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EC Regulation 854/2004

CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES

SANITARY SURVEY REPORT

Brancaster

February 2014

Food Standards Agency

Cover photo: Burnham Overy Windmill

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Statement of use

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

Report prepared by

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Revision history

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1	Draft for internal review	Fiona Vogt	13/02/2014
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Final	Final	Simon Kershaw	26/03/2015

Consultation

Consultee	Date of consultation	Date of response
King’s Lynn & West Norfolk BC	25/02/2014	25/03/2014
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Anglian Water	25/02/2014	10/03/2014
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Brancaster Staithe Fishermen’s Society	25/02/2014	02/04/2014 (and site visit 12/09/2014)

Dissemination

Food Standards Agency, King’s Lynn & West Norfolk BC. The report is available publicly via the Cefas website.

Recommended Bibliographic Reference

Cefas, 2014. Sanitary survey of Brancaster. Cefas report on behalf of the Food Standards Agency, to demonstrate compliance with the requirements for classification of bivalve mollusc production areas in England and Wales under EC regulation No. 854/2004.

Contents

1. Introduction

1.1. Legislative Requirement

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

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

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

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

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

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

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

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

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

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

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

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

This report documents the information relevant to undertake a sanitary survey for mussels (*Mytilus* spp.), Pacific oysters (*Crassostrea gigas*) and cockles (*Cerastoderma edule*) at Brancaster. The area was prioritised for survey in 2013-14 by a shellfish hygiene risk ranking exercise of existing classified areas.

1.2. Area description

The Brancaster survey area is situated on the North Norfolk coast, in the southern North Sea. The shoreline here consists of barrier beaches, behind which there are extensive areas of saltmarsh with complex networks of tidal creeks.

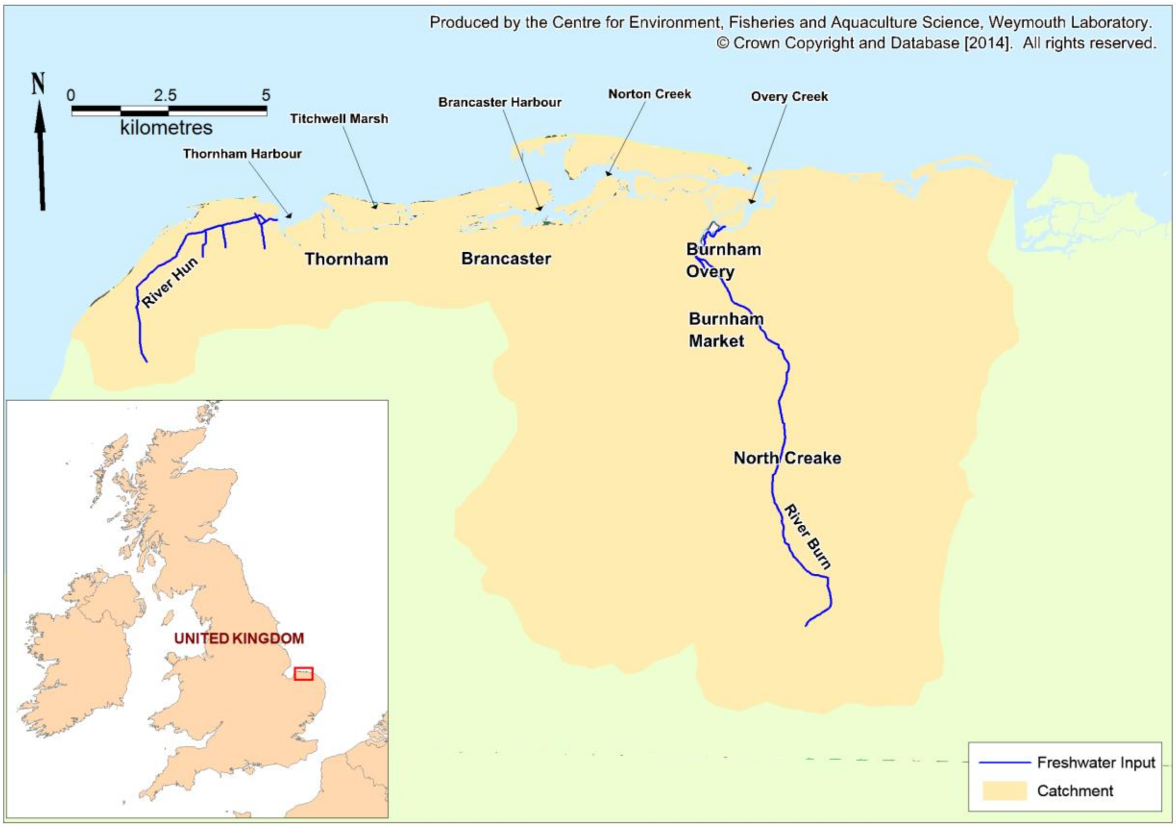


Figure 1.1: Location of the Brancaster survey area

There are three main creeks in the survey area; Thornham Harbour, Brancaster Harbour, and Overy Creek. The latter two are connected via Norton Creek. A small fishing fleet operates from the area, and the creeks are also used for mooring recreational craft. Brancaster Harbour and its tidal creeks support shellfisheries of mussels, cockles and oysters and a tidal creek on Titchwell Marsh, by Thornham Harbour supports an oyster fishery.

1.3. Catchment

The catchment was defined on the basis that the fisheries are in the creeks off Thornham and Brancaster, and all areas draining into these should be considered. The River Burn catchment, which drains to the shore at Burnham, about 3 km to the east of Brancaster, was included as there is a direct hydrological connection between the tidal creeks at Burnham Overy and those at Brancaster. Figure 1.2 illustrates landcover within the catchment area, which covers an area of 173 km^2. It is predominantly (around 80%) rural, principally arable land with some pockets of pasture

(NERC, 2012). There are small areas of forest in the north east of the catchment, and small urbanised areas close to the shore representing the settlements of Brancaster, Burnham Market, North Creake, and part of Hunstanton. Total resident population within the catchment is only about 17,000.

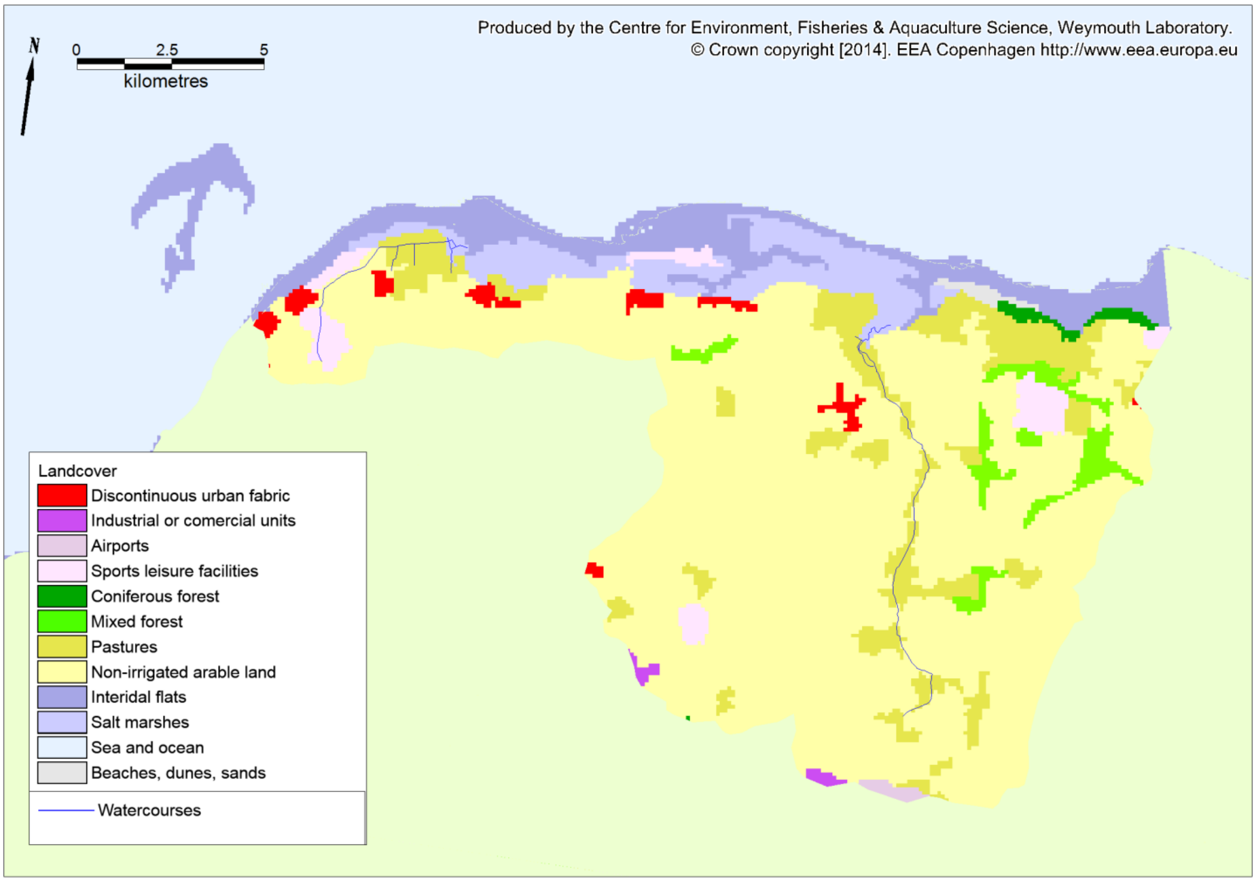


Figure 1.2: Landcover in the Brancaster survey area

Different land cover types will generate differing levels of contamination in surface runoff. Highest faecal coliform contribution arises from developed areas, with intermediate contributions from the improved pastures and lower contributions from the other land types (Kay *et al*. 2008a). The contributions from all land cover types would be expected to increase significantly after marked rainfall events, particularly for improved grassland which increase up to 100 fold. The catchment is comprised predominantly of chalk bedrock and so water movements through the catchment are largely via ground-waters rather than surface watercourses. Consequently, run-off within the catchment is limited except in periods of heavy rainfall, and the two main watercourses are largely spring fed (Environment Agency, 2005). This limits the extent to which contamination from agricultural sources for example is directly washed into watercourses.

2. Recommendations

2.1. Mussels

The following two classification zones are proposed for mussels:

Brancaster Inner

This zone includes the inner reaches of the fishery area, up as far as the confluence with Norton Creek. It also includes the mussel pits, both at the harbour and at Brancaster Staithe, which the competent authority has advised will not require separate monitoring for classification. As well as the mussel lays in the creek, the area by the slipway is used for short term storage of batches of mussels prior to depuration. Potential sources of contamination include birds, moored boats, and minor amounts of land runoff. As such, the more inshore areas around the harbour may represent the most contaminated area. It is therefore recommended that an RMP is established by the slipway where mussels may be held for short periods. As this does not coincide with a specific mussel lay, the use of a sampling bag may be required.

Brancaster Outer

Potential sources of contamination include moored boats, and minor amounts of land runoff originating from further inshore. Identified sources of contamination direct to the zone are probably limited to birds and the occasional transiting boat. The tidal regime in Norton Creek is such that sources of contamination in the Burnham Overy area will not be an influence despite the potential hydrological connection. It is therefore recommended that the RMP is located at the confluence of the Norton Creek channel and the Brancaster Harbour channel, at the inshore boundary of this zone.

Sampling considerations

Monthly sampling is required to maintain a year round classification. Samples should be taken by hand and sampled mussels should be animals of a market size. If bagged mussels are used they should be allowed to equilibrate *in situ* for at least two weeks prior to sampling. A tolerance of 10 m should apply.

2.2. Pacific oysters

The following three classification zones are proposed for Pacific oysters:

Brancaster Inner

This zone includes the inner reaches of the fishery area, up as far as the confluence with Norton Creek. There are no oyster growing areas within this zone, but it does include the mussel pits and an area by the harbour, all of which may be used for short term storage of stocks between harvest and depuration. Following discussion on the status of the mussel pits and on whether they required separate monitoring, the competent authority advised that they do not require separate monitoring for classification. Potential sources of contamination include birds, moored boats, and minor amounts of land runoff. As such, the more inshore areas around the harbour may represent the most contaminated area. It is therefore recommended that an RMP is established by the slipway where stock may be held for short periods. As this does not coincide with an oyster culture area, the use of a sampling bag will be required.

Brancaster Outer

Potential sources of contamination include moored boats, and minor amounts of land runoff originating from further inshore. Identified sources of contamination direct to the zone are probably limited to birds and the occasional transiting boat. The tidal regime in Norton Creek is such that sources of contamination in the Burnham Overy area will not be an influence despite the potential hydrological connection. It is therefore recommended that the RMP is located at the south western corner of the block of trestles at the confluence of the Norton Creek and Brancaster Harbour channels.

Thornham

The Thornham oyster farm lies in a creek which extends east from the Thornham harbour channel towards Titchwell marshes. The tidal regime is such that only sources discharging directly to the creek, or to the outer reaches of the main channel are likely to impact. There may be the occasional overboard discharge made by small boats using the main channel. There is one minor freshwater input feeding into the head of the creek in which the shellfish are located. Birds are likely to be an influence within this zone, albeit a diffuse one. It is therefore recommended that the current RMP at the eastern (upstream) end of the trestle site is retained.

Sampling considerations

Pacific oyster sampling should be monthly, via hand, animals should be of a market size, and a tolerance of 10 m applies.

2.3. Cockles

Cockle stocks are present within both the Inner and Outer zones proposed for mussels. There is a historic precedent in this area for cockles to be classified on the basis of mussel monitoring results. Results from hygiene monitoring show that in general cockles accumulate *E. coli* to similar levels as mussels, however they have a tendency to yield more extreme high results, so ideally it is desirable for the cockles themselves to be monitored. However, mussels have a solid B classification and the existing arrangement was agreed following parallel monitoring of the two species locally. Cockles are mainly found in the outermost areas which are likely to be less contaminated, and there are likely to be difficulties in sampling these relatively sparse stocks. It is therefore considered acceptable that cockles within the Brancaster Outer and Brancaster Inner zones may be classified on the basis of mussel sampling results from their respective RMPs.

3. Sampling Plan

3.1. General Information

Location Reference

Production Area	Brancaster
Cefas Main Site Reference	M05
Ordnance survey 1:25,000 map	Explorer 250 and 251
Admiralty Chart	5614.9

Shellfishery

Species/culture	Pacific oysters (*Crassostrea gigas*) Mussels (*Mytilus* spp.) Cockles (*Cerastoderma edule*)	Trestle culture Ground lays Wild/transplanted
Seasonality of harvest	No closed season	

Local Enforcement Authority

Name & Address	Environmental Health Department King's Lynn & West Norfolk Borough Council Kings Court, Chapel Street, King's Lynn Norfolk PE30 1EX
Environmental Health Officer	Ruth Moore
Telephone number	01553 616333
E-mail	ruth.moore@west-norfolk.gov.uk

3.2. Requirement for Review

The Guide to Good Practice for the Microbiological Monitoring of Bivalve Mollusc Harvesting Areas (EU Working Group on the Microbiological Monitoring of Bivalve Mollusc Harvesting Areas, 2010) indicates that sanitary assessments should be fully reviewed every 6 years, so this assessment is due a formal review in 2020. The assessment may require review in the interim should any significant changes in sources of contamination come to light, such as the upgrading or relocation of any major discharges.

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

Classification zone	RMP code	RMP name	NGR	Latitude & Longitude (WGS84)	Sampling Species	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Comments
Brancaster Inner	B05AR	Brancaster Harbour mussels	TF 7931 4460	52°58.126'N 00°40.121'E	Mussels	Bed culture	Hand	Hand (bagged if required)	10 m	Monthly	Represents mussels and cockles within this zone. Zone includes all mussel pits.
Brancaster Outer	B05AS	Norton Creek mussels	TF 7988 4539	52°58.540'N 00°40.656'E	Mussels	Bed culture	Hand	Hand (bagged if required)	10 m	Monthly	Represents mussels and cockles within this zone.
Brancaster Outer	B05AT	Norton Creek oysters	TF 7993 4539	52°58.539'N 00°40.700'E	Pacific oysters	Trestle culture	Hand	Hand	10 m	Monthly	
Brancaster Inner	B05AU	Brancaster Harbour oysters	TF 7931 4460	52°58.126'N 00°40.121'E	Pacific oysters	-	Hand	Hand (bagged if required)	10 m	Monthly	Represents Pacific oysters within this zone. Zone includes all mussel pits
Thornham	B005Y	Thornham oysters	TF 7422 4465	52°58.254'N 00°35.580'E	Pacific oysters	Trestle culture	Hand	Hand	10 m	Monthly	Existing RMP

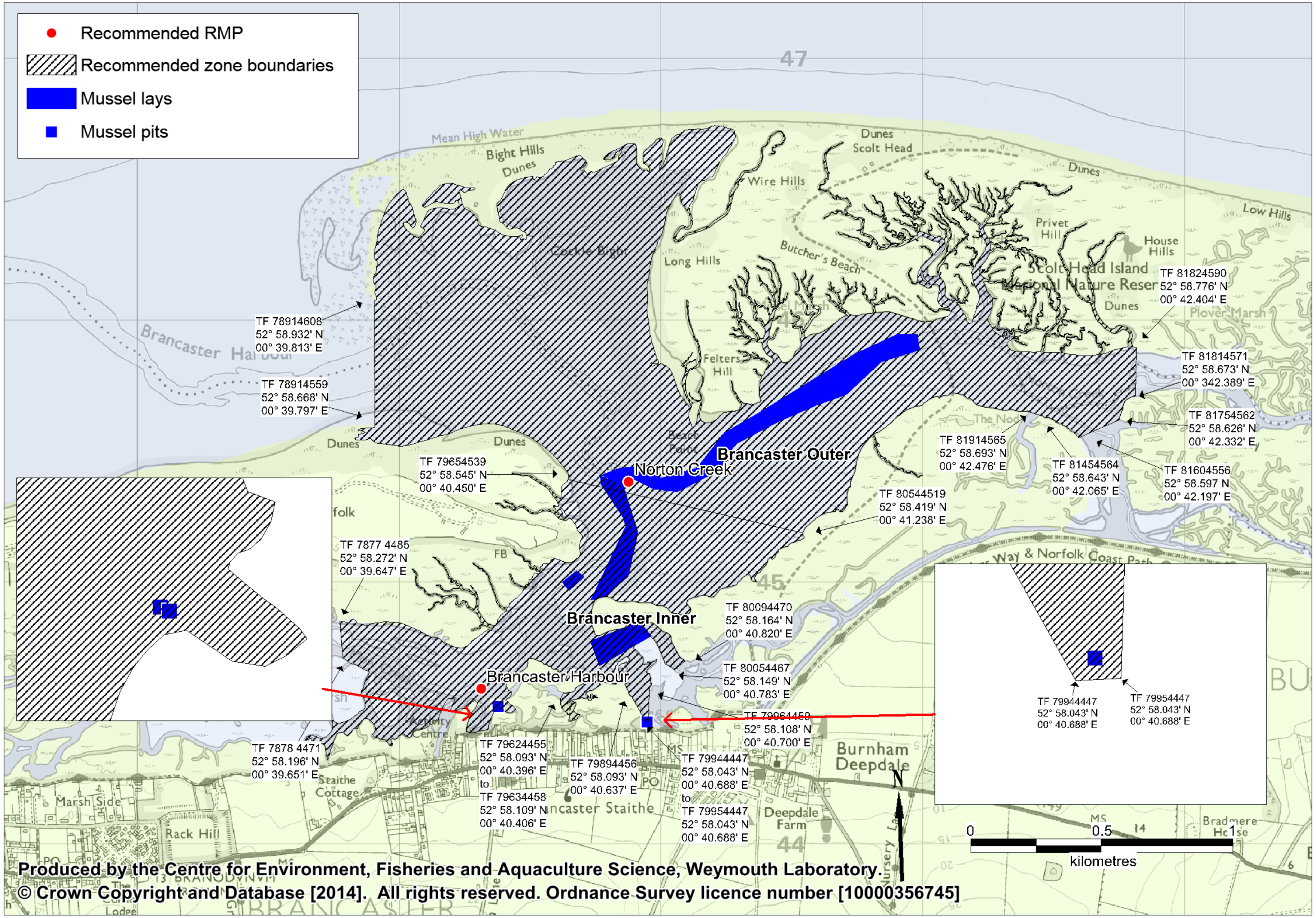


Figure 3.1: Recommended zoning and monitoring arrangements (mussels)

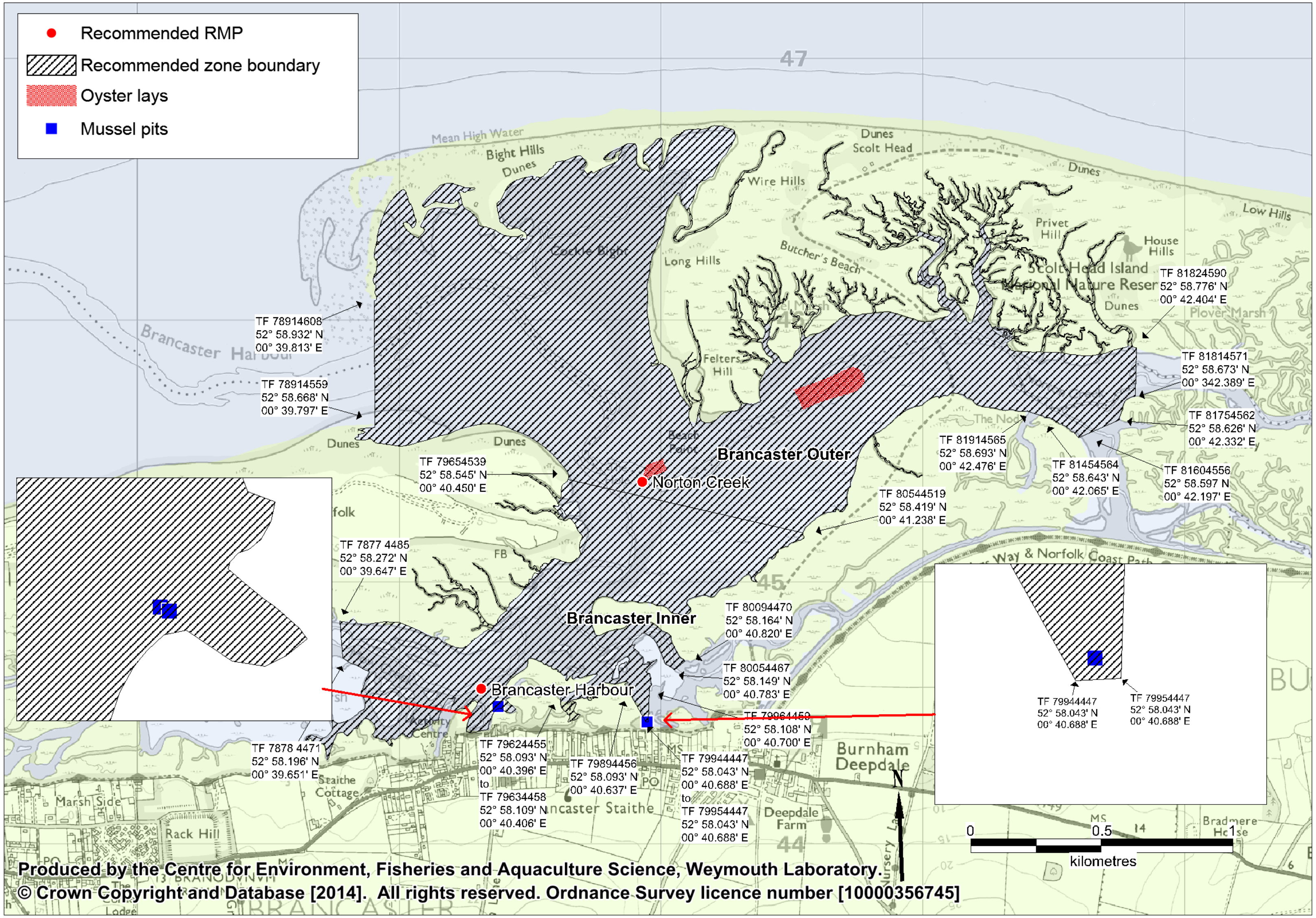


Figure 3.2: Recommended zoning and monitoring arrangements (Pacific oysters at Brancaster)

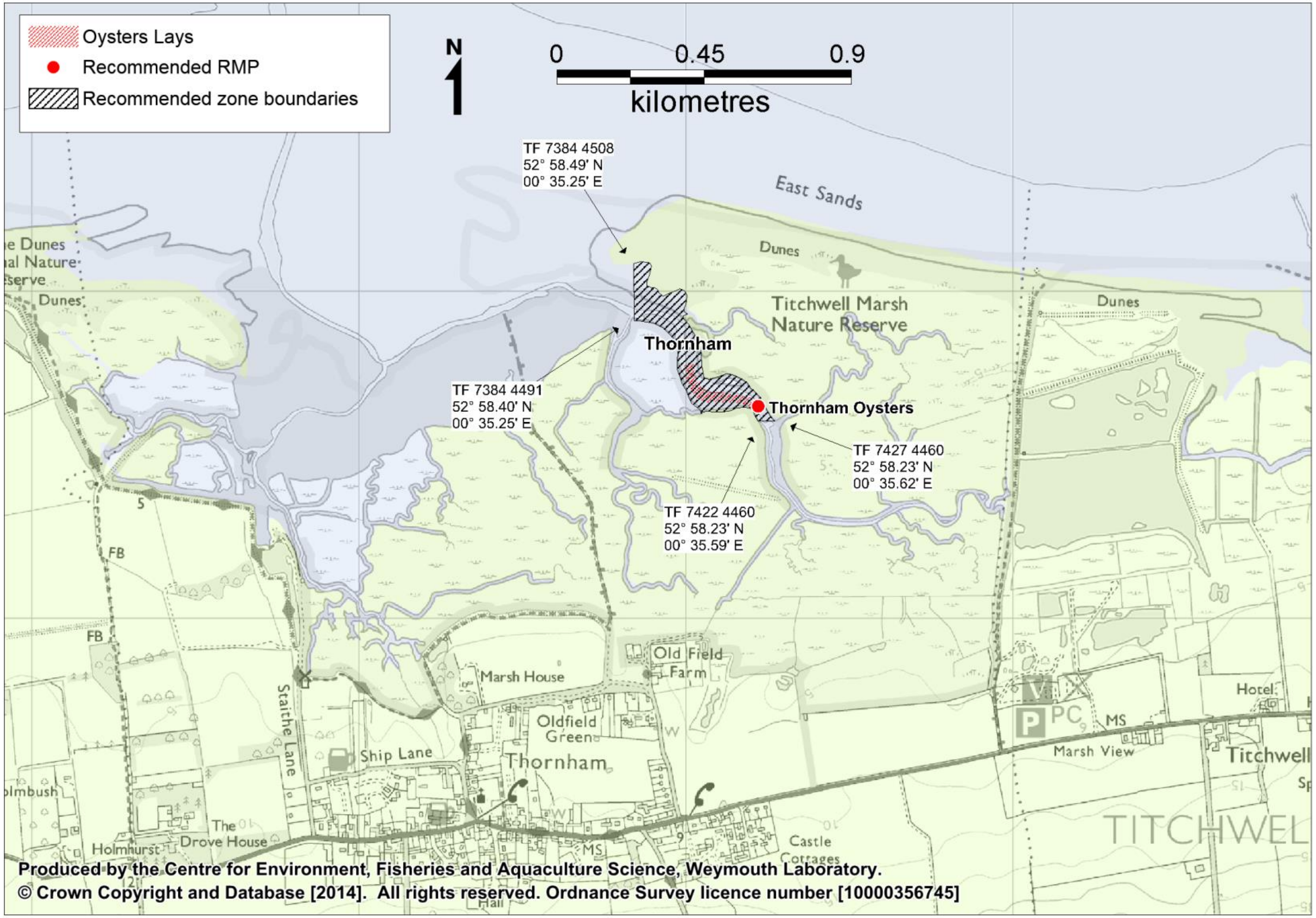


Figure 3.3: Recommended zoning and monitoring arrangements (Pacific oysters at Thornham)

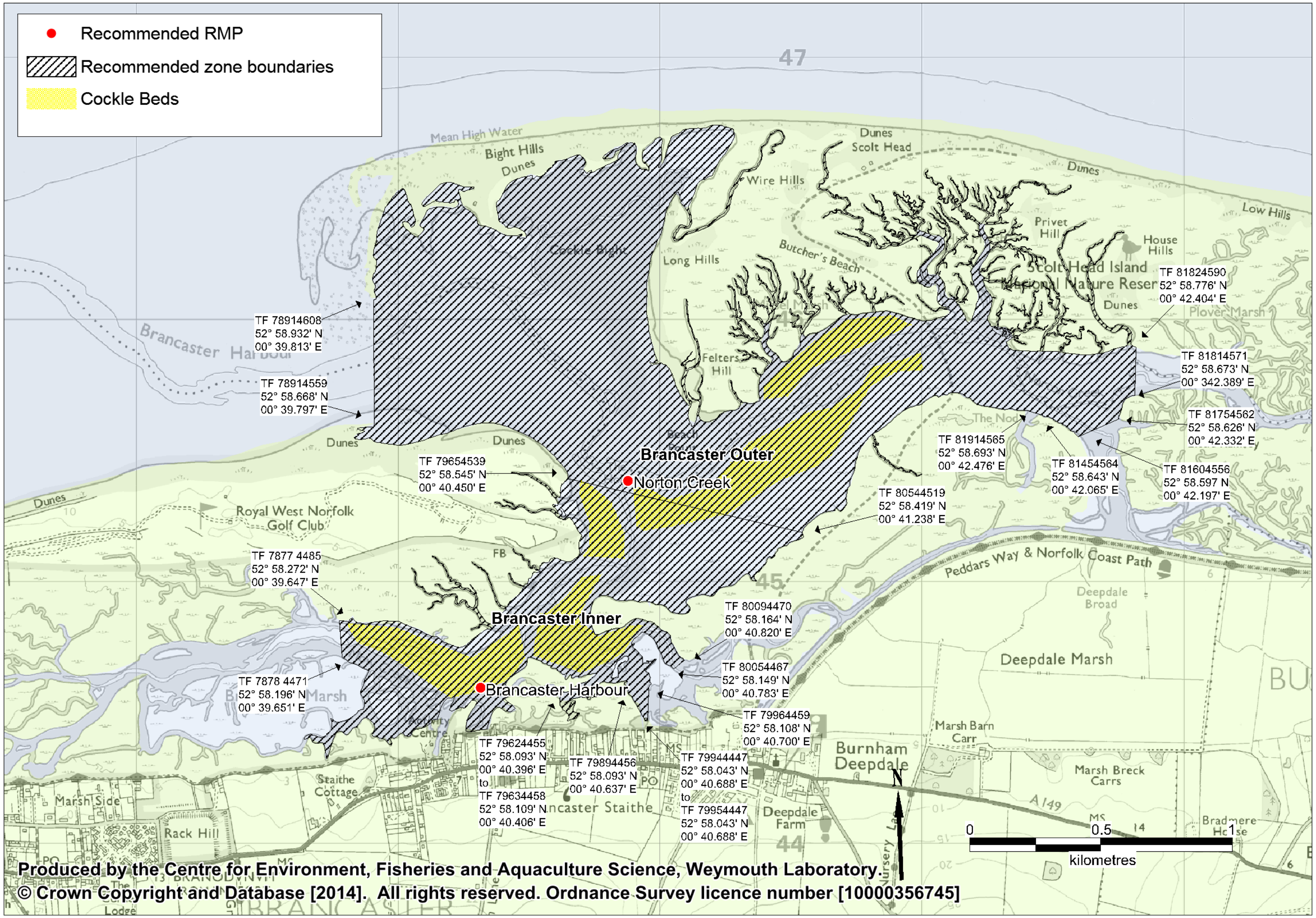


Figure 3.4: Recommended zoning and monitoring arrangements (Cockles)

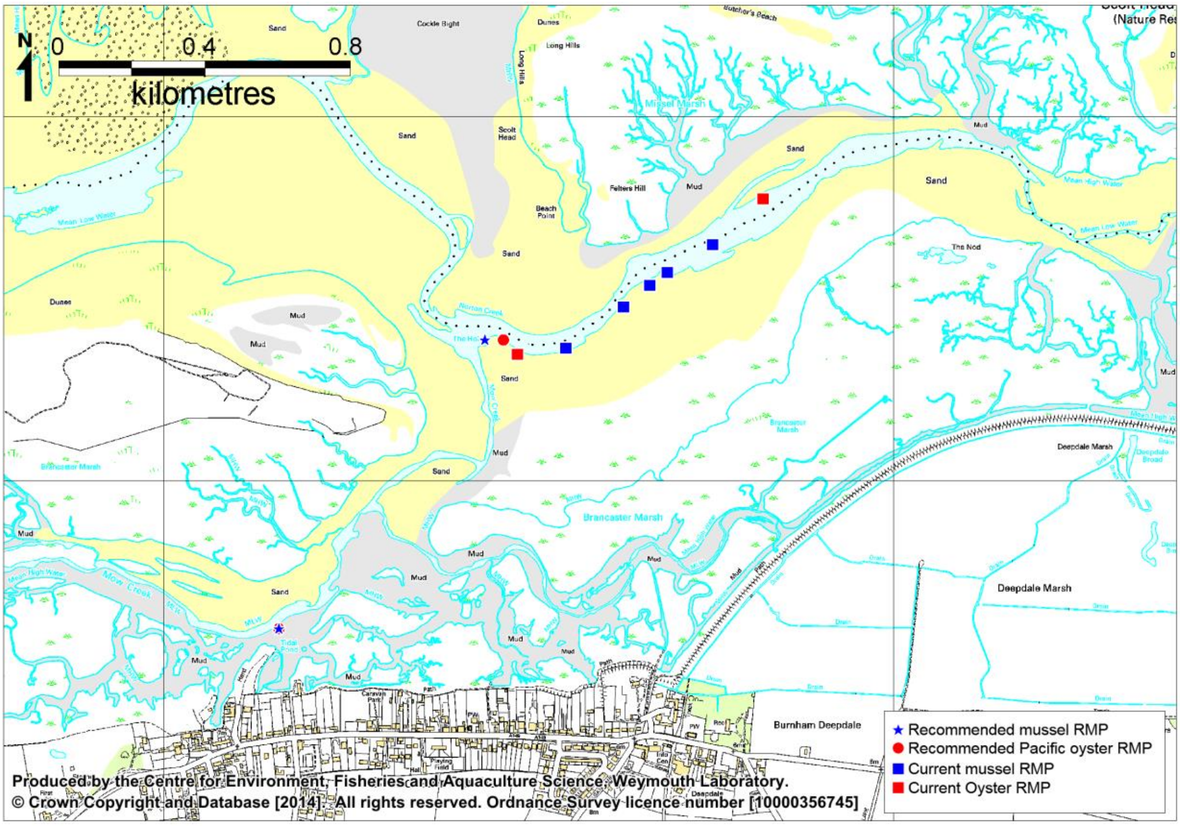


Figure 3.5: Current RMPs and recommended RMPs at Brancaster

Figure 3.5 shows the current RMPs listed on the SHS database alongside the recommended RMPs at Brancaster. Monthly sampling of mussels has been rotated between the various RMPs so each harvester contributes similar amounts of stock for sampling. No changes were recommended to the zoning and monitoring arrangements for the Pacific oyster farm at Thornham.

4. Shellfisheries

4.1. Species, location and extent

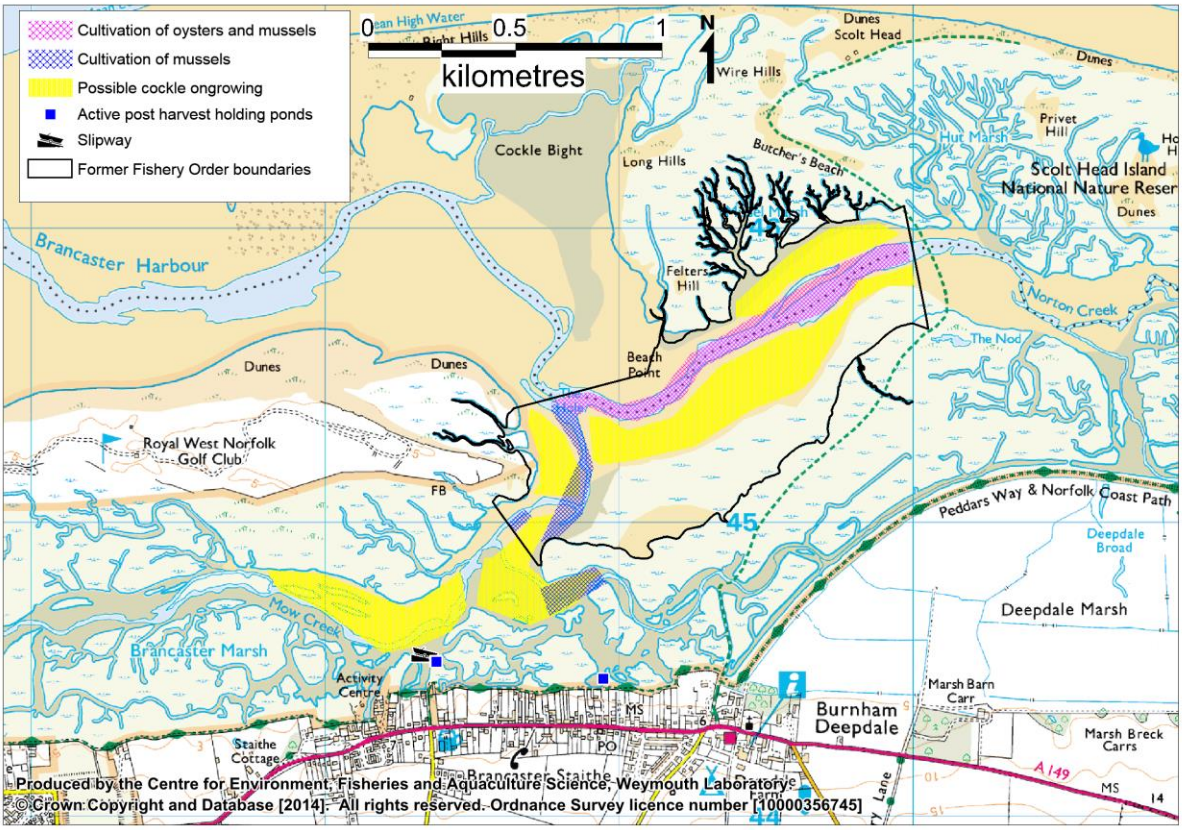


Figure 4.1: Overview of shellfisheries at Brancaster

The principal shellfisheries within the survey area are cultured mussels and Pacific oysters. The majority of these lie on leased grounds within Brancaster Harbour and Norton Creek. This area was formerly subject to a several order held by the Brancaster Staithe Fishermen's Society, which allocates plots to individual fishermen for the culture of mussels and Pacific oysters. The order expired in 2009, but renewal is being sought and the fishery continues. Brancaster Harbour and Norton Creek are also used for the ongrowing of cockles taken from The Wash and there may also be some self seeded stock in places. There is an independent Pacific oyster trestle culture site in a creek that branches east off Thornham Harbour. Formerly, Pacific oyster and mussel culture was undertaken in Overy Creek, but class B compliance was borderline here and this area has now been abandoned and was declassified in 2011.

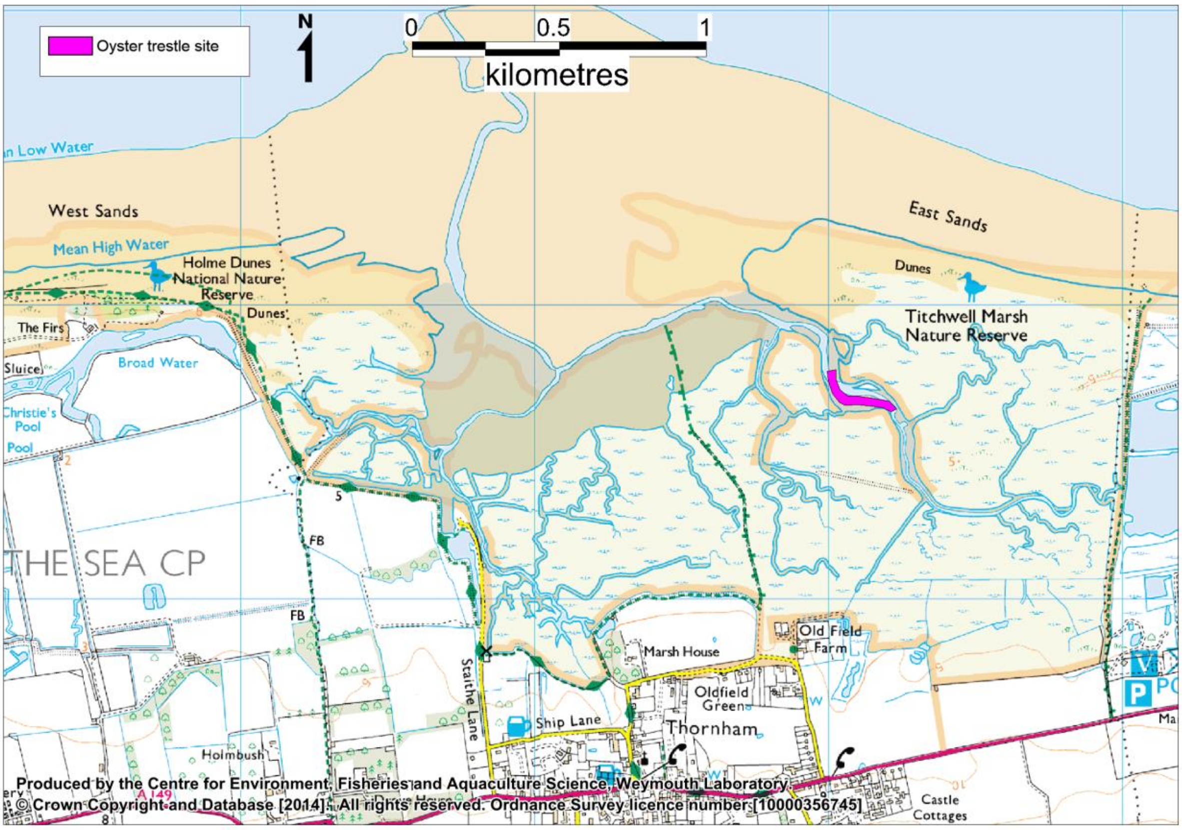


Figure 4.2: Overview of shellfisheries at Thornham

4.2. Growing Methods and Harvesting Techniques

Mussels are cultured from seed stocks which are collected via dredge by the individual lay holders from ephemeral mussel beds off the north Norfolk coast. They are ongrown in the lower intertidal and shallow subtidal areas of Norton Creek and Brancaster Harbour, where it takes them up to two years to reach market size. The exact areas used for ongrowing are rotated from year to year, with harvested areas left fallow for a time to allow the seabed to recover. Harvesting is by hand and the mussels are brought ashore, cleaned and graded, then depurated and sold.

Pacific oysters are cultured on trestles from hatchery seed. Triploids are used where possible at Brancaster. Harvesting is by hand, and they are then brought ashore for depuration.

Cockles are transplanted from the Wash during the summer months to various locations within Brancaster Harbour and Norton Creek. They are then ongrown here then harvested and sold during the winter months when market conditions are favourable. Some naturally occurring cockles may also be present. Harvesting is by hand.

Mussels and oysters may be held for short periods (up to 2 days for mussels, and up to 10 days for oysters) in ‘mussel pits’ at Brancaster (e.g. Figure XI.11) between harvesting/grading and depuration. This practice is intended to purge the shellfish of sediments prior to depuration, and allows the harvesters to put batches through their depuration tanks when the lays further out are not accessible due to tides. There are 10 small pits just to the east of the slipway at Brancaster, but only two are serviceable and in use. There is a further individual pit on the fringes of the saltmarsh at Brancaster Staithe which is also in use. Water within these pits is exchanged regularly from the adjacent creeks on mid to large sized tides, and sediment accumulations are washed out by the harvesters on a regular basis. Stock may also be stored for short periods (a day or two) and re-immersed in the intertidal area by the slipway between grading and depuration.

4.3. Seasonality of Harvest, Conservation Controls and Development Potential

Mussel harvesting typically takes place from September through to March, when the mussel meats are of a higher quality. There is however no formal closed season so harvesting may potentially occur all year round. Harvesting of Pacific oysters or cockles may occur at any time of the year, although cockles are typically harvested during the winter.

From 2006 to 2008 steady production of around 200 tonnes of mussels and 10-15 tonnes of Pacific oysters was reported within the fishery order. Similar volumes of production have been achieved since, and are likely to remain around this level in the future. No information is available on the volumes of cockles harvested.

4.4. Hygiene Classification

Table 4.1 lists all classifications at Brancaster from 2004 onwards.

Table 4.1: Classification history for Brancaster, 2004 onwards

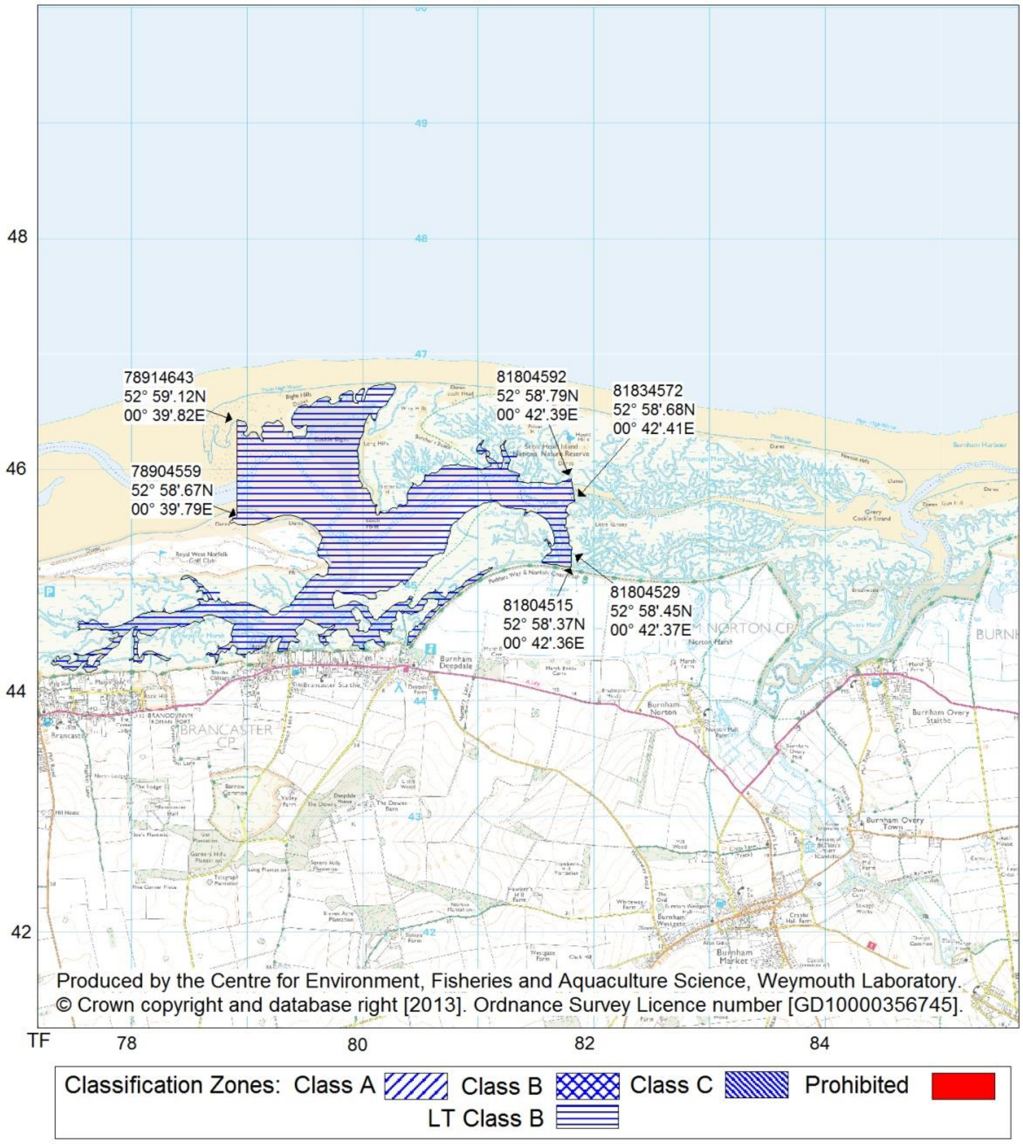
Area	Species	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Brancaster	P. oyster	A	A	A	B	B	B	B-LT	B-LT	B-LT	B-LT
Brancaster	Cockles	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Brancaster	Mussels	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Burnham Overy	Mussels	B	B	B	B	C	C	B	-	-	-
Thornham	P. oyster	B	B	B	B	B	B	B-LT	B-LT	B-LT	B-LT

LT denotes long term classification

All classifications are currently long term B. Cockles are classified on the basis of mussel monitoring results. This arrangement was agreed following parallel monitoring of the two species locally. None of the mussel pits has been sampled for hygiene classification purposes.

Brancaster - Mytilus spp

Scale - 1:47000



Classification of Bivalve Mollusc Production Areas: Effective from 1 September 2013

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)

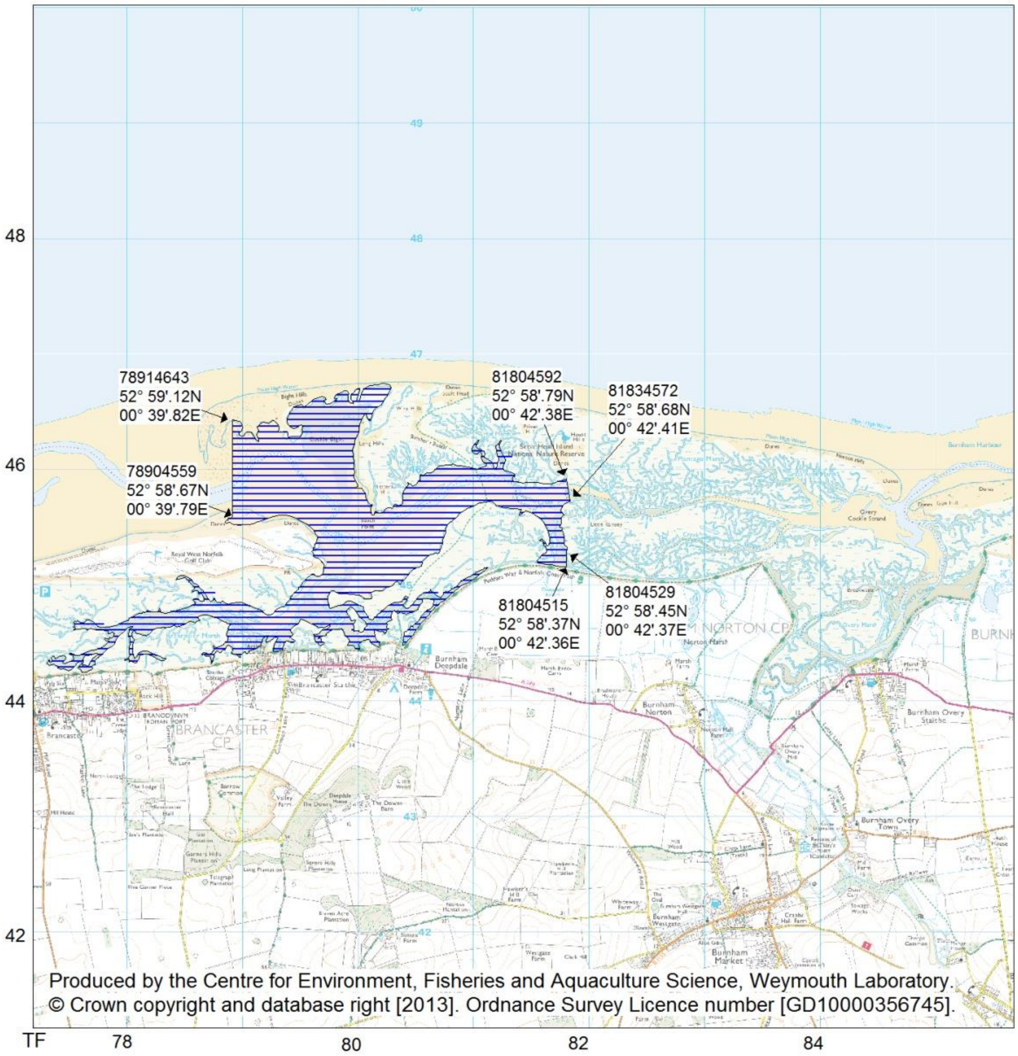
N.B. Lat/Longs quoted are WGS84
Separate maps available for C.edule and C. gigas at Brancaster

Food Authority: Kings Lynn and West Norfolk Borough Council

Figure 4.3: Current mussel classifications

Brancaster - C. gigas

Scale - 1:47000



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

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Separate maps available for C. edule and Mytilus spp. at Brancaster

Food Authority: Kings Lynn and West Norfolk Borough Council

Figure 4.4: Current Pacific oyster classifications (Brancaster)

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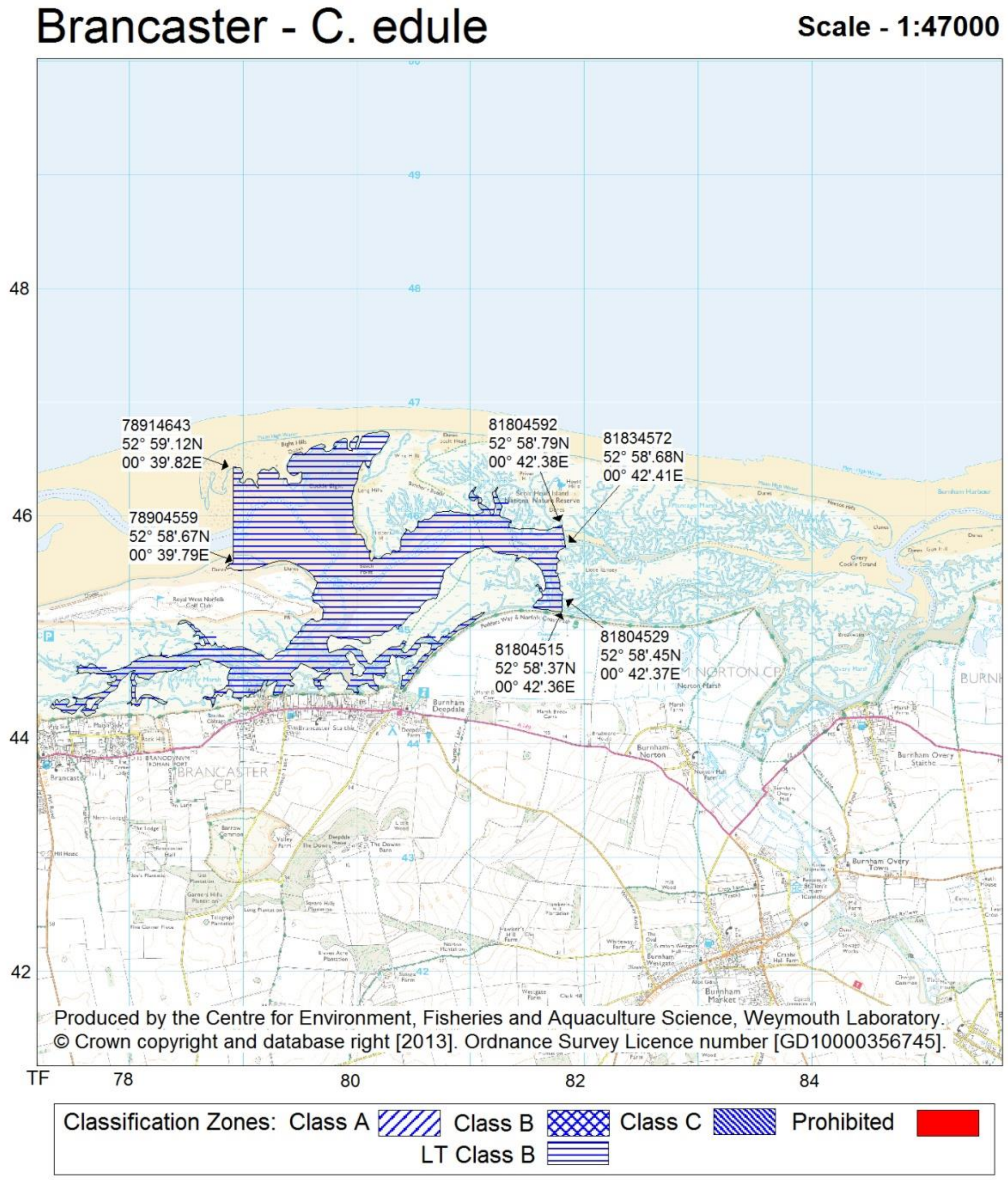
N.B. Lat/Longs quoted are WGS84

Food Authority: Kings Lynn and West Norfolk Borough Council

Figure 4.5: Current Pacific oyster classifications (Thornham)



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N.B. Lat/Longs quoted are WGS84
Separate maps available for C. gigas and Mytilus spp. at Brancaster

Food Authority: Kings Lynn and West Norfolk Borough Council

Figure 4.6: Current cockle classifications

Table 4.2: Criteria for classification of bivalve mollusc production areas.

Class	Microbiological standard[1]	Post-harvest treatment required
A[2]	Live bivalve molluscs from these areas must not exceed 230 Most Probable Number (MPN) of *E. coli* 100g-1 Fluid and Intravalvular Liquid (FIL)	None
B[3]	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	Purification, relaying or cooking by an approved method
C[4]	Live bivalve molluscs from these areas must not exceed the limits of a five-tube, three dilution Most Probable Number (MPN) test of 46,000 *E. coli* 100g-1 FIL	Relaying for, at least, two months in an approved relaying area or cooking by an approved method
Prohibited[6]	>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.
[6] Areas which are not classified and therefore commercial harvesting of LBMs cannot take place. This also includes areas which are unfit for commercial harvesting for health reasons e.g. areas consistently returning prohibited level results in routine monitoring and these are included in the FSA list of designated prohibited beds

5. Overall Assessment

5.1. Aim

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

5.2. Shellfisheries

There is a mixed shellfishery within Brancaster Harbour, which lies on leased ground and was until recently the subject of a fishery order. This fishery order is now in the process of being renewed. Within this area mussels are cultured from wild seed on the sea floor, Pacific oysters are cultured on trestles, and cockles are sometimes transplanted from the Wash in summer and ongrown for harvest in the winter months. There is also a single trestle site in one of the saltmarsh creeks that branches off Thornham Harbour. All these fisheries require continued classification. Mussels and oysters may potentially be re-immersed at the slipway by Brancaster harbour so this area will also require classification for these species. All species may potentially be harvested at any time of year, although mussels are normally harvested from September to March and cockles are usually harvested in the winter. Therefore year round classification is required for all species.

Cockles have been classified on the basis of mussel sample results since at least 2004, and this arrangement was based on parallel monitoring of the two species at Brancaster. Cockles and mussels accumulate *E. coli* to similar levels on average, but a tendency for cockles to return more extreme high results has been noted (Younger & Reese, 2011) so it is preferable that the cockles are monitored and classified separately. A further consideration is the lack of sufficient cockle stock for sampling throughout much of the area requiring classification and the uncertainty of their current status. On balance it is concluded that it is acceptable to classify cockles on the basis of mussel monitoring. As the recommended mussel RMPs are located in areas which are considered to represent the most contaminated areas within their respective classification zones, this will mitigate the species difference to some extent.

There are several mussel pits, where Pacific oysters and/or mussels are held for short periods of up to 2 days for mussels and 10 days for oysters between harvesting and depuration. This process serves two purposes. The shellfish purge sediment whilst immersed in the pits, and they provide a storage facility that allows the harvesters access to stock to feed into their depuration plants when the shellfish on the lays are inaccessible due to tidal conditions. There are several of these in close proximity to one another just to the east of Brancaster Harbour slipway of which two are serviceable and active, and a single pit on the foreshore at Brancaster Staithe which is also in use. They are shallow (<1 m deep), water is exchanged regularly on mid to large sized tides, and there are no sources of contamination discharging directly to any of them. As such it is anticipated that water indicator bacteria carried in when water is exchanged will die off particularly in warm sunny conditions and they will generally contain negligible amounts of microbiological contamination. They may however be vulnerable to contamination from birds and dogs so it may be prudent for the harvesters to prevent these animals from accessing them by fencing or bird scarers for example. The only firm information on their bacterial content is a single water sample taken from the single pit at Brancaster Staithe during the shoreline survey, which contained <10 *E. coli* cfu/100ml. This demonstrates that microbiological contamination within the pit was low at the time of survey, but is insufficient to make a robust assessment of their hygiene status.

Clarification was sought from the competent authority (the FSA) on the status of the pits under legislation since it was not clear whether they should be considered as part of the production area, or as relay sites or some other status, and thus whether they should be separately monitored. The FSA advised that they considered these pits to be part of the same water body as the adjacent harvesting area as water is exchanged between them regularly, and advised that the pits may therefore be classified without the need for additional sampling directly from them for classification. Our recommendations on monitoring have therefore followed this direction. The classified zone should continue to include the pits by the harbour, and should be extended with immediate effect to include the pit at Brancaster Staithe. The operators must however take all reasonable steps to ensure no additional contamination is introduced to stocks held within them.

5.3. Pollution Sources

Freshwater Inputs

The survey catchment is underlain by chalk, so the majority of flows through the area are via groundwaters rather than surface water. Flows of water through aquifers is typically very slow so microbiological contamination from surface sources (e.g. agriculture) or direct to ground-waters (e.g. sewage soakaway systems) will not generally be carried into coastal waters in a viable state. There are only two minor rivers draining to the shore, both of which are largely spring fed. Both flow through areas of pasture so are likely to carry contamination of livestock origin.

The River Burn is the larger of the two, with a mean flow of 0.32 m^3/sec, and drains to the coast at Burnham Overy. Given the location of its outfall its impacts are likely to be limited to Overy Creek, but it is possible that some influence may be felt in the connected tidal creeks off Brancaster. Flow gauging records showed no particularly high flow events and a steady discharge rate that is characteristic of groundwater fed streams. Flows were higher on average from December through to May, which is consistent with recharging of the aquifers during the colder months of the year when there is less evaporation and transpiration.

The River Hun is a smaller watercourse which flows through the west of the catchment into a creek draining to the outer reaches of Thornham Harbour. It may potentially be an influence at the oyster site off Thornham, but this is in a separate creek. There is no flow gauging station on the Hun but the seasonal pattern of flows is likely to be similar to that observed on the Burn.

A series of springs emerge in this coastal strip and directly to coastal waters, and there are several surface water outfalls to the shore which may be of local significance. During the shoreline survey two minor freshwater inputs were observed along the Brancaster shoreline, and two were observed feeding into the creek in which the oysters at Thornham are cultured. The *E. coli* concentrations in water samples from these inputs were very low in all cases (maximum 30 cfu/100ml). All were small and so their impacts are likely to be very minor, although it is possible that the *E. coli* concentrations they contain may vary significantly with time, for example if livestock are moved into any fields that they run through.

Human Population

Total resident population within census areas contained within or partially within the survey catchment was approximately 17,000 at the time of the last census. Population densities are low and the catchment is largely rural. There are small settlements at the head of both Brancaster and Thornham Harbours within which the shellfisheries are located, and these are more extensive at Brancaster. Some urban runoff may therefore be anticipated but the pattern of sewage impacts will depend on the nature of the sewerage infrastructure in the area.

The north Norfolk coast is popular with holiday makers, with several caravan and campsites along the coast for example. It is therefore expected that the population in the area will peak during the summer holiday season, and the volumes of sewage received by sewage works serving the area will fluctuate accordingly.

Sewage Discharges

There are only three water company owned sewage works within the survey catchment. Two of these are small works located a significant distance inland which discharge to ground-waters and so will not be of any influence to the fisheries. The third (Burnham Market STW) discharges to the lower reaches of the River Burn, and is consented for a dry weather flow of 838 m^3/day. The effluent receives UV disinfection, and based on only nine final effluent testing results it is estimated that this STW discharges an average bacterial loading of 2.3×10^{10} faecal coliforms/day. It is therefore concluded that this works will make a fairly minor contribution to the bacterial loading carried into Overy Creek by the River Burn.

Within the survey catchment there are five intermittent sewage discharges associated with the sewer network. No spill records were available for any of these at the time of writing, so it is difficult to assess their impacts apart from noting their location and their potential to discharge storm sewage. Three discharge to the River Hun system, one discharges to the River Burn, and one discharges to soakaway. As such, both the Hun and the Burn may be affected from time to time, and any major or prolonged spills from these assets would significantly increase the bacterial loadings they deliver to coastal waters.

Whilst the vast majority of properties in the survey area are connected to mains sewerage, there are 15 private sewage discharges listed on the Environment Agency permit database. The largest of these is at Holkham Hall, about 9 km east of the nearest shellfishery. It provides lagoon settlement for a maximum flow of 94 m^3/day, and discharges to the marsh drainage ditches at Holkham, and has a second consent for emergency discharges. Given its location it can be concluded that this discharge will have no impact on the shellfisheries. Other private discharges are all small (<5m^3/day), serving one or a small number of properties, and typically provide treatment via package plant. Seven discharge to the River Burn, and four discharge to the River Hun, and these will make minor contributions to the bacterial loading carried by these watercourses. The remainder discharge to soakaway so should be of no influence.

Agriculture

The vast majority of agricultural land within the hydrological catchment of the shellfisheries at Brancaster is used for arable farming. There are also some areas of pasture, and these are located along the banks of most of the River Burn, and some of the fields adjacent to the coast, including the land surrounding the lower reaches of the River Hun. The predominance of groundwater rather than surface water flows in the catchment means that away from coastal areas and the two minor rivers, there is little risk of microbiological contamination from agriculture being carried into coastal waters before it dies off. Numbers and densities of livestock within the survey catchment are relatively low, with totals of 432 cattle, 1979 sheep and 97 poultry recorded in the last detailed census (2010). No livestock was seen during the shoreline survey. However, the geographical distribution of pasture suggests that the two principle watercourses (the Burn and the Hun) and some of the smaller field drains from the coastal areas of reclaimed pasture are likely to be affected. The extent of these impacts will be influenced by the amount of access livestock have to these watercourses. The spatial pattern of application of organic fertilisers (manures, slurries and sewage sludge) to arable crops is uncertain, but arable land is widespread throughout the catchment.

The primary mechanism for mobilisation of faecal matter deposited or spread on farmland to coastal waters is via land runoff. Fluxes of agricultural contamination into the area will be highly rainfall dependent. Rainfall does not vary greatly through the year and high rainfall events may occur at any time. Peak concentrations of faecal indicator bacteria in watercourses are likely to arise when heavy rain follows a significant dry period (the 'first flush').

Numbers of sheep and cattle will increase in the spring with the birth of lambs and calves, and decrease in the autumn when animals are sent to market. Livestock are likely to access watercourses to drink and cool off more frequently during the warmer months. The seasonal pattern of application of manures and slurries to farmland is uncertain, although as the area is within a nitrate vulnerable zone spreading is not permitted during the winter. Therefore peak levels of contamination from livestock may arise following high rainfall events in the summer, particularly if these have been preceded by a dry period which would allow a build up of faecal material on pastures, or on a more localised and possibly more intense basis if wet weather follows a slurry application, which is not permitted during the winter.

Boats

The discharge of sewage from boats is a potential source of bacterial contamination to shellfisheries within the Brancaster survey area. There are small harbours at Burnham Staithe, Brancaster and Thornham, of which Brancaster is the largest and most heavily used. There are large numbers of moorings around these harbours. They are most numerous by Brancaster Harbour, where they extend throughout much of Mow Creek. The shallow nature of the area dictates that only small vessels will enter these harbours, so boat traffic is limited to fishing boats and leisure craft such as small yachts, sailing dinghies and kayaks. Some of the larger craft are likely to be sufficiently large to have on-board toilets, and so may make overboard sewage discharges. This may either occur when the boats are moored, particularly if they are in overnight occupation, or while they are navigating through the area. Therefore, whilst overboard discharges may be made anywhere within the survey area, it is likely that the moorings and the main navigation routes through the area are most at risk of contamination from this source. The more inshore areas of the Brancaster shellfishery are therefore at most risk. The creek in which the Thornham oyster site is located does not have any moorings and is a 'dead end' so is unlikely to see much, if any, boat traffic within it. There are no shellfish resources in the vicinity of Burnham Staithe.

Peak pleasure craft activity is anticipated during the summer, so associated impacts are likely to follow this seasonal pattern. It is difficult to be more specific about the potential impacts from boats and how they may affect the sampling plan without any firm information about the locations, timings and volumes of such discharges.

Wildlife

The survey area encompasses a variety of coastal habitats which support a diversity of wildlife. The most significant wildlife aggregation from the shellfish hygiene perspective is likely to be overwintering waterbirds (wildfowl and waders). Over the five winters up until 2010/11 an average maximum count of 198,969 was recorded along the North Norfolk Coast. This included both wading birds which forage on the intertidal areas for invertebrates, and grazers such as geese which feed on pastures, saltmarsh and seagrass. Contamination from the former will be deposited directly on the intertidal and whilst it may be a significant contaminating influence at times it may be regarded as a diffuse source and will not influence the location of the RMPs. Contamination deposited by grazing birds on fields and saltmarsh will be washed into the area via runoff and tidal inundation, so will tend to be more concentrated in the vicinity of drainage channels from field drains and creeks draining saltmarsh areas. It is possible that birds may be an occasional contaminating influence at the mussel pits.

Whilst most of these birds migrate away from the area to breed, there are significant populations of resident and breeding seabirds (gulls, terns etc). Bird numbers and therefore their likely impacts on shellfish hygiene are considerably lower outside of the overwintering period. A survey undertaken during the breeding season in 2000 recorded a total of 6,044 pairs of terns and gulls from Thornham Harbour through to Overy Creek. The main aggregation was of 5,659 pairs of terns by the western end of Scolt Head Island. These seabirds are likely to forage widely throughout the area so inputs could be considered as diffuse, but are likely to be most concentrated in the immediate vicinity of the nest sites. Their faeces will be carried into coastal waters via runoff from their nesting sites or via direct deposition to the adjacent intertidal. As such the areas adjacent to Scolt Head Island may be more at risk, although the island is large and the nest sites are likely to be quite spread out.

There are major seal colonies within The Wash and at Blakeney, which lie either side of the survey area. The colony in The Wash supported almost 3,000 animals in 2011. They haul out on sandbanks and islands at low tide, and it is at these locations where their impacts will be highest. No regular haul out sites have been identified within the survey area. Given their wide ranging habits they are likely to be a regular presence within the survey area, but their impacts are likely to be minor, and unpredictable in spatial terms and so will have no material bearing on the sampling plan. No other wildlife species likely to be a significant influence on shellfish hygiene in the area have been identified.

Domestic animals

Dog walking takes place on the beaches and paths adjacent to the survey area, and represents a potential source of diffuse contamination to the near shore zone. Footpaths by the more heavily populated areas are likely to see a greater intensity of dog walking. However, as a diffuse source this will have little influence on the location of RMPs. It is possible that dogs may be an occasional contaminating influence at the mussel pits.

Summary of Pollution Sources

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

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

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

Red - high risk; orange - moderate risk; yellow - lower risk; white - little or no risk.

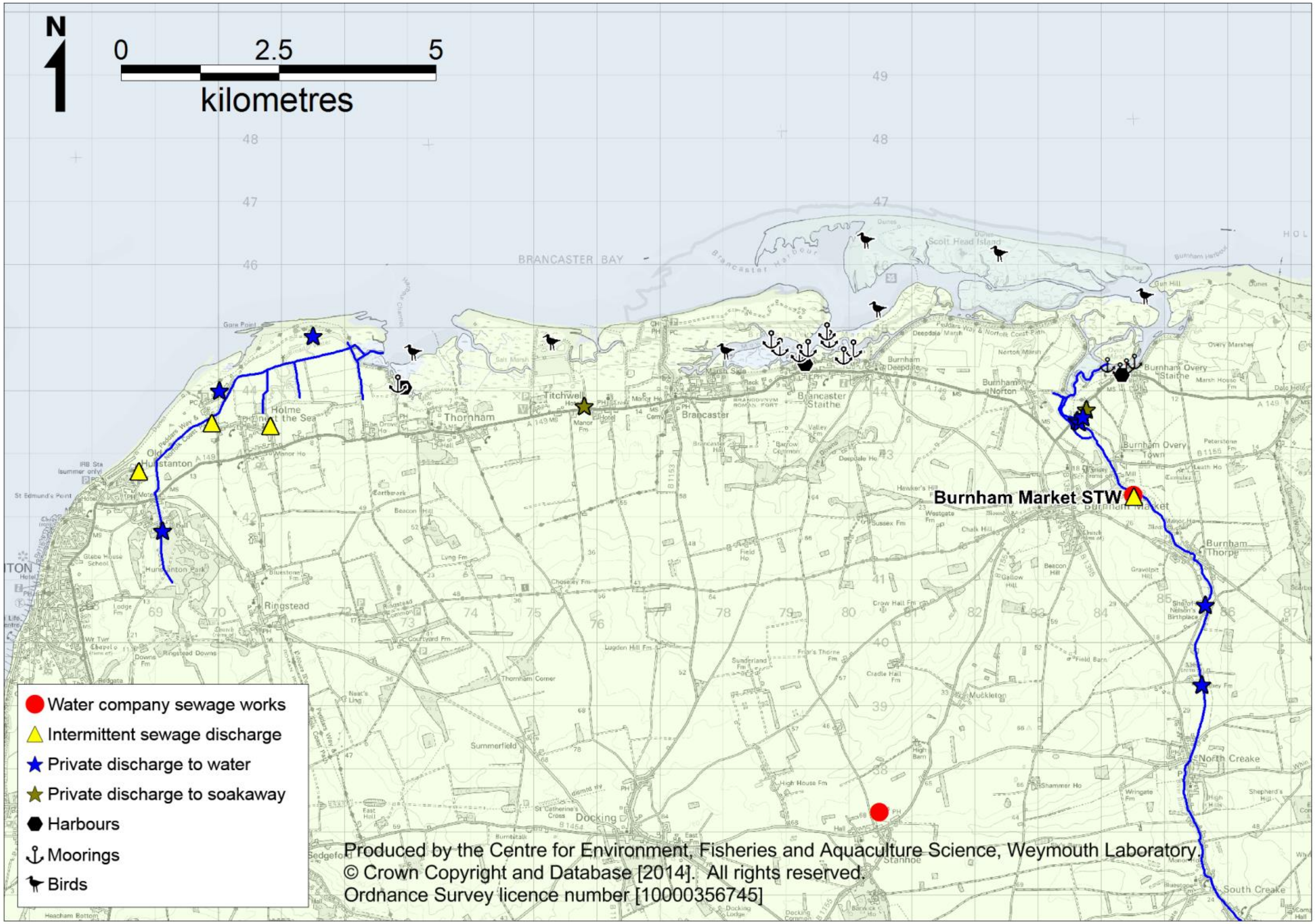

Figure 5.1: Summary of main contaminating influences

5.4. Hydrography

The survey area consists of barrier beaches, behind which there are extensive areas of saltmarsh with complex networks of tidal creeks within which the shellfisheries lie. Offshore from the beaches the subtidal area is shallow and flat, and is characterised by mobile sandbanks. Most of the shellfisheries lie in the network of creeks between Brancaster and Burnham Overy, but there is also a Pacific oyster trestle farm in Thornham Harbour, which is a separate (unconnected) system.

Within Thornham Harbour there is one subtidal connection to the North Sea, which splits into three main arms, off which there are numerous smaller branching intertidal creeks. The eastern arm contains the shellfishery, the central arm contains the harbour, with the village of Thornham at its head, and the western arm receives the River Hun at its head. The network of creeks between Brancaster and Burnham Overy is more extensive and complex. There are two subtidal channels at either end which connect it to the North Sea (Brancaster Harbour and Burnham Overy Harbour). Brancaster Harbour creek splits into a large dendritic network of creeks off Brancaster, Brancaster Staithe and Burnham Deepdale. There are several smaller creeks branching off the main Burnham Overy creek in various directions. The River Burn discharges to the inner reaches of Burnham Overy Creek. Brancaster Harbour and Burnham Overy Harbour are connected via the saltmarsh creeks. The main connection between the two is Norton Creek, although there is at least one other much narrower connection via Trowland Creek. The shallow nature of these creeks will limit the potential for dilution, but will result in a large proportion of the water within them being exchanged each tide.

Currents in coastal waters are predominantly driven by a combination of tide, wind and freshwater inputs. The tidal range is relatively large, and drives extensive water movements through the area. It increases along the Norfolk coast from 4.2 m at Cromer to 6.1 m at Hunstanton on spring tides. It is reduced in the saltmarsh creeks compared to the open coastal stations. The flood streams move in a westerly direction offshore from the survey area, and reverse on the ebb, so water flooding into the inlets arrives from the east. High water arrives at about the same time at the mouths of the three harbour channels considered in this survey.

As water levels rise, flood streams travel up the creeks, splitting as they branch. As the channels fill, water will spread from the channels over the adjacent sand flats and mudflats. After high water, the water levels will drop and the tidal streams will follow the same path back out. Shoreline sources of contamination will therefore primarily impact up and down tide of their locations along the bank to which they discharge. Their impacts will decrease with distance travelled, as the plume becomes progressively more diluted. At lower states of the tide contamination from some shoreline sources such as watercourses will be carried through the intertidal drainage channels where the dilution potential is low. Relatively high concentrations of indicator bacteria may arise in these channels at such times. Sources of contamination discharging to an individual creek will not generally impact on neighbouring branches as tidal streams will be ebbing from both at the same time. This is of importance to the assessment as it indicates that the River Hun will not impact on the Pacific oyster site at Thornham. Similarly it suggests that contamination from shoreline sources at Brancaster will not come into contact with shellfisheries in Norton Creek, apart from those around its mouth. Tides enter Norton Creek from both ends at about the same time, and meet in the middle to the east of the shellfish sites. They then drain away in the opposite direction after high water, so contamination originating from the Burnham Overy area will not impact on the shellfish in the western end of Norton Creek.

Freshwater inputs are limited to two minor rivers, and a series of coastal springs and field drains. As some of these springs feed directly into coastal waters it is difficult to quantify the volumes involved, although they are likely to be minor in relation to the volumes of water exchanged tidally. Repeated salinity measurements taken within the survey area indicate average salinities approaching that of full strength seawater in the outer reaches of the Harbours and at the entrance to Thornham Harbour. There was more variation in salinities in the inner reaches of the tidal creeks at Brancaster Staithe and Burnham Overy, where salinities of less than 10 ppt were recorded on occasion. The River Burn is likely to be largely responsible for the lower salinities at Burnham Overy monitoring points. There are no visible freshwater inputs to the head of Mow Creek where the Brancaster Staithe Shellfish Water is situated, but freshwater springs emerging in the marshes may account for the low salinity readings. The salinity measurements suggest that some density effects may arise in the more inshore areas. When such effects occur, they will result in a shear between surface and bottom currents, with less dense freshwater moving in a net seaward direction at the surface, and a net inshore movement of more saline water lower in the water column. Salinity may be considered a proxy for levels of runoff borne contamination. Although a significant correlation between salinity and levels of faecal coliforms was found at Brancaster Staithe this relationship was much weaker than is typical, suggesting freshwater inputs are not carrying high levels of faecal coliforms and therefore largely originated from groundwaters.

Strong winds can modify circulation by driving surface currents, which in turn create return currents which may travel lower in the water column or along sheltered margins. The low lying land affords minimal shelter from winds, so wind driven currents may significantly modify circulation within the area at times. Exact effects are dependent on the wind speed and direction as well as state of the tide and other environmental variables so a great number of scenarios may arise. Where strong winds blow across a sufficient distance of water they may create wave action, and where these waves break, contamination held in intertidal sediments may be re-suspended. Given the enclosed nature of the survey area strong wave action is not anticipated.

5.5. Summary of Existing Microbiological Data

The survey area has been subject to considerable microbiological monitoring over recent years, deriving from the monitoring of recreational (bathing) water quality, the Shellfish Waters monitoring programme, and shellfish flesh monitoring for hygiene classification purposes. Figure 5.2 shows the locations of the monitoring points referred to in this assessment. Results from 2003 onwards are considered in these analyses.

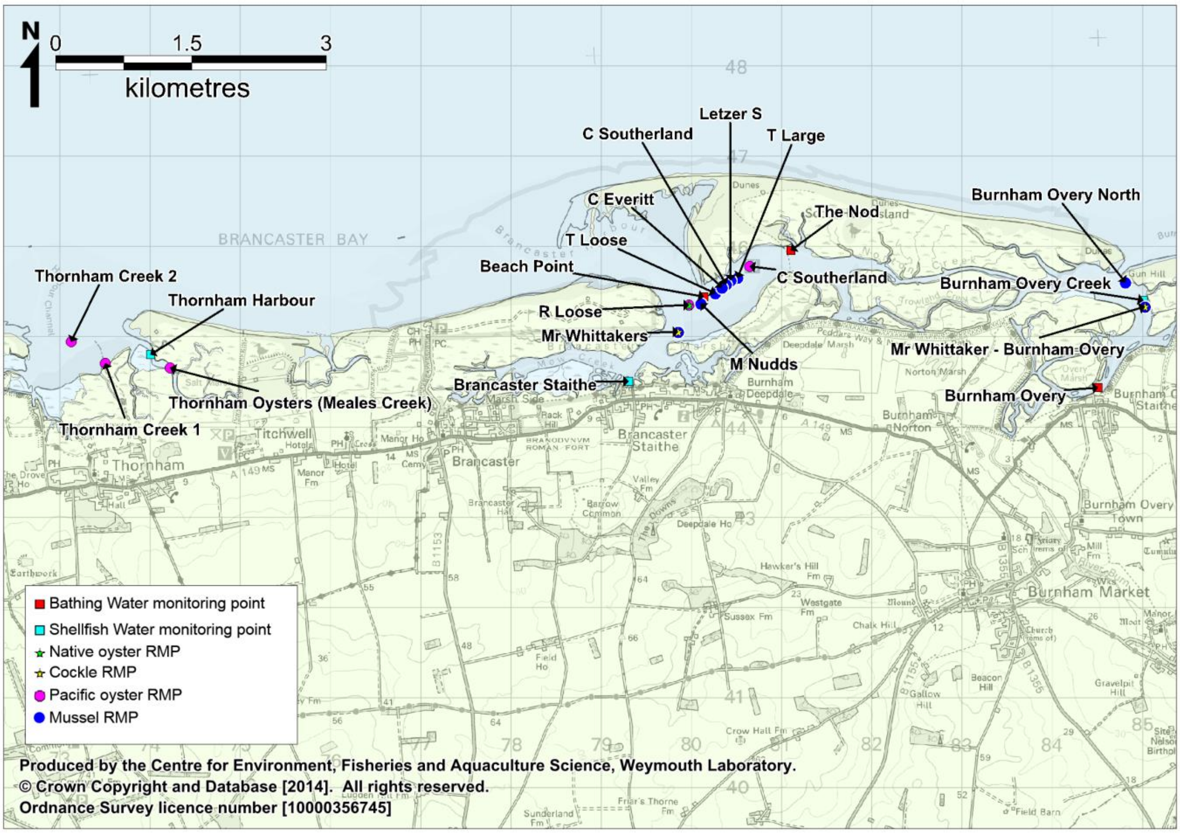

Figure 5.2: Location of microbiological sampling sites.

Although there are no designated bathing waters relevant to the survey area, three locations have been subject to bacteriological sampling to assess the quality of recreational waters in recent years (Beach Point, The Nod and Burnham Overy). Across these three sites, results were significantly higher on average at Burnham Overy compared to Beach Point and The Nod. The geometric mean results at these three sites were 212.9, 11.1 and 12.1 faecal coliforms/100ml respectively, so the average result at Burnham Overy was an order of magnitude higher than at the two sites in Norton Creek. Comparisons of paired (same day) sample results across these three sites showed results were strongly correlated at The Nod and Beach Point, but there was no correlation between either of these two sites and Burnham Overy. This indicates that the inshore reaches of Overy Creek are much more contaminated than Norton Creek, and the two are subject to different sources of contamination.

The seasonal pattern of results at Beach Point and The Nod were similar, with higher average results during the autumn and winter. This was only statistically significant for Beach Point. No seasonal pattern of results was observed at Burnham Overy, again suggesting it is subject to a different profile of contamination sources than the two sites in Norton Creek. Significant variations in levels of faecal coliforms were found in relation to the high/low tidal cycle at The Nod and Burnham Overy, but not at Beach Point. At The Nod higher results tended to occur as the tide was ebbing suggesting sources to the east are of importance. At Burnham Overy, higher results tended to occur towards the end of the ebb and over low water, suggesting that inshore sources are of influence. It may also indicate that the lower scope for dilution around low water results in higher concentrations of faecal indicator organisms in the water column. A significant influence of the spring/neap tidal cycle was found at Burnham Overy only. Here, most of the higher results occurred as tide sizes increased towards spring tides. The reasons for this are unclear. Some limited influence of recent rainfall on faecal coliform concentrations was found at all of the three monitoring points.

There are three shellfish waters monitoring points within the survey area: Brancaster Staithe, Burnham Overy Creek and Thornham Harbour. Water samples are taken from these on a quarterly basis and enumerated for faecal coliforms. Brancaster Staithe has been sampled since 2003, and during some periods of its monitoring history was sampled more frequently than quarterly. Burnham Overy and Thornham Harbour have been sampled since 2011, and total sample numbers were only 11 and 8 from these two monitoring points. The average results from these three sites were broadly similar, ranging from 19.2 (Thornham Harbour) to 62.7 faecal coliforms/100ml (Burnham Overy). The limited sample numbers from two of the sites precluded any meaningful geographic analysis across the shellfish waters monitoring points. The geometric mean result at Brancaster Staithe (52 faecal coliforms/100ml) was higher than that recorded at the two bathing waters sites in Norton Creek. Although the temporal profile of sampling effort differed between the two programmes, this does suggest that levels of contamination increase in the more inshore areas and/or they are higher in the Brancaster Harbour creek than in Norton Creek.

Statistically significant seasonal variation was found at Brancaster Staithe, where results were higher in autumn than the spring, similar to that observed at the two bathing waters sites in Norton Creek. A significant influence of both the spring/neap and high/low tidal cycle was seen at Brancaster Staithe. Across the high/low cycle faecal coliform concentrations tended to be higher at lower states of the tide, and across the spring/neap cycle results tended to be higher on increasing and spring tides. At Brancaster Staithe, significant correlations were found between rainfall in the previous three days and faecal coliform levels suggesting that land runoff is an influence, in the inshore areas at least. There was also a significant correlation between faecal coliform levels and salinity at Brancaster Staithe, but the effect was weaker than is typical.

There are a total of 19 RMPs in the Brancaster production area that have been sampled between 2003 and 2013 for hygiene classification purposes. Two of these RMPs are for cockles, nine are for mussels, one is for native oysters and seven are for Pacific oysters. Both cockle RMPs (Mr Whittakers and Mr Whittakers - Burnham Overy), the native oyster RMP (R Loose), four of the Pacific oyster RMPs (Thornham Creek 1, Thornham Creek 2, T Loose and Whittaker - Burnham Overy) and one mussel RMP (Letzer S) were sampled on less than 10 occasions so were not considered in the statistical analyses.

Across the mussel RMPs at Brancaster Staithe, results were highest on average at the innermost RMP in the Brancaster Harbour channel (Mr Whittakers) and this was the only RMP here that recorded results exceeding 4,600 *E. coli* MPN/100g. Results at the remaining five RMPs here, which are all in Norton Creek, were broadly similar with no apparent gradient of increasing contamination along the length of the creek. The two main Pacific oyster RMPs at Brancaster Staithe (R Loose and C Southerland) are located at either end of Norton Creek. The western RMP had a slightly higher geometric mean result, and was the only one of the two where results exceeding 4,600 *E. coli* MPN/100g were recorded. This may suggest a slight increase in levels of contamination towards the confluence with the Brancaster Harbour channel, although this was not seen in the more comprehensive mussel monitoring data. Within Overy Creek, the results at the two main mussel RMPs (Burnham Overy North and Whittaker – Burnham Overy) were higher on average than at any of the RMPs within the Brancaster Staithe area. Across these two RMPs the geomertric mean results were very similar, but there was a higher proportion of results at the innermost site (11.7%) than at the outermost site (5.9%). As there was only one main RMP in the Thornham area, an assessment of spatial variation in levels of contamination within this water body was not possible.

No overall increasing or decreasing trends in levels of contamination since 2003 were seen for the mussel RMPs, but results from the three main Pacific oyster RMPs suggest an increase in average results during this period. The reasons for the different temporal trend between these two species in unclear, particularly given that the two are sampled in close proximity to one another. Some seasonality was apparent at both the mussel RMPs and the three main Pacific oyster RMPs. The general trend was for lower results in the spring, and higher results in the summer and autumn. Seasonal variation was statistically significant at three of the mussel RMPs (Mr Whittakers, T Loose and Whittaker - Burnham Overy) and all three of the main Pacific oyster RMPs.

A statistically significant influence of the high/low tidal cycle was detected at the three Pacific oyster RMPs, but at none of the mussel RMPs. At the Pacific oyster RMPs, higher results occurred at lower states of the tide, perhaps suggesting that inshore sources are of significance, or possibly resulting from the reduced dilution at such times. A significant influence of the spring/neap cycle was detected at two of the

Pacific oyster RMPs (Thornham Oysters (Meales Creek) and C Southerland). At both of these RMPs results were higher on average during spring tides and tides of increasing size. This suggests that contamination washed from intertidal areas may be of some influence. Rainfall had little or no influence on *E. coli* levels at most sites. A consistent influence was found at Thornham Oysters (Meales Creek) suggesting that rainfall dependent sources are of most significance to shellfisheries in the Thornham area. A more limited influence was found at the innermost RMP in Overy Creek (Whittaker – Burnham Overy) but not at the outermost RMP in this creek (Burnham Overy North). Significant correlations (both positive and negative) were occasionally detected at some RMPs in the Brancaster Staithe area, but it is considered likely that these arose by chance alone. It is therefore concluded that the influence of rainfall dependent sources at Brancaster Staithe does not generally extend out as far as the location of the RMPs.

Bacteriological survey

Due to the extensive monitoring history it was considered that there was little to be gained through undertaking a limited bacteriological survey.

Appendices

Appendix I. Human Population

Figure I.1 shows population densities in census output areas within or partially within the Brancaster catchment area, derived from data collected from the 2011 census.

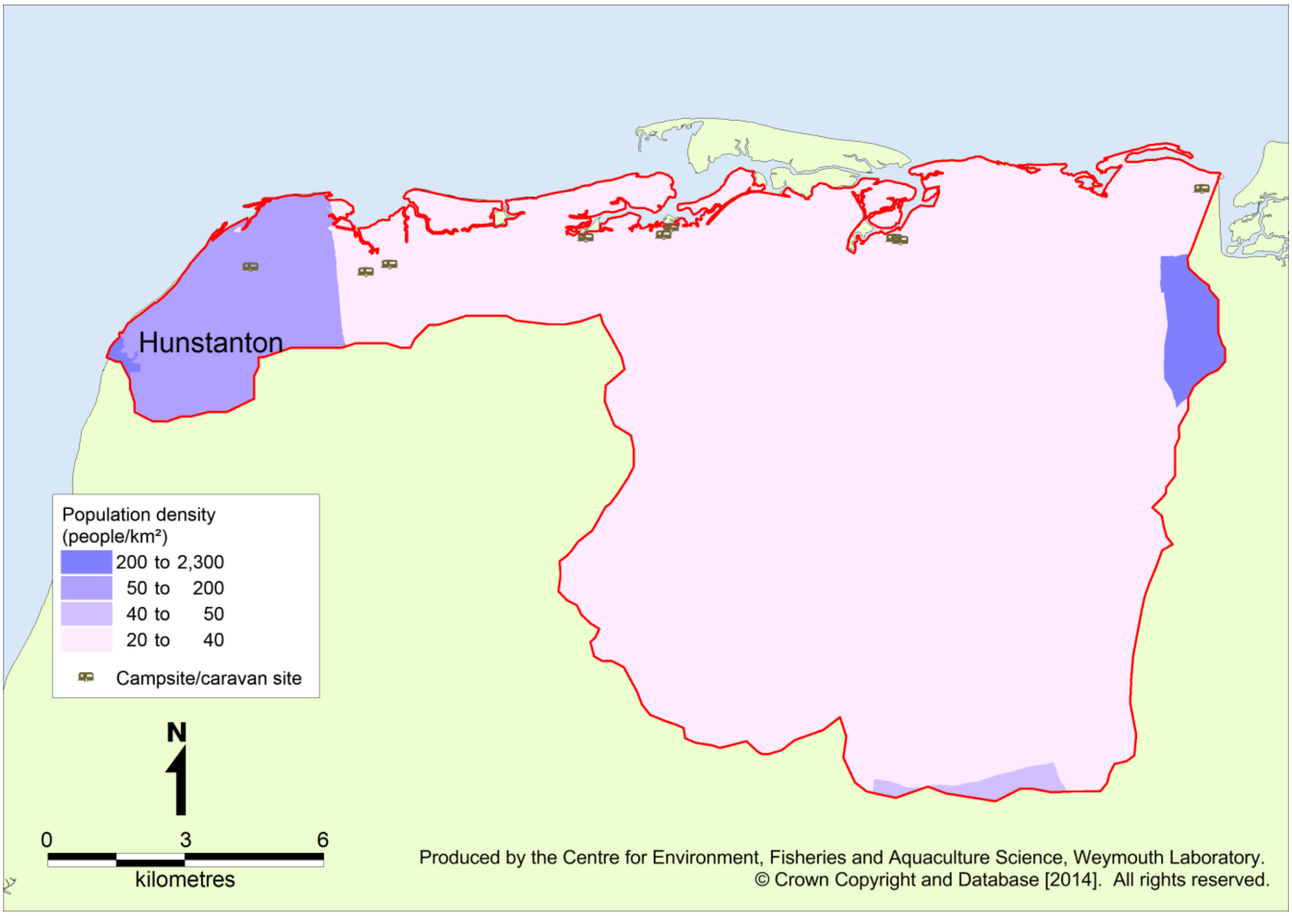

Figure I.1: Human population density in census areas in the Brancaster catchment.

Total resident population within census areas contained within or partially within the catchment area was approximately 17,000 at the time of the last census. The largest settlement in the area is Hunstanton, which had a population of about 5,000, but only 1,300 of which live in the Brancaster catchment. The areas directly adjacent to the shellfisheries had low population densities of less than 40 people/km². There are small settlements at the head of both Brancaster Harbour and Thornham Harbour in which the shellfisheries are located.

In 2010 approximately 694,000 trips were made to North Norfolk, with a total of 2.4 million nights stayed (Tourism South East). The majority of these trips (78 %) were for holidays. About 30 % of trips were made to coastal areas. As these figures are for all of North Norfolk, much of this tourism will be in areas other than the Brancaster catchment. However, there are several caravan and campsites in the catchment mainly concentrated along the coast, (Figure I.1) indicating that there is tourism in this area. Therefore it can be expected that the population of the catchment will fluctuate slightly throughout the year, with increases in sewage outputs fluctuating accordingly, with higher population likely to be during the spring and summer.

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

Details of all sewage discharges in the hydrological catchment were taken from the most recent update of the Environment Agency national permit database (October 2013). These are mapped in Figure II.1, and details are presented in Table II.1.

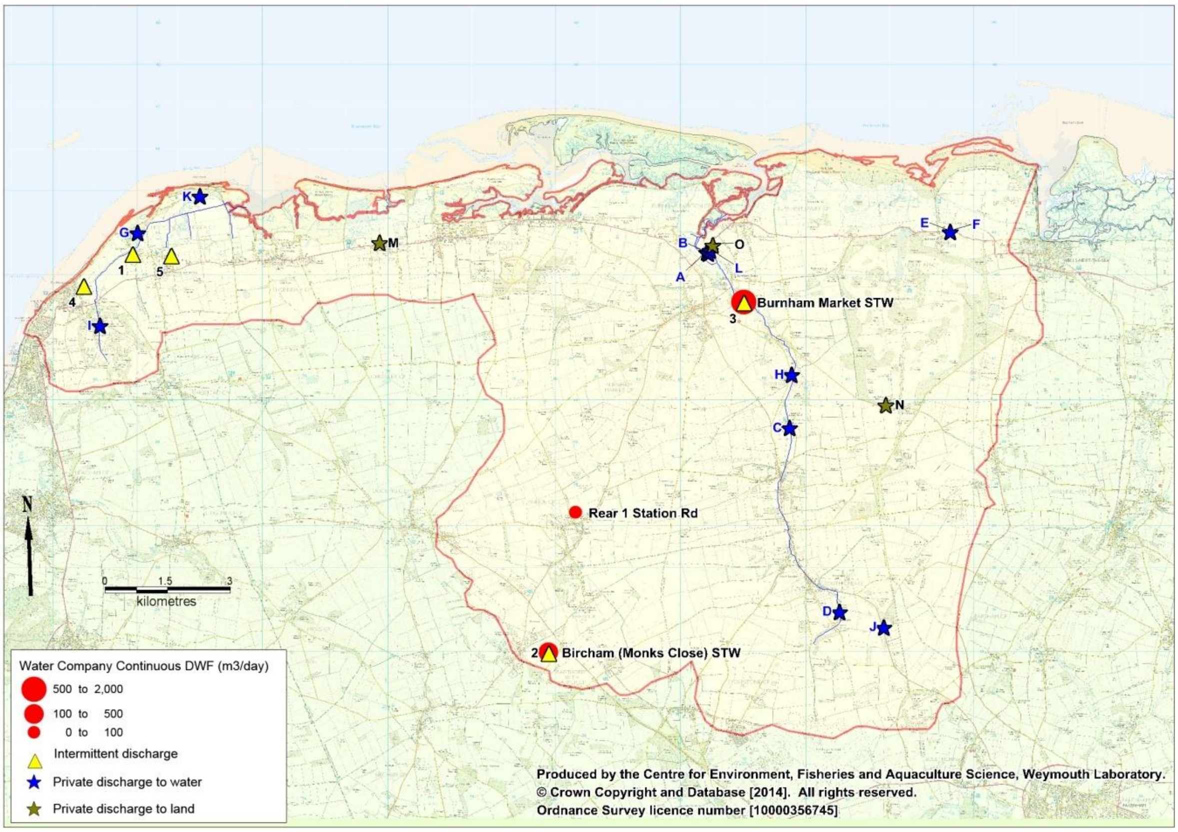

Figure II.1: Sewage discharges in the Brancaster catchment

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

Name	NGR	Treatment	Dry weather flow (m^3/day)	Estimated bacterial loading (cfu/day)*	Receiving environment
Bircham (Monks Close) STW	TF7984033970	Biological Filtration	143	4.72×10^{11}	To Land
Burnham Market STW	TF8451042340	UV Disinfection	838	2.26×10^{10}**	River Burn
Rear 1 Station Rd	TF8048037310	Biodisc	11***	3.63×10^{10}	To Land

*faecal coliforms (cfu/day) based on geometric base flow averages from a range of UK STWs providing secondary treatment (Table II.2).
** *E. coli*/day based on final effluent testing results (Table II.3)
*** Maximum flow used as DWF not provided
Data from the Environment Agency

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

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

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

Table II.3: Final effluent testing results for Burnham Market STW

		E. coli result (cfu/100ml)		
Period covered	No. samples	Mean	Minimum	Maximum
April-Nov 2013	9	2,698	230	35,000

Data from the Environment Agency

The main continuous water company discharge in the catchment is Burnham Market STW which was upgraded to receive UV disinfection from April 2013. Bacteriological testing results from this works are limited but indicate that levels of *E. coli* in the final effluent are quite high for a UV treated works. Nevertheless, the average bacterial loading generated is small, but may occasionally increase significantly. It must be noted that UV disinfection is less effective at eliminating viruses than bacteria (Tree *et al*, 1997). The Burnham Market STW discharges to the River Burn, which in turn flows into Overy Creek. It may therefore potentially impact on the shellfisheries in Norton Creek and Brancaster Harbour, which are connected via the network of saltmarsh creeks between them. Water circulation patterns will determine the extent of these impacts, if any.

There are only two other continuous water company discharges in the catchment: Bircham (Monks Close) STW and Rear 1 Station Road. These are located ~7 km and ~10 km inland respectively and discharge to soakaway. As such they will not impact on the shellfisheries and will not be considered further.

In addition to the continuous sewage discharges, there are several intermittent discharges associated with the sewerage networks. The locations of these and of all private sewage discharges are also shown in Figure II.1.

Table II.4: Details of intermittent discharges in the Brancaster catchment

No.	Name	NGR	Type	Receiving water
1	Beach Rd SPS	TF6989043500	Emergency	River Hun
2	Bircham (Monks Close) STW	TF7984033970	Storm	To Land
3	Burnham Market STW	TF8451042340	Storm	River Burn
4	Smugglers Lane SPS	TF6873042740	Storm	Tributary of River Hun
5	Whitehall Farm SPS	TF7082043460	Emergency	Tributary of Marsh Dyke System

Data from the Environment Agency

No spill records were available for any of these at the time of writing, so it is difficult to assess their impacts apart from noting their location and their potential to discharge sewage. Two are for emergency discharges only (e.g. pump failures or blockages) whereas the other three are storm overflows and so may operate if the sewers become overloaded following heavy rainfall. Three discharge to the River Hun system, one discharges to the River Burn, and one discharges to soakaway.

Although the vast majority of the survey area is served by water company sewerage infrastructure, there are also a number of private discharges in the area. Where specified, these are generally treated by small treatment works such as package plants. The majority of these are small, serving one or a small number of properties. Details of the private discharges are presented in Table II.5.

Table II.5: Details of private sewage discharges in the Brancaster catchment

Ref.	Property served	Location	Treatment type	Max. daily flow (m^3/day)	Receiving environment
A	Burnham Overy Watermill	TF8361143549	Package plant	4	River Burn
B	Burnham Overy Watermill	TF8365043520	Unspecified	4	River Burn
C	Creake Abbey Units	TF8559039360	Package plant	3	River Burn
D	Grove Cottage	TF8679034960	Unspecified	2.2	River Burn
E	Holkham Estate (emergency)	TF8944044040	Screening	0	Holkham Marsh
F	Holkham Estate	TF8944044040	Lagoon Settlement	94	Holkham Marsh
G	Little Wilbur	TF7000344020	Package plant	1.5*	Trib of River Hun
H	Nelson's Barn, Loft and Stables	TF8563940629	Package plant	2.1	River Burn
I	The Clock Tower	TF6910041800	Unspecified	2	Trib of River Hun
J	The Common	TF8785034600	Unspecified	2	Trib of River Burn
K	The Firs plus annex	TF7149444885	Package plant	1	Broadwater
L	Watermill Cottages	TF8370043600	Package plant	3	River Burn
M	Briarfields Hotel	TF7579043780	Package plant	1.5	To Land
N	Pond Cottage	TF8790039900	Unspecified	1	To Land
O	Tower Mill	TF8375343722	Package plant	3.6	To Land

Data from the Environment Agency
*DWF used as no Maximum flow provided

Holkham Estate is the largest private discharge in the catchment with a consented maximum daily flow of 94 m^3/day, discharging effluent that has undergone lagoon settlement. Effluent from this works discharges to Wells Harbour via the network of marsh drainage ditches between Burnham and Wells, so will be of no impact at Brancaster. There is a cluster of small private discharges at Burnham Overy Staithe, approximately 5 km to the south east of the shellfisheries, which will contribute to microbiological loadings carried by the River Burn. One of these discharges to groundwater and as such should not impact on water quality provided the system is working effectively. It is unclear from data received whether the two Burnham Overy Watermill discharges are in fact two distinct discharges (they each have different grid references). There are three small private discharges in the vicinity of the River Hun that will make a minor contribution to the bacterial loading carried by this watercourse. Other private discharges are located at various points inland and will contribute background loadings to water courses leading to the coast, but are unlikely to be of consequence to water quality at the shellfisheries. All private discharges in the catchment are either small and/ or located at such a distance from the shellfisheries that they are unlikely to have a significant impact.

Appendix III. Sources and Variation of Microbiological Pollution: Agriculture

The vast majority of agricultural land within the hydrological catchment of the shellfisheries at Brancaster is used for arable farming. There are some small pockets of pasture. The land immediately adjacent to the River Burn is pasture along almost all of its length, and some of the fields adjacent to the coast are used for grazing, including the land surrounding the lower reaches of the River Hun. (Figure 1.2). Table III.1 presents livestock numbers and densities for the catchment. These data were provided by Defra and are derived from the June 2010 census. Geographic assignment of animal counts in this dataset is based on the allocation of a single point to each farm, whereas in reality an individual farm may span the catchment boundary. Nevertheless, Table III.1 should give a reasonable indication of the numbers and types of livestock within the catchment.

Table III.1: Summary statistics from 2010 livestock census for the Brancaster catchment

Cattle		Sheep		Pigs		Poultry	
No.	Density (no/km^2)	No.	Density (no/km^2)	No.	Density (no/km^2)	No.	Density (no/km^2)
432	2.3	1979	10.5	*	*	97	0.5

Data from Defra

**Data suppressed for confidentiality reasons*

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

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

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

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

Numbers and densities of livestock within the catchment are low, so the overall impact of livestock farming is likely to be relatively small. No livestock was seen during the shoreline survey. However, the geographical distribution of pasture suggests that the two principle watercourses (the Burn and the Hun) and some of the smaller field drains from the coastal areas of reclaimed pasture are likely to be affected. The extent of these impacts will be influenced by the amount of access livestock have to these watercourses. The spatial pattern of application of organic fertilisers (manures, slurries and sewage sludge) to arable crops is uncertain, but arable land is widespread throughout the catchment.

Faecal matter from livestock will either be deposited directly on pastures by grazing animals, or collected from cattle, pig and poultry rearing operations and spread on both arable land and pasture. This in turn may be washed into watercourses which will carry it to coastal waters. As the primary mechanism for mobilisation of faecal matter deposited on pastures into watercourses is via land runoff, fluxes of agricultural contamination into coastal waters will be highly rainfall dependent. Peak concentrations of faecal indicator bacteria in watercourses are likely to arise when heavy rain follows a significant dry period (the ‘first flush’). However, the underlying chalk means that groundwater flows predominate in the area. Faecal matter applied to or deposited on land away from the two principle watercourses or the lowest lying coastal areas will not tend to be washed into watercourses or field drains. Instead it will percolate into aquifers, through which the movement of water is very slow. It is therefore concluded that away from fields immediately adjacent to the main watercourses, or the reclaimed coastal areas, the potential for flux of microbiological contamination originating from agriculture into coastal waters is low.

There is likely to be seasonality in levels of contamination originating from livestock. Numbers of sheep and cattle will increase significantly in the spring, with the birth of lambs and calves, and decrease in the autumn when animals are sent to market. Livestock are likely to access watercourses to drink and cool off more frequently during the warmer months. In winter cattle may be transferred from pastures to indoor sheds, and at these times slurry will be collected and stored for later application to fields. Timing of these applications is uncertain, although the survey area is a nitrate vulnerable zone so spreading is not permitted during the winter. Therefore peak levels of contamination from grazing livestock may arise following high rainfall events in the summer, particularly if these have been preceded by a dry period which would allow a build up of faecal material on pastures, or on a more localised basis if wet weather follows a slurry application, which is not permitted during the winter.

Appendix IV. Sources and Variation of Microbiological Pollution: Boats

The discharge of sewage from boats is a potential source of bacterial contamination to shellfisheries within the Brancaster survey area. Boat traffic in the area is limited to smaller vessels such as fishing boats, small yachts, sailing dinghies and kayaks. Figure IV.1 presents an overview of boating activity derived from the shoreline survey, satellite images and various internet sources.

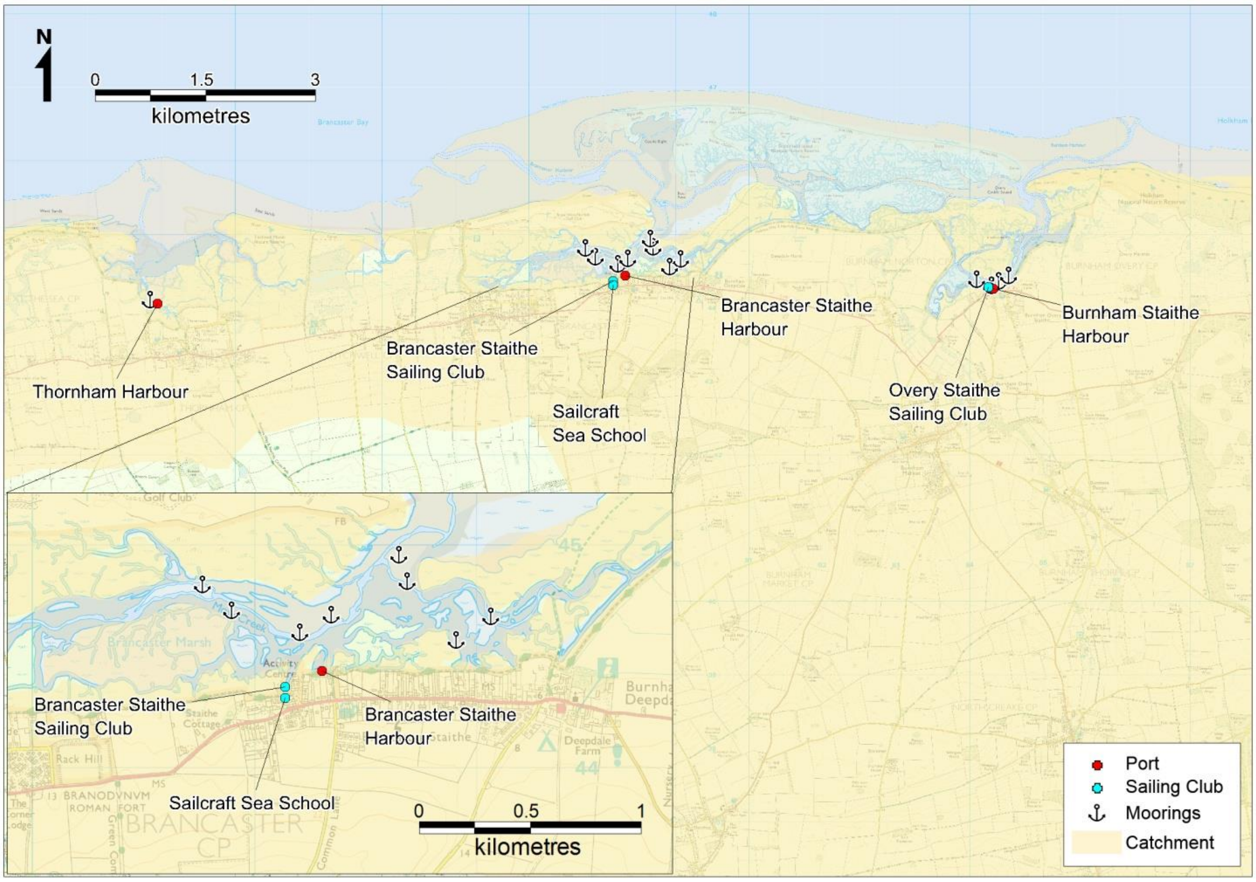

Figure IV.1: Boating activity in the Brancaster survey area

There are three small harbours within the survey area. Numerous moorings are positioned in close proximity to each harbour; the majority are located in the sheltered waters of Mow Creek at Brancaster and at Burnham Overy Creek. Fewer moorings are located further west at Thornham Harbour. Brancaster Staithe Sailing Club and Sailcraft Sea School are also situated in Mow Creek and they offer a variety of watersports including; rowing, water skiing, yachting and dinghy sailing. In addition to this, there is one dinghy sailing club at Burnham. There are no marinas within the survey area, the closest being at Wells Harbour, in Wells-next-the-Sea, where there are numerous mooring and pontoon berths, and sewage pump-out facilities are available (Wells Harbour website, 2013).

Brancaster has a small fishing fleet with 3 fishing vessels under 10 m and 3 vessels above 10 m in length with Brancaster Staithe registered as their home port in December 2013 (MMO, 2013). Fisheries in the area include mussels, lobsters and crabs (Mackintosh, 2013).

Smaller pleasure craft such as kayaks and sailing dinghies will not have onboard toilets and so are unlikely to make overboard discharges. Private vessels such as yachts, motor cruisers and fishing vessels of a sufficient size are likely to make overboard discharges from time to time. This may either occur when the boats are moored or at anchor, particularly if they are in overnight occupation, or while they are navigating through the area. Therefore, whilst overboard discharges may be made anywhere within the survey area, it is likely that the moorings and the main navigation routes through the area are most at risk of contamination from this source. Moorings situated in Mow Creek at Brancaster coincide with where the shellfish beds are located.

Peak pleasure craft activity is anticipated during the summer, so associated impacts are likely to follow this seasonal pattern. It is difficult to be more specific about the potential impacts from boats and how they may affect the sampling plan without any firm information about the locations, timings and volumes of such discharges.

Appendix V. Sources and Variation of Microbiological Pollution: Wildlife

The survey area encompasses a variety of habitats including extensive areas of sand dune and salt marshes, coastal lagoons, reed beds, tidal creeks and mud flats which in turn attract a variety of wildlife. Consequently, the coastal region of the survey area falls within the North Norfolk Coast Special Area of Conservation (SAC). The survey area is also protected by several other international and national environmental legislations including: Special Protection Area (SPA), Sites of Special Scientific Interest (SSSI), a Ramsar Site, RSPB Nature Reserves and Scolt Head Island National Nature Reserve (NNR).

Studies in the UK have found significant concentrations of microbiological contaminants (thermophilic campylobacters, salmonellae, faecal coliforms and faecal streptococci) from intertidal sediment samples supporting large communities of birds (Obiri-Danso and Jones, 2000). The most significant aggregation is of overwintering waterbirds (wildfowl and waders). Over the five winters up until 2010/11 an average total count of 198,969 was recorded along the North Norfolk Coast (Holt *et al*, 2012). Species include Pink-footed geese, Dark-bellied Brent Geese, Ringed Plover, Knot, Black-tailed Godwit and Bar-tailed Godwit. Scolt Head Island has been recognised as an important site for the high numbers of wintering wildfowl that it attracts. On the shoreline survey flocks of birds were observed in a couple of locations, with the largest aggregation, around 1,000 on Titchwell Marsh.

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

Whilst the majority of waterbirds migrate elsewhere to breed, there are resident and breeding populations of various species of seabirds (e.g. gulls and terns) in the area. Bird numbers and hence potential impacts on the hygiene status of the fisheries are lower during the summer. The JNCC Seabird 2000 census recorded a total of 6,044 pairs of terns and gulls from Thornham Harbour through to Overy Creek (Mitchell *et al*, 2004). The main aggregation was of 5,659 pairs of terns by the western end of Scolt Head Island. These seabirds are likely to forage widely throughout the area so inputs could be considered as diffuse, but are likely to be most concentrated in the immediate vicinity of the nest sites. Their faeces will be carried into coastal waters via runoff from their nesting sites or via direct deposition to the adjacent intertidal.

The largest breeding colony of common/harbour seals in the UK is located in the Wash (just west of the survey area) with 2,894 recorded in 2011 (SCOS, 2012). There are also seal colonies at Donna Nook, just south of the Humber estuary, and at Blakeney, on the North Norfolk coast, where both grey and harbour seals are present in significant numbers. They haul out on sandbanks at low tide, and it is at these locations where their impacts will be highest. During the moulting and pupping season, which occurs during the summer for harbour seals and the spring and autumn/winter for grey seals they tend to spend more time on haul out sites so their impacts are likely to be more acute during this period. However, no haul out sites have been identified within the survey area. Given the large area they are likely to forage over they are likely to enter the Brancaster survey area from time to time however their impacts are likely to be minor, and unpredictable in spatial terms.

Otters are present within the survey area, at Holkham Nature Reserve (Royal Haskoning, 2003). No information on numbers was available but the population is likely to be small. Otters generally tend to favour the more secluded areas with access to watercourses. However, given their likely wide distribution and small numbers otters have no material bearing on the sampling plan. No other wildlife species of possible significance to shellfish hygiene in the area have been identified.

Appendix VI. Meteorological Data: Rainfall

The Burnham Market weather station, received an average of 646 mm per year between 2003 and 2012. Figure VI.1 presents a boxplot of daily rainfall records by month at Burnham Market.

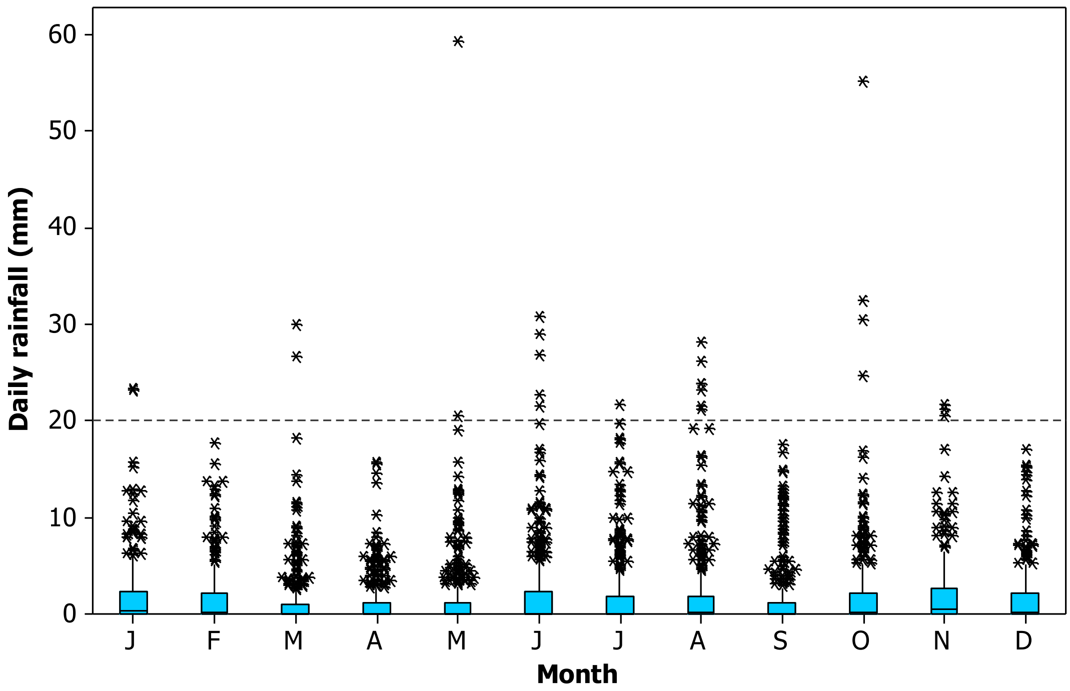

Figure VI.1: Boxplot of daily rainfall totals at Burnham Market, January 2003 to December 2012.
Data from the Environment Agency

Rainfall records from Burnham Market, which is representative of conditions in the vicinity of the shellfish beds, indicate little seasonal variation in average rainfall. However there did appear to be slightly less rainfall in the spring months of March and April than in the summer months of June and August. Rainfall was lowest on average in April and highest on average in June during the period examined. Daily totals of over 20 mm were recorded on 0.7 % of days and 46 % of days were dry. High rainfall events (>20 mm) occurred in all months except February, April, September and December, and were most frequent in June and August.

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

Meteorological Data: Wind

Eastern England is one of the more sheltered parts of the UK, since the windiest areas are to the north and west, closer to the track of Atlantic storms (Met Office, 2012). The strongest winds are associated with the passage of deep depressions across or close to the UK. The frequency of depressions is greatest during the winter months so this is when the strongest winds normally occur.

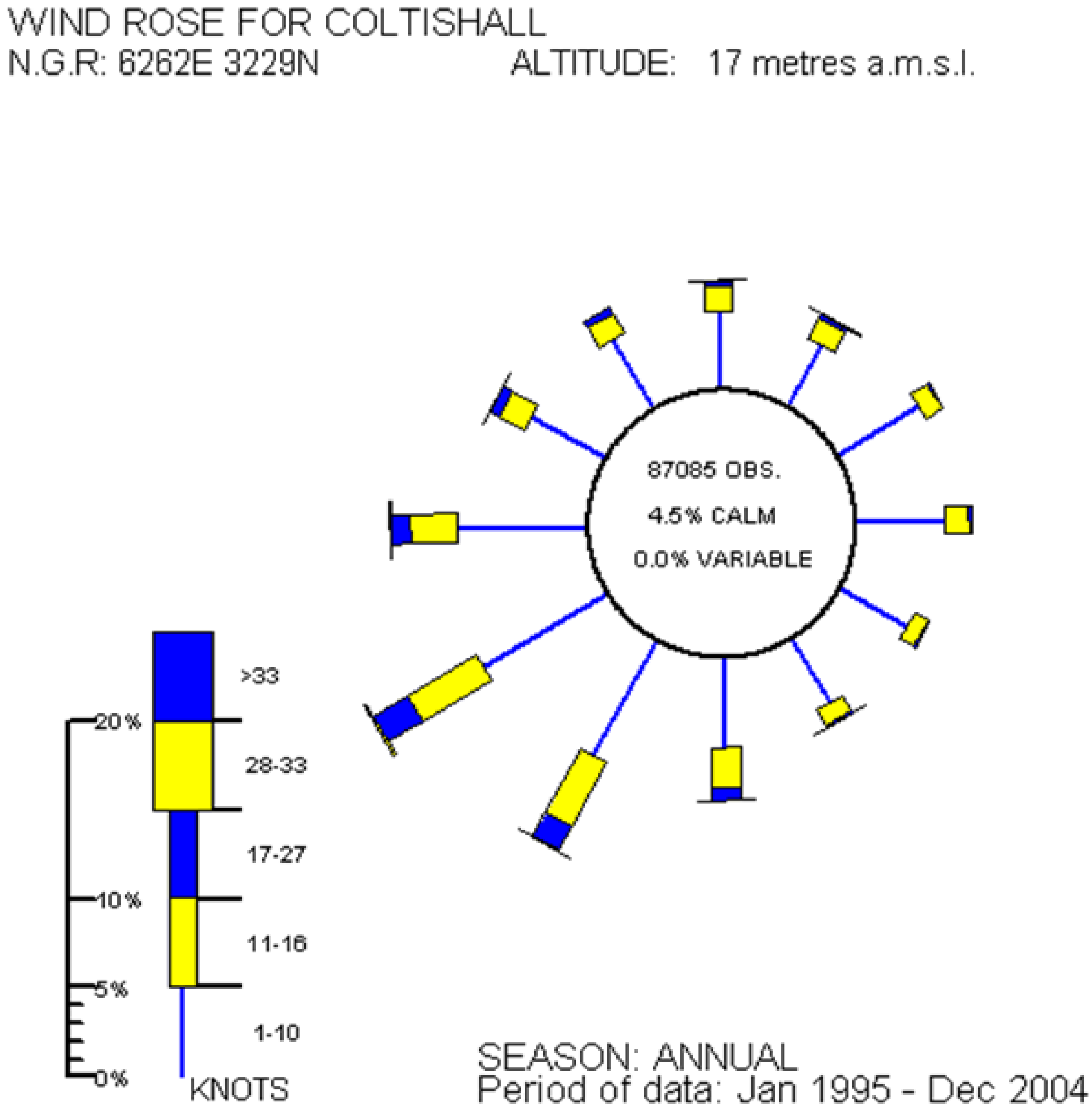

Figure VI.2: Wind Rose for Coltishall, East of England
Produced by the Meteorological Office. Contains public sector information licensed under the Open Government Licence v1.0

The wind rose for Coltishall is typical of open, level locations across the region. There is a prevailing south-westerly wind direction throughout the year. During spring there is a higher frequency of north-easterly winds due to a build up of high pressure over

Scandinavia (Met Office, 2012). Periods of very light or calm winds are more prevalent inland, with coastal areas having similar wind directions to inland locations but higher wind speeds. The Brancaster survey area faces north and is surrounded by relatively low lying land which will offer little shelter from the prevailing winds. The survey area comprises a series of shallow creeks which are fringed with saltmarsh and barrier dunes which provide shelter from North Sea swells.

Appendix VII. Hydrometric Data: Freshwater Inputs

North Norfolk is mainly underlain by chalk, and so the majority of flows through the area are via groundwaters rather than surface water (Environment Agency, 2005). There are only two main watercourses in the survey area. The largest of these is the River Burn, which is about 11 km in length, and drains to the coast at Burnham Overy. Given the location of its outfall its impacts are likely to be limited to Overy Creek, but it is possible that some influence may be felt in the connected tidal creeks off Brancaster. The River Hun is a smaller watercourse, approximately 6 km long, which flows through the west of the catchment into a creek draining to the outer reaches of Thornham Harbour. It may potentially be an influence at the oyster site off Thornham, but this is in a separate creek. Both watercourses are largely spring fed, and discharge to coastal waters via sluice gates. Apart from these, the only other inputs of surface water to the survey area are field drains from the low lying reclaimed farmland immediately adjacent to the coast.

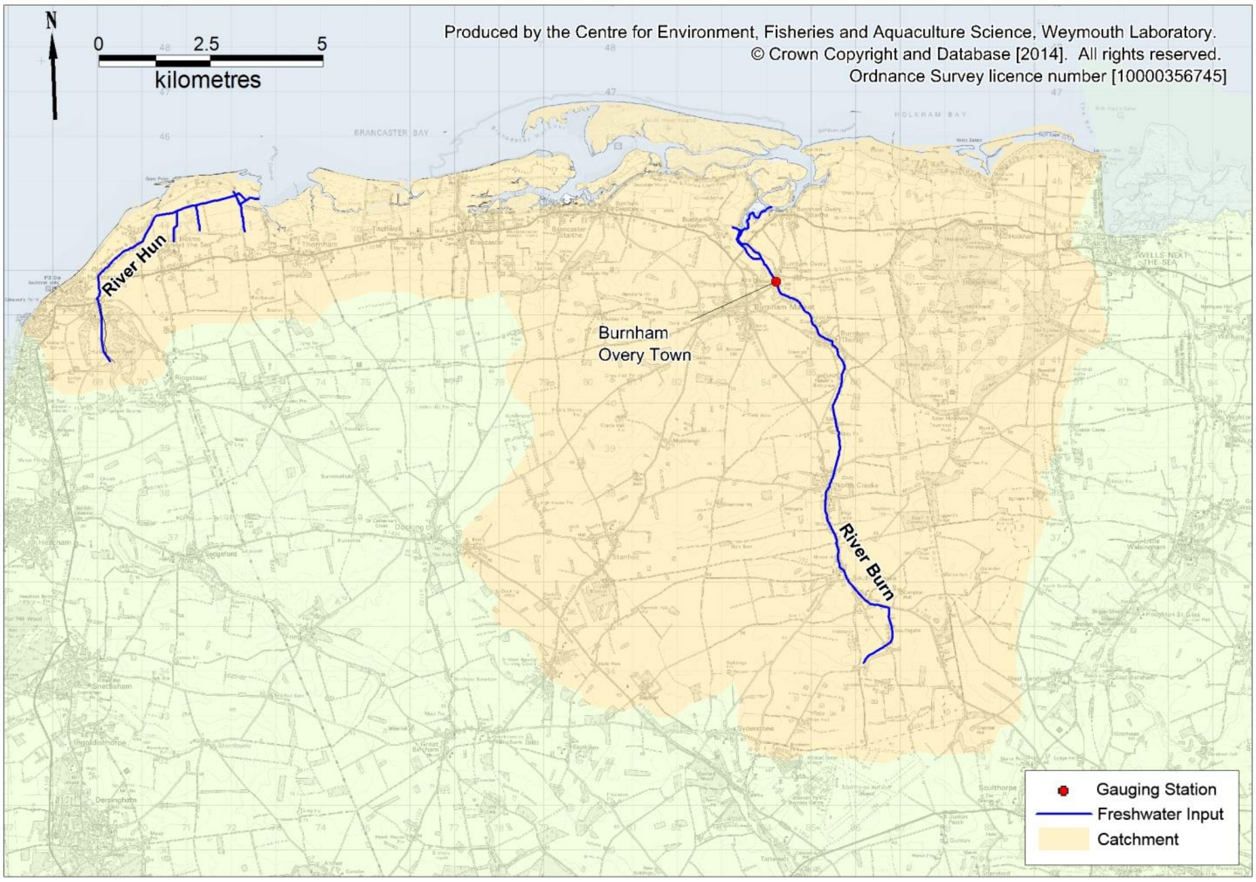

Figure VII.1: Freshwater Inputs into the Brancaster survey area

Flow of water through aquifers is typically very slow at between 1 m/year to 1 m/day (Environment Agency, 2011) and a retention time of 50 days is deemed sufficient in the removal of microbial contamination. As a consequence microbiological contamination from surface sources (e.g. agriculture) or direct to ground-waters (e.g. sewage soakaway systems) apart from those in close proximity to the main watercourses will not be carried into coastal waters in a viable state. Groundwaters may either re-emerge as springs a distance away from the coast, as is the case for those feeding the River Burn, or emerge in the freshwater marshes in the coastal strip or directly into coastal waters (Environment Agency, 2005).

Summary statistics for a flow gauging station in the lower reaches of the River Burn are presented in Table VII.1. Data for mean flow, Q95 and Q10 cover the period from 2003 - 2013.

Table VII.1: Summary flow statistics for the Burnham Overy Town gauging station draining into the Brancaster survey area

Station Name	Water course	Catchment Area (Km^2)	Mean Annual Rainfall 1961-1990 (mm)	Mean Flow (m^3s^{-1})	Q95[1] (m^3s^{-1})	Q10[2] (m^3s^{-1})
Burnham Overy Town	Burn	80	666	0.320	0.130	0.542

[1]Q95 is the flow that is exceeded 95% of the time (i.e. low flow). [2]Q10 is the flow that is exceeded 10% of the time (i.e. high flow).
Data from NERC (2012) and Environment Agency

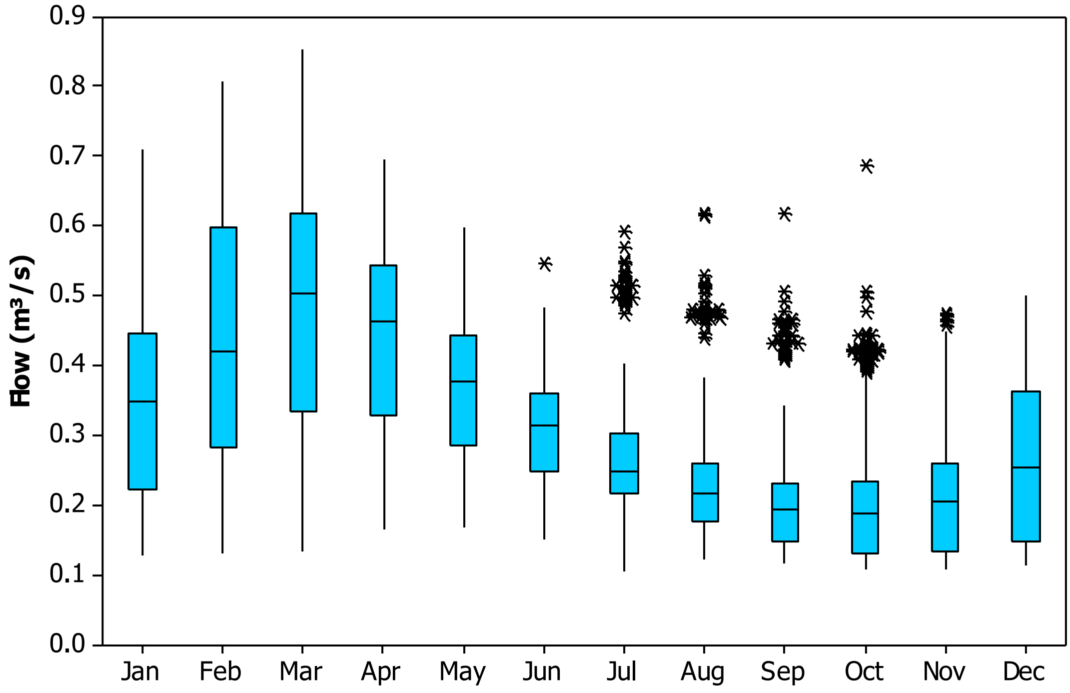

Figure VII.2: Boxplots of mean daily flow records from the Burnham Overy Town gauging station on the Burn watercourse (2003-2013)

There was little difference between the mean flow, Q10 and Q95 and no particularly high flow events were recorded, indicating steady discharge rate that is characteristic of groundwater fed streams. The seasonality of discharge that can be seen in Figure

VII.2 is also consistent with recharging of the aquifers during the colder months of the year when there is less evaporation and transpiration.

During the shoreline survey, which was conducted under dry conditions, watercourses and drainage systems which could be safely accessed were sampled for *E. coli* and spot flow measurements were made. The results and locations are presented in Table VII.2 and Figure VII.3. The shoreline adjacent to the Thornham shellfisheries and Brancaster shellfisheries were surveyed. The Rivers Hun and Burn were not measured due to their distance from the shellfisheries. Marsh drainage sluices were identified at three locations within the survey area but flow readings for these were disregarded as the flow meter was not functioning correctly at the time of measurement.

Table VII.2: *E. coli* sample results, measured discharges and calculated *E. coli* loadings

Reference	Description	*E. coli* concentration (CFU/100 ml)	Flow (m^3s^{-1})	*E. coli* loading (CFU/day)
A	Sluice draining marsh	20	Faulty flow meter	
B	Sluice draining marsh	20	Faulty flow meter	
C	Sluice draining west	<10	Faulty flow meter	
D	Drainage ditch	30	0.006	1.56×10^8

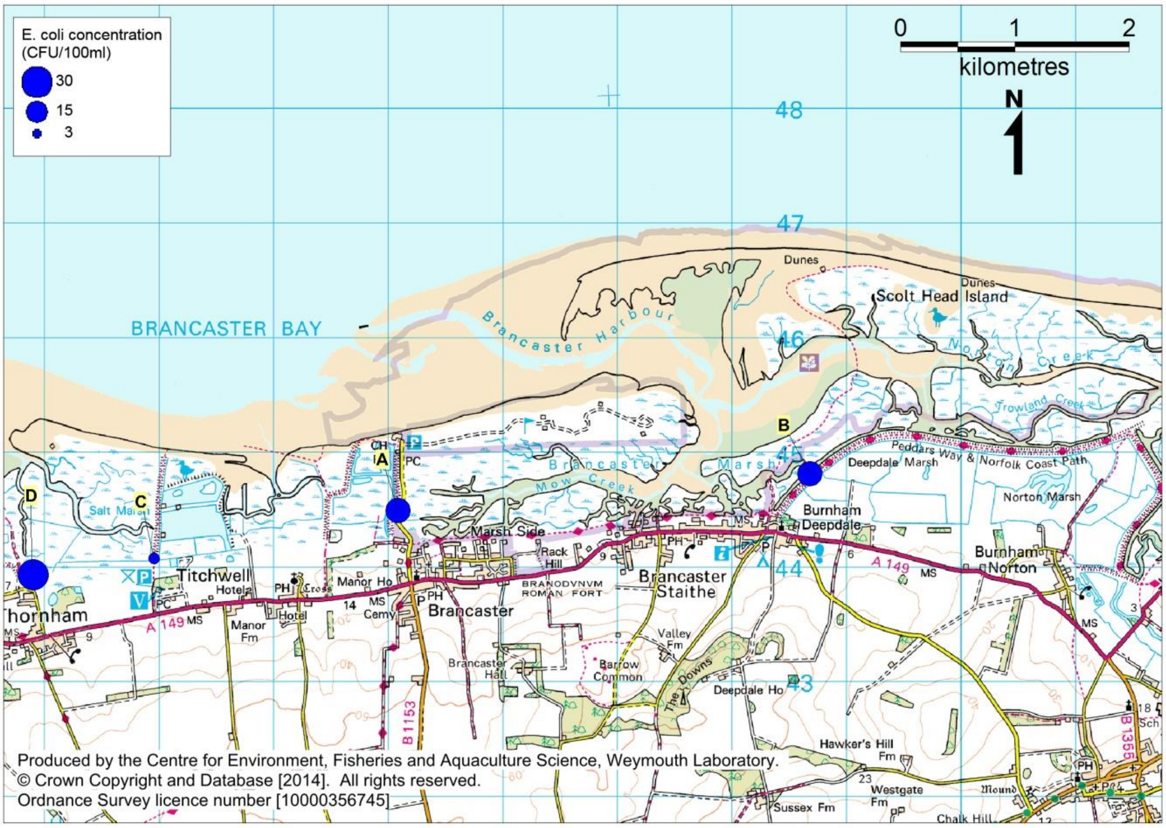

Figure VII.3: Locations of shoreline survey stream observations, Brancaster survey area

The concentration of indicator bacteria in all surface water samples was very low, and all were minor in terms of volumes discharged. As such the bacterial loading they were conveying into coastal waters was low, and their influence on the shellfisheries is likely to be negligible. It is possible that the bacterial concentrations may be higher at other times of the year, for example if livestock are grazed in any fields that they drain. It is therefore concluded that land runoff is likely to be a minor influence at most on the shellfisheries considered in this survey.

Appendix VIII. Hydrography

VIII.1. Bathymetry

The shore within the survey area consists of barrier beaches, behind which there are extensive areas of saltmarsh with complex networks of tidal creeks. Much of the saltmarsh is backed by earth dykes constructed for land reclaim purposes. Offshore from the beaches the subtidal area is shallow and flat, with depths of up to 6 m below Chart Datum (CD) and is characterised by mobile sandbanks. Figure VIII.1 shows the bathymetric chart of the area, although it contains little detail of the tidal creeks in which the shellfisheries are located.

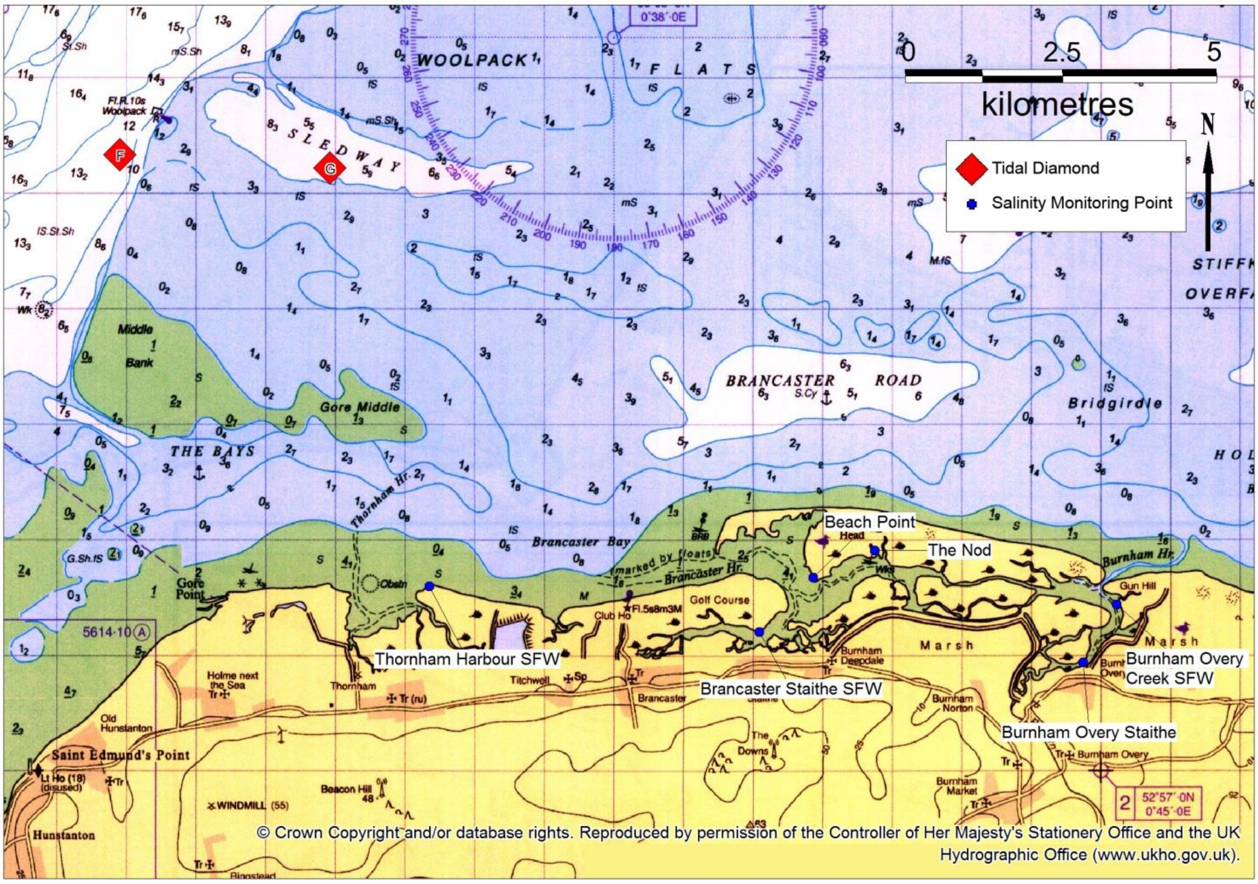

Figure VIII.1: Bathymetry of Brancaster survey area

Thornham Harbour is a small branching inlet at the eastern end of the survey area. It follows a subtidal channel across the beach in a southerly direction, then splits into the two main arms, one of which runs south to Thornham village, the other of which runs east towards Titchwell Marsh. The Thornham oyster trestle site is located in the Titchwell Marsh arm. A third smaller arm branches off to the west, and receives freshwater input from the River Hun at its head. Numerous other smaller dendritic intertidal creeks feed into the main arms. There is no direct hydrological connection between the creeks at Thornham and those between Brancaster and Burnham Overy.

The network of creeks within which the Brancaster mussel, oyster and cockle fisheries lie within is more extensive and complex. There are two subtidal channels at either end which connect it to the North Sea (Brancaster Harbour and Burnham Overy Harbour). Brancaster Harbour creek splits into a large dendritic network of creeks off Brancaster, Brancaster Staithe and Burnham Deepdale. There are also several smaller creeks branching off the main Burnham Overy creek in various directions. The River Burn discharges to the inner reaches of Burnham Overy Creek. Brancaster Harbour and Burnham Overy Harbour are connected via the saltmarsh creeks. The main connection between the two is Norton Creek, although there is at least one other much narrower connection via Trowland Creek. Norton Creek becomes narrower and shallower in its eastern half. The shellfisheries lie in the western end of Norton Creek and the outer reaches of the Brancaster Harbour creek.

The shallow nature of these creeks will limit the potential for dilution, but will result in a large proportion of the water within them being exchanged each tide.

VIII.2. Tides and Currents

Currents in coastal waters are predominantly driven by a combination of tide, wind and freshwater inputs. The average tidal range increases progressively from east to west along the north Norfolk coast, and is reduced in the saltmarsh creeks compared to the open coastal stations. High water at Hunsanton occurs about 5 minutes earlier than at Cromer, so it is concluded that high water arrives at about the same time at the mouths of the three harbour channels considered in this survey.

Table VIII.1: Tidal levels and ranges within the Brancaster survey area

	Height above chart datum (m)				Range (m)	
Port	MHWS	MHWN	MLWN	MLWS	Spring	Neap
Burnham (Overy Staithe)	2.30	0.90	-	-	-	-
Cromer	5.08	4.01	1.94	0.87	4.21	2.07
Hunstanton	6.85	5.31	2.29	0.74	6.11	3.02

Data from Proudman Oceanographic Laboratory

There are two tidal diamonds located approximately 6 km and 8 km north of the survey area confirming the offshore tidal directions; flooding along the coast in a westerly direction and ebbing in the opposite direction (Table VIII.2).

Table VIII.2: Tidal Stream predictions for offshore the Brancaster survey area

Time before /after	Station G	Station F

High Water	Direction	Rate (m/s)		Direction	Rate (m/s)	
		Spring	Neap		Spring	Neap
HW-6	302	0.77	0.36	013	0.26	0.10
HW-5	302	0.67	0.31	-	0.00	0.00
HW-4	283	0.41	0.21	200	0.36	0.15
HW-3	225	0.31	0.15	205	0.72	0.36
HW-2	182	0.36	0.21	211	1.23	0.62
HW-1	155	0.41	0.21	210	1.13	0.57
HW	128	0.51	0.26	203	0.57	0.26
HW+1	108	0.67	0.31	064	0.15	0.10
HW+2	096	0.62	0.31	034	0.72	0.36
HW+3	077	0.41	0.21	031	1.03	0.51
HW+4	018	0.26	0.10	026	0.98	0.51
HW+5	322	0.41	0.21	018	0.72	0.36
HW+6	306	0.67	0.31	015	0.41	0.21
Excursion (flood)		10.5	5.2		13.3	6.5
Excursion (ebb)		10.4	5.0		15.0	7.6

Admiralty chart 5614.9

These tidal diamonds are of little relevance to the circulation of contaminants within the saltmarsh creeks within which the fishery is located, although they do indicate that water flooding into these creeks arrives from the east. No published information was found on the pattern of tidal circulation within the creeks.

As water levels rise, the flood stream will travel up the creeks, splitting as they branch. As the channels fill, water will spread from the channels over the sand flats and mudflats. After high water, the water levels will drop and the tidal streams will follow the same path back out. Shoreline sources of contamination will therefore primarily impact up and down tide of their locations along the bank to which they discharge. Their impacts will decrease with distance travelled, as the plume becomes progressively more diluted. At lower states of the tide contamination from some shoreline sources such as watercourses will be carried through the intertidal drainage channels where the dilution potential is low. Relatively high concentrations of indicator bacteria may arise in these channels at such times.

Sources of contamination discharging to an individual creek will not generally impact on neighbouring branches as tidal streams will be ebbing from both at the same time. This is of importance to the assessment as it indicates that the River Hun will not impact on the Pacific oyster site at Thornham. Similarly it suggests that contamination from shoreline sources at Brancaster will not come into contact with shellfisheries in Norton Creek, apart from those around its mouth. Tides will enter Norton Creek from both ends at about the same time, and meet somewhere in the middle to the north of Ramsey Island, to the east of the shellfish sites (Mr B Southerland, pers comm.). They will then drain away in the opposite direction after high water, so contamination originating from the Burnham Overy area will not impact on the shellfish in the western end of Norton Creek.

In addition to tidally driven currents, are the effects of freshwater inputs and wind. Freshwater inputs are limited to two minor rivers, and a series of coastal springs and field drains. As some of these springs feed directly into coastal waters it is difficult to quantify the volumes involved, although they are likely to be minor in relation to the volumes of water exchanged tidally. Salinity measurements taken between 2003 and 2013 at six points within the survey area indicate average salinities approaching that of full strength seawater in the outer reaches of the Harbours and at the entrance to Thornham Harbour (Figure VIII.2).

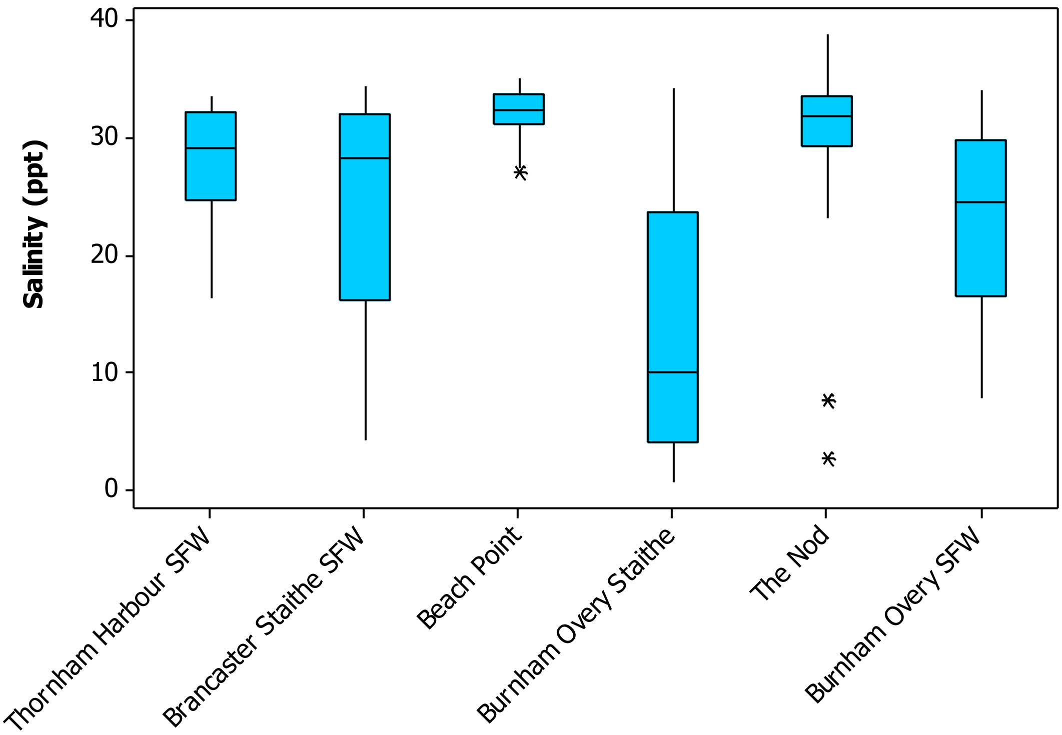

Figure VIII.2: Boxplots of saminity readings
Data from the Environment Agency

There was more variation in salinities in the upper reaches of the tidal creeks at Brancaster Staithe SFW[1], Burnham Overy Staithe and Burnham Overy Creek SFW indicating a higher contribution of freshwater. The River Burn discharges to Burnham Creek which suggests the lower salinities at Burnham Overy monitoring points. There are no visible freshwater inputs to the head of Mow Creek where the Brancaster Staithe SFW is situated however freshwater springs emerging in the marshes may account for the low salinity readings.

[1] SFW is an abbreviation for Shellfish Water

The salinity measurements suggest that some density effects may arise in the more inshore areas. Neap tides may also accentuate density effects as both tidal current velocities (and hence the extent of turbulent mixing) and the volume of tidal exchange will be lower. When such effects occur, they will result in a shear between surface and bottom currents, with less dense freshwater moving in a net seaward direction at the surface, and a net inshore movement of more saline water lower in the water column. Salinity may be considered a proxy for levels of runoff borne contamination. Although a significant correlation between salinity and levels of faecal coliforms was found at Brancaster Staithe (Figure IX.12) this relationship was much weaker than is typical, suggesting freshwater inputs are not carrying high levels of faecal coliforms and therefore largely originated from groundwaters.

Strong winds will modify surface currents. Winds typically drive surface water at about 3 % of the wind speed (Brown, 1991) so gale force wind (34 knots or 17.2 m/s) would drive a surface water currents of about 0.5 m/s. These create return currents which may travel lower in the water column or along sheltered margins. The low lying land affords minimal shelter from winds, so wind driven currents may significantly modify circulation within the area at times. Exact effects are dependent on the wind speed and direction as well as state of the tide and other environmental variables so a great number of scenarios may arise. Where strong winds blow across a sufficient distance of water they may create wave action, and where these waves break, contamination held in intertidal sediments may be re-suspended. Given the enclosed nature of the survey area strong wave action is not anticipated.

Appendix IX. Microbiological Data: Seawater

IX.1. Water Quality Monitoring

There are no bathing waters relevant to the survey area, designated under the Directive 76/160/EEC (Council of the European Communities, 1975). However two non-designated sites within the production area have been sampled regularly for water quality since 2008, and a further one site since 2009.

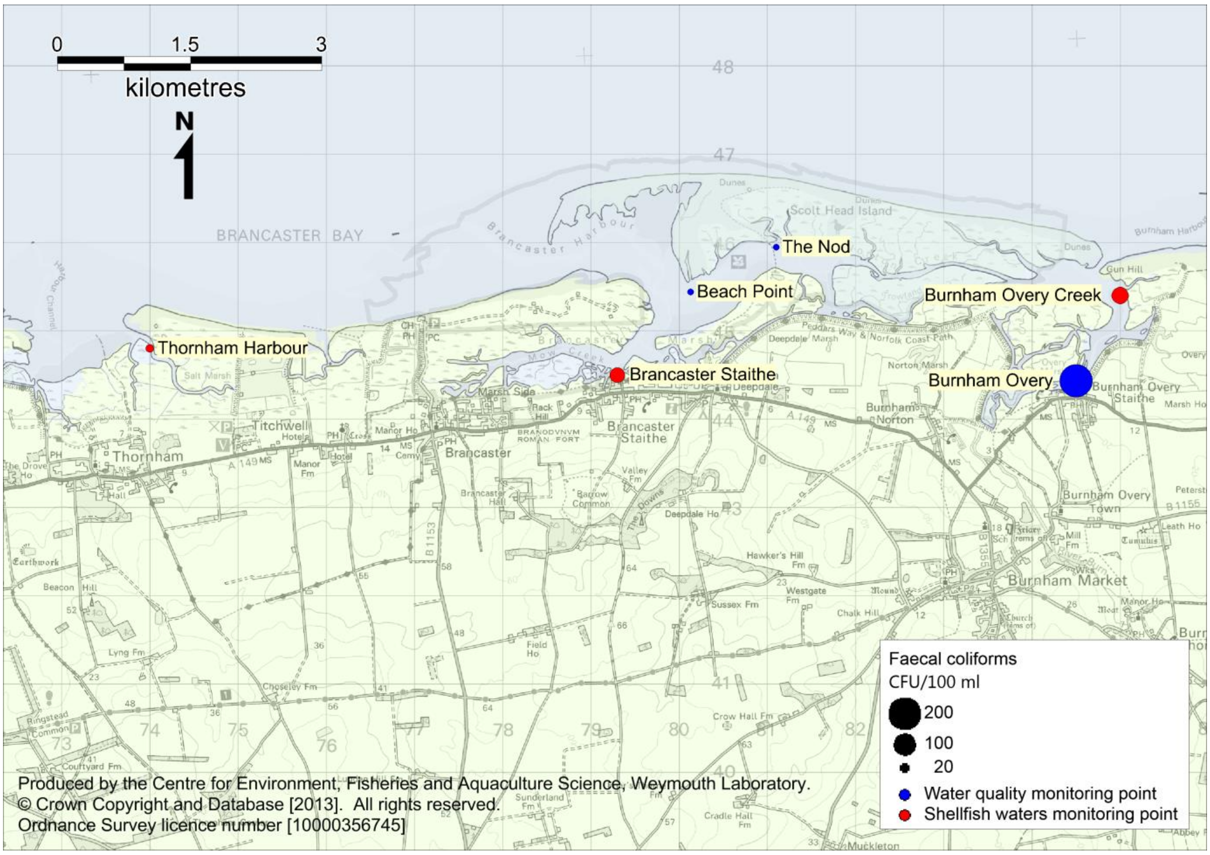

Figure IX.1: Location of designated water quality and shellfish waters monitoring points.

Summary statistics of all results by monitoring point are presented in Table IX.1, and Figure IX.2 presents box plots of these data.

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

Site	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 100	% over 1,000
Beach Point	33	02/07/2008	01/12/2011	11.1	<2	1680	18.2	3.0
The Nod	34	02/07/2008	01/12/2011	12.1	<2	423	11.8	0.0
Burnham Overy	40	13/08/2009	25/04/2013	212.9	4	3150	70.0	15.0

Data from the Environment Agency

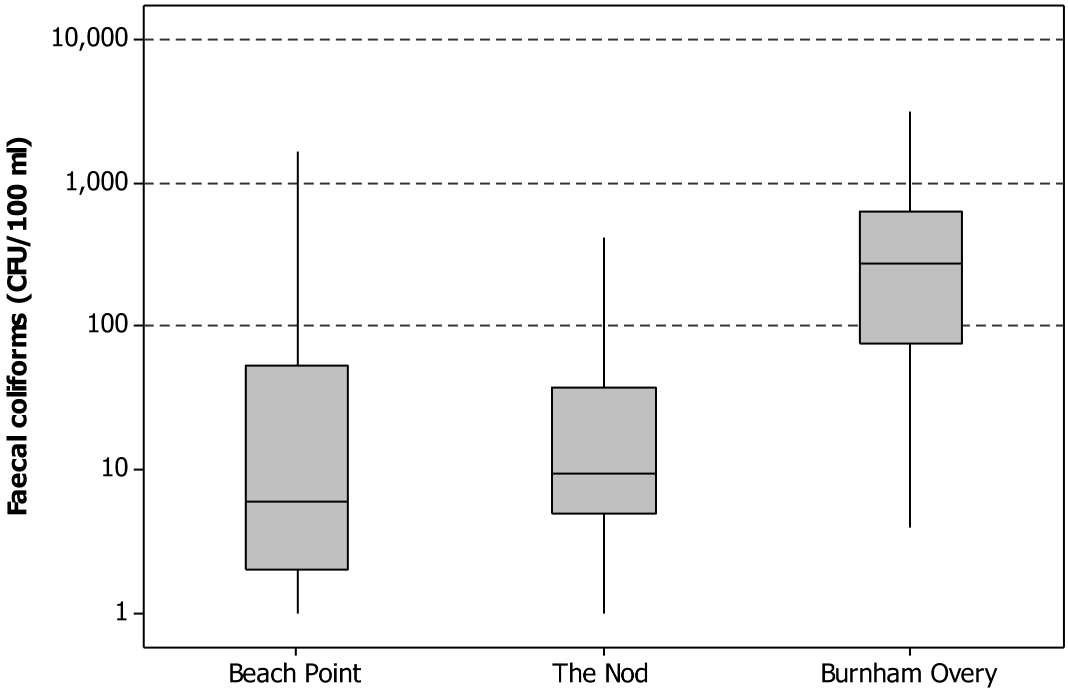

Figure IX.2: Box-and-whisker plots of all faecal coliforms results by site
Data from the Environment Agency

All sites had results exceeding 100 faecal coliforms/100 ml, but The Nod was the only site not to have any samples exceeding 1,000 faecal coliform CFU/100 ml. Burnham Overy had the highest geometric mean (212.9 CFU/100 ml) and the highest maximum faecal coliform concentration (3,150 CFU/100 ml).One way ANOVA tests showed that there was significant variation in faecal coliform levels between sites (p<0.001), and post ANOVA Tukey tests revealed that Burnham Overy had significantly higher faecal coliform levels than the other two sites.

Comparisons of sites were carried out on a pair-wise basis by running correlations (Pearson's) between sites that shared sampling dates, and therefore environmental conditions, on at least 20 occasions. The Nod and Beach Point correlated significantly (p=0.001) indicating that these sites share similar contamination sources. There were no significant correlations between Burnham Overy and Beach Point (p=0.139) or Burnham Overy and The Nod (p=0.481).

Overall temporal pattern in results

The overall variation in faecal coliform levels found at bathing water sites sampled for two years or longer is shown in Figure IX.3.

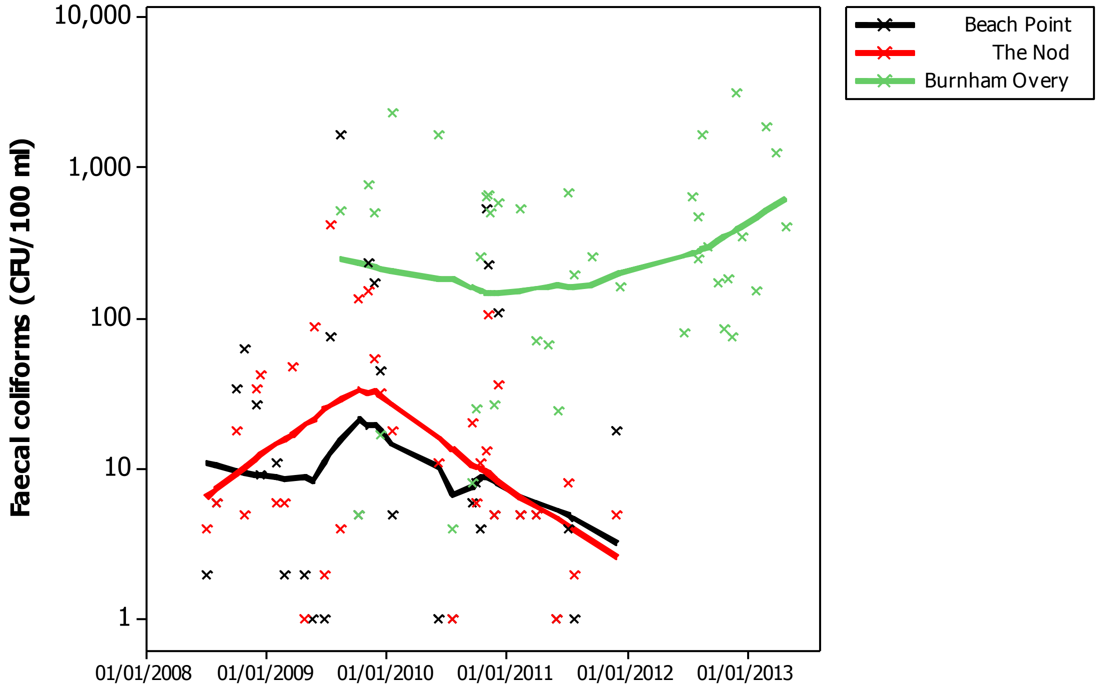

Figure IX.3: Scatterplot of faecal coliform results for bathing waters overlaid with loess lines.
Data from the Environment Agency

Faecal coliform levels have always been higher at Burnham Overy and the other two sites.

Seasonal patterns of results

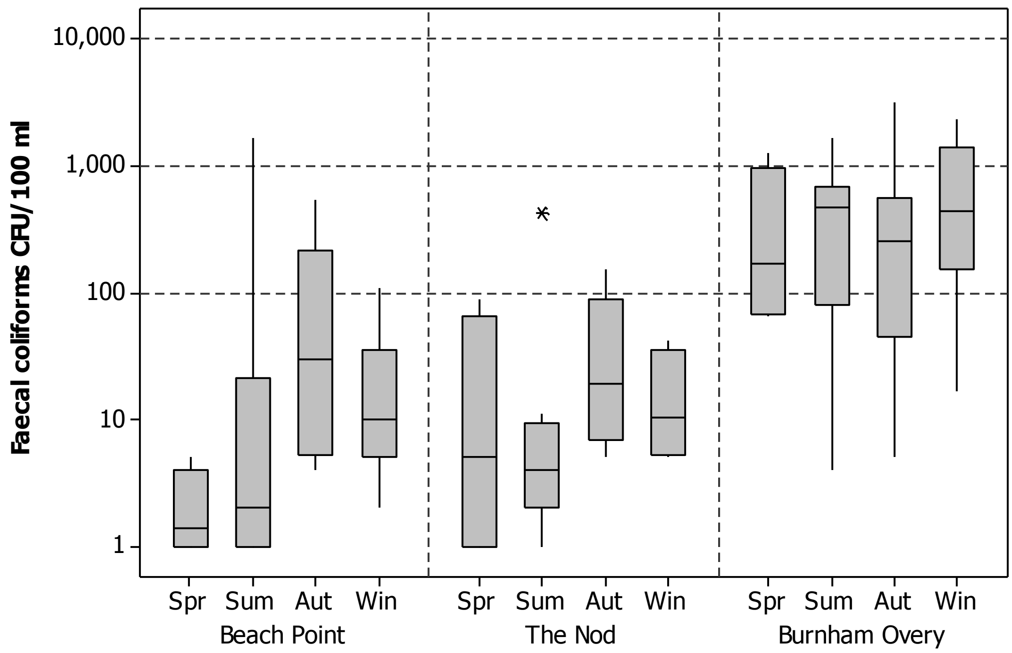

Figure IX.4: Boxplot of faecal coliform results by site and season
Data from the Environment Agency

One-way ANOVA tests showed that there was no significant variation in faecal coliform levels between seasons at The Nod (p=0.207) or Burnham Overy (p=0.762). There was significant variation in faecal coliform levels between seasons at Beach Point (p=0.046). However, post ANOVA Tukey tests did not reveal which seasons differed significantly from each other.

Influence of tides

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

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

	High/low tides		Spring/neap tides	
Site Name	**r**	**p**	**r**	**p**
Beach Point	0.271	0.110	0.098	0.751
The Nod	0.423	0.004	0.099	0.738
Burnham Overy	0.620	<0.001	0.476	<0.001

Data from the Environment Agency

Figure IX.5 presents polar plots of $\log_{10}$ faecal coliform results against tidal states on the high/low cycle where significant correlations were detected. High water at Burnham Overy is at 0° and low water is at 180°. Results of 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1000 are plotted in yellow, and those exceeding 1000 are plotted in red.

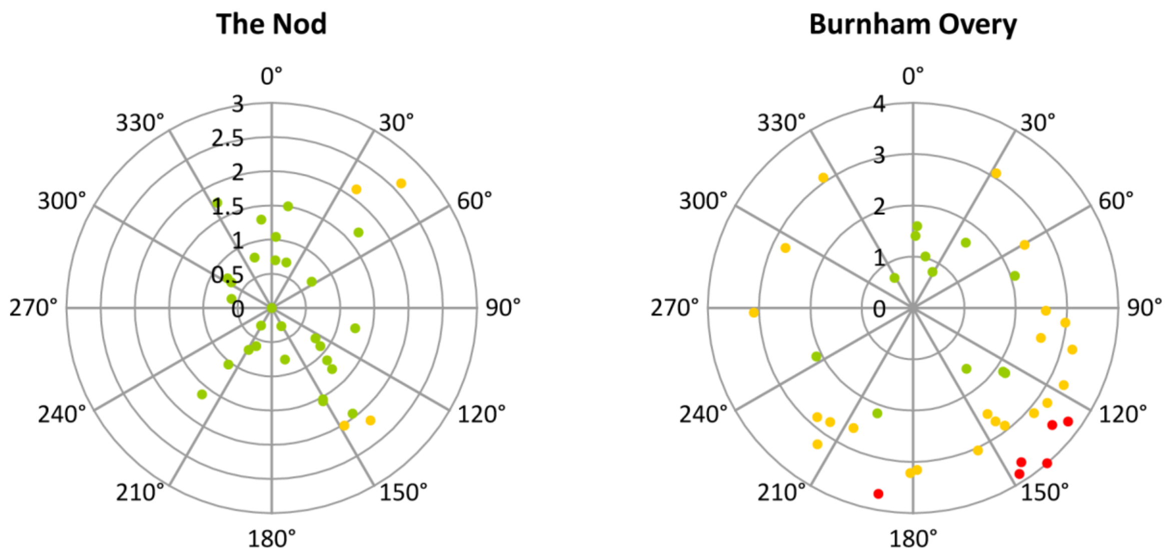

Figure IX.5: Polar plots of $\log_{10}$ faecal coliforms against tidal state on the high/low tidal cycle for bathing waters monitoring points with significant correlations
Data from the Environment Agency

At The Nod, lower results tended to occur during the ebb tide. At Burnham Overy the higher results tended to occur at lower states of the tide.

Figure IX.6 presents polar plots of faecal coliform results against the lunar spring/neap cycle. Full/new moons occur at 0º, and half moons occur at 180º. The largest (spring) tides occur about 2 days after the full/new moon, or at about 45º, then decrease to the smallest (neap tides) at about 225º, then increase back to spring tides. Results of 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1000 are plotted in yellow, and those exceeding 1000 are plotted in red.

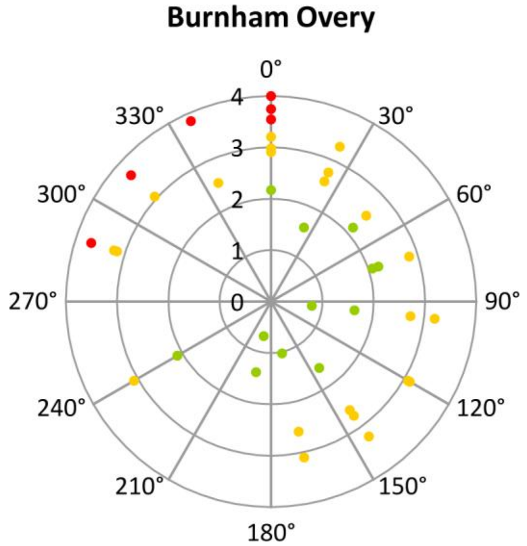

Figure IX.6: Polar plots of log_{10} faecal coliforms against tidal state on the spring/neap tidal cycle for bathing waters monitoring points with significant correlations
Data from the Environment Agency

At Burnham Overy, most of the higher results occurred as tide sizes increased towards spring tides.

Influence of Rainfall

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

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

	Site	Beach Point	The Nod	Burnham Overy
	n	33	34	40
24 hour periods prior to sampling	1 day	0.197	0.275	0.300
	2 days	0.380	0.152	0.176
	3 days	0.481	0.530	0.118
	4 days	-0.043	0.120	-0.186
	5 days	0.445	0.217	-0.047
	6 days	-0.001	0.032	-0.336
	7 days	0.081	-0.006	-0.125
Total prior to sampling over	2 days	0.327	0.127	0.239
	3 days	0.321	0.307	0.224
	4 days	0.194	0.267	0.073
	5 days	0.249	0.273	0.068
	6 days	0.219	0.222	0.025
	7 days	0.192	0.165	-0.011

Data from the Environment Agency

Rainfall had most influence on faecal coliform levels at Beach Point.

IX.2. Shellfish Waters

Summary statistics and geographical variation

There are three shellfish waters monitoring sites designated under Directive 2006/113/EC (European Communities, 2006) in the Brancaster production area. Figure IX.1 shows the location of these sites. Table IX.4 presents summary statistics for bacteriological monitoring results and Figure IX.7 presents a boxplot of faecal coliform levels from the monitoring point. Only eight samples have been taken at Thornham Harbour and so no further analyses have been conducted for this site.

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

Site	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 100	% over 1,000
Thornham Harbour	8	08/02/2011	18/10/2012	19.2	<2	230	12.5	0.0
Brancaster Staithe	95	09/01/2003	27/06/2013	52.0	2	2100	33.7	4.2
Burnham Overy Creek	11	08/02/2011	27/06/2013	62.7	<2	1727	36.4	9.1

Data from the Environment Agency

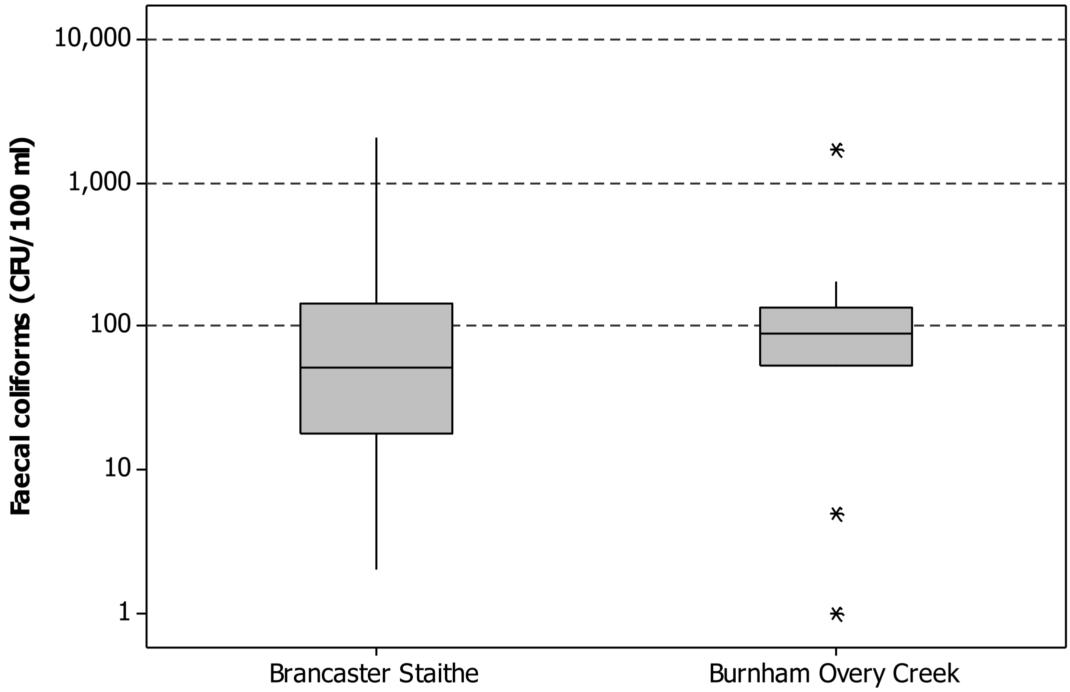

Figure IX.7: Box-and-whisker plots of all faecal coliforms results
Data from the Environment Agency

Both sites that were sampled on 10 or more occasions had results exceeding 1,000 faecal coliform CFU/100 ml, but none exceeded 10,000. There was no significant difference in average faecal coliform concentrations between sites (T-test, p=0.763).

Overall temporal pattern in results

The overall variation in faecal coliform levels found at shellfish water sites over time is shown in Figure IX.8.

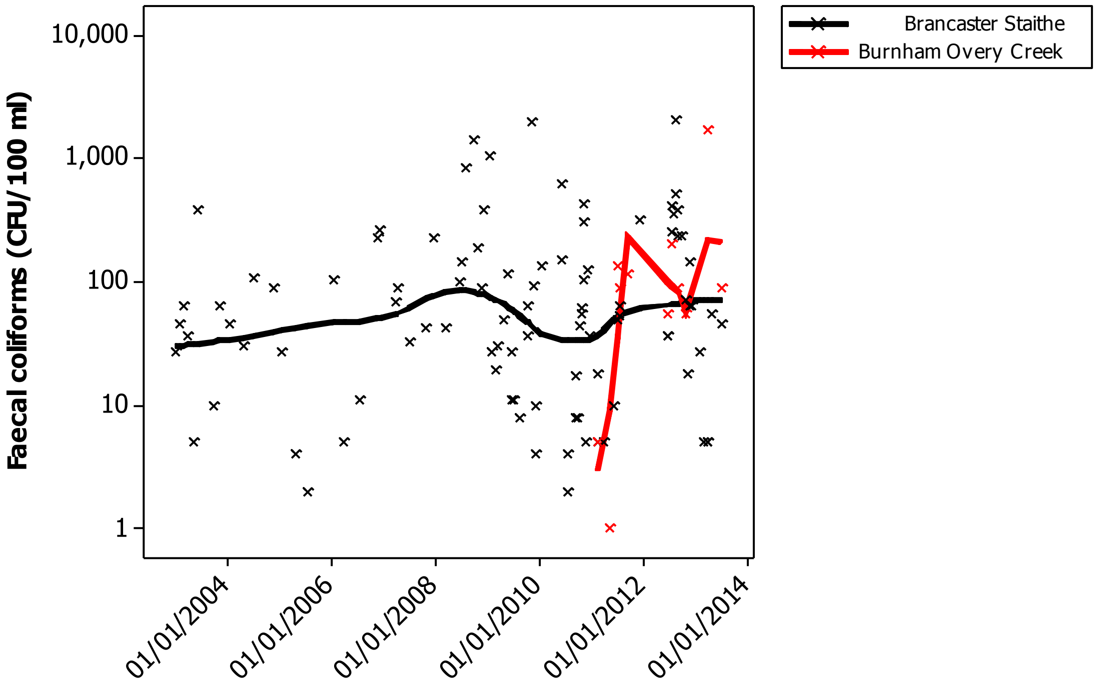

Figure IX.8: Scatterplot of faecal coliform results by date, overlaid with loess lines
Data from the Environment Agency

Faecal coliform levels have remained stable at Brancaster Staithe since 2003. Not enough samples have been taken at Burnham Overy Creek to draw any conclusions about temporal patterns in faecal coliform levels at this site.

Seasonal patterns of results

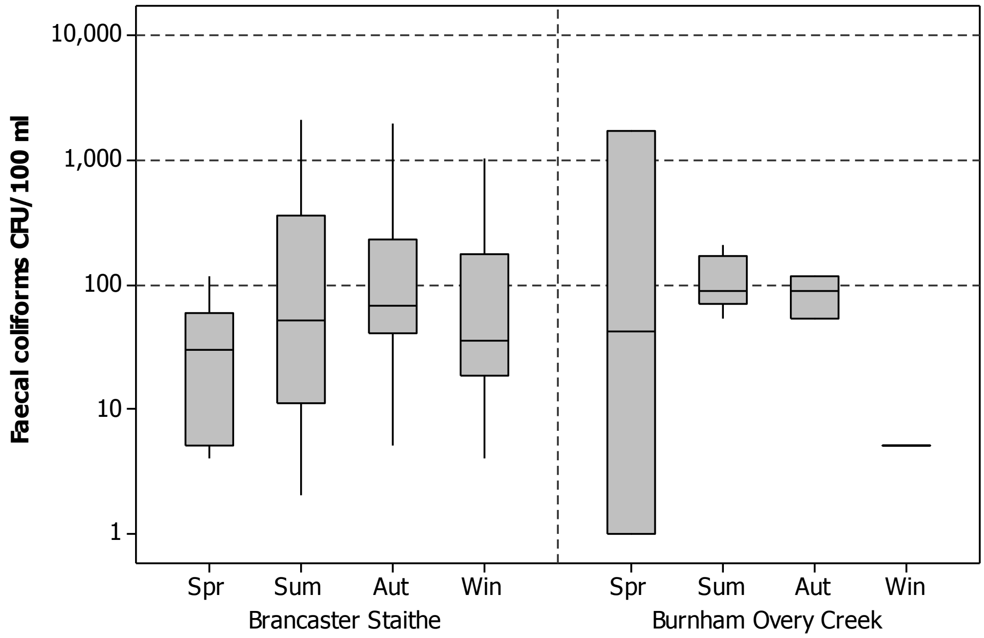

Figure IX.9: Boxplot of faecal coliform results by site and season
Data from the Environment Agency

One-way ANOVA tests showed that there were significant differences in faecal coliform levels between seasons at Brancster Staithe ($p=0.038$), but not at Burnham Overy Creek ($p=0.602$). Post ANOVA Tukey tests revealed that at Brancaster Staithe, there were higher levels of faecal coliforms in autumn than spring.

Influence of tide

To investigate the effects of tidal state on faecal coliform results, circular-linear correlations were carried out against both the high/low and spring/neap tidal cycles for each of these shellfish waters sampling points that were sampled on 30 or more occasions. Correlation coefficients are presented in Table IX.5, with statistically significant correlations highlighted in yellow.

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

	High/low tides		Spring/neap tides	
Site Name	**r**	**p**	**r**	**p**
Brancaster Staithe	0.468	<0.001	0.392	<0.001

Data from the Environment Agency

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

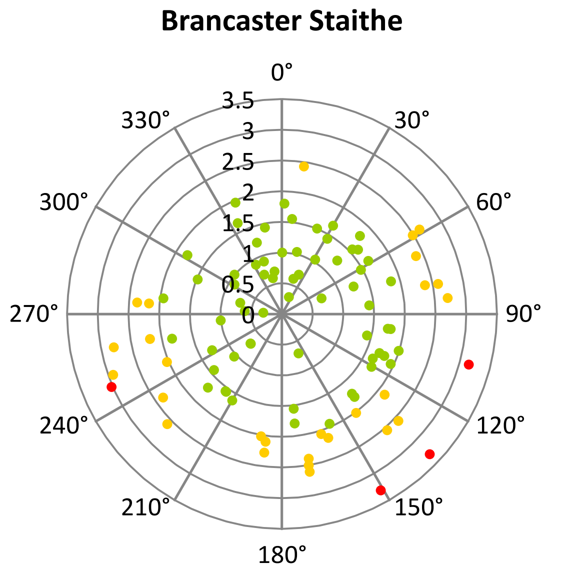

Figure IX.10: Polar plots of log_{10} faecal coliforms against tidal state on the high/low tidal cycle for shellfish waters monitoring points with significant correlations
Data from the Environment Agency

At Brancaster Staithe there tended to be higher levels of faecal coliforms at lower states of the tide.

Figure IX.11 presents a polar plot of faecal coliform results against the lunar spring/neap cycle, where a statistically significant correlation was found. Full/new moons occur at 0º, and half moons occur at 180º. The largest (spring) tides occur about 2 days after the full/new moon, or at about 45º, then decrease to the smallest (neap tides) at about 225º, then increase back to spring tides. Results of 100 faecal coliforms/100ml or less are plotted in green, those from 101 to 1000 are plotted in yellow, and those exceeding 1000 are plotted in red.

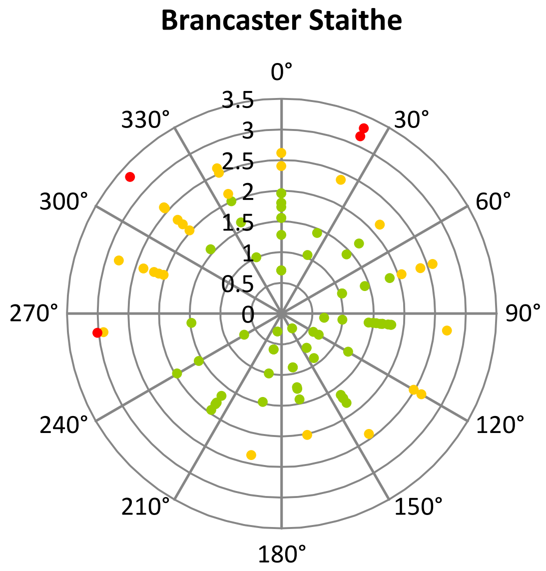

Figure IX.11: Polar plots of $\log_{10}$ faecal coliforms against tidal state on the spring/neap tidal cycle for bathing waters monitoring points with significant correlations
Data from the Environment Agency

There tended to be lower results around the neap tide at Brancaster Staithe.

Influence of rainfall

To investigate the effects of rainfall on levels of contamination at the water quality monitoring sites Spearman's rank correlations were carried out between rainfall recorded at the Burnham Market weather station (Appendix VI for details) over various periods running up to sample collection and faecal coliform results. These are presented in Table IX.6 and statistically significant correlations ($p<0.05$) are highlighted in yellow.

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

	Site	Brancaster Staithe	Burnham Overy Creek
	n	81	11
24 hour periods prior to sampling	1 day	0.295	0.397
	2 days	0.235	-0.049
	3 days	0.210	0.249
	4 days	0.097	-0.057
	5 days	0.029	-0.023
	6 days	0.012	0.120
	7 days	-0.056	0.261
Total prior to sampling over	2 days	0.280	0.269
	3 days	0.337	0.225
	4 days	0.330	0.240
	5 days	0.289	0.165
	6 days	0.243	0.215
	7 days	0.155	0.215

Data from the Environment Agency

Spearman's correlations did not show any effect of rainfall on faecal coliform levels at Burnham Overy Creek. At Brancaster Staithe, rainfall rapidly increased faecal coliform levels but the effect only persisted for three days.

Influence of salinity

Salinity was recorded on most sampling occasions. Figure IX.12 shows scatter-plots of those sites with significant correlations between faecal coliforms and salinity. Pearson's correlations were run to determine the effect of salinity on faecal coliforms at shellfish waters sites.

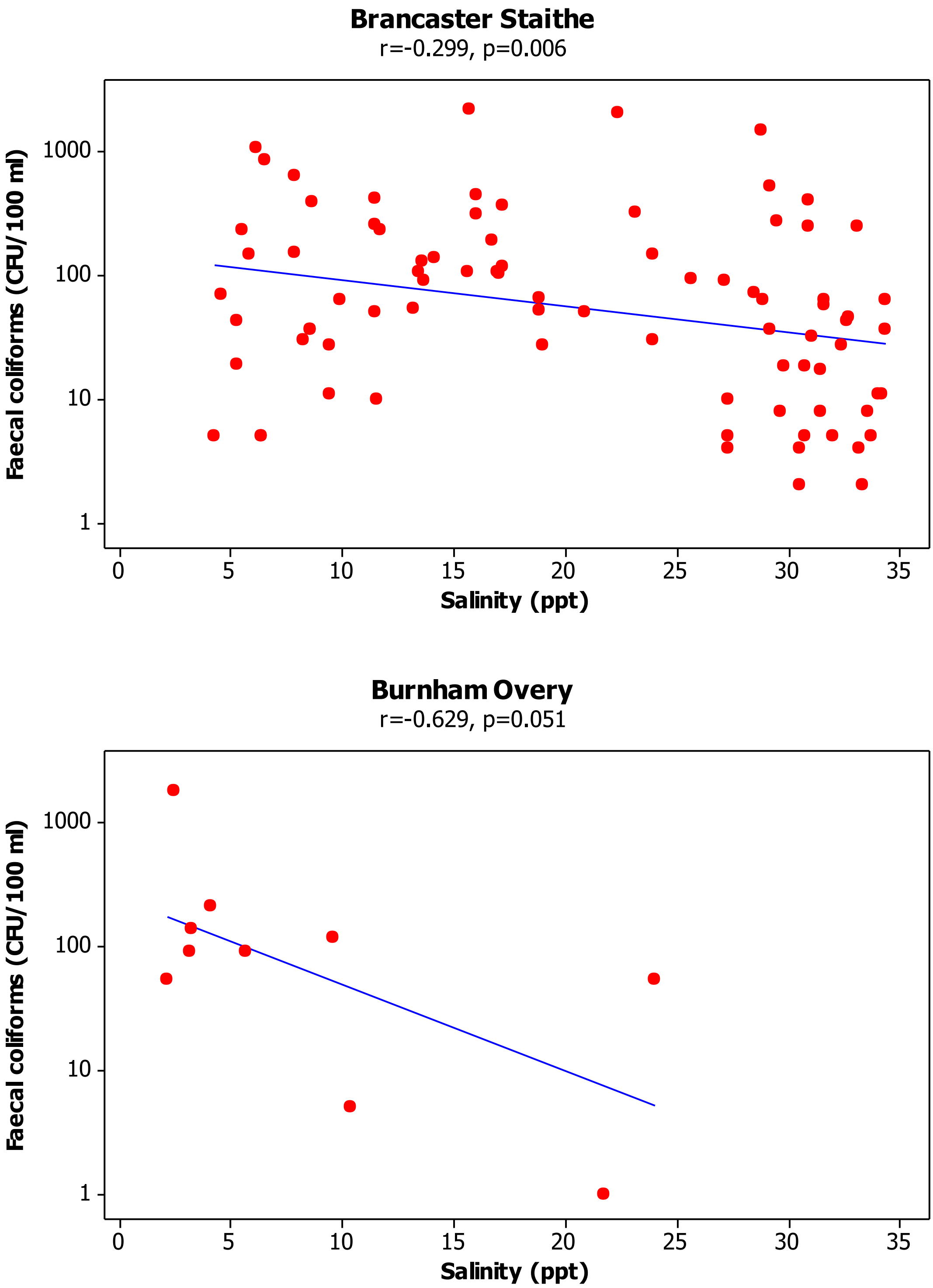

Figure IX.12: Scatter-plots of salinity against faecal coliforms.
Data from the Environment Agency

There were significant correlations between faecal coliform levels and salinity at Brancaster Staithe, but the effect was very slight (r=-0.299). Despite the apparent increase in faecal coliform concentrations at lower salinities, the correlation was not quite significant at Burnham Overy, probably due to the low number of samples.

Appendix X. Microbiological Data: Shellfish Flesh

X.1. Summary statistics and geographical variation

There are a total of 19 RMPs in the Brancaster production area that have been sampled between 2003 and 2013. Nine of these RMPs are for mussels, seven are for Pacific oysters, two are for cockles, and one is for native oysters. The geometric mean results of shellfish flesh monitoring from all RMPs sampled from 2003 onwards are presented in Figure X.1 to Figure X.4. Summary statistics are presented in Table X.1 and boxplots for sites are shown in Figure X.5 to Figure X.6. None of the cockle or native oyster RMPs have been sampled on 10 or more occasions, and neither have the Letzer S mussel RMP or the Thornham Creek 1, Thornham Creek 2, T Loose and Whittaker Burnham Overy Pacific oyster RMPs. These RMPs will therefore not be included in the more detailed analyses.

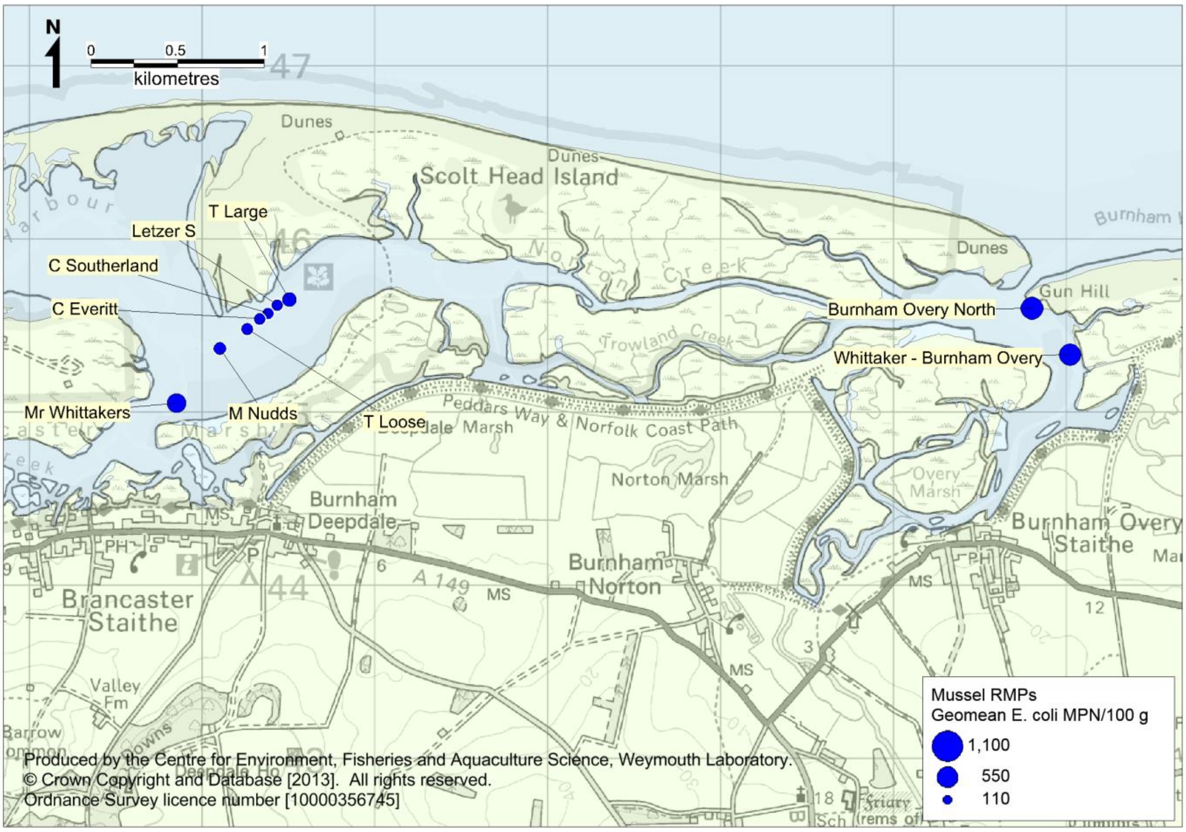

Figure X.1: Mussel RMPs active since 2003

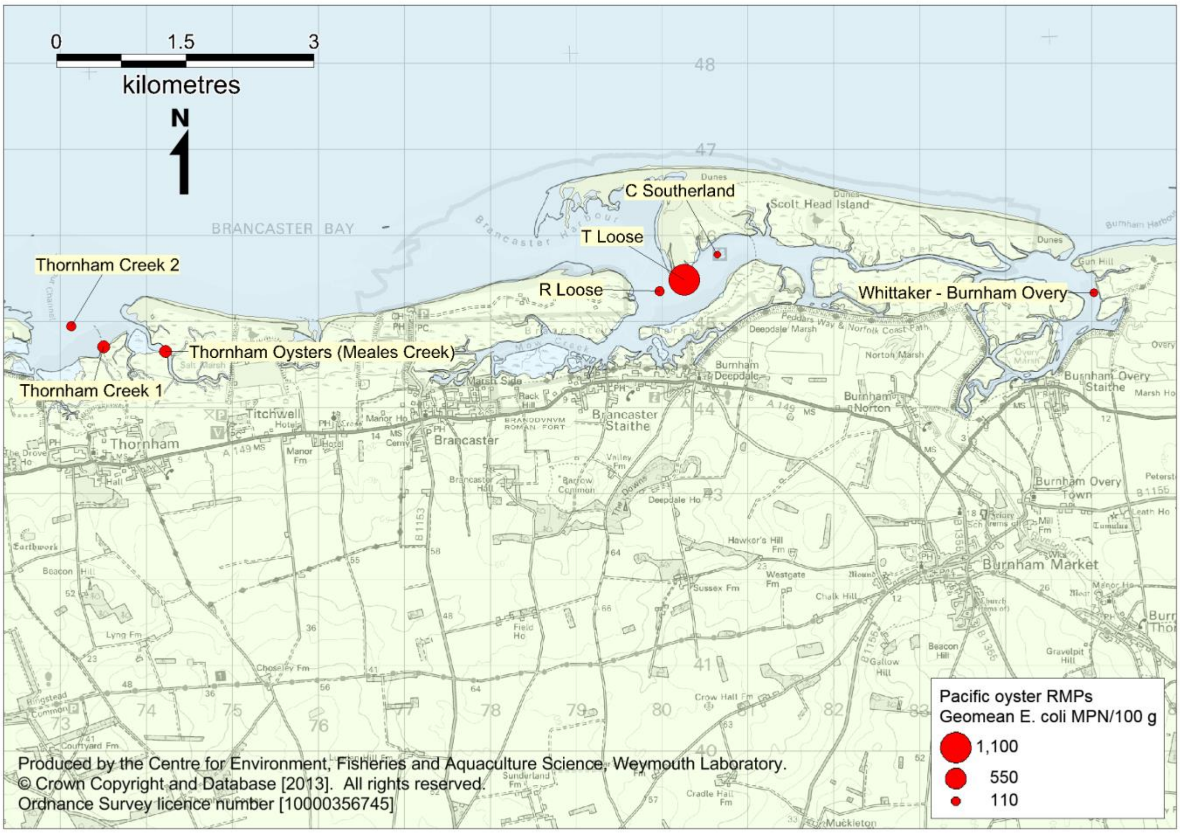

Figure X.2: Pacific oyster RMPs active since 2003

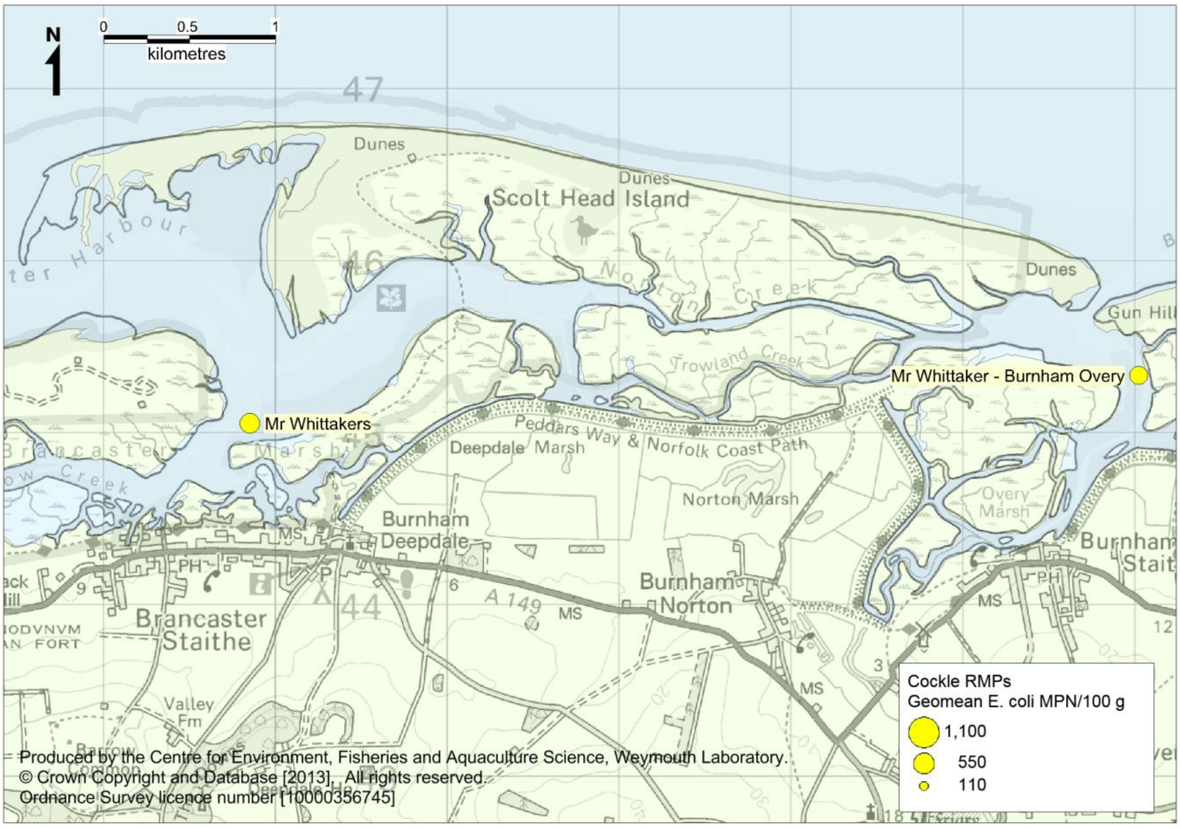

Figure X.3: Cockle RMPs active since 2003

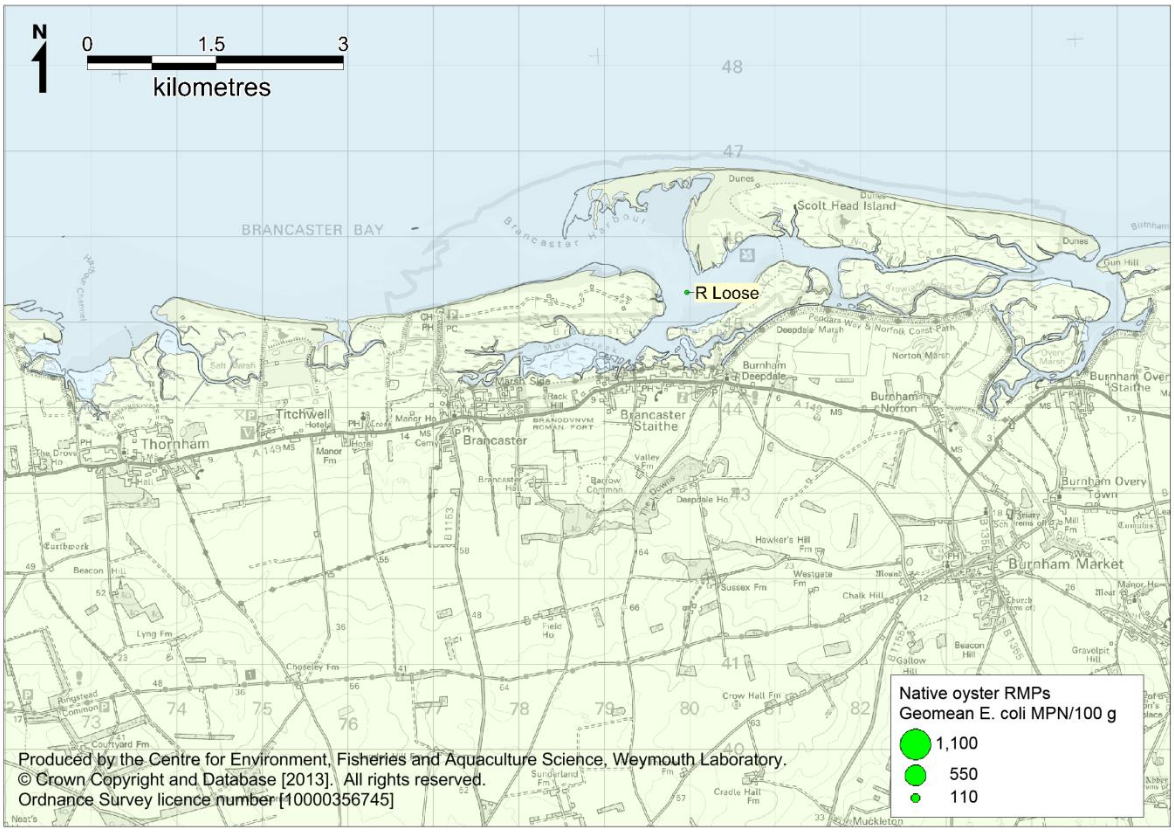

Figure X.4: Native oyster RMP active since 2003

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

Site	Species	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 230	% over 4,600
Mr Whittakers	Mussel	44	20/01/2003	03/03/2008	446.2	<20	9,100	63.6	4.5
M Nudds	Mussel	18	18/06/2007	08/07/2013	201.0	20	1,300	44.4	0.0
T Loose	Mussel	27	17/03/2003	01/10/2013	195.5	<20	1,700	44.4	0.0
C Everitt	Mussel	10	01/10/2008	05/08/2013	158.3	20	790	10.0	0.0
C Southerland	Mussel	42	17/02/2003	04/11/2013	84.7	<20	2,800	19.0	0.0
Letzer S	Mussel	1	29/04/2003	29/04/2003	130.0	130	130	0.0	0.0
T Large	Mussel	33	17/02/2003	03/06/2013	265.4	<20	2,400	57.6	0.0
Burnham Overy North	Mussel	34	15/01/2008	21/07/2011	606.9	20	16,000	76.5	5.9
Whittaker - Burnham Overy	Mussel	60	01/12/2003	03/03/2008	580.5	<20	>18,000	76.7	11.7
Thornham Creek 2	Pacific oyster	7	16/07/2003	22/06/2004	141.0	<20	1,300	42.9	0.0
Thornham Creek 1	Pacific oyster	4	20/01/2003	20/04/2004	212.4	110	290	50.0	0.0
Thornham Oysters (Meales Creek)	Pacific oyster	111	17/02/2003	04/11/2013	203.7	<20	16,000	47.7	2.7
R Loose	Pacific oyster	64	24/03/2003	01/10/2013	130.5	<20	24,000	35.9	3.1
T Loose	Pacific oyster	1	27/09/2004	27/09/2004	1,100.0	1,100	1,100	100.0	0.0
C Southerland	Pacific oyster	63	17/02/2003	04/11/2013	83.3	<20	2,400	23.8	0.0
Whittaker - Burnham Overy	Pacific oyster	2	28/06/2005	19/07/2005	93.8	40	220	0.0	0.0
Mr Whittakers	Cockle	2	20/01/2003	19/05/2003	500.0	500	500	100.0	0.0
Mr Whittaker - Burnham Overy	Cockle	3	28/06/2005	22/05/2006	435.3	220	750	66.7	0.0
R Loose	Native oyster	5	29/04/2003	22/11/2005	37.8	<20	220	0.0	0.0

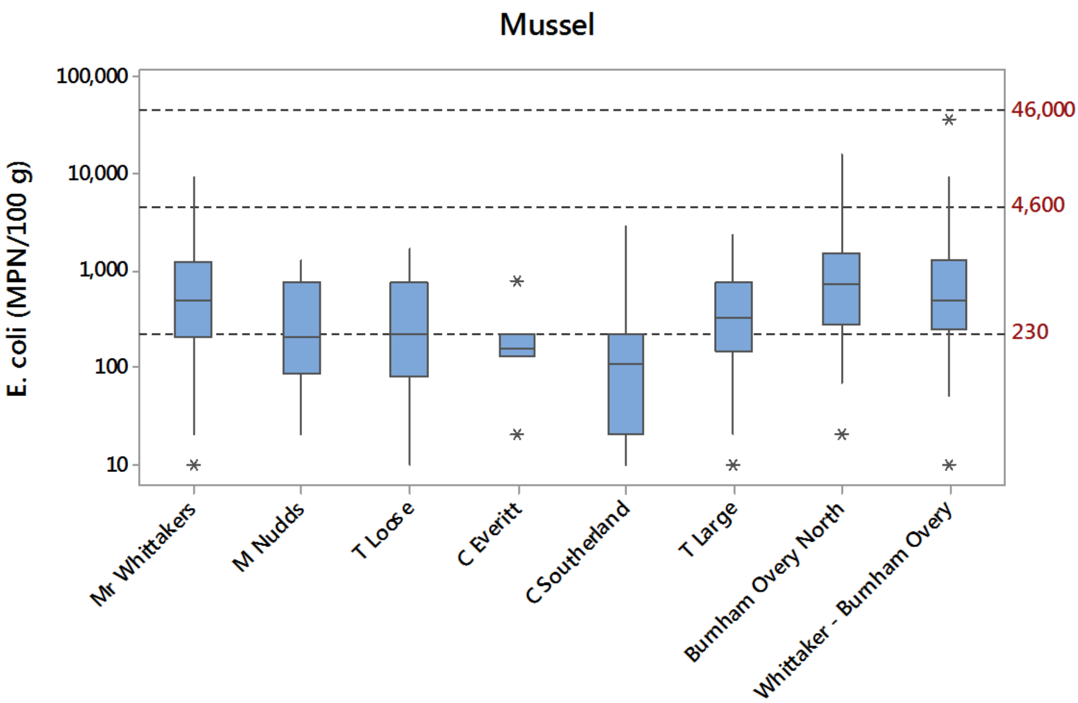

Figure X.5: Boxplots of *E. coli* results from mussel RMPs from 2003 onwards.

The two mussel RMPs in Overy Creek (Burnham Overy and Burnham Overy North) had the highest geometric mean *E. coli* MPN/100 g and the highest proportions of results exceeding 4,600 MPN/100 g. Results were very similar at these two RMPs. Whilst the geometric mean result was marginally higher at the outermost of the two (Burnham Overy North) the proportion of results exceeding 4,600 MPN/100 g exceeded 10% in the innermost only (Whittaker - Burnham Overy). In the Brancaster Staithe area results were broadly similar at the sites within Norton Creek, and were highest at the site within Brancaster Harbour creek (Mr Whittakers), which was the only site here where results of over 4,600 MPN/100 g were recorded.

A one-way ANOVA revealed that there was significant variation in *E. coli* levels between mussel RMPs ($p<0.001$). Post ANOVA Tukey tests showed that Whittaker - Burnham Overy and Burnham Overy North has higher average *E. coli* levels than M Nudds and C Southerland. Additionally Mr Whittakers and T Large had higher levels of *E. coli* than C Southerland. Comparisons of RMPs were carried out on a pair-wise basis by running correlations (Pearson's) between sites that shared sampling dates, and therefore environmental conditions, on at least 20 occasions. Mr Whitakers and Whittaker – Burnham Overy were the only mussel RMPs to share 20 or more sampling days. These sites correlated significantly ($p<0.05$) suggesting that they are influenced by similar sources despite their geographic separation.

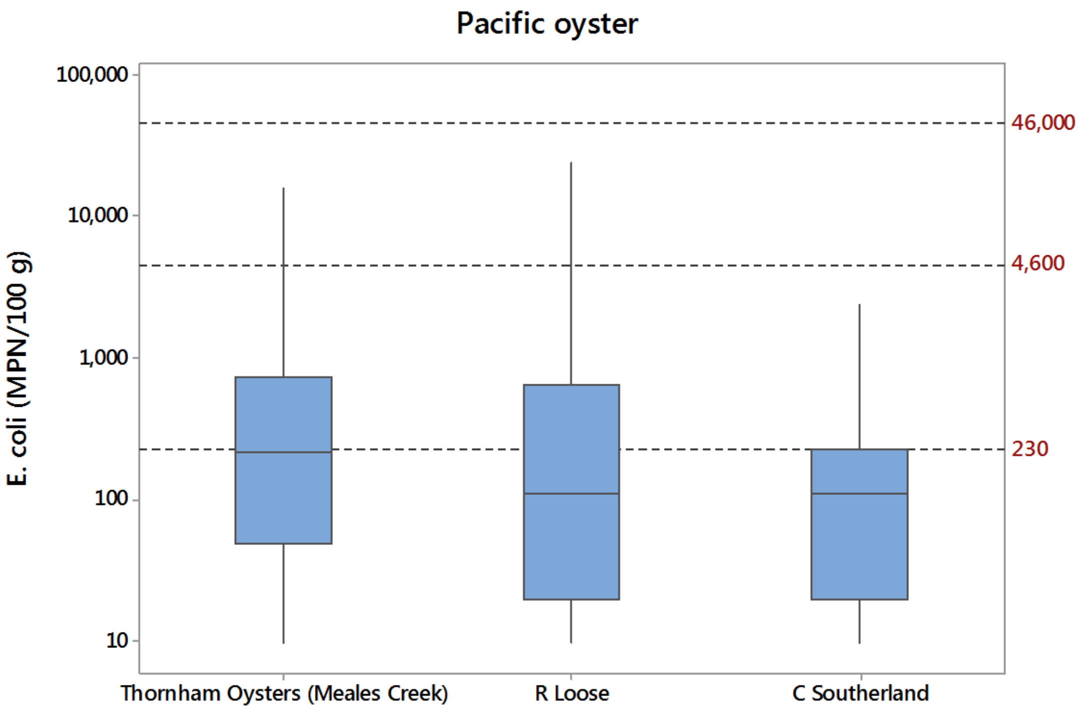

Figure X.6: Boxplots of *E. coli* results from Pacific oyster RMPs from 2003 onwards.

Results were higher on average at Thornham Oysters (Meales Creek) than at the two RMPs in the Brancaster Staithe area. Results were higher on average at R Loose compared to C Southerland, and results exceeding 4,600 MPN/100g were only recorded at the former. A one-way ANOVA showed that there were significant differences in *E. coli* levels between sites (p=0.004), and post ANOVA Tukey tests showed that Thornham Oysters (Meales Creek) had significantly higher levels of *E. coli* than C Southerland. Thornham Oysters shared at least 20 sampling days with both Southerland and Loose-R and correlated significantly (p<0.05) with both. These significant correlations indicate that these sites share similar contamination sources.

X.2. Overall temporal pattern in results

The overall temporal variation in *E. coli* levels found in bivalves is shown in Figure X.7.

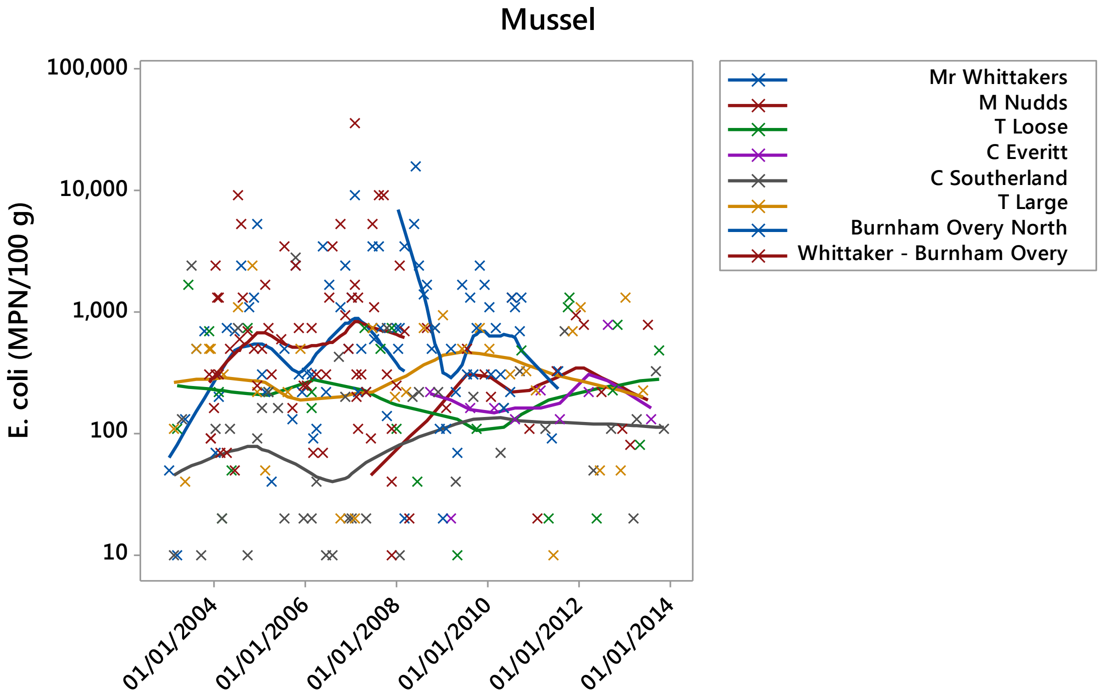

Figure X.7: Scatterplot of *E. coli* results over time for mussels, overlaid with loess line.

Many of the mussel RMPs have not been sampled for long enough to show a reliable trend over time. M Nudds, T Large and C Southerland, which have been sampled since 2003 all show little change in *E. coli* levels through the period considered.

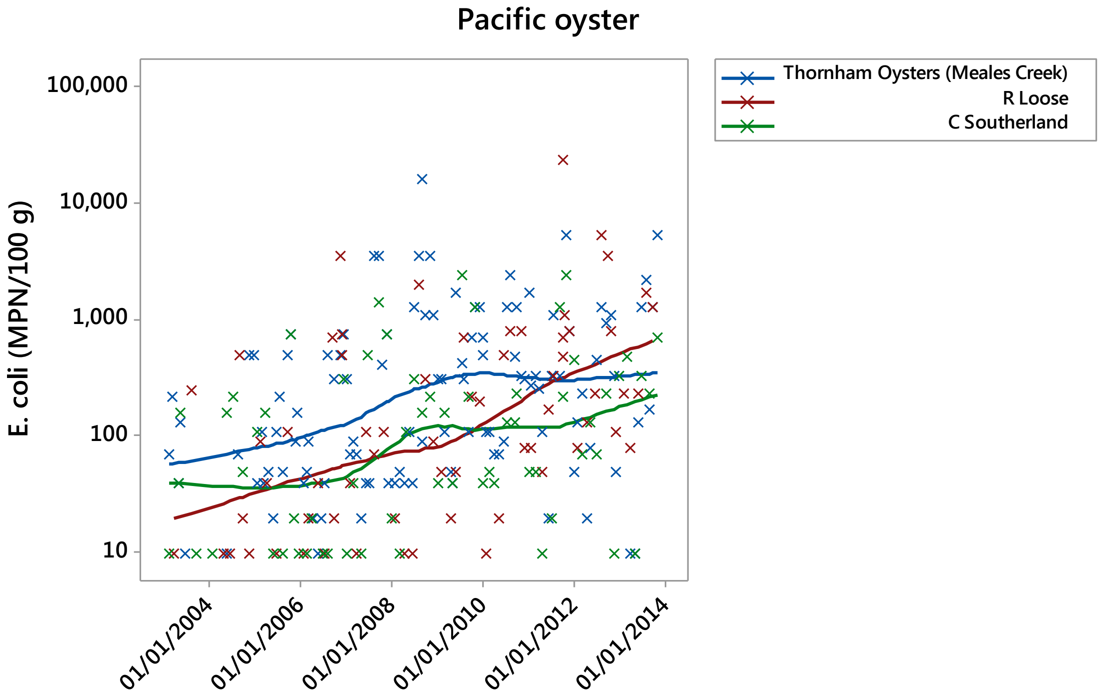

Figure X.8: Scatterplot of *E. coli* results over time for Pacific oysters, overlaid with loess line.

In contrast to mussel monitoring results, all three Pacific oyster RMPs show a trend of increasing *E. coli* levels since 2003.

X.3. Seasonal patterns of results

Figure X.9 and Figure X.10 show the variation in *E. coli* levels between seasons at mussel sites and Pacific oyster sites respectively.

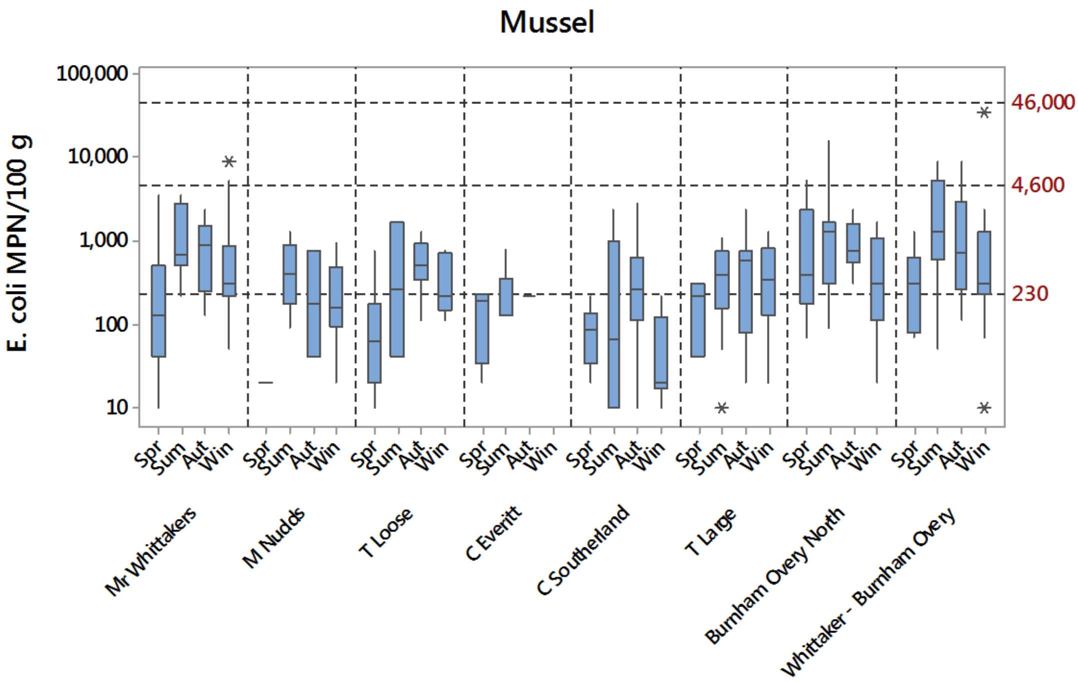

Figure X.9: Boxplot of *E. coli* results for mussels by RMP and season

The general pattern observed across all mussel RMPs was one of higher results in the summer and autumn. Statistically significant seasonal variation was found using one-way ANOVA tests at Mr Whittakers (p=0.014), T Loose (p=0,005) and Whittaker – Burnham Overy (p=0,015). Post ANOVA (Tukey) tests revealed that results were significantly higher in the summer than spring at Mr Whittakers and Whittaker – Burnham Overy, and higher in the autumn compared to the spring at T Loose.

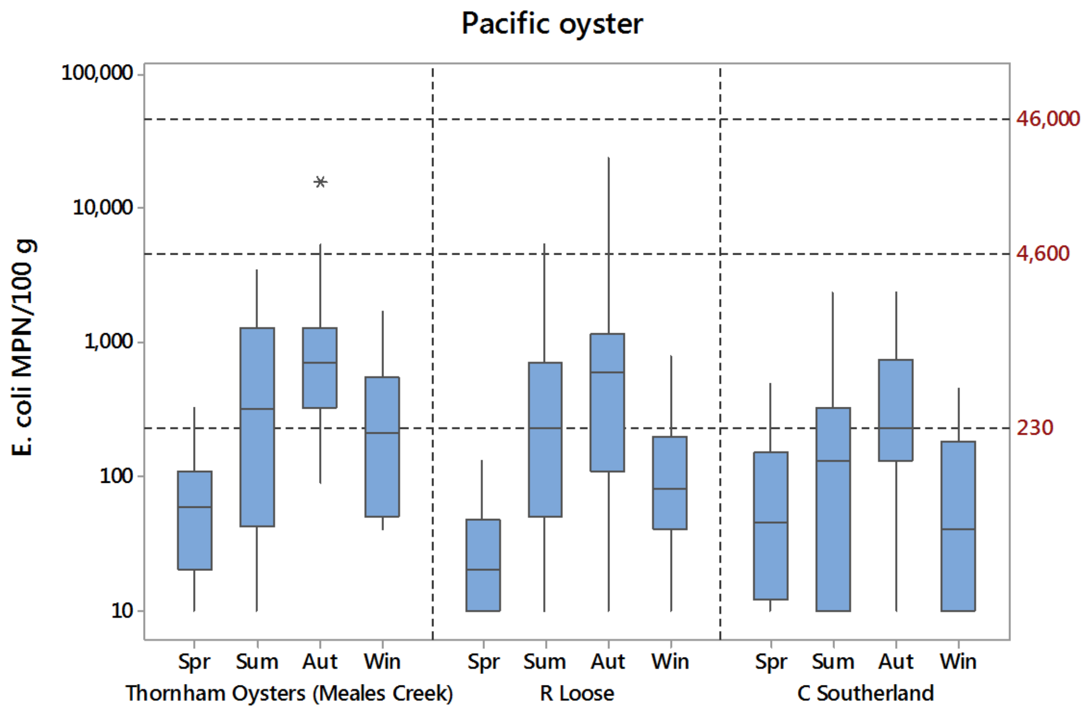

Figure X.10: Boxplot of *E. coli* results for Pacific oysters by RMP and season

Again, a general pattern of higher results in the summer and autumn is apparent. One-way ANOVA tests showed significant variation in *E. coli* levels in Pacific oysters between seasons at all three sites tested (p<0.001, <0.001 and 0.005 at Thornham Oysters (Meales Creek), R Loose and C Southerland respectively). At all three sites, autumn had higher *E. coli* levels than spring and winter. At Thornham Oysters (Meales Creek) autumn had higher levels than all other seasons and spring had lower levels than all other seasons. At R Loose, summer had higher *E. coli* levels than spring.

X.4. Influence of tide

To investigate the effects of tidal state on *E. coli* results, circular-linear correlations were carried out against the high/low tides at Burnham (Overy Staithe) and spring/neap tidal cycles for each RMP where more than 30 samples had been taken. Results of these correlations are summarised in Table X.2, and significant results are highlighted in yellow.

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

Site Name	Species	High/low tides r	High/low tides p	Spring/neap tides r	Spring/neap tides p
Mr Whittakers	Mussel	0.170	0.307	0.012	0.994
C Southerland	Mussel	0.229	0.130	0.170	0.322
T Large	Mussel	0.161	0.461	0.238	0.183
Burnham Overy North	Mussel	0.204	0.277	0.112	0.679
Whittaker - Burnham Overy	Mussel	0.211	0.080	0.066	0.782
Thornham Oysters (Meales Creek)	Pacific oyster	0.225	0.004	0.174	0.037
R Loose	Pacific oyster	0.369	0.000	0.164	0.194
C Southerland	Pacific oyster	0.342	0.001	0.329	0.001

Figure X.11 presents polar plots of log_{10} *E. coli* results against tidal states on the high/low cycle for the correlations indicating a statistically significant effect. High water at Burnham Overy is at 0° and low water is at 180°. Results of 230 *E. coli* MPN/100g or less are plotted in green, those from 231 to 4600 are plotted in yellow, and those exceeding 4600 are plotted in red.

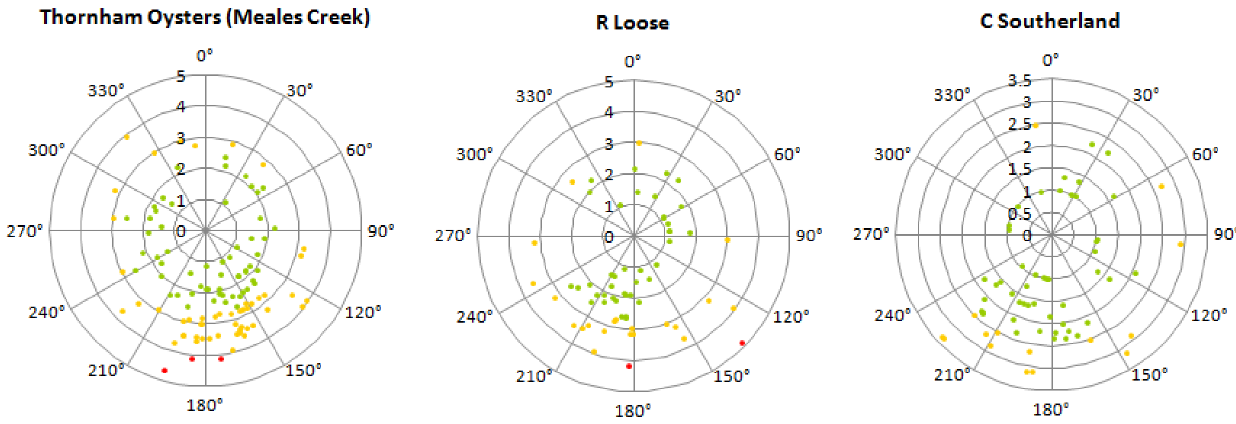

Figure X.11: Polar plot of log_{10} *E. coli* results (MPN/100g) at Pacific oyster RMPs against high/low tidal cycle

At all three Pacific oyster RMPs, there was a trend of higher results around low tide.

Figure X.12 presents polar plots of log10 *E. coli* results against the spring neap tidal cycle for each RMP where a significant correlation was found. Full/new moons occur at 0º, and half moons occur at 180º, and the largest (spring) tides occur about 2 days after the full/new moon, or at about 45º, then decrease to the smallest (neap tides) at about 225º, then increase back to spring tides. Results of 230 *E. coli* MPN/100g or less are plotted in green, those from 231 to 4600 are plotted in yellow, and those exceeding 4600 are plotted in red.

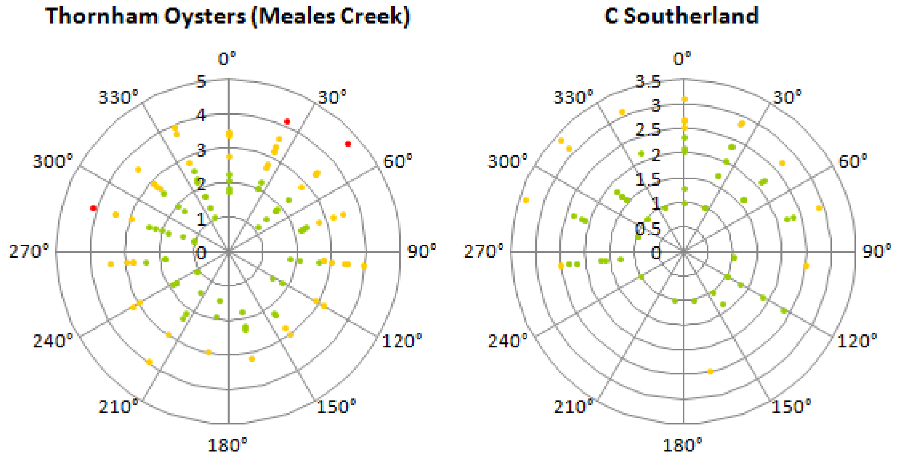

Figure X.12: Polar plot of log_{10} *E. coli* results (MPN/100g) at Pacific oyster RMPs against spring/neap tidal state

At both Pacific oyster RMPs higher results appear to arise around spring tides and as tide sizes increase towards spring tides.

X.5. Influence of rainfall

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

Table X.3: Spearman's Rank correlations between rainfall recorded at Burnham Market and shellfish hygiene results

	Species	Mussel								Pacific oyster		
	Site	Mr Whittakers	M Nudds	T Loose	C Everitt	C Southerland	T Large	Burnham Overy North	Whittaker - Burnham	Thornham Oysters (Meales Creek)	R Loose	C Southerland
	n	44	18	26	10	40	33	34	58	108	62	61
24 hour periods prior to sampling	1 day	0.071	0.007	0.201	**-0.722**	0.106	0.013	0.219	0.028	**0.216**	0.04	0.058
	2 days	0.194	0.11	0.336	-0.093	-0.027	-0.042	0.276	0.248	**0.261**	0.138	0.093
	3 days	0.071	-0.281	0.215	-0.093	-0.109	0.184	0.161	0.162	**0.216**	0.019	-0.002
	4 days	0.017	-0.361	0.059	-0.097	-0.052	0.088	-0.205	0.194	0.139	0.027	0.247
	5 days	0.065	-0.35	-0.152	0.414	0.132	-0.089	-0.139	0.088	-0.009	-0.137	0.005
	6 days	-0.116	**-0.683**	0.371	-0.354	-0.062	0.031	-0.201	0.143	0.065	0.199	0.158
	7 days	0.177	-0.154	-0.049	-0.300	0.030	0.081	-0.02	0.122	-0.002	0.126	0.062
Total prior to sampling over	2 days	0.163	0.106	0.362	-0.408	0.129	-0.056	0.239	0.229	**0.304**	0.120	0.110
	3 days	0.152	0.078	**0.405**	-0.408	0.023	0.075	0.292	0.225	**0.336**	0.121	0.094
	4 days	0.102	0.006	0.310	-0.425	0.013	0.017	0.167	**0.268**	**0.320**	0.085	0.127
	5 days	0.081	-0.053	0.300	-0.200	0.076	0.083	0.177	**0.305**	**0.297**	0.015	0.153
	6 days	0.055	-0.179	**0.416**	-0.170	0.010	0.117	0.105	**0.320**	**0.307**	0.0400	0.205
	7 days	0.056	-0.209	**0.436**	-0.179	-0.003	0.139	0.198	**0.302**	**0.308**	0.074	0.211

Rainfall had little or no influence on *E. coli* levels at most sites. A consistent influence was found at Thornham Oysters (Meales Creek) suggesting that rainfall dependent sources are of most significance to shellfisheries in the Thornham area. A more limited influence was found at the innermost RMP in Overy Creek (Whittaker – Burnham Overy) but not at the outermost RMP in this creek (Burnham Overy North). Significant correlations (both positive and negative) were occasionally detected at some RMPs in the Brancaster Staithe area, but it must be noted that an apparently significant correlation will arise by chance alone 5% of the time on average. The correlation results therefore suggest that there is little or no influence of rainfall dependent sources at the RMPs off Brancaster Staithe.

Appendix XI. Shoreline Survey Report

Date (time):
27th November 2013 (08:40-13:30)

Cefas Officer:
David Walker

Survey Partner:
Ruth Moore (King's Lynn & West Norfolk BC)

Area surveyed:
Brancaster Harbour, from Burnham Norton to Royal West Norfolk Golf Club. Titchwell Marsh nature reserve. Old Field Farm House, Thornham.

Weather:
27th November 12:45, dry, overcast, 10°C, wind bearing 295° at 10 km/h

Tides:
Admiralty TotalTide© predictions for Wells (52°58'N 0°51'E). All times in this report are GMT.

High	00:30	2.3m
Low	08:01	0.0 m
High	14:02	2.0 m
Low	20:13	-0.1 m

Objectives:

The shoreline survey aims to obtain samples of freshwater inputs to the area for bacteriological testing; confirm the location of previously identified sources of potential contamination; locate other potential sources of contamination that were previously unknown and find out more information about the fishery. A full list of recorded observations is presented in Table XI.1 and the locations of these observations are shown in Figure XI.1.

XI.1. Fishery

Two vessels that looked like dredgers were observed in Norton Creek (observation 5). At observation 11 there was a pond with baskets full of mussels. This was directly adjacent to the depuration tanks on a private property at observation 10. This pond is presumably used for the short term storage of harvested mussels before depuration and had an *E. coli* concentration of <10 cfu/100 ml.

XI.2. Sources of contamination

Sewage discharges

No sewage discharges were observed. However two pumping stations at observations 15 and 19 were seen. As they do not have a permit to discharge it can be concluded that they do not have an overflow. A public toilet was observed at observation 1. There is no consent for this toilet on the EA discharge consent database, nor is it connected to the sewerage network according to the Local Authority (Ruth Moore). It is likely that waste from this toilet is stored in a cesspit. There was also a houseboat at observation 7.

Freshwater inputs

All of the freshwater inputs observed, that discharged to the shellfisheries, were marsh drainage (observation 2, 6, 16 and 20). Flow readings for observations 2, 6 and 16 were later discarded on discovery of an equipment fault, and so it was not possible to estimate daily loadings. However *E. coli* concentrations of <10 to 20 cfu/100 ml were measured. At observation 20, the flow was measured and an *E. coli* loading of 1.56×10^8 was calculated from the concentration of 30 cfu/100 ml.

Livestock

No livestock were observed.

Wildlife

At observation 14 there were around 14 geese on the marsh. At observation 17 there were around 1,000 birds in a pond in the RSPB nature reserve.

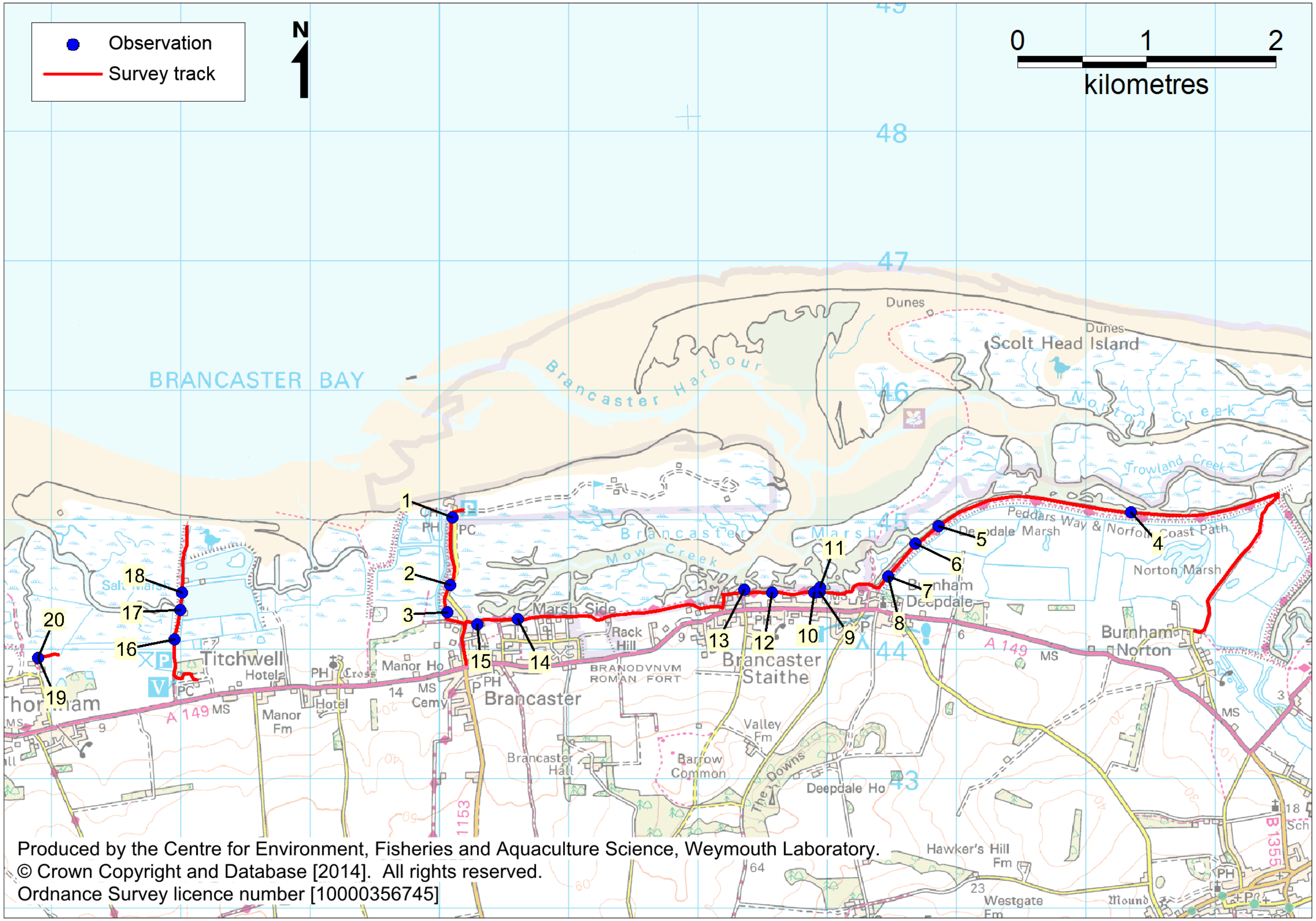

Figure XI.1: Locations of shoreline observations (Table XI.1 for details).

Table XI.1: Details of Shoreline Observations

Observation no.	NGR	Date	Time	Description	Photo
1	TF 77103 45018	27/11/2013	08:54	Public WC (not on mains according to LA). No consent in database.	Figure XI.3
2	TF 77084 44494	27/11/2013	09:04	Sluice draining marsh. Sample B01	Figure XI.4
3	TF 77060 44286	27/11/2013	09:14	Orange plastic pipe (20 cm diameter) into drainage ditch. Not flowing	Figure XI.5
4	TF 82348 45057	27/11/2013	10:16	14 geese landward	
5	TF 80859 44950	27/11/2013	10:41	2 vessels (possibly dredgers). Bearing 310° 1 km.	Figure XI.6 & Figure XI.7
6	TF 80680 44815	27/11/2013	10:47	Sluice draining marsh (50 cm diameter pipe, full except 5 cm from top). Sample B02	Figure XI.8
7	TF 80471 44564	27/11/2013	11:01	1 houseboat	Figure XI.9
8	TF 80471 44564	27/11/2013	11:01	Several boats scattered throughout the creeks	
9	TF 79938 44441	27/11/2013	11:11	Crab nets and a pond	Figure XI.10
10	TF 79901 44439	27/11/2013	11:13	Depuration tanks on private property	
11	TF 79945 44475	27/11/2013	11:15	Mussel holding pond & cleaning equipment (sample B03)	Figure XI.11 & Figure XI.12
12	TF 79572 44439	27/11/2013	11:26	Caravan park	
13	TF 79359 44461	27/11/2013	11:31	Depuration tanks in sheds	Figure XI.13
14	TF 77606 44229	27/11/2013	12:00	Inspection cover, possible for groundwater	Figure XI.14
15	TF 77295 44191	27/11/2013	12:05	Anglian pumping station	Figure XI.15
16	TF 74952 44075	27/11/2013	13:09	Sluice draining west (sample B04)	Figure XI.16
17	TF 74996 44303	27/11/2013	12:45	~1,000 birds in pond (nature reserve)	
18	TF 75011 44435	27/11/2013	13:03	Possible sluice on other side of pond (bearing 105°)	Figure XI.17
19	TF 73898 43932	27/11/2013	13:26	Anglian pumping station	Figure XI.18
20	TF 73898 43932	27/11/2013	13:26	Drainage stream (sample B05)	Figure XI.19

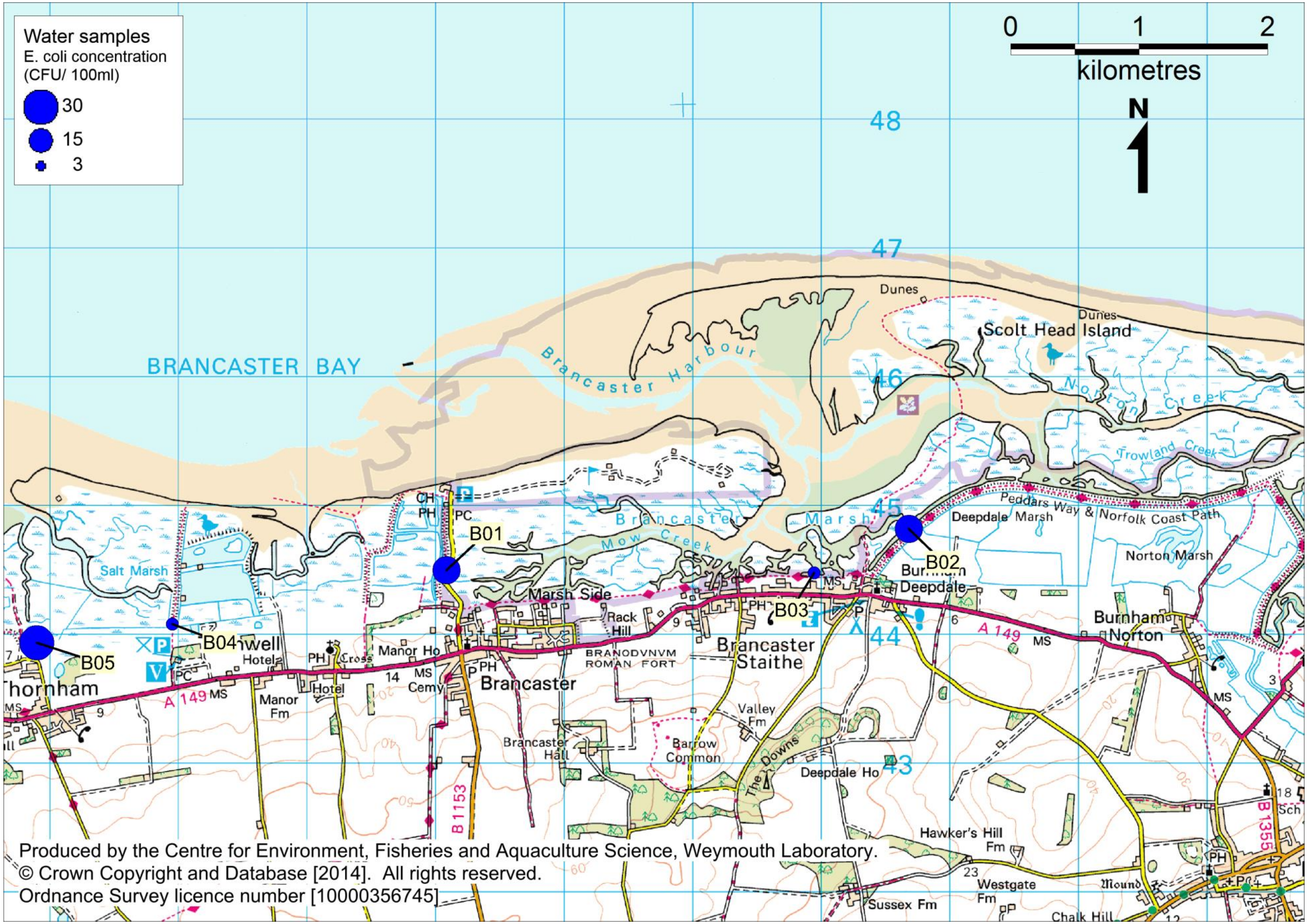

Figure XI.2: Water sample results (Table XI.2 for details)

Table XI.2: *E. coli* results, spot flow gauging results and estimated stream loadings (where applicable).

Sample ID	Observation number	Date and time	Water type	Description	Flow (m^3/s)	*E. coli* concentration (CFU/100 ml)	*E. coli* loading (CFU/day)	NGR
B01	2	27/11/2013	FW	Sluice draining marsh		20		TF 77084 44494
B02	6	27/11/2013	FW	Sluice draining marsh		20		TF 80680 44815
B03	11	27/11/2013	SW	Mussel holding pond		<10		TF 79945 44475
B04	16	27/11/2013	FW	Sluice draining west		<10		TF 74952 44075
B05	20	27/11/2013	FW	Drainage stream	0.006	30	1.56×10^8	TF 73898 43932

Figure XI.3

Figure XI.4

Figure XI.5

Figure XI.6

Figure XI.7

Figure XI.8

Figure XI.9

Figure XI.10

Figure XI.11

Figure XI.12

Figure XI.13

Figure XI.14

Figure XI.15

Figure XI.16

Figure XI.17

Figure XI.18

Figure XI.19

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List of Abbreviations

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

Glossary

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

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

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