## EC Regulation 854/2004

# CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES

## SANITARY SURVEY REPORT

## Dart Estuary (Devon)

2010

**Cover photo:** Pacific oysters in bags at Flat Owers (Dart Estuary).

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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.

**RECOMMENDED BIBLIOGRAPHIC REFERENCE:** Cefas, 2010. Sanitary survey of the Dart Estuary (Devon). Cefas report on behalf of the Food Standards Agency, to demonstrate compliance with the requirements for classification of bivalve mollusc production areas in England and Wales under of Regulation (EC) No. 854/2004.

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# 1 INTRODUCTION

## 1.1 LEGISLATIVE REQUIREMENT

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 area;

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

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

and

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

EC Regulation 854/2004 also specifies the use of *Escherichia coli* as 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.

The outcomes of the sanitary survey should better target the location of representative monitoring points (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.

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

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 farmed mussels (*Mytilus* spp.) and Pacific oysters (*Crassostrea gigas*) at Lower Gurrow Point and Kingswear.

## 1.2 SITE DESCRIPTION

### DART ESTUARY

The Dart Estuary (SX875535) is situated in Devon, southwest coast of England (Figure 1.1). The estuary is sheltered, branched with small tributaries and has a relatively short shoreline (Table 1.1) and narrows significantly towards its upper reaches. It is a type 3b ria[1] without spits with a relatively high river plume discharge (Halcrow Group Ltd, 2002).

***Figure 1.1 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 (25 hectares in total; Boorman, 2003) dominate the intertidal area.

***Table 1.1 Morphological characteristics of the Dart Estuary.***

| | |
|---|---|
| Geomorphological classification | Type 3b ria |
| Shoreline length (km) | 61 |
| Core area (ha) | 863 |
| Intertidal area (ha) | 313 |

*Data compiled from the Estuary Guide (ABPmer and Wallingford, 2009).*

Saltmarsh contributes significantly to pollution control and water quality through nutrient cycling (e.g. nitrogen and phosphorous release during decomposition of

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[1] Drowned river valley in origin, with exposed rock platform and no linear banks.

organic matter) and sediment retention (e.g. adsorption of pollutants onto sediment particles) (Adnitt *et al*., in press).

Sediments in the river channel consist of sands and gravels and a variable amount of silt and clay (Odling-Smee, Oberman Associates Ltd, 2004).

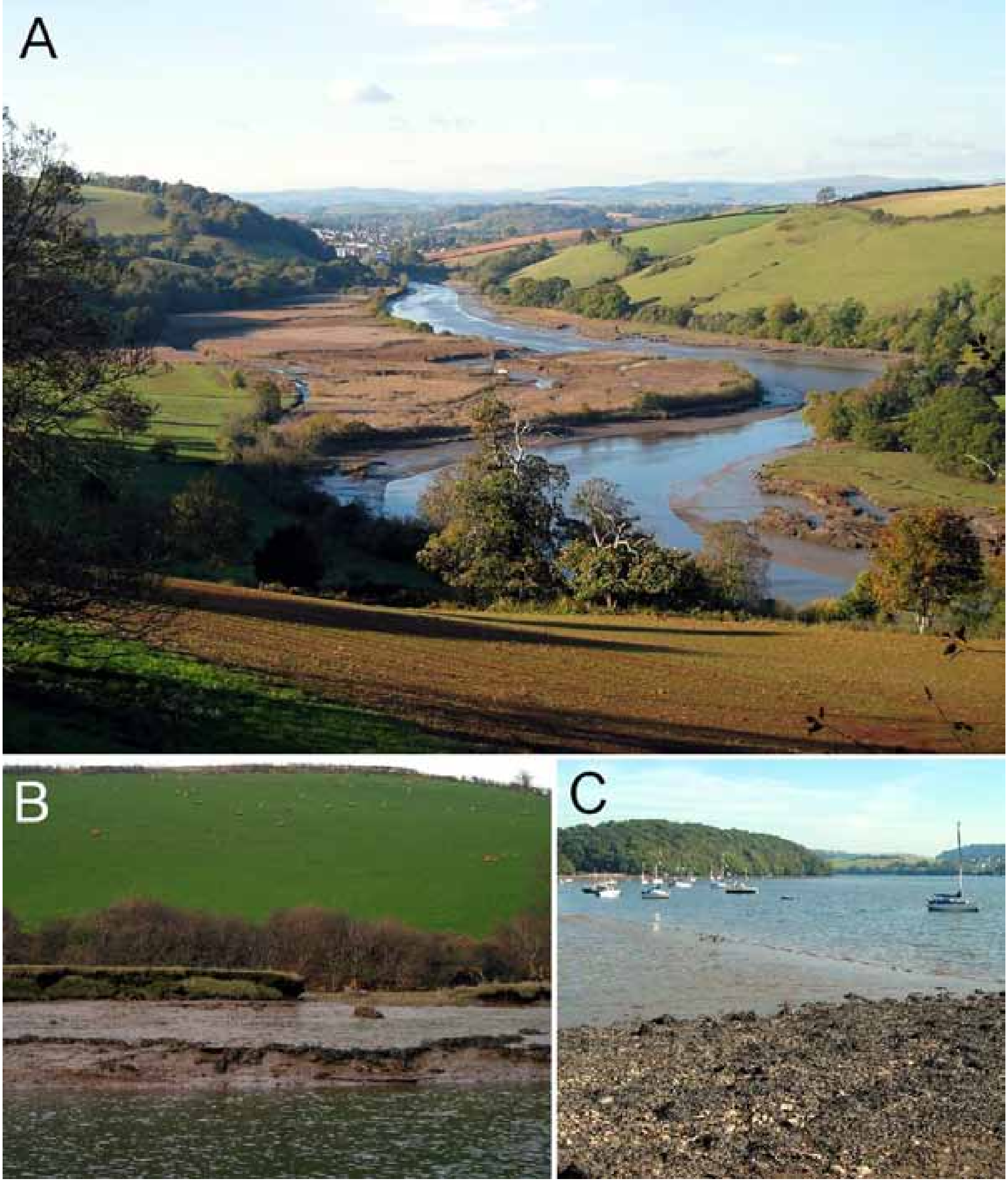

***Figure 1.2 Upper reaches of the Dar Estuary, showing an aerial view of Sharpham marsh (A) and typical profiles of the intertidal at Sharpham Point (B) and Stoke Gabriel (C).***
*Courtesy of Peter Odling-Smee.*

At Dartmouth and Kingswear, the seafront is lined by slipways, marinas, moorings and boatyards. Commercial uses of the estuary include shipping, marine services, fisheries and tourism, being the latter mostly water-based (e.g. boating, fishing, canoeing).

## CATCHMENT

The bivalve mollusc production areas (BMPAs) are under the influence of pollution sources from river catchments shown in Figure 1.3 (total area = 470 km$^2$), from the headwaters on Dartmoor National Park to where the estuary communicates with the sea at Dartmouth.

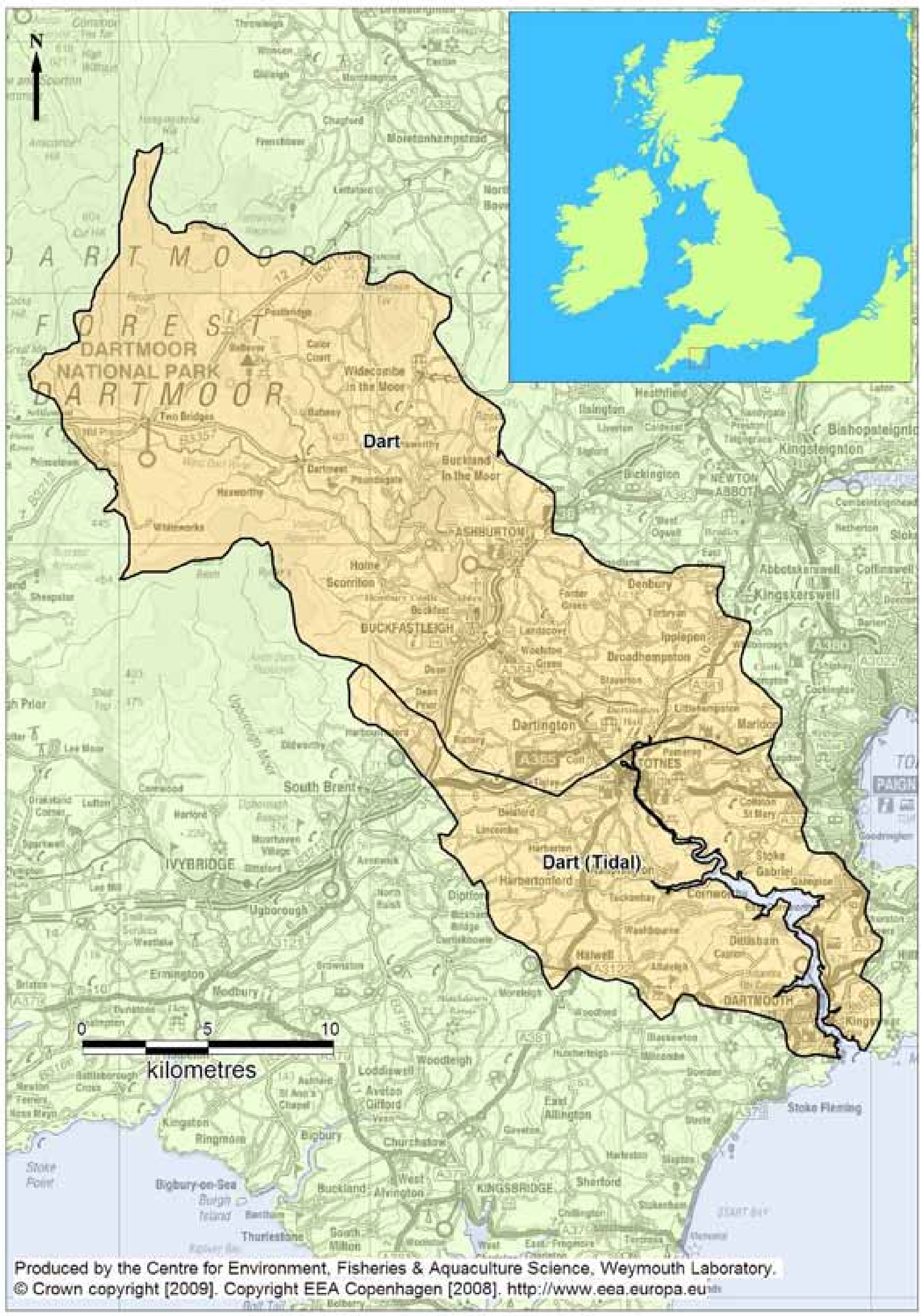

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*Figure 1.3 Location of the Dart Estuary and its river catchments.*

The catchment includes upland moor, steep sided, wooded river valleys and low-lying, undulating land in the lower estuarine reaches.

The elevation in the Dart catchment at Austins Bridge ranges between 25–601m (weighted average=326m) (NERC, 2005). Approximately 69% of the catchment is within the elevation range 250–500m (NERC, 2005).
Steep land is expected to generate significant volumes of surface runoff and potentially microbiological contamination of faecal origin, which can be drained into watercourses under heavy and/or prolonged rainfall.

The northern parts of the catchment comprises of Dartmoor granite, whilst lower down where the East and West Dart rivers merge, the river flows over metamorphic aureole, whereas south of Buckfastleigh and Totnes, the geology is mostly comprised of Middle Devonian slates and shales (Devon Wildlife Trust, 2004).
The hard and steep geology across the upper catchment promotes a “flashy” response of water levels in watercourses to rainfall, i.e. rise rapidly in response to rainfall and then quickly return to lower flows when rainfall subsides.

Dartmoor comprises an area of granite outcrops, open moorland and bogs, 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 (The Wildlife Trust, 2004). There are urbanised areas containing some light industry at Totnes, Buckfastleigh and Dartmouth (Figure 1.3).

Significantly higher levels of faecal indicator microorganisms have been detected in watercourses during high-flow conditions relative to those during low-flow conditions in UK coastal catchments with more than 50% of improved grassland (Crowther *et al.*, 2002; Stapleton *et al.*, 2006).

The Dart catchment contains a wide range of habitats that support a remarkable diversity of plants and animals. There are various habitat conservation designations across 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.

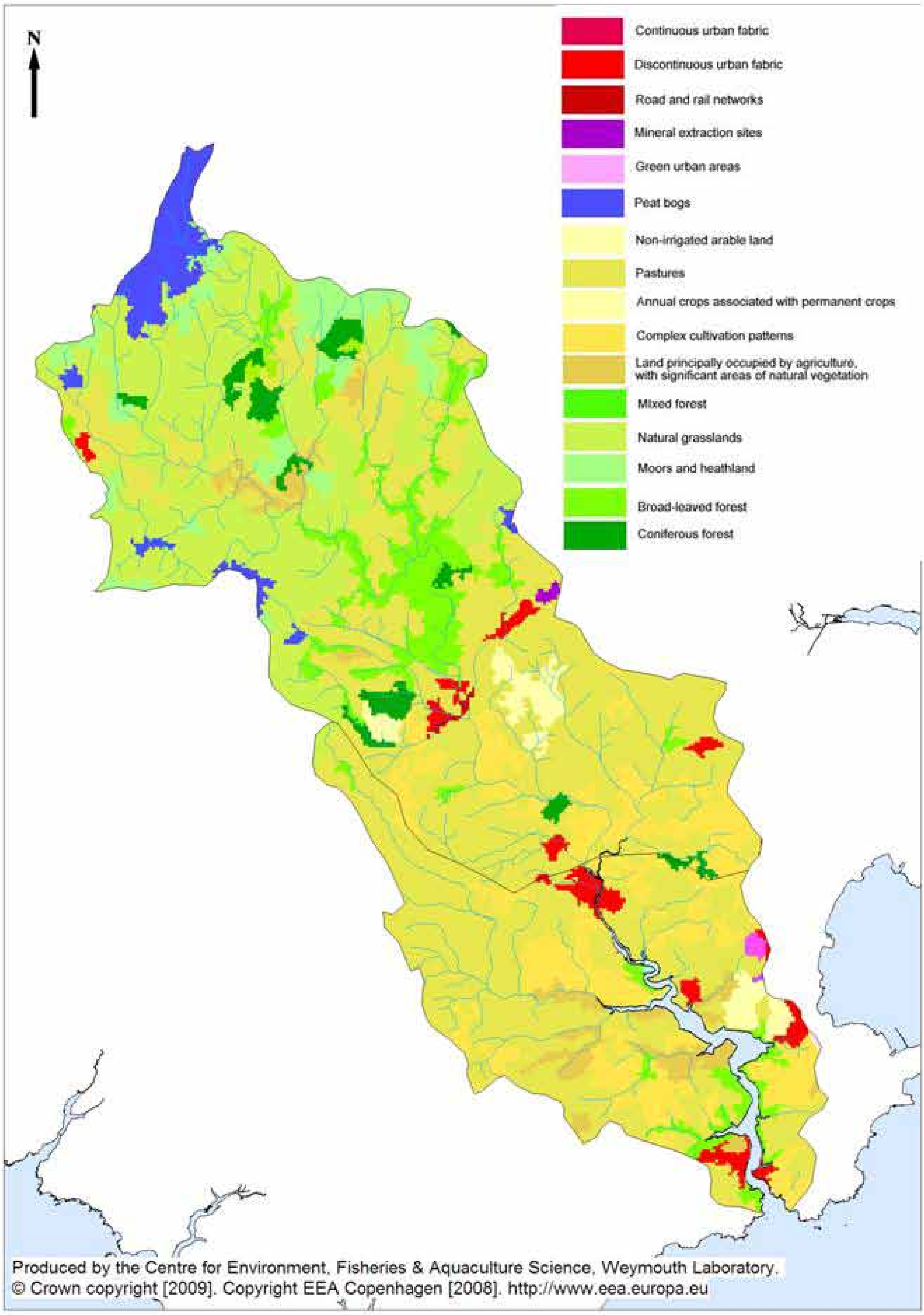

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***Figure 1.3 Land cover in the Dart catchment.***

# 2. SHELLFISHERIES

## 2.1 SPECIES, LOCATION AND EXTENT

The sanitary survey was prompted by an application for classification of farmed mussels (*Mytilus* spp.) and Pacific oysters (*Crassostrea gigas*) at Lower Gurrow Point and Kingswear (Figure 2.1).

The 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 spatfall has been occasionally reported in the estuary, the cultivation is still dependent on the regular supply of juveniles (seed) from commercial hatcheries.

Natural spatfall of mussels *Mytilus* spp. also 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. comm.; Sarah Clark, Devon SFC, pers. comm.].

In 2005, a mussel production area of approximately 0.06 km$^2$ was established in Compass Cove (Figure 2.2). 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).

Literature indicates that both species of mussel *Mytilus galloprovincialis* and *Mytilus edulis* present large morphological, physiological and behavioural similarities and are therefore difficult to differentiate for commercial purposes due to adaptations to environmental conditions (see Wijsman and Smaal, 2006 and references therein). Data from molecular analyses have demonstrated high levels of hybridisation[2] and gene introgression[3] between these species along the coasts of Cornwall. Therefore, in the context of the present sanitary survey, taxonomy of mussels is referred at genus level.

Cefas has been informed by the Devon Sea Fisheries Committee (SFC) that there is no harvesting of mussels at Flat Owers at the moment. However, the SFC have advised Cefas that they wish to maintain classification for this species at this site as commercial interest is likely to return in the future. Therefore, the results of microbiological monitoring at Flat Owers are presented in this report on the basis that they provide information on the levels of contamination in the vicinity of other new and classified bivalve mollusc beds.

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[2] The formation of a hybrid organism, e.g. by a cross between genetically dissimilar organisms.
[3] The incorporation of the genes of one species into the gene pool of another species.

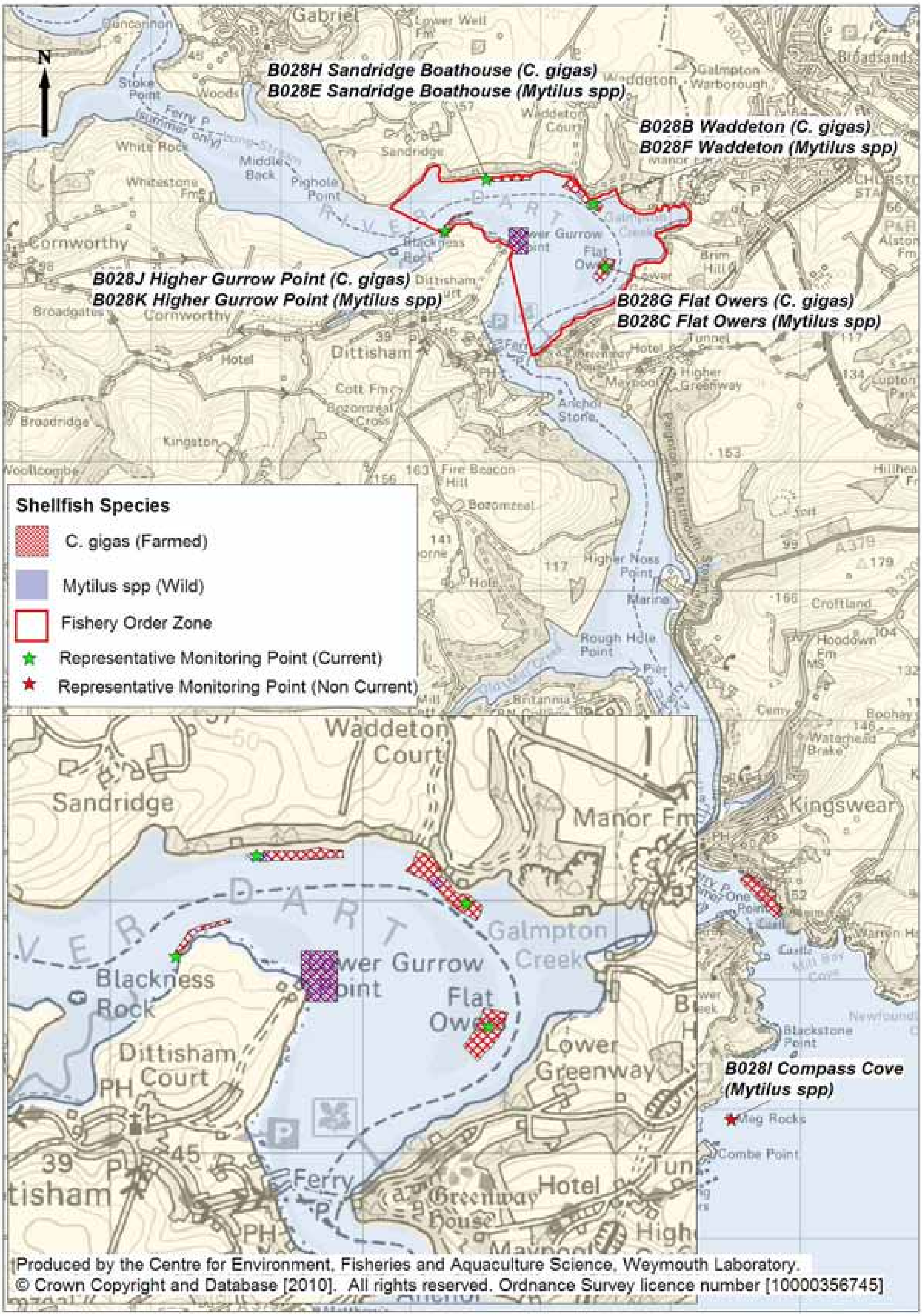


*Figure 2.1 Location of new and classified bivalve mollusc beds and representative monitoring points and boundaries of the Waddeton Fishery order in the Dart Estuary.*

### HYGIENE CLASSIFICATION

Table 2.1 summarises the post-harvest treatment required before bivalve molluscs can be sold for human consumption.

***Table 2.1 Criteria for classification of bivalve mollusc production areas.***

| Class | Microbiological standard[1] | Post-harvest treatment required |
|---|---|---|
| A | Live bivalve molluscs from these areas must not exceed 230 Most Probable Number (MPN) *E. coli* 100g$^{-1}$ FIL[2] | None |
| B | Live bivalve molluscs from these areas must not exceed the limits of a five-tube, three dilution MPN test of 4,600 *E. coli* 100g$^{-1}$ FIL in more than 10% of samples. No sample may exceed an upper limit of 46,000 *E. coli* 100g$^{-1}$ FIL [3] | Purification, relaying or cooking by an approved method |
| C | Live bivalve molluscs from these areas must not exceed the limits of a five-tube, three dilution MPN test of 46,000 *E. coli* 100g$^{-1}$ FIL[4] | Relaying for, at least, two months in an approved relaying area or cooking by an approved method |
| Prohibited | >46,000 *E. coli* 100g$^{-1}$ FIL[5] | Harvesting not permitted |

[1] *The reference method is given as ISO 16649-3.*

[2] *By cross-reference from EC Regulation 854/2004, via EC Regulation 853/2004, to EC Regulation 2073/2005.*

[3] *From EC Regulation 1021/2008.*

[4] *From EC Regulation 854/2004.*

[5] *This level is not specifically given in the Regulation but does not comply with classes A, B or C. The competent authority has the power to prohibit any production and harvesting of bivalve molluscs in areas considered unsuitable for health reasons.*

Classifications were initially given to mussels (1993) and Pacific oysters (1994) at Waddeton. Both species obtained first classifications at Flat Owers in 1998 and later at Sandridge Boathouse in 2000 (Table 2.2).

Pacific oysters have obtained long-term class B in recent years indicating a degree of stability in the microbial quality of oysters. In contrast, mussels were downgraded to class C in 2009 suggesting recent deteriorated microbial quality for this species.

During a shoreline survey conducted on 23 January 2008, it was noted that Pacific oysters at Sandridge Boathouse had been transferred by the industry to Higher Gurrow Point. It was later confirmed by the Local Enforcement Authority (LEA) that this had occurred about 18 months previously (J. Kershaw, South Hams District Council, pers. comm.). The LEA also confirmed that sampling of Pacific oysters for the purposes of microbiological monitoring appears to have continued at Sandridge Boathouse. During the shoreline survey conducted in December 2009 (see Appendix XII), it was noted that harvestable stock was present at Sandridge Boathouse.

The location and extent of classification zones and corresponding classification status are shown in Figures 2.2–2.3.

***Table 2.2 Historical classifications of bivalve mollusc beds in the Dart Estuary.***

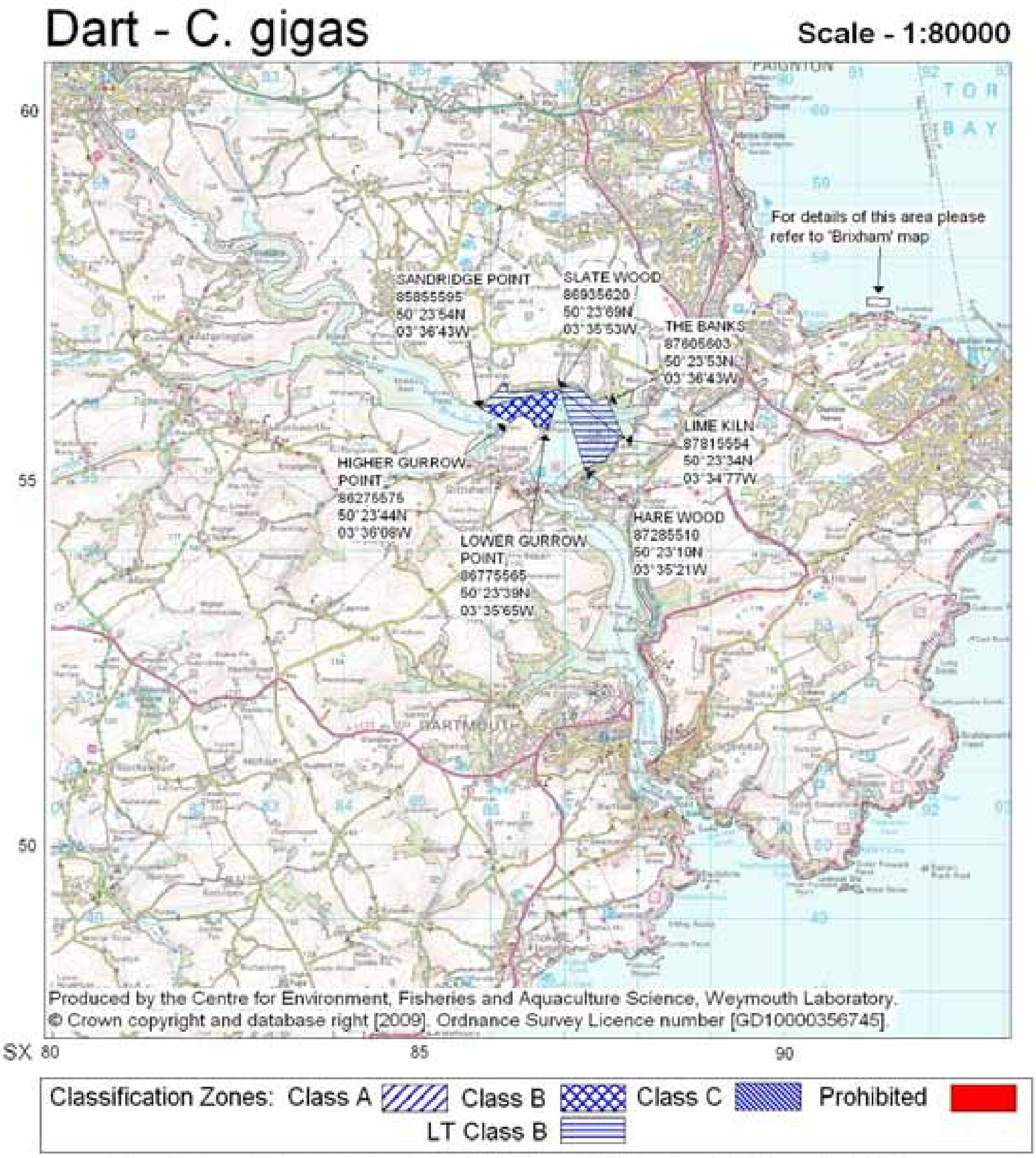
| Bed name | RMP | Species | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Waddeton | B028B | *C. gigas* | - | - | B | B | B | B | C | C | B | B | B | B | B | B-LT | B-LT | B-LT | B-LT | B-LT |
| Waddeton | B028F | *Mytilus* spp. | - | B | - | - | - | - | C | C | C | C | C | C | C | B | B | B seasonal | B$^1$ | C |
| Flat Owers | B028C | *C. gigas* | - | - | - | - | - | - | C | C | C | C | B | B | B | B-LT | B-LT | B-LT | B-LT | B-LT |
| Flat Owers | B028B | *Mytilus* spp. | - | - | - | - | - | - | C | C | C | C | C | C | B | B | B | B | B$^1$ | C$^1$ |
| Sandridge Boathouse | B028H | *C. gigas* | - | - | - | - | - | - | - | - | C | C | C | C | B | B | B-LT | B-LT | B-LT | B-LT |
| Sandridge Boathouse | B028E | *Mytilus* spp. | - | - | - | - | - | - | - | - | C | C | C | C | B | B | B | B seasonal | B seasonal | C |
| Compass Cove | B028I | *Mytilus* spp. | - | - | - | - | - | - | - | - | - | n/c | n/c | n/c | n/c | n/c | B | B | n/c | n/c |

*RMP - representative monitoring point.*

*[1] - Area classified at higher level, due to results close to the tolerance limit. A downgrade may be possible if further failures are returned.*

*n/c - Not classified.*

*LT - Long-term classification system applies. NB. 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.*



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Classification of Bivalve Mollusc Production Areas: Effective from 15 September 2009

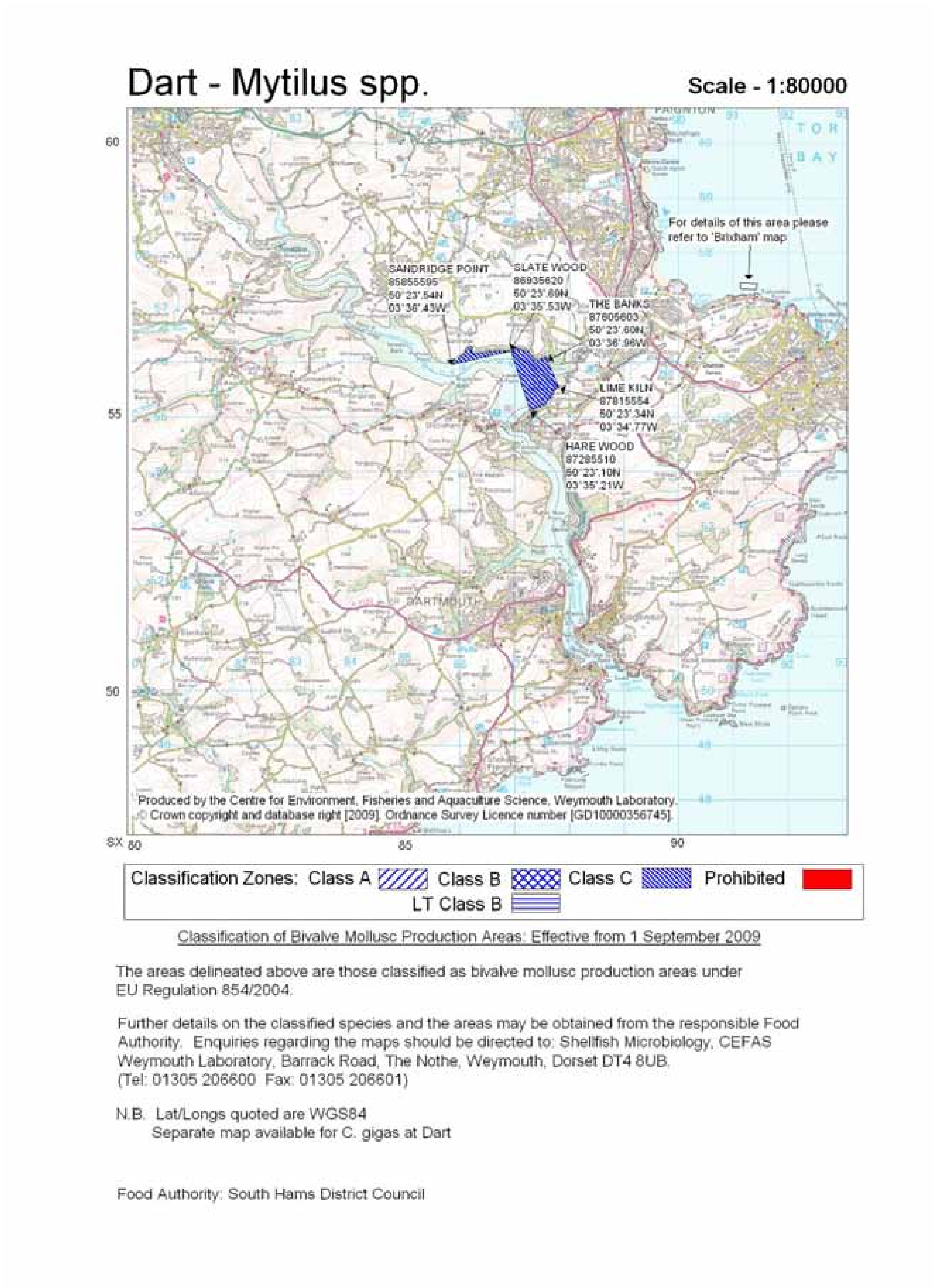
The areas delineated above are those classified as bivalve mollusc production areas under EU Regulation 854/2004.

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 WGS84
Separate map available for Mytilus spp. at Dart

Food Authority: South Hams District Council

***Figure 2.2 Classification zones and current classification status of* C. gigas *in the Dart Estuary.***



Dart - Mytilus spp.

Scale - 1:80000

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Classification Zones: Class A ▨ Class B ▩ Class C ▩ Prohibited 🟥 LT Class B ▤

Classification of Bivalve Mollusc Production Areas: Effective from 1 September 2009

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 WGS84
Separate map available for C. gigas at Dart

Food Authority: South Hams District Council

***Figure 2.3 Classification zones and current classification status of* Mytilus *spp. in the Dart Estuary.***

## 2.2 GROWING METHODS AND HARVESTING TECHNIQUES

At Higher Gurrow Point (Figure 2.4A–B), Sandridge Boathouse (Figure 2.4C) and Waddeton, Pacific oysters are grown in bags supported above the riverbed on trestles or in bags established along the foreshore. At Flat Owers (Figure 2.4D–E), Pacific oysters are grown in bags established on the foreshore along one main head-rope, which is anchored to the riverbed at either end.

Juvenile oysters are placed in 9mm mesh bags attached to longlines on the ground for on growing. When above 40 g, they are taken out of bags and spread directly on the riverbed to mature at 80g harvestable size.

Mussels are grown on the riverbed.

*Figure 2.4 Pacific oysters growing on bags at Higher Gurrow Point (A, B), Sandridge Boathouse (C), Flat Owers (D, E) and the new production area at Kingswear (F).*

At Lower Gurrow Point, mussels and Pacific oysters will be grown in bags suspended on trestles and bags placed directly on the river bed. At Kingswear, both species will be grown in bags disposed in horizontal layers in a rectangular cage (Figure 2.5).

*Figure 2.5 Growing method for mussels and Pacific oysters at Kingswear.*

## 2.3 SEASONALITY OF HARVEST AND CONSERVATION CONTROLS

Mussels and Pacific oysters are harvested on a year round basis. There is higher demand for Pacific oysters on Christmas and Valentine's Day (Sarah Clark, Devon SFC, pers. comm.).

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).

## 2.4 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. comm.).

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. comm.).

The estimated total annual production at Lower Gurrow Point and Kingswear is 25 tonnes of mussels and Pacific oysters in each bed.

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.

## 3 OVERALL ASSESSMENT

### AIM

This section presents an overall assessment of pollution sources on the microbiological contamination of bivalve mollusc beds in the Dart Estuary as a result of a sanitary survey undertaken by Cefas on behalf of the Food Standards Agency. Its main purpose is to inform the sampling plan for the microbiological monitoring and classification of bivalve mollusc production areas (BMPAs) in this geographical area.

The present survey was prompted by an application for microbiological monitoring and classification of farmed mussels (*Mytilus* spp.) and Pacific oysters (*Crassostrea gigas*) at Lower Gurrow Point and Kingswear. The assessment is made in relation to these beds and existing classified beds for both species within the Waddeton Fishery Order (WFO), in the middle reaches of the estuary.

### SHELLFISHERIES

The currently classified beds for mussels and Pacific oysters encompass parts of the meandering river channel between Sandridge Point-Higher Gurrow Point and Flat Owers. Bivalves at these sites are grown in bags suspended above the riverbed on trestles or disposed directly on the riverbed.

The new production area at Kingswear includes subtidal areas on the eastern side of the estuary just south of Kingswear. Mussels and Pacific oysters at this site will be grown in bags suspended above the riverbed in rectangular cages.

These beds fall under the jurisdiction of South Hams District Council (Environmental Health) (Local Enforcement Authority).

### RAINFALL AND FRESHWATER INPUTS

Analysis of rainfall data monitored in three gauging stations across the catchment indicates a decreasing gradient in total rainfall falling across the catchment. The wettest month generally varies between October and January. The impact of rainfall-dependent discharges and runoff from agricultural land on the water quality of the estuary is expected to increase during the autumn-winter period.

The catchment (total area = 470km$^2$) assessed for the purposes of this sanitary survey is drained by a network formed by the rivers East and West Dart, Blackbrook, Cowsick, East and West Webburn and Hems. These constitute the most significant routes of microbial contamination from the wider catchment to the estuary. The river network is formed by other minor freshwater inputs. Locally significant to bivalve mollusc beds in the WFO are streams at Galmpton Creek (sampled during the shoreline survey on 2 December 2009; Faecal coliforms = 83,000 CFU 100ml$^{-1}$) and Stoke Gabriel (also sampled during the shoreline survey on 2 December 2009; Faecal coliforms = 15,000 CFU 100ml$^{-1}$).

Analysis of hydrographs for the River Dart show that water levels in watercourses across the upper reaches of the catchment are characterised by a fast response to rainfall events (typically less than 12h) and a relatively sharp recession limb. This response is caused by the steep topography of the catchment, relatively high rainfall totals and low permeability of the main geological formations. In the lower catchment, flood peaks tend to be delayed (12–24h) as a result of the lower topography.

Historical data from the National River Flow Archive show that the levels of runoff increase significantly during the autumn (September–November). This suggests that the Dart is highly responsive catchment and that autumn is the season of higher risk of runoff contamination.

Recommendations for placement of RMPs at Higher Gurrow Point and Sandridge Boathouse in the confluence of the River Dart and Dittisham Mill Creek were adopted as a result of the review of RMPs undertaken in the previous sanitary survey.

### AGRICULTURE

The Dart is a rural catchment with low levels of development and predominantly used for agriculture (approximately 700 holdings). The main agricultural activities are cereals and livestock production. The catchment is considered to be at risk of diffuse pollution from agricultural land[4].

Livestock production (total number of cattle and sheep is over 104,000) is based on mixed cattle and sheep farming in areas of improved and natural grassland in the valleys and in the uplands.

Soil erosion and compaction and over application of slurry at the wrong time of the year may cause periods of deteriorated water quality in watercourses. The period of high risk is February–March, when a significant number of farmers spread manures prior the growing season and in the autumn, when biosolids are applied for winter cereals. Winter is also critical since large quantities of slurry are applied more frequently because many farms in the catchment do not have adequate storage capacity.

The eastern and southeastern areas of the Dart river catchment and the western area of the Dart (tidal) river catchment are the most vulnerable to diffuse pollution from agricultural land. This is corroborated by a modelling exercise and bacteriological surveys showing higher concentrations of faecal indicator microorgansisms in estuarine surface waters in the vicinity of farms where organic fertilisers are used more frequently.

Deteriorated microbial water quality is expected to occur from faecal matter deposited in these areas when farm yard manure and slurries are spread in

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[4] The Dart is one of the priority catchments for the England Catchment Sensitive Farming Delivery Initiative.

agricultural fields from the wider catchment shortly before/during rainfall events, in particular when these are spread near a watercourse.

### HUMAN POPULATION

Human population density within the catchment is relatively low (<166 people per hectare compared to an average of 383 for England[5]). 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. The resident human population in the catchment (>41,440) is significantly lower than the total number of farmed animals. Population may however double during the summer due to tourism. In June–August 2008, over 60,640 people visited Dartmouth (approximately 145,000 total visitors during the whole year). Dartmouth Castle and Totnes Castle have received more than 35,000 and 21,000 visitors annually. The contribution of pollution sources of human origin is expected to markedly increase during the summer tourist season.

### SEWAGE DISCHARGES

A programme of work has been undertaken by the Environment Agency to upgrade a number of sewage discharges that have, or once had, the potential to influence the Dart Estuary Shellfish Water. Most of the upgrades were completed in 2003–2005[6]. In 2008, a number of crude discharges in South Town area of Dartmouth were transferred to Dartmouth STW. A number of continuous and intermittent water company sewage discharges representing a significant or potentially significant impact on the microbial water quality of bivalve molluscs occur within 10km of the estuary and its tidal limit. The most significant continuous discharges to BMPAs are associated with the urbanised areas of Dartmouth and Totnes, in the upper estuary:

§ Harbertonford STW (secondary; DWF = 242 $m^3 d^{-1}$);
§ Ashprington STW (secondary; DWF = 98 $m^3 d^{-1}$);
§ Totnes (UV; DWF = 3,967 $m^3 d^{-1}$); and
§ Dartmouth & Kingswear STW (UV; DWF = 4,644 $m^3 d^{-1}$);

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. During the desk study of the survey, it was noted that a significant deterioration in the quality of effluent discharges from Dittisham STW (membrane bioreactor) has been occurring since January 2007. This is cause for concern with respect to the quality of shellfish beds within the WFO. Analysis of levels of faecal coliforms in effluent discharges from Dartmouth Sewage Treatment Works (STW) for the period 2003–2008 indicated significant deterioration in the microbial quality of effluent discharges during the summer.

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[5] Source: 2003 data available from Office for National Statistics website.

[6] Secondary treatment and UV disinfection installed at Dartmouth & Kingswear STW in 2002; flows to full treatment were increased at Ashprington STW and SSO operation reduced by increasing flow at Ashprington SSO (Environment Agency Pollution Reduction Plan, 2008).

Twenty-two intermittent discharges (combined sewer overflows, emergency overflows and overflows from pumping stations) discharge to the estuary or its tributaries. Those considered to have potential local significance to shellfish beds within the WFO are:

- Galpton (Dart) PS CSO/EO;
- Higher Dittisham PS CSO/EO;
- Ferry Boat Inn PS CSO/EO;
- Scout Hut CSO; and
- Stoke Gabriel PS CSO/EO.

Those considered to have potential local significance to the new production area at Kingswear are:

- New Ground Storm (Mayors Avenue) PS CSO/EO; and
- Smith Street CSO.

Many of these discharges are designed to spill less than ten times per year in line with the Environment Agency's standard for consenting intermittent discharges to Shellfish Waters[7].

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 have had positive effects in the water quality and the microbiological quality of Pacific oysters and mussels in the estuary. Between 2003 and 2004, the number of class C harvesting areas was reduced from five to one. However, the downgrade of mussel beds within the WFO in 2009 points out the question of further deterioration in the water quality of the estuary. This could be associated with the significant deterioration in the quality of effluent discharges from Dittisham STW and/or a significant increase in sewage spill volumes in Dittisham area.

A number of crude discharges in the South Town area of Dartmouth previously identified as representing a potentially significant impact on the water quality in the estuary were transferred to Dartmouth STW for secondary treatment and UV disinfection in March 2009. The previous sanitary survey (2009) had recommended that the effect of these transferences on the levels of contamination in bivalves should be re-analysed following these improvements. However, it is considered that it will be more appropriate to undertake this analysis at the time of the next review of the sanitary survey, when a more robust dataset from the Shellfish Hygiene monitoring programme will be available.

---

[7] The Environment Agency's design standard for consenting intermittent discharges to Shellfish Waters is that, in aggregation of both frequency and volume, there should be no more than 10 significant spills per annum on average to the Shellfish Water as a whole. The definition of a significant spill can be considered on a site-specific basis, but 50m$^3$ is taken as the default value.

## BOATS

The Dart Estuary is a very important centre for yachting and boating. There are 2,878 moorings of various types on the Dart Estuary. More than 12,000 yacht visitor days have been recorded in the estuary during the year.

A significant percentage of these yachts are accommodated in three marinas situated at the mouth of the estuary. However, a significant number of yachts are moored along the main river channel in the vicinity of Flat Owers and Sandridge Boathouse. In particular there is a high density of boats moored in the lower estuary and in marinas at and just immediately upstream of Kingswear.

It has long been established that sewage discharged from boats could represent a significant public health risk for bivalve mollusc beds. However, the contribution of these sources is difficult to quantify due to the intermittent nature of these discharges. Bivalve mollusc beds within the WFO and the new production area at Kingswear will be vulnerable to pollution from moored boats.

## SUMMARY OF POLLUTION SOURCES

An overview of sources of pollution likely to affect the levels of microbiological contamination in BMPAs in the Dart Estuary is shown in Table 3.1 and Figure 3.1.

***Table 3.1 Qualitative assessment of changes in pollution load in the lower Fal Estuary.***

| | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sewage treatment works* | | | | | | 🟥 | 🟥 | 🟥 | | | | |
| Rainfall | | | | | | Summer storms | | | Increased flows | | | |
| Freshwater inputs | | | | | | Summer storms | | | Increased flows | | | |
| Biosolids | Cereal crops | | | | | | | | | | | |
| Population | | | | | Tourist season | | | | | | | |
| Boats | | | | | Increased days on board | | | | | | | |

**Assessment based on the quality of effluent discharges from Dartmouth STW and therefore, merely indicative of the load attributed to these sources.*

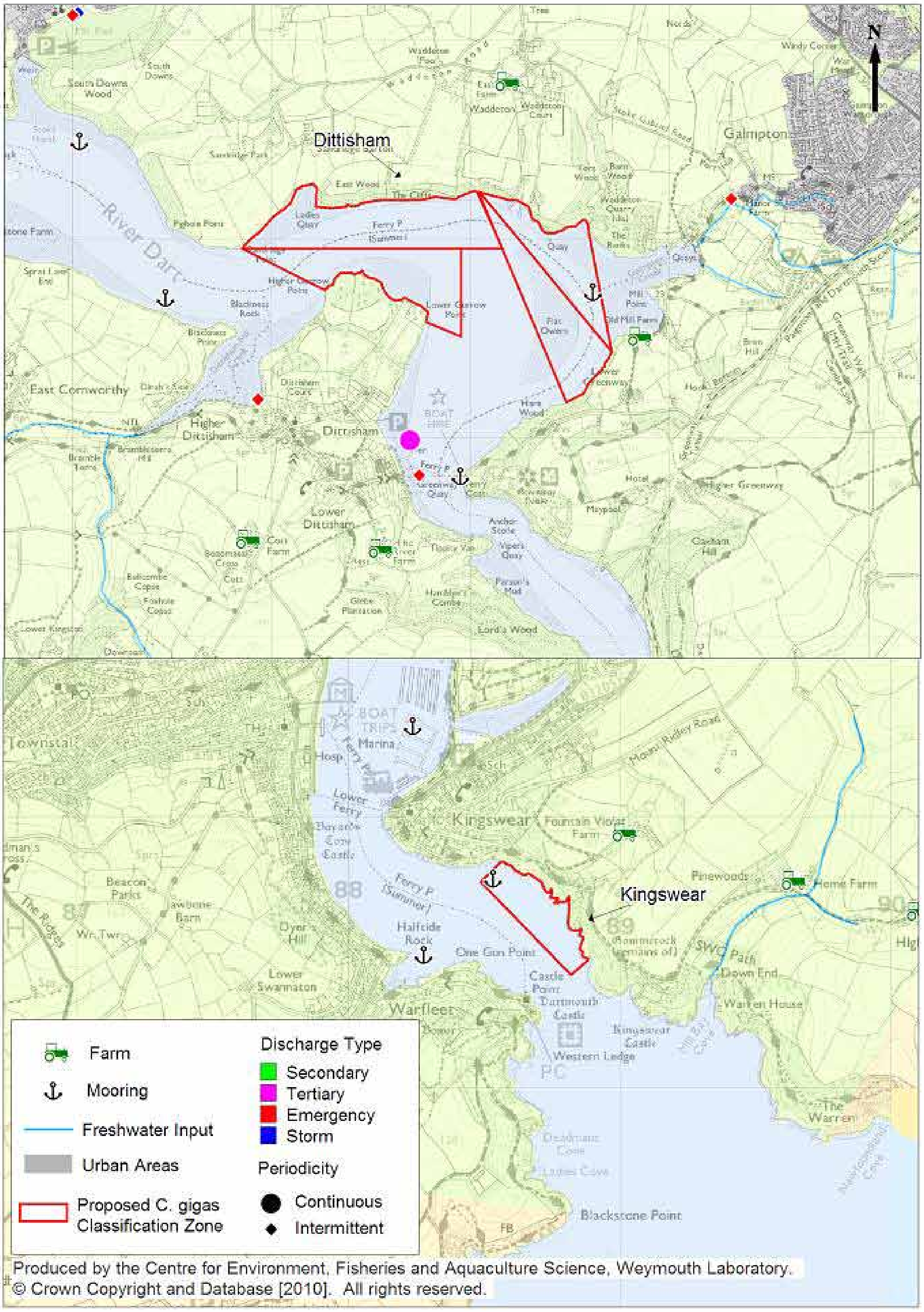

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***Figure 3.1 Overview of sources of pollution likely to affect the levels of microbiological contamination for Pacific oysters in the Dart Estuary.***

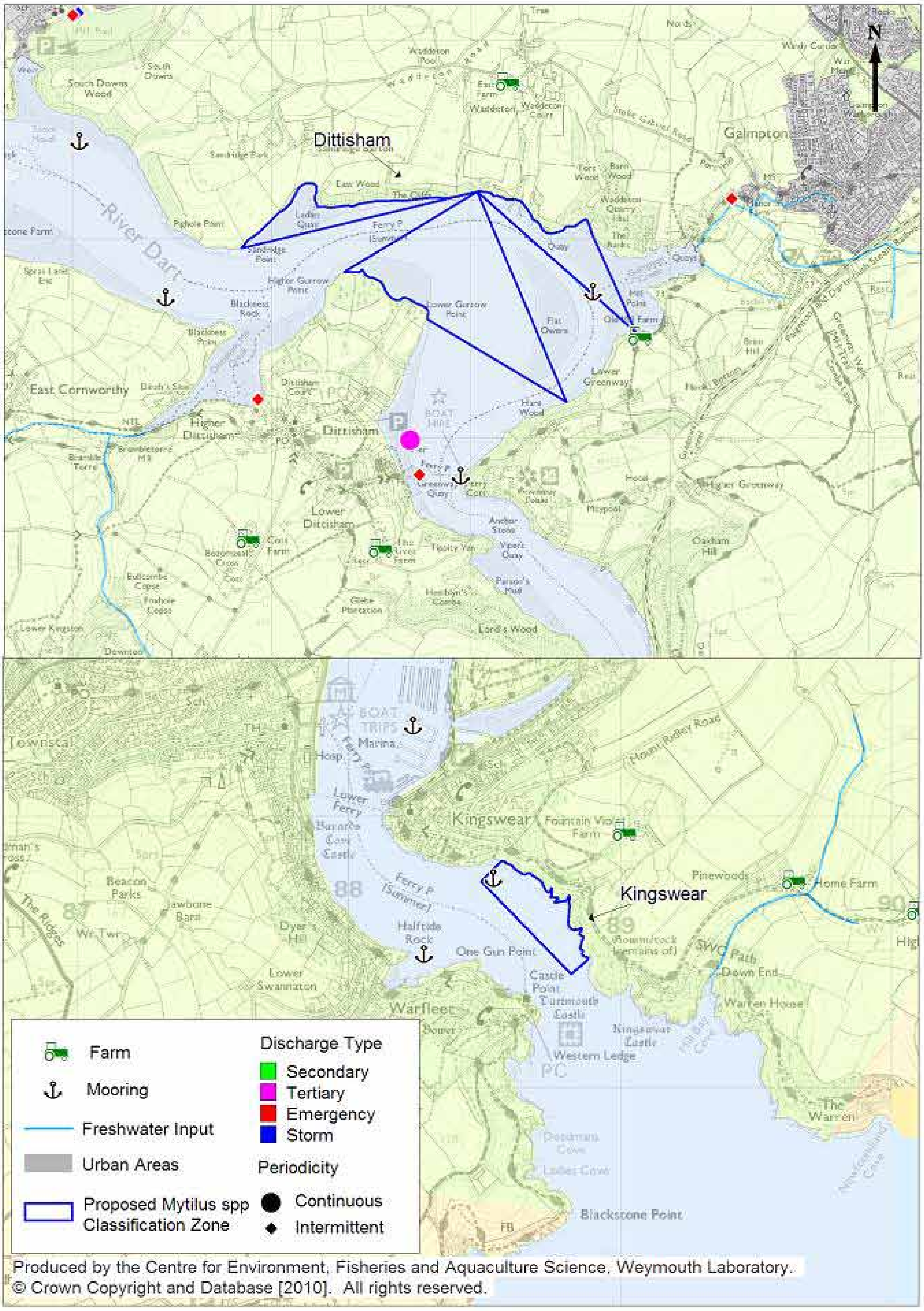

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***Figure 3.2 Overview of sources of pollution likely to affect the levels of microbiological contamination for mussels in the Dart Estuary.***

### HYDRODYNAMICS

The Dart is a shallow macro-tidal (mean range on springs = 4.3m; mean range on neaps = 1.8m) ria with semi-diurnal tides (i.e. two tidal cycles per day). At low water, tidal flows occur along one main river channel, although a secondary channel exists in the middle reaches of the estuary.

The areas where Pacific oyster and mussel beds are established contain significant proportions of intertidal drying areas at Low Water Springs. Bivalves growing in these areas will not be exposed to contamination during periods of low water. Contaminated runoff from retained seawater and/or washed off by rainfall falling on the surface of mudflats into these creeks will be conveyed to the main estuary during the ebb tide. Therefore, nearshore shallow areas are likely to represent worst-case conditions.

The Dart is an ebb dominant macro-tidal estuary. The longer and slower ebb tide is likely to promote the dispersion of pollution towards the sea, in particular that from sources situated near the mouth of the estuary. The flow ratio suggests that a freshwater plume may develop and emerge from the mouth of the estuary during ebb tides under maximum river flows. 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.

The long tidal length (approximately 19km to Totnes) indicates that significant distances may be involved in the transport of microbial contaminants along the estuary between developed areas at the mouth (Dartmouth/Kingswear areas) to the upper reaches of Totnes.

The high tidal length and likely 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 suspension 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.

During the flood tide, the anticlockwise pattern of circulation in the estuary is likely to promote the transport of contaminants to bivalve mollusc beds at Sandridge Boathouse and Higher Gurrow Point. The impact would be particularly significant in relation to discharges at Dittisham.

The flushing time in the estuary is long and the estuary experiences 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, literature indicates that strong stratification occurs during neap tides. This factor combined with increased stratification in the estuary driven by water temperature changes is the likely factor accounting for the increase in geometric mean of *E. coli* detected in mussels from all existing RMPs in July.

A tidal front is formed at the mouth of the Dart Estuary during spring tides. This intrusion front acts as temporary barrier to the exchange of water masses entrapping fine particulate matter. This may concentrate particulate material which could impact on the new production area at Kingswear.

SUMMARY OF MICROBIOLOGICAL DATA

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 beds. Mussels from Waddeton and Sandridge Boathouse were shown to have higher levels of contamination than those from Flat Owers. However, mussels from Sandridge Boathouse show higher prevalence of unusual results. A period of low microbiological contamination is also apparent from April–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.

Levels of faecal coliforms monitored in the designated Shellfish Water have decreased substantially in 2008 relative to the previous two years. This could be associated with better water quality in the estuary following the upgrades in STW.

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. Strong positive correlation coefficients were found with a seven day time lag between the rainfall event and the sampling occasion.

In order to reflect the potential worst-case scenario of microbiological contamination consideration could be given by the LEA to undertake sampling when rainfall in the upper catchment exceeds 2mm and/or when water levels in the river Dart exceed the mean flow, 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.

## 4 RECOMMENDATIONS

**PACIFIC OYSTERS**

4.1 It is recommended that the currently classified Pacific oyster beds within the WFO should be represented by four classification zones (CZs), each with its own representative monitoring point (RMP). This represents the same number of CZs recommended following the 2009 sanitary survey. The boundaries of these CZs have been reviewed following the application for classification of a new bed at Lower Gurrow Point as described below.

4.2 It is recommended that the currently classified Pacific oyster bed at Higher Gurrow Point should encompass the new bed at Lower Gurrow Point. This is justified by the assessment of pollution sources on the microbial contamination of this CZ, which supports that both beds are predominantly impacted by pollution from the wider catchment discharged via the River Dart and its tributaries. This CZ will be defined by lines crossing the main river channel at Higher Gurrow Point-Sandridge Point, northern boundary defined by a line between Sandridge Point and SX 8695 5595, eastern boundary define by a line between the latter point and SX 8695 5551 and southern boundary defined by a line from the latter point to Lower Gurrow Point (SX 8678 5559).

4.3 An RMP situated in the western edge of the bed at Higher Gurrow Point will be representative of microbial contamination from sewage discharges and diffuse pollution delivered from the Dart catchment via the rivers Dart and its tributaries transported down the river during ebb tides and/or during periods of high river flow discharges.

4.4 The revised boundaries of the Sandridge Boathouse CZ are defined by lines extending from the Mean High Water Mark between Sandridge Point and Slate Wood (SX 8703 5624). From Slate Wood, the CZ extends towards the main river channel to the point SX87165595. The southern boundary is defined by a line along the river channel from the latter point to Sandridge Point.

4.5 An RMP situated in the centroid of the Sandridge Boathouse bed will be representative of microbial contamination from sewage discharges and diffuse pollution delivered from the Dart catchment via the rivers Dart and its tributaries during ebb tides and/or during periods of high river flow discharges and contamination from Galmpton Creek during the flood tide.

4.6 A CZ is recommended at Waddeton. This will be defined by lines crossing the WFO between Slate Wood, The Banks (SX 8760 5603) and Lower Greenway (SX 8771 5543). The northern boundary between Slate Wood and The Banks is defined by the Mean High Water Mark.

4.7 An RMP situated in the eastern edge of the bed will be representative of contamination from sewage discharges and diffuse pollution delivered to the estuary via Galmpton Creek.

4.8 A CZ is recommended at Flat Owers. This will be defined by lines crossing the WFO between Slate Wood, Lower Greenway and Hare Wood (SX 8748 5518). The southern boundary of the CZ is defined by the Mean High Water Mark.

4.9 An RMP situated in the northern edge of the bed will be representative of contamination from sewage discharges and diffuse pollution delivered to the estuary via Galmpton Creek and sewage discharges in the vicinity of Dittisham.

4.10 A new CZ is recommended to encompass the new Pacific oyster bed at Kingswear. The boundaries of the CZ will be defined by lines 10 metres around the edge of the bed and referred to the Mean High Water Mark.

4.11 It is recommended that the RMP for the new bed should be situated in the northern edge of the bed as this is considered more representative of the principal potential sources of contamination from sewage discharged to the estuary at Kingswear and Dartmouth.

### MUSSELS

4.12 It is recommended that the currently classified mussel beds within the WFO should be represented by four CZs, each with its own RMP. This represents the same number of CZs recommended following the 2009 sanitary survey. The boundaries of these zones will be the same as those defined for Pacific oysters.

4.13 The RMPs for mussels at Sandridge Boathouse, Waddeton and Flat Owers should be situated in the same locations referred above for Pacific oysters.

4.14 The RMP for mussels representing the CZ at Higher Gurrow Point should be relocated to the northwestern edge of the bed. This point will be representative of microbial contamination from sewage discharges and diffuse pollution delivered from the Dart catchment via the rivers Dart and its tributaries transported down the river during ebb tides and/or during periods of high river flow discharges.

4.15 A new CZ is recommended to encompass the new mussel bed at Kingswear. The boundaries of this CZ will be similar to those described in 4.10.

### TOLERANCE OF SAMPLING POINTS

4.16 The recommended maximum tolerance for all RMPs is 10 metres. Given that there are no difficulties in obtaining sufficient numbers of oysters and mussels for sampling, it is considered that this tolerance preserves the fixed location concept and minimises the effect of spatial variability in the extent of microbial contamination.

# 5 SAMPLING PLAN

## 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)<br>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 | Peter J. Wearden (Divisional EHO) |
| Telephone number ( | 01803 861234 |
| Fax number | 01803 861294 |
| E-mail Š | Pete.Wearden@southhams.gov.uk |

## REQUIREMENT FOR REVIEW

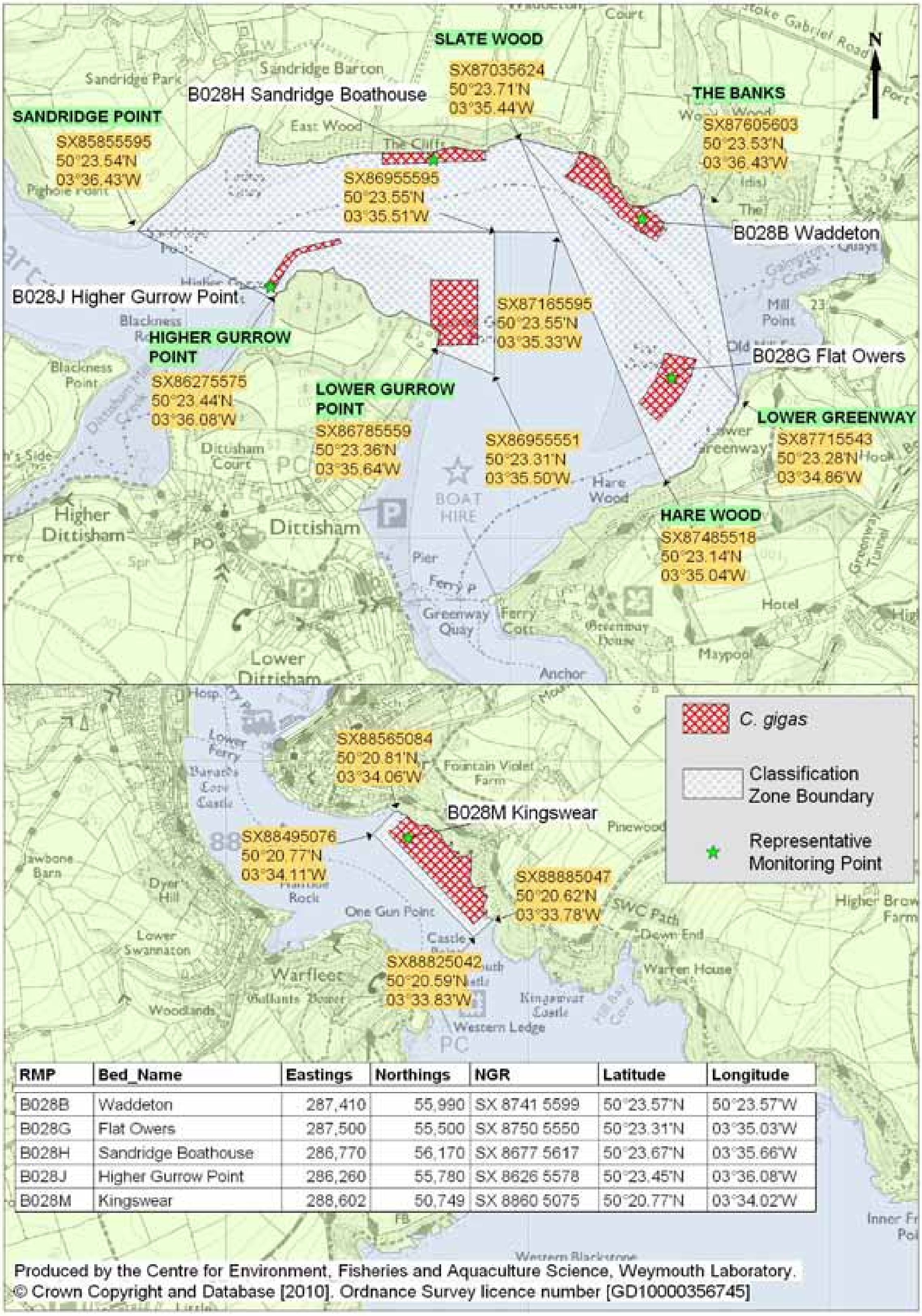
The need for this sampling plan to be reviewed will be assessed by the competent authority within six years or in light of any obvious known changes in sources of pollution of human (e.g. improvements in sewage treatment works) or animal origin likely to be a source of contamination for the bivalve mollusc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

**_Table 5.1 Number and location of representative monitoring points (RMPs) and frequency of sampling._**

| RMP | Bed name | Geographic grid references (datum) of sampling points* | | | | | Species | Growing method | Harvesting technique | Sampling method | Depth | Frequency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | OSGB36 | | | WGS84 | | | | | | | |
| | | Easting | Northing | NGR | Latitude | Longitude | | | | | | |
| 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 | At least monthly |
| 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 | At least monthly |
| 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 |
| B028N | Lower Gurrow Point | 286780 | 55765 | SX 8678 5577 | 50° 23.45'N | 3° 35.64'W | Mussels (*Mytilus* spp.) | Trestles/ 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 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B028M | Kingswear | 288602 | 50749 | SX 8860 5075 | 50° 20.76’N | 3° 34.02’W | Pacific oysters (*C. gigas*) | Bags in cage | Recovered by boat | Hand-picked from bags recovered by boat | 3m | *Preliminary classification:* 10 samples taken over at least 3 months (interval between sampling not less than 1 week).<br>*Full classification:* at least monthly over one year |
| B028L | Kingswear | 288602 | 50749 | SX 8860 5075 | 50° 20.76’N | 3° 34.02’W | Mussels (*Mytilus* spp.) | Bags in cage | Recovered by boat | Hand-picked from bags recovered by boat | 3m | *Preliminary classification:* 10 samples taken over at least 3 months (interval between sampling not less than 1 week).<br>*Full classification:* at least monthly over one year |

* Tolerance for representative monitoring points: 10 metres.



| RMP | Bed_Name | Eastings | Northings | NGR | Latitude | Longitude |
|---|---|---|---|---|---|---|
| B028B | Waddeton | 287,410 | 55,990 | SX 8741 5599 | 50°23.57'N | 50°23.57'W |
| B028G | Flat Owers | 287,500 | 55,500 | SX 8750 5550 | 50°23.31'N | 03°35.03'W |
| B028H | Sandridge Boathouse | 286,770 | 56,170 | SX 8677 5617 | 50°23.67'N | 03°35.66'W |
| B028J | Higher Gurrow Point | 286,260 | 55,780 | SX 8626 5578 | 50°23.45'N | 03°36.08'W |
| B028M | Kingswear | 288,602 | 50,749 | SX 8860 5075 | 50°20.77'N | 03°34.02'W |

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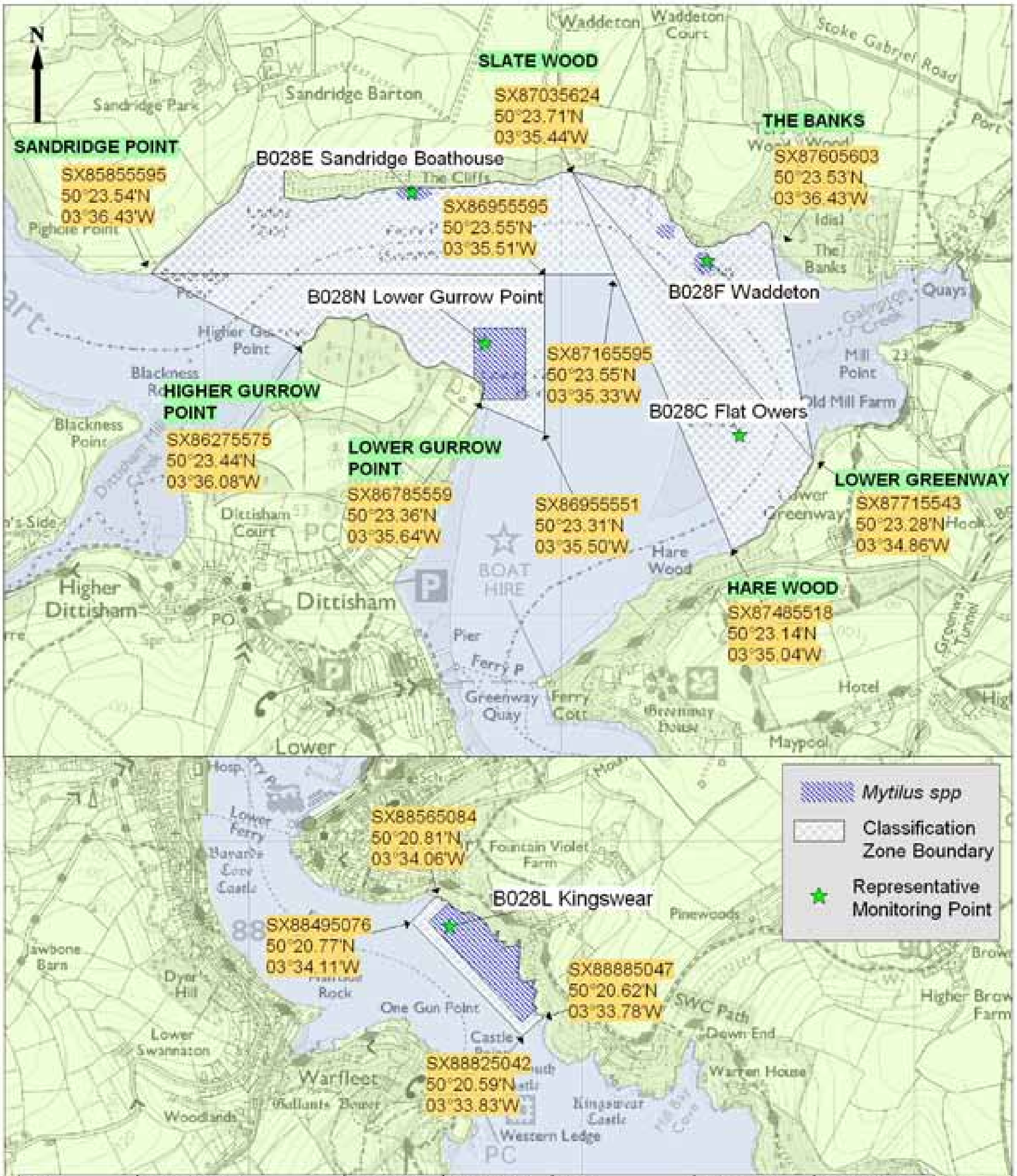
***Figure 5.1 Location of representative monitoring points (RMPs) and production area boundaries for Pacific oysters (*C. gigas*) in the Dart Estuary.***



| RMP | Bed_Name | Eastings | Northings | NGR | Latitude | Longitude |
|---|---|---|---|---|---|---|
| B028F | Waddeton | 287,410 | 55,990 | SX 8741 5599 | 50°23.57'N | 50°23.57'W |
| B028C | Flat Owers | 287,500 | 55,500 | SX 8750 5550 | 50°23.31'N | 03°35.03'W |
| B028E | Sandridge Boathouse | 286,580 | 56,180 | SX 8658 5618 | 50°23.67'N | 03°35.82'W |
| B028L | Kingwear | 288,602 | 50,749 | SX 8860 5075 | 50°20.77'N | 03°34.02'W |
| B028N | Lower Gurrow Point | 286,780 | 55,765 | SX 8678 5577 | 50°23.45N | 03°35.65'W |

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***Figure 5.2 Location of representative monitoring points (RMPs) and production area boundaries for mussels (Mytilus* spp.*) in the Dart Estuary.***

# APPENDICES

## APPENDIX I
## HUMAN POPULATION: DENSITY AND ACTIVITIES

The Dart catchment is predominantly rural and sparsely populated. There is very little heavy industry within the catchment (Devon Wildlife Trust, 2004). The distribution of resident human population by Super Output Area Boundary[8] totally or partially included within the river catchment areas draining to the Dart Estuary is shown in Figure I.1. The more populated areas occur in the lower Dart catchment and in the upper and lower Dart (tidal) catchment, at the head and the mouth of the estuary, respectively.

The main urbanised areas within river catchments are Ashburton (total population=4,277), Buckfastleigh (3,918), Totnes (8,439) and Dartmouth (5,540) (Office for National Statistics, pers. comm.). These urbanised areas account for the majority of the population within the tidal river catchment (Table I.1).

***Table I.1 Human population in the Dart river catchments.***

| River catchment | Resident population |
|---|---|
| Dart | 18,591 |
| Dart (tidal) | 22,857 |
| Total | 41,448 |

*Source: Office for National Statistics, Crown copyright 2007. Crown copyright material is reproduced with the permission of the Controller of HMSO.*
*NB. Based on provisional mid-2005 population estimates for river catchment areas within England and Wales.*

Urbanised areas contain the majority of point-sources of pollution (continuous and intermittent sewage discharges) in these catchments. An inventory of the significant sewage discharges to the estuary is presented in the Appendix VII. Urbanised areas also contain the vast majority of impervious surfaces[9] (e.g. roads, parks, pavements), which are known to contribute with significant loads of microbiological contaminants (Ellis and Mitchell, 2006)[10]. In general, bivalve molluscs commercially harvested in the vicinity of urbanised areas tend to show deteriorated microbiological quality.

Human population in these catchments fluctuates seasonally due to tourism. 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).

---

[8] Super Output Area (SOA) boundaries are in part derived from Ordnance Survey information and some SOA boundaries which follow ward or parish boundaries reproduce limited parts of the OS Boundary-Line product.

[9] In the context of the present report, impervious surfaces are any surface in the urban landscape that does not infiltrate rainfall.

[10] Concentrations of *E. coli* (MPN $100ml^{-1}$) quoted in literature are: $10-10^3$ for residential areas and highways and $10^2-10^4$ for roof runoff and commercial areas (Ellis & Mitchell, 2006)

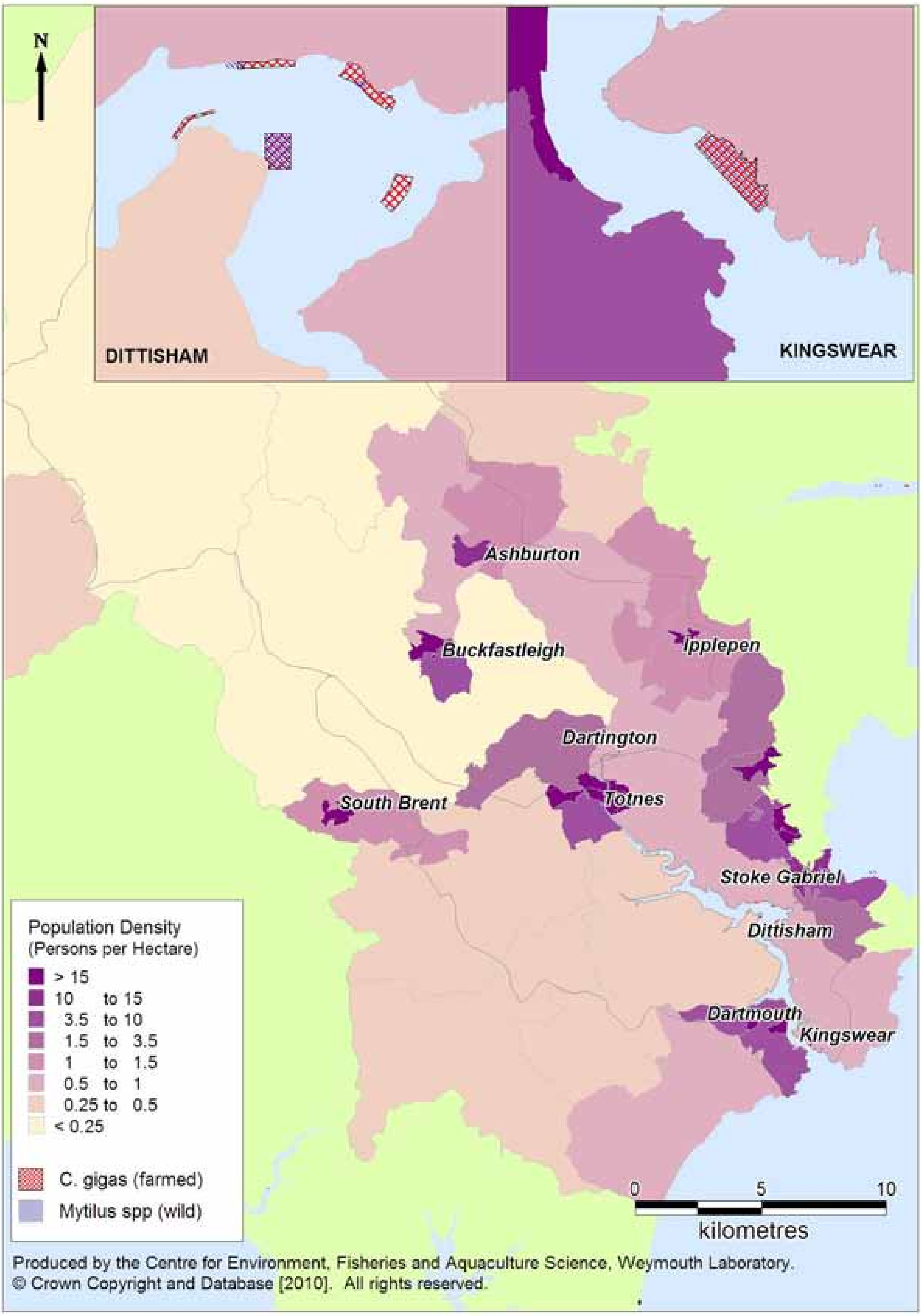

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***Figure I.1 Human population in Census Area Wards in the Dart catchment area.***
*Data provided by the Devon County Council (2009) and based on data from the Office for National Statistics, Census Area Statistics (England and Wales). © Crown Copyright. Dart Estuary catchment boundary refers to Mean High Water. Census Area Ward boundaries refer to Mean Low Water.*

Tourism within the Dartmoor National Park is a major component of the local economy as a whole (Devon Wildlife Trust, 2004). Tourism activities in the Dart catchment have long been associated with the countryside, yachting and boating. Table I.2 summarises the total number of visits to the main tourist attractions for the period 2004–2007.

***Table I.2 Total number of visits to local tourist attractions in the Dart catchment.***

| Attraction | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|
| Buckfast Butterfly Farm and Dartmoor Otter Sanctuary* | 60,000 | 50,000 | 40,000 | 45,000 |
| Dartmouth Castle | 34,795 | 36,865 | 38,293 | 37,940 |
| Dartmouth Museum | 6,790 | 7,047 | 9,123 | 9,600 |
| High Cross House, Dartington Hall, Totnes | 1,209 | 1,513 | 1,679 | 1,440 |
| Totnes Castle | 23,098 | 22,634 | 23,624 | 21,239 |
| Totnes Guildhall* | 1,380 | 1,380 | 2,211 | 3,693 |
| Totnes Elizabeth House Museum | 5,790 | 4,852 | 4,891 | 4,467 |
| Woodlands Leisure Park, Blackawton | 400,125 | 400,000 | 400,362 | 400,265 |

*Data from South West Tourism.*
**Estimated figures.*

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 A1.2 shows an increase in the number of tourists to Dartmouth area from January to August and the popularity of summer months.

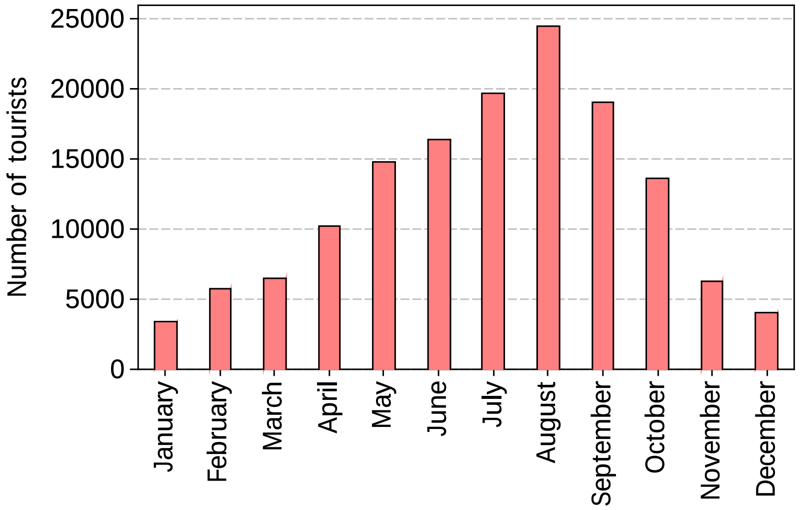

***Figure I.2 Monthly variation in numbers of tourists in Dartmouth.***
*Figures indicate both overnight and day visitors.*
*Data from Dartmouth Tourist Information Centre (2008).*

Seasonal changes in human population due to tourism will result in increased microbiological loads from sewage treatment plants on a seasonal basis (Younger *et al.*, 2003). An assessment of the impact of the most significant sewage discharges to the estuary is given in the Appendix VII.

# APPENDIX II
## HYDROMETRIC DATA: RAINFALL

The southwest of England is one of the wettest regions in the UK. The pattern of rainfall variation is heavily influenced by the topography, which forces the moisture-laden air to precipitate high levels of rainfall throughout the upper reaches of the catchments. 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 operating across the Dart catchment were analysed for the period January 2003–June 2007. The location of these gauges is given in Figure II.1 and monthly variation in rainfall at each is shown in Figure II.2.

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 II.2).

Rainfall may lead to the discharge of raw or partially treated sewage from combined sewer overflows (CSO) and other intermittent discharges as well as runoff from faecally contaminated land (Younger *et al.*, 2003). Representative monitoring points located in parts of shellfish beds closest to discharges and freshwater inputs will reflect the combined effect of rainfall on the contribution of individual pollution sources.

Results from analyses of the relationships between the levels of *E. coli* in bivalve molluscs in the Dart Estuary and rainfall levels is given in the Appendix XII.

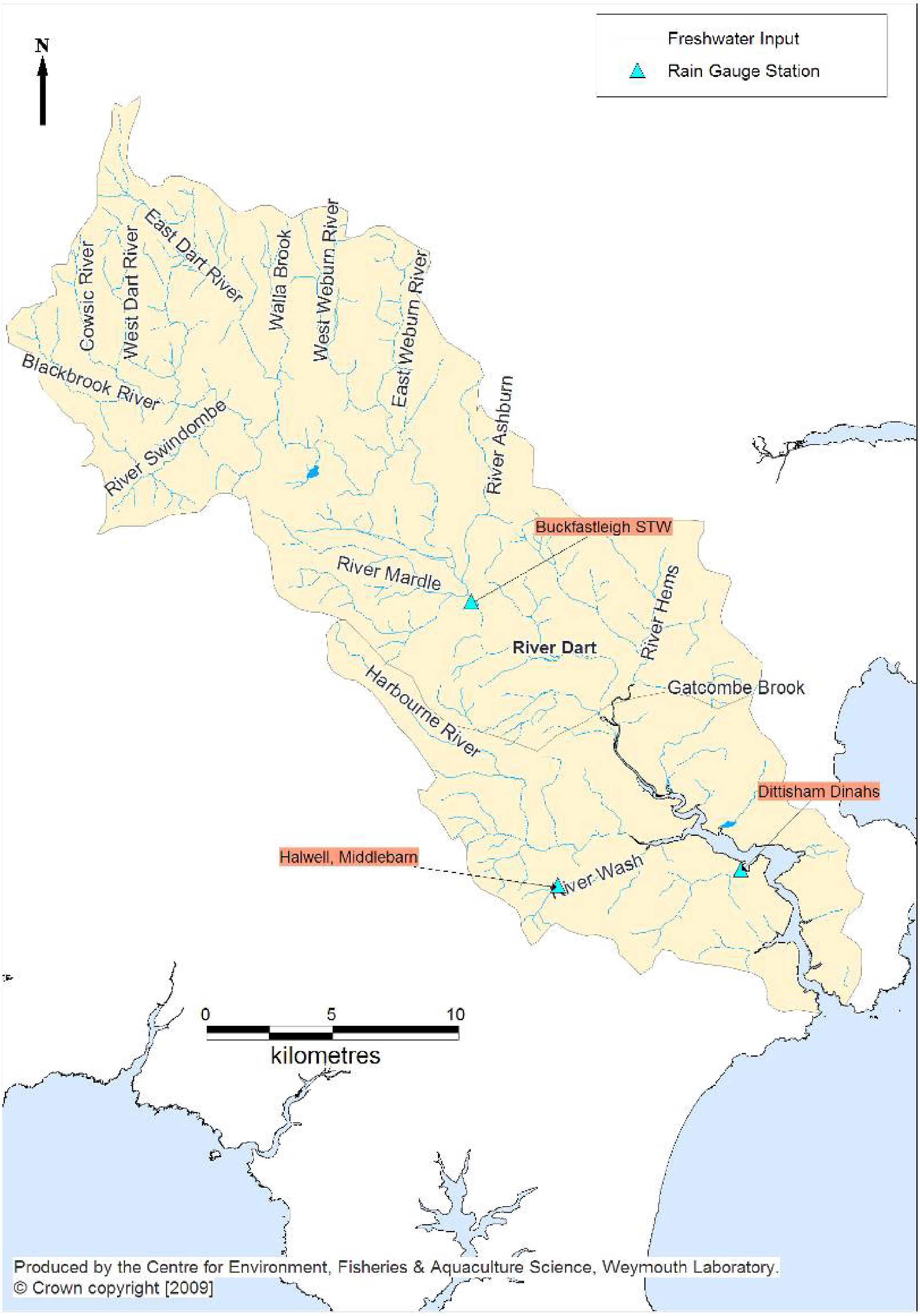

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***Figure II.1 Freshwater inputs to the Dart Estuary and location of rain gauging station mentioned in this report.***

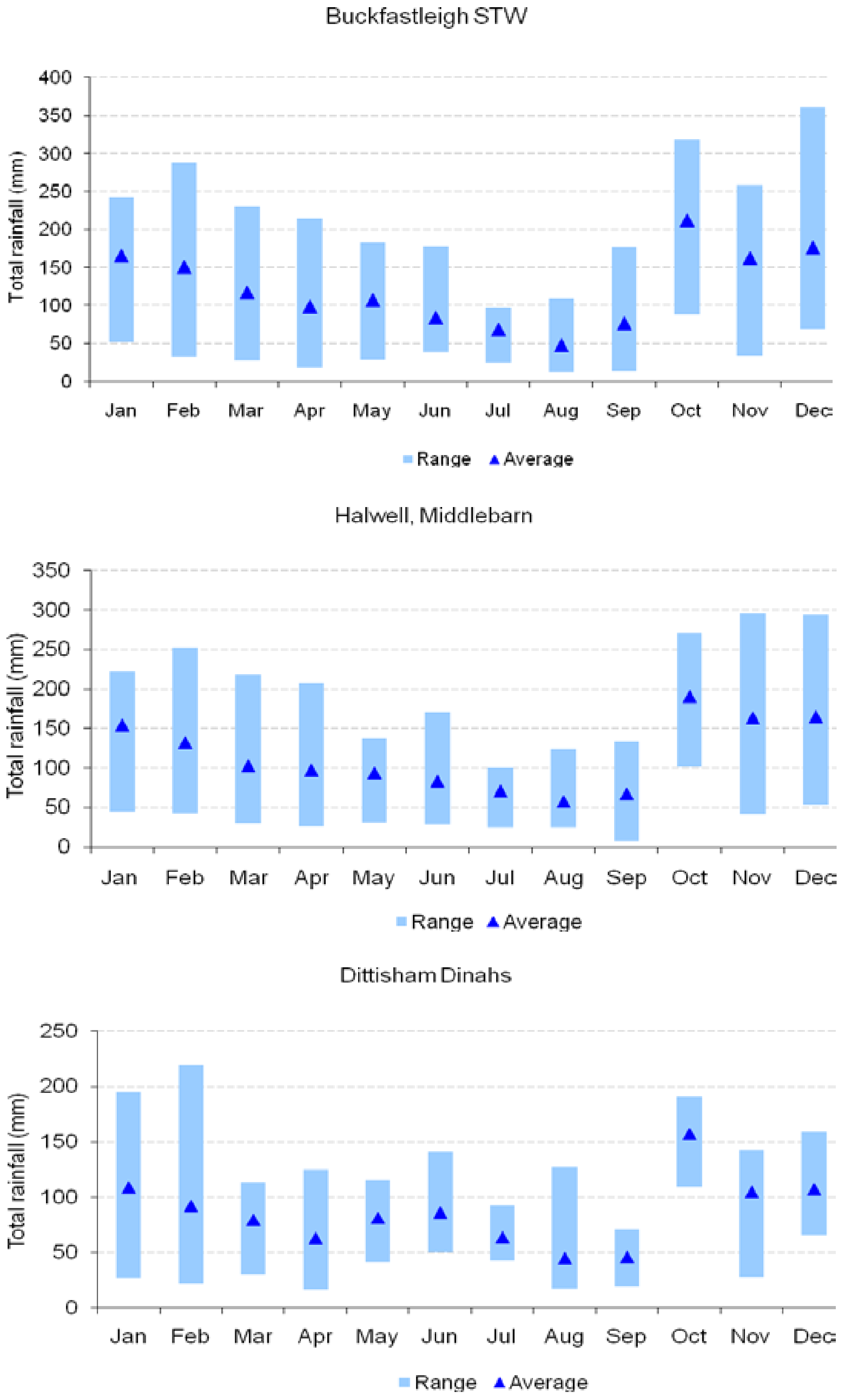

***Figure II.2 Monthly variation of rainfall in three gauging stations in the Dart catchment.***
*Data from the Environment Agency.*

## APPENDIX III
## HYDROMETRIC DATA: FRESHWATER INPUTS

The Dart catchment drains a total area of approximately 470 km$^2$. The main freshwater inputs to the Dart Estuary are the rivers East and West Dart, Blackbrook, Cowsick, East and West Webburn and Hems (Figure III.1).

The East and West Dart extend for approximately 44km and 41km, respectively from Dartmoor to the tidal limit just above the confluence with the River Hems. There are a number of other smaller tributaries in the catchment.

Table III.1 shows mean flows for the two gauging stations marked on Figure III.1.

***Table III.1 Hydrological characteristics in the Dart.***

| | River gauging station* | |
|---|---|---|
| | Bellever | Austins Bridge |
| Sub catchment area (km$^2$) | 21.5 | 247.6 |
| Level of station (m) | 309 | 22.4 |
| Maximum altitude (m) | 604 | 604 |
| 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 |
| Q95/Qmean | 0.167 | 0.135 |

*data recorded during the period 1964–2006. Data from the National River Flow Archive (2008) and Thomas and 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, 2005; Thomas and Murdoch, 2005) to river flows than that from the River Dart measured at Bellever and Austin's Bridge gauging stations.

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 exceedance in all the upper Dart tributaries.

Figure III.2 shows increased flow rates in the River Dart at Bellever during autumn-winter months. Peak flows occur throughout the year.

Water levels in the River Dart, particularly in the upper reaches, 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 (Q95/Qmean≈0.1). In the River Ashburn, water levels tend to respond within 5 h to rainfall. In the lower Dart, flood peaks tend to be delayed as a result of the lower topography peaking approximately 12–24 h (Environment Agency, 2004). Odling-Smee, Oberman Associates Ltd (2004) 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.

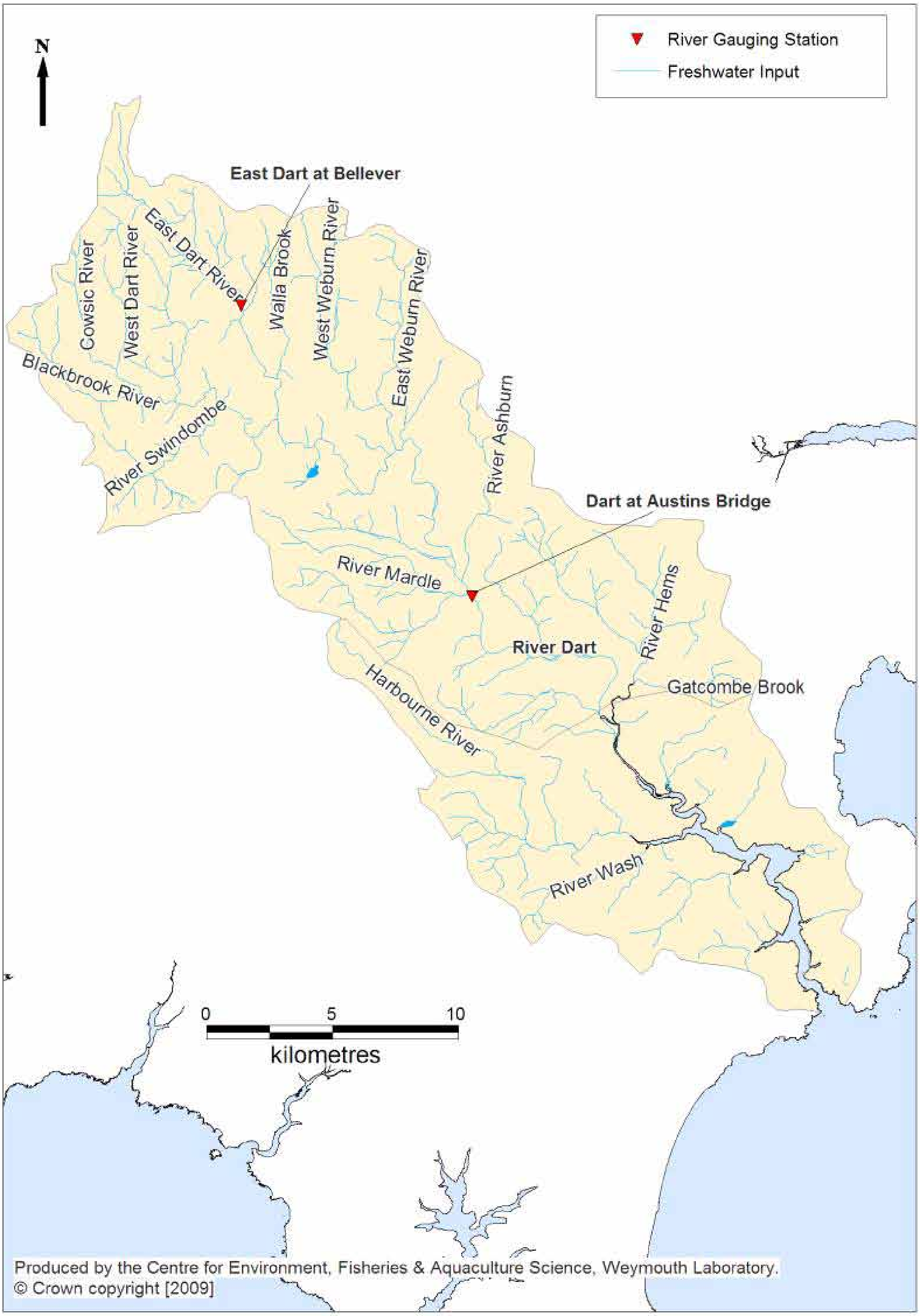

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*Figure III.1 Rivers and river gauging stations in the Dart catchment.*

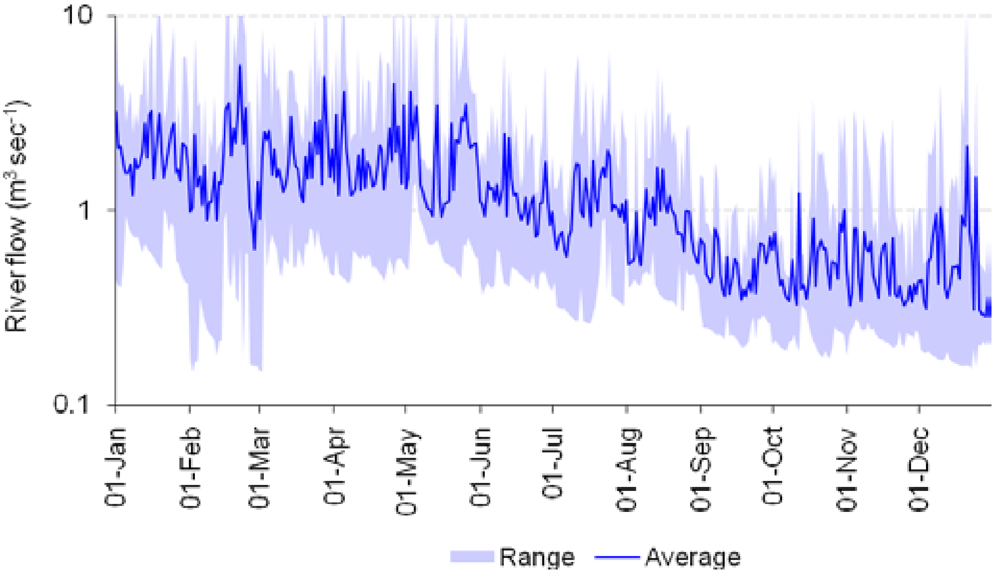

***Figure III.2 Hydrograph for the East Dart at Bellever for the period January 2000–December 2005.***

Figure III.3 shows a seasonal pattern in the rainfall-runoff response in the River Dart. During autumn months, the response is mostly driven by significant increases in rainfall levels in October to peak in December. The period of high runoff (October–January) represents a potentially higher risk of contamination for bivalve molluscs.

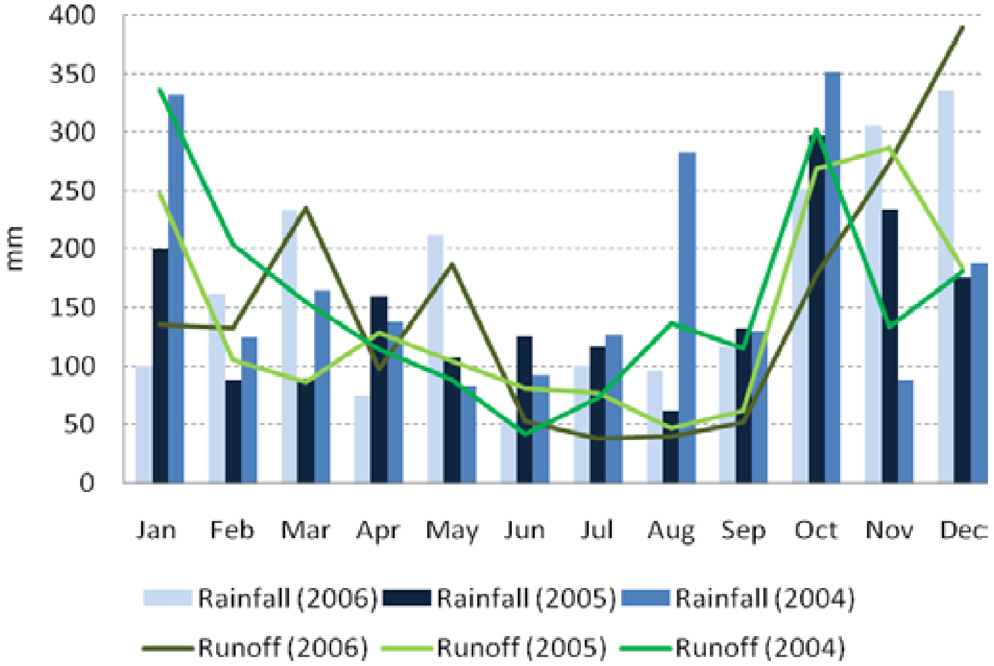

***Figure III.3 Monthly variation of rainfall and runoff for the River Dart at Bellever for the period 2004–2006.***
*Data from the National River Flow Archive (NERC, 2009).*
*NB. In the context of this report, runoff can be understood as the passage of water on the surface of the Earth.*

## APPENDIX IV
## HYDRODYNAMIC DATA: BATHYMETRY

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

The area between Higher Gurrow Point-Sandridge Point and Greenway Quay, which encompasses the shellfish beds within the Waddeton Fishery Order is shallow, with less than 6m relative to CD. Most of the areas where shellfish beds are established dry on Low Water Springs (Figures IV.1–IV.3).

The mean depth of water in the lower reaches of the estuary at Dartmouth is less than 15m relative to Chart Datum (CD) reaching 20m at the elongated depression in the centre of the channel at the mouth of the estuary. The new production area at Kingswear extends from the Mean High Water Mark to charted 10m bathymetric contour (Figure IV.3). The deepest area within the bed is the southwest corner, which is approximately 8m deep.

Pacific oysters and mussels cultivated in intertidal areas are exposed during significant periods of the tidal cycle. Furthermore, solar radiation will increase decay rates of microbial contaminants in shallow areas, although there is growing evidence that wetting/drying may allow some microorganisms to persist or even replicate. Pacific oysters and mussels in subtidal areas at Kingswear have the potential to accumulate microbiological contamination over the whole tidal cycle. Consideration is given to these factors for the purposes of informing the sampling plan.

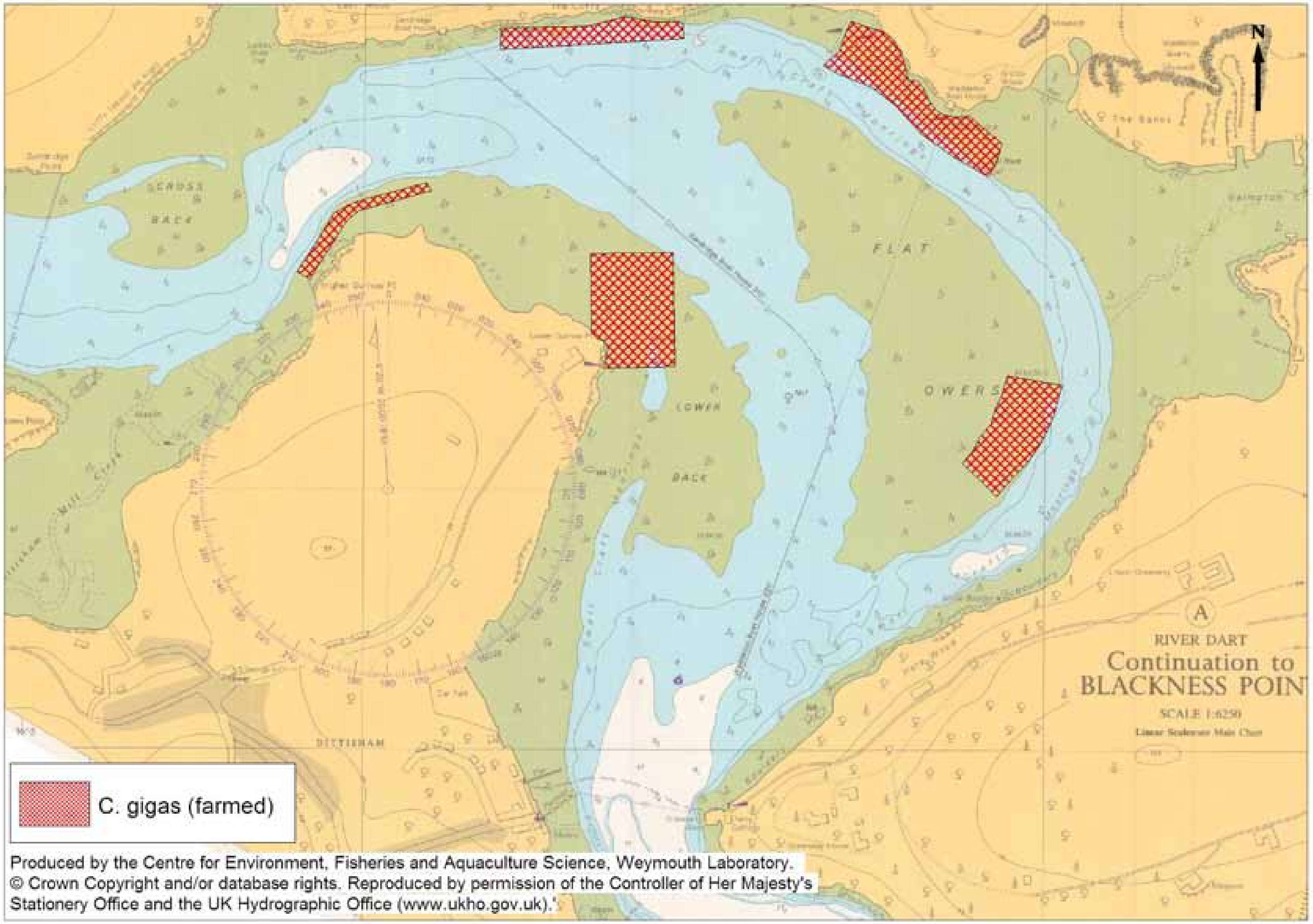

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***Figure IV.1 Bathymetry in the middle section of the Dart Estuary showing location of Pacific oyster beds.***

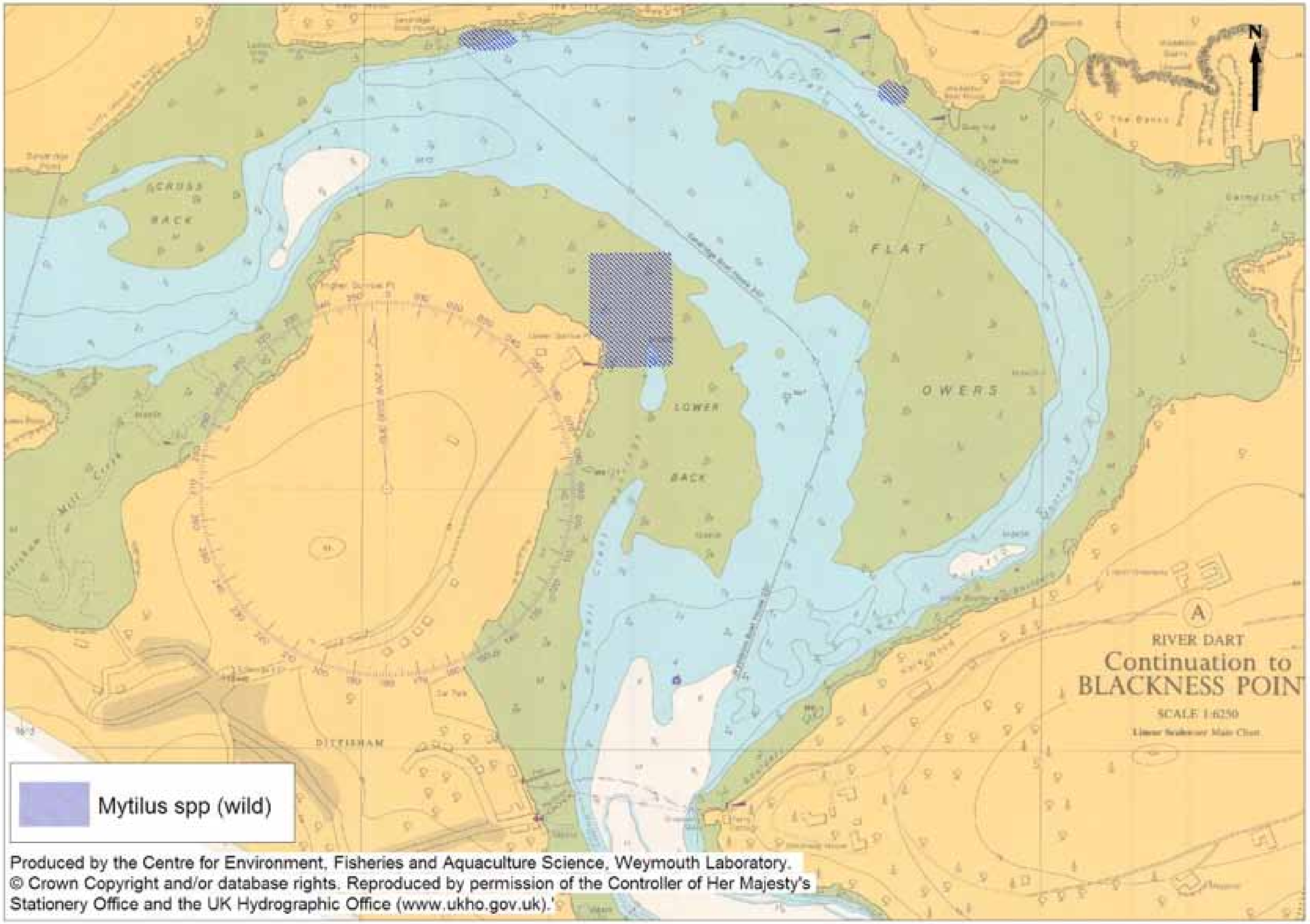

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***Figure IV.2 Bathymetry in the middle section of the Dart Estuary showing location of mussel beds.***

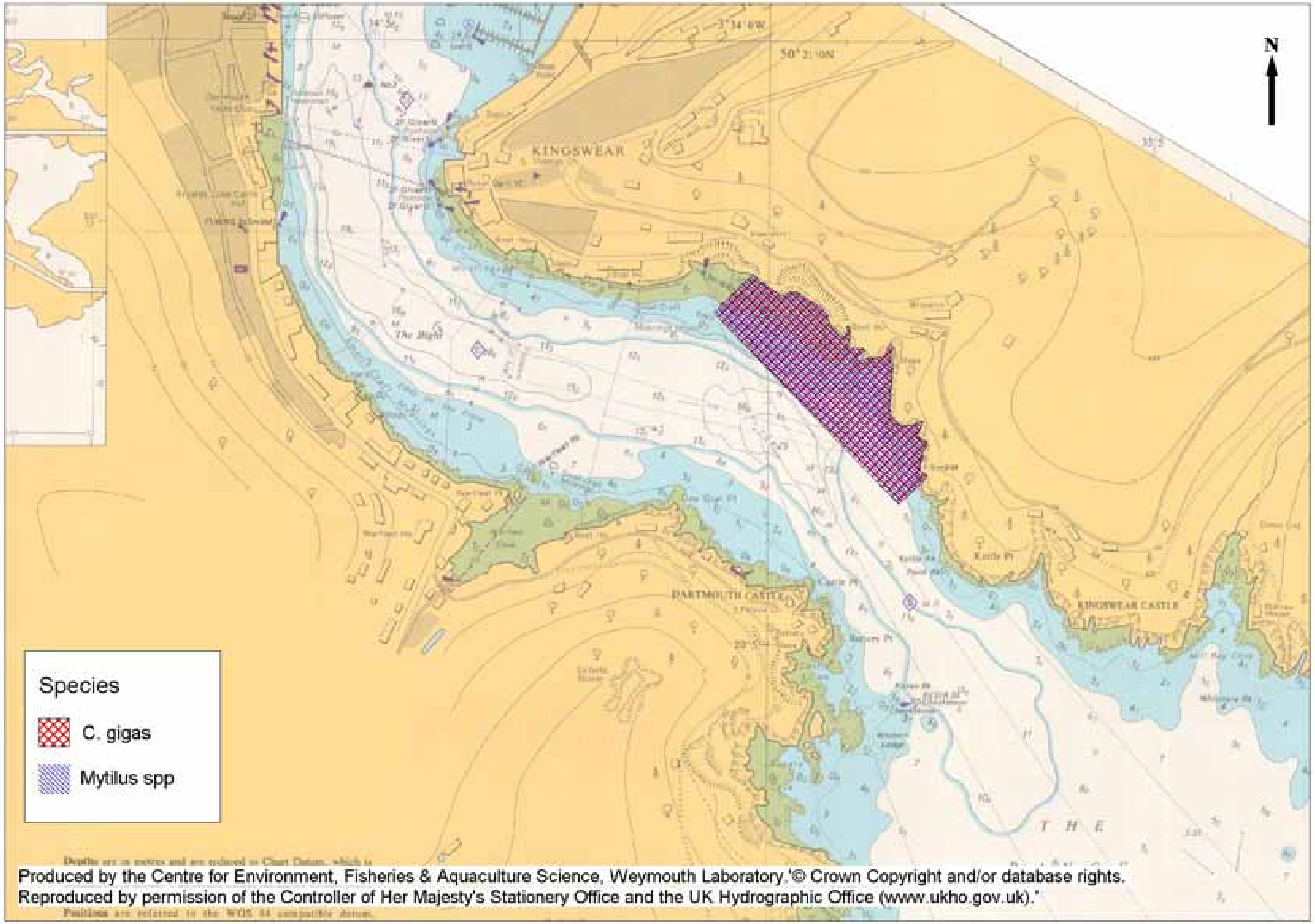

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***Figure IV.3 Bathymetry in the lower Dart Estuary showing location of mussel and Pacific oyster bed.***

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 (Halcrow Group Ltd., 2002; Uncles *et al.*, 2002). Sedimentation of microbiological contaminants and re-suspension of potentially contaminated sediment are expected to dominate within the muddy shallow creeks of the Dart Estuary. Extensive drying areas often produce continued drainage long after the tide has receded and the mudflats are exposed (see Whitehouse *et al*., 2000). Contaminated runoff from retained seawater and/or washed off by rainfall falling on the surface of mudflats into these creeks will be conveyed along the channel(s). Therefore, nearshore shallow areas are likely to represent worst-case conditions. In contrast, deeper estuarine areas at Kingswear will contain more water for dilution and dispersion of contaminants.

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 riverbed 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 are 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.

## APPENDIX V
## HYDRODYNAMIC DATA: TIDES AND CURRENTS

The Dart Estuary has an asymmetrical macro tidal regime with semi-diurnal tides (i.e. two tidal cycles per day). The flooding spring tide typically has the duration of 6:30[11] and the ebb tide a duration of 5:40 (Thain *et al.*, 2004).

At Dartmouth, tidal amplitude is within the macro-tidal range (mean spring tide range = 4.3m; mean neap tide range = 1.8m) (Table V.1).

***Table V.1 Tidal constants for 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 tidal excursion (mouth to limit of reversing tidal currents) is estimated to be 19km (Uncles *et al.*, 2002). Microbial contaminants may be transported over this distance with the tidal wave along the estuary.

The estuary is ebb dominant, i.e. the ebb tide is longer than the flood tide with a flow ratio suggesting that a freshwater plume may develop and emerge from the mouth of the estuary during ebb tides under maximum river flows (Halcrow Group Ltd., 2002; Thain *et al.*, 2004). Odling-Smee, Oberman Associates Ltd (2004) 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 estimated residence (flushing) time[12] is estimated to be approximately seven days (Uncles *et al.*, 2002). This is higher than that for other estuaries with similar tidal lengths, such as the Bristol Avon (tidal length (TL) = 17km; residence time (RT) = 1.5 days), Exe (TL = 15km; RT = 6 days) and Camel (TL = 16km; RT = 2.5 days). Overall, the estuary is considered to be partially mixed to almost well mixed (R. Thain, pers. comm.). During winter floods a salt-wedge

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[11] Figures referring to tide times are denoted as hours:minutes.

[12] The residence time is the ratio between the tidal volume and the freshwater input to the estuary.

front is formed leading to differing levels of stratification (Odling-Smee, Oberman Associates Ltd, 2004).

Partially mixing conditions in the estuary are prevalent during high river flow discharges (R. Thain, pers. comm.). 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).

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 V.1) are shown in Figure V.2.

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© Crown copyright. All rights reserved FSA. Licence number GD100035675 [2008]. Based on the Ordnance Survey 1:25,000 map.

***Figure V.1. Sampling points of surface water for temperature and salinity profiles.***

Figure V.2 shows an increasing horizontal salinity gradient from 0ppt at Totnes Weir to 23.6ppt at The Anchor Stone during high river flow conditions. The highest difference in median salinity (4.7ppt) 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 20ppt (Laing and Spencer, 2006). There are no commercial beds in the river above Blackness Point where salinities reduce below 20ppt during high flow conditions. 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.

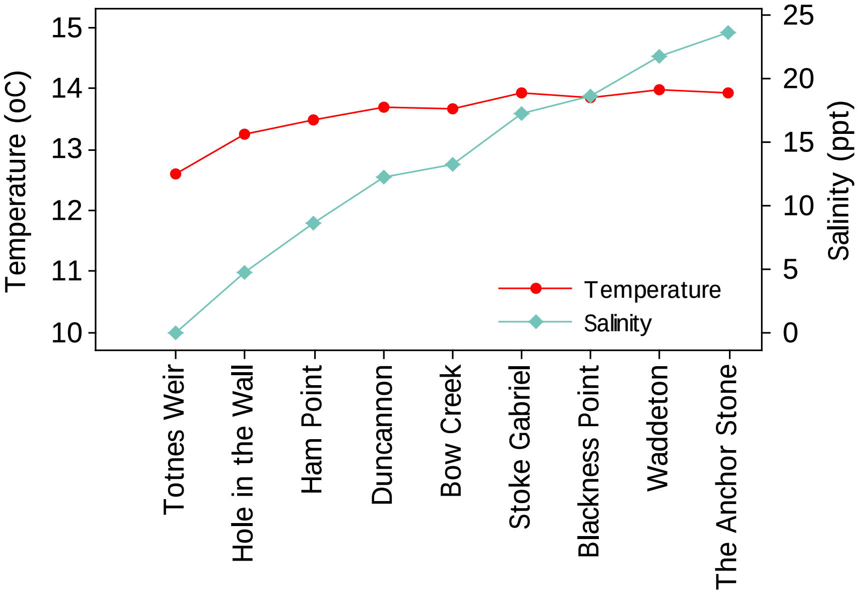

***Figure V.2 Surface median water temperature and salinity at nine locations along the Dart Estuary.***
*Measurements taken weekly and following rainfall events over a six-month period in 2000.*
*Data from Allen (2001) with the permission of the author.*

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 V.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 A5.3 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.

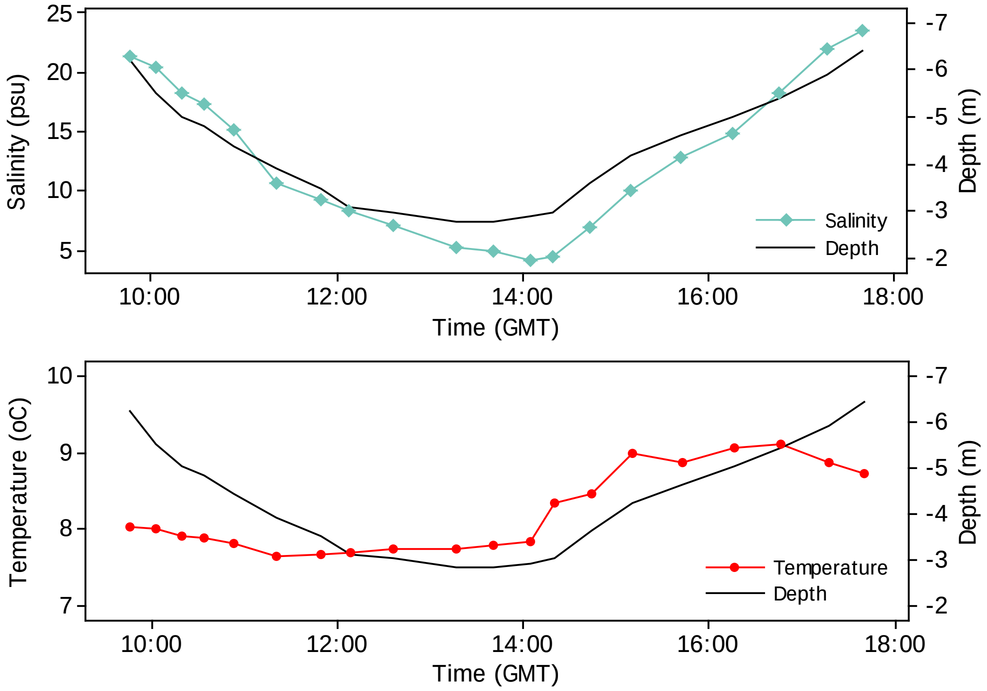

***Figure V.3 Water temperature and salinity profiles between Sandridge Point and Blackness Point, Dart Estuary.***

*Data from Allen (2001) with the permission of the author.*

The Devon Sea Fisheries Committee has recorded salinity values ranging between 10psu and 32psu (mean = 22.3) and water temperature between 5°C and 20°C (mean temperature = 13.5°C) in Pacific oyster beds in the estuary.

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 an adequate parameter to predict the variation of microbiological contamination in bivalves.

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

The pattern of circulation of pollutants at the mouth of the estuary results from the predominant rectilinear flow within the main channel and the progressive offshore wave along the English Channel. The combination of these tidal flows will result of 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 bivalve mollusc beds within the Waddeton Fishery Order. The anticlockwise pattern of circulation on the ebb would promote the transport of contamination from sources discharging in close proximity to bivalve mollusc beds, particularly those along the western shoreline.

A very characteristic transient V-shaped tidal intrusion front is formed near the mouth of the estuary during flooding spring tides (Figure V.4). The tidal intrusion, which was observed at Dittisham progressing upstream during the shoreline survey, 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 50m 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. The turbulence generated by the front may result in temporally and spatially sediment resuspension events at Kingswear.

Whenever possible, it is 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.

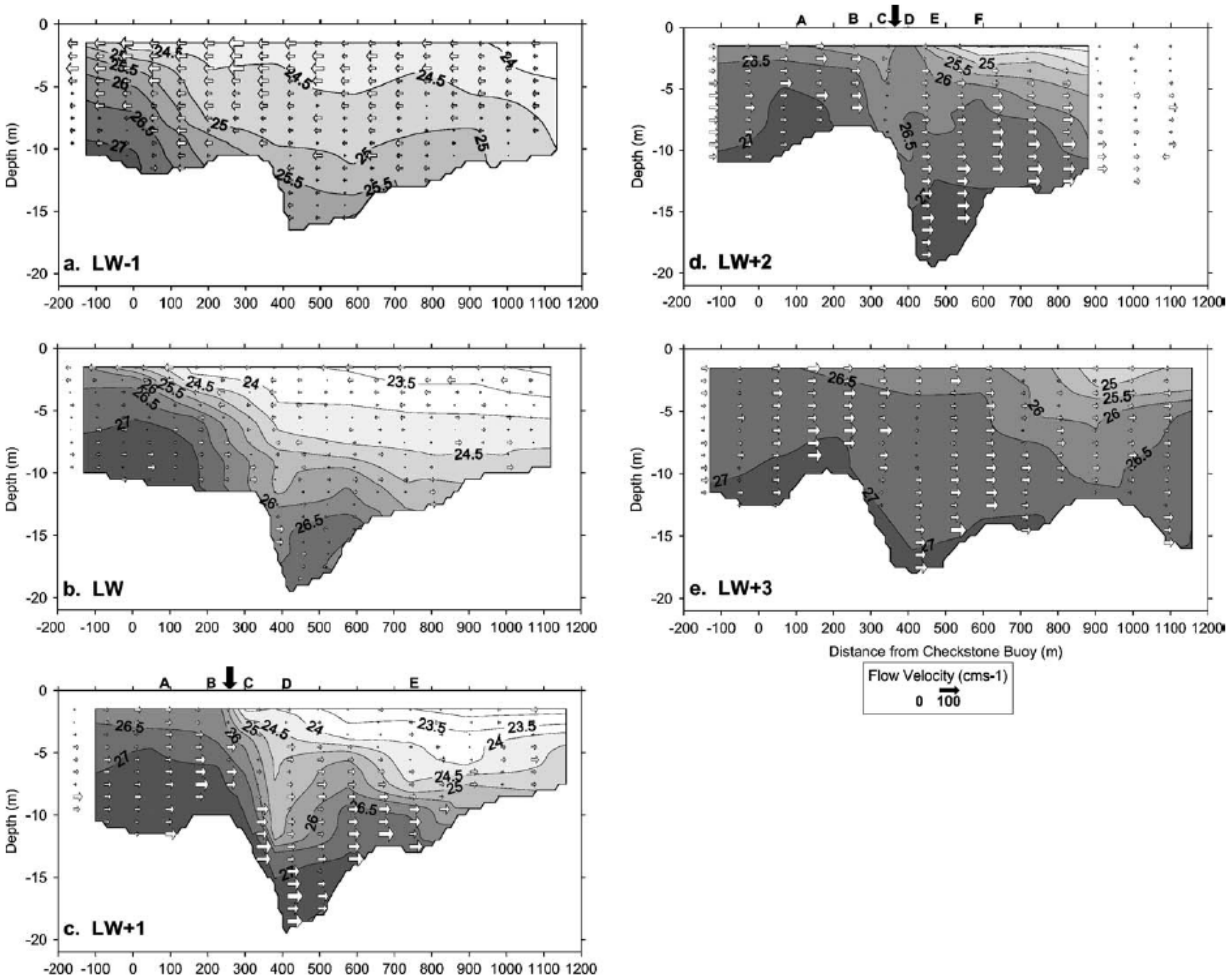

***Figure V.4 Hourly contours of density anomaly at spring tides from 1 h before low water (a) to 3 h after low water (e). From Checkstone Buoy to the lower ferry (1200 m distance), at the mouth of the estuary. Flow vectors overlayed. The constricted section of the mouth starts approximately 150 m from 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.***
*Modified from Thain* et al*. (2004) with the permission of the author.*

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 V.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 V.2 Results of t-tests examining the relationship between tidal stage at the 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)<br>*C. gigas* | 197 | 21 | 340 | 36 | 0.478 |
| Waddeton (B028F)<br>*Mytilus* spp. | 933 | 20 | 908 | 36 | 0.941 |
| Sandridge Boathouse (B028E)<br>*Mytilus* spp. | 738 | 35 | 1,071 | 23 | 0.215 |
| Sandridge Boathouse (B028H)<br>*C. gigas* | 291 | 30 | 218 | 24 | 0.243 |
| Flat Owers (B028C)<br>*Mytilus* spp. | 734 | 23 | 659 | 30 | 0.387 |
| Flat Owers (B028G)<br>*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 noted 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 V.5). These results are therefore inconclusive regarding the likely effect of tidal stage on the levels of microbiological contamination in BMPAs.

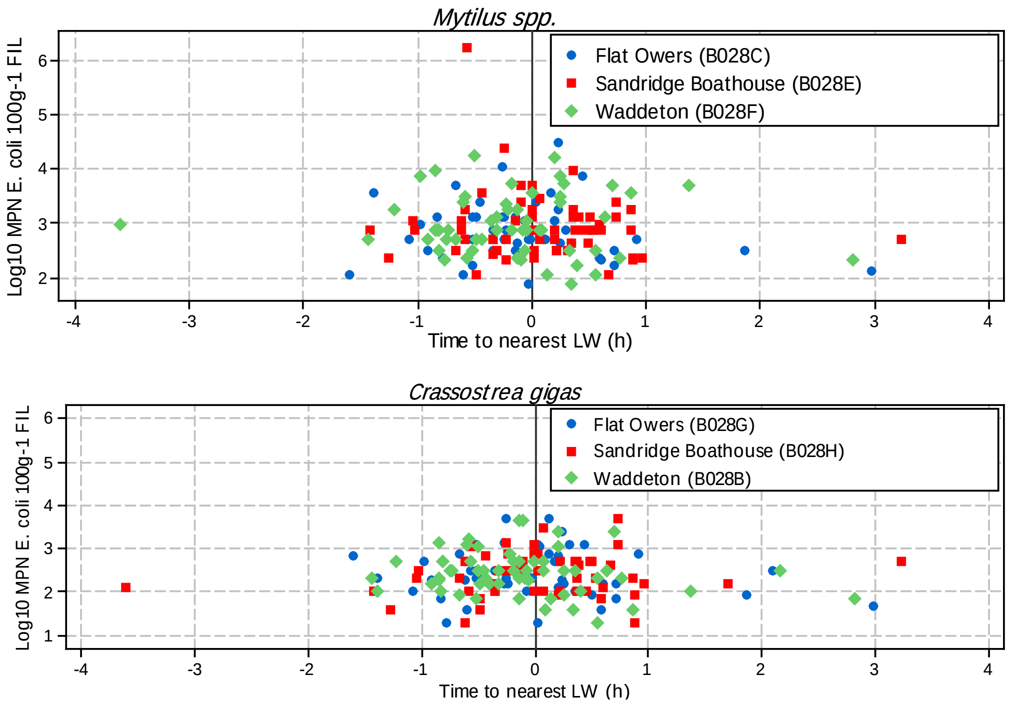

***Figure V.5 Scatterplot of* E. coli *levels in mussels and Pacific oysters from six monitoring points according to time to Low Water.***

## APPENDIX VI

## METEOROLOGICAL DATA: WIND

The southwest is one of the more exposed areas of the United Kingdom. The strongest winds are associated with the passage of deep depressions and the frequency and strength of depressions is greatest in the winter (Met Office, 2007). As Atlantic depressions pass the UK, the wind typically starts to blow from the south or southwest, but later comes from the west or northwest as the depression moves away.

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 VI.1 shows that the prevailing wind is south-westerly.

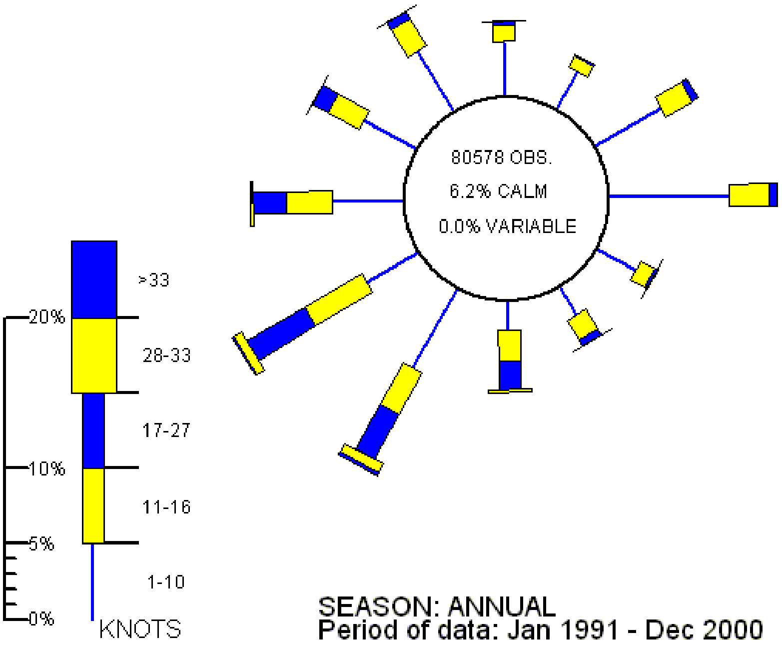

***Figure VI.1. Wind direction and speed (knots) at Plymouth.***

*Modified under permission of Met Office (2007).*

Whilst the contours of the land around the estuary will modify the prevailing wind to some extent, in the Dart the potential for wind driven advection of potentially contaminated surface waters is predominantly from the mouth towards the head of 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).

Is it known that light silting occurs occasionally under easterly winds. Observations indicate that a layer of approximately 10cm of sediment is accreted, which quickly disperses when prevailing southwest winds re-establishes themselves (T. Robbins, pers. com., 20 May 2008).

## APPENDIX VII
## SOURCES AND VARIATION OF MICROBIOLOGICAL POLLUTION: SEWAGE DISCHARGES

Sewage discharges pose a significant risk of contamination of faecal origin to bivalve molluscs. The risk is diverse and depends on the contributing human population and volume of discharge. Sewage effluents in the catchment draining to the Dart Estuary are treated in a number of sewage treatment works (STWs).

Figures VII.1–VII.3 show the locations of continuous and intermittent sewage discharges likely to be a source of microbiological contamination to bivalve mollusc beds. The larger STW are associated with urbanised areas in the upper and lower catchment and receive UV disinfection. Smaller discharges are located in the vicinity of Dittisham, Harbertonford and Ashprington.

There are a number of continuous minor discharges (not listed in the Environment Agency Pollution Reduction Plan; Environment Agency, 2008; see Figure VII.1) in the vicinity of Stoke Gabriel, Dittisham and Galmpton, which could be significant to shellfish beds.

The sewerage infrastructure is also served by numerous overflows, including combined sewer overflows (CSO), emergency overflows (EO) and overflows from sewage pumping stations (PS) (Table VII.1). Of particular significance to bivalve mollusc beds within the Waddeton Fishery Order are those intermittent discharges in Dittisham and Galmpton (less than 3km from bivalve mollusc beds) and, to a lesser extent, Stoke Gabriel and Ashprington.

*Table VII.1 Significant continuous sewage discharges in the Dart Catchment.*

| | Discharge[†] | | | | Approximate (fluvial) distance from bivalve mollusc bed (km) | | | |
|---|---|---|---|---|---|---|---|---|
| Map Ref. ID | Continuous | Type of treatment | DWF (m$^3$ d$^{-1}$) | Pop. eq. | 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) | 242 | 754[‡] | 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 |

*[†] - 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.*

Twenty-two intermittent discharges were identified as having a potentially significant impact on the microbiological status of bivalve mollusc beds within the Waddeton Fishery Order and Kingswear (Table VII.2).

***Table VII.2 Significant intermittent sewage discharges in the Dart cachment.***

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

*[†] - only discharges into the Dart tidal waters or its main tributaries are listed.*
*STW - sewage treatment works.*
*EO - emergency overflow.*
*SO - storm overflow.*
*CSO - combined sewer overflow.*
*PS - pumping station.*

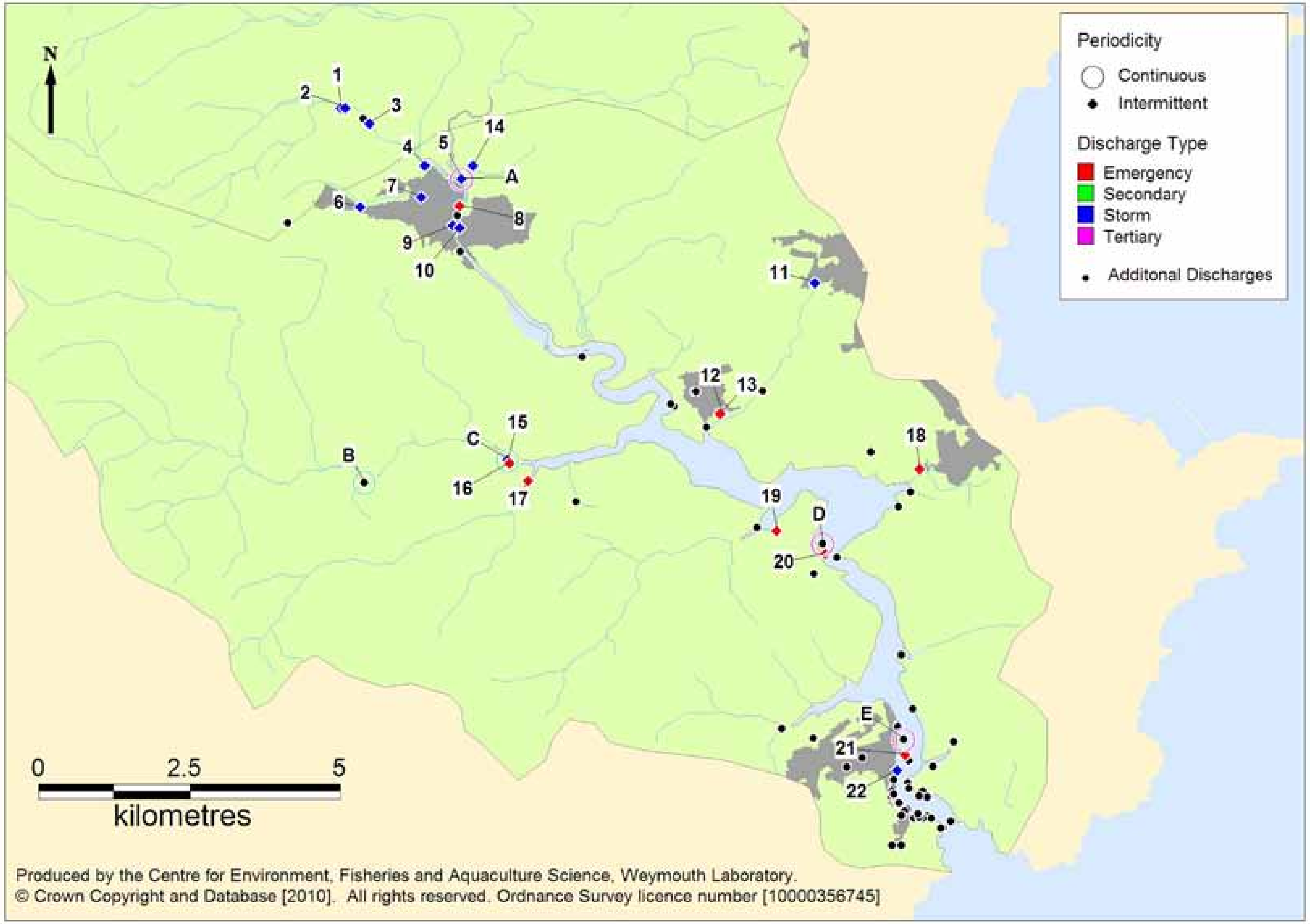

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***Figure VII.1 Significant sewage discharges to the Dart Estuary.***
*For details on discharges, refer to Tables VII.1–VII.2.*

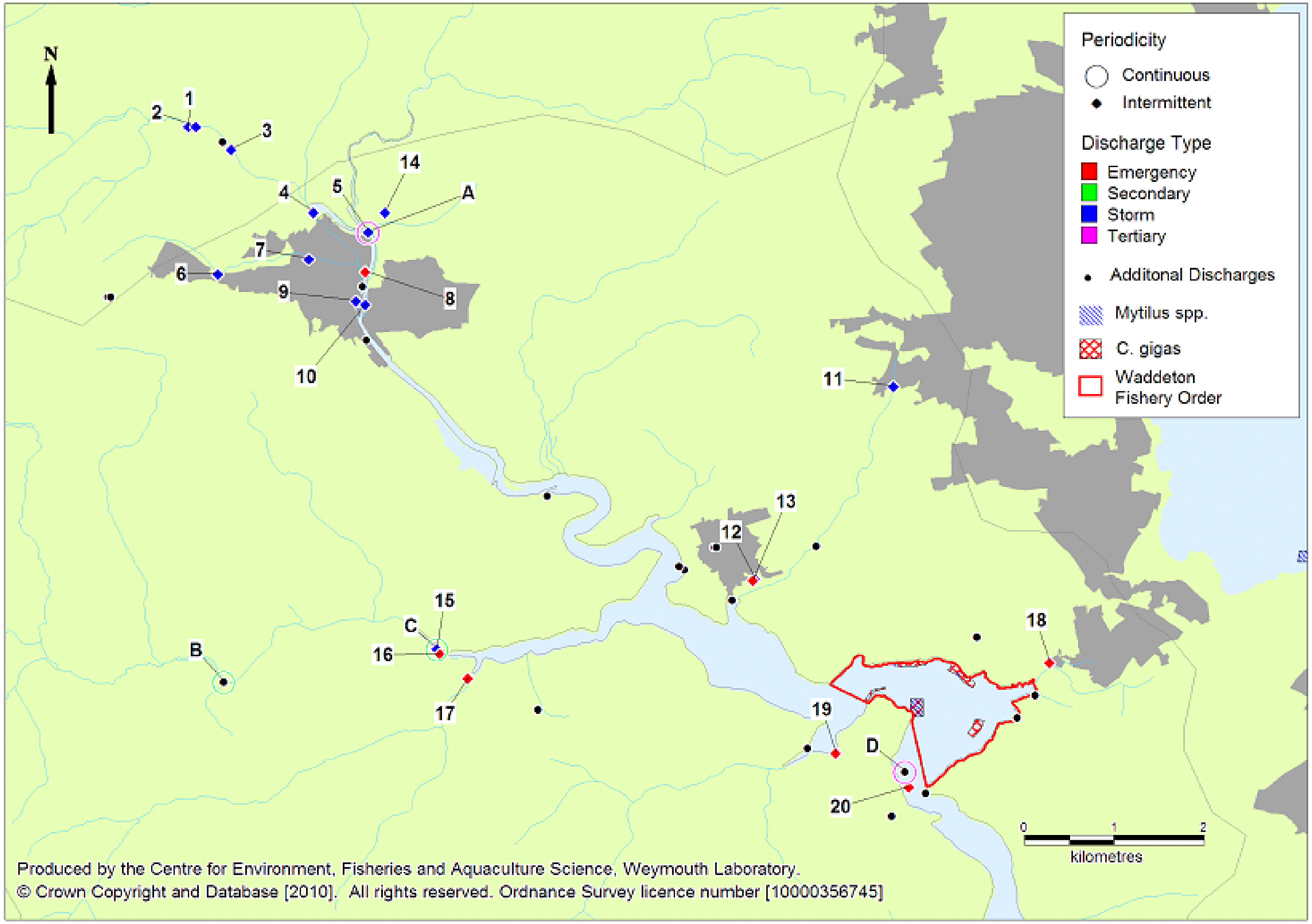

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***Figure VII.2 Significant sewage discharges to the upper Dart Estuary.***
*For details on discharges, refer to Tables VII.1–VII.2.*

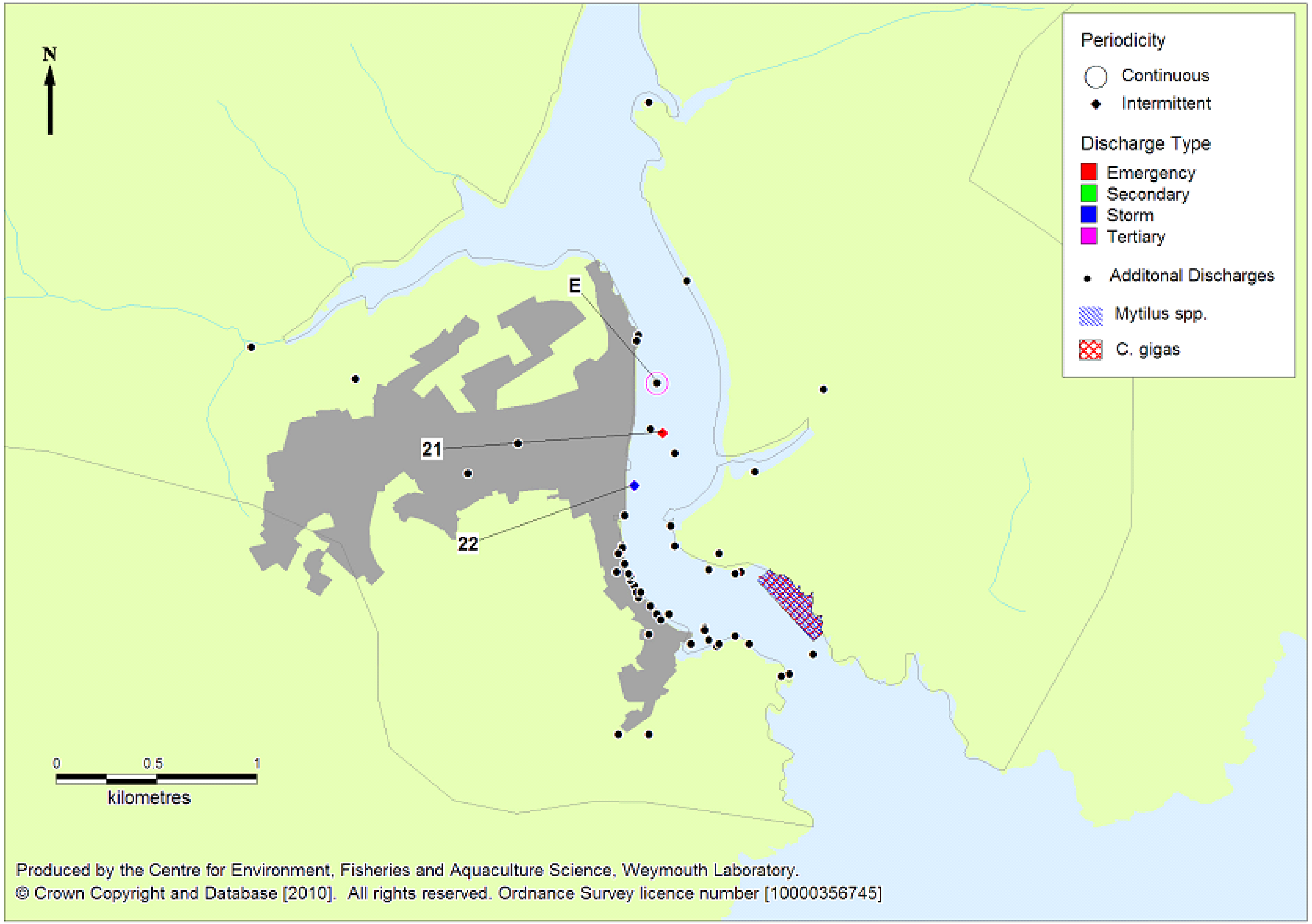

***Figure VII.3 Significant sewage discharges to the lower Dart Estuary.***
*For details on discharges, refer to Tables VII.1–VII.2.*

Many of the intermittent discharges to the Dart Estuary are designed to discharge less than 10 significant (>50m$^3$) storm spills per year on average, aggregated with other impacting CSOs, in order to meet water quality standards in the Shellfish Water (EA Shellfish Waters Policy: Standards for Consenting Discharges to Achieve the Requirements of the Shellfish Waters Directive (Microbial Quality) (Environment Agency, 2006).

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 bivalve mollusc beds (Younger *et al.*, 2003).

Table VII.3 indicates that the three six discharges recording the highest number of spill events and spill duration. In 2009, high number of spill events occurred from Dittisham STW. Totnes STW CSO has consistently shown the highest spill duration over the three-year period. Both discharges will represent a significant impact to shellfish beds within the Waddeton Fishery Order, in particular Dittisham STW.

**Table VII.3 Total number of sewage spill events and spill duration from six significant intermittent discharges for the period 2006–2009.**

| | Total spill events | | | Total duration (hours) | | |
|---|---|---|---|---|---|---|
| Discharge name | 06/07 | 07/08 | 08/09 | 06/07 | 07/08 | 08/09 |
| Dittisham STW | 75 | 12 | 60 | 639.82 | 10.16 | 185.02 |
| Totnes STW CSO | 62 | 61 | 54 | 1,440.53 | 423.34 | 411.70 |
| Higher Dittisham | 31 | 36 | 27 | 93.84 | 24.60 | 232.40 |
| Galmpton PSTN | 33 | 29 | 17 | 94.22 | 40.79 | 20.52 |
| Ferry Boat Inn | 70 | 68 | 13 | 283.52 | 146.99 | 4.15 |
| Stoke Gabriel PSTN | 19 | 16 | 7 | 303.43 | 55.24 | 20.40 |

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 x $10^1$, with occasional periods of low efficacy reaching 3.9 x $10^4$.

Table VII.4 presents summary statistics for levels of faecal coliforms monitored in the final UV-treated effluent from three sewage treatment works discharging to the Dart Estuary. Maximum levels indicate episodes of low efficiency in the three STW. The geometric means for effluent discharges from Dartmouth and Totnes correspond to typical values reported for UV-treated effluents (see Kay *et al*., 2007).

**Table VII.4 Summary statistics of presumptive levels of faecal coliforms in the final effluent post UV disinfection monitored in three sewage treatment works discharging to the Dart Estuary.**

| | | CFU faecal coliforms 100ml$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|
| Discharge name | Number of Samples | Minimum | Maximum | Median | Geometric mean | 95% CI for mean | |
| | | | | | | Lower | Higher |
| Dartmouth STW | 171 | 0 | 51,000 | 22 | 31 | -128.4 | 1,055.3 |
| Dittisham STW | 229 | 0 | 17,000,000 | 340 | 11,197 | 215,248 | 689,979 |
| Totnes STW | 138 | 0 | 11,000 | 55 | 77 | 302.1 | 799.2 |

*CI - Confidence interval.*
*STW - sewage treatment works.*
*CFU - colony forming units.*

Side-by-side box-and-whisker plots of faecal coliform data amalgamated by season (Figure VII.4) show deteriorated quality of the effluent discharge (as evidenced by the distribution of faecal coliform levels) from Dartmouth STW during summer and from Dittisham STW during the whole year. Figure VII.5 shows significant deterioration of the quality of effluent discharge from Dittisham STW between January 2007 and June 2009.

The 75th percentile for faecal coliform data from Dartmouth STW during spring, autumn and winter have been below typical levels in UV-treated effluents mentioned in the literature.

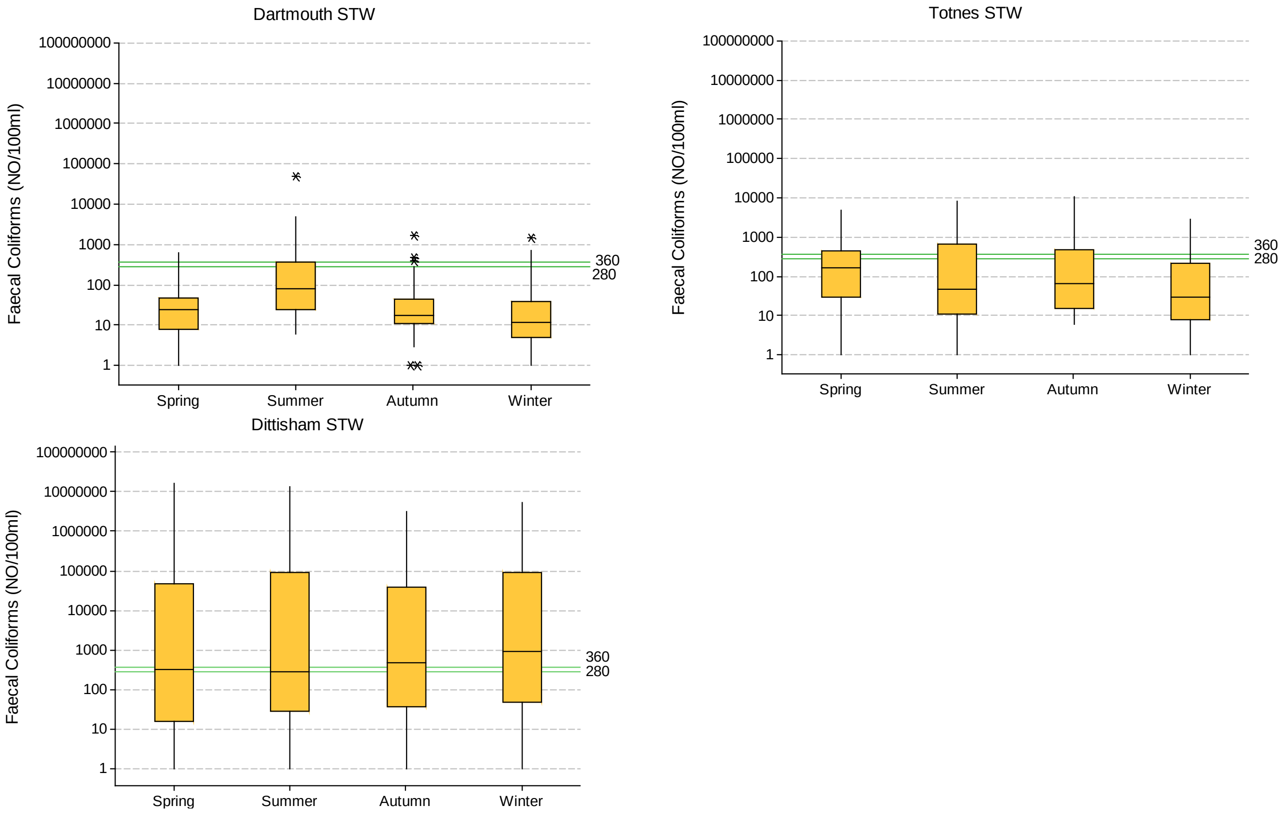

***Figure VII.4 Box-and-whisker plots of seasonal presumptive levels of faecal coliforms in the final effluent post UV disinfection monitored in three sewage treatment works discharging to the Dart Estuary.***

*N.B: Spring: March–May, Summer: June–August, Autumn: September–November, Winter: December–February*

*Monitoring periods:*

*Dartmouth (January 2003–December 2008, n=171)*

*Dittisham (January 2004–December 2008. n=229)*

*Totnes (January 2005–December 2008, n=138)*

*Reference lines corresponding to typical levels of faecal coliforms in UV-treated effluents under base-flow and high flow conditions as observed in a range of effluents by Kay* et al. *(2008).*

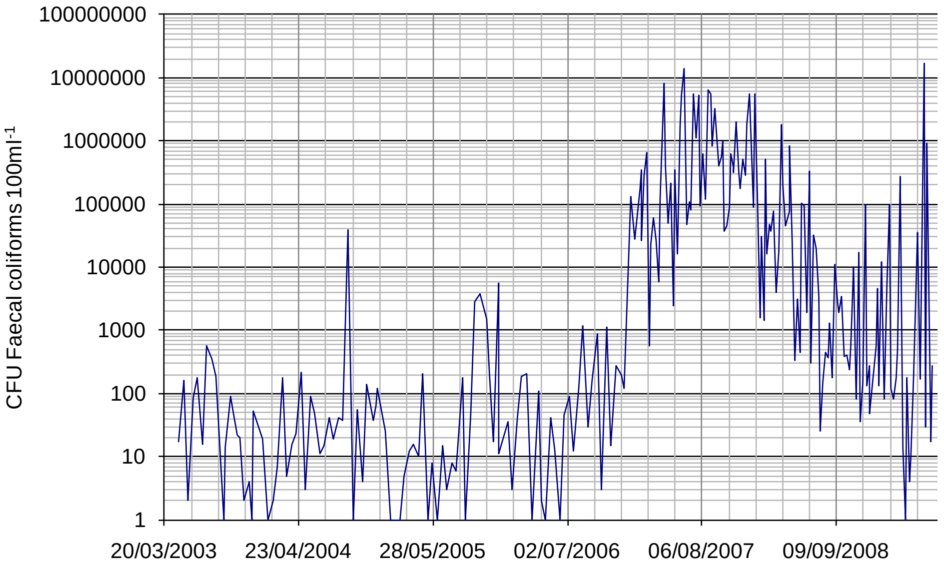

***Figure VII.5 Time series of presumptive levels of faecal coliforms in the final effluent from Dittisham STW (membrane bioreactor).***

## APPENDIX VIII
## SOURCES AND VARIATION OF MICROBIOLOGICAL POLLUTION: AGRICULTURE

Agriculture is one of the main activities in river catchments draining to the Dart Estuary, mainly cattle and sheep production and cereals. Approximately 45% of the cereal crop grown in the catchment is summer barley (Devon Wildlife Trust, 2004).

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 VIII.1).

***Figure VIII.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.*

There are over 163,600 farmed animals in these catchments (Table VIII.1). Approximately 56% of livestock are cattle and sheep, which predominate in the upper Dart catchment; poultry predominate in lowland areas (Figure VIII.2).

***Table VIII.1 Numbers of farmed animals in catchments draining to the Dart Estuary.***

| Subcatchment | Cattle | Pigs | Sheep | Poultry |
|---|---|---|---|---|
| Dart (upper) | 18,053 | 510 | 39,759 | 29,615 |
| Dart (tidal) | 12,937 | 3,695 | 33,334 | 25,790 |
| Total | 30,990 | 4,205 | 73,093 | 55,405 |

*Data from Defra June 2008 Agricultural Census.*

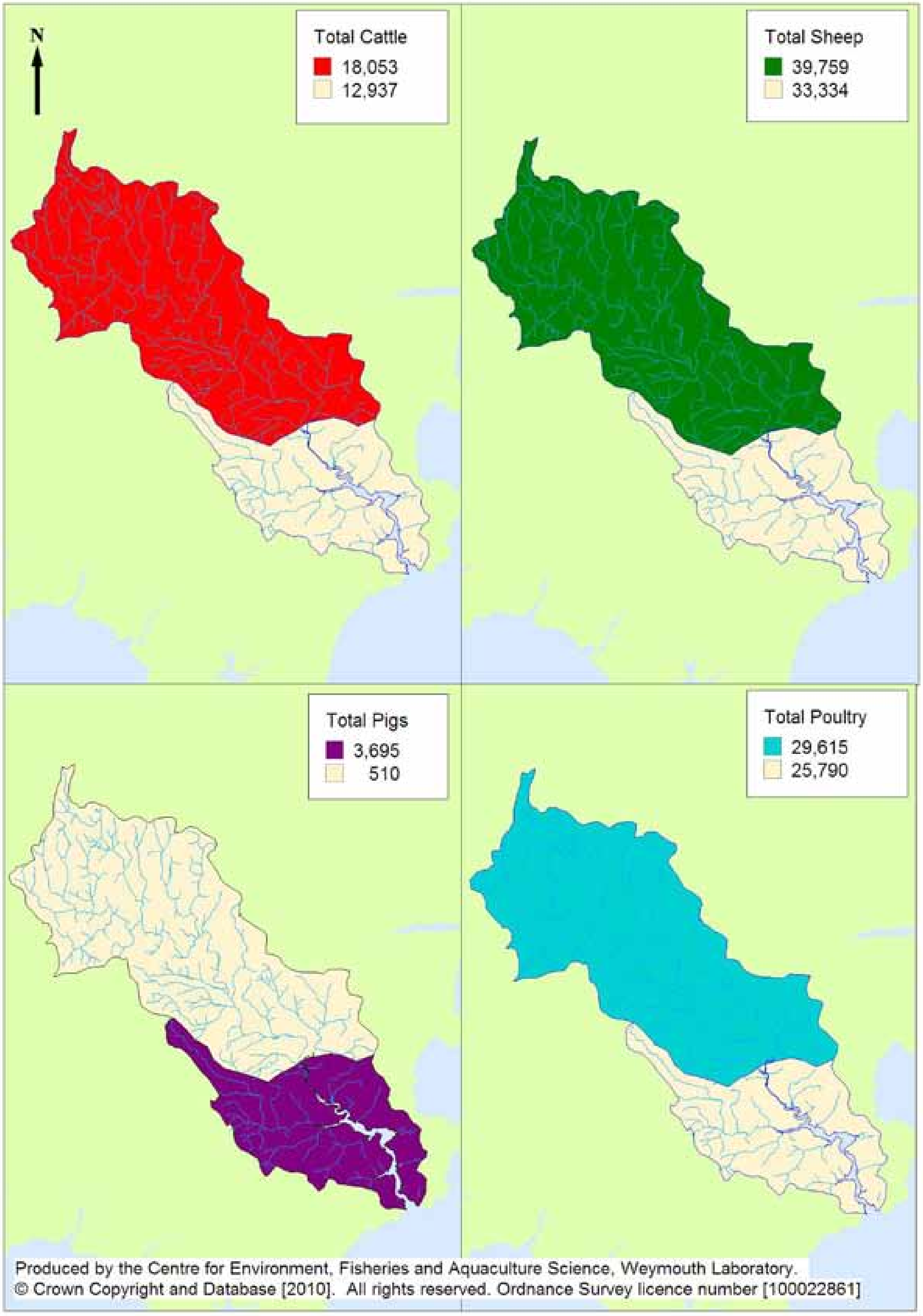

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***Figure VIII.2 Numbers of farmed animals in the Dart river catchments.***
*Based on livestock numbers supplied by Defra, Farming Statistics.*

Livestock densities in the Dart (tidal) catchment are approximately 103 (animals per km$^2$) for cows, 10 for pigs and 261 for sheep. This compares to densities of

63 for cows, 4 for pigs and 140 for sheep in the Dart catchment (Devon Wildlife Trust, 2007).

Farmyards can significantly contribute to loads of faecal indicator microorganisms to watercourses or coastal waters when they have a ready and renewable source of faecal material, a direct hydrological connection with open water channels exists and a sufficient proportion of livestock farms are present in the catchment (Edwards *et al*., 2008).

The concentration of faecal coliforms excreted in the faeces of these animal species and humans and corresponding daily loads are summarised in Table VIII.2.

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

| Farm Animal | Faecal coliforms (No. $g^{-1}$ wet weight) | Excretion rate (g $day^{-1}$ wet weight) | Faecal coliform load (No. $day^{-1}$) |
|---|---|---|---|
| Chicken | 1,300,000 | 182 | $2.3 \times 10^{8}$ |
| Cow | 230,000 | 23,600 | $5.4 \times 10^{9}$ |
| Pig | 3,300,000 | 84,000,000 | $8.9 \times 10^{8}$ |
| Sheep | 16,000,000 | 38,000,000 | $1.8 \times 10^{10}$ |
| Human | 13,000,000 | 3,000,000 | $1.9 \times 10^{9}$ |

*Data from Geldreich (1978) and Ashbold* et al*. (2001).*

As part of the Cycleau Project, an integrated database assisted by Geographic Information System was developed to assess the risk of diffuse pollution across the Dart catchment. The output was a diffuse pollution risk map based on Agricultural Census data, catchment slope, soil characteristics and rainfall variation across the catchment (see McGonigle, 2006, 2006a). Results indicated that the intensively farmed subcatchments in the south of the Dart (tidal) catchment would be at high or very high risk of diffuse pollution, in particular areas of the catchment drained by the rivers Harbourne and Wash (Figure VIII.3).

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

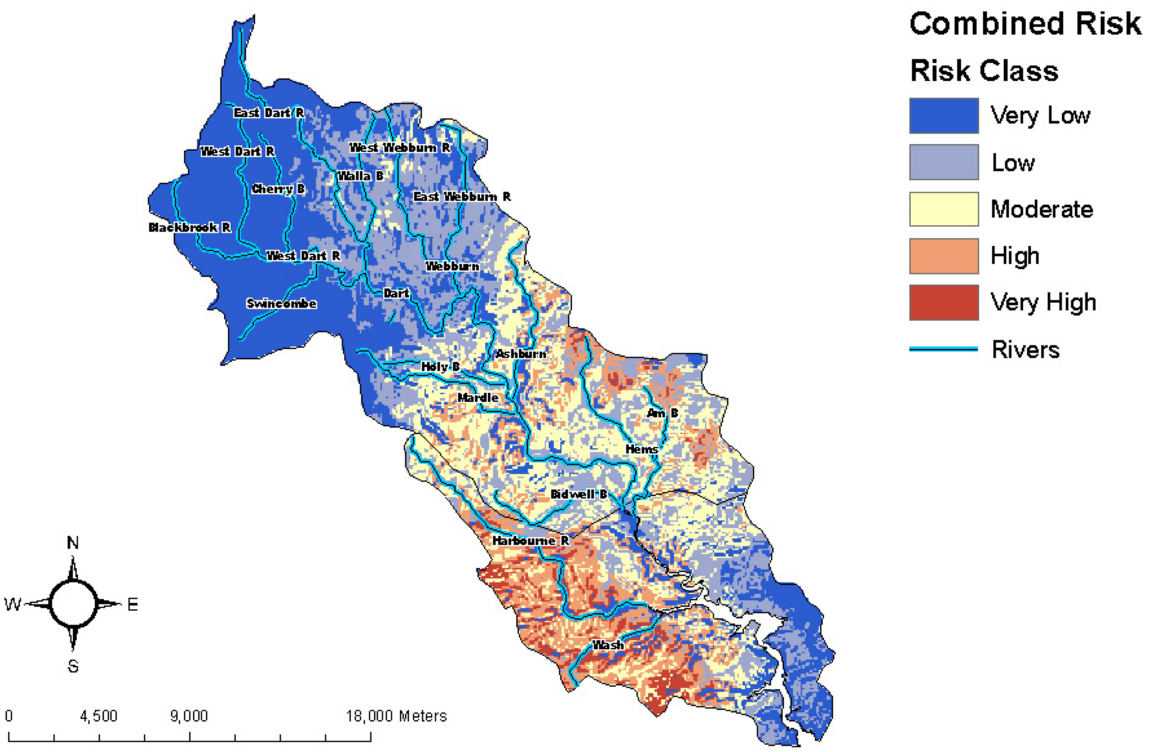
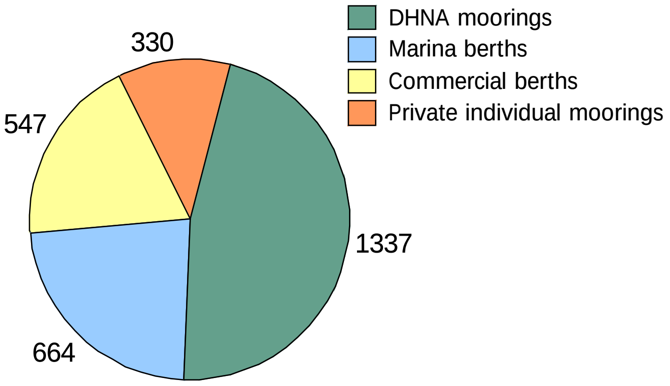


***Figure VIII.3 Potential diffuse pollution risk map in the Dart catchment.***
*Republished with permission by Daniel McGonigle.*

## APPENDIX IX
## SOURCES OF MICROBIOLOGICAL POLLUTION: BOATS

The Dart Estuary has received more than 12,000 yachts per year, in particular during the peak season of July–August (R. Humphreys, pers. comm.). The Port of Dartmouth Royal Regatta takes place annually over three days at the end of August. Most of these yachts are accommodated in the Dart Marina, Darthaven Marina and Noss Marina.

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 A9.1).



Private: include 210 running moorings.

***Figure IX.1 Types of moorings in the Dart Estuary.***
*Data from Humphreys (2006).*

Moorings are established in various 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 IX.2).

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. comm.).

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

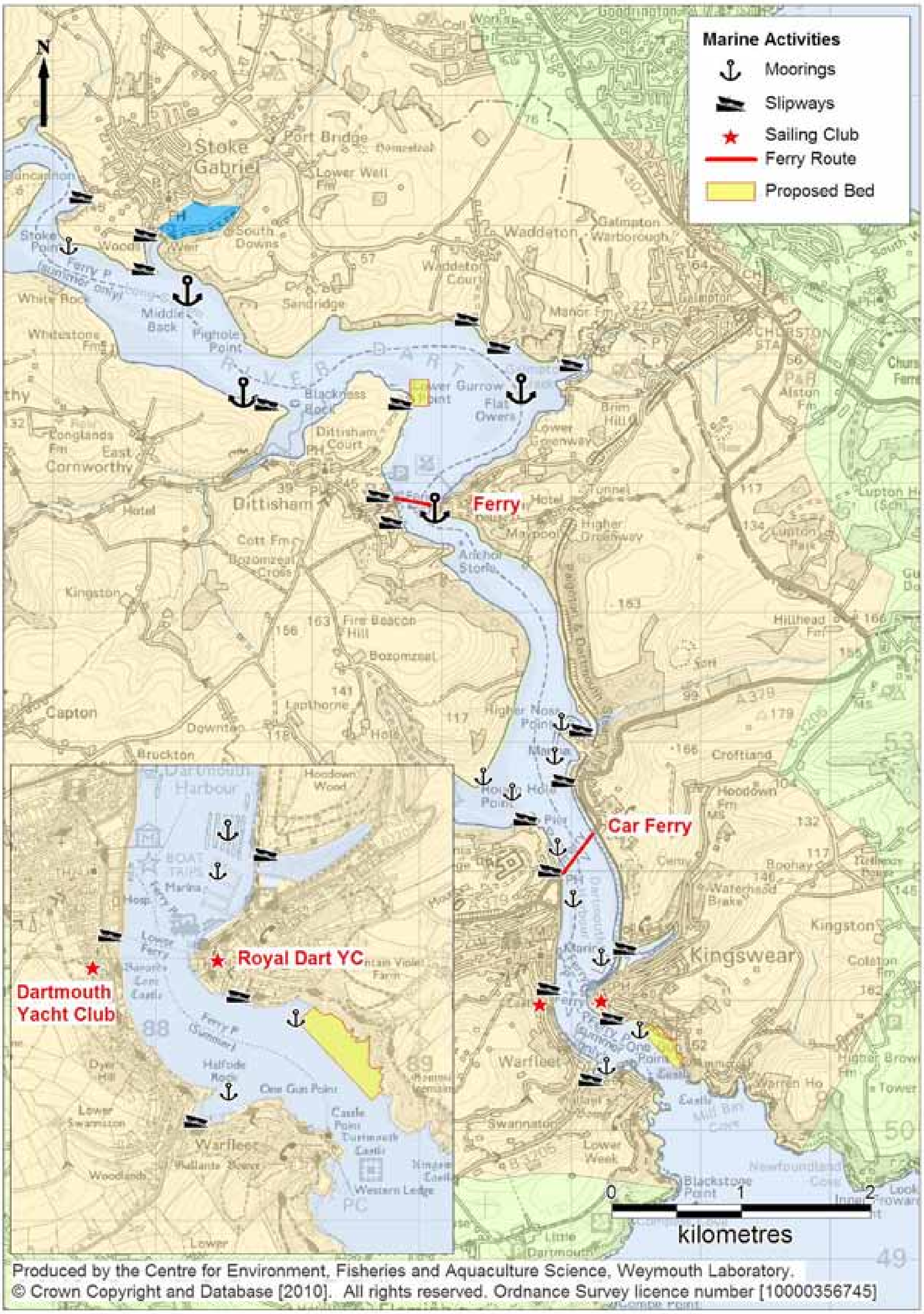


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***Figure IX.2 Location of moorings in the Dart Estuary.***

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).

Historical data from the Shellfish Waters monitoring programme do not show significant increases in the levels of faecal coliforms in water during summer months. The intermittent discharge of small quantities of raw sewage from moored boats at Blackness Point, Vipers Quay and Dittisham are however likely to have a higher impact on bivalve mollusc beds at Blackness Point and Flat Owers.

There are no pump-out facilities for vessels visiting the estuary. 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).

An assessment of the potential impact of sewage discharges from boats and marinas on the microbiological status of bivalve mollusc beds requires detailed quantitative information on boat movements, occupancy rates and seasonality and accurate knowledge on dilution of contaminants in receiving waters. The high numbers of moorings in parts of the lower estuary suggest that boats can be considered a locally significant source of contamination in the estuary. Bivalves commercially harvested at Higher Gurrow Point, Flat Owers are in the vicinity of areas extensively occupied by mooring areas and Kingswear and are likely to be impacted by waste discharges from boats. Overall, it can be assumed that summer is the season of highest risk of contamination.

# APPENDIX X
## MICROBIOLOGICAL DATA: WATER

### BATHING WATERS

There are two bathing waters designated under the Directive 76/160/EEC (European Communities, 2006)[13]: Blackpool Sands (designated in 1988) and Dartmouth Castle and Sugary Cove (designated in 2006) (Figure X.1). These are 4km and 750m from the nearest bivalve mollusc production area (Kingswear), respectively.

Both bathing waters have complied with the microbiological standards and achieved overall classifications of “excellent”.

The overall quality of these Bathing Waters is summarised in Table X.1.

***Table XI.1 Overall quality of Blackpool Sands and Dartmouth Castle and Sugary Cove Bathing Waters for the period 2004−2008.***

| Compliance | Bathing Water | Bathing season | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Excellent (Guideline Pass) | Blackpool Sands | √ | √ | √ | √ | √ | √ |
| | Dartmouth Castle and Sugary Cove | | | √ | √ | √ | √ |
| Good (Mandatory Pass) | Blackpool Sands | | | | | | |
| | Dartmouth Castle and Sugary Cove | | | | | | |
| Poor (Mandatory Fail) | Blackpool Sands | | | | | | |
| | Dartmouth Castle and Sugary Cove | | | | | | |

*Data from the Environment Agency.*
*NB. The descriptions in this table are based on compliance monitoring and assessment against the current Bathing Water Directive. This will be replaced by assessment against the Directive in 2014.*

Under the revised BW Directive, both BWs would meet an overall “excellent” classification status (Environment Agency, 2009).

---

[13] 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 (2,000 faecal coliforms 100ml$^{-1}$) and the Guideline (G) value (100 faecal coliforms 100ml$^{-1}$) 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 faecal streptococci standards.

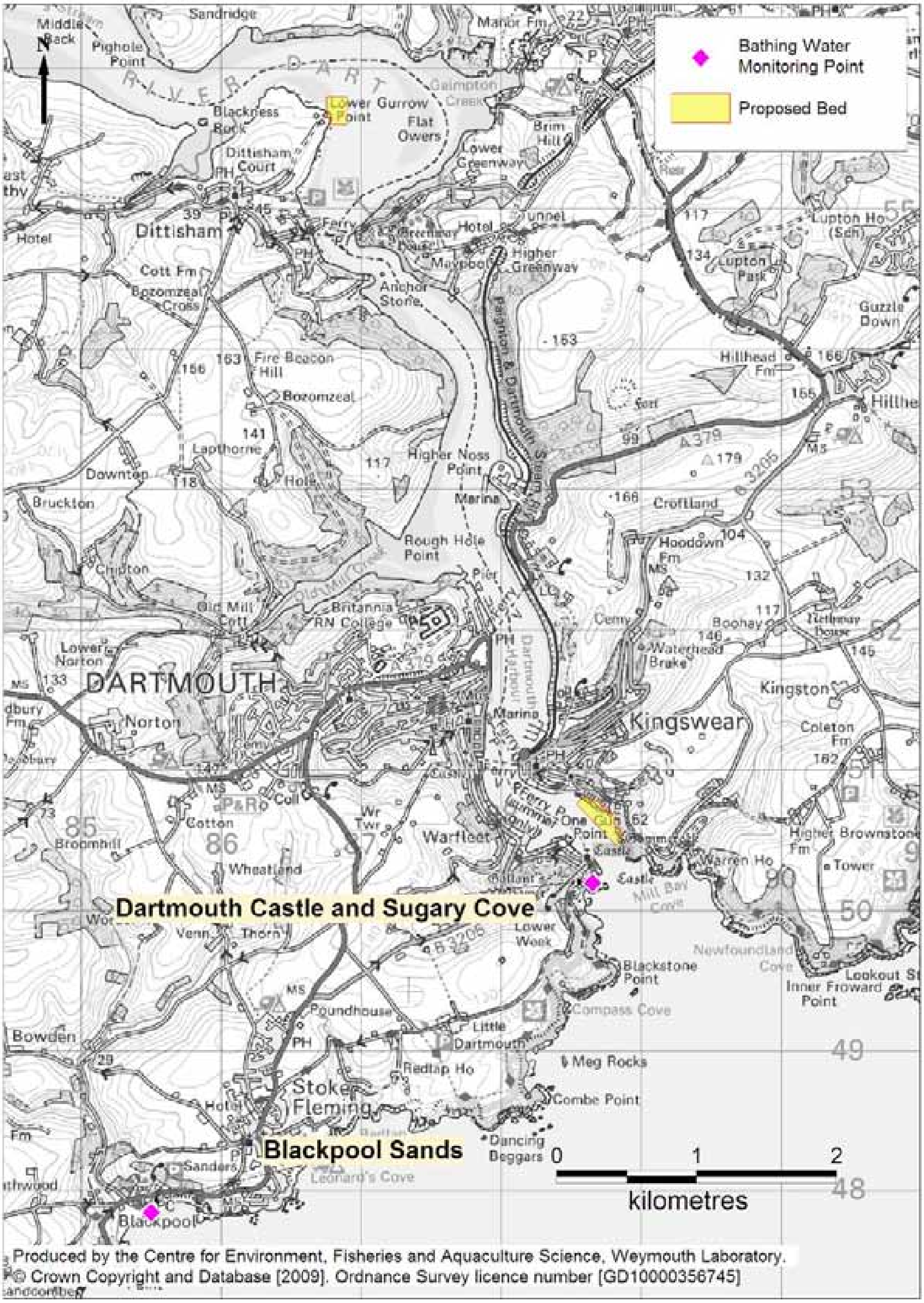

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***Figure X.1 Location of designated bathing waters in the vicinity of the Dart Estuary.***

Table XI.3 shows summary statistics during the bathing seasons 2004–2009. Levels of faecal coliforms in surface waters have been higher at Dartmouth Castle than those at Blackpool Sands.

Unusual high levels of faecal coliforms were detected in water sampled from both bathing waters (Figure X.2). In general, very low levels of surface water contamination with faecal coliforms were detected during the monitoring period. Levels of faecal streptococci were also very low during most of the monitoring period and followed the pattern found in faecal coliforms (data not shown).

***Table XI.3 Summary statistics of faecal coliforms in two designated bathing waters in the Dart Estuary for the period 2006–2009.***

| | Range (Min.–Max.) (number of samples) | | Geometric mean | | Median | |
|---|---|---|---|---|---|---|
| Year | Blackpool Sands | Dartmouth Castle | Blackpool Sands | Dartmouth Castle | Blackpool Sands | Dartmouth Castle |
| 2006 | <2–77 (20) | <2–1,480 (20) | 3 | 17 | 2 | 15 |
| 2007 | <2–2,000 (20) | <2–640 (20) | 5 | 17 | 3 | 15 |
| 2008 | <2–231 (20) | <2-840(20) | 4 | 8 | 2 | 8 |
| 2009 | <2-9(20) | <2-231(20) | 2 | 7 | 1 | 6 |
| 2004–2009 | <2–2,000 (80) | <2–1,480 (40) | 3 | 11 | 2 | 11 |

*Data provided by the Environment Agency.*

The similar sizes of top and bottom halves and similar lengths of whiskers[14] for levels of faecal coliforms in water from Dartmouth Castle and Sugary Cove indicate similar variation in the levels of contamination in this bathing water (Figure X.2).

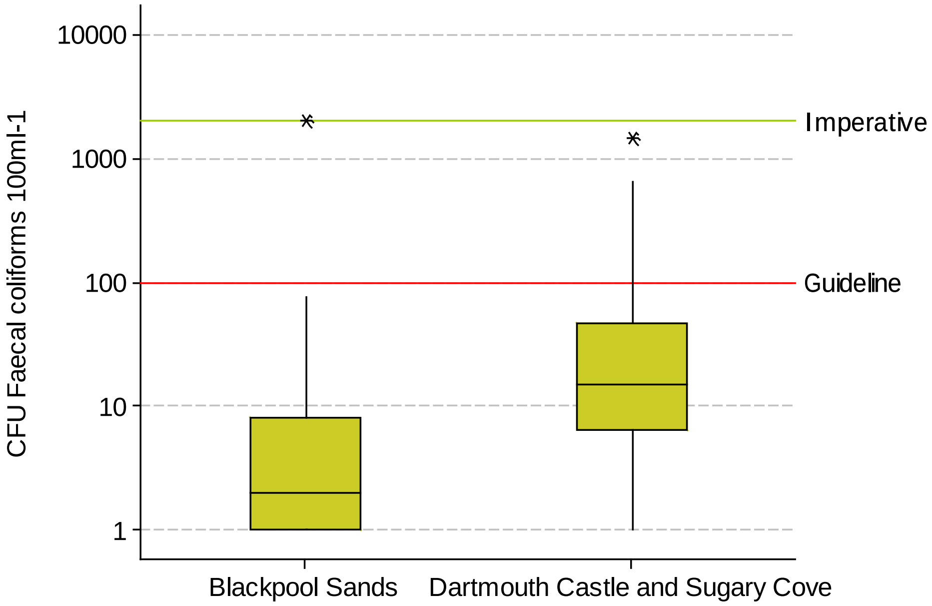

***Figure X.2 Box-and-whisker plots of levels of faecal coliforms in two designated bathing waters in the mouth of the Dart Estuary for the period 2006–2009.***

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[14] 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).

## 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 X.3).

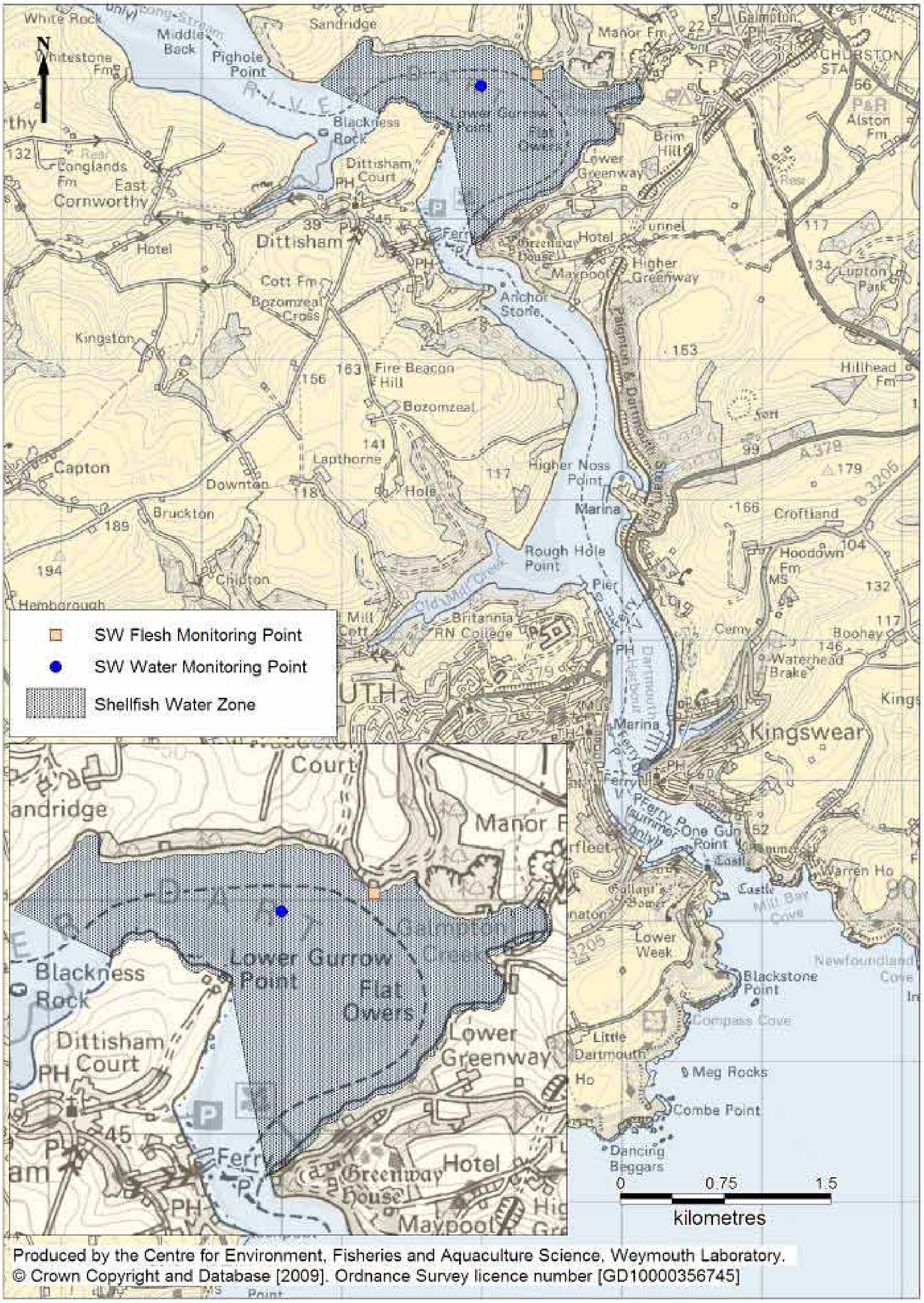

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*Figure A12.3 Location of the designated shellfish water in the Dart Estuary.*

Table XI.4 shows summary statistics for levels of faecal coliforms in surface waters during the period January 2002–November 2008.

***Table A12.2 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 |
| 2008 | 4 | <10–231 | 36 | 48 |
| 2002–2008 | 41 | <10–5,000 | 116 | 101 |

*Data provided by the Environment Agency.*

Sampling effort has decreased substantially in recent years. The geometric mean and median of faecal coliforms decreased significantly in 2008 relative to the previous two years. This might be the result of better water quality in the estuary following the upgrades in STW.

## APPENDIX XI
## MICROBIOLOGICAL DATA: SHELLFISH FLESH

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. Analyses of historical microbiological data are therefore only relevant and confined to the period following these improvements.

Table A13.1 summarises the results in terms of sampling effort, geometric mean, median and range of *E. coli* levels in bivalves 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, i.e. 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, i.e. 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).

Table XI.1 suggests the following relationships in the levels of contamination between beds:

§ Flat Owers≈Sandridge Boathouse≈Waddeton (Pacific oysters);
§ Flat Owers>Sandridge Boathouse>Waddeton (mussels).

It should be noted that these relationships are merely indicative of the overall microbial quality of bivalves at these sites.

One result above the class C threshold (MPN≤46,000 *E. coli* 100g$^{-1}$ FIL) indicates that this site is vulnerable to episodes of deteriorated microbial quality.

***Table XI.1 Summary statistics of* E. coli *levels in bivalve molluscs from six RMPs in the Dart Estuary for the period 2004–2008.***

| | | | | | | MPN *E. coli* 100g$^{-1}$ FIL | | | |
|---|---|---|---|---|---|---|---|---|---|
| RMP | Bed name | Species | n | Date of first sample | Date of last sample | 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 distribution of levels of *E. coli* in bivalves is represented in the box-and-whisker plots shown in Figure XI.1.

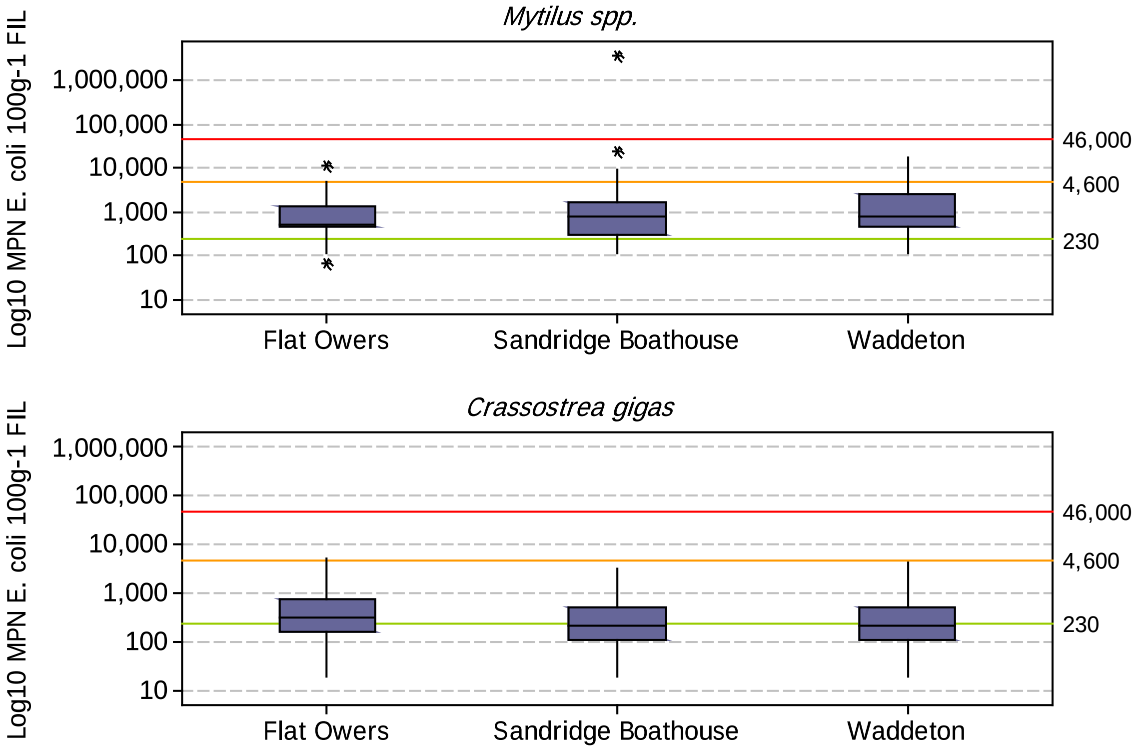

***Figure XI.1 Box-and-whisker plots of levels of* E. coli *in bivalve molluscs from three beds in the Dart Estuary for the period 2005–2007.***

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 XI.1 also shows that *E. coli* levels in Pacific oysters tend to be more symmetric, i.e. 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 may correspond to intermittent episodes of contamination, many of these 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 XI.2–XI.3).

*Crassostrea gigas*

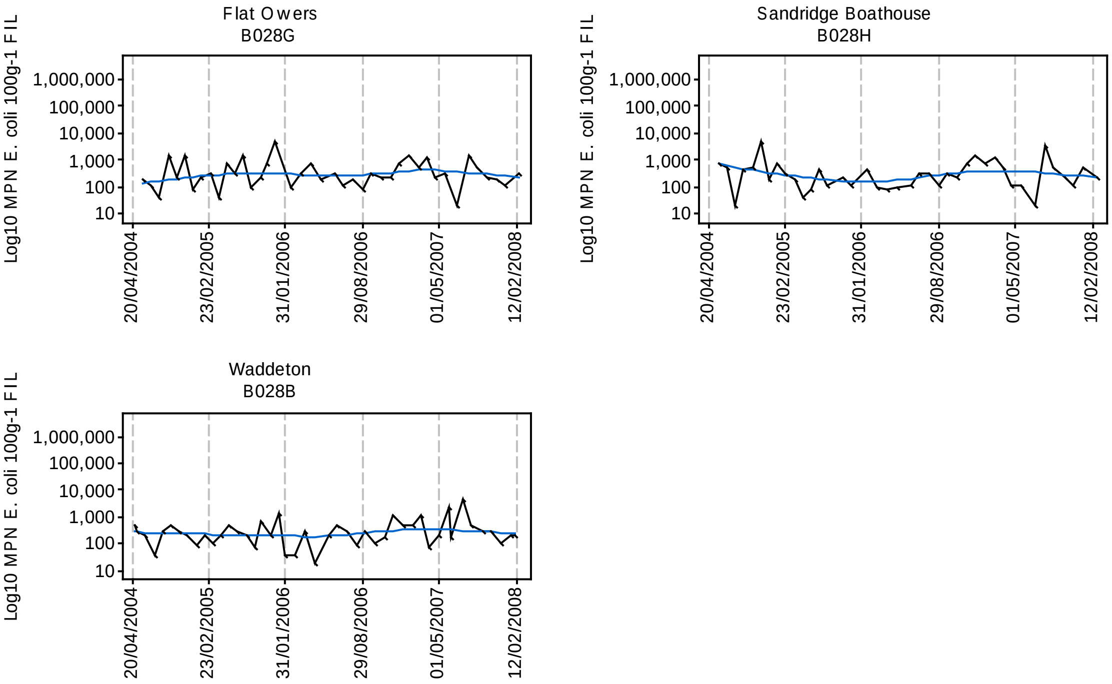

***Figure XI.2 Locally weighted scatterplot smoothing of monthly variation in the levels of* E. coli *in Pacific oysters from three RMPs in the Dart Estuary for the period 2004–2008.***

*Mytilus spp.*

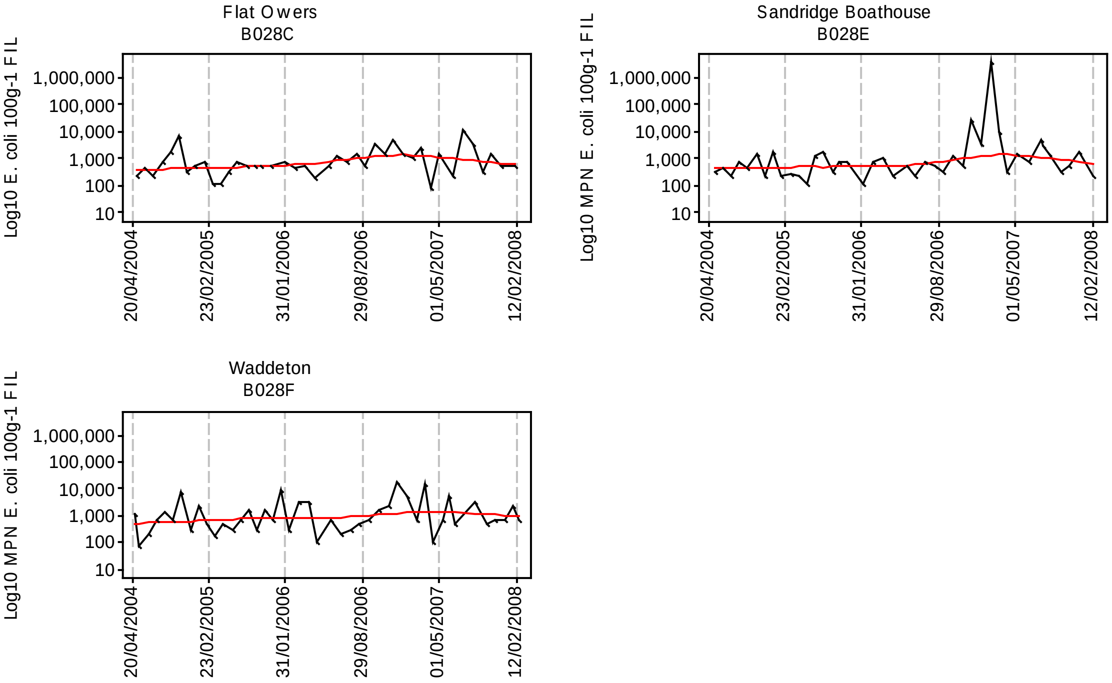

***Figure XI.3 Locally weighted scatterplot smoothing of monthly variation in the levels of* E. coli *in mussels from three RMPs in the Dart Estuary for the period 2004–2008.***

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 1.

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

### SEASONAL VARIATION OF *ESCHERICHIA COLI*

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[15]. 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 A6.1). 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 XI.4–XI.5). 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,

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[15] 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).

therefore, February should be considered the month when higher levels of contamination are detected in this shellfish bed.

*Mytilus spp.*

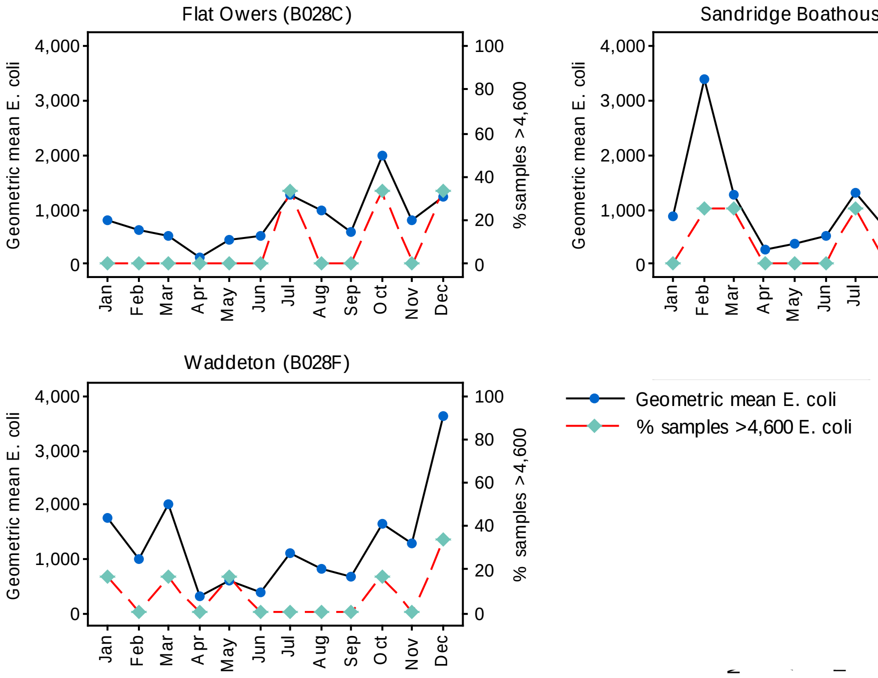

***Figure XI.4 Monthly variation of geometric means and number of results of*** **E. coli** ***higher than 4,600 in mussels from three RMPs in the Dart Estuary for the period 2004–2008.***

*Crassostrea gigas*

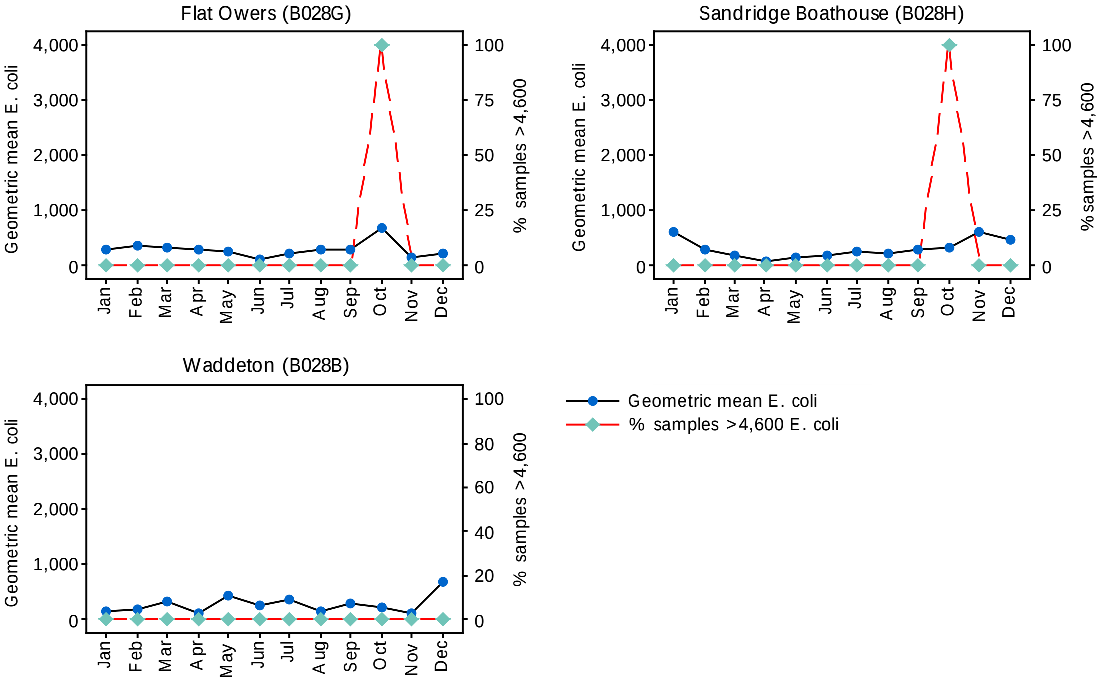

***Figure XI.5 Monthly variation of geometric means and number of results of*** **E. coli** ***higher than 4,600 in Pacific oysters from three RMPs in the Dart Estuary for the period 2004–2008.***

*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 XI.6). However, these corresponded to less than 1 $\text{Log}_{10}$ 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 XI.7).

*Mytilus spp.*

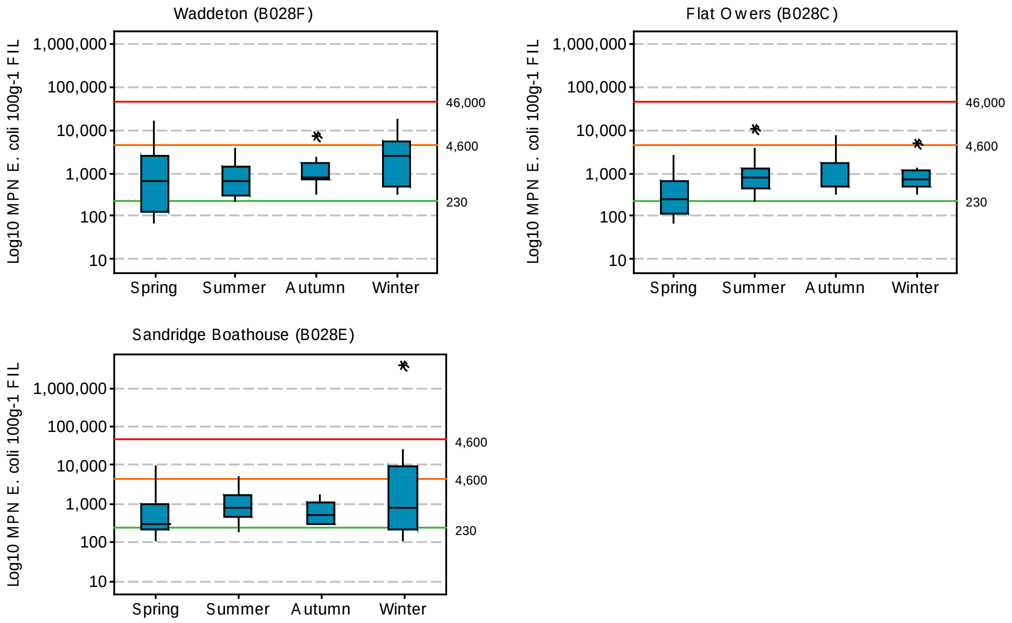

**Figure XI.6 Box-and-whisker plots of seasonal variation of** E. coli **levels in mussels from three RMPs in the Dart Estuary for the period 2004–2008.**

*C. gigas*

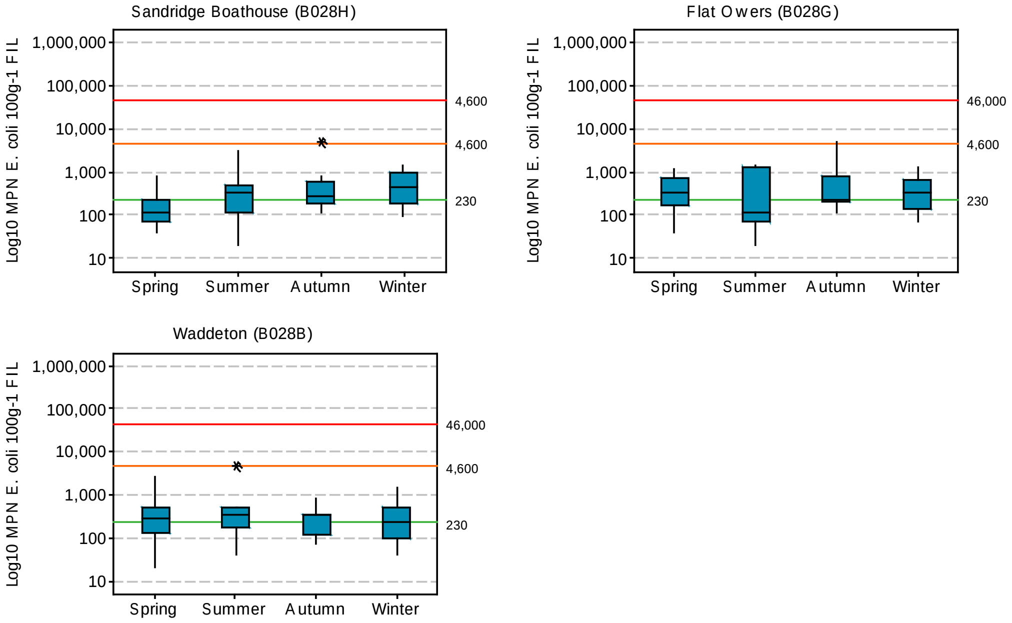

**Figure XI.7 Box-and-whisker plots of seasonal variation of** E. coli **levels in Pacific oysters from three RMPs in the Dart Estuary for the period 2004–2008.**

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. comm.). 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. This indicates that sampling frequency should be at least monthly if the classification status of mussels is to be maintained at Flat Owers.

### VARIATION OF *E. COLI* ACCORDING TO RAINFALL

Rainfall data from Dittisham Dinah's rain-gauge station 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. Spearman's *rho* was used to estimate correlations between MPN *E. coli* 100 $g^{-1}$ FIL and daily and total rainfall up to seven days before sampling.

Statistically significant positive relationships were found between total rainfall and *E. coli* levels in bivalves from all RMPs (Table XI.2). Figure XI.8 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. Higher correlation coefficients were found between daily rainfall and *E. coli* in mussels from Sandridge Boathouse. 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 4th to 6th 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 2nd to 7th 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 XI.8). 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.

***Table XI.2 Spearman's rho coefficients between rainfall (mm) recorded at Buckfastleigh, Halwell and Dittisham rainfall gauging stations 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 | | Sandridge Boathouse (B028H) (*C. gigas*) | Sandridge Boathouse (B028E) (*Mytilus* spp.) | Waddeton (B028B) (*C. gigas*) | Waddeton (B028F) (*Mytilus* spp.) | Flat Owers (B028G) (*C. gigas*) | Flat Owers (B028C) (*Mytilus* spp.) |
|---|---|---|---|---|---|---|---|
| Buckfastleigh STW | Time | (n=71) | (n=69) | (n=77) | (n=69) | (n=66) | (n=71) |
| Daily | Day of sampling | 0.088 | 0.230 | 0.296* | 0.251 | 0.128 | 0.189 |
| | -1 day | 0.181 | 0.408* | 0.401* | 0.380* | 0.344* | 0.227 |
| | -2 days | 0.322* | 0.510* | 0.407* | 0.382* | 0.373* | 0.413* |
| | -3 days | 0.510* | 0.666* | 0.598* | 0.588* | 0.643* | 0.593* |
| | -4 days | 0.342* | 0.584* | 0.333* | 0.466* | 0.451* | 0.375* |
| | -5 days | 0.206 | 0.477* | 0.279* | 0.387* | 0.463* | 0.335* |
| | -6 days | 0.126 | 0.355* | 0.269* | 0.434* | 0.407* | 0.260* |
| | -7 days | 0.079 | 0.274* | 0.124 | 0.183 | 0.327* | 0.107 |
| Cumulative | -2 days | 0.194 | 0.374* | 0.429* | 0.348* | 0.283* | 0.266* |
| | -3 days | 0.260* | 0.461* | 0.478* | 0.407* | 0.386* | 0.342* |
| | -4 days | 0.370* | 0.577* | 0.561* | 0.551* | 0.513* | 0.488* |
| | -5 days | 0.434* | 0.652* | 0.542* | 0.585* | 0.524* | 0.528* |
| | -6 days | 0.439* | 0.690* | 0.571* | 0.613* | 0.584* | 0.525* |
| | -7 days | 0.448* | 0.707* | 0.552* | 0.624* | 0.596* | 0.543* |
| Halwell, Middlebarn | | (n=62) | (n=60) | (n=67) | (n=54) | (n=53) | (n=54) |
| Daily | Day of sampling | -0.029 | 0.196 | 0.184 | 0.168 | 0.104 | 0.174 |
| | -1 day | 0.200 | 0.314* | 0.392* | 0.191 | 0.333* | 0.147 |
| | -2 days | 0.332* | 0.486* | 0.472* | 0.310* | 0.190 | 0.406* |
| | -3 days | 0.406* | 0.620* | 0.550* | 0.473* | 0.555* | 0.464* |
| | -4 days | 0.299* | 0.578* | 0.258* | 0.310* | 0.319* | 0.346* |
| | -5 days | 0.096 | 0.398* | 0.251* | 0.380* | 0.340* | 0.282* |
| | -6 days | 0.025 | 0.371* | 0.193 | 0.379* | 0.424* | 0.175 |
| | -7 days | -0.036 | 0.216 | 0.140 | 0.181 | 0.227 | 0.065 |
| Cumulative | -2 days | 0.102 | 0.339* | 0.331* | 0.260 | 0.276* | 0.211 |
| | -3 days | 0.178 | 0.411* | 0.402* | 0.315* | 0.270 | 0.289* |
| | -4 days | 0.270* | 0.521* | 0.486* | 0.438* | 0.423* | 0.412* |
| | -5 days | 0.340* | 0.633* | 0.467* | 0.471* | 0.406* | 0.444* |
| | -6 days | 0.355* | 0.668* | 0.496* | 0.510* | 0.474* | 0.445* |
| | -7 days | 0.368* | 0.697* | 0.497* | 0.545* | 0.526* | 0.460* |
| Dittisham | | (n=68) | (n=70) | (n=72) | (n=70) | (n=67) | (n=66) |
| Daily | Day of sampling | 0.154 | 0.227 | 0.245* | 0.160 | 0.096 | 0.181 |
| | -1 day | 0.242* | 0.387* | 0.351* | 0.286* | 0.304* | 0.121 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | -2 days | 0.344* | 0.426* | 0.407* | 0.370* | 0.295* | 0.368* |
| | -3 days | 0.526* | 0.642* | 0.596* | 0.636* | 0.583* | 0.492* |
| | -4 days | 0.432* | 0.562* | 0.336* | 0.427* | 0.437* | 0.480* |
| | -5 days | 0.240* | 0.474* | 0.172 | 0.382* | 0.395* | 0.268* |
| | -6 days | 0.157 | 0.398* | 0.279* | 0.479* | 0.432* | 0.312* |
| | -7 days | 0.098 | 0.344* | 0.171 | 0.289* | 0.366* | 0.190 |
| Cumulative | -2 days | 0.170 | 0.345* | 0.305* | 0.272* | 0.229 | 0.190 |
| | -3 days | 0.281* | 0.457* | 0.400* | 0.390* | 0.313* | 0.315* |
| | -4 days | 0.392* | 0.577* | 0.530* | 0.545* | 0.469* | 0.454* |
| | -5 days | 0.478* | 0.662* | 0.507* | 0.574* | 0.489* | 0.517* |
| | -6 days | 0.512* | 0.706* | 0.517* | 0.616* | 0.566* | 0.544* |
| | -7 days | 0.519* | 0.730* | 0.525* | 0.650* | 0.609* | 0.565* |

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.

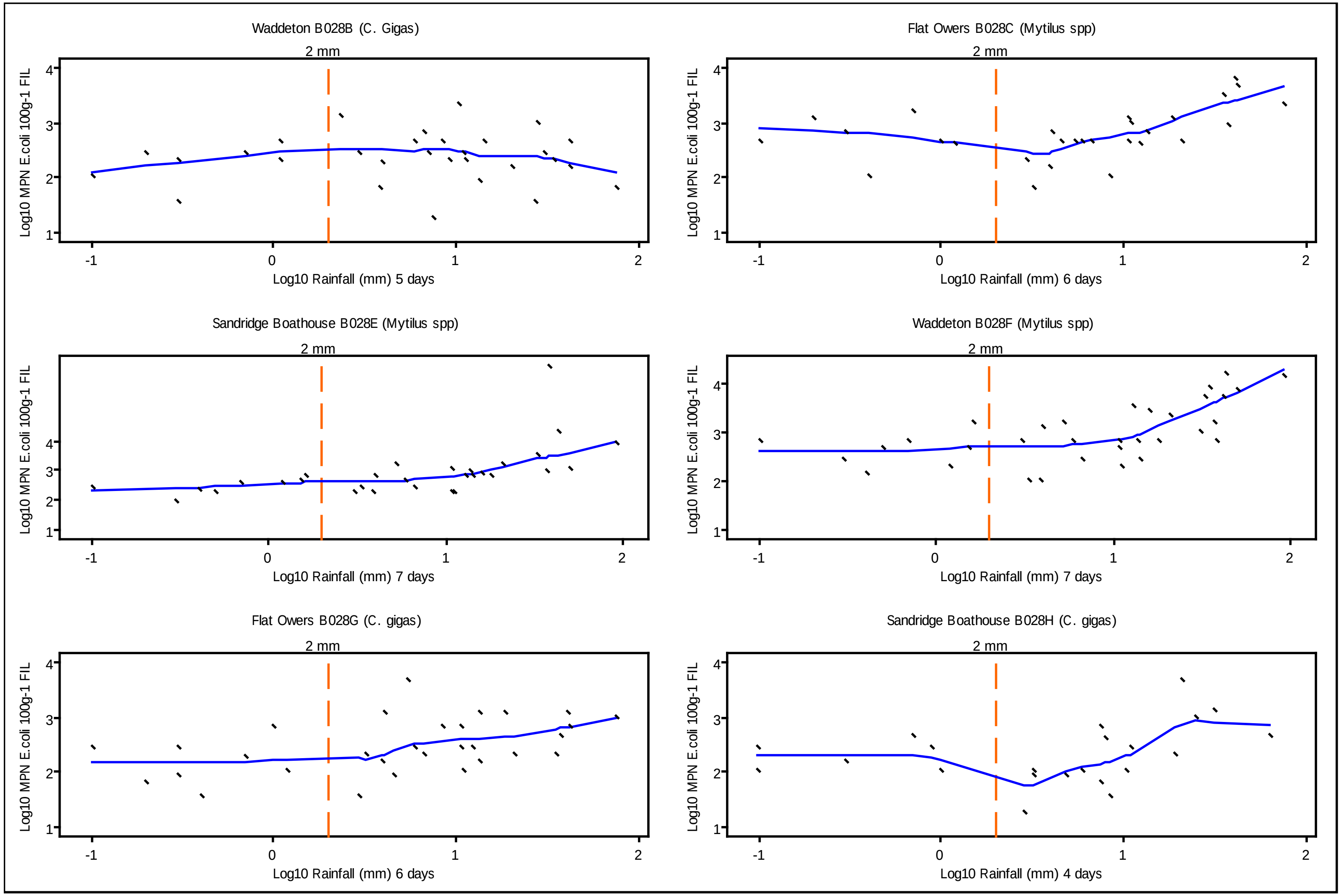

***Figure XI.8 Locally weighted scatterplot smoothing of rainfall (mm) recorded at Dittisham rain-gauge station and MPNs of*** **E. coli** ***100g$^{-1}$ FIL in bivalves from six monitoring points in the Dart Estuary.***

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

### VARIATION IN *E. COLI* ACCORDING TO RIVER FLOW

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. Spearman's *rho* was used to estimate correlations between MPN *E. coli* 100g$^{-1}$ FIL and daily and total river flows.

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 XI.3). 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 XI.3).

The upward trend of LOWESS lines evidences the positive association between river flows and *E. coli* levels in bivalves (Figure XI.9).

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 XI.9). 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.

***Table XI.3 Spearman's rank correlation coefficients between river flow (m$^3$ s$^{-1}$) in the Dart recorded at Bellever andAustins Bridge 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.***

| River flow | | MPN *E. coli* 100g$^{-1}$ FIL | | | | | |
|---|---|---|---|---|---|---|---|
| | | Sandridge Boathouse (B028H) (*C. gigas*) | Sandridge Boathouse (B028E) (*Mytilus* spp.) | Waddeton (B028B) (*C. gigas*) | Waddeton (B028F) (*Mytilus* spp.) | Flat Owers (B028G) (*C. gigas*) | Flat Owers (B028C) (*Mytilus* spp.) |
| Bellever | Time | | | | | | |
| Daily | Day of sampling | 0.345** | 0.489** | 0.437** | 0.540** | 0.425** | 0.321** |
| | -1 day | 0.429** | 0.520** | 0.477** | 0.598** | 0.488** | 0.460** |
| | -2 days | 0.407** | 0.499** | 0.431** | 0.573** | 0.520** | 0.425** |
| | -3 days | 0.373** | 0.521** | 0.443** | 0.564** | 0.521** | 0.396** |
| | -4 days | 0.314** | 0.456** | 0.349** | 0.511** | 0.478** | 0.377** |
| | -5 days | 0.265* | 0.417** | 0.286** | 0.520** | 0.416** | 0.300** |
| | -6 days | 0.172 | 0.336** | 0.205* | 0.397** | 0.418** | 0.234* |
| | -7 days | 0.196 | 0.348** | 0.206* | 0.360** | 0.390** | 0.192 |
| Cumulative | -2 days | 0.404** | 0.528** | 0.473** | 0.571** | 0.456** | 0.378** |
| | -3 days | 0.421** | 0.549** | 0.501** | 0.608** | 0.496** | 0.414** |
| | -4 days | 0.415** | 0.556** | 0.493** | 0.612** | 0.526** | 0.432** |
| | -5 days | 0.405** | 0.557** | 0.476** | 0.611** | 0.522** | 0.419** |
| | -6 days | 0.403** | 0.552** | 0.478** | 0.619** | 0.523** | 0.424** |
| | -7 days | 0.375** | 0.547** | 0.462** | 0.612** | 0.527** | 0.417** |
| Austins Bridge | | | | | | | |
| Daily | Day of sampling | 0.429** | 0.494** | 0.425** | 0.573** | 0.435** | 0.400** |
| | -1 day | 0.456** | 0.488** | 0.419** | 0.565** | 0.446** | 0.449** |
| | -2 days | 0.432** | 0.480** | 0.380** | 0.545** | 0.495** | 0.437** |
| | -3 days | 0.405** | 0.470** | 0.379** | 0.545** | 0.482** | 0.418** |
| | -4 days | 0.372** | 0.456** | 0.316** | 0.498** | 0.435** | 0.418** |
| | -5 days | 0.325** | 0.374** | 0.233* | 0.434** | 0.406** | 0.329** |
| | -6 days | 0.237* | 0.297** | 0.166 | 0.335** | 0.349** | 0.244* |
| | -7 days | 0.247* | 0.308** | 0.176 | 0.327** | 0.345** | 0.244* |
| Cumulative | -2 days | 0.454** | 0.506** | 0.441** | 0.589** | 0.459** | 0.434** |
| | -3 days | 0.460** | 0.518** | 0.433** | 0.593** | 0.469** | 0.444** |
| | -4 days | 0.454** | 0.519** | 0.436** | 0.600** | 0.486** | 0.449** |
| | -5 days | 0.444** | 0.510** | 0.415** | 0.592** | 0.475** | 0.443** |
| | -6 days | 0.436** | 0.510** | 0.405** | 0.587** | 0.471** | 0.441** |
| | -7 days | 0.411** | 0.489** | 0.385** | 0.572** | 0.465** | 0.428** |

n - number of samples. *Statistically significant ($p$<0.05).** Statistically significant ($p$<0.01)

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.

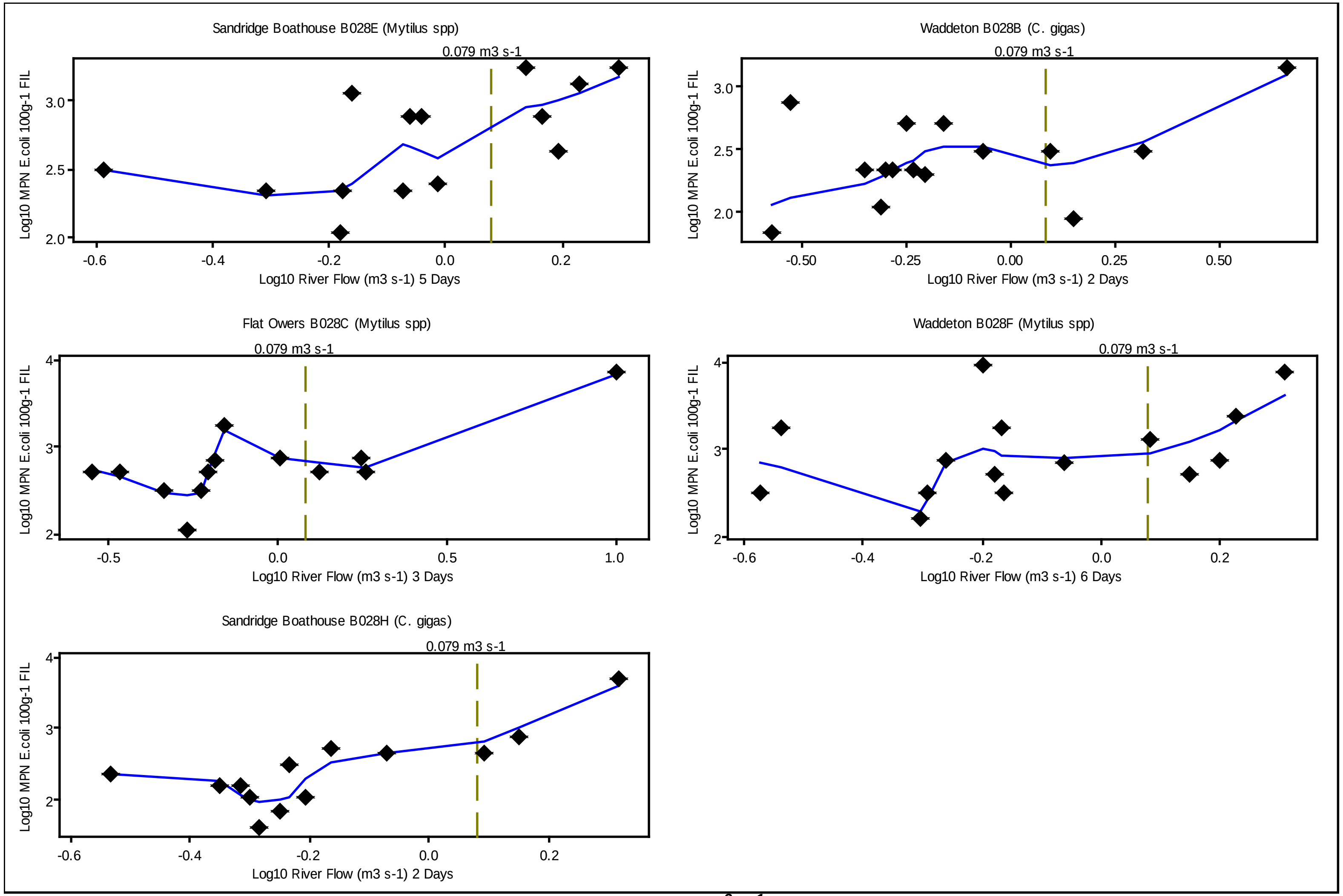

***Figure XI.9 Locally weighted scatterplot smoothing of river flow (m$^{3}$ s$^{-1}$) recorded at Bellever gauging station and MPNs of E. coli 100g$^{-1}$ FIL in bivalves from five monitoring points in the Dart Estuary.***

*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 A3.4. 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.

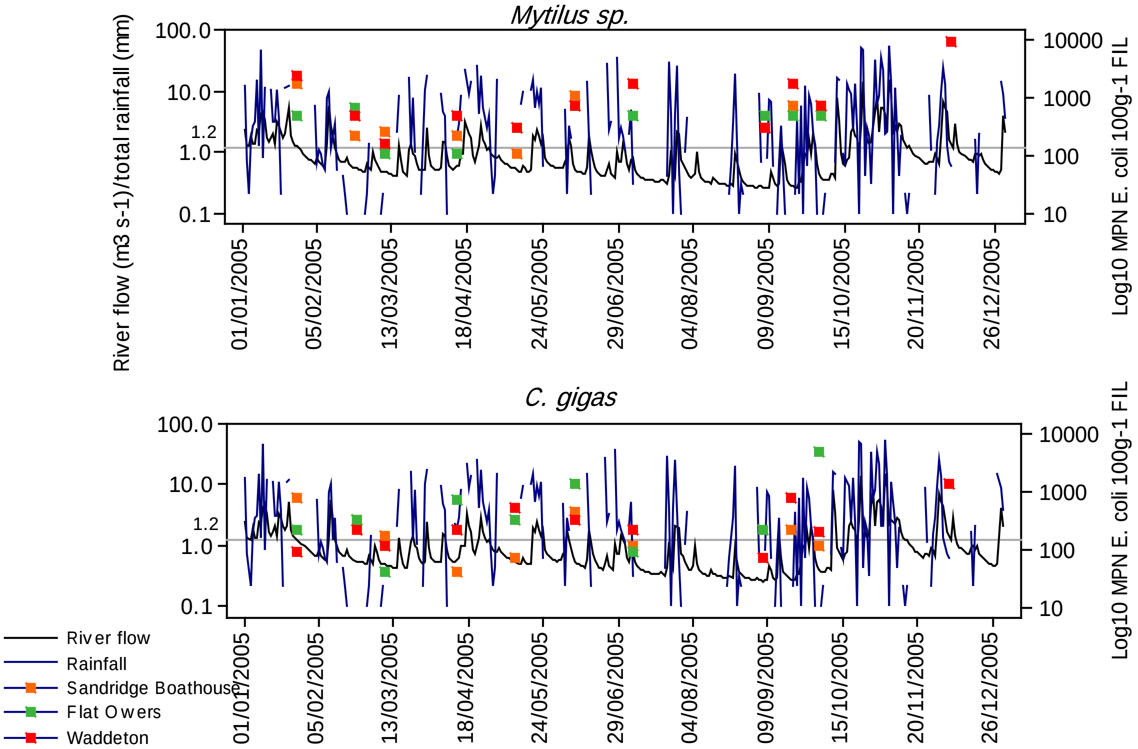

***Figure XI.10 Daily rainfall (Buckfastleigh weather station) and river flow (East Dart at Bellever gauging station) and MPNs of* E. coli *100g$^{-1}$ FIL monitored in bivalves from three monitoring points in the Dart Estuary in 2005.***

*Reference lines indicate mean flow at river gauging station.*

## APPENDIX XII
## SHORELINE SURVEY

**Date (time):** 2 December 2009 (09:40−15:00 GMT); 3 December 2009 (10:00−15:30 GMT)
**Applicant:** George Congdon/Pat Tucker
**Cefas Officers:** Carlos Campos, Lesley Bickerstaff
**Local Enforcement Authority Officer:** Peter Wearden (South Hams District Council).
**Devon Sea Fisheries Committee Officers:** Tim Robbins, Sarah Clarke

**Area surveyed:** shoreline walk conducted in Kingswear (including the area requiring classification for mussels and Pacific oysters at this site), Galmpton Creek and Stoke Gabriel, followed by boat survey along the middle and lower reaches of the estuary (Figure XIII.2–3).

**Objectives:** (a) confirm the existence of pollution sources identified during the desk study likely to constitute sources of microbiological contamination for bivalve mollusc beds; (b) identify any additional pollution sources in the area; and (c) confirm the extent of the new beds.

The predicted times and heights of high and low waters and tidal curve on the days of the survey are given in Figure XIII.1 and Table XIII.1.

***Table XII.1 Predicted high and low water times and heights for Dartmouth on 2–3 December 2009.***

| | Time (height) | |
|---|---|---|
| | 2 December 2009 | 3 December 2009 |
| Low Water | 11:35 (0.9m) | 09:56 (1.3m) |
| High Water | 05:42 (4.9m) | 03:56 (4.5m) |
| Low Water | 23:56 (0.9m) | 22:20 (0.9m) |
| High Water | 18:10 (4.8m) | 16:03 (4.5m) |

*Predicted heights are in metres above Chart Datum. Republished with permission from Admiralty Total Tide (UK Hydrographic Office) by permission of Her Majesty's Stationery Office and the UK Hydrographic Office.*
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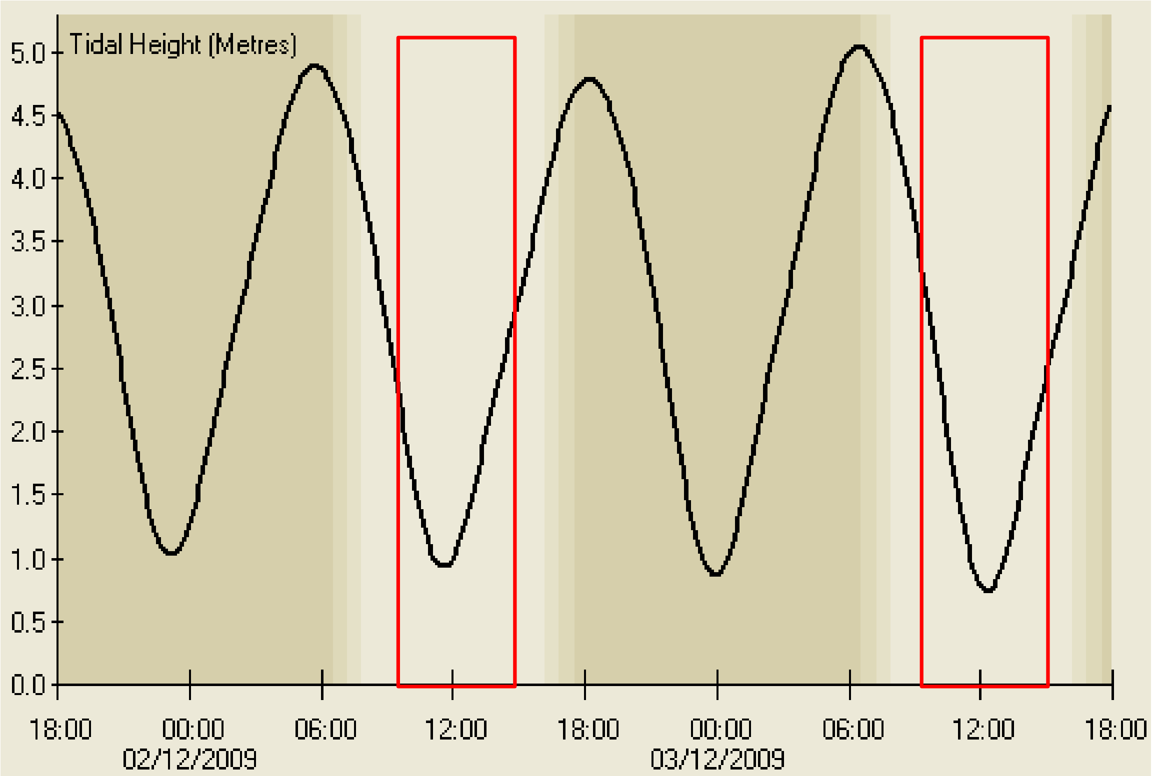

***Figure XII.1 Tidal curve at Dartmouth on 2–3 December 2009.***
*Dartmouth is a Standard Harmonic port.*
*Predicted heights are in metres above Chart Datum Republished with permission from Admiralty Total Tide (United Kingdom Hydrographic Office) by permission of Her Majesty's Stationery Office and the UK Hydrographic Office.*
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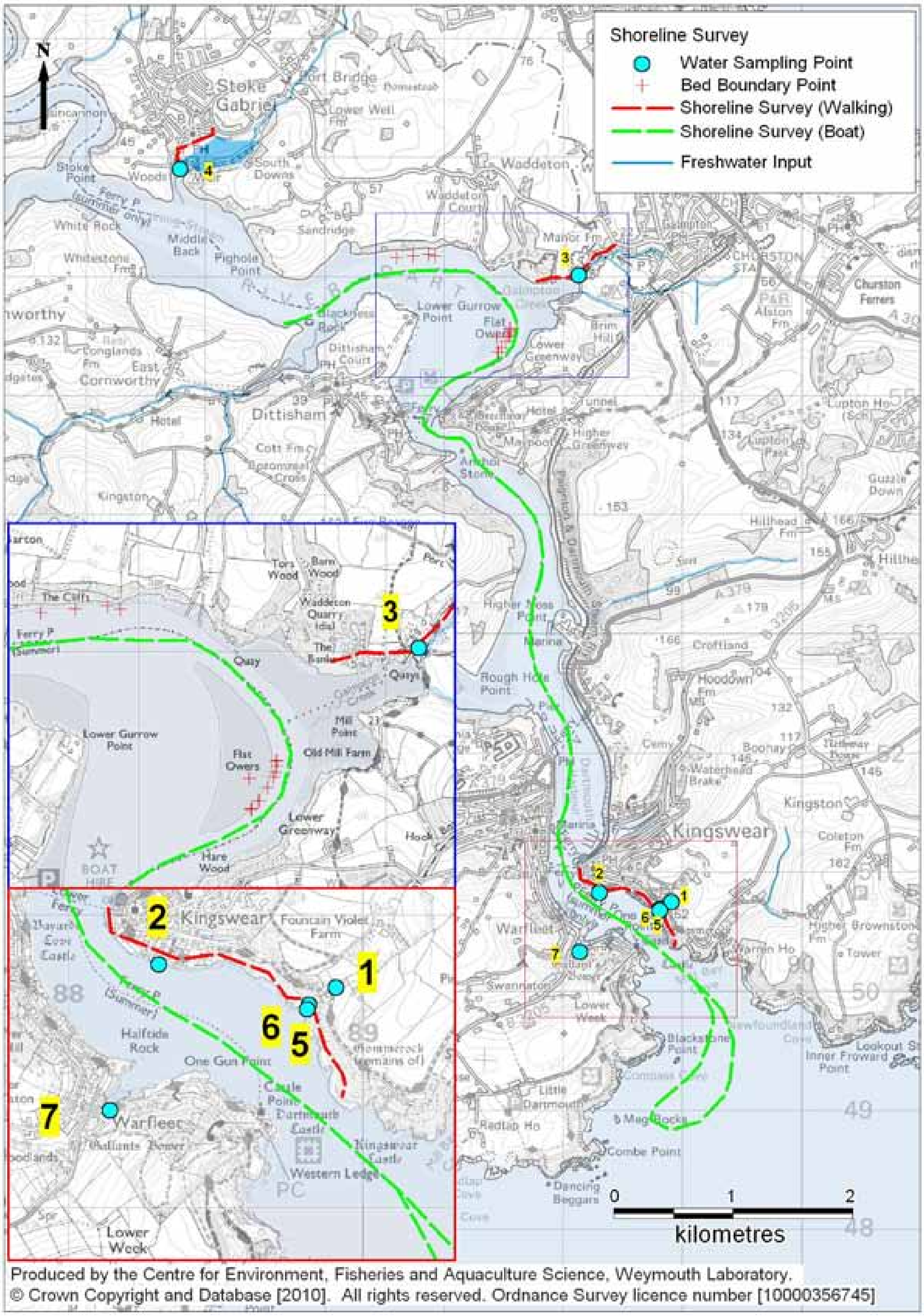

Produced by the Centre for Environment, Fisheries and Aquaculture Science, Weymouth Laboratory.

*Figure XII.2 Locations of sites surveyed and sampled in the Dart Estuary on 2–3 December 2009.*

Table XIII.2 summarises the observations made during the survey.

***Table XII.2 Observations and results made during the shoreline survey.***

| | | |
|---|---|---|
| Classification zones and ID/species | Classification zones/bed names: Lower Gurrow Point, Higher Gurrow Point, Sandridge Boathouse, Waddeton, Flat Owers, Kingswear | |
| Location of beds /Coordinates OSGB36 (Easting, Northing) | Flat Owers:<br>287,454/55,365<br>287,457/55,363<br>287,486/55,398<br>287,489/55,397<br>287,523/55,450<br>287,546/55,494<br>287,449/55,489<br>287,555/55,515 | Sandridge Boathouse:<br>286,925/56,171<br>286,875/56,186<br>286,743/56,170<br>286,605/56,158<br>Mean Higher Water Line |
| | Lower Gurrow Point:<br>Bed confirmed during the 2009 survey (see sanitary survey report) | Kingswear:<br>289,027/50,288<br>288,832/50,473<br>Mean High Water Line |
| Production area | Dart Estuary | |
| Area of beds | Higher Gurrow Point = 0.005810km$^2$<br>Lower Gurrow Point = 0.02762km$^2$<br>Flat Owers = 0.01865km$^2$<br>Waddeton (*C. gigas*) = 0.02395km$^2$<br>Waddeton (*Mytilus* spp.) = 0.033026km$^2$<br>Sandridge Boathouse (*C. gigas*) = 0.01133km$^2$<br>Sandridge Boathouse (*Mytilus* spp.) = 0.05214km$^2$<br>Kingswear = 0.04386km$^2$ | |
| SWD Flesh Point | (Dart) SX87005590 | |
| SWD Water Point | (Dart) SX87005590 | |
| BWD Sampling point | Dartmouth Castle and Sugary Cove SX88655020 | |
| Applicant | George Congdon/Pat Tucker<br>Ticklemore Cheese Dairy<br>Ashprington<br>Totnes<br>TQ9 7DX<br>( 07779 719984 | |
| Cefas officers | Simon Kershaw, Carlos Campos | |
| Local Enforcement Authority Officer | Peter Wearden<br>South Hams District Council<br>Follaton House, Plymouth Road<br>Totnes<br>TQ7 5NE<br>( 01803 861294 | |
| Extent of survey area | 2 December 2009:<br>Kingswear–Stoke Gabriel<br>3 December:<br>Blackness Point–approaches | |
| Map/Chart references | UKHO Admiralty 2253: Dartmouth Harbour<br>OS Explorer OL20: (South Devon) | |

| | |
|---|---|
| Weather conditions | Southerly or southwesterly 5 to 7, occasionally gale 8 at first. Rough becoming very rough in west. Rain then squally showers. Moderate or good, occasionally poor. Southwesterly veering northwesterly 5 to 7, occasionally gale 8. Rough or very rough, occasionally high in west. Squally showers. Moderate or good. |
| Maximum air temperature | 2 December 2009: 10°C |
| Wind | 2 December 2009: 17mph |
| Streams/springs | Stream at Kingswear (adj. Fountain Violet Farm); sampled (see Figure XII.11E; Table XII.3)<br>Stream at Warfleet; sampled (see Figure XII.11F; Table XII.3)<br>Galmpton Creek; sampled (see Figure XII.11C; Table XII.3)<br>Stream at Stoke Gabriel; sampled (see Figure XII.11D; Table XII.3) |
| Sewage discharges (observed) | Yarrow Bank Pumping Station (Figure XII.3)<br>Unidentified piped discharge from private property onto steps at Kingswear (SX8830850834) (Figure XII.4); sampled (see Table XII.3)<br>Iron pipe adj. going out into the river (identified as Toft Quay Outfall). Discharge point underwater. Not determined whether there was any flow associated (Figure XII.5)<br>Unidentified piped discharge with flap valve at Kingswear (SX8826550878) (Figure XII.6)<br>Unidentified discharge at Kingswear (SX883275084) (Figure XII.8)<br>Stoke Gabriel Pumping Station; sampled downstream discharge point (see Table XII.3; Figure XII.9)<br>Four pipes were observed on the northern side of Warfleet Creek. Figure XII.10 shows one of them. These pipes were not discharging at the time of the survey and were thought to be associated with surface water. |
| Boats/port | The location of mooring areas at Blackness Point, Waddeton, Flat Owers and Dartmouth-Kingswear areas observed has not changed significantly since the 2009 survey.<br>Approx. 25 unoccupied moorings at Warfleet Creek.<br>Unoccupied moorings in the immediate vicinity of the new production area at Kingswear (*NB.* Google Earth shows approximately 35 boats moored in this area). |
| Dogs | None |
| Birds | Wild birds/ducks in Warfleet Creek |
| Strand line/Sewage Related Debris | None observed. The shoreline in the vicinity of the new production area at Kingswear, Sandridge Boathouse and Waddeton was noted to be very clean. The applicant informed that locals use the area as bathing water during the summer. |

| | |
|---|---|
| Bivalve harvesting activity and production area capacity | Harvesting activity at Waddeton and Blackness Point. *NB.* Cefas has been informed by the LEA that Blackness Point has been used as a holding area for oysters and not for on growing operations.<br>The applicant informed that cages at Kingswear will be recovered by hand from boat.<br>The harvester communicated that the business is expanding and the currently classified beds within the Waddeton Fishery Order might have reached their maximum capacities. Cefas Officer suggested that the stretch of shoreline between Higher and Lower Gurrow Point could be requested to be classified in the future.<br>Estimated maximum capacity at Flat Owers = 193 bags; 21 bags of Pacific oysters were counted at the time of the survey.<br>Pacific oyster bags at Higher Gurrow Point, Sandridge Boathouse, Waddeton and Flat Owers.<br>High numbers of clam shells at Waddeton. |
| Sewage related debris | None |
| Water appearance | Seawater: clear in the middle and lower reaches of the estuary. Slightly turbid at Warfleet Creek and Kingswear. Stoke Gabriel: turbid with high proportion of suspended sediment. |
| Human population | Shoreline survey undertaken outside the tourist season. High number of unoccupied moorings suggests low tourist activity. |
| Topography | Steep sided river valley. |
| Land Use | Urban and suburban at Dittisham, Waddeton, Dartmouth and Kingswear.<br>Agricultural land across the upper/middle reaches of the catchment (natural and improved grassland for livestock production and cereals). |
| Hydrodynamics/temperature/salinity | High ebb tide surface water flows between Anchor Stone and Higher Noss Point.<br>Flat Owers and Sandridge Boathouse beds were noted to be totally exposed at the time of the survey.<br><br>Salinity/temperature measurements:<br><br>289,369/50,112: 31ppt/11.1°C<br>289,027/50,288: 28.2ppt/11.1°C<br>288,832/55,50,473: 29.3ppt/11.1°C<br>288,723/50,649: 27.5ppt/10.7°C<br>288,532/50,746: 28ppt/10.6°C<br>288,606/50,710: 29.2ppt/10.9°C<br>288,726/49,962: 31.3ppt/11.2°C |

*Figure XII.3 Yarrow Bank Pumping Station.*

*Figure XII.4 Unidentified discharge at Kingswear (SX8830850834).*

*Figure XII.5  Toft Quay outfall.*

*Figure XII.6  Unidentified piped discharge at Kingswear (SX8826550878).*

*Figure XII.7 Man-hole cover for sewer at Kingswear.*

*Figure XII.8 Unidentified discharge at Kingswear (SX883275084).*

*Figure XII.9 Stoke Gabriel Pumping Station.*

*Figure XII.10 Unidentified piped discharge at Warfleet Creek.*

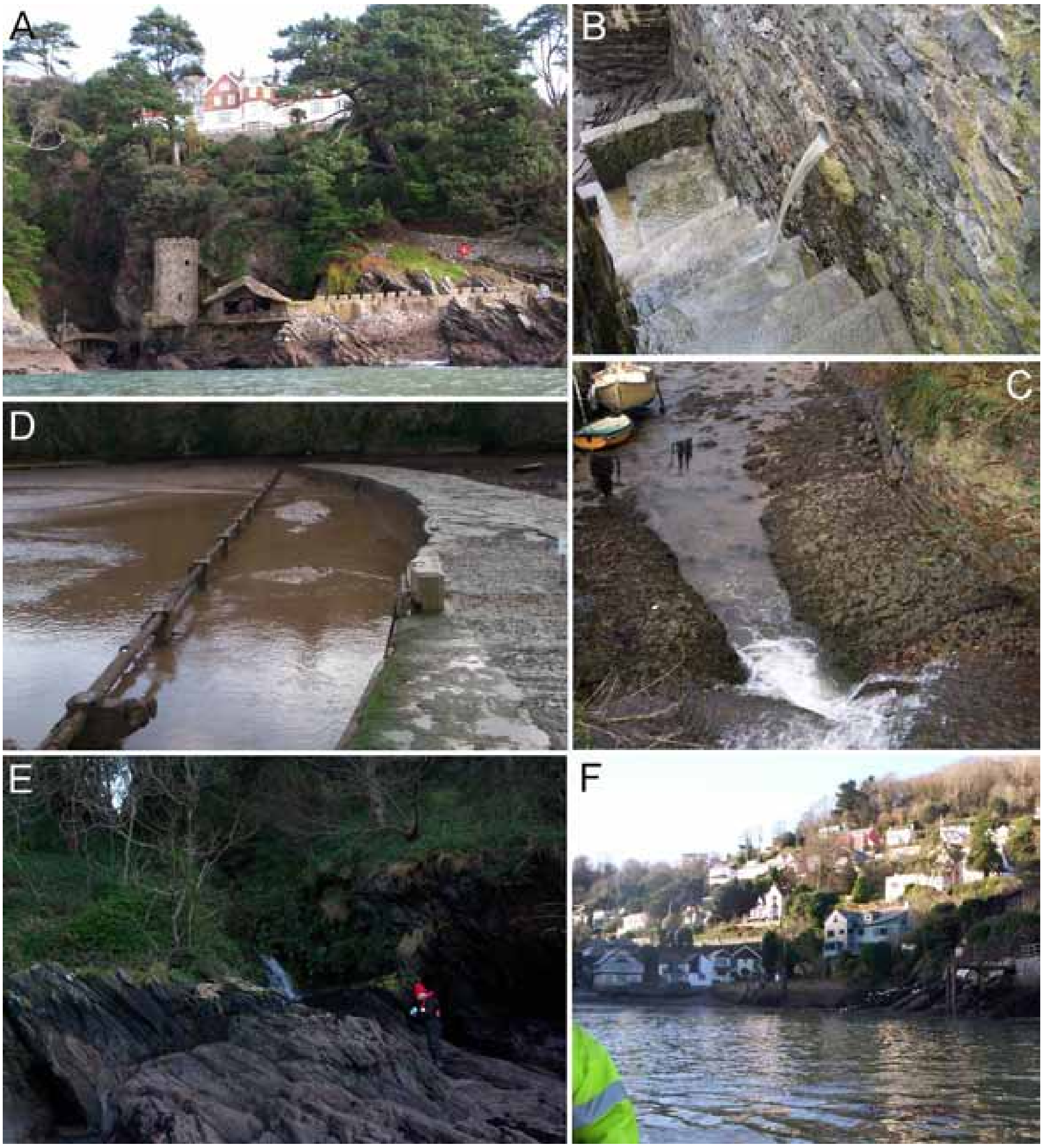

*Figure XII.11 Sites sampled during the shoreline survey.*

***Table XII.3 Results of samples collected during the shoreline survey.***

| Fig.XII.10 ID | Matrix | Collection time | Easting | Northing | *E. coli* (CFU 100ml$^{-1}$) | Salinity (ppt) | Temperature (°C) | Water appearance |
|---|---|---|---|---|---|---|---|---|
| A | Freshwater (stream) | 10:30 | 288,912 | 50,756 | 200 | 0 | 11.9 | Clear |
| B | Water (piped discharge) | 11:04 | 288,308 | 50,834 | 95,000 | - | - | Turbid (brown) |
| C | Freshwater (stream) | 12:10 | 288,130 | 56,009 | 83,000 | 0 | 10.7 | Clear |
| D | Seawater (downstream Stoke Gabriel PS) | 13:00 | 284,790 | 56,915 | 15,000 | 1 | 10.3 | Turbid (brown) |
| E | Freshwater (stream) | 10:27 | 288,829 | 50,697 | 200 | - | - | Clear |
| E | Water (piped discharge) | 10:30 | 288,829 | 50,697 | 76,000 | - | - | Clear |
| F | Freshwater (stream) | 11:16 | 288,142 | 50,337 | 400 | - | - | Clear |

## CONCLUSIONS

The following conclusions can be drawn from the shoreline survey:

1. The new production area at Kingswear is likely to be vulnerable to microbial contamination from upstream pollution sources (sewage discharges at Dartmouth/Kingswear) and waste discharges from boats during the summer. However, the underlying microbial quality of bivalves growing at this site is potentially better than those growing within the Waddeton Fishery Order.

2. The temperature/salinity measurements at the mouth of the estuary suggested a body of water with similar characteristics at the time of the shoreline survey.

3. The bed requiring classification at Lower Gurrow Point is likely to be impacted by the same sources/types of pollution identified as impacting on bivalve molluscs at Upper Gurrow Point following the 2009 sanitary survey.

4. The levels of *E. coli* in water samples collected on 3 December 2009 under wet weather conditions indicate that Galmpton Creek and Stoke Gabriel as potentially significant routes of contamination of faecal origin impacting on bivalve mollusc beds within the Waddeton Fishery Order.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| ABPmer | Associated British Ports Marine Environmental Research |
| AMPs | Asset Management Plans |
| AONB | Area of Outstanding Natural Beauty |
| B | Biological Treatment |
| BMPA | Bivalve Mollusc Production Area |
| °C | Degrees Celsius |
| *C. gigas* | *Crassostrea gigas* |
| CD | Chart Datum |
| Cefas | Centre for Environment, Fisheries & Aquaculture Science |
| CFU | Colony Forming Units |
| CI | Confidence Interval |
| cm | Centimetre |
| cSAC | Candidate Special Area of Conservation |
| 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 |
| g | Grams |
| GM | Geometric Mean |

| | |
|---|---|
| GMT | Greenwich Mean Time |
| ha | Hectare (10,000 square metres) |
| HAT | Highest Astronomical Tide |
| HW | High Water |
| ID | Identification |
| ISO | International Organization for Standardization |
| km | Kilometre |
| LEA | Local Enforcement Authority |
| $\text{Log}_{10}$ | Base ten logarithm |
| LT | Low tide |
| Ltd | Limited |
| LW | Low water |
| M | Million |
| m | Metres |
| Ml | Millilitres |
| mm | Millimetres |
| $m^3 s^{-1}$ | Cubic metres per second |
| $m^3 d^{-1}$ | Cubic metres per day |
| 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 |
| n | Number of samples |
| n/a | Not applicable or not available |
| NERC | Natural Environment Research Council |
| NGR | National Grid Reference |
| OSGB36 | Ordnance Survey Great Britain 1936 |
| Pers. comm. | Personal communication |
| Pop. Eq. | Population equivalent |
| ppt | Parts per thousand |
| PS | Pumping Station |
| RMP | Representative Monitoring Point |
| S | Secondary Treatment |
| SEPA | Scottish Environmental Protection Agency |
| SFC | Sea Fisheries Committee |
| SAC | Special Area of Conservation |
| SO | Storm Overflow |
| SSO | Storm sewer overflow |
| spp. | Species |
| SSSI | Site of Special Scientific Interest |
| STW | Sewage Treatment Works |
| T | Tertiary Treatment |
| Tukey HSD | Honestly Significant Differences |
| U | Untreated |
| UK | United Kingdom |
| UV | Ultraviolet |
| WFO | Waddeton Fishery Order |
| WGS84 | World Geodetic System 1984 |

## GLOSSARY

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| 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. |
| EC Regulation | Body of European Union law involved in the regulation of state support to commercial industries, and of certain industry sectors and public services |
| Emergency Overflow | A system for allowing the discharge of sewage (usually crude) from a sewer system or sewage treatment works in the case of equipment failure. |
| *Escherichia coli (E. coli*) | A species of bacterium that is a member of the faecal coliform group (see below). It is more specifically associated with the intestines of warm-blooded animals and birds than other members of the faecal coliform group. |
| *E. coli* O157 | E. *coli* O157 is one of hundreds of strains of the bacterium *Escherichia coli*. Although most strains are harmless, this strain produces a powerful toxin that can cause severe illness. The strain O157:H7 has been found in the intestines of healthy cattle, deer goats and sheep. |
| 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. |

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| 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.<br>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. |
| Shellfish Waters | Under the EC Shellfish waters Directive (2006/113/EEC) the standard guidelines for water quality in estuaries and other areas where shellfish grow and reproduce are outlined. The directive will be replaced in 2013 by the EC Water Framework Directive (WFD). |
| Storm Water | Rainfall which runs off roofs, roads, gulleys, etc. In some areas, storm water is collected and discharged to separate sewers, whilst in combined sewers it forms a diluted sewage. |
| Waste water | Any waste water but see also “sewage”. |

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