9.6	10	10.7	11.1
13	Tor Park Road (Yalberton) PS CSO/EO Paignton	EO	5.6	6	6.7	7.2
14	Scout Hut CSO	SO	2.5	2.9	3.6	4.1
15	Stoke Gabriel PS CSO/EO	SO	2.2	2.6	3.2	3.8
16	Swallowfields Kevics CSO	SO	11.2	11.6	12.3	12.8
17	Ashprington STW SSO	SO	5.4	5.8	6.3	6.8
18	Tuckenhay and Ashprington Number 2 (Perchwood) PS EO	EO	5.4	5.8	6.3	6.8
19	Tuckenhay and Ashprington Number 1 (Tuckenhay Bridge) PS EO	EO	5	5.4	6.1	6.6
20	Galmpton (Dart) PS CSO/EO	EO	1.9	1.8	1	0.9
21	Higher Dittisham PS CSO/EO	SO	1.4	1.2	1.2	0.9
22	Ferry Boat Inn PS CSO/EO	SO	1.5	1.5	1.3	0.9
23	New Ground Storm (Mayors Avenue) PS CSO/EO	SO	5.4	5.3	5.1	4.7
24	Smith Street CSO	SO	5.7	5.6	5.4	5

[†] - only discharges into the Dart tidal waters or its main tributaries are listed.
EO - emergency overflow.
SO - storm overflow.

Table 7.2 summarises the results from the microbiological control undertaken in sewage treatment works using UV (Totnes STW and Dartmouth STW) and membrane bioreactor (Dittisham STW) representative of tertiary-treated effluents discharging into the Dart Estuary.

Table 7.2. Summary statistics of levels of faecal coliforms in effluent discharges from three sewage treatment works in the Dart catchment.

	Totnes STW	Dittisham STW	Dartmouth STW
Date of first sample	01/04/04	04/12/03	09/01/03
Date of last sample	28/09/06	27/11/03	28/09/06
Number of samples	67	91	99
Minimum	1	1	1
Maximum	8,100	39,000	5,000
Median	160	24	32
Geometric mean	117	29	38

Results show the variability of levels of faecal coliforms in these tertiary-treated effluents, indicating episodes of low efficiency in these STW. However, the geometric means correspond to typical values reported for UV-treated effluents (see Kay *et al*., 2007).

In general it is considered that for most of the time the contribution of tertiary-treated effluents as sources of microbiological contamination impacting on BMPAs is low when compared with other sewage discharges or sources of contamination of diffuse origin. However, during the flood tide, the anticlockwise pattern of circulation in the estuary (see Section 6.3) is likely to promote the transport of contaminants to BMPAs, particularly those at Sandridge Boathouse and Higher Gurrow Point. The impact would be particularly significant from discharges from Dittisham STW.

8 Diffuse sources of microbiological pollution

8.1 Farm animals

In a recent survey on the perceived risk of farming activities, it was found that a significant percentage of farmers in the Dart catchment frequently spread manure shortly before/during rainfall, have insufficient storage of slurry, spread manure near a water course or use dirty water irrigation systems (Figure 8.1).

Figure 8.1. Grassland at Blackness Point and view of Dittisham (A), storage of manure at East Cornworthy, North of Dittisham (B) and soil poaching by livestock at crossing points in tributaries (C, D) of the Dart Estuary.
Photos C and D republished with permission by Daniel McGonigle.

As part of the Cycleau Project, a Geographic Information System was developed to assess the areas potentially vulnerable to diffuse water pollution from agricultural land in the Dart catchment. The assessment was based on Agricultural Census data, slope, soil types and rainfall variation in the catchment (McGonigle, 2006). Results indicated that the western area of the Dart (tidal) catchment and the eastern and southeastern area of the Dart subcatchment, where rivers Harbourne, Hems and Wash discharge to the estuary generally correspond to high to very high risk of diffuse pollution (Figure 8.2). This is due to the more intensively farmed land in these areas than the less intensively farmed upland areas on Dartmoor.

Livestock densities per km^2 in the Dart (tidal) catchment are approximately 103 for cows, 10 for pigs and 261 for sheep. This contrasts to densities of 63 for cows, 4 for pigs and 140 for sheep in the Dart catchment, which includes the more heavily farmed area of the Hems (Devon Wildlife Trust, 2007).

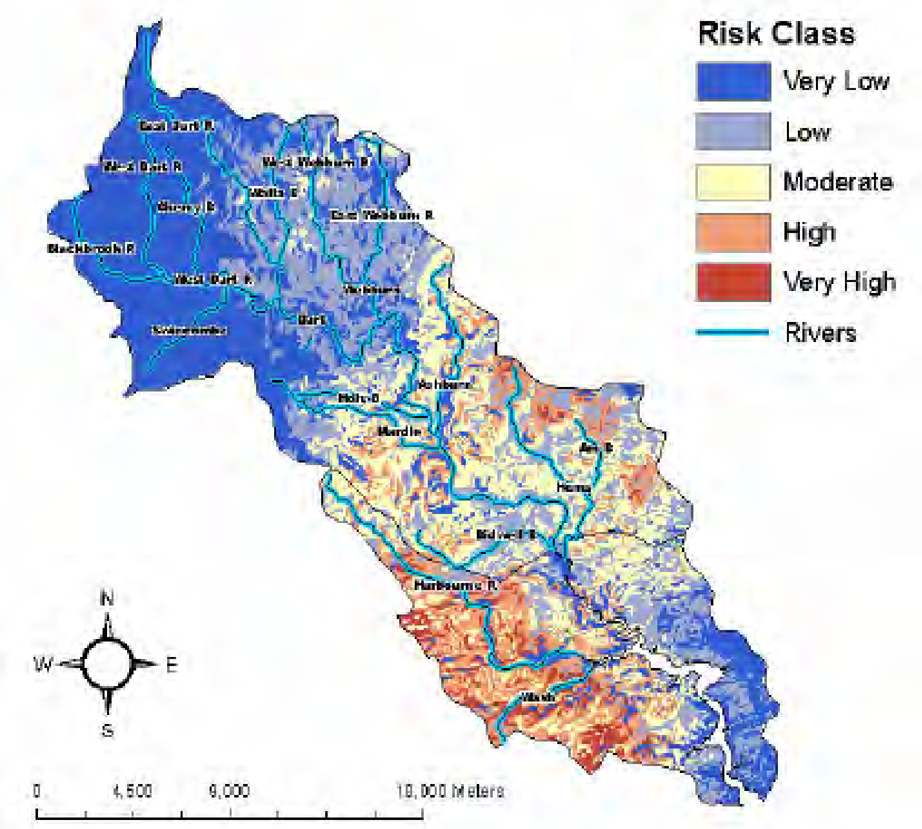


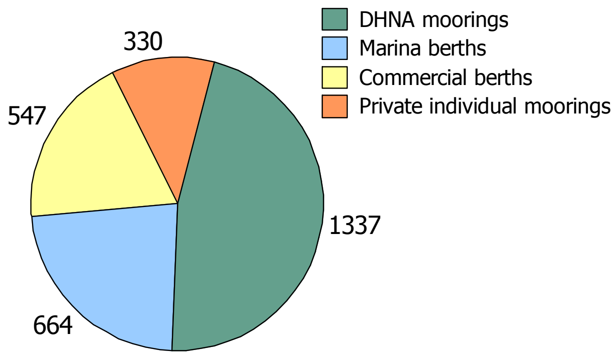
Figure 8.2. Potential diffuse pollution risk map in the Dart catchment.
Republished with permission by Daniel McGonigle.

The areas showing higher risk of diffuse pollution also coincide with rivers showing the highest concentrations of nutrients (see Murdoch, 2000; Thomas and Murdoch, 2005). These results also corroborate results previously obtained by Allen (2001) with respect to higher concentrations of faecal coliforms and *E. coli* in samples of surface water taken in the vicinity of farms where organic fertilisers are used on a more frequent basis. It is therefore considered that RMPs located on the upstream boundary of shellfish beds and close to the influence of freshwater inputs will be more representative of faecal contamination from livestock production areas.

8.2 Boats and marinas

It is estimated that there are approximately 12,000 yacht visitor days during the year; most of these visits occur during the peak season of July-August (R. Humphreys, pers. com., 3 April 2008). Most of these yachts are accommodated in the Dart Marina, Darthaven Marina and Noss Marina. The Port of Dartmouth Royal Regatta takes place annually over three days at the end of August.

There are 2,878 moorings of various types on the Dart Estuary (Humphreys, 2006). Approximately 46% of these moorings are operated by the Dartmouth Harbour and Navigation Authority (DHNA) (Figure 8.3).



Private: include 210 running moorings.

Figure 8.3. Types of moorings in the Dart Estuary.
Data from Humphreys (2006).

Moorings are in several areas along the estuary, but most of them are concentrated between Noss/Sandquay to Lower Ferry including central Dartmouth and Kingswear, Lower Gurrow Point to Vipers Quay at Dittisham, Sandridge to Greenway and some north of the slipway at Blackness Point up to Totnes (Figure 8.4).

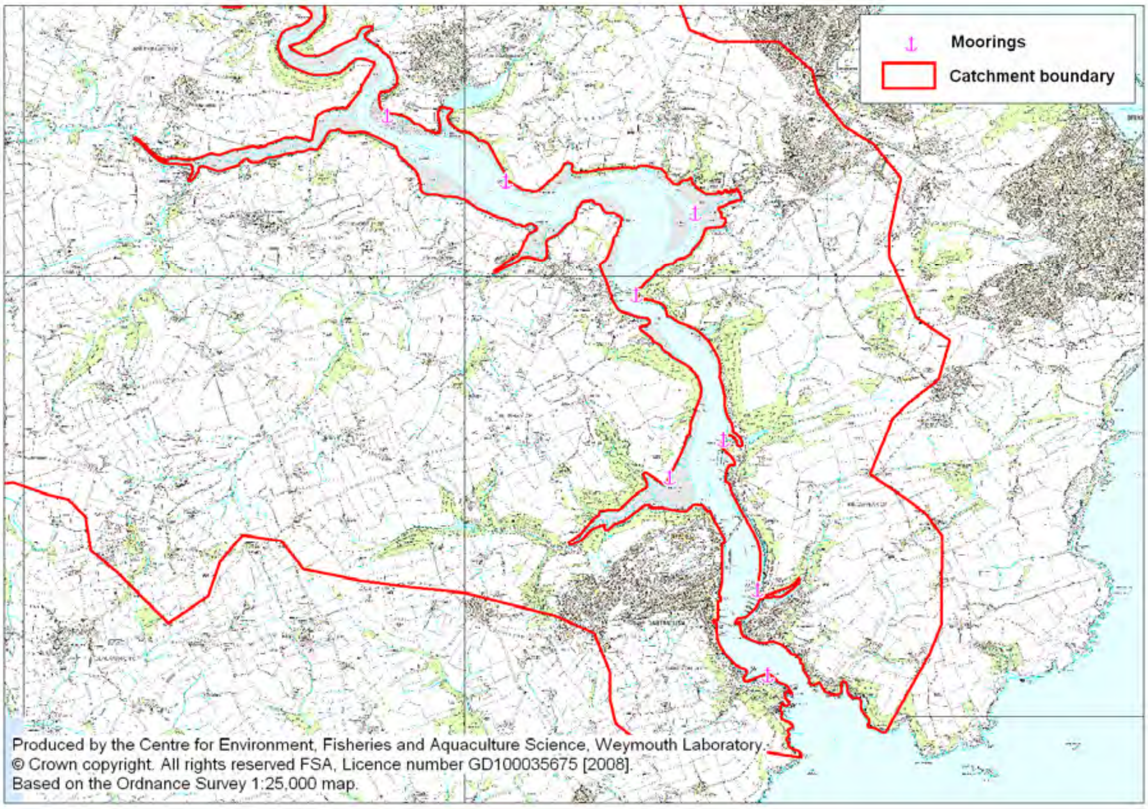


Figure 8.4. Location of moorings in the Dart Estuary.

The DHNA is considering reinstating moorings that have fallen into disuse at Galmpton Creek (Dartmouth Harbour and Navigation Authority, 2005).

Blackness Marine has recently established a storage/maintenance facility at Blackness Point and has approximately 37 members using the slipway during summer (Blackness Marine, pers. com., 05 April 2008).

Studies have found elevated levels of microbiological contaminants in coastal waters used for the commercial production of bivalve molluscs in the vicinity of ports and marinas (see Sobsey *et al*., 2003). There have been concerns on the impacts of sewage discharges from boats on the water quality in the Dart Estuary (Devon Wildlife Trust, 2004). However, historical data from the Shellfish Waters monitoring programme do not show significant increases in the levels of faecal coliforms in water during summer months (see Section 9.2). The intermittent discharge of small quantities of raw sewage from moored boats at Blackness Point, Vipers Quay and Dittisham are likely to have a higher impact on BMPAs at Blackness Point and Flat Owers, respectively.

The DHNA has implemented a Waste Management Plan aimed to coordinate and improve the facilities for the disposal of waste within the Port of Dartmouth (Dart Harbour and Navigation Authority, no date).

The *Good Practice Guide for Microbiological Monitoring of Bivalve Mollusc Harvesting Areas* (Cefas-CRL, 2007) recommends an exclusion zone of 300 m radius for class A or class B BMPAs from active harbours and marinas. Although this is accomplished by the new bed at Higher Gurrow Point, a number of moorings are within the existing classified BMPA between Greenway Quay and Flat Owers. Whenever possible, recommendations for revised boundaries of BMPAs presented in Section 10.2 take the recommended exclusion zone into consideration.

9 Microbiological data

A programme of sewage discharge improvements by South West Water in 2003 resulted in significant improvements to the microbiological water quality in the Dart Estuary in recent years. Analysis to historical microbiological data is therefore only relevant and confined to the period following these improvements.

9.1 Bivalve mollusc flesh and intravalvular liquid data

9.1.1 Hygiene classification

Following introduction of hygiene controls in 1992 several beds of both Pacific oysters and mussels have been classified in the Dart Estuary. Following the programme of water company discharge improvements in 2003 the number of class C areas reduced from five to one. Table 9.1 shows the individual bed classifications for the period following these improvements. Presently, all BMPAs in the Dart Estuary are class B. Mussels from Waddeton and Sandridge boathouse have a seasonal[7] B classification for the period 1 June to 30 November only, reverting to class C at all other times.

Table 9.1. Classifications of bivalve mollusc production areas in the Dart Estuary for the period 2004–2007.

Bed name	RMP	Species	2004	2005	2006	2007
Waddeton	B028B	*C. gigas*	B	B-LT	B-LT	B-LT
Waddeton	B028F	*Mytilus* spp.	C	B	B	C/seasonal B
Flat Owers	B028G	*C. gigas*	B	B-LT	B-LT	B-LT
Flat Owers	B028C	*Mytilus* spp.	B	B	B	B
Sandridge Boathouse	B028H	*C. gigas*	B	B	B-LT	B-LT
Sandridge Boathouse	B028E	*Mytilus* spp.	B	B	B	C/seasonal B
Compass Cove	B028I	*Mytilus* spp.	n/c	n/c	B	B

Refer to Figure 2.1 for location of RMPs.
n/c - not classified.
LT - Long-Term classification system applies. Note: Long-Term (LT) classification system was introduced in England and Wales alongside the annual classification system, and applies to class B areas only. New class B areas will initially be given annual classification until they meet criteria for a long-term classification.
seasonal - class B only for the period 1 June–30 November, reverting to class C at all the other times.

[7] The requirements for seasonal classification are (a) at least two year's worth of data showing a clear seasonal trend; (b) the 'active' season intended must be preceded by two months in situ relay period from class C to B (one month from class B to A), i.e. the historical results during this lead up period prior to the start of the active season must also conform to the 'better' classification category to allow cleansing of the bivalves; (c) a valid season should be at least three months in length and be of benefit to the industry i.e. fall during a period when harvesting would normally take place; (d) it is normally encouraged that monthly monitoring should continue throughout the year (e.g. to check that Prohibited level results do not occur during the closed season). If this is not possible, then 12 samples should be taken during the season itself and the preceding two months. If the season is short (<six months) then samples may be taken at fortnightly intervals if necessary. The minimum interval between samples in any event should be seven days.

Bivalve molluscs from class B areas need to be purified, relayed or cooked by an approved method before sold for human consumption. Bivalve molluscs from class C areas need to be relayed or cooked by an approved method before sold for human consumption.

9.1.2 Historical *Escherichia coli* data

Table 9.2 summarises the results in terms of sampling effort, geometric mean, median and range of *E. coli* levels in bivalves sampled from the existing RMPs.

The similar number of samples for RMPs from all the BMPAs in the mid-estuary indicates a continued and consistent sampling effort in the Dart over the period.

The highest range of *E. coli* was detected in mussels from Sandridge Boathouse.

The geometric mean is the mean value of logarithms and is often reported for positively skewed data sets, ie data sets with number of high extreme values. The median (or 50th percentile) is the central value of the distribution when the data are ranked in order of magnitude, ie for an odd number of observations, is the data point, which has an equal number of observations both above and below it. The analysis of median values is preferable to the analysis of geometric means when the data set is not strongly influenced by a few extreme observations (Helsel and Hirsch, 2002). This is particularly evident for median values of *E. coli* in Pacific oysters shown in Table 9.2, which indicate similar levels of contamination in oysters from Waddeton and Flat Owers. Geometric means of *E. coli* in mussels seems a better representation of the levels of contamination in mussels due to high numbers of extreme values in this species.

Table 9.2. Summary statistics of* E. coli *levels in bivalve molluscs from six RMPs in the Dart Estuary for the period 2004–2008.

RMP	Bed name	Species	n	Date of first sample	Date of last sample	MPN *E. coli* $100g^{-1}$ FIL			
						Min.	Max.	GM	Median
B028B	Waddeton	*C. gigas*	45	20/04/04	12/02/08	20	4,300	251	220
B028F	Waddeton	*Mytilus* spp.	44	20/04/04	12/02/08	70	17,000	929	750
B028G	Flat Owers	*C. gigas*	41	18/05/04	12/02/08	20	5,000	275	220
B028C	Flat Owers	*Mytilus* spp.	41	18/05/04	12/02/08	70	11,000	677	500
B028H	Sandridge Boathouse	*C. gigas*	40	18/05/04	12/02/08	20	5,000	252	261
B028E	Sandridge Boathouse	*Mytilus* spp.	42	18/05/04	12/02/08	110	>1,800,000	814	612

n - number of samples.
GM - geometric mean.
FIL - flesh and intravalvular liquid.

The comparisons in the levels of contamination between RMPs and between species are also represented in the box-and-whisker plots shown in Figure 9.1.

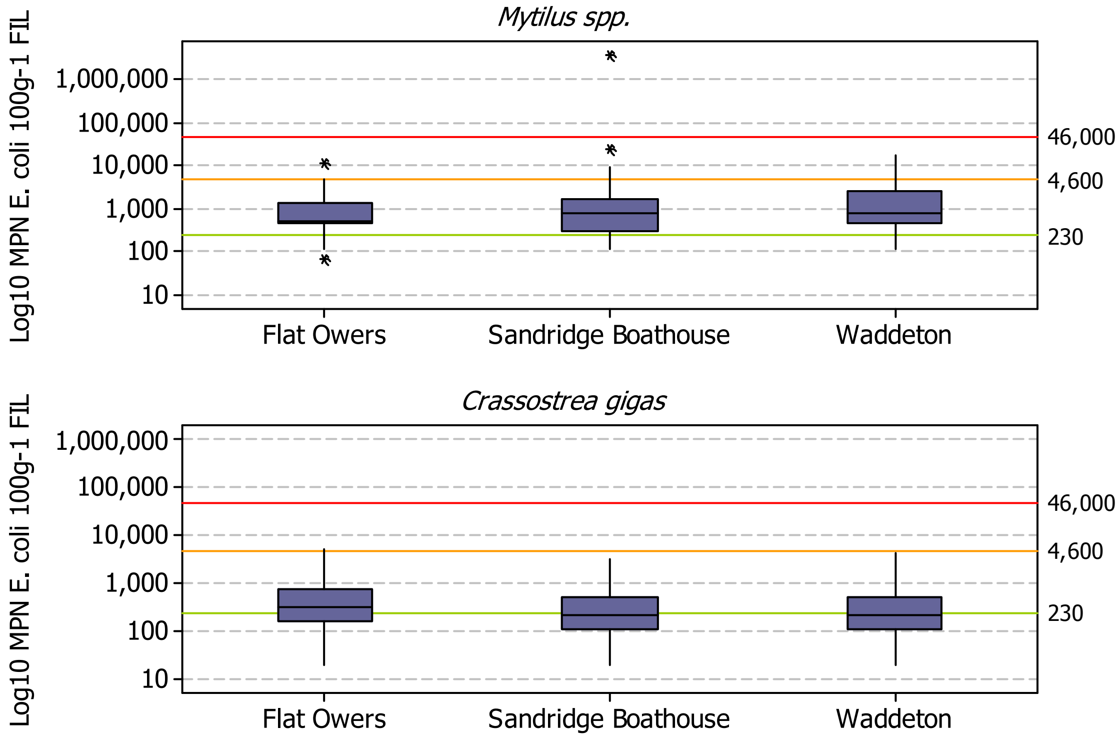


Figure 9.1. Box-and-whisker plots of levels of* E. coli *in bivalve molluscs from three beds in the Dart Estuary for the period 2005–2007.

These plots indicate higher levels of microbiological contamination in mussels from Waddeton and Sandridge Boathouse than those from Flat Owers. These results indicate higher impact of pollution sources on the levels of contamination at Sandridge Boathouse and Waddeton.

Figure 9.1 also shows that *E. coli* levels in Pacific oysters tend to be more symmetric, ie with similar variation or spread than those detected in mussels, as evidenced by the similar sizes of top and bottom box halves and similar lengths of whiskers. These plots also show the occasional occurrence of high *E. coli* results (or outliers) in mussels from Sandridge Boathouse and Flat Owers.

Outliers correspond to the intermittent detection of contamination events, many of them have been historically associated with operational problems in sewage discharges. This was the case of two *E. coli* results (MPN $100g^{-1}$ FIL = 24,000 on 4 December 2006 and MPN $100g^{-1}$ FIL > 1,800,000 on 20 February 2007) detected in mussels from Sandridge Boathouse. This indicates that, despite the upgrades in sewage discharges, operational problems can still lead to episodes of high microbiological contamination.

Monthly *E. coli* levels in bivalve molluscs were also plotted together with LOWESS lines (degree of smoothing = 0.5; number of steps = 2; minimum number of samples per year = 7). LOWESS can be used to (a) emphasize the shape of the relationship between variables, aiding the judgement of how these could be related; (b) compare and contrast multiple large data sets demonstrating both linear or non-linear relationships (Helsel and Hirsch, 2002).

LOWESS lines for *E. coli* levels in mussels and Pacific oysters do not show a particularly marked tendency to increase or decrease over the four year data set analysed (Figures 9.2 and 9.3).

Crassostrea gigas

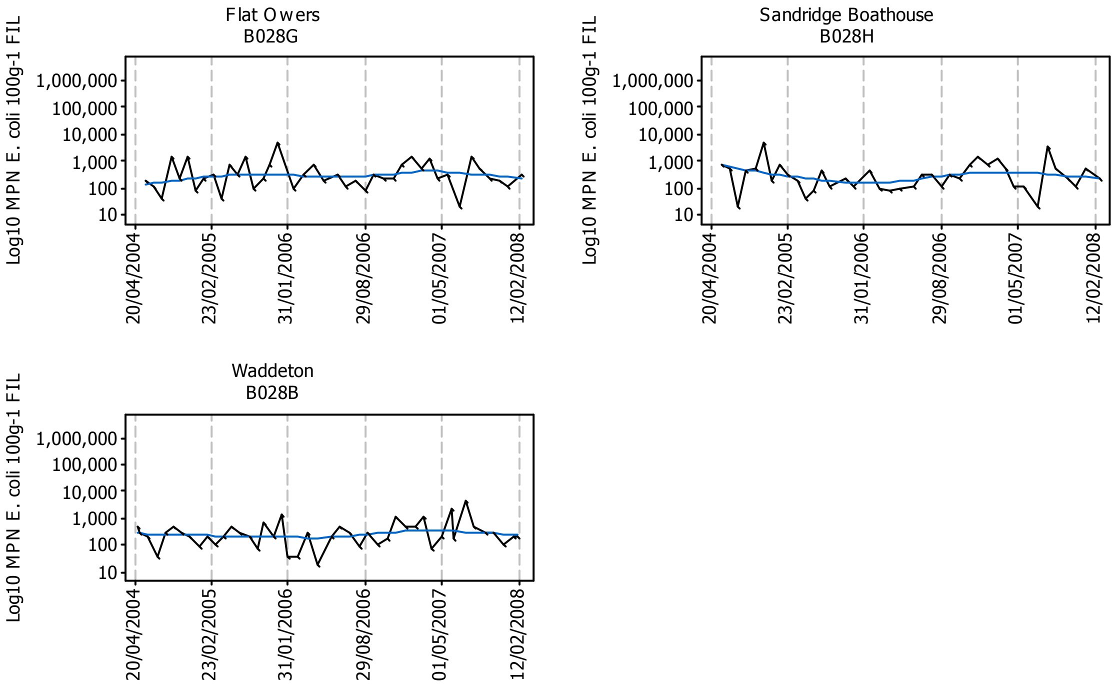


Figure 9.2. Locally weighted scatterplot smoothing of monthly variation in the levels of* E. coli *in Pacific oysters from three RMPs in the Dart Estuary for the period 2004–2008.

Mytilus spp.

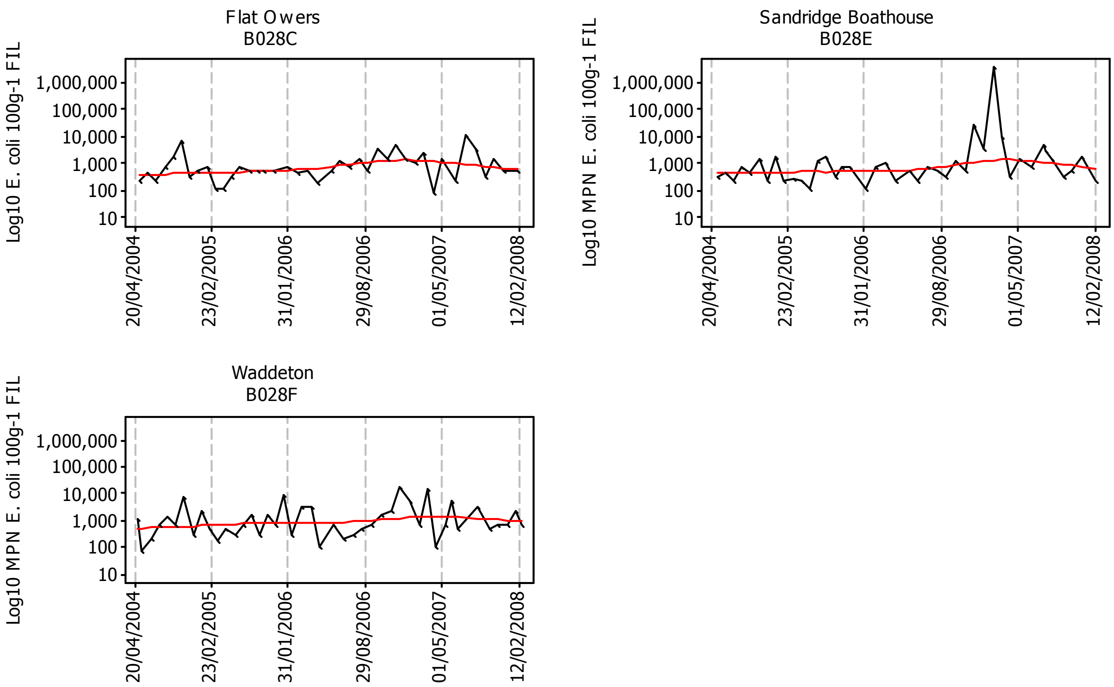


Figure 9.3. Locally weighted scatterplot smoothing of monthly variation in the levels of* E. coli *in mussels from three RMPs in the Dart Estuary for the period 2004–2008.

The prevalence of higher levels of *E. coli* in mussels than in Pacific oysters corresponds to the general pattern of contamination found in many BMPAs in England and Wales. The pattern is usually attributed to different physiological characteristics and growing methods of those species and/or the effect of stratification of contaminants in the water column (see Younger *et al.*, 2003). A more detailed description on density gradient in the Dart Estuary was presented in Section 6.4.

The future planned measures to reduce the number of crude sewages to the Dart Estuary (see Section 7.1) and to reduce pollution of diffuse origin (see Section 8) may have the effect of reducing *E. coli* levels in bivalve molluscs in the future.

9.1.3 Variation of *Escherichia coli* according to rainfall

Rainfall data from Dittisham Dinah's rain-gauge station (Figure 5.1) was correlated with *E. coli* levels in Pacific oysters and mussels from six existing RMPs in the Dart Estuary for the period January 2003–June 2007. Pearson correlation coefficient (*r*) was used to estimate correlations between MPN *E. coli* 100 g^{-1} FIL and daily and total rainfall up to seven days before sampling.

Pearson coefficient is a measure of the linear association between variables and is based on the assumption that the data follow a bivariate normal distribution (Helsel and Hirsch, 2002). Because *E. coli* levels frequently demonstrate outliers and an increasing variance, these were Log_{10}-tranformed before correlation analyses.

The results shown in Table 9.3 show statistically significant relationships between total rainfall and *E. coli* levels in bivalves from all RMPs. Figure 13 shows scatterplots fitted with LOWESS (LOcally WEighted Scatterplot Smoothing; Cleveland *et al.*, 1979) lines displaying the relationship between the two parameters.

The upward trend of LOWESS lines evidence the positive association between rainfall and *E. coli* levels. In general, both total rainfall and daily rainfall show higher relationships with *E. coli* levels in mussels than with *E. coli* levels in Pacific oysters (Table 9.3). Higher correlation coefficients were found between daily rainfall and *E. coli* in mussels from Sandridge Boathouse (Figure 9.4). The levels of *E. coli* in bivalves from all RMPs and their association with total rainfall increase in statistical significance for a period of, at least, three days. This usually occurs from the 4^{th} to 6^{th} day before sampling. In the case of *E. coli* levels in mussels from Waddeton, the levels of significance with total rainfall increase consistently from the 2^{nd} to 7^{th} day before sampling.

These results indicate that rainfall is a useful parameter to predict the levels of microbiological contamination in mussels and Pacific oysters from the Dart Estuary. The majority of *E. coli* levels detected both in Pacific oysters and in mussels corresponded to total rainfall levels exceeding 2 mm in any 24 h period (see reference lines in Figure 9.4). This is the threshold used by the Met Office to generate maps of rainfall intensity (Perry, 2006). The average annual number of rain days >2mm in data analysed in the present section varied between 87 days in 2005 and 98 days in 2004.

Consideration could be given by LEA to sampling under these conditions in order to reflect the potential worst-case scenario of microbiological contamination, if this aspect of the recommendations of the *Good Practice Guide for Microbiological Monitoring of Bivalve Mollusc Harvesting Areas* (Cefas-CRL, 2007) is adopted in the UK at some point in the future.

In recent decades, there has been a tendency for an increase in winter precipitation in the entire west of the UK. This is associated with an upward trend in the winter North Atlantic Oscillation and is likely to increase the occurrence of extreme heavy rainfall events in the region (Perry, 2006). The potential effect of this change on the risk of microbiological contamination from runoff or rainfall dependent sewage discharges should be evaluated at the time of the next review of the sanitary survey, when a larger dataset is likely to be available.

Table 9.3. Pearson correlation coefficients between rainfall averages (mm) recorded at Dittisham rain-gauge station and MPNs of* E. coli *$100g^{-1}$ FIL in bivalves from six monitoring points in the Dart Estuary for the period January 2003–June 2007.

						Rainfall (mm)												
													Total					
MPN *E. coli* $100g^{-1}$ FIL: RMP	Bed name	Species	n		Day of sampling	-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
B028B	Waddeton	*C. gigas*	38	*r*	0.136	-0.049	0.443	0.256	0.669*	-0.275	0.435	0.324	0.114	0.328	0.406*	0.497*	0.391*	0.397*
				p	0.603	0.900	0.075	0.358	0.001	0.241	0.071	0.259	0.632	0.117	0.039	0.005	0.024	0.022
B028C	Flat Owers	*Mytilus* spp.	35	*r*	0.052	0.394	0.648*	0.247	0.346	0.223	0.408	0.358	0.088	0.353	0.390	0.422*	0.357	0.399*
				p	0.854	0.382	0.009	0.439	0.173	0.374	0.104	0.230	0.737	0.117	0.066	0.028	0.053	0.029
B028E	Sandridge Boathouse	*Mytilus* spp.	35	*r*	0.110	0.618	0.264	0.100	0.424	0.254	0.419	0.501	0.405	0.481*	0.481*	0540*	0.557*	0.565*
				p	0.696	0.139	0.341	0.758	0.090	0.310	0.094	0.081	0.107	0.027	0.020	0.004	0.001	0.001
B028F	Waddeton	*Mytilus* spp.	38	*r*	0.081	-0.225	0.544*	0.481	0.652*	0.160	0.529*	0.271	0.049	0.372	0.542*	0.595*	0.584*	0.614*
				p	0.757	0.560	0.024	0.069	0.002	0.501	0.024	0.349	0.837	0.074	0.004	0.001	0.000	0.000
B028G	Flat Owers	*C. gigas*	35	*r*	-0.020	0.542	0.498	0.359	0.456	0.386	0.650*	0.050	0.015	0.326	0.424	0.428*	0.459*	0.517*
				p	0.945	0.209	0.059	0.252	0.066	0.114	0.005	0.871	0.955	0.150	0.044	0.026	0.011	0.003
B028H	Sandridge Boathouse	*C. gigas*	34	*r*	-0.100	0.490	0.503	0.302	0.650*	0.217	0.329	0.703*	-0.065	0.213	0.319	0.320	0.267	0.234
				p	0.734	0.264	0.056	0.367	0.005	0.387	0.198	0.007	0.812	0.368	0.147	0.110	0.161	0.222

Pearson correlation coefficient (*r*) ranges between +1 and -1. The significance of *r* is tested by determining whether its value differs from 0.
A correlation of +1 means that there is a perfect positive linear relationship between rainfall and Log_{10} MPN of *E. coli* $100g^{-1}$ FIL.
A correlation of -1 means that there is a perfect negative linear relationship between rainfall and Log_{10} MPN of *E. coli* $100g^{-1}$ FIL.
A correlation of 0 means that there is no linear relationship between rainfall and Log_{10} MPN of *E. coli* $100g^{-1}$ FIL.
n – number of samples.
* Statistically significant (p<0.05).
Correlation analysis performed using Log_{10}-transformed *E. coli* concentrations. Less-than *E. coli* results were assigned half the numerical value before transformation. Greater-than *E. coli* results were assigned double the numerical value before transformation.

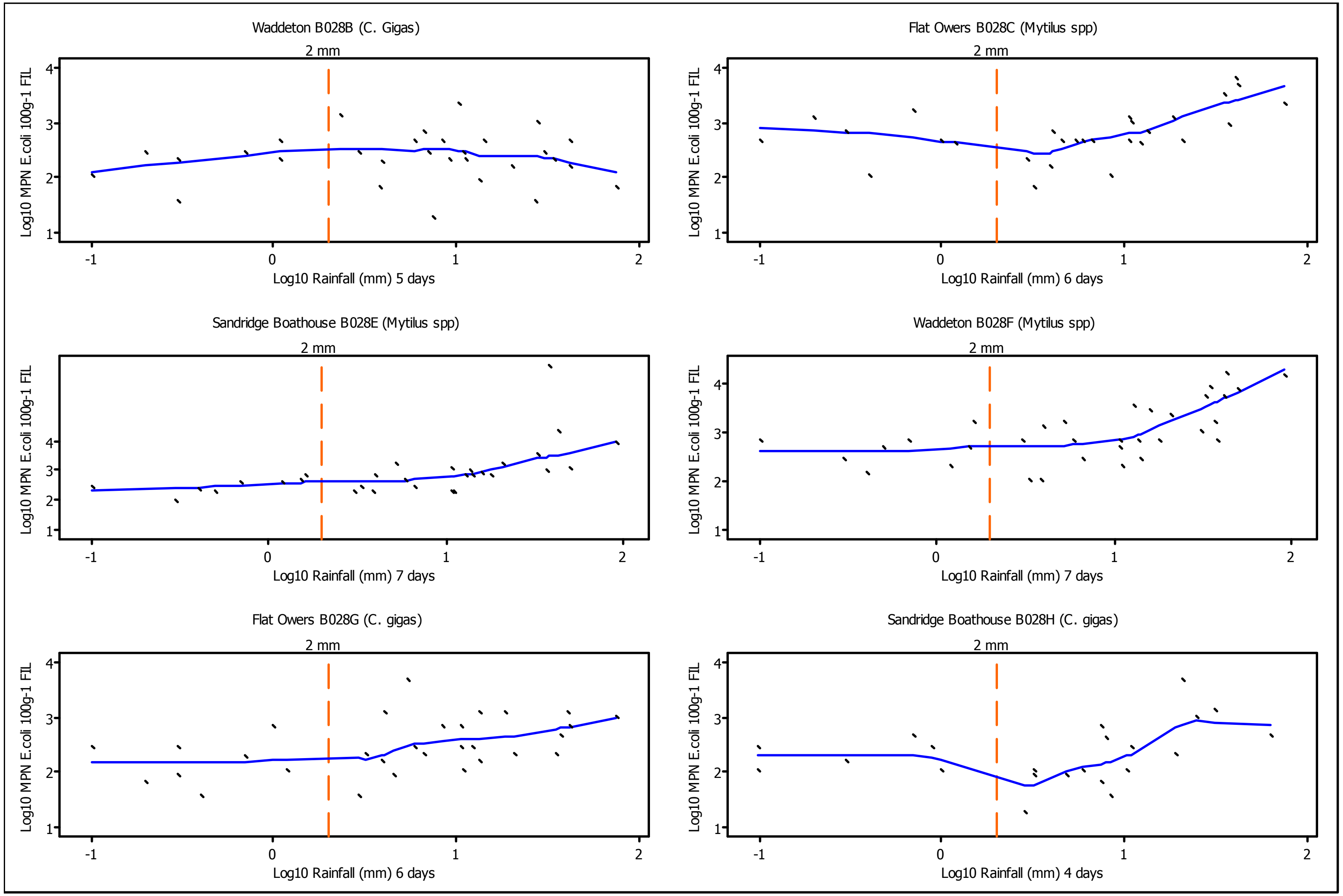


Figure 9.4. Locally weighted scatterplot smoothing of rainfall (mm) recorded at Dittisham rain-gauge station and MPNs of* E. coli *100g*$^{-1}$ *FIL in bivalves from six monitoring points in the Dart Estuary.

Only plots for the day of maximum statistical significance are highlighted.

9.1.4 Variation of *Escherichia coli* according to river flows

River flow data recorded at Bellever during the period August 2004–December 2005 was correlated with *E. coli* levels in bivalve molluscs from six existing RMPs. Pearson correlation coefficient (*r*) was used to estimate correlations between MPN *E. coli* $100g^{-1}$ FIL and daily and total river flows. The results from this analysis may be compared with those presented in Section 9.1.3 to assess the combined effect of rainfall and river flows in determining the levels of microbiological contamination in bivalve molluscs.

Significant strong positive correlations were found between both daily and total river flows and *E. coli* levels in bivalve molluscs from all RMPs except Pacific oysters from Flat Owers (Table 9.4). In both species, higher correlations were obtained between river flows and *E. coli* levels than those found between rainfalland *E. coli* levels. This is particularly evident in mussels from Waddeton and Pacific oysters from Sandridge Boathouse. The correlation coefficients between river flows and *E. coli* levels were not consistent with those between rainfall and *E. coli* levels for Pacific oysters from Waddeton and Flat Owers. However and similarly to correlations between rainfall and *E. coli* levels, the levels of statistical significance between total river flows and *E. coli* levels increase consistently from the 4th and 6th day before sampling in mussels from Sandridge Boathouse and Waddeton and in Pacific oysters from Sandridge Boathouse. These similarities are less evident for mussels from Flat Owers, although levels of statistical significance between river flow and *E. coli* also increase from the 3rd to 4th day before sampling (Table 9.4).

The upward trend of LOWESS lines evidences the positive association between river flows and *E. coli* levels in bivalves (Figure 9.5).

The results indicate that river flow explains a significant variation of *E. coli* in mussels from Sandridge Boathouse and Waddeton and in Pacific oysters from Sandridge Boathouse. However, the results show that high number of class B/C results occurred when the mean river flow (1.2 $m^3 s^{-1}$ at Bellever) was exceeded (Figure 9.5). Therefore and unlike rainfall, it is not possible to establish a river flow threshold to be used as reference for worst-case scenario of contamination.

Mussels from Sandridge Boathouse and Waddeton have a seasonal classification system in place. Section 9.1.5 presents a re-evaluation of seasonal variation of *E. coli* levels in mussels and Pacific oysters from existing production areas undertaken using a larger dataset.

Table 9.4. Pearson correlation coefficients between river flow (m^3 s^{-1}) in the Dart recorded at Bellever and MPNs of* E. coli *$100g^{-1}$ FIL in bivalves from six monitoring points in the Dart Estuary for the period August 2004–December 2005.

MPN *E. coli* $100g^{-1}$ FIL

RMP	Bed name	Species	n		River flow (mm)													
													Total					
					Day of sampling	-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
B028B	Waddeton	*C. gigas*	38	*r*	0.249	0.276	0.421	0.314	0.277	0.450	-0.061	-0.055	0.264	0.360	0.337	0.315	0.375	0.354
				p	0.370	0.319	0.118	0.254	0.317	0.092	0.829	0.846	0.341	0.188	0.219	0.253	0.168	0.195
B028C	Flat Owers	*Mytilus* spp.	35	*r*	0.472	0.559*	0.588*	0.691*	0.467	0.343	0.316	0.098	0.521	0.560*	0.660*	0.615*	0.618*	0.583*
				p	0.088	0.038	0.027	0.006	0.092	0.230	0.270	0.738	0.056	0.037	0.010	0.019	0.018	0.029
B028E	Sandridge Boathouse	*Mytilus* spp.	35	*r*	0488	0.520	0.526	0.569*	0.665*	0.601*	0.341	0.248	0.507	0.538*	0.563*	0.630*	0.675*	0.642*
				p	0.077	0.057	0.053	0.034	0.009	0.023	0.233	0.393	0.064	0.047	0.036	0.016	0.008	0.013
B028F	Waddeton	*Mytilus* spp.	38	*r*	0.731*	0.753*	0.755*	0.786*	0.808*	0.729*	0.392	0.323	0.745*	0.774*	0.800*	0.825*	0.864*	0.846*
				p	0.002	0.001	0.001	0.001	0.000	0.002	0.148	0.241	0.001	0.001	0.000	0.000	0.000	0.000
B028G	Flat Owers	*C. gigas*	35	*r*	0.035	0.138	0.357	0.470	0.389	0.105	0.442	0.262	0.092	0.203	0.345	0.385	0.371	0.401
				p	0.907	0.637	0.211	0.090	0.169	0.722	0.113	0.365	0.756	0.486	0.227	0.175	0.192	0.156
B028H	Sandridge Boathouse	*C. gigas*	34	*r*	0.641*	0.728*	0.772*	0.793*	0.650*	0.507	0.341	0.201	0.691*	0.743*	0.798*	0.785*	0.814*	0.764*
				p	0.018	0.005	0.002	0.001	0.016	0.077	0.254	0.510	0.009	0.004	0.001	0.001	0.001	0.002

Pearson correlation coefficient (*r*) ranges between +1 and -1. The significance of *r* is tested by determining whether its value differs from 0.
A correlation of +1 means that there is a perfect positive linear relationship between river flow and Log_{10} MPN of *E. coli* $100g^{-1}$ FIL.
A correlation of -1 means that there is a perfect negative linear relationship between river flow and Log_{10} MPN of *E. coli* $100g^{-1}$ FIL.
A correlation of 0 means that there is no linear relationship between river flow and Log_{10} MPN of *E. coli* $100g^{-1}$ FIL.
n – number of samples.
*Statistically significant ($p<0.05$).
Correlation analysis performed using Log_{10}-transformed *E. coli* concentrations. Less-than *E. coli* results were assigned half the numerical value before transformation. Greater-than *E. coli* results were assigned double the numerical value before transformation.

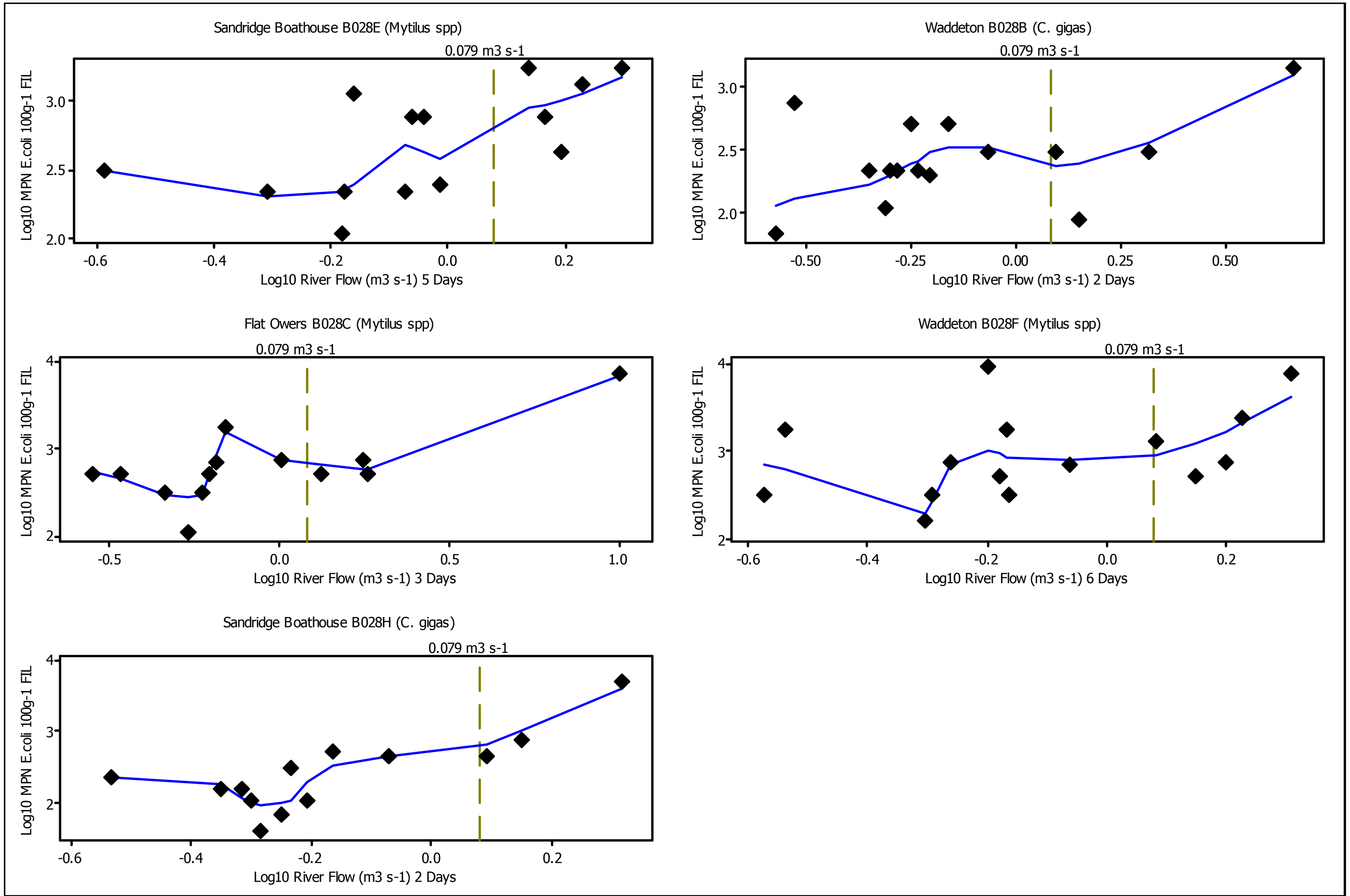


Figure 9.5. Locally weighted scatterplot smoothing of river flow ($m^3\ s^{-1}$) recorded at Bellever gauging station and MPNs of E. coli 100g^{-1} FIL in bivalves from five monitoring points in the Dart Estuary.

Only plots for the day of maximum statistical significance are highlighted.

Reference lines indicate mean flow at river gauging station.

The cumulative effect of rainfall and river flows on the levels of *E. coli* in bivalve molluscs is illustrated in Figure 9.6. This shows levels of *E. coli* detected in mussels and Pacific oysters from Sandridge Boathouse, Flat Owers and Waddeton during, total daily rainfall recorded at Buckfastleigh and river flow from East Dart recorded at Bellever during the period January–December 2005. Elevated levels of *E. coli* were detected in both species when mean river flow level was exceeded. *E. coli* levels in mussels particularly reflected the coupled increase of river flows determined by one or more days of heavy rainfall.

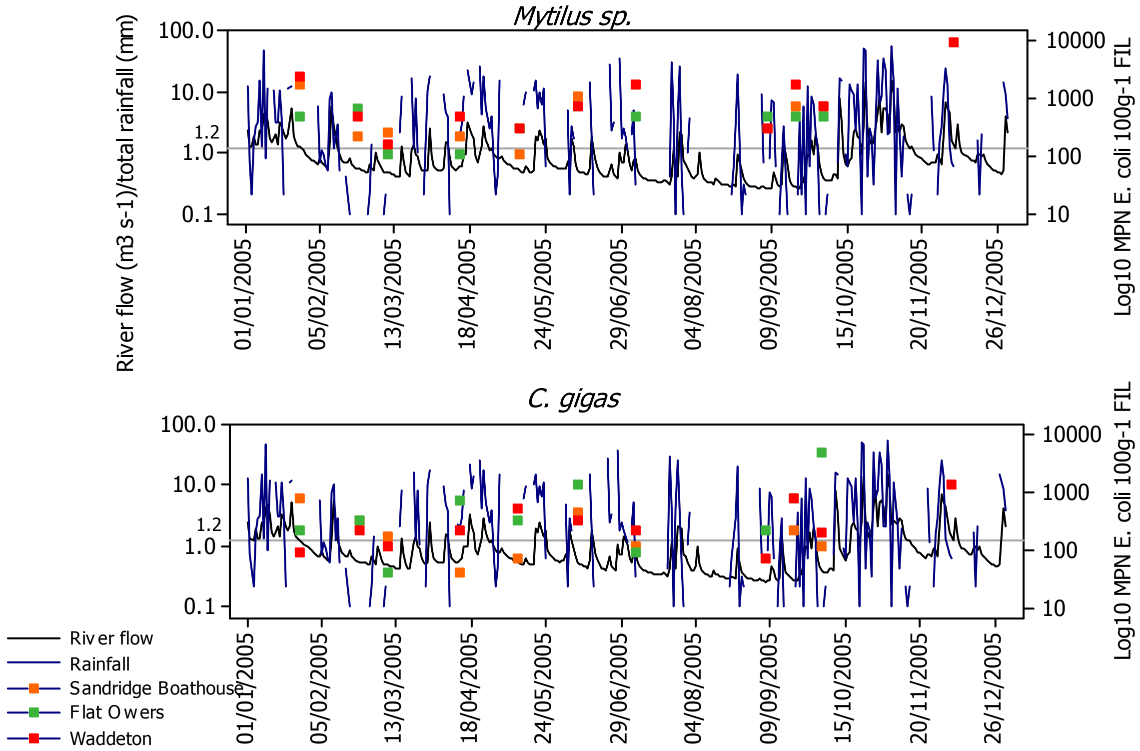


Figure 9.6. Daily rainfall (Buckfastleigh weather station) and river flow (East Dart at Bellever gauging station) and MPNs of E. coli 100g^{-1} FIL monitored in bivalves from three monitoring points in the Dart Estuary in 2005.

Reference lines indicate mean flow at river gauging station.

9.1.5 Seasonality of *Escherichia coli*

Mussels from Waddeton and Sandridge Boathouse are currently subject to a seasonal classification (see Table 9.1). Seasonality in the levels of *E. coli* was identified after statistical analysis of the microbiological monitoring results for the period January 2004–March 2007. This section presents the results from a more in depth investigation of historical *E. coli* data in order to conclude whether the seasonal pattern has been maintained following the upgrades in sewage discharges impacting on BMPAs (see Section 7.1).

Investigation of seasonality for BMPAs in the Dart was undertaken for *E. coli* levels in Pacific oysters and mussels for the period April 2004–February 2008. This represents the period following improvements in STW likely to impact on BMPAs. The first method consisted of the analysis of monthly geometric means of *E. coli* together with the percent of *E. coli* results > 4,600 MPN100g^{-1} FIL in mussels and Pacific oysters from existing RMPs in the estuary. The second method consisted of the analysis of the seasonal variation of *E. coli* levels, as represented by box-and-whisker plots[8]. Data was amalgamated by season considering spring (March–May), summer (June–August), autumn (September–November) and winter (December–February). One-way analysis of variance (ANOVA) was used to test differences between months and between seasons followed by a Tukey HSD test using a significance level (α) of 0.05.

Monthly geometric means of *E. coli* show a period of low microbiological contamination in mussels from Sandridge Boathouse, Waddeton and Flat Owers during spring-early summer (April–June) (Figure 9.7). July shows an increase in geometric means of *E. coli* in the three RMPs. A period of high geometric means takes place during autumn-early spring (October–March). This also corresponds to the period when the higher number of *E. coli* results > 4,600 were detected. However, no significant differences (all yielded p>0.05) were found in *E. coli* levels between months.

The magnitude of microbiological contamination detected throughout the year in mussels is higher than the magnitude detected in Pacific oysters (Figure 9.8). In general, geometric means of *E. coli* in Pacific oysters from Sandridge Boathouse increase from April to January. The higher geometric means of *E. coli* in Pacific oysters were detected in different months between RMPs (e.g. December in Waddeton, November and January in Sandridge Boathouse). The higher geometric mean of *E. coli* in Flat Owers corresponds to one result and, therefore, February should be considered the month when higher levels of contamination are detected in this shellfish bed.

[8] Box-and-whisker plots depict the distribution (central tendency and spread) of a data set. These plots show (a) the centre or median of the data (centre line of the box), (b) the spread or inter-quartile range (box height), (c) quartile skew (relative size of box halves) and (d) the presence of extreme values or outliers (asterisks).

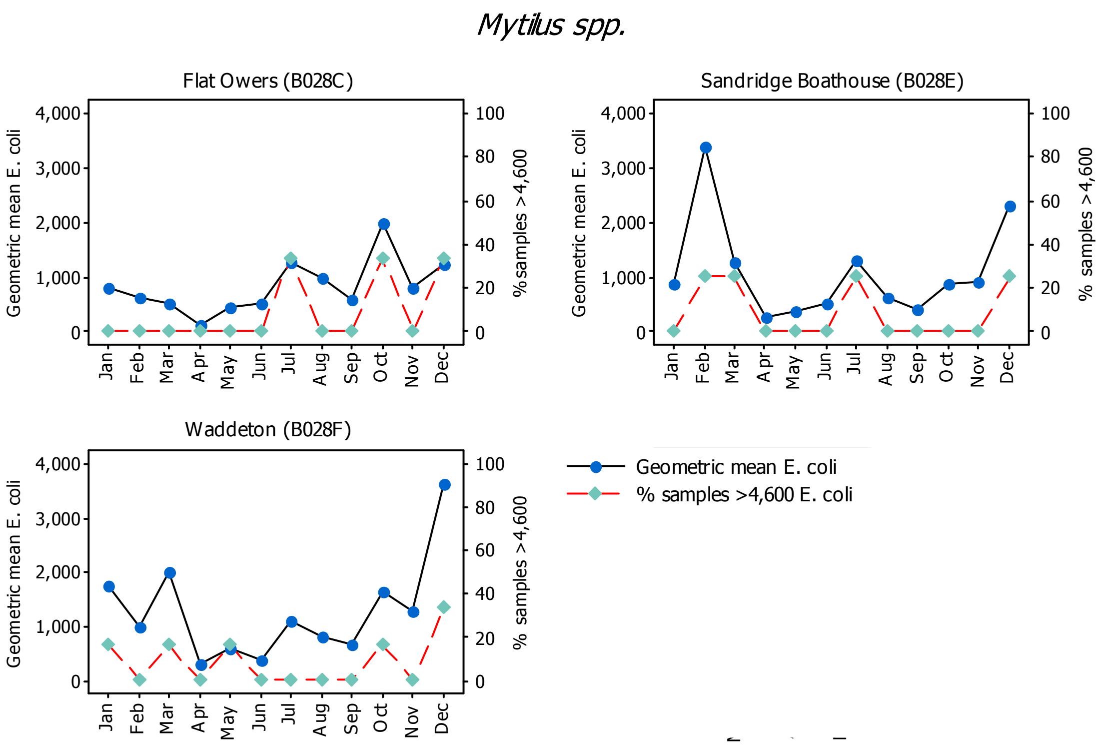


Figure 9.7. Monthly variation of geometric means and number of results of* E. coli *higher than 4,600 in mussels from three RMPs in the Dart Estuary for the period 2004–2008.

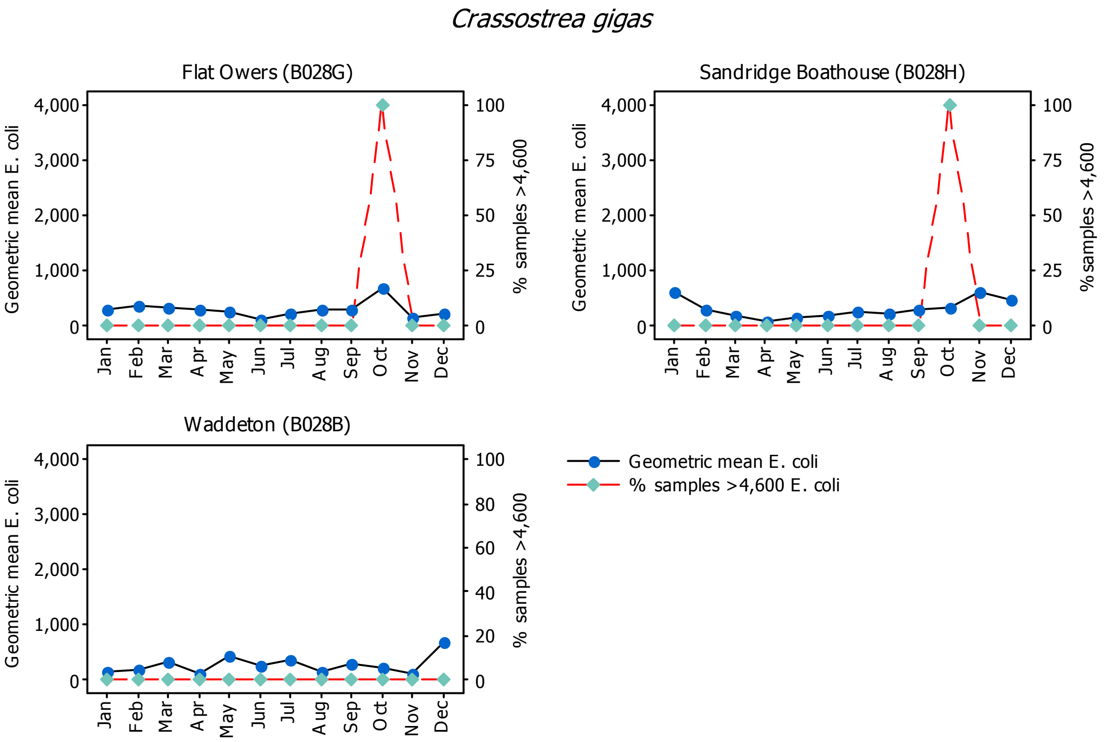


Figure 9.8. Monthly variation of geometric means and number of results of* E. coli *higher than 4,600 in Pacific oysters from three RMPs in the Dart Estuary for the period 2004–2008.

Percentage of samples >4,600 of Pacific oysters from Flat Owers and Sandridge Boathouse refer to one sample.

Only mussels from Flat Owers showed significant (p=0.05) differences in *E. coli* levels between seasons (Figure 9.9). However, these corresponded to less than 1 Log_{10} in difference in *E. coli* levels detected in mussels between the season showing lower levels of contamination (spring) and the season showing higher levels of contamination (winter). One-way ANOVA showed no significant differences (p>0.05) in *E. coli* levels in Pacific oysters between seasons, indicating the lack of clearly defined seasonality in the levels of contamination in Pacific oysters (Figure 9.10).

Mytilus spp.

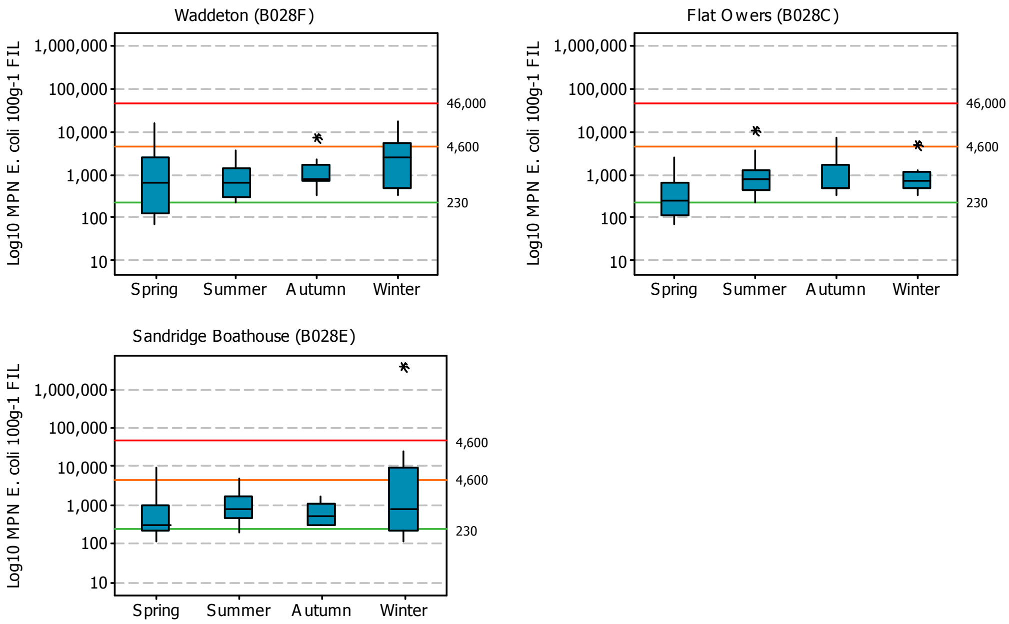


Figure 9.9. Box-and-whisker plots of seasonal variation of* E. coli *levels in mussels from three RMPs in the Dart Estuary for the period 2004–2008.

C. gigas

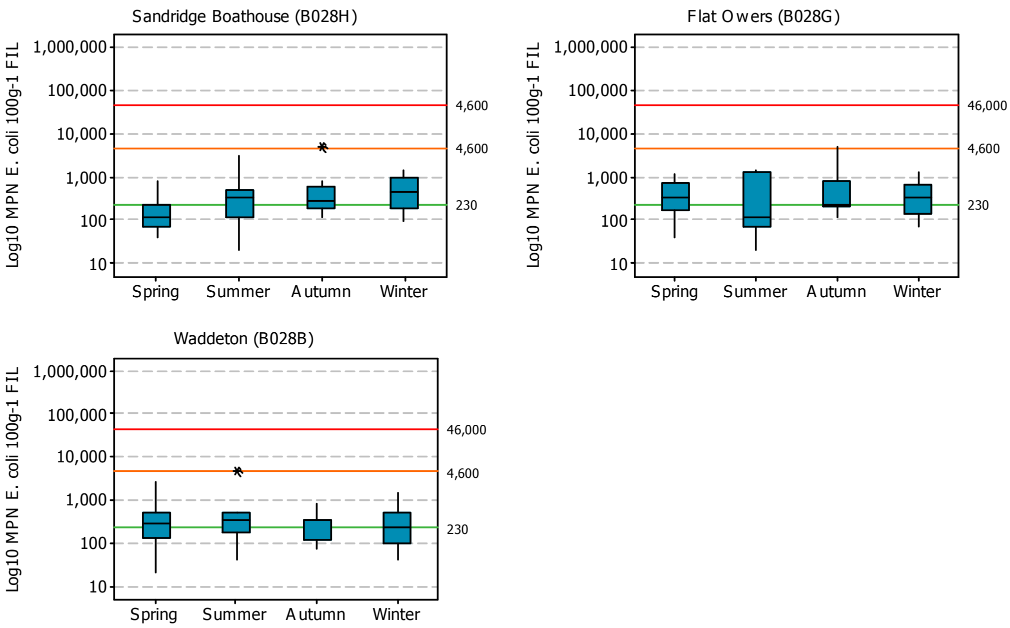


Figure 9.10. Box-and-whisker plots of seasonal variation of* E. coli *levels in Pacific oysters from three RMPs in the Dart Estuary for the period 2004–2008.

Despite the significant differences in *E. coli* levels in mussels from Flat Owers, it should be pointed out that the production area is not being used for commercial harvesting as owing to a lack of exploitable stock. The Devon SFC commented that mussel sampling has been maintained should industry wish to reinitiate mussel culture on Flat Owers in the future (T. Robbins, Devon SFC, pers. com., 8 April 2008). The microbiological results summarised in the present section indicate a degree of instability in *E. coli* levels detected in mussels from Flat Owers throughout the year (cf. Figure 9.7, Figure 9.9). This indicates that sampling frequency should be at least monthly if the classification status of mussels is to be maintained at Flat Owers.

9.2 Shellfish Waters

The mid-estuarine area from Higher Gurrow Point-Sandridge to Greenway House at Dittisham has been designated under Directive 2006/113/EC as Shellfish Water since 1999 (European Communities, 2006) (Figure 9.1). Microbiological monitoring of mussels at Waddeton (Bed B028F) has been based on results from the Shellfish Hygiene monitoring programme (Environment Agency, 2007) and as such was reviewed in Section 9.1, for this reason, only microbiological results from a programme of water sampling (not a requirement of the Directive) are presented in this section.

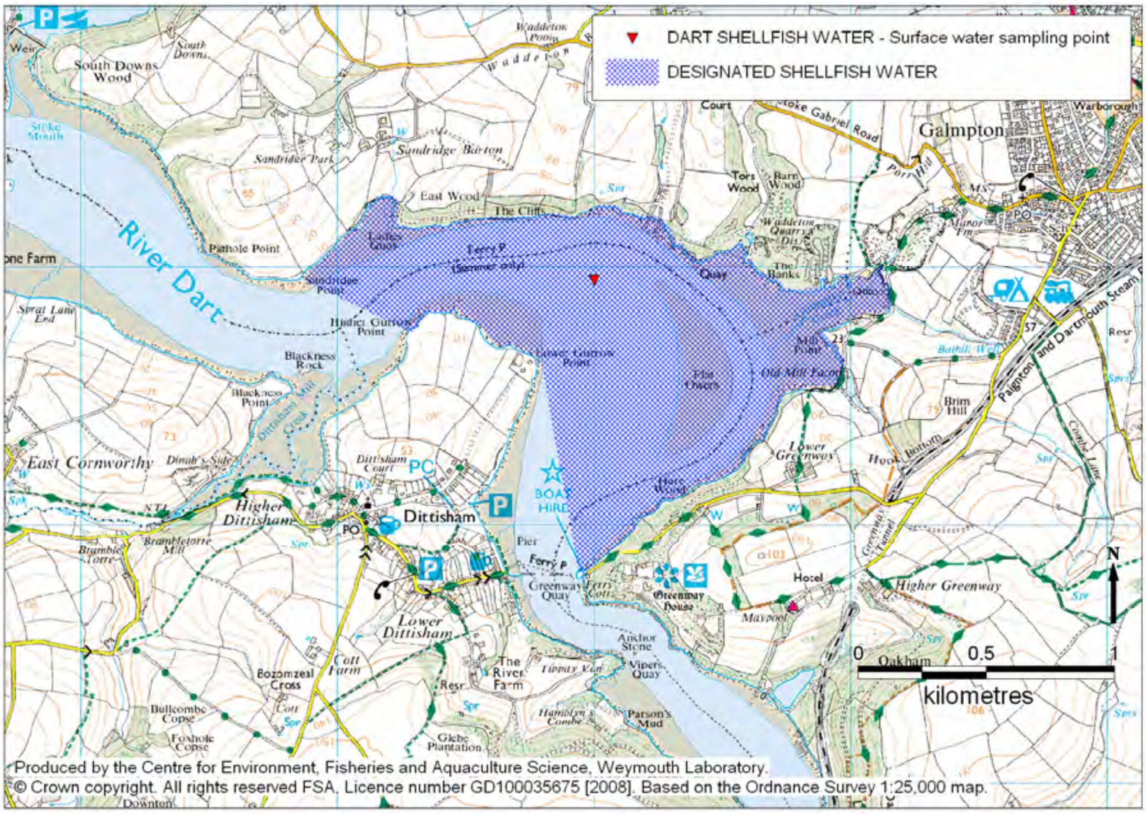


Figure 9.11. Location of the designated shellfish water in the Dart Estuary.

Table 9.5 summarises the results of the non-statutory surface water sampling for faecal coliforms in the Dart at Lower Gurrow Point shellfish water. A substantial decrease in sampling effort has been evident in recent years. The geometric mean and median of faecal coliforms decreased significantly in 2003. This might be the result of better water quality in the estuary following the upgrades in STW. However, the geometric means of faecal coliforms would be equivalent to class B/C in bivalve mollusc fluid and intravalvular liquid. Owing to the low number of results between 2004 and 2007, it is not possible to identify if the decreasing trend has been continued in recent years.

Table 9.5. Summary statistics of faecal coliforms in the designated shellfish water in the Dart Estuary for the period 2002–2007.

Year	Number of samples	CFU Faecal coliforms 100 ml^{-1}		
		Range (Min.–Max.)	Geometric mean	Median
2002	11	<10–1,009	137	306
2003	12	<10–1,364	80	88
2004	4	<10–2,268	82	142
2005	4	27–1,182	101	63
2006	4	19–5,000	334	856
2007	2	40–370	122	205
2002-2007	37	<10–5,000	116	101

Data provided by the Environment Agency (2007).

9.3 Bathing Waters

Two bathing waters are designated in the proximity of the approaches to the Dart Estuary under the Directive 76/160/EEC (European Communities, 1976, 2006) concerning the quality of bathing water, Blackpool Sands (in 1988) and Dartmouth Castle and Sugary Cove (in 2006) (Figure 9.12)[9].

Both bathing waters have complied with the microbiological standards and achieved overall classifications of “excellent”. In general, very low levels of surface water contamination with faecal coliforms (Table 9.6) were detected during this monitoring period. Levels of faecal streptococci detected were also very low during most of the monitoring and generally follow the pattern found in faecal coliforms (data not shown). Higher levels of faecal coliforms were detected in water from Dartmouth Castle than those found in water from Blackpool Sands in 2006 and 2007. Considering the distance of these bathing waters from the bivalve mollusc beds, these results do not suggest any appreciable sources of pollution seaward of the mouth of the estuary.

[9] The bathing season runs from 15 May to 30 September. Water is sampled throughout the season. Levels of bacteria must not exceed the Imperative (I) value (2000 for faecal coliforms 100 ml^{-1}) and the Guideline (G) value (100 for faecal coliforms 100 ml^{-1}) represents the ideal maximum value. Bathing waters in England and Wales are classified as:
Poor – fails at least one coliform I standard;
Good – passes coliform I standards but fails at least one coliform G standard;
Excellent – passes coliform G standard and national faecal streptococci standard.

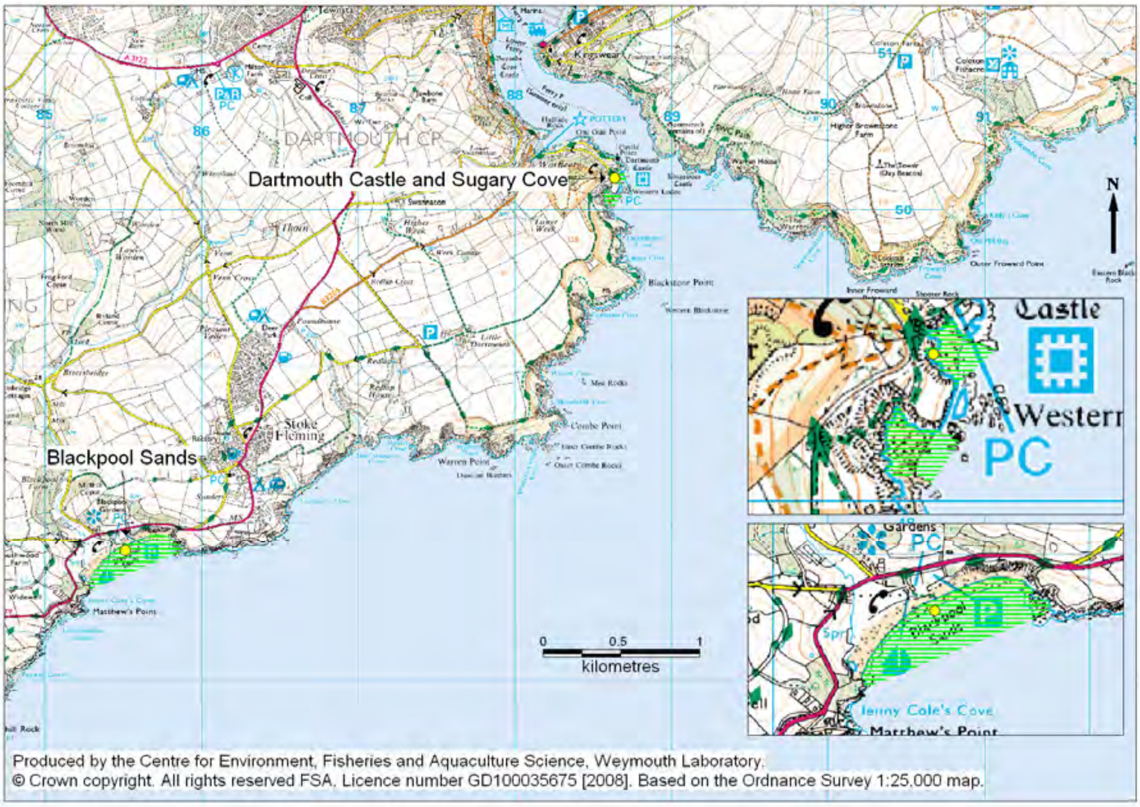


Figure 9.12. Location of the designated bathing waters in the Dart Estuary.

Table 9.6. Summary statistics of faecal coliforms in two designated bathing waters in the Dart Estuary for the period 2004–2007.

	Range (Min.-Max.) (number of samples)		Geometric mean		Median	
Year	Blackpool Sands	Dartmouth Castle	Blackpool Sands	Dartmouth Castle	Blackpool Sands	Dartmouth Castle
2004	<2–21 (20)	–	3	–	2	–
2005	<2–22 (20)	–	3	–	2	–
2006	<2–77 (20)	<2–1,480 (20)	3	17	2	15
2007	<2–2,000 (20)	<2–640 (20)	5	17	3	15
2004–2007	<2–2,000 (80)	<2–1,480 (40)	3	17	2	15

Data provided by the Environment Agency.

The similar sizes of top and bottom halves and similar lengths of whiskers[10] for levels of faecal coliforms in water from Dartmouth Castle indicate similar variation in the levels of contamination in this bathing water (Figure 9.13). Unusual high levels of faecal coliforms were detected in water sampled from both bathing waters.

[10] Box-and-whisker plots depict the distribution (central tendency and spread) of a data set. These plots show (a) the centre or median of the data (centre line of the box), (b) the spread or inter-quartile range (box height), (c) quartile skew (relative size of box halves) and (d) the presence of extreme values or outliers (asterisks).

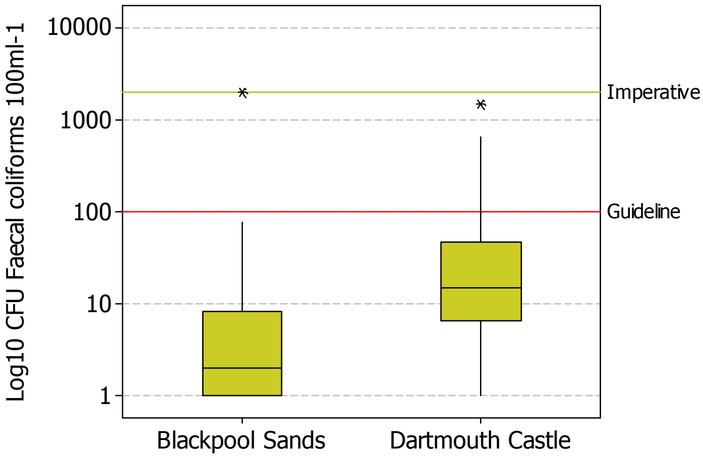


Figure 9.13. Box-and-whisker plots of levels of faecal coliforms in two designated bathing waters in the mouth of the Dart Estuary for the period 2006–2007.

10 OVERALL ASSESSMENT OF POLLUTION SOURCES ON THE MICROBIOLOGICAL CONTAMINATION OF BIVALVE MOLLUSC PRODUCTION AREAS

10.1 Qualitative assessment

The Dart Estuary is located in a catchment with low levels of development and predominantly used for agriculture. On average human population density within the catchment is relatively low (<166 people per hectare compared to an average of 246 for the U.K.[11]). The most significant urbanised areas are Totnes (8,210 inhabitants) and Dartmouth (5,678 inhabitants) at the head and the mouth of the estuary, respectively. Resident human population in the upper Dart catchment is significantly lower than numbers of cattle and sheep indicating potential higher microbiological load from livestock production areas.

The high levels of rainfall (over 2,000 mm) combined with the steep sided and low-lying topography and well drained soils in many areas of the catchment lead to fast (within 12 h) response of river flows to intense rainfall and sediment sink. These characteristics promote high runoff and retention of microbiological contaminants from agricultural land, especially when manure is spread shortly before/during rainfall, when there is insufficient storage of slurry or when manure is spread near a water course, which prevail in the catchment. The eastern and southeastern areas of the higher Dart catchment and the western area of the lower Dart are the most vulnerable to diffuse pollution from agricultural land.

Statistically significant relationships were obtained between total rainfall and *E. coli* levels and daily and total river flows and *E. coli* levels in Pacific oysters and mussels from all the existing RMPs. The rivers Dart, Harbourne, Hems and Wash consitute the most significant routes of faecal material from agricultural areas to the estuary. Freshwater samples taken during the shoreline survey on 23 January 2008 under conditions of light precipitation also indicated that Dittisham Mill Creek is a potentially significant route of contamination to BMPAs at Blackness Point and Higher Gurrow Point. More quantitative information on the application of agricultural wastes to land should be obtained to better estimate the relationship between microbiological concentrations, land use and its management regime.

The results also suggested significant impacts of contamination from rainfall-dependent sewage discharges on the levels of *E. coli* in bivalves. A number of continuous and intermittent sewage discharges were identified to represent a significant or potentially significant impact on the levels of microbiological contamination to BMPAs. Those with the highest potential to impact on the levels of microbiological contamination in BMPAs are the combined sewer overflows at Higher Dittisham, Stoke Gabriel, Totnes and Perchwood and, to a lesser extent, Harbertonford STW and Ashprington STW. Recommendations for siting RMPs at Higher Gurrow Point and Sandridge Boathouse in the confluence of the River Dart and Dittisham Mill Creek are made in Section 10.2 in order

[11] Source: 2003 data available from Office for National Statistics (2007).

reflect the potential worst-case scenario of microbiological contamination, if the recommendations of the *Good Practice Guide for Microbiological Monitoring of Bivalve Mollusc Harvesting Areas* (Cefas-CRL, 2007) are adopted in the UK at some time in the future. If such, consideration could also be given by the LEA to undertake sampling when rainfall exceeds 2mm.

It is also recommended that the relationship between increased trend in rainfall in the Dart and event discharges from combined sewer overflows and its effect on the levels of microbiological contamination in bivalve molluscs should be evaluated at the time of the next review of the sanitary survey.

It is considered that for most of the time the contribution of tertiary-treated effluents as sources of microbiological contamination impacting on BMPAs is low when compared with other sewage discharges or sources of contamination of diffuse origin. However, during the flood tide, the anticlockwise pattern of circulation in the estuary is likely to promote the transport of contaminants to BMPAs at Sandridge Boathouse and Higher Gurrow Point. The impact would be particularly significant from discharges from Dittisham STW.

The high tidal length and predominant rectilinear flow within the main river channel promote the removal of microbiological contaminants from these discharges with the dominant ebb tide plume. The turbulence caused under these conditions promotes resuspension of sediments and the release of sediment-bound faecal bacteria and viruses into the water column and the subsequent uptake by bivalve molluscs. The more persistent exposure of mussels to resuspended sediments would explain the higher levels of *E. coli* found in this species than those found in Pacific oysters, as they are grown on the river-bed and therefore are immersed longer.

Stronger ebb flows and, consequently, increases sediment transport out of the channels are induced during the complete tidal cycle when winter floods are coincident with neap tides. Consideration could be given by the LEA under these conditions in order to reflect the potential worst-case scenario of microbiological contamination, if the recommendations of the *Good Practice Guide for Microbiological Monitoring of Bivalve Mollusc Harvesting Areas* (Cefas-CRL, 2007) are adopted in the UK at some time in the future.

The flushing time in the estuary is high and the estuary experiences high levels of salinity stratification under high river flows and during the spring-neap transition. Due to the lack of *E. coli* results representing the complete tidal amplitude, it was not possible to determine the effect of tidal stage on the levels of microbiological contamination in bivalves. However, available literature indicates that strong variations in stratification occur during neap tides. Consideration could be given by the LEA to sampling during neap tides in order to reflect the potential worst-case scenario of microbiological contamination, if the recommendations of the *Good Practice Guide for Microbiological Monitoring of Bivalve Mollusc Harvesting Areas* (Cefas-CRL, 2007) are adopted in the UK at some time in the future.

Over the last years, a number of continuous and intermittent sewage discharges have been upgraded as a result of water company investment to meet the standards required in European Directives on water quality, including that to endeavour to achieve the guideline standard of the Shellfish Waters Directive. The upgrades had positive effects in the water quality and the microbiological quality of Pacific oysters and mussels in the estuary. From 2003 to 2004, the number of class C areas was reduced from five to one.

A number of crude discharges in the South Town area of Dartmouth are within 5-7 km from BMPAs and are likely to potentially impact on BMPAs during the flood. The Environment Agency has programmed to transfer these discharges to Dartmouth STW for secondary treatment and UV disinfection by March 2009. The effect of these transferrences on the levels of contamination in bivalves should be reanalysed at the time of the next review of the sanitary survey. This will be particularly relevant for Pacific oysters, which have shown consistent tendency between the class A/class B threshold (MPN $100g^{-1}$ FIL = 230) in all the existing RMPs.

The Dart Estuary supports a variety of recreation and tourism activities, with relevance to ecological tourism, sailing and boating and other water based recreational activities. During a typical year, the number of visitors to the main attractions throughout the catchment reaches 1.39 M people. The number of visitors to Dartmouth area increases from January to a peak during summer months. Approximately 12,000 yacht visitor days are recorded in the estuary during the year. Although a significant percentage of these yachts are accommodated in three marinas located at the mouth of the estuary, many yachts are moored along the estuary in the vicinity of BMPAs at Flat Owers and Sandridge Boathouse. This increase in human occupation in the estuary represents a significant factor accounting for deterioration of the water quality of the estuary during summer months. This factor combined with increased stratification in the estuary driven by water temperature changes is the most likely factor accounting for the increase in geometric mean of *E. coli* detected in mussels from all existing RMPs in July.

Bird faeces deposited directly onto the sandbanks in Flat Owers also constitute a potentially significant input of faecal contamination for Pacific oysters and mussels.

Analysis of historical data from the Shellfish Hygiene monitoring programme for the period April 2004–February 2008 (post- improvements in sewage treatments) showed differences in *E. coli* levels between species and between BMPAs. Mussels from both Waddeton and Sandridge Boathouse were shown to have higher levels of contamination than Flat Owers. However, mussels from Sandridge Boathouse show higher prevalence of unusual results. A period of low microbiological contamination is also apparent from April to June in mussels from Sandridge Boathouse, Waddeton and Flat Owers. However, no significant differences were found in *E. coli* levels in mussels or Pacific oysters from active production areas between months or between seasons.

Local authorities are considering undertaking dredging operations to prevent further bank erosion and siltation in the upper reaches of the estuary. Maintenance and capital dredging in the estuary would cause further river-bed disburbance. It is therefore recommended that the local authority monitors the potential effects of this activity on the levels of bivalve contamination and this should be considered at the time of the next sanitary survey review.

A tidal intrusion front is formed at the mouth of the Dart Estuary during spring tides. The front act as temporary barrier to the exchange of water masses entrapping fine particulate matter. This may contribute to temporary extreme levels of contamination in the estuary. Sampling after spring tides in order to reflect the potential worst-case scenario of microbiological contamination, if the recommendations of the *Good Practice Guide for Microbiological Monitoring of Bivalve Mollusc Harvesting Areas* (Cefas-CRL, 2007) are adopted in the UK at some time in the future.

A schematic representation showing the most significant pollution sources likely to cause microbiological contamination to the BMPAs is shown in Figure 10.1.

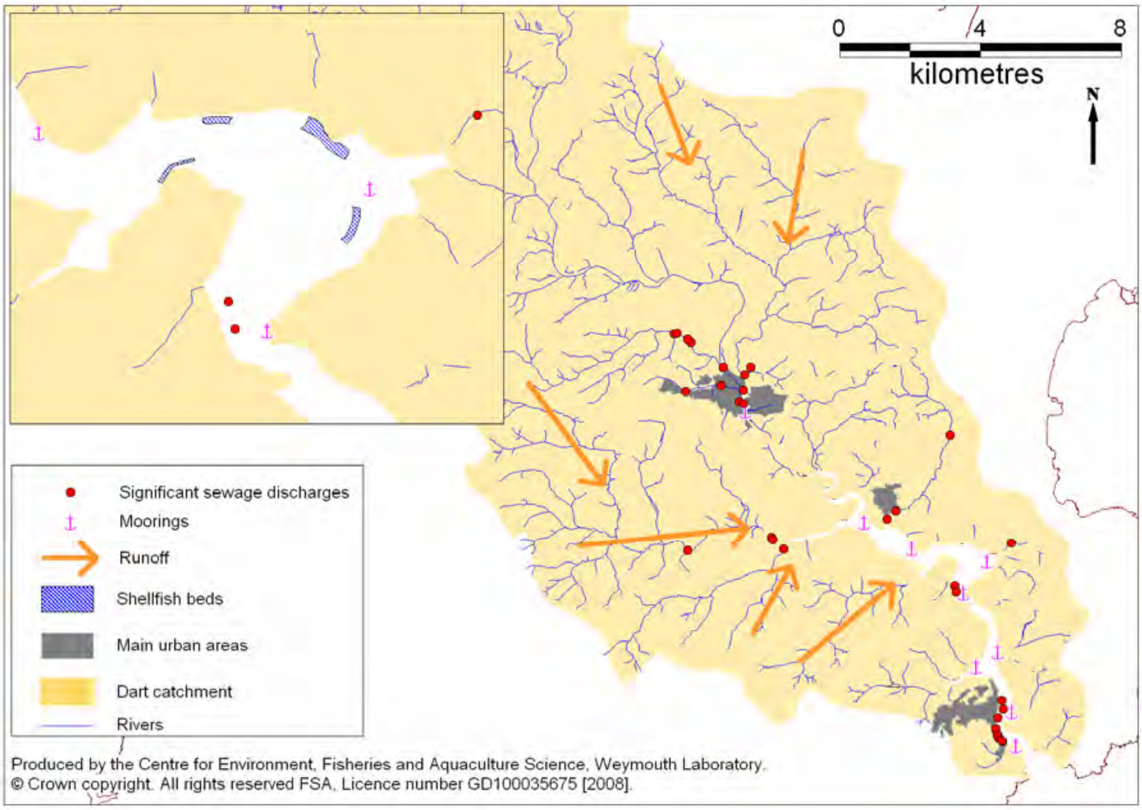


Figure 10.1. Overview of sources of pollution likely to affect the levels of microbiological contamination in bivalve molluscs in the Dart Estuary.

10.2 Recommendations for production area boundaries and monitoring points

- A single RMP should be located at the Western limit of Higher Gurrow Point in confluence with Dittisham Mill Creek for the production area of Pacific oysters with the same name since this adequately reflects the impact of pollution sources of human and animal origin from the upper Dart Estuary and Dittisham Mill Creek.

- It is recommended to maintain the RMP at Sandridge Boathouse (B028E for *Mytilus* spp. and B028H for *C. gigas*)) as the most representative of prevalent contamination from pollution sources of human and animal origin in the upper Dart Estuary delivered via the River Dart and Dittisham Mill Creek.

- Monitoring arrangements at Sandridge Boathouse and Higher Gurrow Point should be reviewed once sufficient data is available to determine whether the number of RMPs can be reduced to a single point.

- It is recommended to maintain the RMP at Waddeton (B028F for *Mytilus* spp. and B028B for *C. gigas*) as the most representative of prevalent contamination from pollution sources of human and animal origin in the upper Dart Estuary delivered via the River Dart.

- Existing RMPs at Flat Owers (B028G for *C. gigas* and B028C for *Mytilus* spp.) should be maintained since this adequately reflects the impacts from pollution sources prevalent contamination from pollution sources of human and animal origin in the upper Dart Estuary delivered via the River Dart or contamination from Dartmouth transported up river and impacting on the levels of contamination in Flat Owers.

- The recommended maximum tolerance for all RMPs is 10 metres. It is considered that this tolerance minimises the effect of spatial variability in the extent of microbiological contamination whilst preserving the fixed location concept.

  Boundaries for the revised BMPAs and representative monitoring points in the wider Dart Estuary are shown in Figures A1−A2 of the Sampling Plan (Appendix II).

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List of Abbreviations

AMPs	Asset Management Plans
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
Defra	Department for Environment, Food and Rural Affairs
DHNA	Dartmouth Harbour and Navigation Authority
DWF	Dry Weather Flow
EA	Environment Agency
E. coli	*Escherichia coli*
EC	European Community
EEC	European Economic Community
EO	Emergency Overflow
ESA	Environmentally Sensitive Area
FIL	Fluid and Intravalvular Liquid
FSA	Food Standards Agency
HAT	Highest Astronomical Tide
ISO	International Organization for Standardization
km	Kilometre
LEA	Local Enforcement Authority
M	Million
m	Metres
ml	Millilitres
mm	Millimetres
MPN	Most Probable Number
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MSL	Mean Sea Level
OSGB36	Ordnance Survey Great Britain 1936
PS	Pumping Station
RMP	Representative Monitoring Point
SAC	Special Area of Conservation
SSSI	Site of Special Scientific Interest
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 Regulation (EC) No 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. Ebb-dominant estuaries have asymmetric tidal currents with a shorter ebb phase with higher speeds and a longer flood phase with lower speeds. In general, ebb-dominant estuaries have an amplitude of tidal range to mean depth ratio of less than 0.2.
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.
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.
Faecal coliforms	A group of bacteria found in faeces and used as a parameter in the Hygine 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 N^{th} 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 a skewed data such as one following a log-normal distribution.
Hepatitis A	Hepatitis A virus is a RNA virus that has a single strand of RNA surrounded by a protein capsid. It is classified with the Picornaviridae family of the enterovirus group. Hepatitis A virus infection is transmitted through contaminated water and foods via the faecal-oral route. Outbreaks associated with the consumption of bivalve molluscs have been reported since the 1950s. The infectious dose is low (10-100 viruses) and the incubation period is 3-6 weeks. The clinical disease is generally mild, characterised by prodrome of fatigue, myalgias, anorexia, nausea, and upper abdominal discomfort.
Hydrodynamics	Scientific discipline concerned with the mechanical properties of liquids.
Hydrography	The study, surveying, and mapping of the oceans, seas, and rivers.
Norovirus	Noroviruses (previously called Norwalk-like viruses or small round-structured viruses) have single-strand RNA with positive polarity and show non-distinct capsid edges on microscopy. Norovirus has been referred as the leading cause of gastroenteritis associated with the consumption of raw bivalve molluscs. Noroviruses infect people of all ages, a feature that distinguishes them from other agents of acute viral gastroenteritis. The infectious dose is low (<100 viruses). Norovirus infection usually presents as acute-onset vomiting, watery non-bloody diarrhea with abdominal cramps and nausea. Symptoms usually begin about 18-48h (average of approximately 33h), but they can appear as early as 12h after exposure.
Salmonellosis	Salmonellae are Gram-negative, non-spore forming, facultatively anaerobic bacilli that ferment glucose and reduce nitrates. The disease caused by salmonella may be broadly categorised into two syndromes: enteric (or typhoid) fever and gastroenteritis. Enteric fever is a systemic infection characterised by high fever, abdominal cramps in the first week of illness followed by watery diarrhoea. Non-typhoidal salmonella causes a syndrome of gastroenteritis, after an incubation period of 8-72h, but is usually about 12-36h.
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”.

APPENDICES

Appendix I - SHORELINE SURVEY

General information

A shoreline survey was conducted on the 23 January 2008 along the western coastal area of the Dart Estuary by Cefas staff and the Environmental Health Sampling Officer of the South Hams District Council.

The objectives of the survey were to (a) confirm the existence of pollution sources identified during the desk study likely to constitute sources of microbiological contamination for the BMPAs, (b) identify any additional pollution sources in the area and (c) confirm the extent of the new production area.

The survey took place between 11:50 and 15:00 under light precipitation (drizzle) with sunny intervals and light airs from SW (20 mph). The maximum air temperature recorded at Exmouth meteorological station was 12 ℃ at 12:00. The survey was undertaken during the lower half of the tidal range according to the tidal curve for the day (Figure S1).

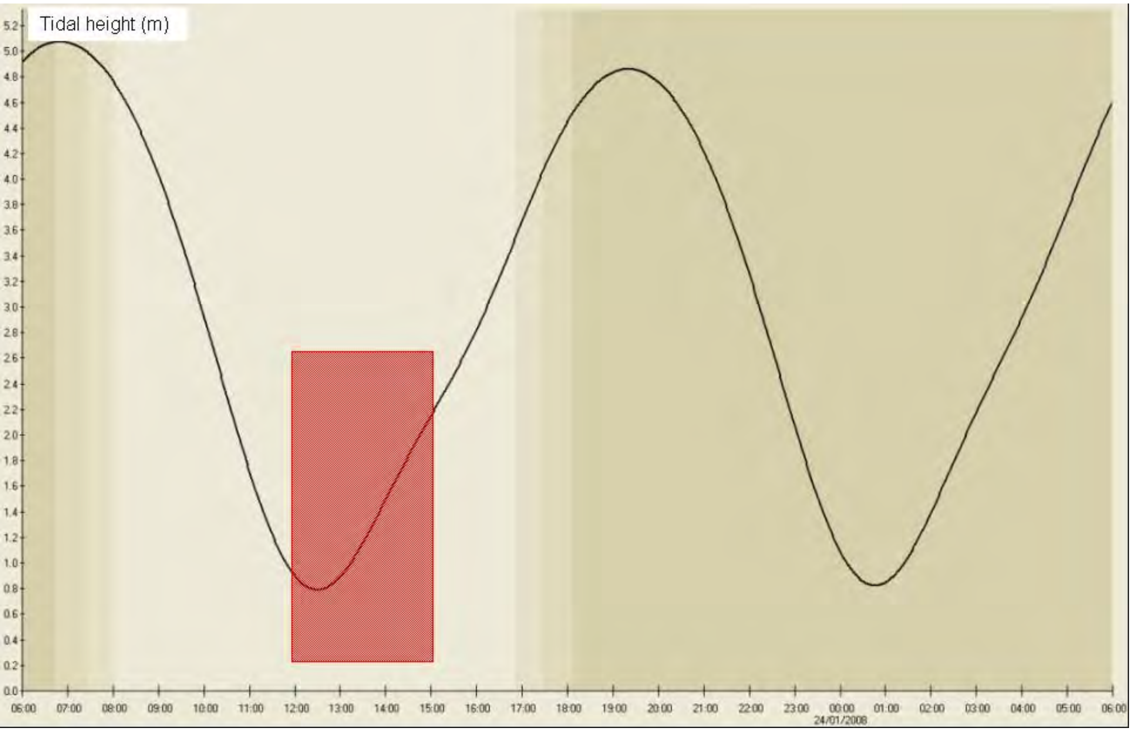

Figure S1. Tidal curve at Dartmouth on 23 January 2008.
Red box indicates the period surveyed.
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Observations and results

Area surveyed

The area surveyed included the coastal area between The River Farm at Lower Dittisham and Blackness Rock (Figure S2). The survey was divided in two stretches. The access to the intertidal areas of Dittisham Mill Creek from Higher Dittisham, Vipers Quay and Parson's Mud was not possible for health and safety reasons.

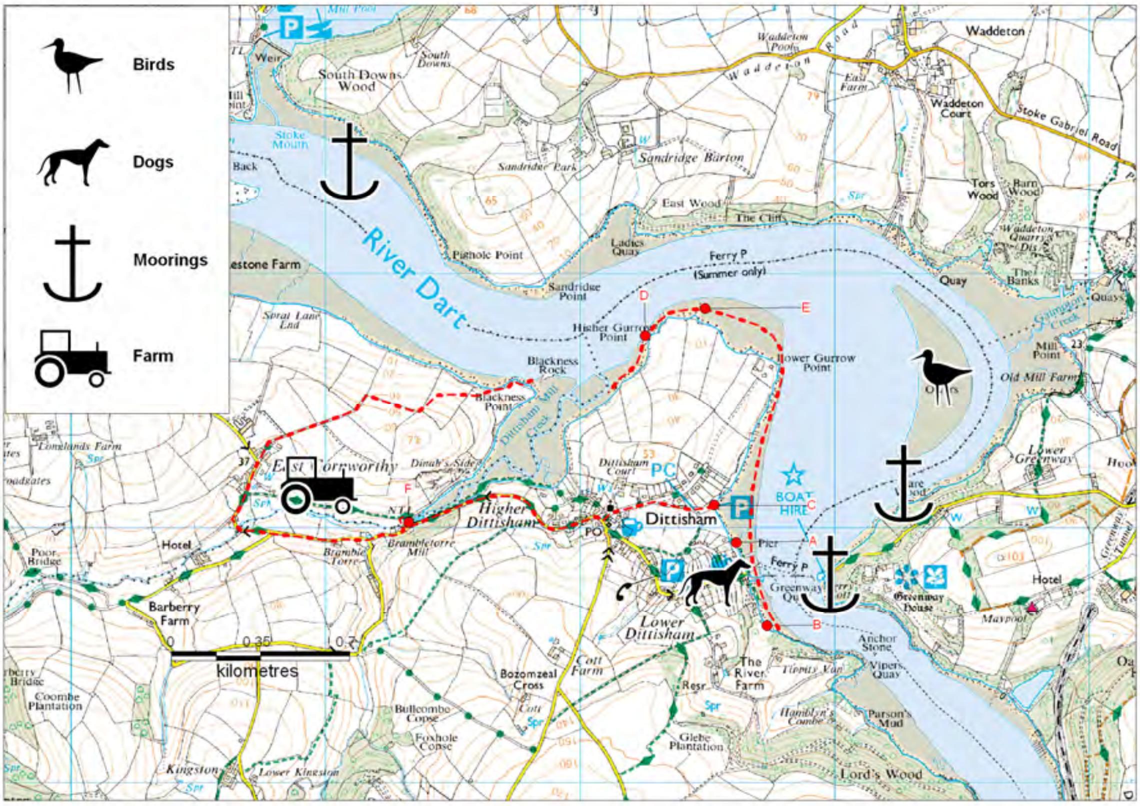

Figure S2. Area surveyed (red line) and sites sampled (red circles) in the Dart Estuary on 23 January 2008.

All the intertidal area was noted to be clean, with the exception of the mudflat between Lower Gurrow Point and Higher Gurrow Point, where detritus, plastics, cans and bottles were concentrated in low quantities.

Mussels, cockles and oysters of commercial size were observed in the intertidal area of Greenway Quay (Figure S3).

Figure S3. Cockles, mussels (A) and oysters (B) on the intertidal at Greenway Quay.
Refer to Figure S2 for location.

Agricultural activities

The Higher Dittisham to Bozomzeal and East Cornworthy is essentially constituted by arable land and grassland supporting livestock production, often bordered by small and transitional woodlands at Dinah's Side (Figure S6).

Figure S6. Farm at East Cornworthy.
Refer to Figure S2 for location.

Animals

Two dogs were observed on the pleasure park at Lower Dittisham (Figure S2).

Approximately 50 Gulls and a few Cormorants were observed concentrated at Flat Owers sandbank (Figure S2).

Boats

A degree of boating activity in the Dart Estuary was evident for the time of year. Approximately 60 boats were observed moored off Dittisham (Figures S2, S4).

Figure S4. Boats moored between Dittisham and Ferry Cottage (A, B) and Dittisham Mill Creek (C).

Water Quality

The water of the River Dart was noted to be very turbid at the time of the survey. A ‘V’- tidal front was observed from Lower Gurrow Point in progress towards the head of the estuary during the first half of the flood tide (Figure S5). The tidal intrusion was visible from Lower Gurrow Point as a line of foam and detritus, which became less evident at the end of the survey (14:30) when it reached Whitestone Farm, approximately 1,200 m upstream Blackness Point.

Figure S5. Tidal intrusion front observed in the river channel between East Wood and Lower Gurrow Point, in the Dart Estuary.
Refer to Figure S2 for locations.

The locations and descriptions of sewage discharges inspected during the shoreline survey at Dittisham are given in Table S1 and Figure S6.

Table S1. Sewage discharges inspected during the shoreline survey.

Discharge	Location		Obs.
	Eastings	Northings	
Dittisham STW	286,450	55,070	Identified. Not sampled.
Higher Dittisham PS CSO/EO	-	-	Discharge point not identified. Access to Higher Dittisham was not possible.
Ferry Boat Inn PS CSO/EO	286,740	54,820	Identified. Not sampled. See Figure S6A.
Smugglers Cottage	286,576	54,997	Identified and sampled. See Table A2.
Dittisham Sailing Club Boathouse	-	-	Not identified. Effluents transferred to new Dittisham STW
Piped discharge at Higher Gurrow Point	286,599	55,717	Dried. Current status being investigated. See Figure S6B.
Dittisham Dinah's Side	-	-	Not identified. Not listed in EA Pollution Reduction Plan.

Figure S6. Discharges identified and not sampled during the shoreline survey.

Details of additional sewage discharges and streams discharging to the estuary and sampled during the survey are given in Table S2 and Figure S7. Four samples of freshwater, one sample of seawater and one sample of Pacific oysters were taken during the survey for quantification of *E. coli*. Site descriptions and microbiological results of these samples are shown in Table A2 below.

Table S2. Levels of **E. coli** ***in samples collected during the shoreline survey.***

ID in Figure S7	Matrix	Time	Location	Result
A	Freshwater	12:18	Smugglers Cottage *	110 CFU $100ml^{-1}$
B	Freshwater	12:38	Stream at Lower Dittisham	41 CFU $100ml^{-1}$
C	Freshwater	12:56	Stream at Dittisham Car Park	65 CFU $100ml^{-1}$
D	*C. gigas*	14:15	Higher Gurrow Point	220 MPN $100g^{-1}$ FIL
D	Seawater	14:30	Higher Gurrow Point	555 CFU $100ml^{-1}$
E	Freshwater	15:00	Dittisham Mill Creek	2,880 CFU $100ml^{-1}$

** sample taken in light precipitation. All other samples collected in dry conditions.*
Refer to Figure S2 for locations of samples.

The results indicate that:

- Dittisham Mill Creek as a potential source of localised microbiological contamination to the estuary.
- The small streams running into the estuary in the vicinity of Dittisham contained low levels of *E. coli*.
- The *E. coli* result for Pacific oysters sampled at Higher Gurrow Point was within the range required for ‘class A’ i.e. <230 MPN 100 g^{-1} FIL.

<u>Shellfisheries</u>

The transference of stock of Pacific oysters from Sandridge Boathouse to Higher Gurrow Point was noted when the surveyors approached Lower Gurrow Point. The Environmental Health Sampling Officer contacted the two fishermen who were at the time working on the boat in order to obtain more information on the terms of this transference. The local authority pointed out that sampling for microbiological monitoring remained at Sandridge Boathouse. Geographic grid references detailing the perimeter of the production area were then obtained and authorisation to collect shellfish and water samples was requested from the local authority. The delay caused by these tasks and the beginning of the flood tide prevented the access to Dittisham Mill Creek and the collection of a sample at Higher Dittisham PS CSO/EO.

Conclusions

The survey highlighted the re-location of harvesting activity from Waddeton to Higher Gurrow Point and associated anomalies in the monitoring regime. The exact extent of the harvesting area initially requiring classification at Blackness Point was re-defined following on-site inspection and discussion with the industry. Results from sampling at Dittisham Mill Creek highlighted this as a potential source of contamination impacting on the beds at Higher Gurrow Point.

Figure S7. Sites sampled during the shoreline survey.

Appendix II – SAMPLING PLAN

EC Regulation 854/2004

CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES

SAMPLING PLAN

Dart Estuary (Devon)

2009

GENERAL INFORMATION

Location Reference

Production Area	Dart Estuary
Cefas Main Site Reference	M028
Cefas Area Reference	FDR 3531
Ordnance survey 1:25000 map	Explorer OL20 (South Devon) 1:25 000
Admiralty Chart	Admiralty 2253 (Dartmouth Harbour)

Shellfishery

Species/culture	Mussels (*Mytilus* spp.)	Farmed
	Pacific oysters (*Crassostrea gigas*)	Farmed
Seasonality of harvest	Pacific oysters (year round) Mussels (year round)	

Local Food Authority

Name	South Hams District Council, Environmental Health, Follaton House, Plymouth Road, TOTNES, Devon, TQ9 5NE
Telephone number ☎	01803 861234
Name of Environmental Health Officer	Mr Peter J. Wearden (Divisional EHO)
Telephone number ☎	01803 861234
Fax number	01803 861294
E-mail	pete.wearden@southhams.gov.uk
Sampling Officer	Mr Jim Kershaw
E-mail	Jim.Kershaw@southhams.gov.uk

REQUIREMENT FOR REVIEW

This sampling plan will be reviewed by the competent authority within six years or in light of any obvious known changes in sources of pollution of human (eg improvements in sewage treatment works) or animal origin likely to be a source of contamination for the bivalve mollusc production areas.

Table A1. Number and location of representative monitoring points (RMPs) and frequency of sampling.

RMP	Bed name	Geographic grid references (datum) of sampling points * OSGB36 Eastings	Northings	NGR	WGS84 Latitude	Longitude	Species	Growing method	Harvesting technique	Sampling method	Depth	Frequency
B028J	Higher Gurrow Point	286260	055780	SX 8626 5578	50° 23.45'N	3° 36.08'W	Pacific oysters (*C. gigas*)	Trestles	Hand-picking	Hand-picked from bags via shore	Depth of trestles	*Preliminary classification:* 10 samples taken over at least 3 months (interval between sampling not less than 1 week). *Full classification:* at least monthly over one year
B028K	Higher Gurrow Point	286260	055780	SX 8626 5578	50° 23.45'N	3° 36.08'W	Mussels (*Mytilus* spp.)	River-bed culture	Hand-picking	Hand-picked from river-bed	Riverbed	*Preliminary classification:* 10 samples taken over at least 3 months (interval between sampling not less than 1 week). *Full classification:* at least monthly over one year
B028H	Sandridge Boathouse	286580	056180	SX 8658 5618	50° 23.67'N	3° 35.82'W	Pacific oysters (*C. gigas*)	Trestles	Hand-picking	Hand-picked from bags via shore	Depth of trestles	At least monthly
B028E	Sandridge Boathouse	286580	056180	SX 8658 5618	50° 23.67'N	3° 35.82'W	Mussels (*Mytilus* spp.)	River-bed culture	Hand-picking	Hand-picked from river-bed	Riverbed	At least monthly
B028B	Waddeton	287410	55990	SX 8741 5599	50° 23.57'N	3° 35.12'W	Pacific oysters (*C. gigas*)	Trestles	Hand-picking	Hand-picked from bags via shore	Depth of trestles	At least monthly
B028F	Waddeton	287410	55990	SX 8741 5599	50° 23.57'N	3° 35.12'W	Mussels (*Mytilus* spp.)	River-bed culture	Hand-picking	Hand-picked from river-bed	Riverbed	At least monthly
B028G	Flat Owers	287500	055500	SX 8750 5550	50° 23.31'N	3° 35.03'W	Pacific oysters (*C. gigas*)	Trestles	Hand-picking	Hand-picked from bags via shore	Depth of trestles	At least monthly
B028C	Flat Owers	287500	055500	SX 8750 5550	50° 23.31'N	3° 35.03'W	Mussels (*Mytilus* spp.)	River-bed culture	Hand-picking	Hand-picked from river-bed	Riverbed	At least monthly

* Tolerance for representative monitoring points: 10 metres.

RMP	Bed_name	Eastings	Northings	NGR	Latitude	Longitude	Species
B028G	Flat Owers	287,500	55,500	SX 8750 5550	50° 23.31'N	3° 35.03'W	Pacific oysters (C. gigas)
B028J	Higher Gurrow Point	286,260	55,780	SX 8626 5578	50° 23.45'N	3° 36.08'W	Pacific oysters (C. gigas)
B028H	Sandridge Boathouse	286,580	56,180	SX 8658 5618	50° 23.67'N	3° 35.82'W	Pacific oysters (C. gigas)
B028B	Waddeton	287,410	55,990	SX 8741 5599	50° 23.57'N	3° 35.12'W	Pacific oysters (C. gigas)

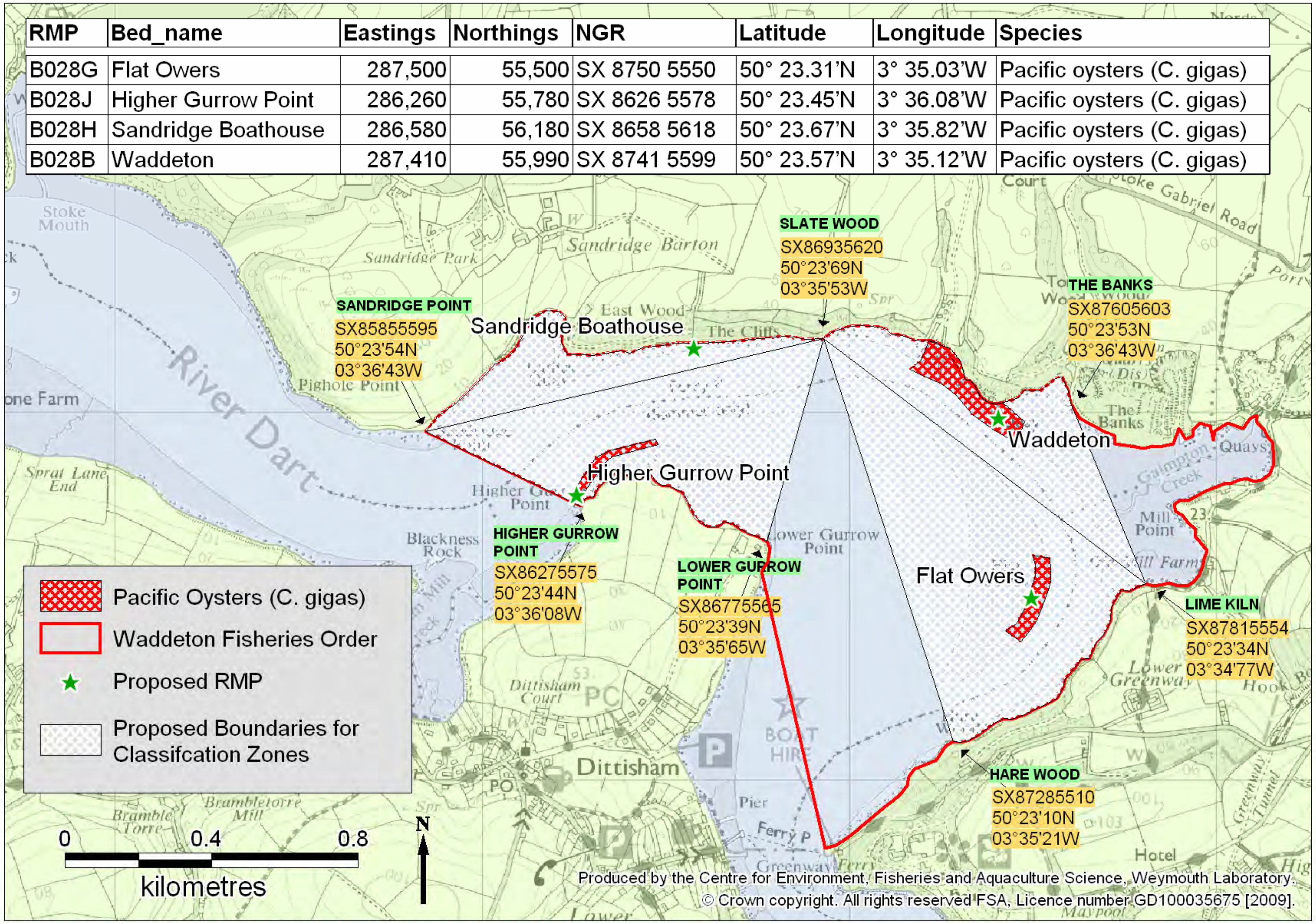

Figure A1. Location of representative monitoring points (RMPs) and production area boundaries for Pacific oysters (C. gigas) in the Dart Estuary.

RMP	Bed_name	Eastings	Northings	NGR	Latitude	Longitude	Species
B028C	Flat Owers	287,500	55,500	SX 8750 5550	50° 23.31'N	3° 35.03'W	Mussels (Mytilus spp.)
B028K	Higher Gurrow Point	286,260	55,780	SX 8626 5578	50° 23.45'N	3° 36.08'W	Mussels (Mytilus spp.)
B028E	Sandridge Boathouse	286,580	56,180	SX 8658 5618	50° 23.67'N	3° 35.82'W	Mussels (Mytilus spp.)
B028F	Waddeton	287,410	55,990	SX 8741 5599	50° 23.57'N	3° 35.12'W	Mussels (Mytilus spp.)

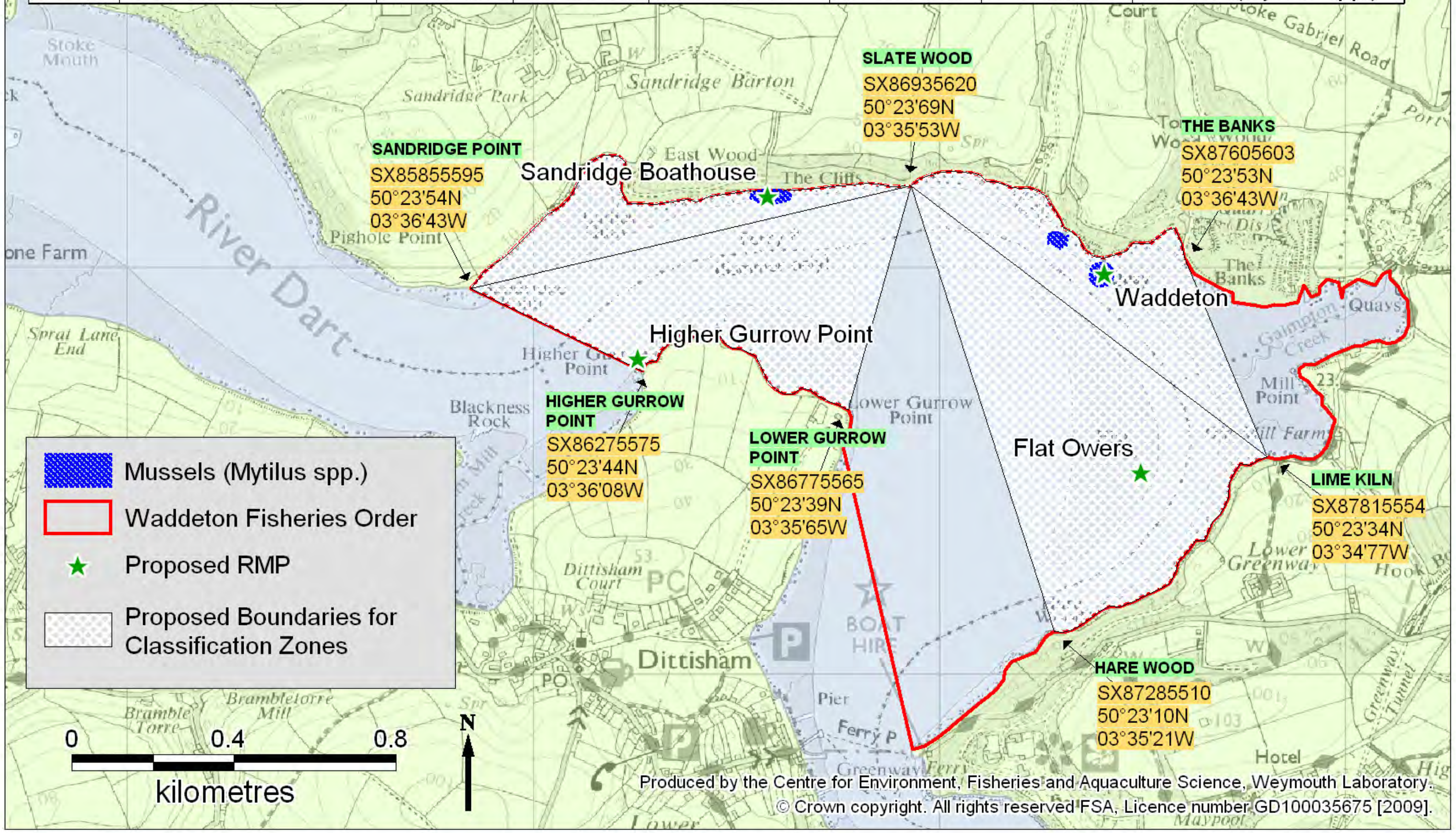

Figure A2. Location of representative monitoring points (RMPs) and production area boundaries for mussels (Mytilus spp.) in the Dart Estuary.