Centre for Environment Fisheries & Aquaculture Science

www.cefas.defra.gov.uk

EC Regulation 854/2004

CLASSIFICATION OF BIVALVE MOLLUSC PRODUCTION AREAS IN ENGLAND AND WALES

SANITARY SURVEY REPORT

Holy Island

October 2014

Food Standards Agency

Cover photo: St Cuthbert's Isle.

Current Cefas sanitary survey reports and reviews are available on our website at:

http://www.cefas.defra.gov.uk/our-science/animal-health-and-food-safety/food-safety/sanitary-surveys/england-and-wales.aspx

Contacts

For enquires relating to this report or further information on the implementation of sanitary surveys in England and Wales:

Simon Kershaw
Food Safety Group
Cefas Weymouth Laboratory
Barrack Road
The Nothe
Weymouth
Dorset
DT4 8UB

☎ +44 (0) 1305 206600
✉ fsq@cefas.co.uk

For enquires relating to policy matters on the implementation of sanitary surveys in England:

Karen Pratt
Hygiene Delivery Branch
Local Delivery Division
Food Standards Agency
Aviation House
125 Kingsway
London
WC2B 6NH

☎ +44 (0) 207 276 8970
✉shellfishharvesting@foodstandards.gsi.gov.uk

Statement of use

This report provides a sanitary survey relevant to bivalve mollusc fisheries at Holy Island, 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

Alastair Cook, David Walker, Rachel Parks, Owen Morgan, Fiona Vogt.

Revision history

Version	Details	Approved by	Approval date
1	Draft for internal consultation	Fiona Vogt	17/10/2014
2	Draft for client/consultee comment	Simon Kershaw	22/10/2014
3	Final	Andrew Younger	29/01/2015

Consultation

Consultee	Date of consultation	Date of response
Northumberland County Council	29/10/2014	-
Northumberland IFCA	29/10/2014	26/11/2014
Natural England	29/10/2014	26/11/2014
Environment Agency	29/10/2014	13/11/2014
Shellfish Association of Great Britain	29/10/2014	-
Northumbrian Water	29/10/2014	14/11/2014
Defra	29/10/2014	-

Dissemination

Food Standards Agency, Northumberland County Council. The report is available publicly via the Cefas website.

Recommended Bibliographic Reference

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

Contents

1. Introduction

1.1. Legislative Requirement

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

When consumed raw or lightly cooked, bivalves contaminated with pathogenic microorganisms may cause infectious diseases (e.g. Norovirus-associated gastroenteritis, Hepatitis A and Salmonellosis) in humans. In England and Wales, fish and shellfish constitute the fourth most reported food item causing infectious disease outbreaks in humans after poultry, red meat and desserts (Hughes *et al.*, 2007).

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

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

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

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

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

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

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

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

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

This report documents the information relevant to undertake a sanitary survey for Pacific oysters (*Crassostrea gigas*) and mussels (*Mytilus* spp.) at Holy Island. The area was prioritised for survey in 2014-15 by a risk ranking exercise.

1.2. Area description

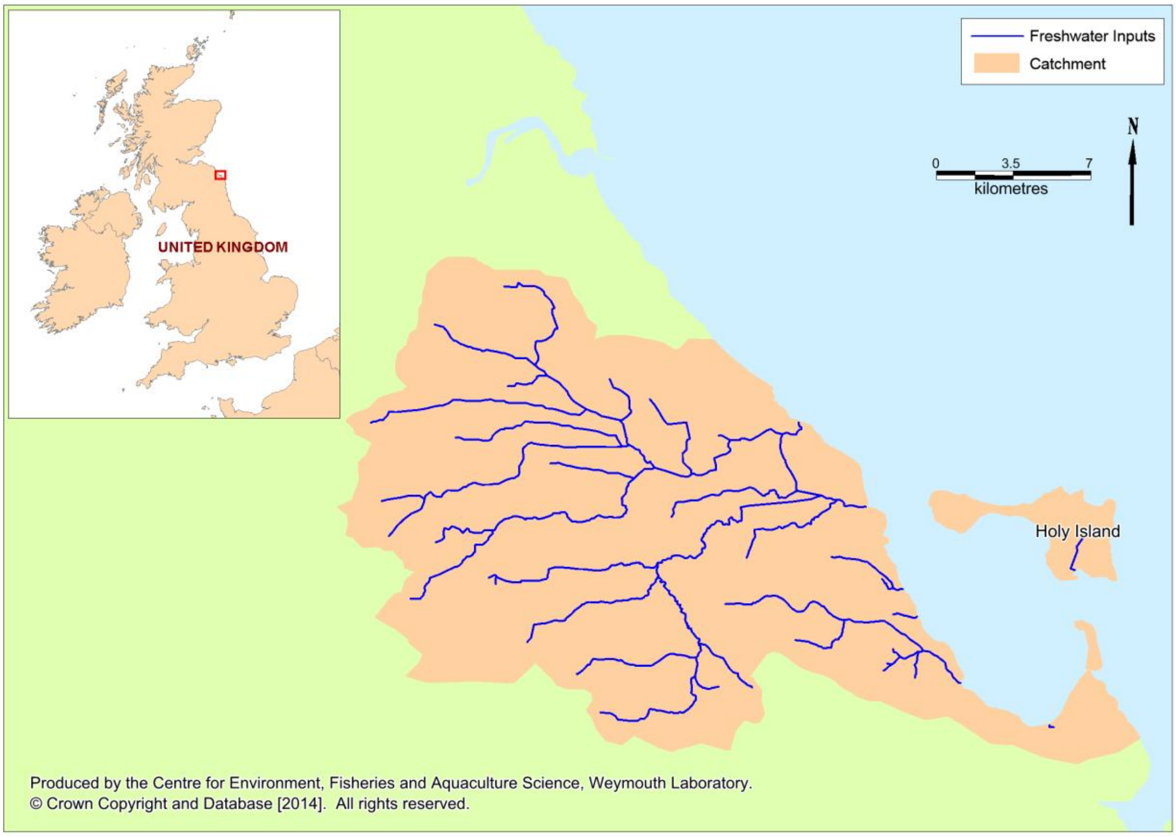

Figure 1.1: Location of the survey area

Holy Island is a small island situated just off the Northumbrian coast that is accessed via a tidal causeway. The island is a popular tourist attraction and also supports a small fishing fleet and some limited agriculture. The adjacent mainland is rural in nature and sparsely populated, and is mainly devoted to agriculture with some tourism also. There are several watercourses draining from the mainland. Between the island and the mainland there is a shallow, semi-enclosed embayment which supports a long established Pacific oyster farm as well as extensive naturally occurring mussel beds.

1.3. Catchment

The catchment area draining to Holy Island Sands is approximately 132 km². It lies on the Northumbrian coastal plain, a relatively flat and low lying strip of land bordering the coast and has a maximum elevation of 202 m in the south of the catchment at Kyloe Wood. Figure 1.2 shows land cover within this area.

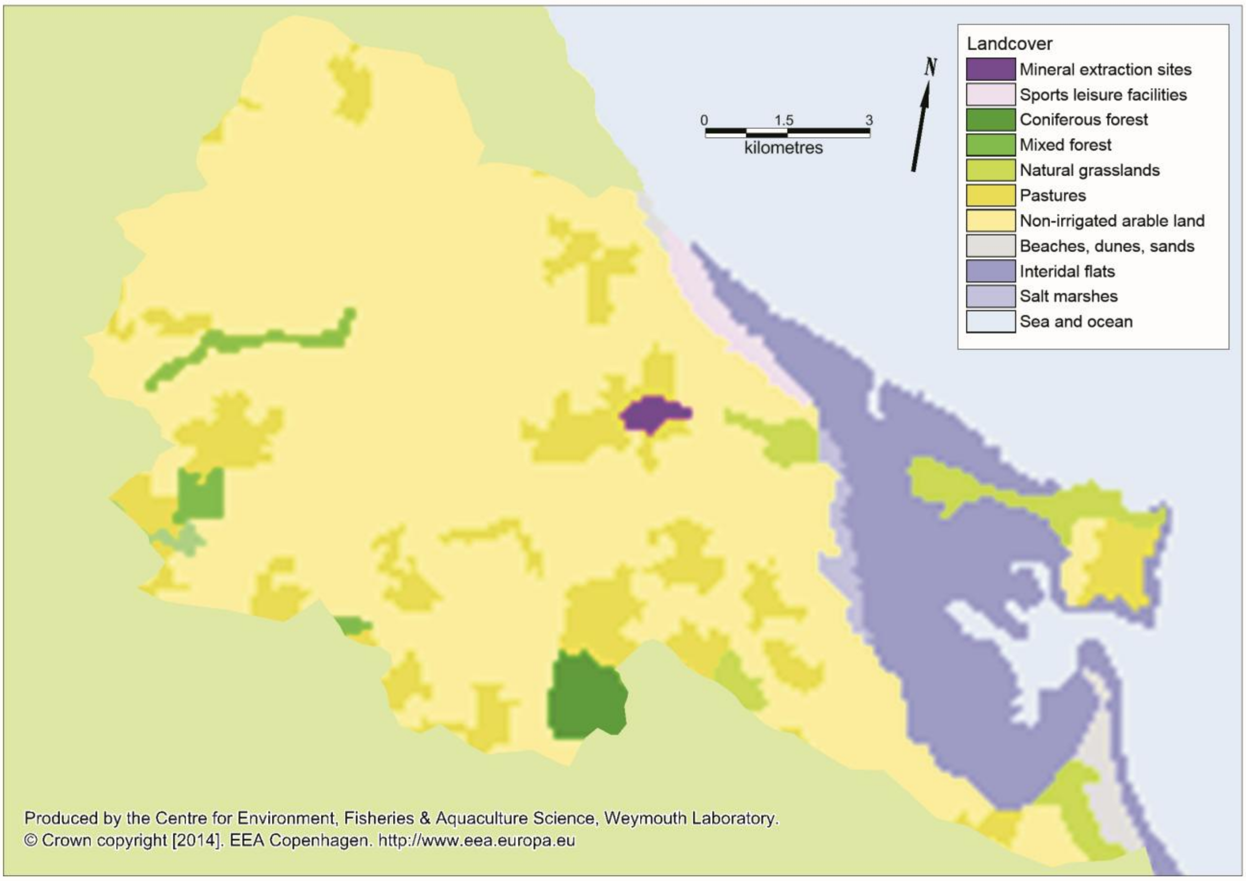

Figure 1.2: Landcover in the Holy Island catchment area

Arable farm land dominates the mainland catchment interspersed with some pockets of pasture and woodlands. Holy Island comprises largely of grassland and pasture, with some arable land. 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 may increase up to 100 fold. Hydrogeology maps indicate that the catchment geology is of moderate permeability throughout (NERC, 2012). River levels are therefore likely to respond to rainfall but will not be particularly flashy as there will be some discharge from and recharge to ground waters.

2. Recommendations

Pacific oysters

Within the area requiring continued classification there will be a general tendency for reduced flushing and dilution potential towards the southern end. There are some freshwater inputs which may influence the hygiene status of the fishery. The South Low and Beal Cast watercourses converge and drain to the channel which lies just north of the fishery, and the Fenham Burn drains to the channel which lies to the west of the fishery, roughly at the midpoint of the main row of trestles oriented in a north south direction. Runoff carried by these watercourses will be subject to significant dilution before arriving in the vicinity of the fishery. Stocks held at lower elevations immediately adjacent to these channels will be more exposed to contamination from these watercourses when there is less scope for dilution around low water. Seals may also be a significant contaminating influence. Their haul out sites are on sandbanks to the north west of the fishery. Contamination deposited here will be mobilised as the tide covers the sandbanks, particularly if wave action from the North Sea penetrates the entrance. This will generally be carried away from the fishery during the flood, but towards it on the ebb, although the initial covering on the flood is likely to be the time when mobilisation into the water column is most rapid. Sources of contamination from the south shore of Holy Island (Holy Island STW and the intermittent discharge at the harbour) will initially be carried past the fishery to its north on the flood tide so will probably not impact directly.

On balance, it is recommended that the RMP is located at the northern end of the fishery to capture potential impacts from the South Low/Beal Cast, as well as the seal haulout sites. Bacteriological survey results tentatively support this conclusion. This would also capture to some extent any influence from the Fenham Burn, although if this was the only consideration an RMP near where its drainage channel joins the subtidal channel adjacent to the fishery may be slightly more effective. The RMP should be located on the edge of the trestles at the lowest elevation accessible to reflect reduced dilution potential towards the end of the ebb tide. Samples should be collected by hand on a year round monthly basis, and should consist of animals of a market size. A tolerance of 10 m applies.

Mussels

There is no commercial interest in the mussel stocks at present, but historically there has been and they are a considerable resource. A sampling plan is therefore provided, which only requires implementation subject to renewed commercial interest in the fishery and approval from Natural England and/or the Northumberland IFCA. As the mussel bed lies in the same geographic area, the rationale for RMP location is the same as that described above for oysters, so it is recommended that the RMP is positioned at the same point. Samples should be collected by hand on a year round monthly basis, and should consist of animals above whatever minimum size is applied if the fishery opens. The sampling frequency may require review if any formal closed seasons are imposed. Should a more rapid classification be required, this may be awarded provisionally on submission of 10 samples taken not less than one week apart. Given the dense covering, a tolerance of 10 m should be sufficient to allow repeated sampling.

3. Sampling Plan

3.1. General Information

Location Reference

Production Area	Holy Island
Cefas Main Site Reference	M001
Ordnance survey 1:25,000 map	Explorer 340
Admiralty Chart	111

Shellfishery

Species/culture	Pacific oysters	Trestle farm
	Mussels	Wild
Seasonality of harvest	Year round (although mussels historically harvested September to April)	

Local Enforcement Authority

Name	Commercial Team Public Protection Service Northumberland County Council Loansdean Morpeth Northumberland NE61 2AP
Environmental Health Officer	Rose Mary Ayre
Telephone number ☎	01670 623830
Fax number	01670 626059
E-mail	rosemary.ayre@northumberland.gcsx.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, 2014) 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 or any changes to the shellfishery occur other than those currently planned.

Table 3.1: Location of representative monitoring point (RMP) and frequency of sampling for Holy Island

Classification zone	RMP*	RMP name	NGR	Latitude & Longitude (WGS84)	Species	Growing method	Harvesting technique	Sampling method	Tolerance	Frequency	Comments
Fenham Flats	B001P	Fenham Flats North	NU 1195 4062	55° 39.538'N 01° 48.698'W	Pacific oysters	Trestle culture	Hand	Hand	10 m	Monthly	
Fenham Flats	B001Q	Fenham Flats North	NU 1195 4062	55° 39.538'N 01° 48.698'W	Mussels	Wild	Hand	Hand	10 m	Monthly	Only requires classification on request. Sampling frequency may require revision if a closed season is imposed in the future. If a more rapid classification is required this can be awarded following 10 samples taken not less than a week apart

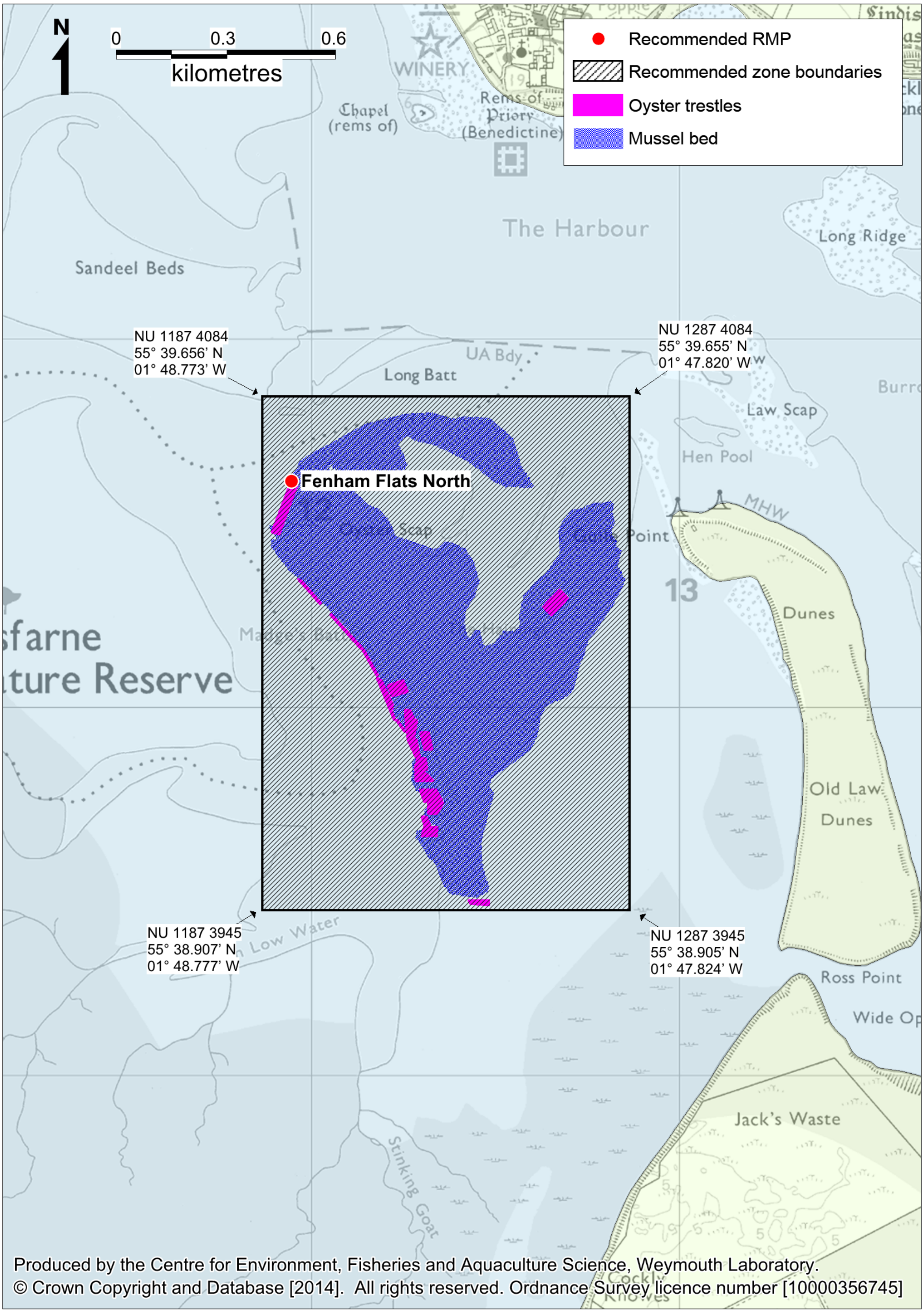

Figure 3.1: Recommended zoning and monitoring arrangements (applies to both mussels and oysters)

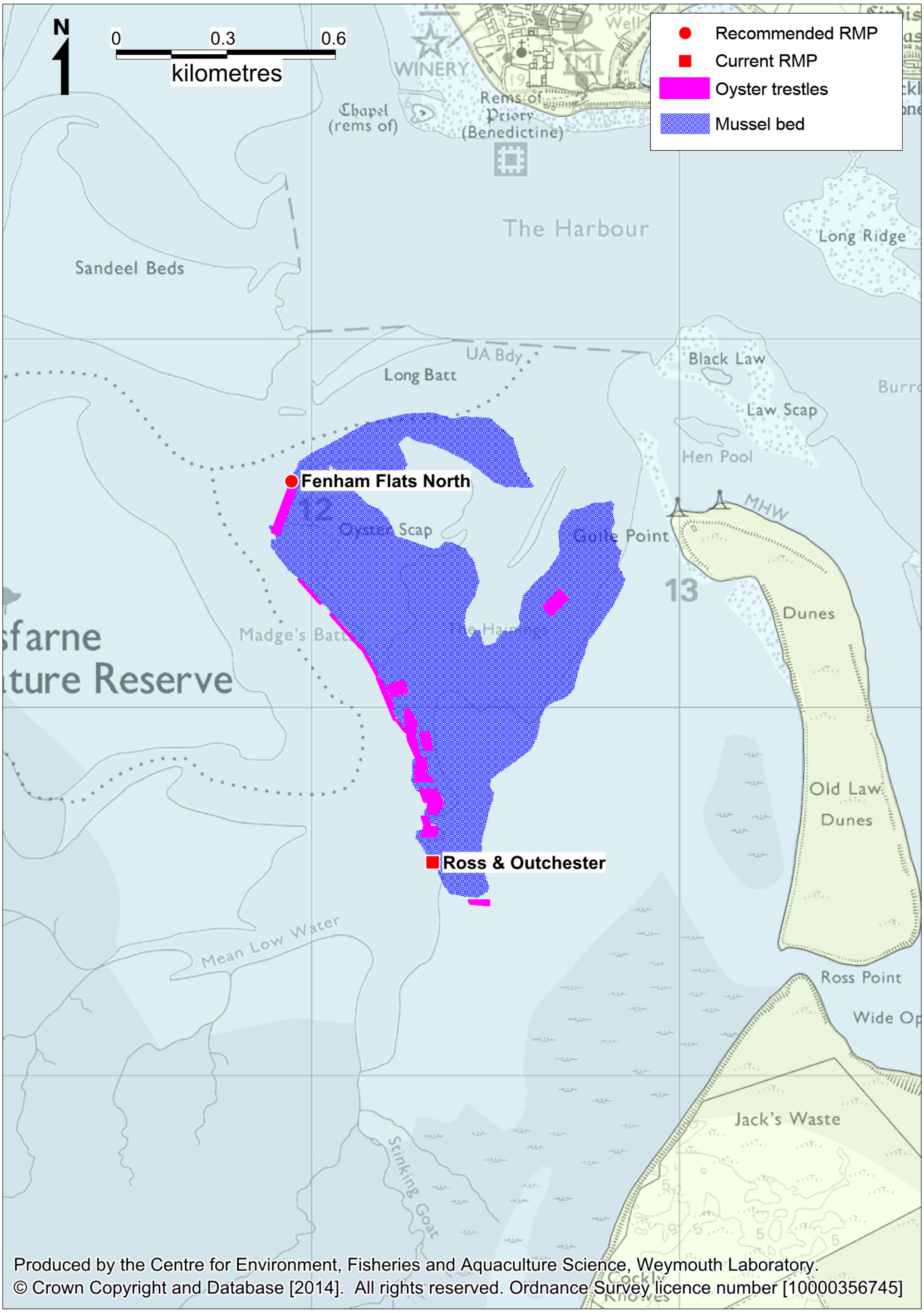

Figure 3.2: Comparison of RMP locations before and after survey (both species)

4. Shellfisheries

4.1. Description of fisheries

The subject of this survey is a Pacific oyster trestle farm, which was established in 1989. There are also extensive naturally occurring mussel beds within the survey area which have been subject to light commercial exploitation in the past. Figure 4.1 shows the locations of the trestles (provided by Natural England), the extent of the mussel bed and the distribution of seagrass within which any shellfish gathering is prohibited.

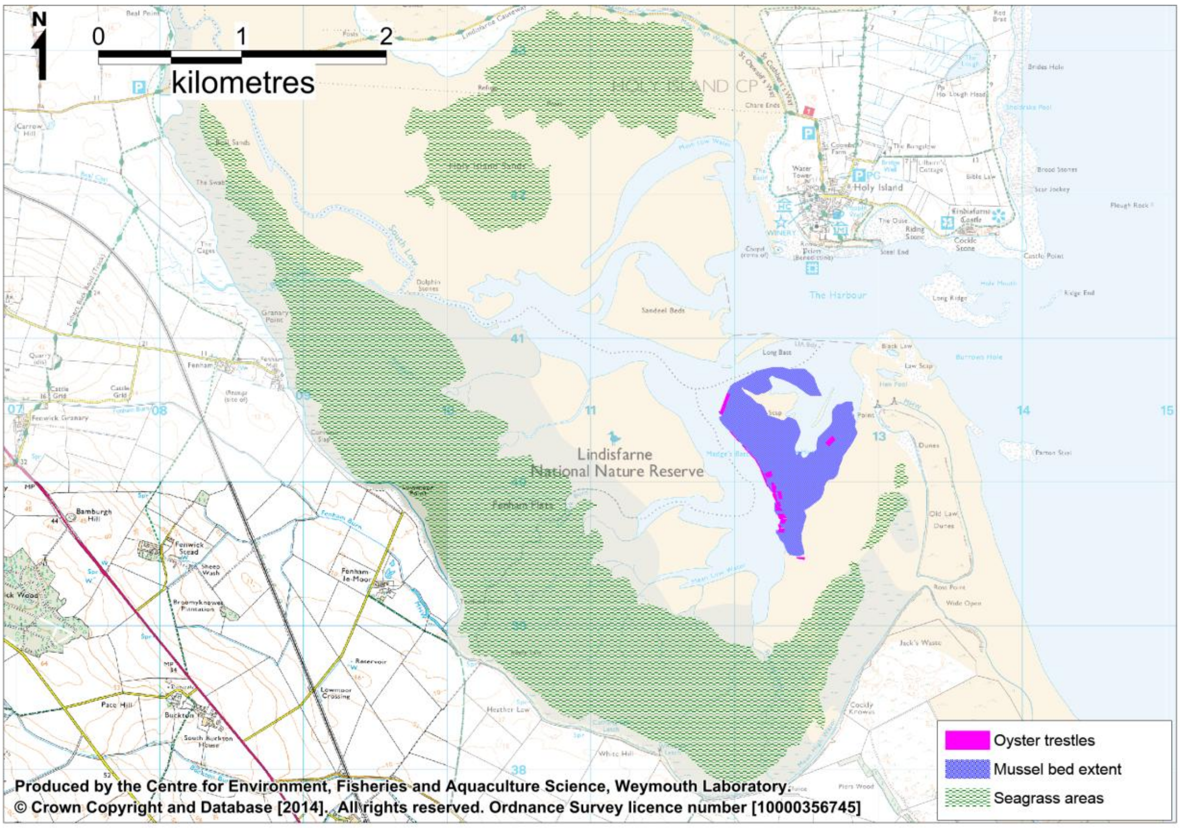

Figure 4.1: Location of shellfish resources within the survey area

The trestle farm is relatively large. It consists of a series of discrete blocks of trestles along the lower intertidal area adjacent to a subtidal channel known as Madge's Batts. Here, hatchery seed is placed in mesh bags and grown to market size, a process that takes about 3 years. Harvesting is undertaken by hand, and the annual production is in the order of 50 tonnes. The harvesters have their own depuration facilities and supply to a wide range of markets including local outlets and London restaurants. The oyster farm is not subject to any conservation controls such as minimum size or closed seasons.

Mussels are widespread throughout the survey area. The main bed, which has been subject to commercial gathering in the past, is located in the same privately owned area as the oyster farm. It is surveyed annually by the Northumberland IFCA. The 2013 survey indicated that this bed covered an area of 41.3 Ha and contained 3,503 tonnes of mussels, of which a relatively high proportion were of a marketable size (Green and Royle, 2013). Recent recruitment was poor, as evidenced by a lack of juveniles in 2013, although the as yet unpublished survey in 2014 indicates some fresh settlement had occurred since (Northumberland IFCA, pers. comm.). It used to be subject to hand gathering by one operator from Berwick, who was licensed to take up to 10 tonnes from the fishery each year. These were purified and sold at farmers markets and to local restaurants. Harvesting was undertaken from September to April, when the mussels were in best condition. Exploitation of these mussels stopped in 2010 for a number of reasons, including a fall in their quality and marketability, the causes of which are unclear. No formal expressions of interest in reopening the fishery have been lodged with the IFCA.

The only IFCA byelaw applicable to the mussel fishery is Byelaw 17, which prohibits gathering within areas of seagrass. Responsibility for the management of the mussel beds largely lies with Natural England, due to their location within the Lindisfarne National Nature Reserve. In response to applications to harvest here they decide if the fishery can be permitted, and assign quotas, minimum sizes and open periods. When the fishery was previously exploited, a precautionary management approach was adopted due to the sensitive nature of the site, and allowable catches were small relative to stock size.

Other patches of mussels within the survey area do not hold the quantity and quality as on the main mussel bed so will not require a sampling plan. Additionally, most are in close proximity to and in some cases coincide with the seagrass beds.

4.2. Hygiene Classification

Table 4.1 lists all classifications within the survey area since 2005.

Table 4.1: Classification history for Holy Island, 2004 onwards

Area	**Species**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Ross Links R9	P. oyster	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Ross Links A	Mussels	B	B	B	B	B	B-LT	-	-	-	-

LT denotes long term classification

Mussels have not been classified since 2010. The oyster farm has held a long term B classification during recent years.

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, 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 are two shellfish resources in the survey area which require a sampling plan. The first is a large and long established Pacific oyster trestle farm which requires continuing year round classification in its entirety. The second is a large, naturally occurring mussel bed in the same privately owned area where the oyster farm is located. In 2013, this mussel bed supported an estimated biomass of 3,503 tonnes of mussels, of which a relatively high proportion were of a marketable size. It has been exploited in the past, from September to April when meat yields were most favourable, although there is no formal closed season within the district. It was declassified in 2010 when the sole harvester ceased activity, largely due to a decline in the quality/condition of the mussels. There has been no formal interest expressed in re-opening the fishery. Natural England would decide on quotas, minimum sizes and other management measures should the fishery re-open. A precautionary approach is taken to management (e.g. small quotas relative to stock size) due to the sensitive nature of the area.

There are additional patches of mussels within the survey area, but these are not of the same quality nor do they hold the quantities found on the main mussel bed. Also, many are close to seagrass beds where harvesting is prohibited under a Northumberland IFCA byelaw. As such, a sampling plan is only required for the main mussel bed. Classification zone boundaries should exclude any seagrass areas to avoid implying that harvesting would be possible in those sensitive areas.

5.3. Pollution Sources

Freshwater Inputs

The catchment area draining into the shellfishery around Holy Island is approximately 132 km^2, the vast majority of which lies on the mainland, with the remainder on Holy Island itself. Arable land dominates the catchment with smaller areas of pasture and woodland and very few built up areas. It is low lying, with elevations mainly below 100 m, so watercourses draining the area are of a relatively low gradient. The hydrogeology of the catchment is described as of moderate permeability throughout. The discharge from watercourses will therefore respond to rainfall events, at which times there will be a greater amount of faecal indicator bacteria washed off the land and into watercourses. However, their responses will be damped to some extent by the discharge and recharge of groundwaters. Watercourse discharge rates are likely to be higher on average in winter due to reduced evaporation and transpiration and a higher water table, although this will not necessarily result in higher average fluxes of faecal indicator bacteria. There are no gauging stations within the survey area so the day-to-day and seasonal variability in discharge rates could not be examined in detail.

The mainland is drained by a series of streams and minor rivers, and there is only one small freshwater outfall from Holy Island. Most land runoff entering the survey area will therefore originate from mainland watercourses. The North Low and the South Low are the two largest watercourses draining the mainland, and whilst they have separate outfalls they are connected via a channel which conveys some of the flow from the North Low to the South Low. This artificial channel is no longer maintained so most of the water in the North Low drains from its outfall at Goswick. This outfall drains to the beach some distance north of the causeway so is unlikely to impact on the survey area. The South Low outfall drains to a channel which passes under the causeway and into the northern end of the survey area. Shoreline survey observations indicate that the majority of runoff from these watercourses drains to the shore via the South Low. Its bacterial loading, measured under the causeway bridge, was 2.1×10^{11} *E. coli* cfu/day. The two other main streams in the area are the Beal Cast and the Fenham Burn. The former could not be accessed during the shoreline survey so no estimate of its discharge or bacterial loading could be made. Beal Cast meets with the South Low on the intertidal area to the north-west of the fishery area. The bacterial loading carried by the Fenham Burn was 1.0×10^{11} *E. coli* cfu/day at the time of shoreline survey. It follows a drainage channel across the Fenham Flats and towards the fishery. The two other flowing freshwater inputs encountered were both minor in terms of discharge volume and bacterial loading so are considered to be of negligible impact on the fishery. One was just to the south of the Fenham Burn (7.3×10^{6} *E. coli* cfu/day) and the other was at Holy Island harbour (2.9×10^{8} *E. coli* cfu/day).

It is therefore concluded that the main freshwater inputs originate from the mainland, and they are relatively minor. Those likely to impact on the fishery (South Low, Beal Cast and Fenham Burn) follow drainage channels across the Fenham Flats and into the subtidal channel which lies to the west of the fishery.

Human Population

Total resident population within census areas contained within or partially within the catchment area is just under 2,300. The largest settlement in the area is the village of Scremerston in the north of the catchment, but there are a few other scattered villages and small settlements including one by the south shore of Holy island. The area is a popular tourist attraction, and it has been estimated that there are about 500,000 visits to Holy Island and the surrounding coastal region per year. There is also a large holiday park at Haggerston. During holiday periods the sewage output of tourist destinations such as Holy Island Village and the caravan park will therefore increase significantly.

Sewage Discharges

Details of all permitted sewage discharges within the survey catchment were taken from the March 2014 update of the Environment Agency national permit database. There are six continuous water company sewage works within the survey area. Four of these discharge to the Lows, one to the Fenham Burn, and one to the North Sea. The four draining to the Lows (Bowsden, Lowick, Shoresdean and Haggerston Castle Caravan Park STWs) generate an estimated combined bacterial loading of around 6×10^{12} faecal coliforms/day. They are therefore likely to make a significant contribution to the bacterial loading delivered by these watercourses. The population served by the caravan park sewage works will be highly seasonal, peaking during the summer months. The works discharging to the Fenham Burn (Fenwick STW) is small and generates an estimated loading of about 9×10^{10} faecal coliforms/day, but will nevertheless make a consistent contribution to faecal indicator organisms delivered by this watercourse. The Holy Island STW generates an estimated bacterial loading of 3×10^{11} faecal coliforms/day, and discharges to the North Sea off the east coast of Holy Island, around the low water mark. While this is not a particularly large works it may have some impact on the fishery, although the extent of this will depend on tidal circulation patterns.

There are nine water company owned intermittent overflow discharges within the survey area. Six of these discharge to the Lows, one discharges to Fenham Burn, one discharges via the main Holy Island sewage outfall, and one discharges to the shore at Holy Island Harbour. No spill records were available for any of these so it is difficult to assess their significance, apart from noting their location and potential to spill untreated sewage. As none of the sewage catchments within which they are located are particularly extensive their potential spill volumes are limited.

Although a high proportion of properties within the survey area are served by water company sewerage infrastructure, there are also 47 permitted private discharges, of which seven discharge to soakaway and 40 discharge to watercourses. Where specified, these are generally treated by small treatment works such as package plants, and the majority of these are small, serving one or two properties. All are located on the mainland. Those discharging to soakaway should be of no impact assuming they are functioning correctly. Most discharging to watercourses are to the Lows, but the Fenham Burn and Beal Cast also receive effluent from private discharges. The largest of these by a considerable margin is the Haggerston Castle Caravan Parks second works, where the effluent is treated via reedbed then discharged to the Lows. It is uncertain how effective this is at bacterial removal, but it will contribute to the bacterial loadings delivered via the South Low outfall. The population it serves will vary significantly with season, peaking in the summer. It is possible that there are further private discharges in the area which do not hold permits, and so do not feature on the database from which this information was derived.

Agriculture

Land cover within the survey catchment is a mosaic of arable and pasture land, with the former predominating. Holy Island itself is largely pasture, with a few arable fields and a grassy dune system along its north shore. At the time of the last detailed census (2010) there were 13,726 sheep, 3,664 cattle, but only small numbers of pigs and poultry recorded within the catchment. There are therefore significant numbers of grazing animals within the catchment so some impacts from agriculture are anticipated.

During the shoreline survey, grazing livestock were commonly encountered all around the perimeter of the embayment. These were generally in fenced fields with no access to the shore. However, on the mainland shore to the north of the causeway sheep had access to the beach, and a patch of heavily grazed saltmarsh was observed by the South Low outfall. Also, there were significant amounts of dried cattle droppings on the grassy dune system that extends from the north west tip of Holy Island, although no cattle were observed there during the survey. Small numbers of cattle are grazed here in early spring and autumn. They have access to the shore in places but whether they regularly access intertidal areas is uncertain.

Livestock manures will either be deposited directly on pastures by grazing animals, or collected from operations such as cattle sheds and spread on either arable land or pasture. This in turn may be washed into watercourses which will carry it to coastal waters. Watercourses which animals can access will be more vulnerable than those that are fenced off. Given the ubiquity of farmland throughout the survey area, all watercourses may potentially be affected at times. Where animals have access to the shore they may deposit faeces directly on intertidal areas, which will subsequently be washed into coastal waters via tidal inundation on larger tides. The saltmarsh by the South Low is likely to represent the principal area where this occurs. It is also possible that the cattle on the Holy Island dunes deposit directly on the intertidal in places.

The geographical pattern of agricultural impacts is likely to closely mirror that of land runoff, with additional contributions from direct deposition on the intertidal areas on the mainland to the north of the causeway, and possibly around the north west tip of Holy Island. 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’). In contrast, impacts from animals on the intertidal will be greatest as tide size increases towards, and during, spring tides.

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 unfenced 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. Other manures may also be spread on pastures and arable lands at various time of the year. The southern part of the mainland catchment and the island itself are within a nitrate vulnerable zone so spreading is subject to a closed period from September/October to the end of December or January, depending on soil and biosolid types. The area drained by the North and South Lows however largely falls outside this zone so organic fertilizers may be applied here at any time of the year.

Boats

The discharge of sewage from boats is a potential source of bacterial contamination to the survey area. Boat traffic in the area is centred around Holy Island Harbour, and is limited to a fleet of six under 10 m fishing boats and small numbers of recreational craft such as yachts, sailing dinghies and kayaks. The latter, smaller, vessels are unlikely to make overboard discharges so will not be considered further. Given the shallow and largely intertidal nature of the survey area, the larger vessels (yachts and fishing vessels) will be limited to the Holy Island Harbour area, and the navigation route out into the North Sea. Vessels within the harbour area are prohibited from making overboard discharges, although it is uncertain how strictly this is adhered to. It is therefore concluded that the risk of significant impacts from boat discharges is low, and limited to the navigation route out into the North Sea, and possibly around the harbour area. 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. Peak pleasure craft activity is anticipated during the summer, so any associated impacts are likely to follow this seasonal pattern.

Wildlife

The survey area encompasses a variety of habitats including mud and sand flats, sand dunes, salt marsh and eel grass beds. These and other coastal features support significant populations of birds and other wildlife. Large numbers of waterbirds (wildfowl and waders) use the area for overwintering, with average peak counts over the five winters up until 2012/2013 of 45,843 birds. Some are grazers (e.g. ducks and geese) and these will forage on saltmarsh, coastal pastures, and eel grass beds. Their faeces may therefore be directly deposited on the lower or upper intertidal areas, or be carried into coastal waters via runoff from grasslands. RMPs within or near to the drainage channels from freshwater inputs and saltmarsh areas will be best located to capture contamination from this source. Wading species feed upon invertebrates and so will forage (and defecate) directly on any shellfish beds on the intertidal. As such, they are a direct input in the immediate vicinity of the mussel beds and oyster trestle sites and are likely to contribute to *E. coli* counts found in shellfish. However, as a diffuse input no particular RMP location can be identified to best capture their impacts. The benthic mussel beds may be at more risk from direct deposition upon them than the oysters, which are held on raised trestles.

In addition to overwintering and wildfowl flocks, seabirds such as gulls and terns are present within the area all year round. There is a small gull/tern colony on Holy Island where 472 pairs were recorded during a survey in 2000. There is a much larger seabird breeding colony on the Farne Islands, about 10 km to the south east where 166,510 (individual) birds were recorded during the survey in 2000. 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. Some of these species (e.g. terns) migrate away from the area outside of the breeding season, and it is likely that resident species disperse somewhat at these times. As the nesting colonies are not in the immediate vicinity of the fishery, their presence will have no influence on the sampling plan.

Up to 3,000 grey seals were counted hauled out in the vicinity of Holy Island between April and September 2008. This is not a breeding site, so it is likely that use of the area decreases during the breeding season (August to December) although they will still frequent the vicinity given that there is a large breeding colony at the Farne Islands. There is also a much smaller colony of common seals (around 12 individuals) that frequent the Holy Island area. The oyster harvester indicated that several hundred seals are often observed hauled out on sandbanks just to the north of the trestle site. They may be a significant source of contamination to the fishery, and a monitoring point at its northern end would best capture their impacts.

Domestic animals

Dog walking takes place on paths adjacent to the shoreline of the survey area and could represent a potential source of diffuse contamination to the near shore zone. The intensity of dog walking is likely to be higher closer to the more heavily used paths, such as those around Holy Island. As a diffuse source, this will have little influence on the location of RMPs.

Summary of Pollution Sources

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

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

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

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

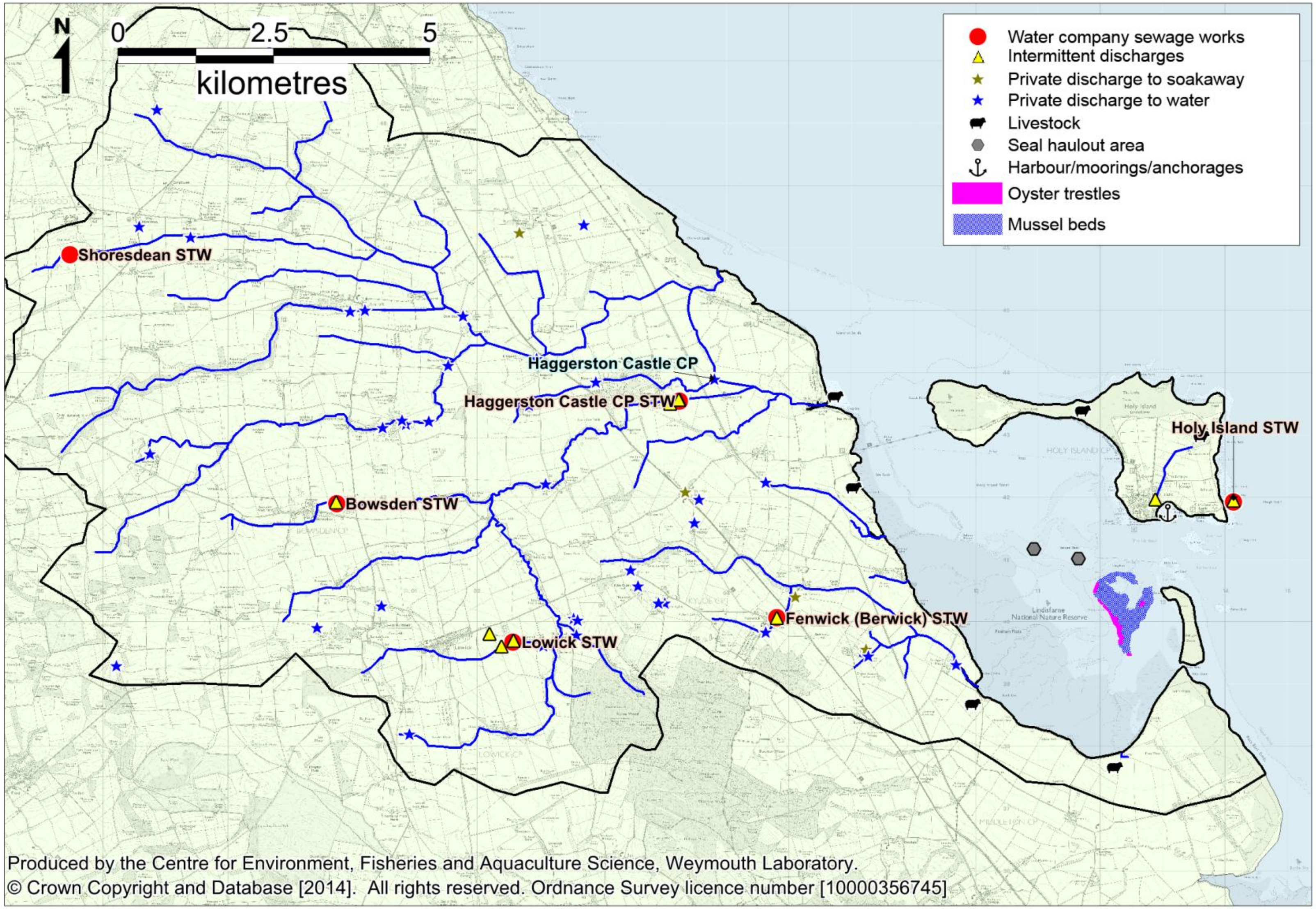

Figure 5.1: Summary of main contaminating influences

5.4. Hydrography

The survey area is a large, semi-enclosed shallow embayment of the North Sea that lies between Holy Island and the mainland. It is largely intertidal, with some subtidal channels. The substrate is generally sandy, with muddier areas on the upper parts of the Fenham Flats and some rocky and shingly areas around Holy Island. There are areas of saltmarsh inside of Ross Point and around the mainland end of the causeway. Its shallow nature will result in a high proportion of water being exchanged each tide, but the dilution potential will be limited.

The embayment connects to the North Sea in two places. The main connection is the subtidal channel between the southern tip of Holy Island and the Old Law dunes. This is where the deepest point is located. The second connection is over the causeway between the island and the mainland, which is intertidal. The elevation increases slightly to the north of the causeway peaking about 500 m further north at around 3-4 m above chart datum. Incoming tides are likely to meet here, and a connection will only be formed around high water. It is therefore concluded that the vast majority of tidal exchange is via the main connection.

Within the embayment there is a network of channels that drain to the main connection to the North Sea. Those draining the southern part of the Fenham Flats feed into the southern end of the subtidal channel that lies just to the west of the trestles (Madge’s Batts). The drainage channels carrying the Beal Cast and the South Low split around a sandbank. The southern channel converges with Madge’s Batts at the northern end of the oyster farm, whereas the northern channel passes to the north of the sandbank then converges with the main entrance channel. At lower states of the tide there may be elevated levels of faecal indicator organisms within these drainage channels, deriving from land runoff and saltmarsh washings. The dilution potential will increase within these channels as they widen and deepen towards the main North Sea connection.

Water circulation patterns within the area are primarily driven by tides. The tidal range at Holy Island is 4.2 m on spring tides, and 2.2 m on neap tides. Tidal streams off the Northumberland coast flood in a southerly direction and ebb in a northerly direction. This indicates that effluent from the Holy Island sewage works may be carried in through the main entrance on the flood tide, although the plume will probably tend to remain to the north of the fishery, initially at least.

There are no tidal diamonds within the survey area, nor were any observational or modelling studies describing tidal circulation patterns found during the literature search. As such, the patterns described below are solely based on an appraisal of the bathymetry of the area. The tide will flood in through the main entrance and progress up the channels. As these channels fill, the rising water levels will fill the creeks and spread over the extensive intertidal areas. Current velocities are likely to be fastest in the subtidal channels, and decrease over the intertidal areas. Water arriving from the main entrance will cross the causeway then meet water arriving from the north, somewhere north of the causeway, an hour or two before high water. As such there will be very little exchange of water through the northern entrance. Contamination delivered via the South Low and Beal Cast may have some impacts at the northern end of the fishery but may largely pass them by to the north. Contamination delivered by the Fenham Burn will arrive in the channel to the west of the fishery then travel northwards alongside the fishery towards the end of the ebb tide.

Circulation in coastal waters may be modified by density effects arising from freshwater inputs. The freshwater inputs to the survey area are minor, so such effects are likely to be negligible. The low freshwater influence in the area is confirmed by a series of salinity measurements made at the fishery, where the average was 33.8 ppt and no salinities of less than 31 ppt were recorded. Slight decreases in salinity may however be associated with increased levels of faecal indicator bacteria in the water column, deriving from land runoff.

Strong winds can modify circulation by driving surface currents, which will in turn create return currents which may travel lower in the water column or along sheltered margins. South westerly winds will tend to push surface water from the Fenham Flats towards the fishery for example. 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. Where these waves break, contamination held in intertidal sediments may be re-suspended. Although the surrounding land offers protection, some wave action is likely to occur during strong winds from any direction as the embayment is large. Onshore swells from the north sea may penetrate the main entrance to the embayment and break over the sandbanks just to the north of the fishery area.

5.5. Summary of Existing Microbiological Data

The survey area has a limited microbiological monitoring history, deriving from the shellfish waters monitoring programme, and hygiene classification monitoring. Figure 5.2 shows the locations of the monitoring points referred to in this assessment. Results of samples taken from 2004 onwards are considered in these analyses.

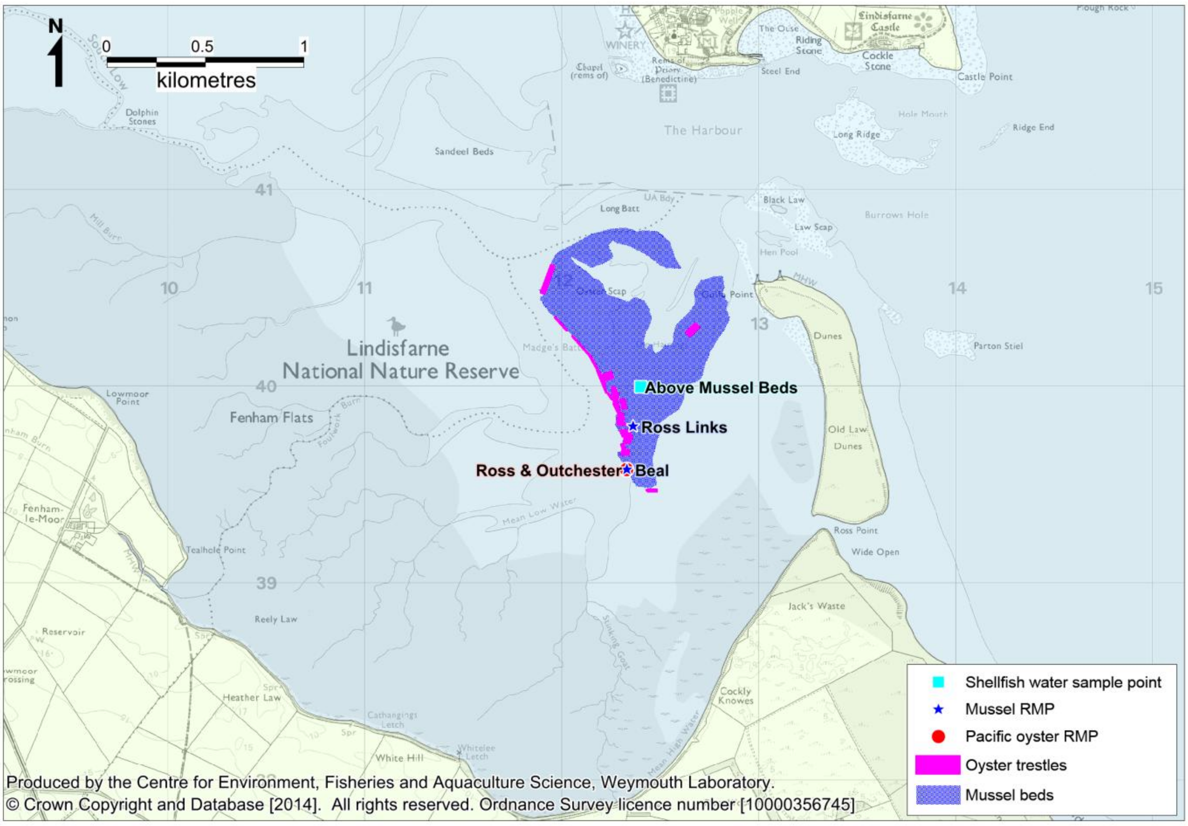

Figure 5.2: Microbiological sampling locations

Shellfish Waters monitoring

There is one shellfish water monitoring point, where water samples have been taken on a quarterly basis and enumerated for faecal coliforms. Faecal coliform concentrations here were low, with a geometric mean of 2.9 cfu/100 ml and only one result exceeding 50 cfu/100 ml. The one result which did exceed 50 cfu/100 ml was 1,182 cfu/100 ml, so was excluded from the statistical analyses to avoid biasing them. The circumstances under which this sample was collected were examined individually instead.

There do not appear to have been any overall increases or decreases in results since 2004. A statistically significant seasonal pattern was apparent, with higher results on average during the winter compared to other seasons. A statistically significant influence of the high/low tidal cycle was found, with the higher results occurring around low water when dilution potential was lowest. A significant influence of the spring/neap tidal cycle was also found, but no strong patterns were apparent when the data was plotted. No relationship was found between faecal coliform levels and rainfall or salinity.

The high result arose in a sample taken in July 2012, towards the end of a prolonged period of wet weather. The salinity at the time was the lowest recorded (31 ppt). It was taken about half way through the ebb tide, rather than around low water when other elevated results were recorded. It is therefore concluded that the high result is likely to be a consequence of summer storms resulting in increased fluxes of contamination from agricultural land, possibly augmented by spills from overloaded sewer networks.

Shellfish Hygiene classification monitoring

There are three RMPs in the Holy Island production area that have been sampled between 2004 and 2014. Two of these RMPs are for mussels and one for Pacific oysters. One of the mussel RMPs (Ross Links) was only sampled on one occasion and so will not be considered further. The remaining mussel and Pacific oyster RMPs are both in the same location.

The Pacific oyster RMP (Ross & Outchester) was sampled on a more or less monthly basis from 2004 to present. The geometric mean result was 139 *E. coli* MPN/100 g, the maximum was 7,000 *E. coli* MPN/100 g and only 1.6% of results exceeded 4,600 *E. coli* MPN/100 g. The mussel RMP (Beal) was sampled monthly from 2004 until August 2010. The geometric mean result was 64.7 *E. coli* MPN/100 g, with a maximum result of 4,600 *E. coli* MPN/100 g.

Throughout the period considered, Pacific oyster results appear to have declined slightly on average between 2004 and 2008, whereas mussel results were stable. Seasonal variation was statistically significant for Pacific oysters, with significantly higher *E. coli* results in summer and autumn than spring and winter. At the mussel RMP, results were lower on average during the spring, and similar throughout the other three seasons. However, seasonal variation was much less marked than observed for Pacific oysters, and was not statistically significant. As these RMPs are in the same location, this is presumably down to differences in the level to which the two species accumulate *E. coli* under different conditions (e.g. in relation to temperature). No influence of the spring/neap of high/low tidal cycles was found for either of the RMPs. Whilst some statistically significant associations were found between *E. coli* levels and antecedent rainfall at both RMPs, its influence was minor and delayed.

Bacteriological survey

An additional eight samples (four of each species) were collected by Northumberland County Council on the 20th January 2015. Little spatial variation was apparent, with results ranging from <18 to 170 *E. coli* MPN/100g. The highest result for both species arose towards the north western end of the site.

Appendices

Appendix I. Human Population

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

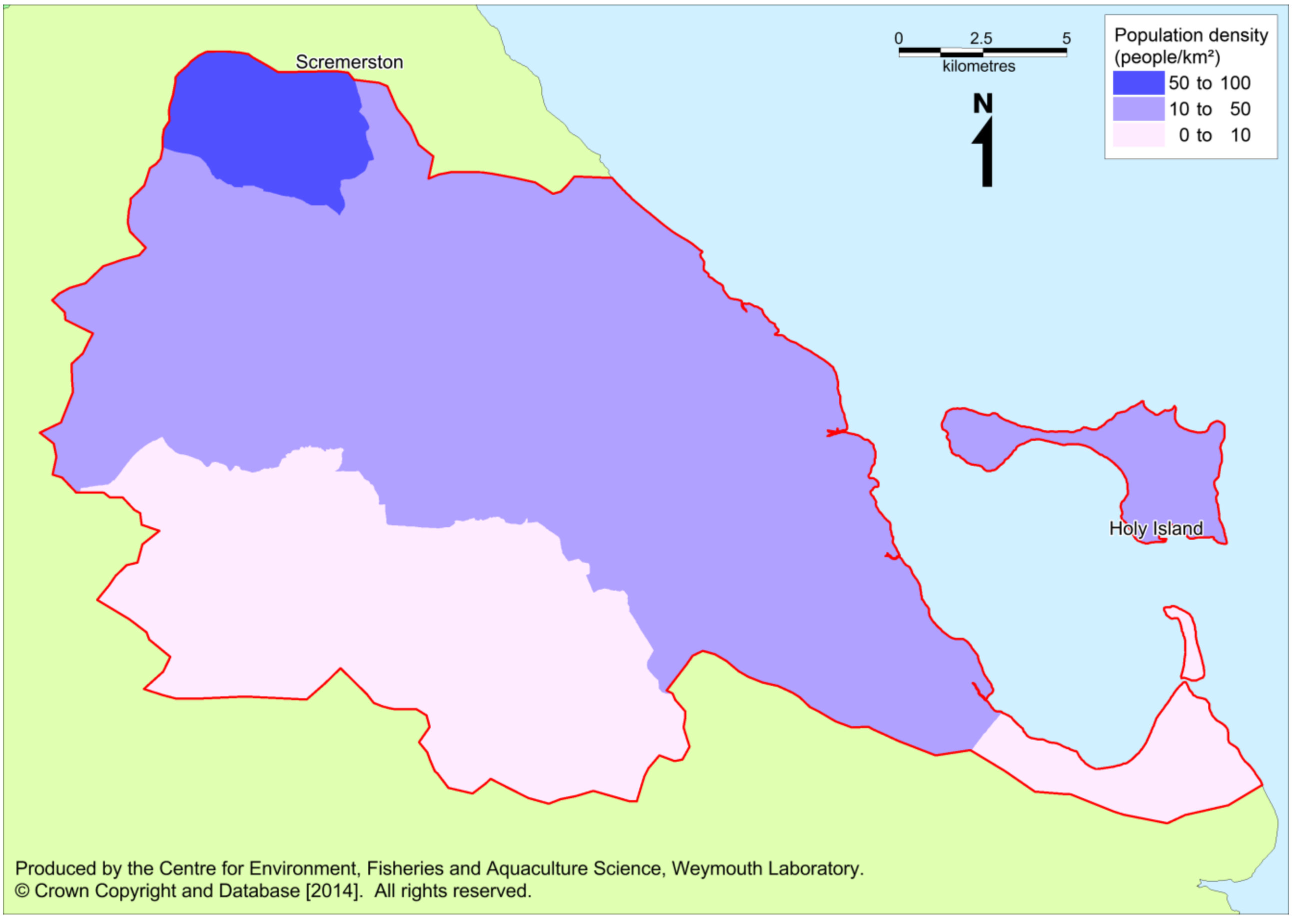

Figure I.1: Human population density in census areas in the Holy Island catchment.
Source: Office for National Statistics

Total resident population within census areas contained within or partially within the catchment area was approximately 6,300 at the time of the last census. However, these census areas do not align with the catchment boundary and in some cases extend into more populated areas such as the outskirts of Berwick. The Environment Agency (pers comm.) estimates the population to be 2,295.

There are an estimated 500,000 visitors to Holy Island and the surrounding coastal region per year (Hamilton-Baillie Associates Ltd 2012). There is also a large caravan park at Haggerston. During the peak summer holiday season, the sewage output of tourist destinations such as Holy Island Village and the caravan park will increase significantly.

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

Details of all consented sewage discharges within the survey catchment were taken from the Environment Agency national permit database (March 2014). These are mapped in Figure II.1.

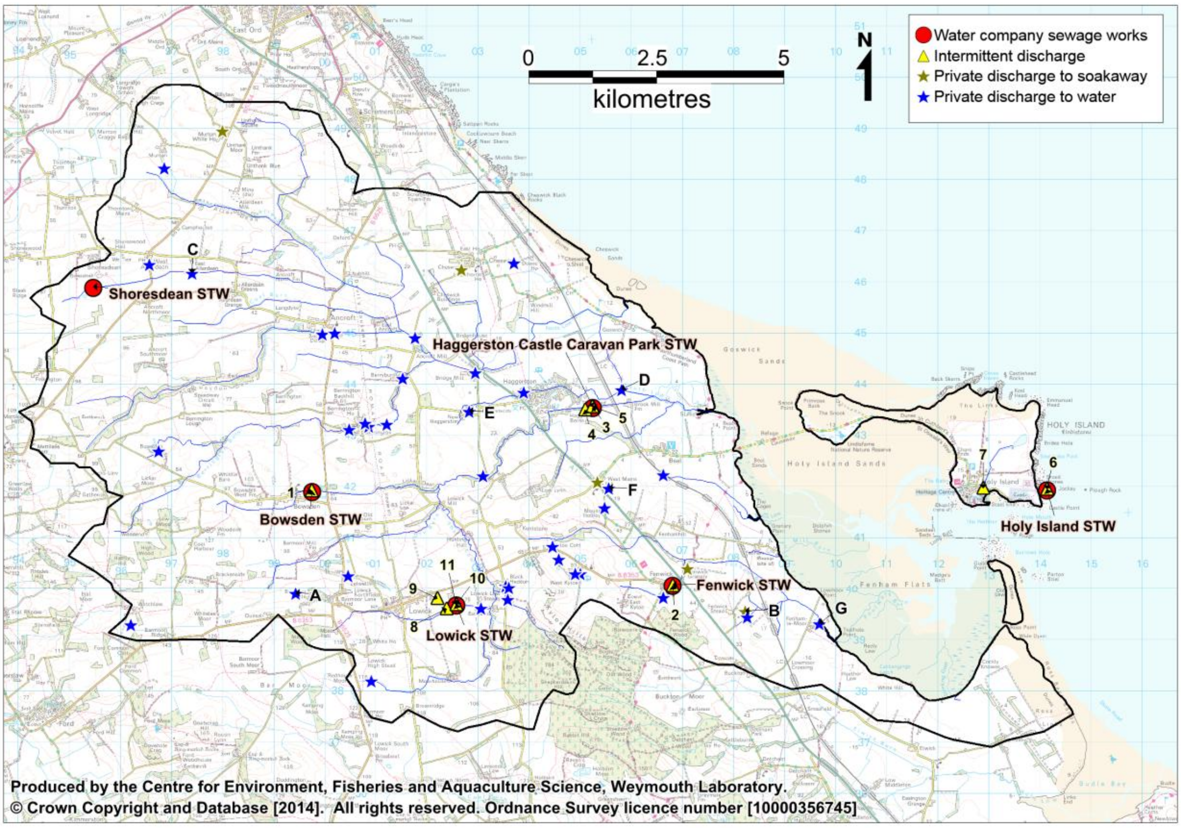

Figure II.1: Permitted sewage discharges to the Holy Island catchment
Contains Environment Agency information © Environment Agency and database right

There are six continuous water company sewage works discharging within the survey area, details of which are presented in Table II.1.

Table II.1: Details of continuous water company sewage works within the survey area

Name	NGR	Treatment	DWF (m^3/day)	Estimated bacterial loading (cfu/day)*	Receiving environment
Bowsden STW	NT9974041910	Activated Sludge	20.8**	$6.9x10^{10}$	Bowsden
Fenwick (Berwick) STW	NU0680040080	Biological Filtration	27	$8.9x10^{10}$	Fenham Burn
Haggerston Castle	NU0524043560	Biological	250	$8.3x10^{11}$	South Low

Name	NGR	Treatment	DWF (m^3/day)	Estimated bacterial loading (cfu/day)*	Receiving environment
Caravan Park STW		Filtration			
Holy Island STW	NU1413041940	Biological Filtration	102	$3.3x10^{11}$	North Sea
Lowick STW	NU0257239688	Biological Filtration	149	$4.9x10^{11}$	Low trib.
Shoresdean STW	NT9546045910	Septic Tank	42 (max)	$4.2x10^{12}$ (max)	Allerdean Mill Burn trib.

Contains Environment Agency information © Environment Agency and database right
*Faecal coliforms (cfu/day) based on geometric base flow averages from a range of UK STWs providing secondary treatment (Table II.2)
**Estimated from population served

Table II.2: Summary of reference faecal coliform levels (cfu/100 ml) 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	$7.2x10^6$
Primary (12)	127	$1.0x10^7$	14	$4.6x10^6$
Secondary (67)	864	$3.3x10^5$	184	$5.0x10^5$
Tertiary (UV) (8)	108	$2.8x10^2$	6	$3.6x10^2$

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

The only water company sewage works discharging directly to coastal waters is the Holy Island STW. This is a relatively small secondary works which discharges to the east shore of the island around the low water mark. Its' spatial pattern of impacts will depend on water circulation patterns in the area. Fenham Burn receives the effluent from one small treatment works (Fenwick STW). There are four sewage works (Lowick, Bowsden, Shoresdean and Haggerston Castle Caravan Park STWs) discharging to the complex of streams and drains that discharge to the shore via the North Low and South Low outfalls, just to the north of the causeway. These will contribute to the faecal indicator loading delivered to coastal waters via these two outfalls. The population served by the caravan park sewage works will be highly seasonal, peaking during the summer holidays.

In addition to the continuous sewage discharges, there are several intermittent water company discharges associated with the sewerage networks also shown on Figure II.1. Details of these are shown in Table II.3.

Table II.3: Intermittent discharges to the survey area

No.	Name	Grid reference	Receiving water
1	Bowsden STW CSO	NT9973041910	Bowsden Burn
2	Fenwick STW CSO	NU0680040060	Fenham Burn
3	Haggerston Castle Caravan Park STW	NU0524043560	South Low
4	Haggerston Castle Caravan Park STW	NU0509043500	South Low
5	Haggerston Castle CSO	NU0523043560	South Low
6	Holy Island STW PS & CSO	NU1413041940	North Sea
7	Inlet & Outlet SPS	NU1288041960	North Sea
8	Kyloe View SSO	NU0238039600	Low trib.
9	Lowick STW	NU0219039800	Low trib.
10	Lowick STW CSO no. 1	NU0257239688	Low trib.
11	Lowick STW CSO no. 2	NU0257239688	Low trib.

The geographical distribution of these intermittent outfalls is almost identical to that of the water company sewage works discharges discussed above. Additionally, and of possible significance, there is an intermittent outfall to the south shore of Holy Island (Inlet and Outlet SPS). Spill records were not available for any of these discharges at the time of writing. It is therefore difficult to assess their significance apart from noting their locations and their potential to spill storm sewage.

Although a high proportion of properties within the survey area are served by water company sewerage infrastructure, there are also a number of private discharges. Where specified, these are generally treated by small treatment works such as package plants, and the majority of these are small, serving one or two properties. All permitted private sewage discharges are mapped in Figure II.1, and Table II.4 presents details of those consented to discharge more than 5 m^3/day.

Table II.4: Details of private sewage discharges to the catchment >5m^3/day

Ref.	Property served	Location	Treatment type	Max. daily flow (m^3/day)	Receiving environment
A	Barmoor Castle Country Park	NT9942139911	Package Plant	61	Dry Burn trib.
B	Cottages (7)	NU0822939562	Package Plant	5	Soakaway
C	East Allerdean Farm Steading	NT9739046180	Package Plant	10	Allerdeanmill Burn
D	Haggerston Castle Caravan Park	NU0580043900	Reedbed	500	North Low
E	New Haggerston	NU0282043480	Septic Tank	5	Engine Low
F	Plough Hotel	NU0555041970	Package Plant	14.5	Beal Cast
G	Steading Development Fenham Le Moor	NU0968039320	Package plant	5	Foulwork Burn

The largest of these by a considerable margin is the Haggerston Castle Caravan Parks second (private) works, where the effluent is treated via reedbed. It is uncertain how effective this is at bacterial removal, but it will make some contribution to the bacterial loadings delivered by the North and/or South Lows. The population served by this treatment works will be highly seasonal, peaking during the summer holidays. Most other private discharges are also to this drainage network, but there are also a number to the Fenham Burn and tributaries. There is also one small private discharge to the Beal Cast, but none on Holy Island. Those discharging to soakaway should be of no influence to coastal waters, assuming they are functioning correctly. It is possible that there are further private discharges in the area which do not hold permits, and so do not feature on the database from which this information was derived.

Appendix III. Sources and Variation of Microbiological Pollution: Agriculture

Land cover within the survey catchment is a mosaic of arable and pasture land, with the former predominating. There is also a significant forested area on the mainland, just inland from the A1. Holy Island itself is largely pasture, with a few arable fields and a grassy dune system along its north shore.

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 as this provides more detail than censuses undertaken in subsequent years. 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 Holy Island 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)
3664	27.8	13726	104.2	*	*	1348	10.2

*Data suppressed for confidentiality reasons as it relates to a small number of holdings

Data from Defra

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.

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).

Table III.1 indicates that there are large numbers of sheep within the catchment, as well as significant numbers of cattle, but few pigs or poultry. During the shoreline survey, grazing livestock were commonly encountered all around the perimeter of the embayment. These were generally in fenced fields with no access to the shore. However, on the mainland shore to the north of the causeway sheep had access to the beach, and a patch of heavily grazed saltmarsh was observed by the South Low outfall. Also, there were significant amounts of dried cattle droppings on the grassy dune system that extends from the north west tip of Holy Island, although no cattle were observed there during the survey. It is reported that small numbers of cattle (38) are grazed on the grassy dunes along the north shore of Holy Island dunes in early spring and autumn (Grazing Animals Project Website, 2014). These have access to the shore in places but whether they regularly access intertidal areas is uncertain.

Livestock manures will either be deposited directly on pastures by grazing animals, or collected from operations such as cattle sheds and poultry houses and spread on both arable land and pasture. This in turn may be washed into watercourses which will carry it to coastal waters. Watercourses which animals can access will be more vulnerable than those that are fenced off. Given the ubiquity of farmland throughout the survey area, all watercourses may potentially be affected at times. Where animals have access to the shore they may deposit faeces directly on intertidal areas, which will subsequently be washed into coastal waters via tidal inundation. The saltmarsh by the South Low is likely to represent the principle area where this occurs. As the saltmarsh is high up the foreshore it will only be inundated on the larger tides. It is also possible that the cattle on the Holy Island dunes deposit directly on the intertidal in places.

The geographical pattern of agricultural impacts is likely to closely mirror that of land runoff, with additional contributions from direct deposition on the intertidal areas on the mainland to the north of the causeway, and possibly around the north west tip of Holy Island. 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'). In contrast, impacts from animals on the intertidal will be greatest as tide sizes increase towards, and during, spring tides.

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 unfenced 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. Other manures and sewage sludge may also be spread on pastures and arable lands, although no sewage sludge applications have been made within the catchment for two years (Environment Agency, pers. comm.). Timing of biosolids applications is uncertain. The southern part of the mainland catchment and the island itself are within a nitrate vulnerable zone so spreading is subject to a closed period from September/October to the end of December or January, depending on soil and biosolid types. The area drained by the North and South Lows however largely falls outside this zone so organic fertilizers may be applied here at any time of the year. It is therefore concluded that 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. It may also occur or on a more localised basis if wet weather follows a biosolids application, which is not permitted during the late autumn and early winter across a large part of the survey catchment.

The survey catchment is a priority area for the ongoing catchment sensitive farming initiative. This project involves working in partnership with farmers to tackle agricultural diffuse pollution, although in this area it is targeted towards reducing nutrients in general rather than faecal contamination specifically (Environment Agency, 2009). Nevertheless, works undertaken under this project should reduce the amount of diffuse microbiological contamination of agricultural origin carried into coastal waters by watercourses draining the area.

Appendix IV. Sources and variation of microbiological pollution: Boats

The discharge of sewage from boats is a potential source of bacterial contamination to the survey area. Boat traffic in the area is limited to fishing boats and recreational craft such as 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.

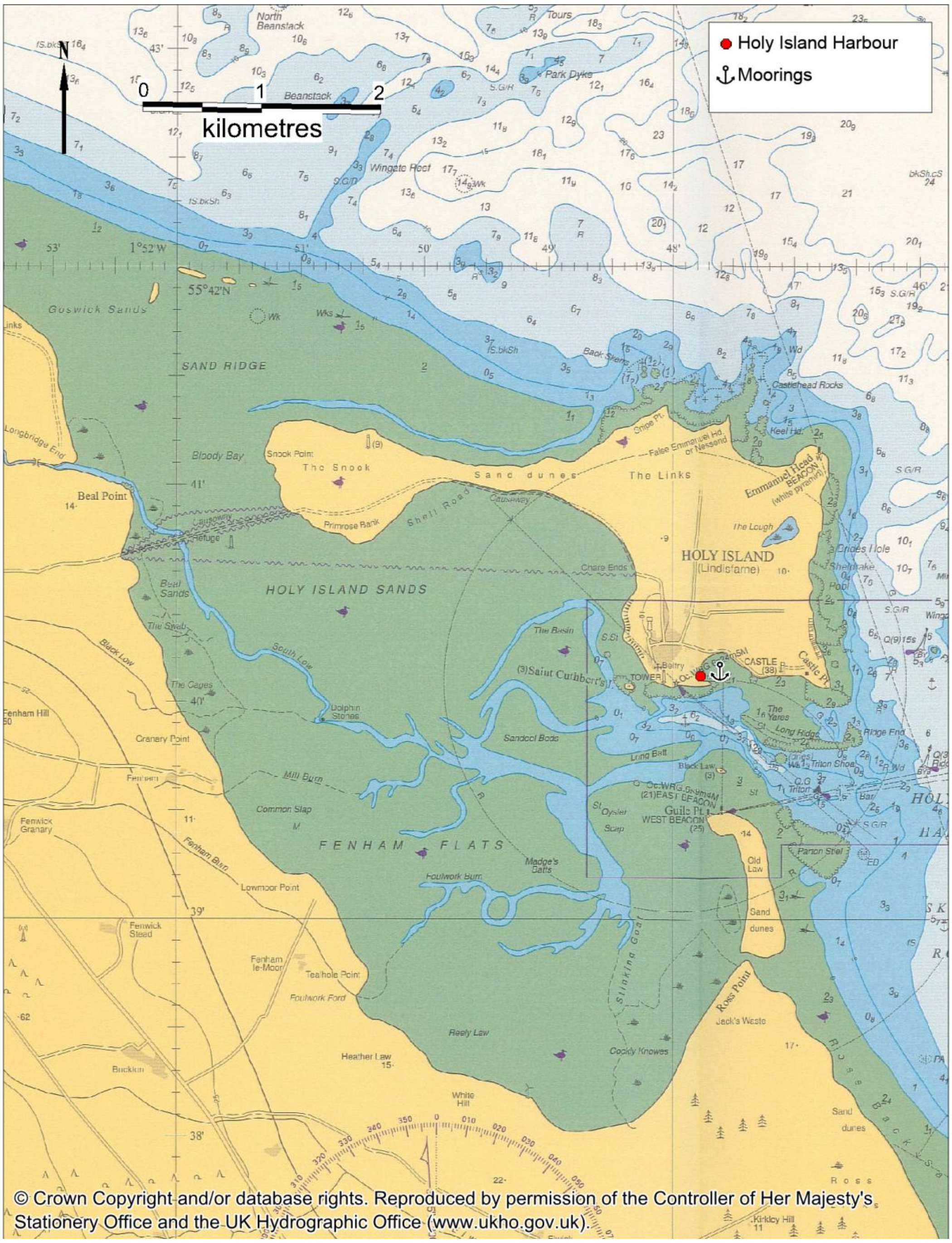

Figure IV.1 Boating Activity within the Holy Island survey area

The closest marinas are situated at Berwick-Upon-Tweed to the north and at Amble to the south, neither of which have sewage pump out facilities. There are limited swinging and drying moorings located in Holy Island Harbour for recreational craft such as yachts, the locations of which are shown in Figure IV.1. In the terms and conditions for the usage of Holy Island harbour it is stated that, boats are prohibited from making overboard discharges during their stay (Holy Island of Lindisfarne Community Development Trust, 2013) although the extent to which this is observed is uncertain. In addition to the larger recreational craft, watersports such as dinghy sailing, kayaking and motor boating also take place in the waters surrounding Holy Island and a slipway is located on the outer limits of Holy Island Harbour. A small fishing fleet operates from Holy Island Port with 6 fishing vessels under 10 metres in length listed as having Holy Island as their home port (MMO, 2014). Due to the bathymetry, boats of sufficient size (i.e. those big enough to contain onboard toilet facilities) can only approach the harbour from the south of the island. To the west and north of the harbour large expanses of intertidal sand and mudflats exist making it hard to navigate and restricts access from the north.

It is therefore concluded that boat traffic within the area is limited to pleasure craft and fishing vessels. Smaller pleasure craft such as sailing dinghies and kayaks will not have onboard toilets and so are unlikely to make overboard discharges. Private vessels such as yachts and motor cruisers 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 it is likely that the moorings and the main navigation route into Holy Island Harbour are most at risk of contamination from this source, although this potential risk is relatively minor. 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 Holy Island survey area encompasses a variety of habitats including the largest expanse of intertidal mud and sand flats in the north-east of England, sand dunes, saltmarsh and eel grass beds. These and other coastal features support significant local populations of birds and other wildlife. Consequently the survey area falls under several national and international conservation statuses, including the Northumberland Coast Area of Outstanding Natural Beauty (AONB), a Ramsar site, a Special Protection Area (SPA), the Lindisfarne National Nature Reserve (NNR) and a Special Site of Scientific Interest (SSSI) and the Berwickshire and North Northumberland Coast Special Area of Conservation (SAC).

Aggregations of overwintering waterbirds (wildfowl and waders) which use the area are likely to be of significance to shellfish hygiene. 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). Over the five winters up until 2012/2013 an average total count of 45,843 overwintering waterbirds was recorded in the Lindisfarne area (Austin *et. al*, 2014). Species include wigeon, knot, grey plover, bar-tailed godwit, curlew and 40% of the world's population of light bellied brent geese (Natural England, 2014).

Grazers such as geese and ducks will frequent saltmarsh, coastal pastures, and eel grass beds. Their faeces may therefore be directly deposited on the lower or upper intertidal areas, or be carried into coastal waters via runoff from grasslands. RMPs within or near to the drainage channels from freshwater inputs and saltmarsh areas will be best located to capture contamination from this source. Waders, such as dunlin and oystercatchers feed upon invertebrates 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 their preferred size and species of prey, but this location 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. The benthic mussel beds may be at more risk from direct deposition upon them than the oysters, which are held on raised trestles. At high tide waders are likely to rest in the less disturbed areas such as the Old Law Dunes. Due to the diffuse and spatially unpredictable nature of contamination from wading birds it is difficult to select specific RMP locations to best capture this, although they may well be a significant influence particularly during the winter months.

In addition to overwintering and wildfowl flocks, seabirds such as gulls and terns are also widespread throughout the area all year round. A survey in the early summer of

2000 recorded only 472 pairs of breeding seabirds on Holy Island including Northern fulmar, Black-headed gull, Little terns and Common terns (Mitchell *et al*, 2004). No other breeding sites were recorded in the survey area. There is however a major seabird breeding colony on the Farne Islands, about 10 km to the south east. During the seabird 2000 survey 166,510 birds were recorded on this archipelago. 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. Some of these species (e.g. terns) migrate away from the area outside of the breeding season, and it is likely that resident species disperse somewhat at these times. As the nesting colonies are not in the immediate vicinity of the fishery, their presence will have no influence on the sampling plan.

Up to 3,000 grey seals were counted hauled out in the vicinity of Holy Island between April and September 2008 (Thompson & Duck, 2010). This is not a breeding site, so it is likely that use of the area decreases during the breeding season (August to December) although they will still frequent the vicinity given that there is a large breeding colony at the Farne Islands. In addition to the grey seals, a much smaller colony of harbour seals is reported to haul out on the Holy Island sand flats. On average, over 5 years between 1994 and 2007 12 harbour seals were recorded at Holy Island (SCOS, 2013). The harvester confirmed that large numbers of seals (several hundred) haul out on the sand flats just north of the oyster trestles. They may be a significant source of contamination to the fishery, and a monitoring point at its northern end would best capture their impacts. No other wildlife species which may have an influence on the sampling plan have been identified.

Appendix VI. Meteorological Data: Rainfall

The monthly rainfall data for the East Kyloe weather station, which lies approximately at the centre of the mainland catchment area, is shown in Figure VI.1.

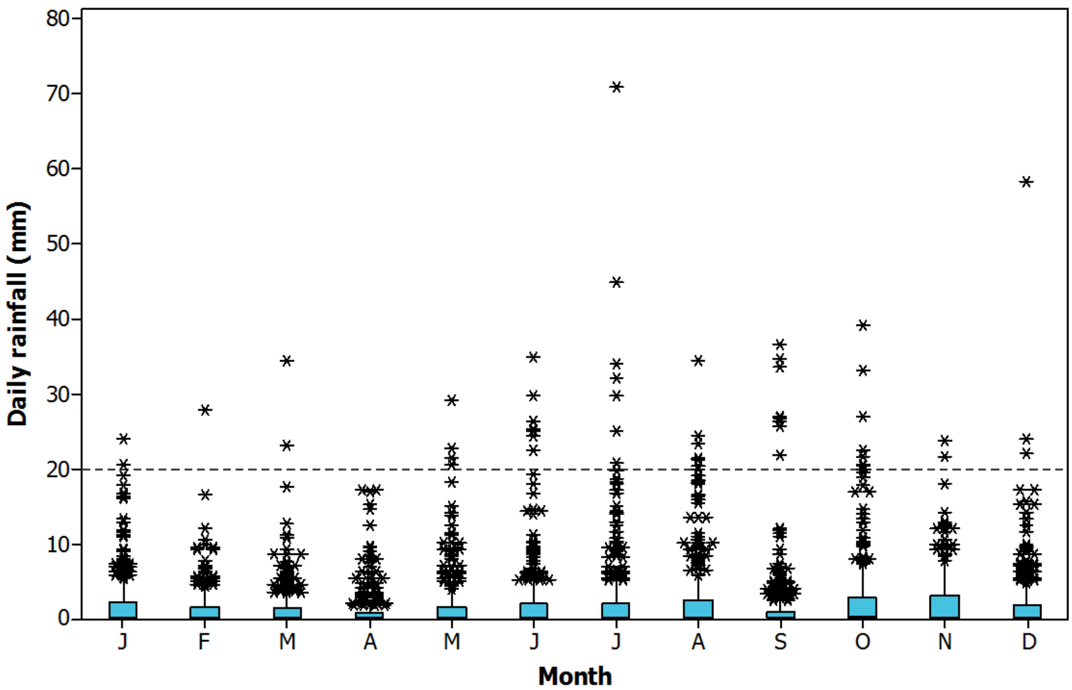

Figure VI.1: Boxplot of daily rainfall totals at East Kyloe, January 2003 to December 2013.
Contains Environment Agency information © Environment Agency and database right

The East Kyloe weather station received an average of 683 mm of annual rainfall 2003 and 2014. In general, the summer months received most rainfall, with July having the highest average daily rainfall (2.7 mm). Late winter and spring had the lowest rainfall, with April having the lowest average daily rainfall (1.1 mm). Heavy rainfall (over 20 mm) occurred on 1.3% of days and 54.5% of days had no rainfall.

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

Appendix VII. Meteorological Data: Wind

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 (Met Office, 2012a).

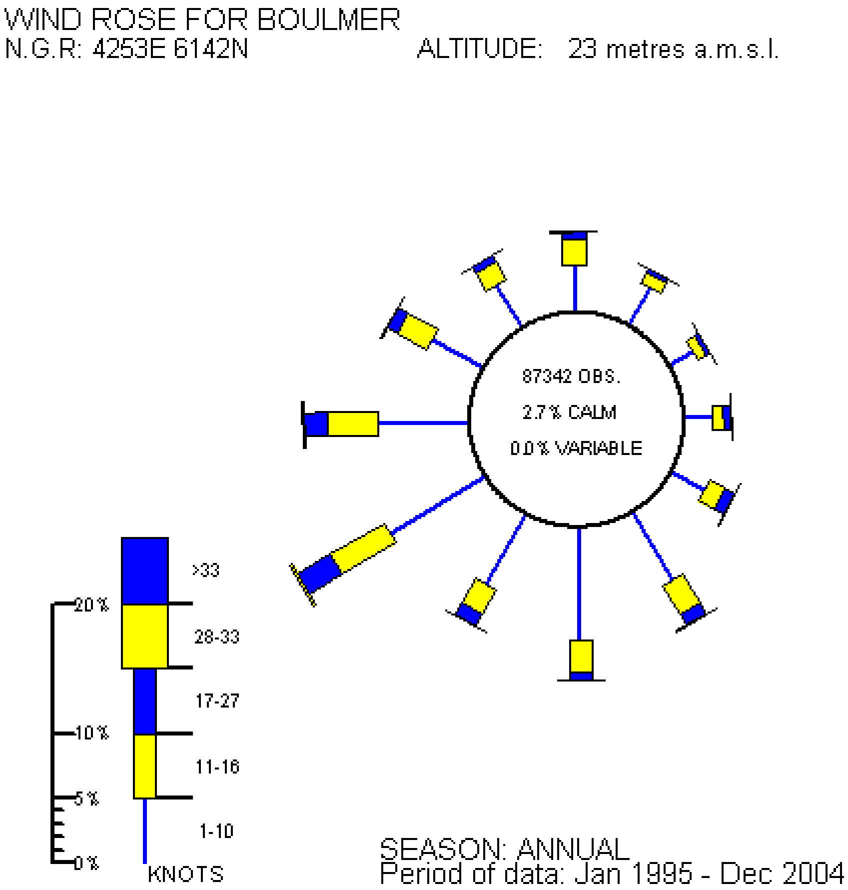

Figure VII.1: Wind Rose for Boulmer

Produced by the Meteorological Office. Contains public sector information licensed under the Open Government Licence v1.0

The wind rose for Boulmer is typical of open, level locations across the region. There is a prevailing south-westerly wind direction throughout the year. During spring there is also a high frequency of north to north-easterly wind's due to a build up of pressure over Scandinavia. 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 (Met Office, 2012). The survey area is reasonably well protected from the prevailing winds and is partially sheltered by Holy Island and the Old Law dunes from easterly winds and swells. However, it is surrounded by low lying land which will offer a limited amount of shelter to the prevailing winds. The survey area will be exposed to winds from the south east and north west quadrants which will be funnelled between Holy Island and the mainland.

Appendix VIII. Hydrometric Data: Freshwater Inputs

The catchment area draining into the shellfishery around Holy Island is approximately 132 km² and is illustrated in Figure VIII.1. Land runoff is conveyed to the Holy Island embayment by a series of minor watercourses.

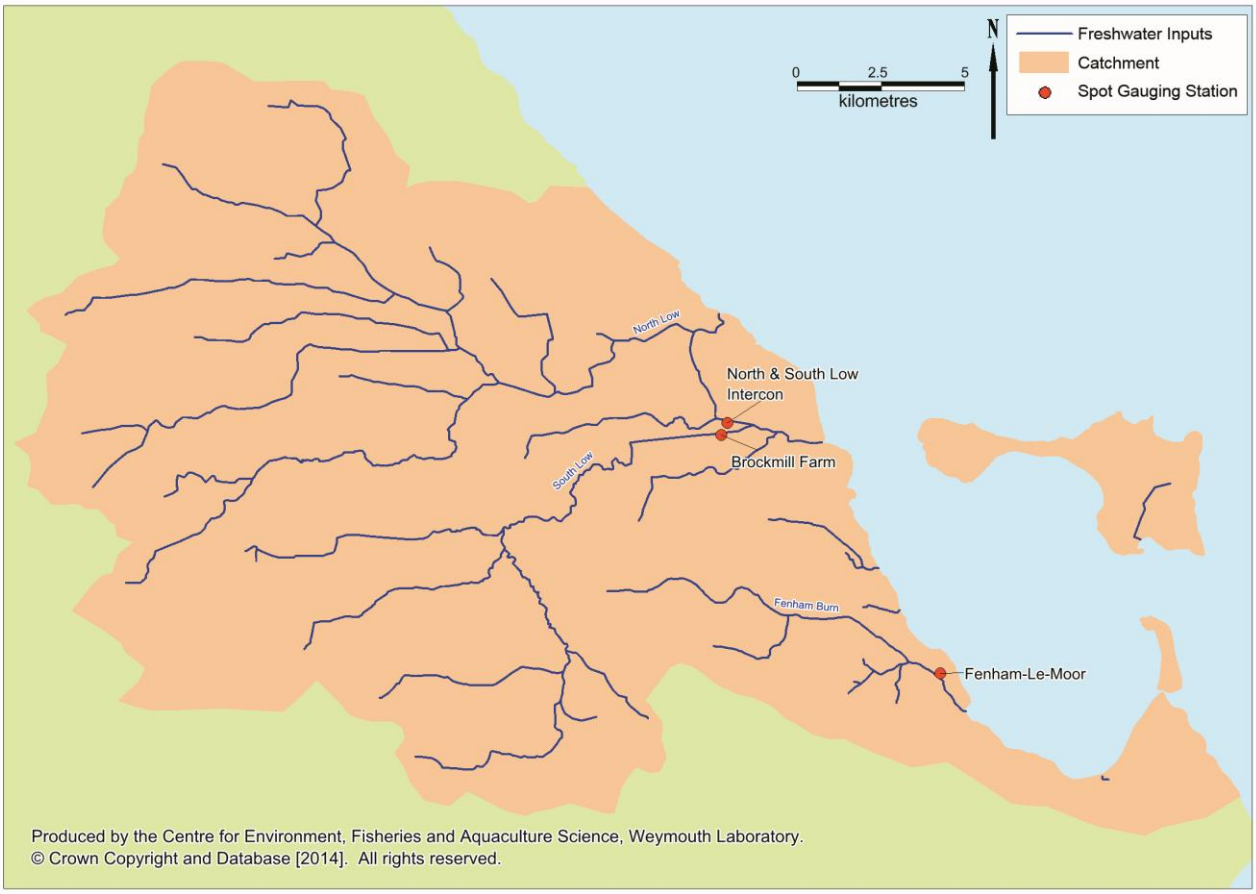

Figure VIII.1: Main watercourses in the Holy Island catchment

Arable land dominates the catchment with smaller areas of pasture and woodland and very few built up areas. It is low lying, with elevations mainly below 100 m, so watercourses draining the area are of a relatively low gradient. The hydrogeology of the catchment is described as of moderate permeability throughout (NERC, 2012) so there will be both surface water and groundwater flows. Whilst stream discharge rates will respond to rainfall, the response will be damped to some extent by discharge from, and recharge to, ground waters.

There are no fixed flow gauging stations within the catchment and therefore it is not possible to examine the hydrological characteristics of these watercourses in any detail. There are three locations on the Fenham Burn, North Low and South Low where a few spot flow measurements were made in 1999 and 2000. Summary statistics for these are presented in Table VIII.1.

Table VIII.1 Summary flow statistics for spot gauging stations on watercourses draining into the Holy Island survey area (1999-2000)

Site	Watercourse	Number of samples	Mean flow (m^3s^{-1})	Maximum flow (m^3s^{-1})
Fenham –Le-Moor	Fenham Burn	4	0.019	0.031
North and South Low Intercon	North Low	13	0.238	0.555
Brockmill Farm	South Low	7	0.094	0.256

Mean discharge at all three spot flow gauging stations is minor (< 0.3 m^3/s). The highest mean discharge was recorded on the North Low, on the channel which connects with the South Low. This actually flows into the South Low, so does not represent discharge rates from the North Low outfall, but can be added to the discharge from the South Low at Brockmill Farm to approximate that from the South Low outfall. The connecting channel is no longer maintained (Environment Agency, pers. comm.) so flows through this channel have reduced since these measurements were made, and most of the North Low now discharges at Goswick. Also, due to the low the number of samples taken at each site they will not be fully representative of the variation in flow rates in these watercourses.

River flow will generally be highest after periods of heavy rainfall, with a proportion reaching the watercourses rapidly via surface run-off and a proportion gradually via groundwater. The seasonal pattern of flows is not entirely dependent on rainfall as during the colder months there is less evaporation and transpiration. This in turn leads to a greater level of runoff immediately after rainfall. Increased levels of runoff are likely to result in an increase in the amount of microorganisms carried into coastal waters. Additionally, higher runoff will decrease residence time in rivers, allowing contamination from more distant sources to have an increased impact during high flow events.

During the shoreline survey, spot flow measurements were made and water samples taken at all watercourses that could be accessed (Table VIII.2, Figure VIII.2).

Table VIII.2: Water sample results, measured discharge flow rates and calculated *E. coli* loadings

Sample	Description	Discharge (m^3/sec)	*E. coli* (cfu/100 ml)	*E. Coli* loading (cfu/day)
A	North Low	0.20	390	6.7×10^{10}
B	South Low (u/s tidal flap)	Inaccessible	1300	-
C	South Low at causeway	0.53	460	2.1×10^{11}
D	Unnamed FW outfall	5.9×10^{-4}	560	2.9×10^{8}
E	Unnamed FW outfall	1.8×10^{-4}	46	7.3×10^{6}
F	Fenham Burn	0.061	1900	1.0×10^{11}

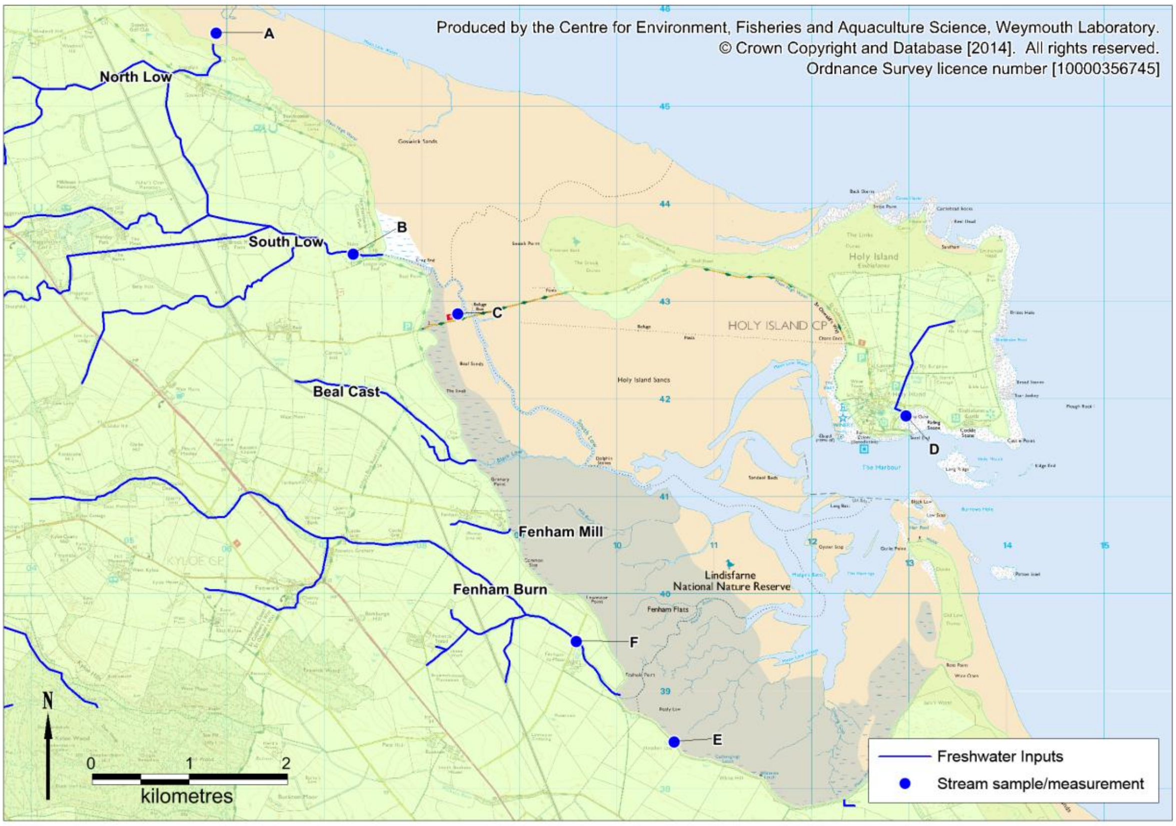

Figure VIII.2: Shoreline survey stream sampling locations

The North Low carried a potentially significant bacterial loading, but drains across the beach to the North Sea a large distance from the fishery so is unlikely to impact. The South Low gave both highest recorded flow rate and largest *E. coli* loading, and follows a drainage channel under the causeway and onto the Fenham Flats so may be of some influence at the fishery. It was not possible to access the Beal Cast, the drainage channel from which converges with that of the South Low. No flowing outfall was observed at Fenham Mill, although it is possible that one was present but not seen as the surveyors had to divert inland slightly at this point. The Fenham Burn was generating a potentially significant bacterial loading at the time of survey, and follows a drainage channel across the Fenham Flats and towards the fishery. A further two very minor freshwater outfalls were found, one just south of the Fenham Burn and one at Holy Island Harbour. Neither was of sufficient size to be of any significance to the fishery.

It is therefore concluded that the main freshwater inputs originate from the mainland, and they are relatively minor. Those likely to impact on the fishery (South Low, Beal Cast and Fenham Burn) follow drainage channels across the Fenham Flats and into the subtidal channel which lies to the west of the fishery.

Appendix IX. Hydrography

IX.1. Bathymetry

Figure IX.1: Bathymetry of the Holy Island embayment

The survey area is a large, semi-enclosed shallow embayment of the North Sea that lies between Holy Island and the Old Law dune system, and the mainland. It is largely intertidal, with some subtidal channels. The substrate is generally sandy, with muddier areas on the upper parts of the Fenham Flats and some rocky and shingly areas around Holy Island. There are areas of saltmarsh inside of Ross Point and around the mainland end of the causeway. Its shallow nature will result in a high proportion of water being exchanged each tide, but the dilution potential will be limited.

The embayment connects to the North Sea in two places. The main connection is the subtidal channel between the southern tip of Holy Island and the Old Law dunes. This is where the deepest point is located, at 12.8 m relative to Chart Datum (CD). The second connection is over the causeway between the island and the mainland, which is intertidal. When surveyed in 2011, the majority of this causeway was at least 1 m higher than Ordnance Datum at Newlyn (ODN) which is equivalent to at least 3.4 m higher than CD (Northumberland County Council, 2012). There was a very small section (under the bridge over the South Low channel) where the elevation was 0 – 0.5 m relative to ODN which is equivalent to 2.4 – 2.9 m above CD. The vast majority of water exchange will therefore be through the subtidal channel that runs south of Holy Island, and any exchange which may occur over the causeway will be limited to the period around high water. Elevations to the north of the causeway are not shown on the chart. LiDAR tiles viewed at the Channel Coastal Observatory website (www.channelcoast.org) indicate that the elevation increases slightly to the north of the causeway peaking about 500 m further north. Incoming tides are likely to meet here.

Within the embayment there is a dendritic network of channels that drain to the main connection to the North Sea. Those draining the southern part of the Fenham Flats feed into the southern end of the subtidal channel that lies just to the west of the trestles (Madge's Batts). One of these carries the Fenham Burn. The drainage channels carrying the Beal Cast and the South Low split around a sandbank (Sandeel Beds). The southern channel converges with Madge's Batts at the northern end of the oyster farm, whereas the northern channel passes to the north of the sandbank then converges with the main entrance channel. At lower states of the tide there may be elevated levels of faecal indicator organisms within these drainage channels, deriving from land runoff and saltmarsh washings. The dilution potential will increase within these channels as they widen and deepen towards the main North Sea connection.

IX.2. Tides and Currents

Water circulation patterns within estuaries and coastal waters are primarily driven by tides, which are regular and predictable, with more dynamic and unpredictable effects from freshwater inputs, barometric pressure and winds superimposed on this.

Table IX.1 Tidal levels and ranges at Holy Island

Port	Height above chart datum (m)				Range (m)	
	MHWS	MHWN	MLWN	MLWS	Spring	Neap
Holy Island	4.80	3.70	1.50	0.60	4.20	2.20

Data from Admiralty TotalTide©

The tidal range is large and drives extensive water movements through the area on the twice daily high/low tidal cycle. Tidal curves for Holy Island are slightly asymmetric, with the flood tide lasting about half an hour longer than the ebb. The amount of water exchanged will be much greater on spring tides, which occur every two weeks.

Tidal streams off the Northumberland coast flood in a southerly direction and ebb in a northerly direction. This indicates that effluent from the Holy Island sewage works may be carried in through the main entrance the flood tide. Tidal currents along the coast are generally weak, with spring tides reaching 0.3 m/s while neap tides are about 0.15 m/s, although they do increase locally in the vicinity of islands and headlands (Royal Haskoning, 2009). High water arrives earlier at the northern end of this stretch of coast. Given that the difference in high water times between Berwick and Amble, which are 50 km apart, is only about half an hour, the difference in arrival times to the two North Sea connections to the survey area will be negligible.

There are no tidal diamonds within the survey area, nor were any observational or modelling studies describing tidal circulation patterns found during the literature search. As such, the patterns described below are solely based on an appraisal of the bathymetry of the area. The flood tide will convey water originating from the North Sea into the area, whereas the ebb tide will carry contamination from shoreline sources out through the embayment. The tide will flood in through the main entrance and progress up the channels. As these channels fill, the rising water levels will fill the creeks and spread over the extensive intertidal areas. Current velocities are likely to be fastest in the subtidal channels, and decrease over the intertidal areas. Water arriving from the main entrance will cross the causeway and meet water arriving from the northern entrance somewhere north of the causeway an hour or two before high water.

Circulation in coastal waters may be modified by density effects arising from freshwater inputs. The freshwater inputs to the survey area are minor, so such effects are likely to be negligible. The low freshwater influence in the area is confirmed by a series of salinity measurements made at the fishery as part of the shellfish water monitoring programme (Figure IX.2).

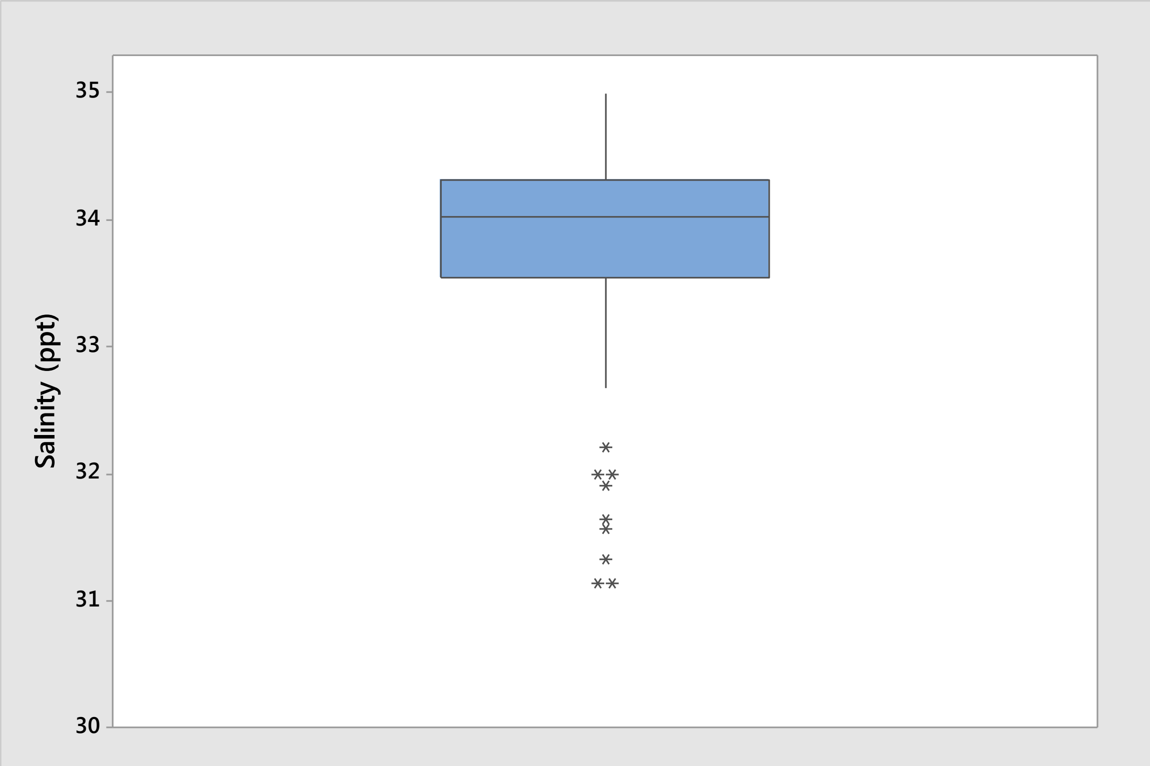

Figure IX.2: Boxplot of salinity measurements at the shellfish water monitoring point
Contains Environment Agency information © Environment Agency and database right

The average salinity was around that of full strength seawater (33.8 ppt), and no salinities of less than 31 ppt were recorded. Slight decreases in salinity may be associated with increased levels of faecal indicator bacteria in the water column, deriving from land runoff.

Strong winds will modify surface currents. Winds typically drive surface water at about 3% of the wind speed (Brown, 1991) so a gale force wind (34 knots or 17.2 m/s) would drive 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. South westerly winds will tend to push surface water from the Fenham Flats towards the fishery for example. 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. Where these waves break contamination held in intertidal sediments may be re-suspended. Although the surrounding land offers protection, some wave action is likely to occur during strong winds from any direction as the embayment is large. Onshore swells from the north sea may penetrate the main entrance to the embayment and break over the sandbanks just to the north of the fishery area.

Appendix X. Microbiological data: Shellfish Waters

Summary statistics and geographical variation

There was one shellfish waters monitoring site that was designated under Directive 2006/113/EC (European Communities, 2006) (now repealed) relevant within the Holy Island production area. Figure X.1 shows the location of this site. Table X.1 presents summary statistics for bacteriological monitoring results and Figure X.2 presents a boxplot of faecal coliform levels from the monitoring point.

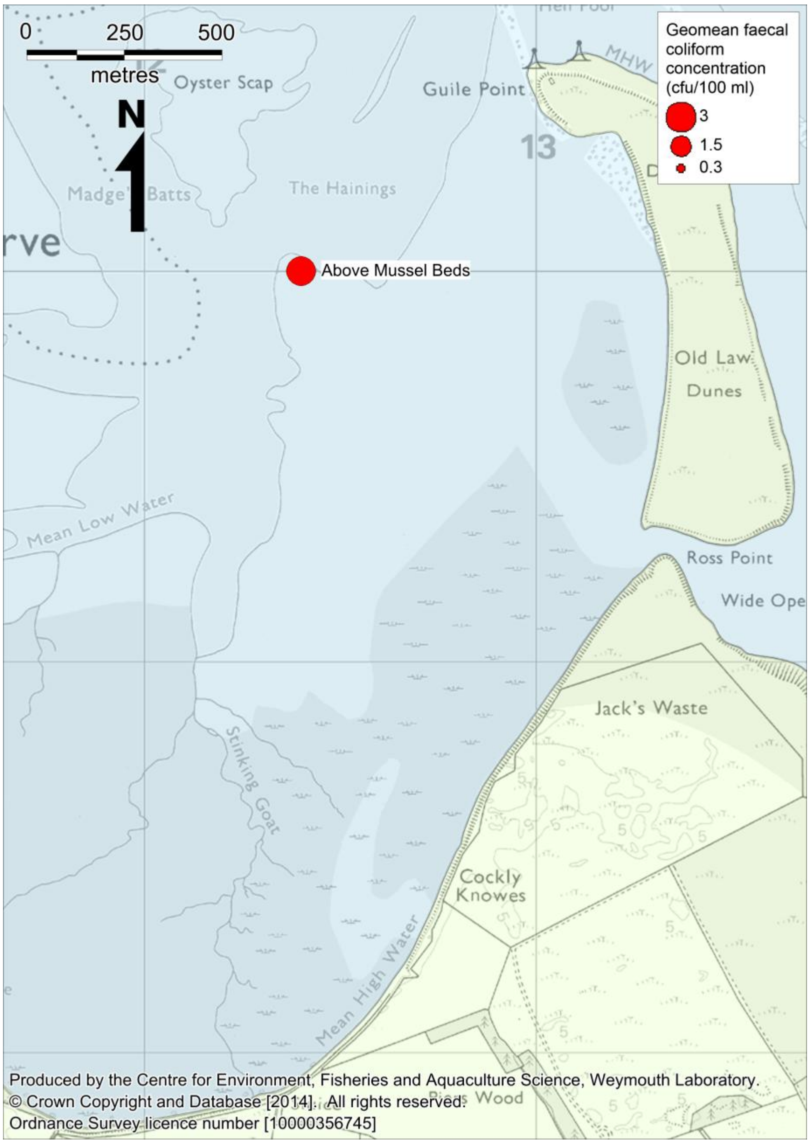

Figure X.1: Location of designated shellfish waters monitoring points.
Contains Environment Agency information © Environment Agency and database right

Table X.1: Summary statistics for shellfish waters faecal coliform results, 2004 to 2014 (cfu/100 ml).

Site	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 100	% over 1,000	% over 10,000
Above Mussel Beds	37	13/05/2004	03/07/2013	2.9	<2	1,182	2.7	2.7	0.0

Contains Environment Agency information © Environment Agency and database right

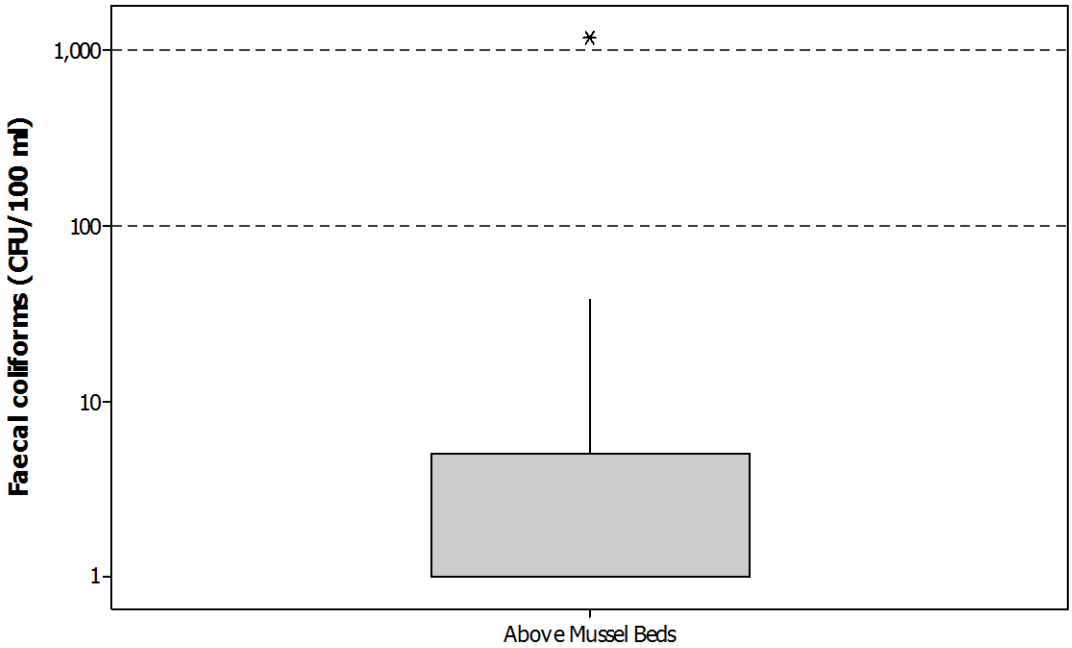

Figure X.2: Box-and-whisker plots of all faecal coliforms results
Contains Environment Agency information © Environment Agency and database right

Only one sample had >100 faecal coliform cfu/100 ml, and this result also exceeded 1,000 cfu/100 ml. As this result is nearly two orders of magnitude higher than any other result, it was removed from the following analyses to avoid biasing results towards this datum. However, the circumstances for this high result are summarised in Table X.4.

Overall temporal pattern in results

The overall variation in faecal coliform levels found at shellfish water sites over time is shown in Figure X.3.

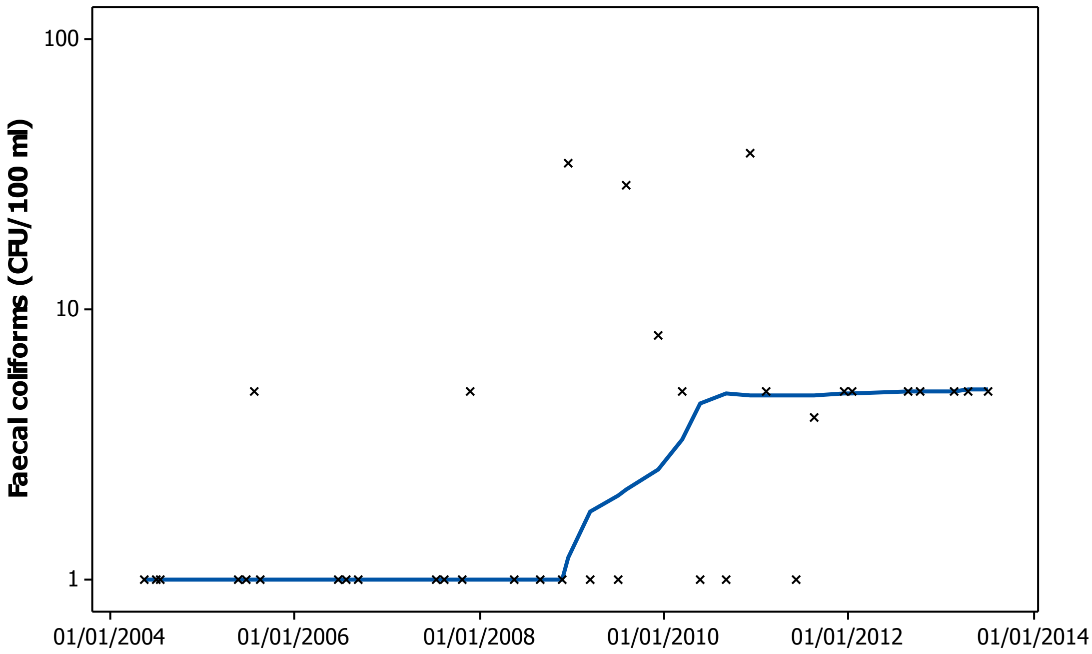

Figure X.3: Scatterplot of faecal coliform results by date, overlaid with loess lines
Contains Environment Agency information © Environment Agency and database right

While Figure X.3 appears to show an increase in faecal coliform levels at Above Mussel Beds between 2008 and 2011, the Loess line is misleading, and there was little change in faecal coliform concentrations. However in 2011 it appears that the threshold for faecal coliform detection increased from two to 10 cfu/100 ml.

Seasonal patterns of results

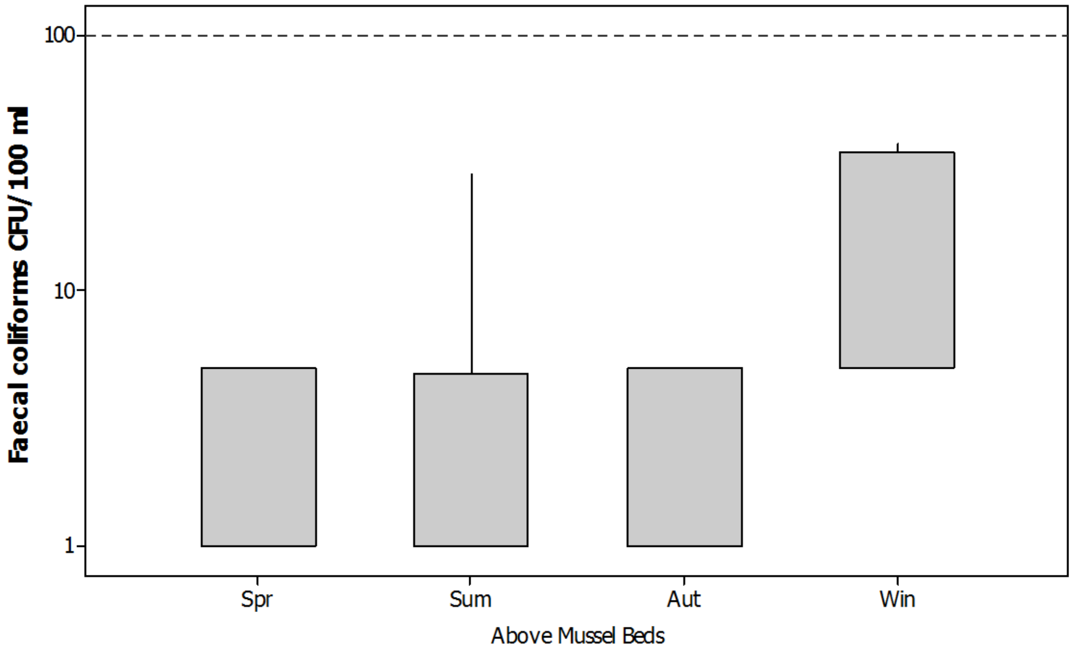

Figure X.4: Boxplot of faecal coliform results by site and season
Contains Environment Agency information © Environment Agency and database right

One-way ANOVA tests showed that there were significant variations in faecal coliform concentrations between seasons (p=0.002). Post-hoc Tukey tests showed that faecal coliform levels were significantly higher in winter than any other season.

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. Correlation coefficients are presented in Table X.2, with statistically significant correlations highlighted in yellow.

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

	High/low tides		Spring/neap tides	
Site Name	**r**	**p**	**r**	**p**
Home Reach	0.667	<0.001	0.484	<0.001

Contains Environment Agency information © Environment Agency and database right

Figure X.5 presents polar plots of $\log_{10}$ faecal coliform results against tidal states on the high/low cycle. High water at Holy Island is at 0° and low water is at 180°. Results of 100 faecal coliforms/100 ml or less are plotted in green, those from 101 to 1,000 are plotted in yellow, and those exceeding 1,000 are plotted in red.

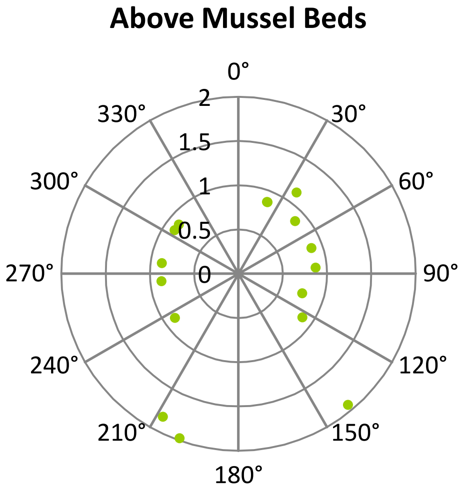

Figure X.5: Polar plots of log10 faecal coliforms against tidal state on the high/low tidal cycle for shellfish waters monitoring points with significant correlations
Contains Environment Agency information © Environment Agency and database right

The majority of samples had a faecal coliform concentration of <2 cfu/100 ml, and so it is difficult to draw firm conclusions about the relationship between tidal state and faecal coliform concentration at Above Mussel Beds. However, the majority of samples with greater than 10 faecal coliform cfu/100 ml were taken around low tide.

Figure X.6 presents polar plots of faecal coliform results against the lunar spring/neap cycle, where a statistically significant correlation was found. Full/new moons occur at 0º, and half moons occur at 180º. The largest (spring) tides occur about 2 days after the full/new moon, or at about 45º, then decrease to the smallest (neap tides) at about 225º, then increase back to spring tides. Results of 100 faecal coliforms/100 ml or less are plotted in green, those from 101 to 1,000 are plotted in yellow, and those exceeding 1,000 are plotted in red.

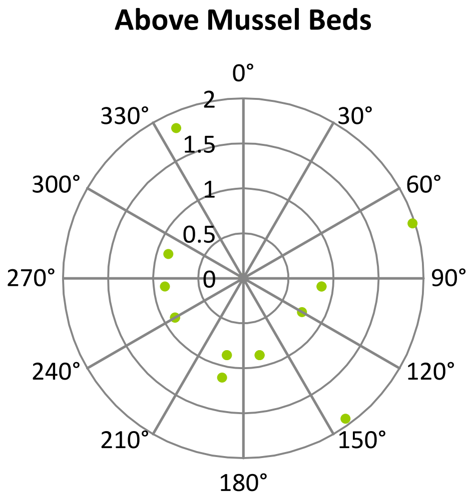

Figure X.6: Polar plots of log10 faecal coliforms against tidal state on the spring/neap tidal cycle for bathing waters monitoring points with significant correlations
Contains Environment Agency information © Environment Agency and database right

Most sampling effort was between spring and neap tide. No pattern in faecal coliform concentration and the spring/neap tidal cycle is apparent from the polar plot.

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 Woodbridge weather station (Appendix VI for details) over various periods running up to sample collection and faecal coliform results. These are presented in Table X.3 and statistically significant correlations ($p<0.05$) are highlighted in yellow.

Table X.3: Spearman's Rank correlation coefficients for faecal coliform results against recent rainfall

	Site	Above Mussel Beds
	n	**37**
24 hour periods prior to sampling	1 day	0.047
	2 days	0.217
	3 days	0.006
	4 days	0.000
	5 days	-0.153
	6 days	0.054
	7 days	0.138
Total prior to sampling over	2 days	0.153
	3 days	0.076
	4 days	0.046
	5 days	-0.107
	6 days	0.007
	7 days	0.021

No relationship was found between faecal coliform levels and rainfall.

Influence of salinity

Salinity was recorded on most sampling occasions. Figure X.7 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.

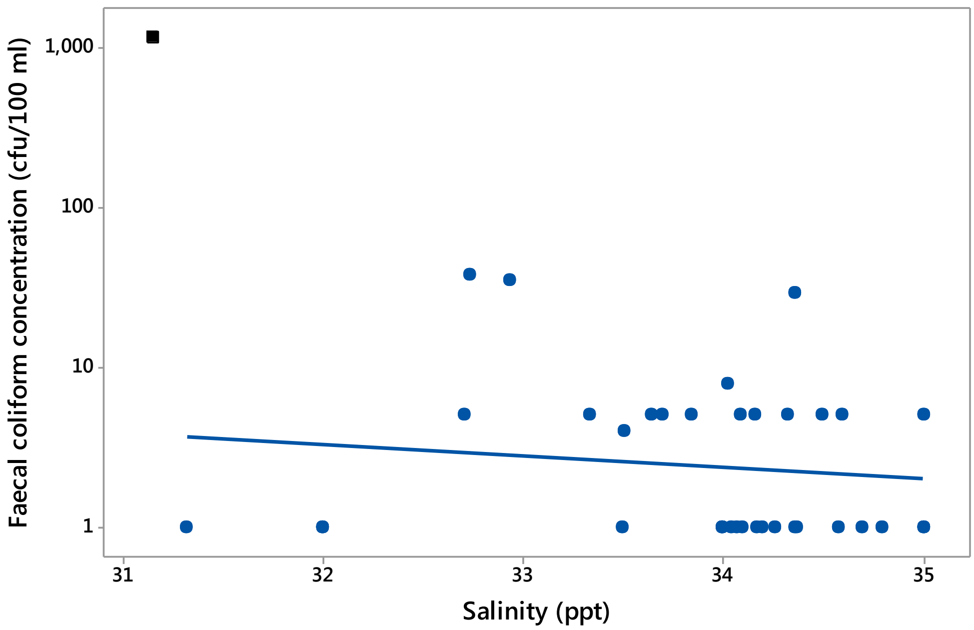

Figure X.7: Scatter-plots of salinity against faecal coliforms.
Contains Environment Agency information © Environment Agency and database right

No significant correlation was found between salinity and faecal coliform concentration (r=-0.131, p=0.447) when the anomalous datum was omitted from the analysis. However, when the anomalous datum (black square in Figure X.7) was included in the analysis, a significant correlation was seen (r=-0.402, r=0.014). While this analysis is not completely valid, it suggests that the cause of the anomalous result was from a freshwater source.

Circumstances of high result

Table X.4 shows the conditions under which the single sample with a high result was taken.

Table X.4: Sampling conditions for anomalously high result taken at Above Mussel Beds

Faecal coliform concentration (cfu/100 ml)		1,182
Sample date		09/07/2012
Sample time		09:43
Season		Summer
High/low tidal state		Mid ebb (69°)
Spring/neap tidal state		Mid-decreasing tide (144°)
Millimetres of recent rainfall (days prior to sampling)	**1**	1.8
	2	12.3
	3	0.7
	4	24.9
	5	10.2
	6	0.0
	7	0.8

The sample was taken in summer, whereas more typically elevated results were observed in winter. It was taken during the ebb tide rather than around low water when other elevated results were recorded. The salinity recorded at the time was the lowest recorded and there were significant rainfall events in the days before sampling. However, other samples in this dataset had much lower faecal coliform levels when there had been higher antecedent rainfall recorded at East Kyloe. The Met Office (2012b) report that June and early July of 2012 was a very wet period. It is therefore concluded that the high result is likely to be a consequence of summer storms resulting in increased fluxes of contamination from agricultural land, possibly augmented by spills from overloaded sewer networks.

Appendix XI. Microbiological Data: Shellfish Flesh Hygiene

XI.1. Summary statistics and geographical variation

There are a total of three RMPs in the Holy Island production area that have been sampled between 2004 and 2014. Two of these RMPs are for mussels and one for Pacific oysters. The geometric mean results of shellfish flesh monitoring from all RMPs sampled from 2004 onwards are presented in Figure XI.1. Summary statistics are presented in Table XI.1 and boxplots for sites are show in Figure XI.2 and Figure XI.3. The Ross Links mussel RMP was only sampled on one occasion and so will not be considered further.

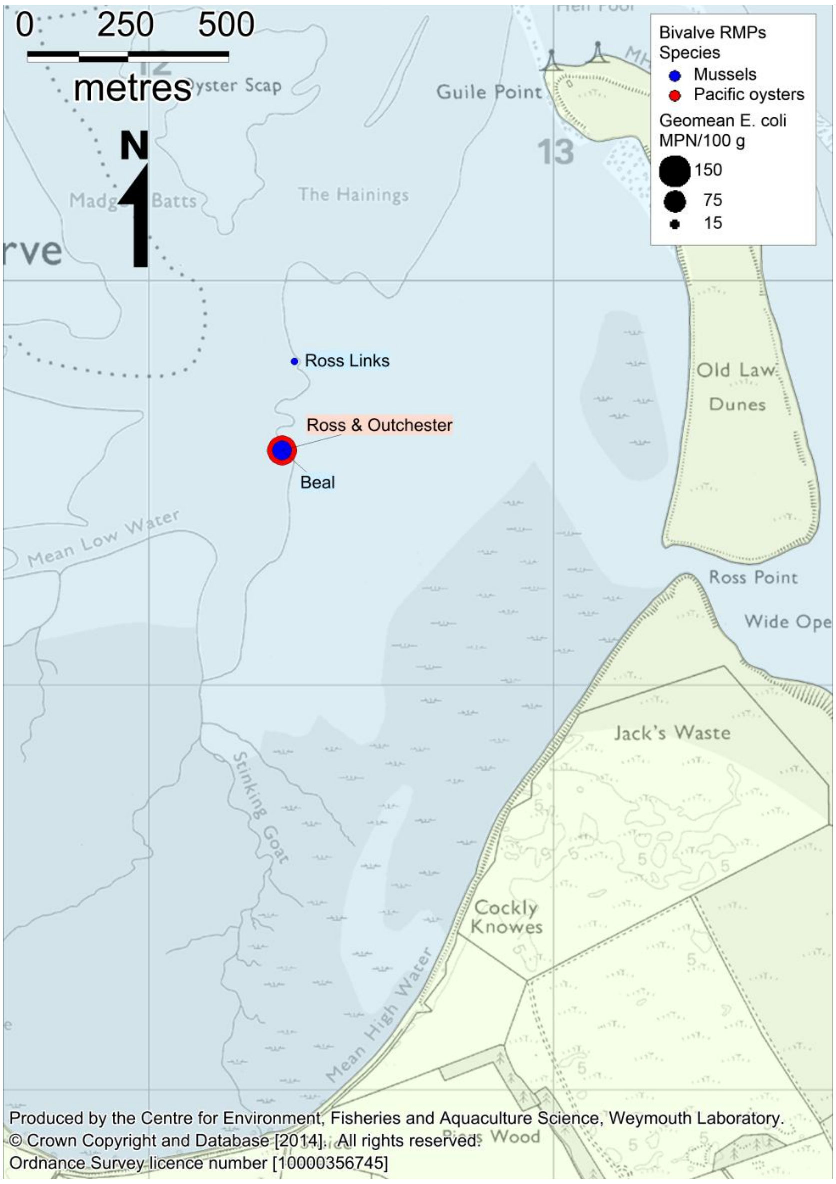

Figure XI.1: Bivalve RMPs active since 2004

Table XI.1: Summary statistics of *E. coli* results (MPN/100 g) from RMPs sampled from 2004 onwards

Site	Species	No.	Date of first sample	Date of last sample	Geometric mean	Min.	Max.	% over 230	% over 4,600
Ross Links	Mussel	1	03/04/2006	03/04/2006	<20	<20	<20	0.0	0.0
Beal	Mussel	76	03/08/2004	09/08/2010	64.7	<20	4,600	19.7	0.0
Ross & Outchester	Pacific oyster	123	21/01/2004	03/03/2014	139.0	<20	7,000	37.4	1.6

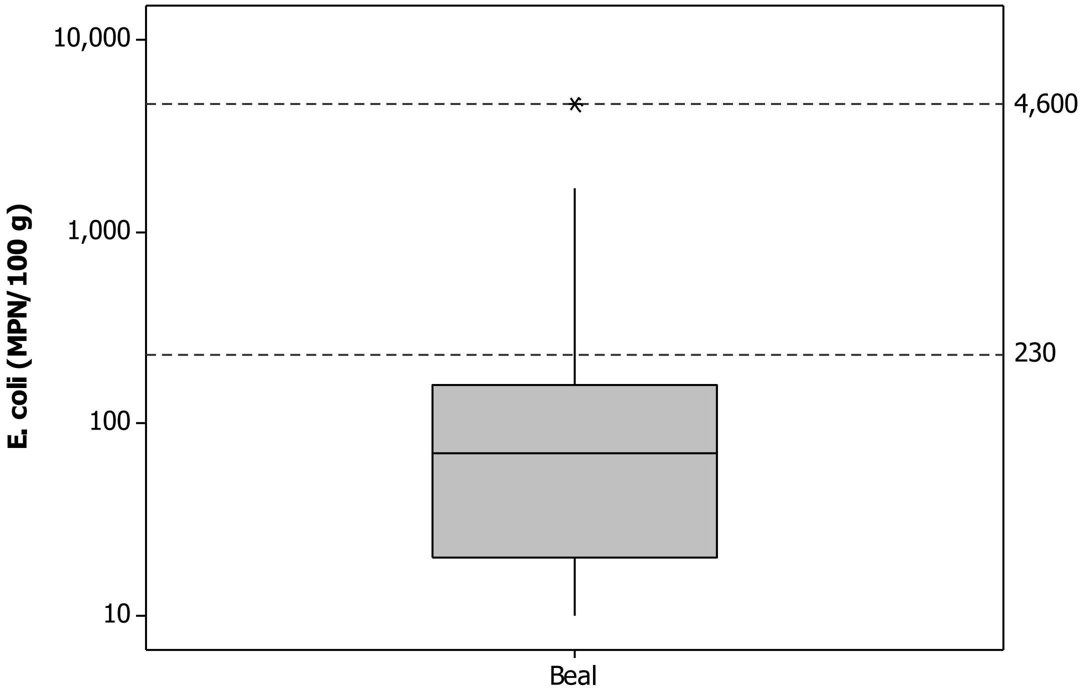

Figure XI.2: Boxplot of *E. coli* results from the Beal mussel RMP from 2004 onwards.

The majority of results at Beal did not exceed 230 *E. coli* MPN/100 g, and none exceeded 4,600 *E. coli* MPN/100 g.

Figure XI.3: Boxplot of *E. coli* results from the Ross & Outchester Pacific oyster RMP from 2004 to 2010.

The distribution of *E. coli* results for Pacific oysters was similar to that observed for mussels, although the average result was slightly higher and two results exceeded 4,600 *E. coli* MPN/100 g.

XI.2. Overall temporal pattern in results

The overall temporal variation in *E. coli* levels found in bivalves since 2004 is shown in Figure XI.4 and Figure XI.5.

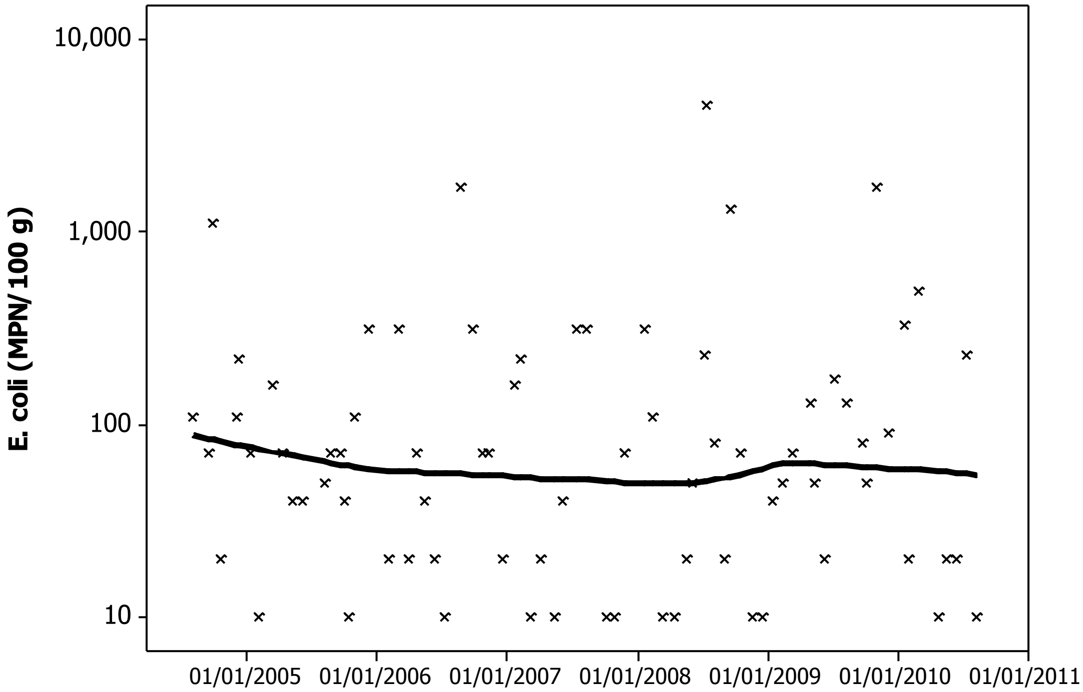

Figure XI.4: Scatterplot of *E. coli* results for mussels overlaid with loess line.

E. coli levels at the Beal mussel RMP have remained fairly stable on average throughout the period considered.

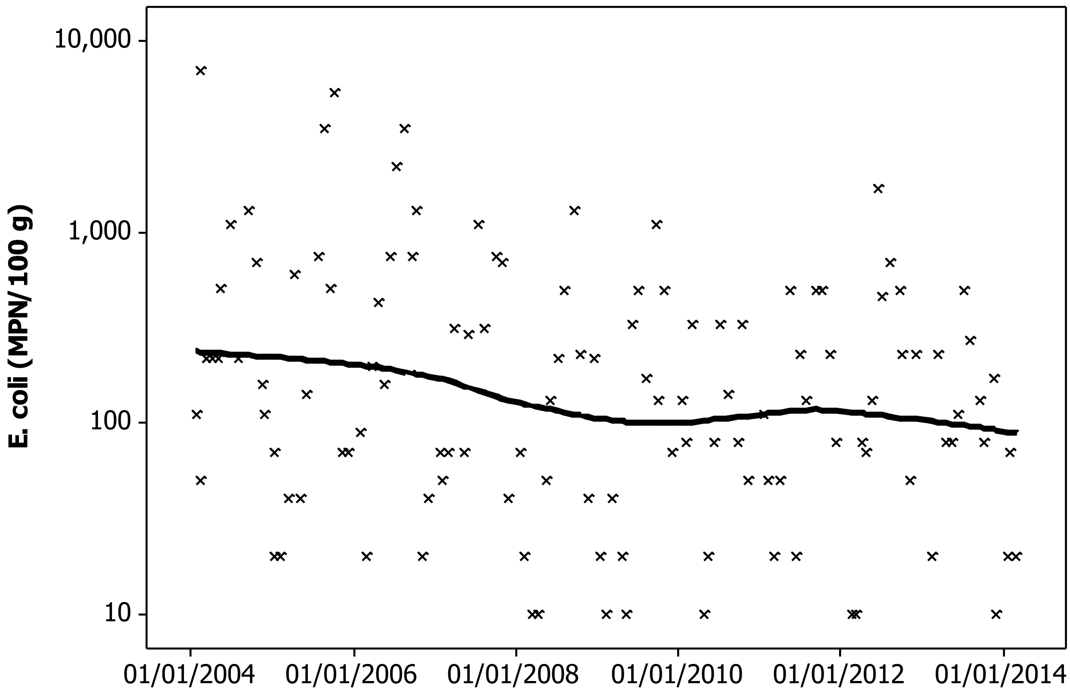

Figure XI.5: Scatterplot of *E. coli* results for Pacific oysters overlaid with loess line.

At the Ross & Outchester Pacific oyster RMP *E. coli* levels declined slightly on average between 2004 and 2008, but have remained fairly stable since.

XI.3. Seasonal patterns of results

The seasonal patterns of results were investigated by RMP. Figure XI.6 and Figure XI.7 show box plots of *E. coli* levels at each site by season.

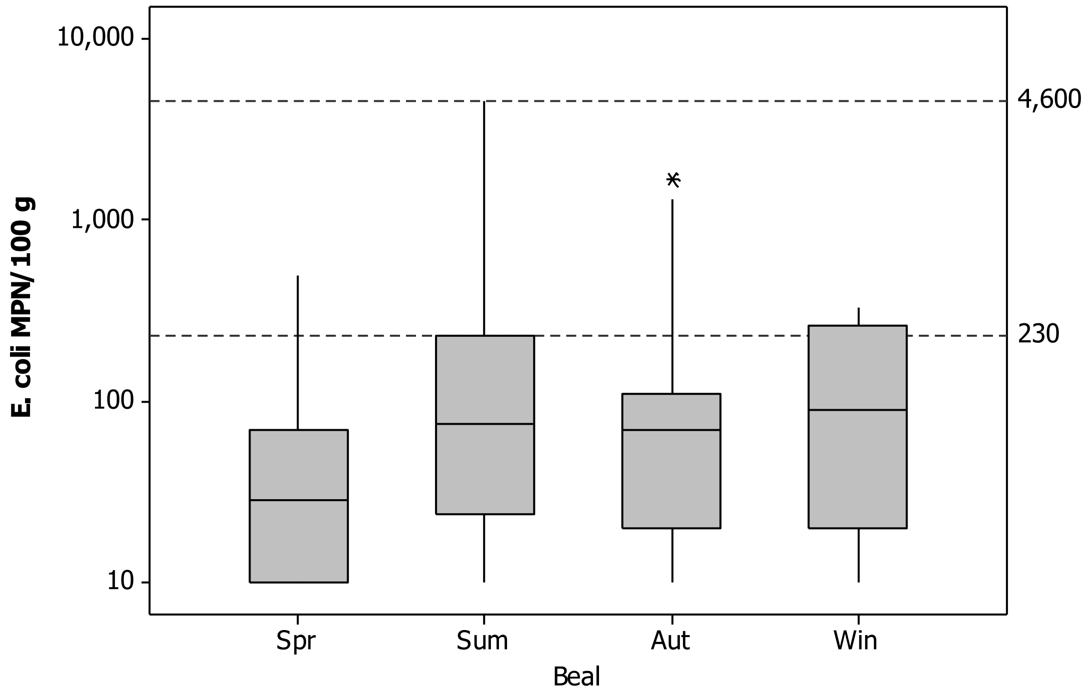

Figure XI.6: Boxplot of *E. coli* results for mussels by season

Results were lower on average during the spring, and similar throughout the other three seasons. One-way ANOVAs showed that these differences were not statistically significant (p=0.171).

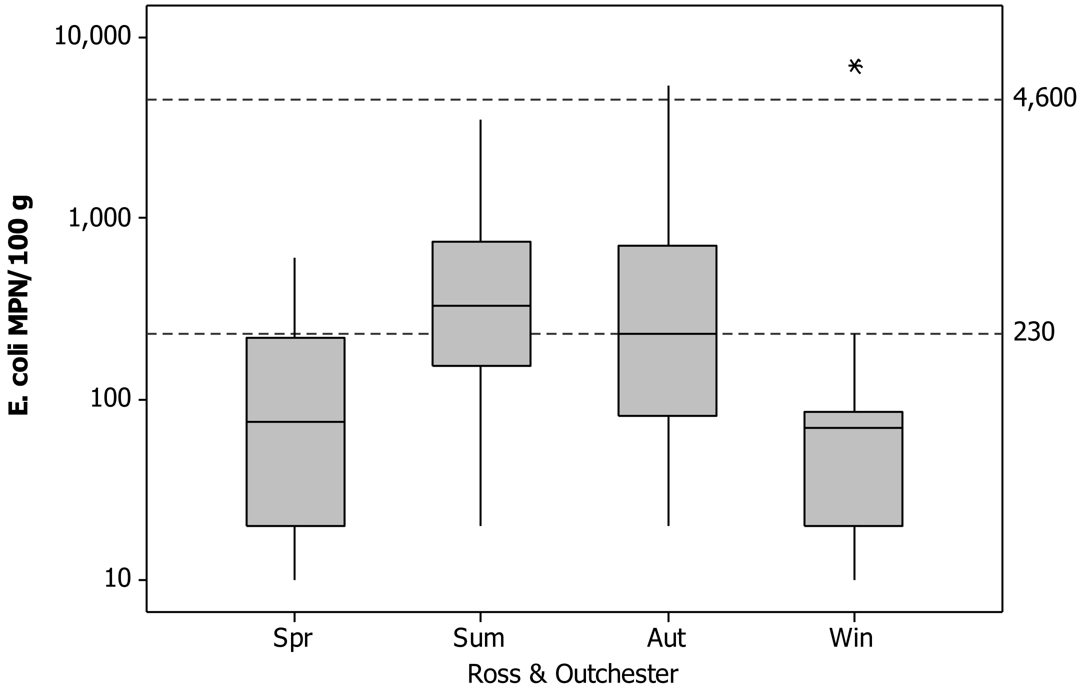

Figure XI.7: Boxplot of *E. coli* results for Pacific oysters by RMP and season

One-way ANOVAs showed that there was significant variation in *E. coli* levels between seasons at the Ross & Outchester Pacific oyster RMP ($p<0.001$). Post-ANOVA Tukey tests showed that there were significantly higher *E. coli* results in summer and autumn than spring and winter.

XI.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 and spring/neap tidal cycles for each RMP where more than 30 samples had been taken. Results of these correlations are summarised in Table XI.2.

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

		High/low tides		Spring/neap tides	
Site Name	**Species**	**r**	**p**	**r**	**p**
Beal	Mussel	0.148	0.201	0.047	0.850
Ross & Outchester	Pacific oyster	0.126	0.150	0.066	0.593

There were no significant correlations between *E. coli* levels and tidal state.

XI.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 East Kyloe weather station (Appendix VI for details) over various periods running up to sample collection. These are presented in Table XI.3, and statistically significant correlations ($p<0.05$) are highlighted in yellow.

Table XI.3: Spearman's Rank correlations between rainfall recorded at East Kyloe and shellfish hygiene results

	Site	Beal	Ross & Outchester
	Species	Mussel	Pacific oyster
	n	76	121
24 hour periods prior to sampling	1 day	0.114	0.057
	2 days	0.126	0.103
	3 days	-0.035	0.024
	4 days	0.134	0.186
	5 days	-0.001	-0.022
	6 days	0.121	0.045
	7 days	0.130	-0.076
Total prior to sampling over	2 days	0.183	0.095
	3 days	0.090	0.129
	4 days	0.197	0.226
	5 days	0.163	0.200
	6 days	0.204	0.186
	7 days	0.224	0.175

Whilst some statistically significant associations were found between *E. coli* levels and antecedent rainfall, its influence was minor and delayed.

Appendix XII. Bacteriological survey

An additional eight samples (four of each species) were collected by Northumberland County Council on the 20th January 2015. Results are shown in Figure XII.1.

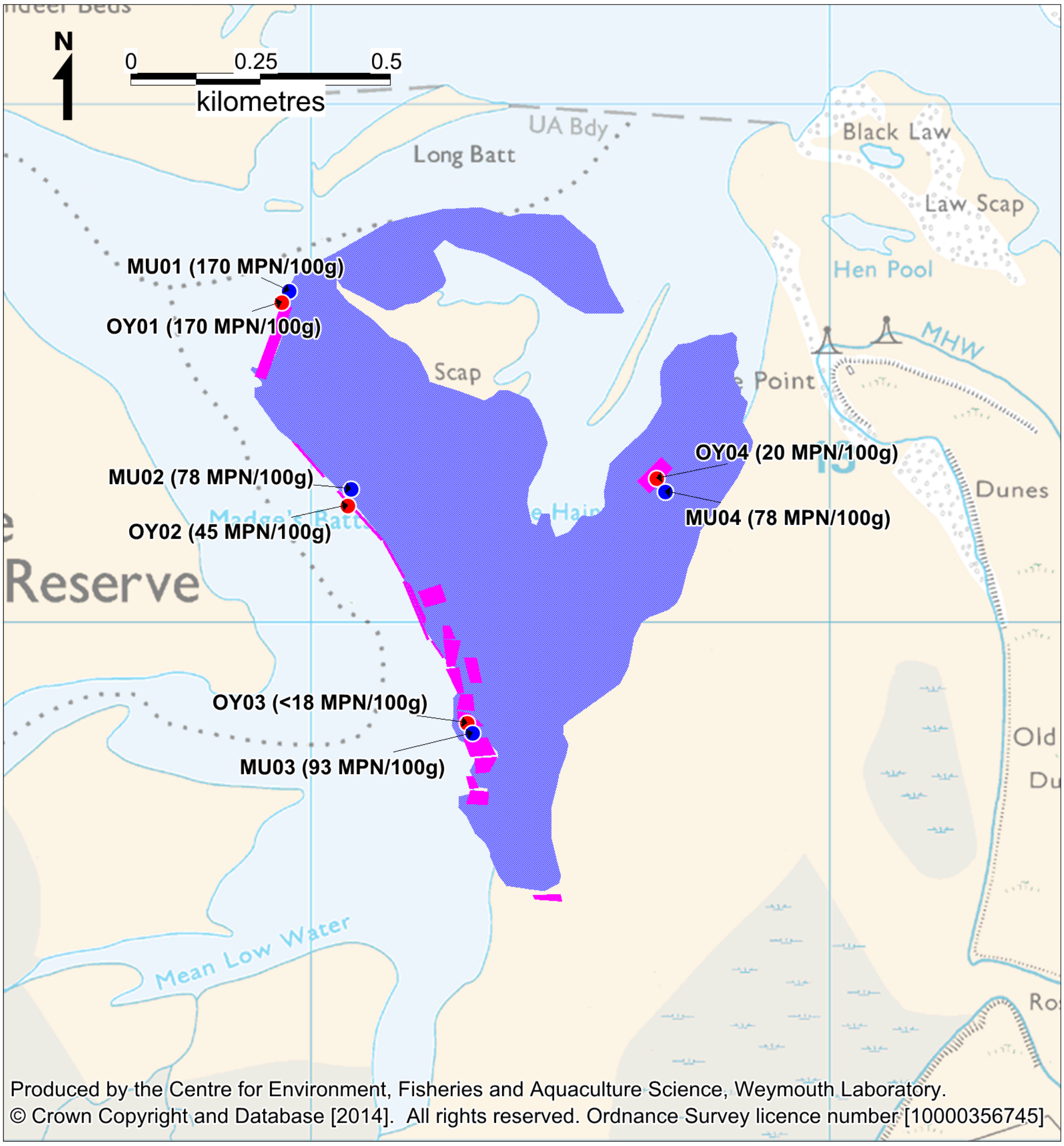

Figure XII.1: Bacteriological survey results

Little spatial variation was apparent, with all results for both species less than 230 *E. coli* MPN/100g. The highest result for both species arose towards the north western end of the site.

Appendix XIII. Shoreline Survey Report

Date (time): 21/05/2014 (08:45 – 15:00)

22/05/2014 (08:30 – 12:30)

Cefas Officers: Alastair Cook, David Walker (21/05/2014 only)

Local Enforcement Authority Officers: Charles Copeland (22/05/2014 only).

Harvester: Mr Sutherland

Area surveyed: Perimeter of Holy Island and the mainland shore of the catchment (Figure XII.1).

Weather: 21/05/2014 dry, sunny, 15°C, winds W force 2.

22/05/2014 heavy rain, 10°C, winds N force 5.

Tides:

Admiralty TotalTide© predictions for Holy Island (50°47'N 0°56'W). All times in this report are BST.

21/05/2014	22/05/2014
High 01:50 1.3 m High 07:53 4.8 m Low 14:25 1.0 m Low 20:46 4.6 m	High 01:50 1.3 m High 07:53 4.8 m Low 14:25 1.0 m Low 20:46 4.6 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 and to locate other potential sources of contamination that were previously unknown. A brief meeting was held with the harvester to ascertain further information on the fishery. A full list of recorded observations is presented in Table XIII.1 and the locations of these observations are mapped in Figure XIII.1. Photographs are presented in Figure XIII.3 – Figure XIII.9.

Description of Fishery

The fishery is a long established Pacific oyster trestle farm. Seed stocks are purchased and grown to market size, a process that takes around three years. The harvester has his own depuration tanks. Annual production is around 50 tonnes. The trestles were not visited, but the harvester advised that a Natural England officer had recently marked out the locations of the trestles accurately by GPS. This information was subsequently obtained.

Mussels have been commercially exploited in the past by one fisherman across the area in which the trestles are located. The mussels observed just off the west shore of Holy Island were generally small and barnacle encrusted.

Sources of contamination

Sewage discharges

The sewage works serving Holy Island is by the main visitor car park (observation 20) and discharges to the North Sea to the east of the island, but the outfall was not seen during the survey as it was covered by the tide. A possible septic tank was recorded at Fenham Mill (observation 28).

Freshwater inputs

All but one of the significant watercourses draining to the area were sampled and measured. On the mainland, there were four watercourses of potential significance (North Low, South Low, Beal Cast and Fenham Burn). Flap gates were observed at the head of tide on the South Low and the Beal Cast, which means they will not discharge at higher states of the tide. The largest of these in terms of both flow and bacterial loading was the South Low, which was sampled at the tidal gates, and then sampled and measured where it flows under the causeway later in the day. It was not possible to safely access the Beal Cast to sample and measure it (observation 30). The sluice gates and minor field drain marked on the ordnance survey map at the southern end of the mainland survey were no longer present. The only freshwater input originating from Holy Island was very minor in terms of both discharge and bacterial loading.

Boats and Shipping

A small number of boats were observed within a bay on the south shore of Holy Island (observation 15).

Livestock

On the mainland to the north of the South Low outfall sheep were observed in locations where they had access to the shore (observations 1 and 2). A patch of saltmarsh by the South Low outfall showed evidence of recent sheep grazing (observation 8). Less recent evidence of cattle grazing was seen on the dunes at the western end of Holy Island (observation 12) where animals would also be able to access the shore. Numerous fenced fields holding livestock were observed at other locations (observations 13, 14, 22, 23, 26, 28 & 29).

Wildlife

Birds (including gulls and waders) were commonly sighted, but no major aggregations were recorded. The harvester advised that large numbers (hundreds) of seals haul out on the sandbanks just north of the trestle site.

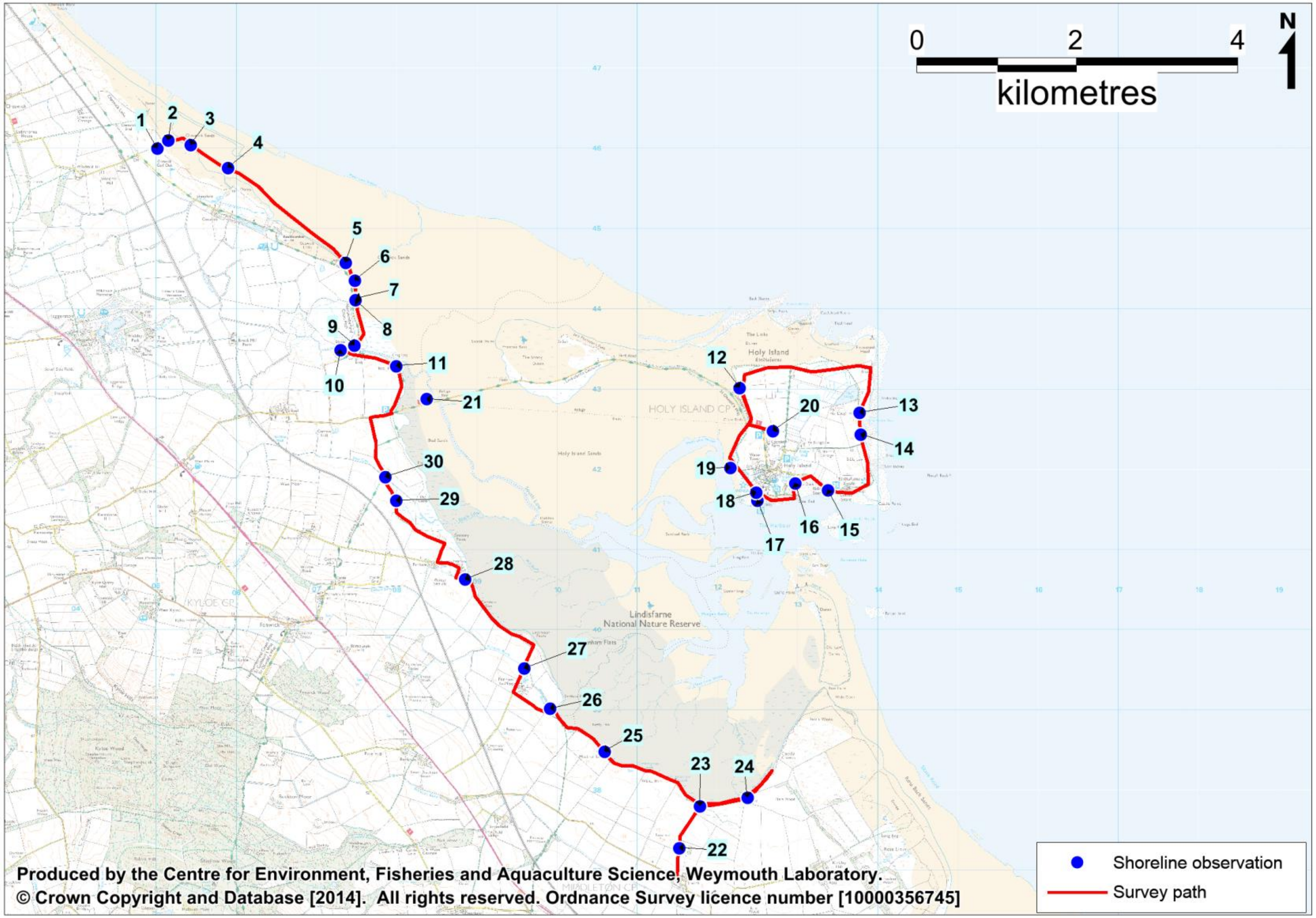

Figure XIII.1: Locations of shoreline observations (see Table XII.1 for details)

Table XIII.1: Details of Shoreline Observations

No	Time and Date	NGR	Photograph	Observation
1	21/05/2014 09:18	NU 05007 46007		35 sheep on dunes
2	21/05/2014 09:21	NU 05141 46104		45 sheep
3	21/05/2014 09:25	NU 05422 46050		Flock of ~50 gulls at water's edge
4	21/05/2014 09:34	NU 05886 45758		North Low watercourse 3.5mx25cmx0.228m/s. Water sample 1.
5	21/05/2014 10:06	NU 07357 44580		Horse droppings in tideline.
6	21/05/2014 10:09	NU 07472 44353		Horse droppings in tideline.
7	21/05/2014 10:13	NU 07484 44125		Dead porpoise
8	21/05/2014 10:14	NU 07478 44109	Figure XIII.3	Saltmarsh with sheep droppings and footprints
9	21/05/2014 10:26	NU 07463 43550		Small sluice gate, small amount of water draining tidally. Sheep droppings around the creek.
10	21/05/2014 10:30	NU 07293 43488	Figure XIII.4	South Low sluice gate, not possible to access to measure. Water sample 2 taken upstream of sluice gates.
11	21/05/2014 10:50	NU 07986 43290		No evidence of sheep on this side of the channel.
12	21/05/2014 12:02	NU 12266 43016	Figure XIII.5	Cattle dung (old and dry)
13	21/05/2014 12:40	NU 13769 42711		About 100 sheep in fields (and 2 escaped on grass by the shoreline)
14	21/05/2014 12:44	NU 13782 42436		~30 sheep in field
15	21/05/2014 13:06	NU 13374 41740		1 yacht, 3 fishing vessels and several open dinghies.
16	21/05/2014 13:14	NU 12963 41828	Figure XIII.6	Freshwater outfall 3cmx5cmx0.393m/s. Water sample 3.
17	21/05/2014 13:34	NU 12490 41611		Scattered mussels
18	21/05/2014 13:36	NU 12477 41715		Access point
19	21/05/2014 13:44	NU 12153 42024		Denser mussel bed
20	21/05/2014 14:11	NU 12687 42481	Figure XIII.7	Sewage works
21	21/05/2014 14:29	NU 08367 42879		South Low at causeway, 11.5mx15cmx0.307m/s. Water sample 4.
22	22/05/2014 09:14	NU 11517 37279		15 sheep and 25 cattle in fields.
23	22/05/2014 09:22	NU 11776 37801		15 cattle and 30 sheep in fields
24	22/05/2014 09:42	NU 12366 37907		Cotton bud in tideline
25	22/05/2014 10:22	NU 10587 38482		Field drain 6cmx1cmx0.305m/s. Water sample 5.
26	22/05/2014 10:44	NU 09904 39016		40 sheep in field
27	22/05/2014 10:58	NU 09581 39517		Stream 160cmx12cmx0.316m/s. Water sample 6
28	22/05/2014 11:25	NU 08846 40633	Figure XIII.8	Possible septic tank cover (although no vent or outfall observed). 2 sheep.
29	22/05/2014 11:53	NU 07983 41611		~50 sheep in field
30	22/05/2014 12:00	NU 07846 41909	Figure XIII.9	Beal Cast watercourse, not possible to access to either sample or measure.

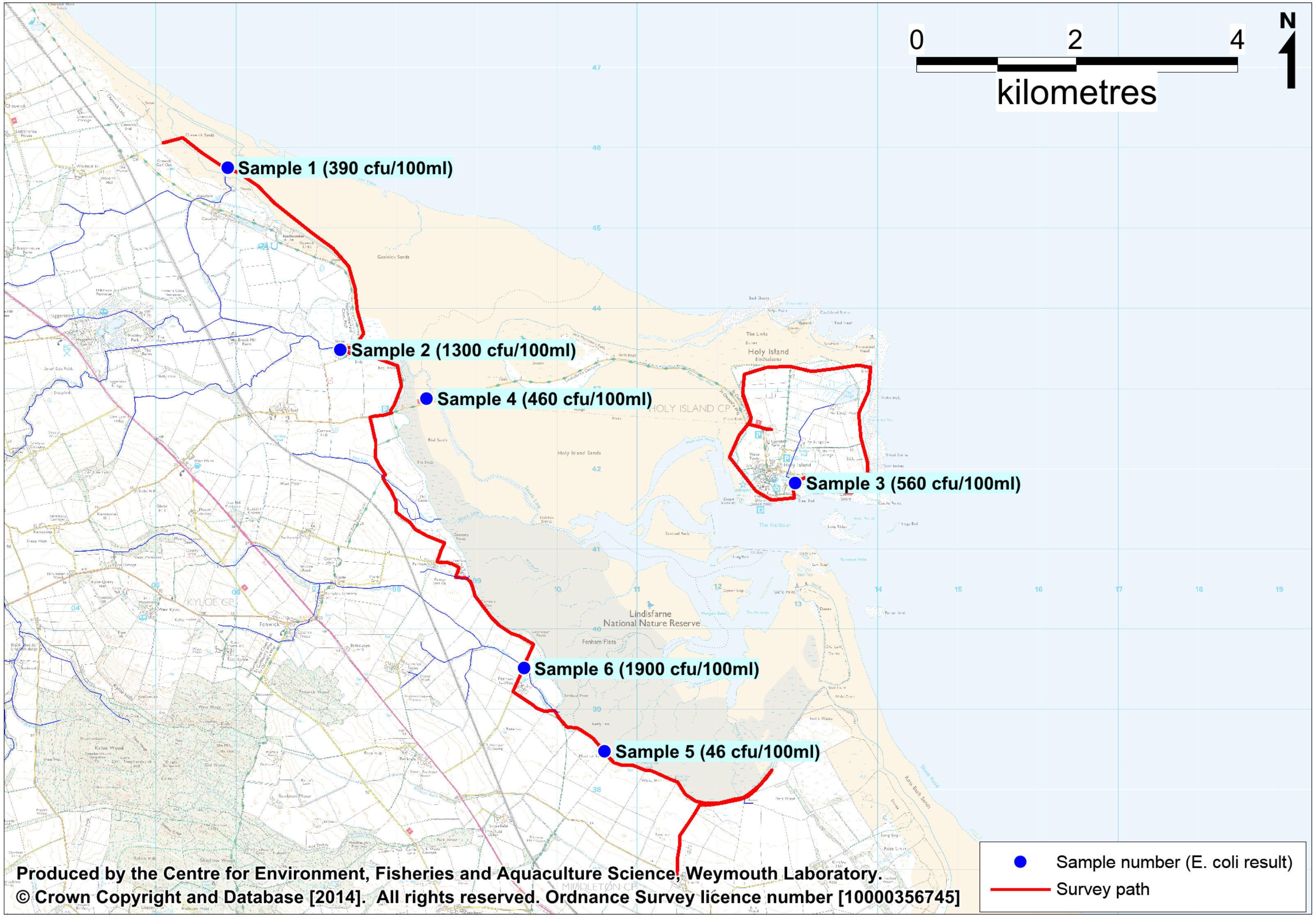

Figure XIII.2: Water sample results

Table XIII.2: Water sample *E. coli* results and spot flow gauging results

Sample no.	Date and time	NGR	Name	*E. coli* (cfu/100 ml)	Discharge (m^3/sec)	*E. coli* loading (cfu/day)
1	21/05/2014 09:34	NU 05886 45758	North Low	390	0.20	$6.7x10^{10}$
2	21/05/2014 10:30	NU 07293 43488	South Low	1,300	Not measured	-
3	21/05/2014 13:14	NU 12963 41828	Unnamed freshwater outfall	560	$5.9x10^{-4}$	$2.9x10^{8}$
4	21/05/2014 14:29	NU 08367 42879	South Low	460	0.53	$2.1x10^{11}$
5	22/05/2014 10:22	NU 10587 38482	Unnamed freshwater outfall	46	$1.8x10^{-4}$	$7.3x10^{6}$
6	22/05/2014 10:58	NU 09581 39517	Fenham Burn	1,900	0.061	$1.0x10^{11}$

Figure XIII.3

Figure XIII.4

Figure XIII.5

Figure XIII.6

Figure XIII.7

Figure XIII.8

Figure XIII.9

References

Ashbolt, J. N., Grabow, O. K., Snozzi, M., 2001. Indicators of microbial water quality. In Water quality: guidelines, standards and health. Fewtrell, L. and Bartram, J. (Eds). IWA Publishing, London. pp. 289−315.

Austin, G.E., Read, W.J., Calbrade, N.A., Mellan, H.J., Musgrove, A.J., Skellorn, W., Hearn, R.D., Stroud, D.A., Wotton, S.R. and Holt, C.A. 2014. Waterbirds in the UK 2012/13. The Wetland Bird Survey. BTO, RSPB and JNCC, in association with WWT. British Trust for Ornithology, Thetford.

Brown J., 1991. The final voyage of the Rapaiti. A measure of surface drift velocity in relation to the surface wind. Marine Pollution Bulletin 22: 37-40.

channelcoast.org website, 2014. Lidar maps. Available at www.channelcoast.org. Accessed September 2014.

Environment Agency, 2009. Pollution reduction plan for Holy Island Shellfish Water.

EU Working Group on the Microbiological Monitoring of Bivalve Harvest Areas, 2014. Microbiological Monitoring of Bivalve Harvest Areas. Guide to Good Practice: Technical Application. Issue 5, June 2014.

European Communities, 2004. EC Regulation No 854/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific hygiene rules on products of animal origin intended for human consumption. Official Journal of the European Communities L226: 83-127.

European Communities, 2006. Directive 2006/113/EC of the European parliament and of the Council of 12 December 2006 on the quality required of shellfish waters (codified version). Official Journal of the European Communities L376: 14-20.

Futurecoast, 2002. Department of Environment, Food and Rural Affairs (Defra), Halcrow Group Ltd 3 CD set.

Geldreich, E.E., 1978. Bacterial and indicator concepts in feces, sewage, stormwater and solid wastes. In Berg, G. (ed.). Indicators of Viruses in Water and Food. MI: Ann Arbor.

Grazing Animals Project Website, 2014. Lindisfarne NNR grazing project. Available at:http://www.grazinganimalsproject.org.uk/gap_site/lindisfarne_nnr_grazing_project.html. Accessed August 2014.

Green, J., Royle, J., 2013. Stock Assessment of the Littoral Mussel (Mytilus edulis) Beds on Fenham Flats (Holy Island). Northumberland IFCA report, March 2013.

Hamilton-Baillie Associates Ltd. 2012. Holy Island of Lindisfarne, Village life and visitor access: maintaining a balance. Available from:

http://70.33.241.140/~ciycc830/HIP/Key_Documents_files/BHB%20Village,%20Traffic%20and%20Parking%20Report%20Final.pdf. Accessed 15/04/2014

Holy Island of Lindisfarne Community Development Trust, 2013. Terms and conditions of use. Available at: http://www.holyislandharbour.org/harbourfees.pdf Accessed: July 2014

Hughes, C., Gillespie, I.A., O'Brien, S.J., 2007. Foodborne transmission of infectious intestinal disease in England and Wales 1992-2003. Food Control 18: 766−772.

Kay, D., Crowther, J., Stapleton, C.M., Wyler, M.D., Fewtrell, L., Anthony, S.G., Bradford, M., Edwards, A., Francis, C.A., Hopkins, M. Kay, C., McDonald, A.T., Watkins, J. and Wilkinson, J., 2008a. Faecal indicator organism concentrations and catchment export coefficients in the UK. Water Research 42, 442-454.

Kay, D., Crowther, J., Stapleton, C.M., Wyer, M.D., Fewtrell, L., Edwards, A., Francis, C.A., McDonald, A.T., Watkins, J., Wilkinson, J., 2008b. Faecal indicator organism concentrations in sewage and treated effluents. Water Research 42: 442-454.

Lee, R.J., Younger, A.D., 2002. Developing microbiological risk assessment for shellfish purification. International Biodeterioration and Biodegradation 50: 177−183.

Met Office, 2012a. Regional Climates. Available at: http://www.metoffice.gov.uk/climate/regional/ Accessed February 2014.

Met Office, 2012b. UK overview, July 2012. Available at: http://www.metoffice.gov.uk/climate/uk/2012/july.html Accessed September 2014.

Mitchell, P. Ian, S. F. Newton, N. Ratcliffe & T. E. Dunn, 2004. Seabird Populations of Britain and Ireland, Results of the Seabird 2000 Census (1998-2002). T&AD Poyser, London.

MMO, 2014. UK vessel lists 2014. July 2014. http://www.marinemanagement.org.uk/fisheries/statistics/vessel.htm Accessed: July 2014.

Natural England, 2014. Lindisfarne NNR. Available at: http://www.naturalengland.org.uk/ourwork/conservation/designations/nnr/1006092.aspx. Accessed July 2014

NERC, 2012. National River Flow Archive, Catchment Spatial Information. Available at: http://www.ceh.ac.uk/data/nrfa/data/search.html. Accessed September 2013.

NIFCA, 2012. Insight into Fisheries and Enforcement. 2012 Yearly Summary

Northumberland County Council, 2012. Cell 1 Regional Coastal Monitoring Programme. Analytical Report 4: ‘Full Measures’ Survey 2011.

Obiri-Danso, K. and Jones, K., 2000. Intertidal sediments as reservoirs for hippurate negative campylobacters, salmonellae, and faecal indicators in three EU recognised bathing waters in North-West England. Water Research 34(2): 519−527.

SCOS, 2013. Scientific Advice on Matters Related to the Management of Seal Populations: 2013. Available at: http://www.smru.st-andrews.ac.uk/pageset.aspx?psr=41. Accessed July 2014

The Green Blue, 2010. Pump Out Directory. Available at: http://www.thegreenblue.org.uk/pump_out_directory.aspx. Accessed February and April 2014

Thompson, D. and Duck, C., 2010. Berwickshire and North Northumberland Coast European Marine Site: grey seal population status. Report to Natural England : 20100902-RFQ Available at: http://www.xbordercurrents.co.uk/core_files/greyseal.pdf. Accessed July 2014

Younger, A.D., Lee, R.J. and Lees, D.N. 2003. Microbiological monitoring of bivalve mollusc harvesting areas in England and Wales: rationale and approach. In: Villalba, A., Reguera, B., Romalde, J. L. and Beiras, R. (eds). Molluscan Shellfish Safety. Consellería de Pesca e Asuntos Marítimos de Xunta de Galicia and Intergovernmental Oceanographic Commission of UNESCO, Santiago de Compostela, Spain. pp. 265−277.

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
mtDNA	Mitochondrial DNA
NM	Nautical Miles
NRA	National Rivers Authority
NWSFC	North Western Sea Fisheries Committee
OSGB36	Ordnance Survey Great Britain 1936
ppt	parts per thousand
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.
Loess	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 LOESS fit is complete after regression function values have been computed for each of the n data points. LOESS 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”.

Acknowledgements

Mark Mitchell, Charles Copeland and Rose Mary Ayre (Northumberland County Council), Mr Southerland (harvester), Catherine Scott (Natural England), Jonathon Green (Northumberland IFCA).