EASTERN SEA FISHERIES JOINT COMMITTEE

RESEARCH REPORT 2010

R. W. JESSOP

S. HINNI

J. SKINNER

J. R. WOO

CONTENTS

PRODUCTIVITY RESEARCH

SUFFOLK RIVERS SURVEYS

LUGWORM (*Arenicola marina*), SAND MASON (*Lanice conchilega*), and TELLIN (*Macoma balthica*) RESEARCH

BACTERIOLOGICAL SAMPLING

1.0 SUMMARY

The annual autumn mussel surveys found the stock of mussels on the intertidal sandbanks of the Wash to be 9,626 tonnes. Not only is this a significant decrease from the 15,188 tonnes recorded following the 2009 surveys, it means the stocks have fallen below the 12,000 tonnes Conservation Objective set for the site by Natural England. This decline greatly exceeded anticipated losses following the 2009/10 fishery, during which approximately 800 tonnes of mussels had been relayed from the intertidal beds into the several fishery. On some beds, such as the Gat, losses were as high as 60%. High numbers of gaping shells on several of the beds indicated recent mortalities were not just limited to older mussels but that large numbers two and three year old mussels had recently died, too. Although it is currently uncertain what caused the deaths, high numbers of the parasitic copepod Mytilicola intestinalis were found in mussel samples taken from several of the beds.

Although it was not possible to open the intertidal mussel stocks to the 2010/11 fishery following their decline, two beds of sublittoral mussel seed were identified in February 2011. One, along the Lincolnshire Coast, near to the Lynn and Inner Dowsing windfarm was found to support very young seed that was too small for relaying. The other, however, situated along the Norfolk Coast, north of Mundesley, did support suitable mussels for a fishery. Although the stock on this bed was estimated to be approximately 22,000 tonnes, a large part of this bed was situated within the ESFJC 3-mile boundary in an area restricted to dredging. Following consultation with crab and lobster fishermen, to resolve potential gear conflict issues, it was possible to open 7,700 tonnes of these stocks to the mussel fishery.

The spring cockle surveys found that the cockle stocks in the Wash had declined from 22,419 tonnes in 2009 to 16,256 tonnes. Apart from approximately 1,400 tonnes that had been harvested during the year by the handworked fishery, most of the losses were attributed to the atypical mortality that was first noticed to be occurring in the Wash in 2008. The cause of the mortalities is still unknown, but has resulted in the cockle stocks declining from their second highest recorded biomass in 2007 to a situation in which it has been difficult for the industry to find patches of adult cockles dense enough to fish. Because of the difficulties in identifying sufficient adult stocks that were discrete from juvenile stocks, the dredge fishery remained closed during 2010. Although the 29 vessels that participated in the handwork fishery exhausted the available TAC of 2,081 tonnes by December, several vessels were resorting to landing small cockles from Herring Hill by the end of the season.

Following concerns that the practice of "propeller washing" associated with the handwork cockle fishery might be damaging the ecology of the site a study was conducted to assess the potential disturbance. Over a four-month period, core samples were taken from five rings created by propeller washing and compared with samples taken from five unfished control sites. Apart from expected changes in the abundance of cockles, no significant differences were found to either the infauna or

substratum between the fished and unfished sites, indicating the handwork fishery was not having an adverse impact on the site.

The Committee has a byelaw prohibiting the removal of egg-bearing "berried" lobsters from the district. Identifying berried lobsters can be problematic, however, if the eggs have been forcibly scrubbed off before landing. Over the past five years, therefore, the Committee has developed a staining technique to facilitate the detection of scrubbed lobsters. The crustacean section of this report details the development of the staining technique and the blind trials that have been conducted to test its accuracy.

Surveys have been conducted through the year to identify and map the distribution of Sabellaria spinulosa reefs. These surveys included monitoring five areas within the Wash that had been surveyed in 2009 and four additional areas along the Lincolnshire coast that had been subject to a broadscale survey in 2008. Data collected from these surveys, combined with past data, will help to identify core areas that have been found to regularly support reef features.

Following the unexplained mortalities of cockles in 2008, ESFJC initiated a project to study the productivity of the Wash in case localised food limitations were a causal effect. Regular monitoring of chlorophyll levels have been conducted at several sites throughout the year, to determine whether shellfish stocks might be exceeding their localised carrying capacities. Because the several fishery lays have the highest concentrations of stock in the Wash, the majority of monitoring has occurred around these areas. Although analysis of the data have found the chlorophyll levels to be heterogeneous, the study has so far not detected any consistent reduction in Chlorophyll levels above the lays that could be attributed to the mussels' filter feeding. These studies have concentrated on chlorophyll levels at 1m depth, however, which depending on states of the tide could be several metres above the mussels. Further studies are planned to measure chlorophyll levels closer to the seabed during 2011.

Surveys conducted in the Rivers Stour and Orwell found cockle stocks along the banks of both rivers had increased slightly from their low levels the previous year, but were still much lower than levels recorded in 2001 and 2003. A small population of native oysters at Holbrook Bay was similarly found to have grown from the low levels recorded in 2009, but had not recovered to levels recorded prior to 2006. This population appeared to have spread, however, to a nearby area at Copperas Bay, where juveniles were found on a gravel bank. These surveys also investigated the distribution of Manila clams that had been identified in the rivers during the 2009 surveys. The results from the survey found the population was currently too sparse to support a sustainable commercial fishery.

2.0 WASH MUSSEL STOCKS

2.1 Summary

The annual surveys of the Wash intertidal mussel beds were conducted between September 9th and November 6th 2010. During this period 20 intertidal beds, plus the Welland Bank, were surveyed. This included two areas of new settlement on Daseley's and the Blackshore that had not been included in previous surveys.

The total stock of mussels on the intertidal beds was found to be 9,626 tonnes. This was a significant decrease from the 15,188 tonnes recorded following the 2009 surveys and greatly exceeded anticipated losses following the 2009/10 fishery, during which approximately 800 tonnes of mussels had been relayed from the intertidal beds into the several fishery. Excluding the two new beds, all but two of the existing beds were found to have declined in stock, some by quantities exceeding 60%. Some of the largest declines were seen on beds that had not been exploited during the 2009/10 fishery, including the Gat beds from which an estimated 3,419 tonnes of mussels (61% of the 2009 stock) had been lost. Other affected beds included the South and East Mare Tail, Shellridge, Roger, Herring Hill, Main End, Holbeach, Breast, and Scotsman's Sled. Reductions were also seen on the Toft and Trial Bank beds, but these two beds had attracted a high proportion of the effort during the 2009/10 fishery and losses were consistent with those anticipated from fishery returns data. On several of the beds where losses had occurred, high numbers of gaping shells, indicative of recent mortality, indicated mortality was not just limited to older mussels, but affected a high proportion of two and three year old mussels too. This was particularly noticeable on the Gat beds where whole patches of young mussels were found to have recently died. It is still uncertain what caused the deaths, but samples from the Mid Gat bed sent to CEFAS to test for potential pathogens found relatively high numbers of the parasitic copepod *Mytilicola intestinalis* to be present in the mussels. Although there is scientific debate as to how damaging *M. intestinalis* may be to mussel hosts, some studies have reported decreased condition of infected mussels while on occasions mass mortality in mussel beds have been associated with this parasite (Korringa, 1968). Subsequent samples taken from the Toft, Trial Bank and Mare Tail beds also found heavy infestations of this parasite to be present.

These losses meant that during the year the intertidal mussel stocks had declined from their healthiest level since the 1980s to their lowest level since 2001, falling well below the agreed Conservation Objective of 12,000 tonnes. Although fisheries may still proceed below this level of stock, these may only occur if it can be demonstrated that stocks are likely to achieve the Conservation Objective by the time of the following survey. As it appears unlikely that stocks will recover sufficiently to achieve the Conservation Objective by autumn 2011, it was agreed at a Wash Management meeting held in November 2010 that no mussel fishery should occur on the intertidal beds during the 2010/2011 season.

2.2 Method

The survey method used for the 2010 mussel surveys was a procedure demonstrated by the Dutch marine consultants, MarinX, during the 2004 mussel surveys.

The perimeter of each bed was defined by walking around the bed at low water and entering waypoints into a portable GPS unit. These waypoints were transferred to a Geographic Information System (GIS), MapInfo, from which the perimeter of each bed was plotted, allowing an estimation of their area to be made. Transect surveys were conducted across the bed to ascertain the coverage and density of mussel. Transects were chosen that would attain the most even coverage of the bed that the low water period and the extent of the bed would allow. The route of transects across the bed were recorded by entering waypoints into the GPS unit and later plotting them in MapInfo.

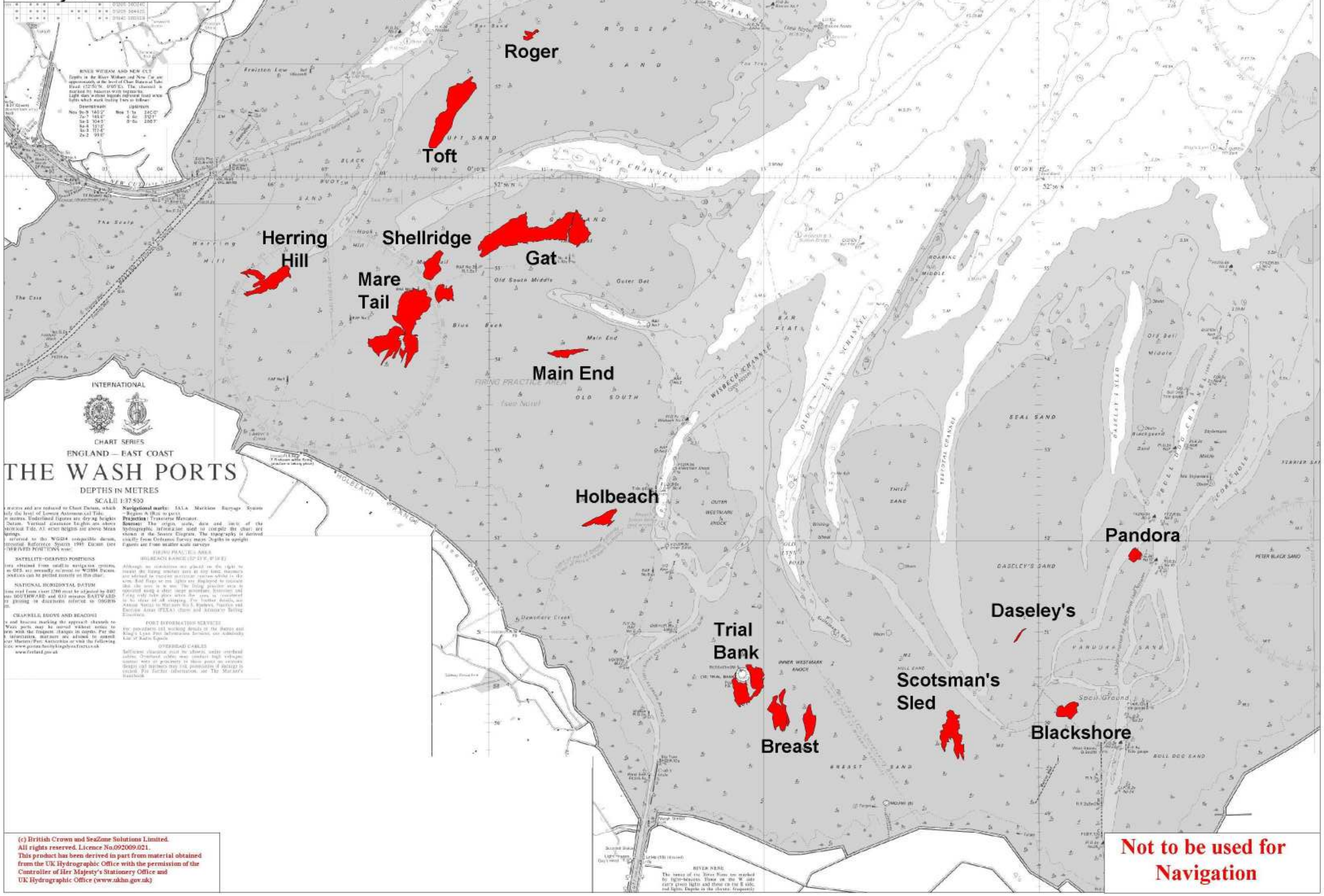
As transects were walked across the bed, the coverage of mussels was determined using an 11cm ring attached to a pole. Every three paces the ring was placed down on the mussel bed and the presence ("hit") or absence ("miss") of mussels within the ring recorded. Randomisation was achieved by placing the ring down to one side, outside of the field of vision of the user. Mussel samples, used to determine the biomass of the mussels on the bed, were collected from those contained within the rings. Depending on the length of the track and the mussel density, it was decided in advance if all hits were to be sampled, or whether a lower proportion could be used to provide a total sample large enough to determine the average density and size frequency of the population. In the case of these surveys, a sampling frequency of between once every second hit and once every seventh hit was used.

Samples taken from the rings were collected in a container. Every 450 paces, after 150 hit/miss determinations had been conducted, the samples were washed using a 0.5mm sieve and placed in labelled bags. On returning to the research vessel, the live mussel was separated from the debris in each sample. The length of each mussel was determined, and the samples divided into those mussels that were of marketable size (≥45mm) and those that were smaller. The weights of these samples were then recorded. During this year's surveys, the number and weight of mussels ≥25mm length were also recorded as this size range is favoured by oystercatchers.

The coverage, density and area of the mussel bed were multiplied together to estimate the biomass of mussels on the bed. Size distributions were obtained from the length measurements of mussel in the retained samples.

Figure 2.0 shows the positions of 14 areas of intertidal mussel bed surveyed during 2010, which for survey purposes are divided into 20 discrete beds.

Figure 2.0 Distribution of Intertidal Mussel Beds Surveyed in 2010



2.3 Results

2.3.0 Mare Tail Beds

There are four discrete areas of mussel bed present on the Mare Tail sand, which for survey and management purposes are referred to as the North, South, and East Mare Tail beds and the Shellridge (figure 2.1). Until 2004 the area supported a fifth bed near the RAF No.2 beacon, but following heavy exploitation during the 2004/2005 fishery this bed disappeared and has shown little sign of subsequent resettlement.

The other beds attracted heavy fishing activity during the 2004/2005 and the 2006/2007 seasons, but although management measures attempted to limit exploitation of individual beds beyond what was considered sustainable, disparate fishing effort across the beds did cause heavy disturbance in some areas while others remained relatively untouched. In the areas where disturbance was the heaviest, such as the Shellridge bed and the northern part of the North Mare Tail bed, subsequent recovery has been slow. During 2008 there was a good settlement of spat across the southern parts of these beds, sufficient to allow these areas to be opened to the 2010 relaying fishery. Unfortunately, although the area attracted little fishing activity, the 2010 survey found mortality among this year class had been high.

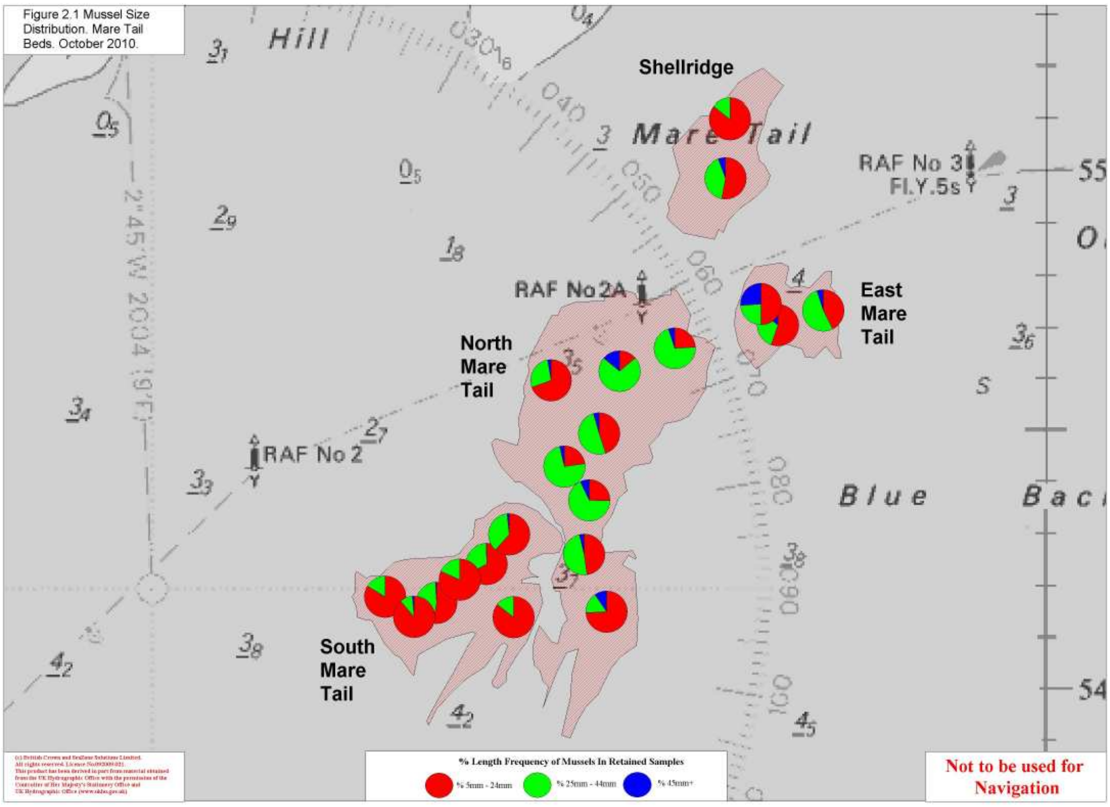


Figure 2.1 Mussel Size Distribution. Mare Tail Beds. October 2010.

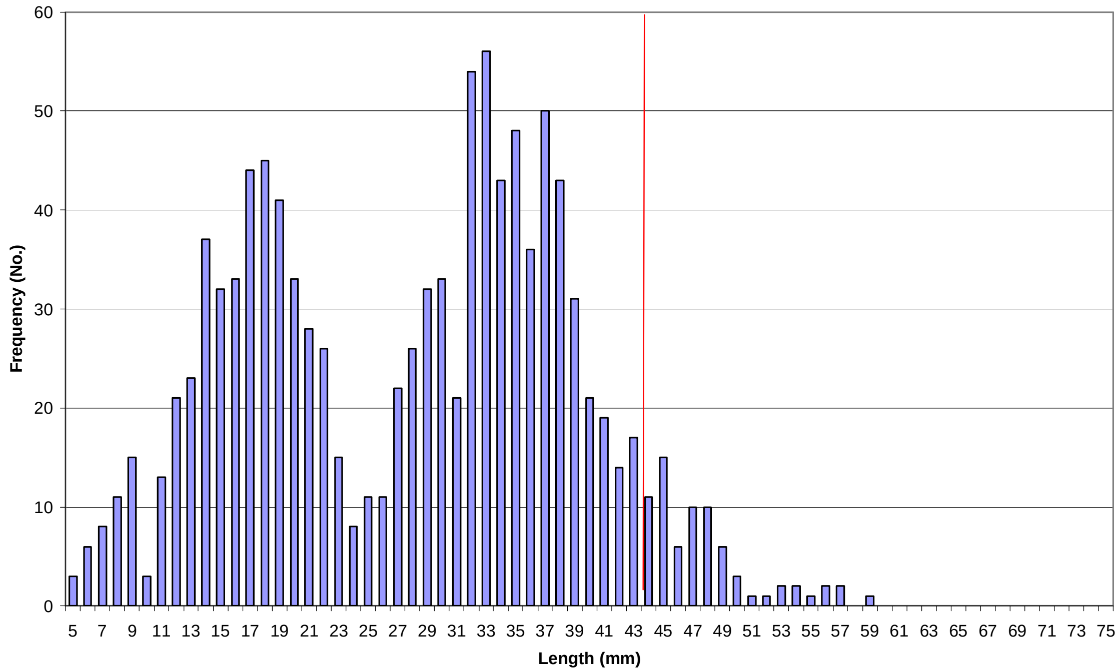
2.3.1 North Mare Tail

- Area: 55.9 hectares
- Coverage: 42%
- Mean Density: 0.73 $kg/0.1m^2$
- Total Stock: 1,685 tonnes
- Stock ≥ 45mm: 370 tonnes

The North Mare Tail bed was surveyed on September 12th 2010. Samples were collected from every sixth "hit", producing 83 samples from eight transects. Figure 2.2 shows the mussel size frequency within the population taken from these samples.

The area of the bed was found to have increased from 50.6 hectares in 2009 to 55.9 hectares, mainly as a result of mussels washing out of the bed onto the surrounding ground. This thinning resulted in a reduced mussel coverage from 47% to 42%, but growth of the 2008 year-class mussels during the same period meant the mean density increased slightly from 0.64 $kg/0.1m^2$ to 0.73 $kg/0.1m^2$. The total mussel stock on this bed was calculated to be 1,685 tonnes, 12% higher than the 1,509 tonnes recorded in 2009. The stock of marketable sized mussels was also found to have improved, increasing from 324 tonnes to 370 tonnes. Although this was one of the only intertidal beds to have increased in mussel biomass during 2010, the northern parts of the bed were observed to have become sparse in coverage and quite shelly. This bed was opened to the 2010 relaying fishery but attracted little effort, mainly as a result of the dense coverage of fucoid seaweed growing there. .

Figure 2.2 Mussel Size Frequency. North Mare Tail. September 2010



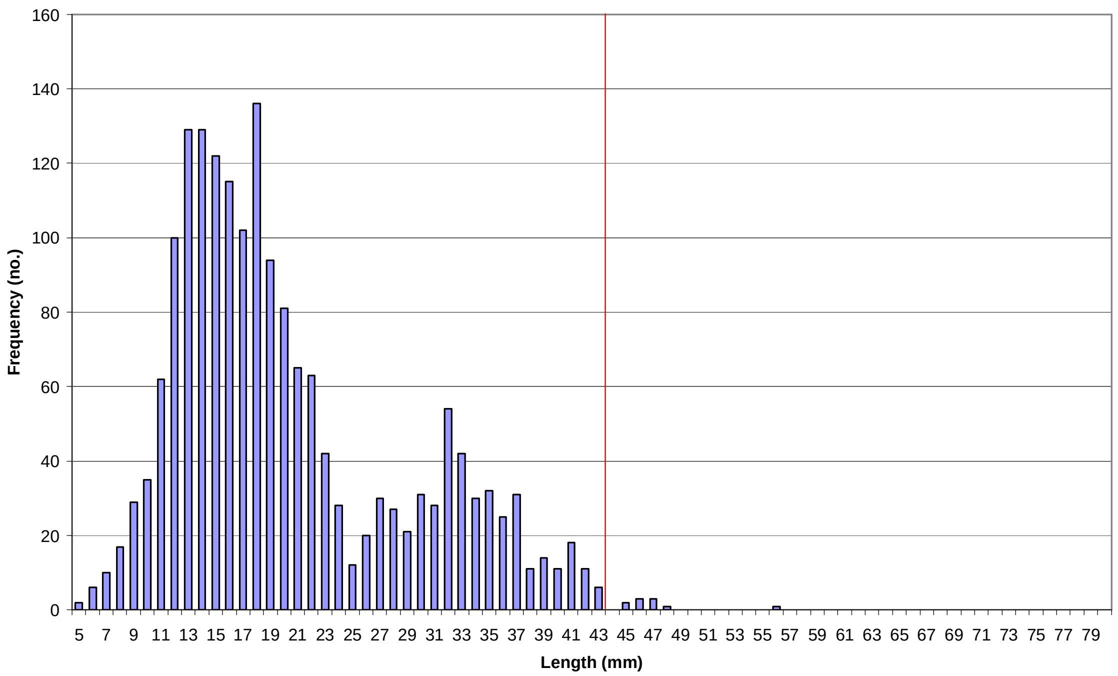
2.3.2 South Mare Tail

- Area: 26.1 hectares
- Coverage: 30%
- Mean Density: 0.65 kg/0.1m^2
- Total Stock: 503 tonnes
- Stock ≥ 45mm: 25 tonnes

The South Mare Tail bed was surveyed on September 11th 2010. Samples were taken from every fifth "hit", producing 62 samples from seven transects. Figure 2.3 shows the mussel size frequency within the population taken from these samples.

This bed had received a good settlement of spat in 2008, though rejuvenating the bed had caused smothering to some of the older mussels during 2009. The 2010 survey found there had been high mortality among this cohort, however, since the previous survey. Due to the high losses along the edges of the bed, the area of the bed was found to have decreased from 28.3 hectares recorded in 2009 to 26.1 hectares. Similar losses within the bed had also caused the coverage to fall from 40% to 30% and the mean density to decline from 0.76kg/0.1m^2 to 0.65 kg/0.1m^2. Together these reductions meant the total mussel stock had fallen 42%, from 863 tonnes in 2009 to 503 tonnes. Of these, 25 tonnes had attained marketable size, a similar figure to the 26 tonnes recorded the previous year. Although this bed had been opened to the 2010 relaying fishery, no evidence of dredging was seen during the survey.

Figure 2.3 Mussel Size Frequency. South Mare Tail. September 2010



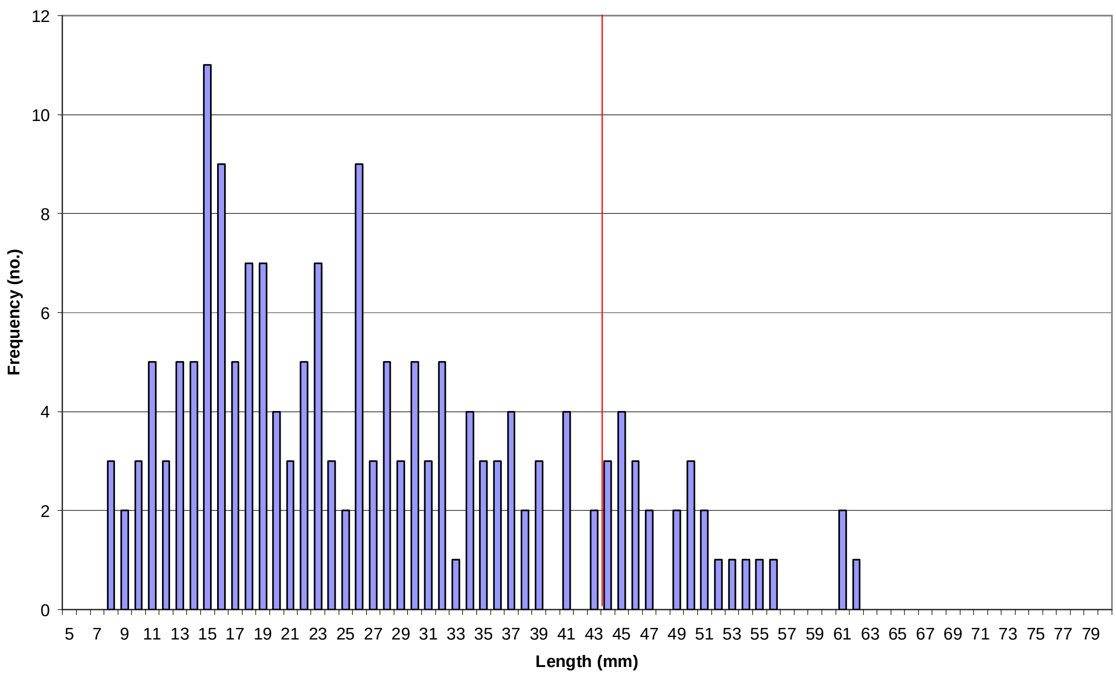
2.3.3 East Mare Tail

- Area: 9.8 hectares
- Coverage: 22%
- Mean Density: 0.58 kg/0.1m^2
- Total Stock: 126 tonnes
- Stock ≥ 45mm: 69 tonnes

The East Mare Tail bed was surveyed on September 13th 2010. Samples were collected from every fourth "hit", resulting in 20 samples being taken from three transects. Figure 2.4 shows the mussel size frequency within the population taken from these samples.

Originally this bed had been composed of two areas of mussels in close proximity that for management purposes were surveyed as a single bed. In 2009, however, mussels were found to have washed out of the main patches, creating an area of low-density mussels that had linked the two patches into a single bed. The 2010 survey found that further mussels had washed out of the main patches and had been spread over a wider area. As a consequence, the area of the bed had increased from 6.9 hectares in 2009 to 9.8 hectares but the coverage had fallen from 35% to 22% and the mean density from 0.71 kg/0.1m^2 to 0.58 kg/0.1m^2. From these figures the total mussel biomass in this bed was calculated to be 126 tonnes, 28% lower than the 174 tonnes recorded in 2009. Of these, 69 tonnes had attained marketable size, a slight reduction from the 86 tonnes recorded in 2009. This bed has not benefited from a significant spatfall since 2001, leading to an ageing population that is gradually declining. In addition to the mussels, relatively high numbers of Pacific oysters, *Crassostrea gigas*, were observed to be established within the bed, in places beginning to form chains of two or three individuals.

Figure 2.4 Mussel Size Frequency. Mare Tail East. September 2010



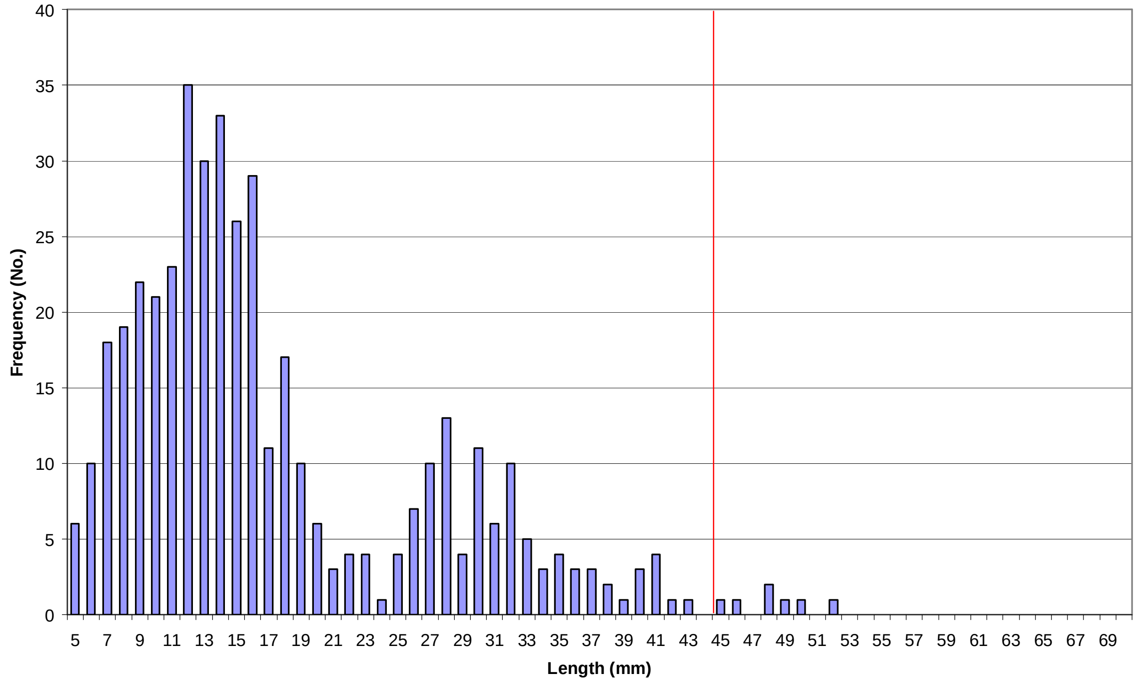
2.3.4 Shellridge

- Area: 13.94 hectares
- Coverage: 31%
- Mean Density: $0.38kg/0.1m^2$
- Total Stock: 166 tonnes
- Stock ≥ 45mm: 29 tonnes

The Shellridge bed was surveyed on September 13th 2010, following the survey on the East Mare Tail bed. Samples were taken from every fourth "hit", producing 23 samples from two transects. Figure 2.5 shows the mussel size frequency within the population taken from these samples.

Although in 2006 this bed had covered 23.0 hectares and supported over 500 tonnes of mussels, heavy exploitation during the 2006/2007 dredge mussel fishery had caused the bed to rapidly decline, from which there has been little subsequent recovery. The 2010 survey found the bed to cover 13.9 hectares, slightly more than the 11.4 hectares recorded in 2009. With reductions in the coverage from 43% to 31%, and the mean density from $0.43kg/0.1m^2$ to $0.38kg/0.1m^2$, however, only a sparse coverage of mussels was found to persist in this area, mainly attached to a substrate containing dense patches of cockles and cockle shells. From these figures the mussel biomass in this bed was calculated to be 166 tonnes, 20% fewer than the 208 tonnes recorded in 2009. Of these, 29 tonnes had attained marketable size, a significant reduction from the 80 tonnes recorded in 2009.

Figure 2.5 Mussel Size Frequency. Shellridge. September 2010



2.3.5 Gat Sand

The Gat sand supports the largest area of natural intertidal mussel bed in the Wash, which for survey purposes is divided into three beds (Figure 2.6). These beds were closed to fishing in 1993 following the wide scale decline of intertidal stocks throughout the Wash during the late 1980s. Although the beds were subject to heavy poaching between 2000 and 2002, they were not officially opened to a major dredge fishery until 2006, following an exceptionally good settlement in 2004 that had rejuvenated them. Having been closed for so long, these beds have matured and, particularly along the exposed northern fringes of the bed, developed into important biogenic reef features. Because of their environmental importance, these features remained protected during the 2006 dredge fishery and also from the small-scale handwork fisheries that have been opened subsequently between 2007 and 2010.

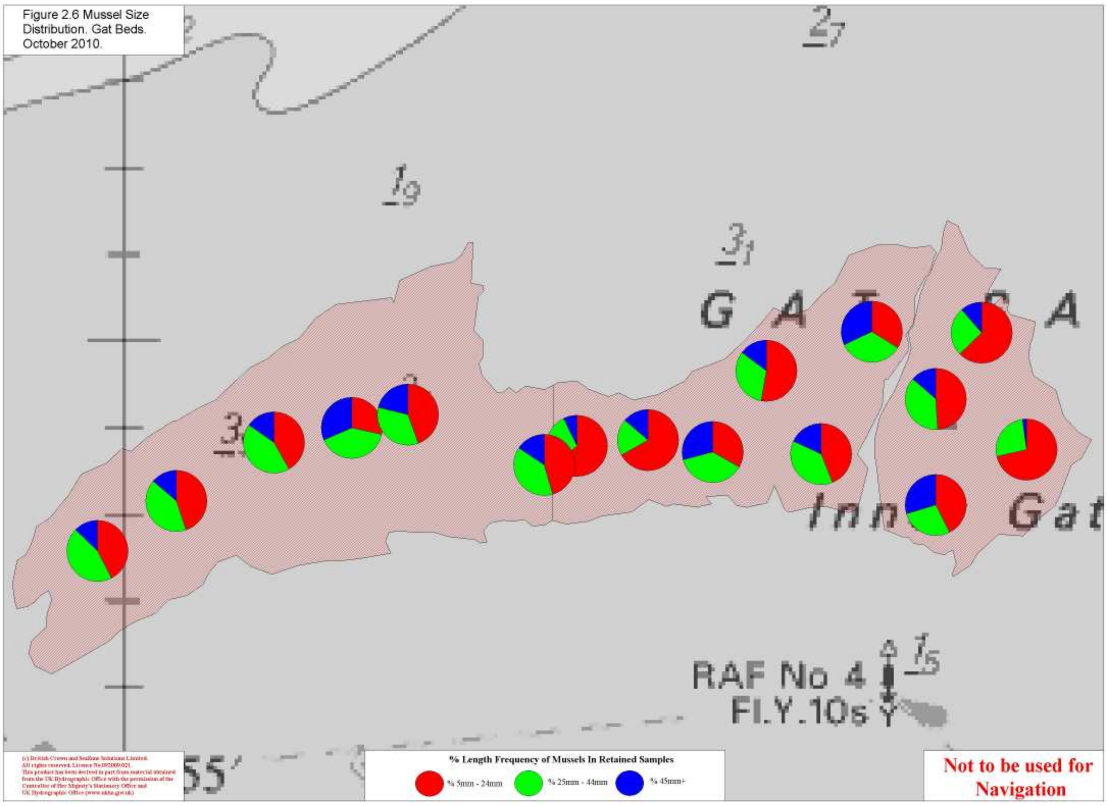


Figure 2.6 Mussel Size Distribution. Gat Beds. October 2010.

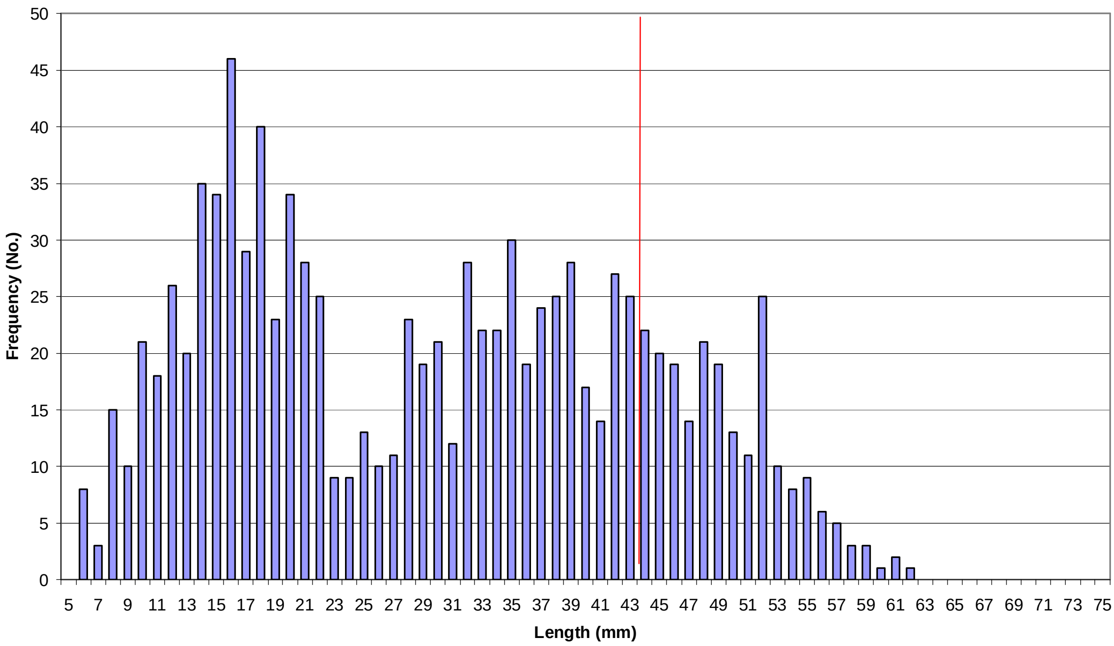
2.3.6 West Gat

- Area: 48.0 hectares
- Coverage: 33%
- Mean Density: 0.73kg/0.1m^2
- Total Stock: 1,164 tonnes
- Stock ≥ 45mm: 756 tonnes

As part of their “in house” training regime, two new research officers surveyed the West Gat on October 5th 2010, under the supervision of the senior research officer. Samples were collected from every sixth “hit”, producing 50 samples from six transects. The results of this survey indicated there had been a significant loss of stock from this bed, from 2,943 tonnes in 2009 to just 957 tonnes. The presence of gaping shells did indicate there had been recent mussel mortality on the bed, but the extent of the decline raised concerns that there might be a serious underlying flaw in the survey technique itself. In order to test the accuracy of methodology, two parallel surveys were conducted on this bed on October 8th, one team comprising the two trainee officers who had conducted the first survey and the other team led by the senior research officer. The results of these two surveys produced stock estimations of 1,067 tonnes and 1,254 tonnes respectively, confirming that a) there had indeed been a significant mussel mortality on this bed, and b) the survey methodology was producing results within acceptable limits of +/- 15%. The data from the latter two surveys were subsequently pooled, providing 113 samples from six pairs of parallel transects, from which the estimated stock of the bed was calculated.

Since the previous survey, slight erosion around the edges of the bed had caused the area to decline from 50.5 hectares to 48.0 hectares. Widespread mussel mortality within the bed was responsible during the same period for the reductions to both the coverage, from 56% to 33%, and the mean mussel density, from 1.03kg/0.1m^2 to 0.73kg/0.1m^2. From these figures, the total mussel biomass on this bed was estimated to be 1,164 tonnes, 60% lower than the previous year. Of these, 756 tonnes had attained marketable size, 58% fewer than in 2009. Figure 2.7 shows the mussel size frequency within the population taken from these samples.

Figure 2.7 Mussel Size Frequency. West Gat. October 2010



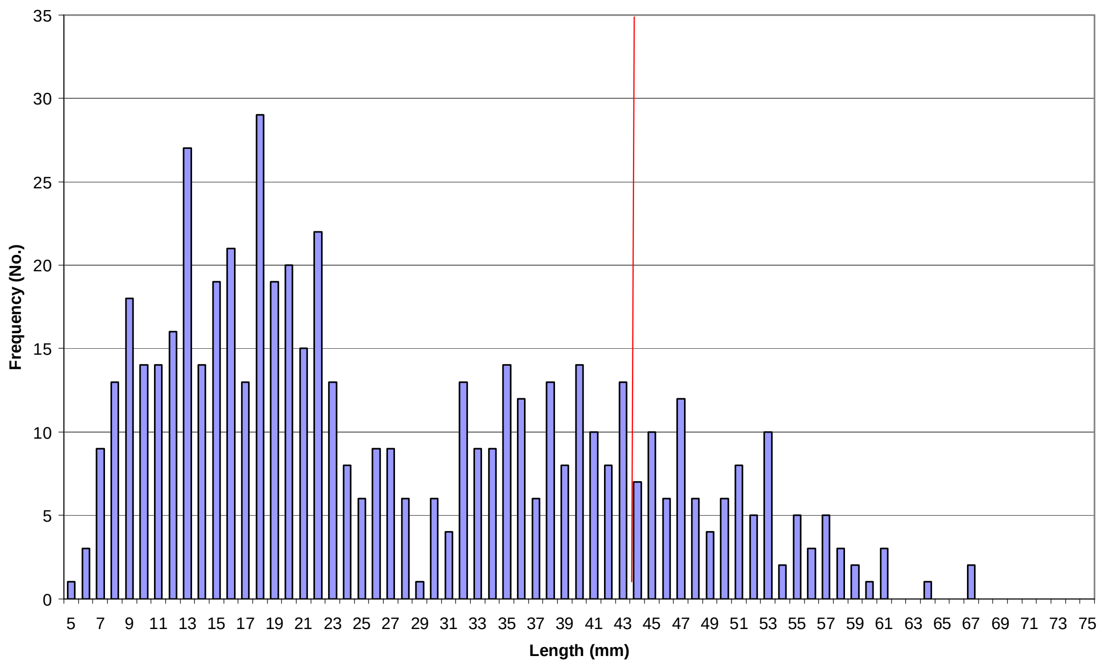
2.3.7 Mid Gat

- Area: 25.9 hectares
- Coverage: 32%
- Mean Density: 0.77kg/0.1m^2
- Total Stock: 634 tonnes
- Stock ≥ 45mm: 375 tonnes

The Mid Gat was surveyed on October 13th 2010. Samples were collected from every fifth "hit", producing 53 samples from six transects. Figure 2.8 shows the mussel size frequency within the population taken from these samples.

The area of the bed was found to have declined slightly from 26.8 hectares in 2009 to 25.9 hectares, mainly as a result of erosion along the exposed northern edge of the bed. The presence of high numbers of gaping shells indicated there had been a recent high mussel mortality, reflected in the reductions in coverage from 45% to 32%, and the mean density from 1.31kg/0.1m^2 to 0.77kg/0.1m^2. From these figures the total mussel biomass on the Mid Gat was calculated to be 634 tonnes, a 60% reduction to the 1,575 tonnes recorded in 2009. Of these, 375 tonnes were of marketable size, 66% fewer than the 1,103 tonnes recorded the previous year.

Samples sent from this bed to CEFAS for pathology tests found high numbers of the parasitic copepod *Mytilicola intestinalis* to be present. Although this species is not usually fatal to its host, it has on occasions been associated with widespread mortality events in mussel beds.



2.3.8 East Gat

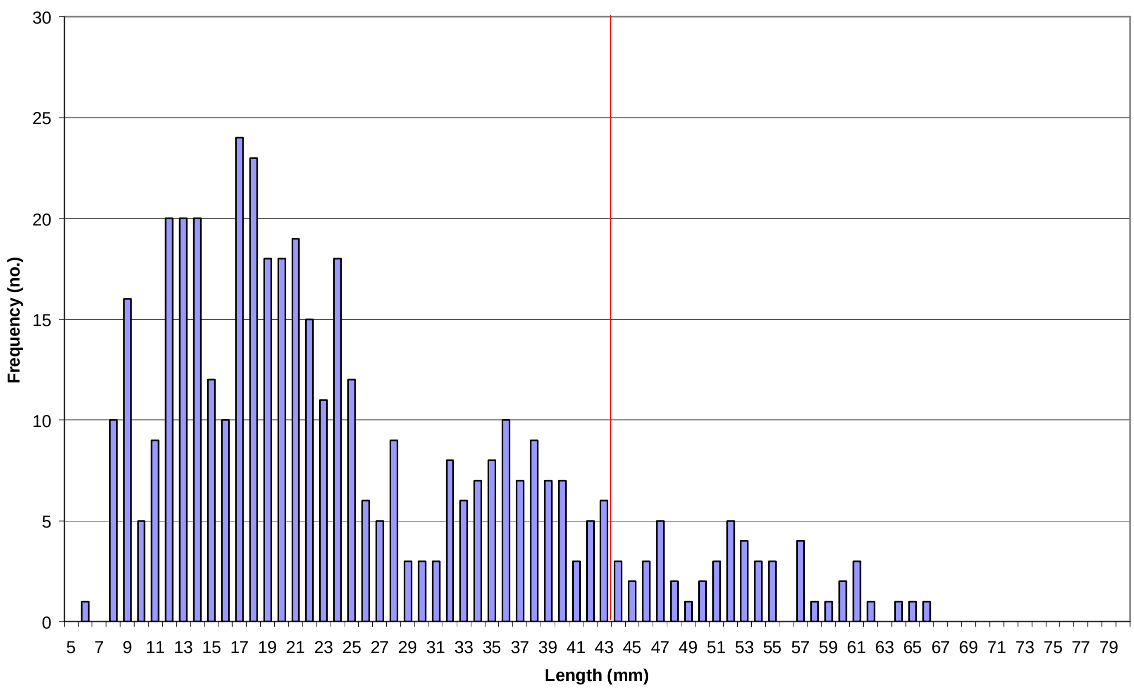
- Area: 19.3 hectares
- Coverage: 34%
- Mean Density: $0.58kg/0.1m^2$
- Total Stock: 387 tonnes
- Stock ≥ 45mm: 214 tonnes

The East Gat was surveyed on November 5th 2010. Samples were taken from every fourth "hit", producing 42 samples from four transects. Figure 2.9 shows the mussel size frequency within the population taken from these samples.

The area of the bed was found to have increased slightly from 18.7 hectares in 2009 to 19.3 hectares. As had been the case on both the West and Mid beds high mussel mortality had occurred, causing the coverage to decline from 46% to 34% and the mean density to fall from $1.27kg/0.1m^2$ to $0.58kg/0.1m^2$. From these figures the total mussel biomass on this bed was calculated to be 387 tonnes, a 64% reduction from the 1,086 tonnes present in 2009. During the same period the biomass of marketable sized mussels had declined 71% from 730 tonnes to 214 tonnes.

Following the 2010 surveys the combined biomass of mussels on the three Gat beds was found to be 2,185 tonnes, a loss of 3,419 tonnes from the previous year. This is the lowest level of stock recorded on these beds since 2001, when the combined stock had been 1,912 tonnes.

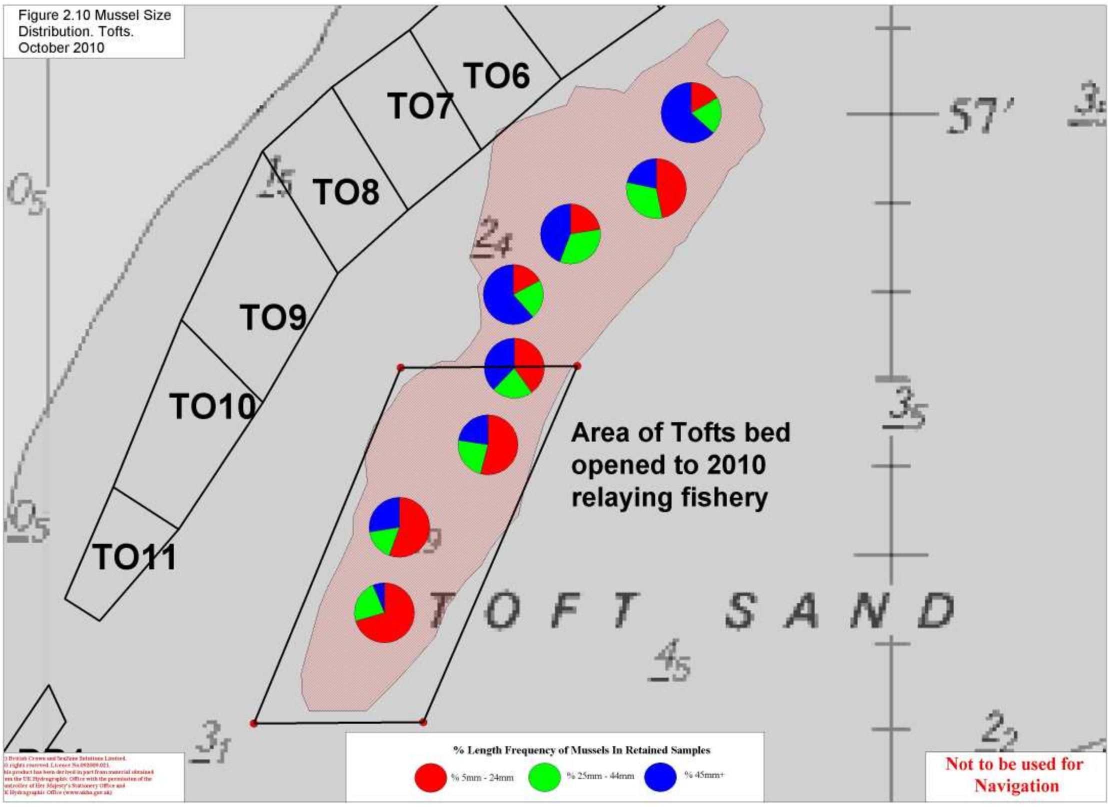
Figure 2.9 Mussel Size Frequency. East Gat. November 2010



2.3.9 Tofts

- Area: 47.0 hectares
- Coverage: 33%
- Mean Density: 1.51 kg/0.1m^2
- Total Stock: 2,357 tonnes
- Stock ≥ 45mm: 1,904 tonnes

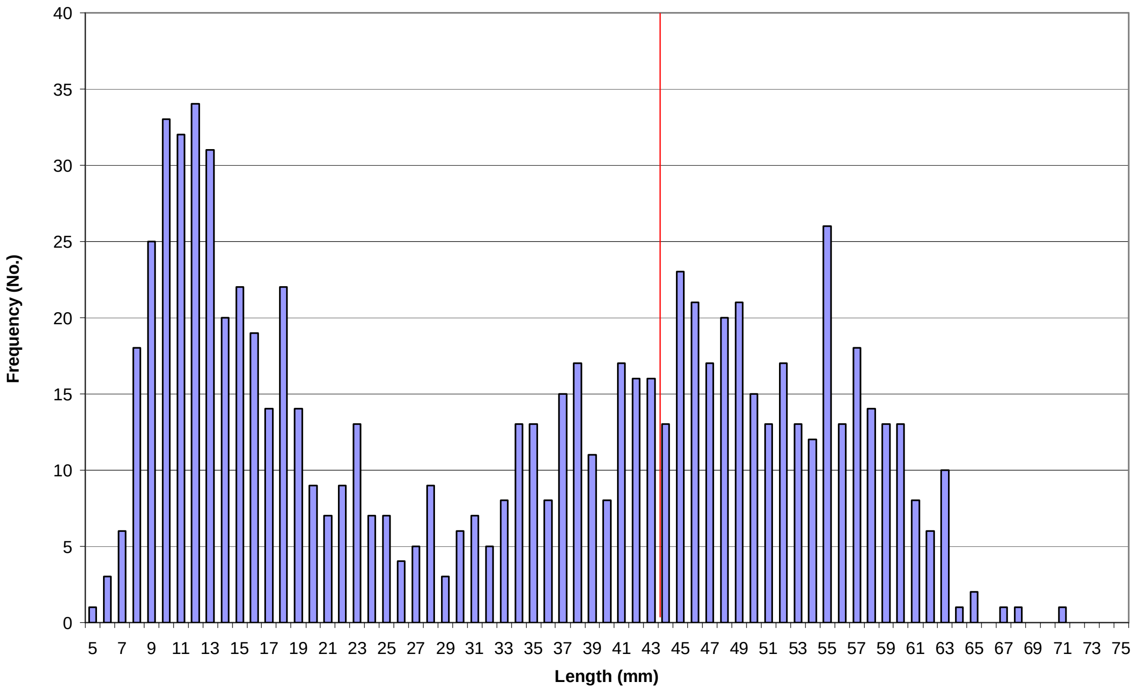
The Tofts bed had grown rapidly in both area and mussel biomass between 2004 and 2009. Although officers had proposed opening this bed to both the 2008 and 2009 fisheries, there had been reluctance from the industry towards these proposals, mainly from members with private lays close to the bed. The 2009 survey had found that the southern part of this bed in particular supported a high proportion of young mussels that were at their prime condition for relaying. As a consequence the southern part of the bed was opened to the 2010 relaying fishery (figure 2.10), during which approximately 400 tonnes of mussels were removed.



Because the size of the bed was causing difficulties surveying it in a single day, during the 2010 surveys the perimeter was mapped on September 28th and the transects conducted on October 22nd. Samples were collected from every sixth "hit", producing 65 samples from eight transects. Figure 2.11 shows the mussel size frequency within the population taken from these samples.

The area of the bed was found to have increased slightly from 43.3 hectares in 2009 to 47.0 hectares. This was mainly where mussels had washed out of the bed, possibly as the result of fishery disturbance. As had been anticipated following the fishery, the coverage had declined from 42% in 2009 to 33%. As the fishing effort had been limited to the southern half of the bed, however, this change in coverage was found to be disparate across the bed. In the northern part of the bed, where the coverage had been 42% in 2009, it had only declined slightly to 40%. In the southern half of the bed, however, the coverage had changed during the same period from 41% to 27%. Although the fishery had reduced the mussel coverage, the mean density of mussels in the patches was little changed, declining only slightly from 1.53 kg/0.1m^2 in 2009 to 1.51 kg/0.1m^2. From these figures the total mussel biomass on the bed was calculated to be 2,357 tonnes, 417 tonnes less than the 2,774 tonnes recorded following the 2009 survey. As most of this loss can be attributed to the fishery, this bed appears to have suffered fewer natural losses than were found on most of the other intertidal beds.

Figure 2.11 Mussel Size Frequency. Tofts. October 2010



2.3.10 Roger

- Area: 3.1 hectares
- Coverage: 39%
- Mean Density: 0.46 kg/0.1m^2
- Total Stock: 55 tonnes
- Stock ≥ 45mm: 32 tonnes

This bed was surveyed on September 28th 2010 (Figure 2.12). Samples were collected from every third "hit", producing 22 samples from two transects. Figure 2.13 shows the mussel size frequency within the population taken from these samples.

The area of the bed was found to have declined from 3.8 hectares in 2009 to 3.1 hectares. Within the bed the coverage had increased from 32% to 39% but during the same period the mean density within the mussel patches had fallen significantly from 1.13 kg/0.1m^2 to 0.46 kg/0.1m^2. From these figures the total mussel biomass in the bed was calculated to be 55 tonnes, a 61% reduction from the 140 tonnes recorded to present in 2009. Of these 32 tonnes were found to be of marketable size compared to 88 tonnes the previous year.

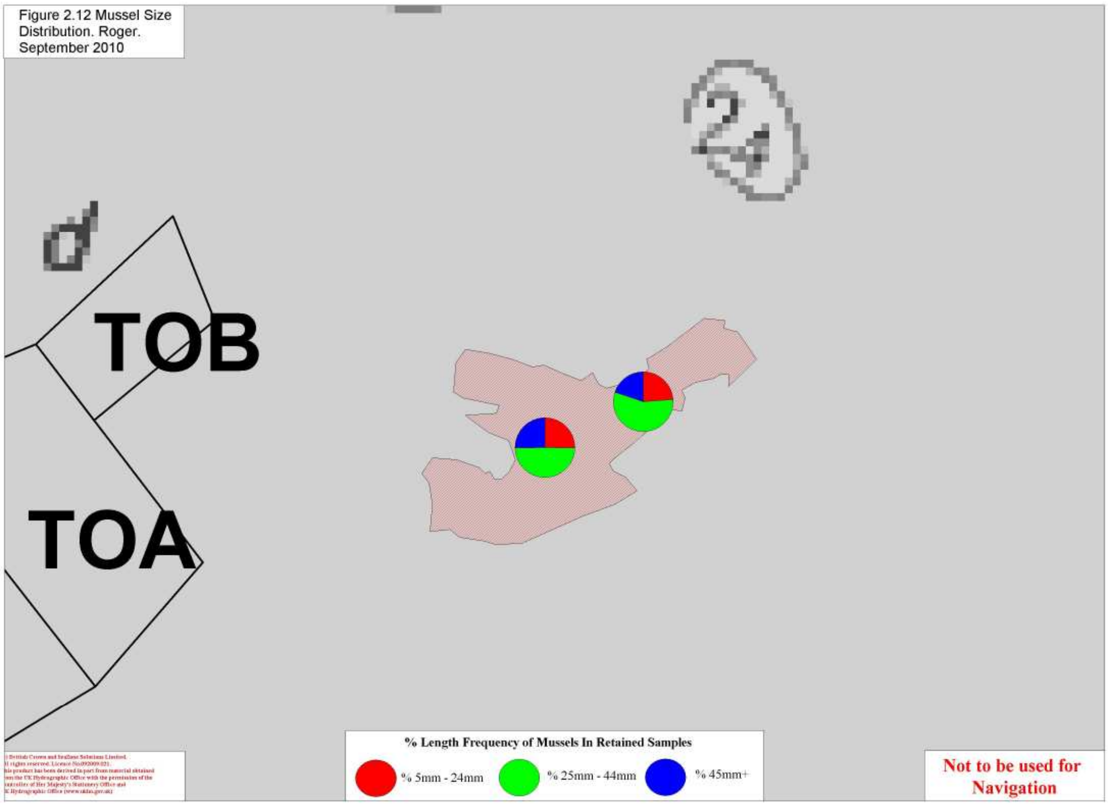
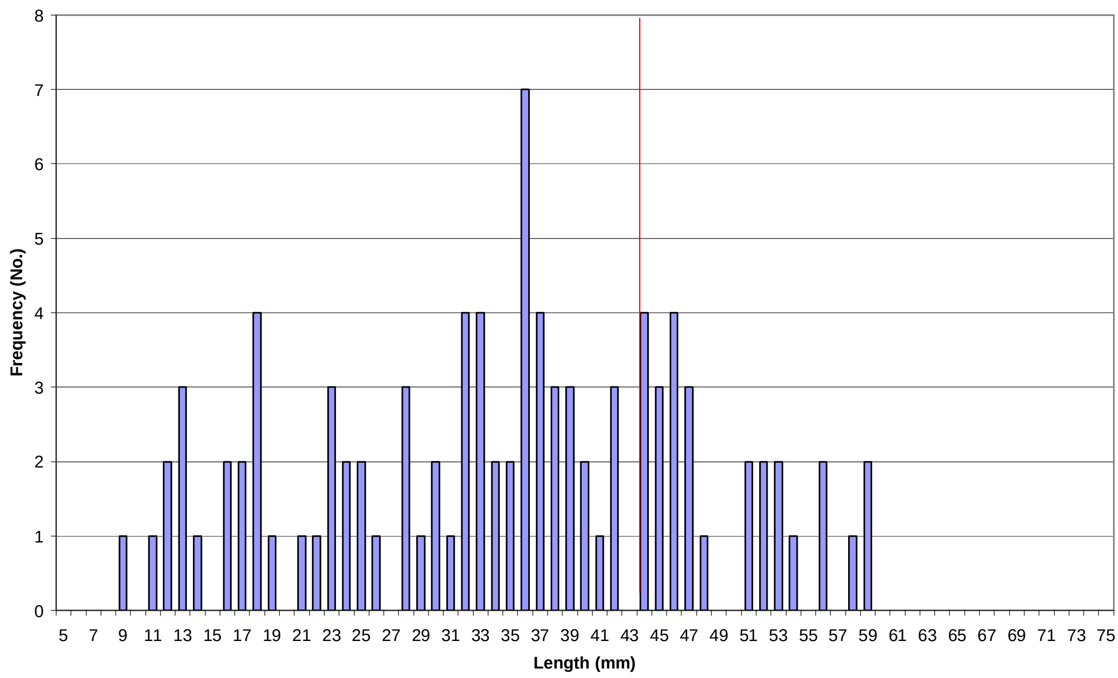


Figure 2.13 Mussel Size Frequency. Roger. September 2010



2.3.11 Herring Hill

- Area: 25.0 hectares
- Coverage: 27%
- Mean Density: 0.34 kg/0.1m^2
- Total Stock: 235 tonnes
- Stock ≥ 45mm: 8 tonnes

The Herring Hill bed was surveyed on September 9th 2010 (Figure 2.14). Samples were taken from every fifth "hit", producing 56 samples from seven transects. Figure 2.15 shows the mussel size frequency within the population taken from these samples.

The survey found there had been changes around the perimeter of this bed since the 2009 survey, erosion occurring in some parts of the bed, mainly along the north eastern edges, while along other parts of the bed mussels had scattered onto previously bare ground. Overall, the area of the bed was found to have decreased from 26.1 hectares in 2009 to 25.0 hectares. This bed had benefited from a good settlement of spat in 2008, but the 2009 survey had found there had been a high mortality among these juveniles (Jessop, *et al*. 2009). The recent survey found mortality on this bed had continued, particularly among some of the larger mussels situated along the southern regions of the bed where the ground is slightly lower. As a consequence the coverage had decreased from 34% in 2009 to 27% and the mean density of the mussel patches had declined during the same period from 0.50 kg/0.1m^2 to 0.34

kg/0.1m^2. From these figures the mussel biomass on this bed was calculated to be 235 tonnes, 46% lower than the 436 tonnes recorded following the 2009 survey. The loss of the larger mussels from the lower ground meant the stock of mussels that had attained marketable size had fallen from 33 tonnes to 8 tonnes.

Figure 2.14 Mussel Size Distribution. Herring Hill. September 2010

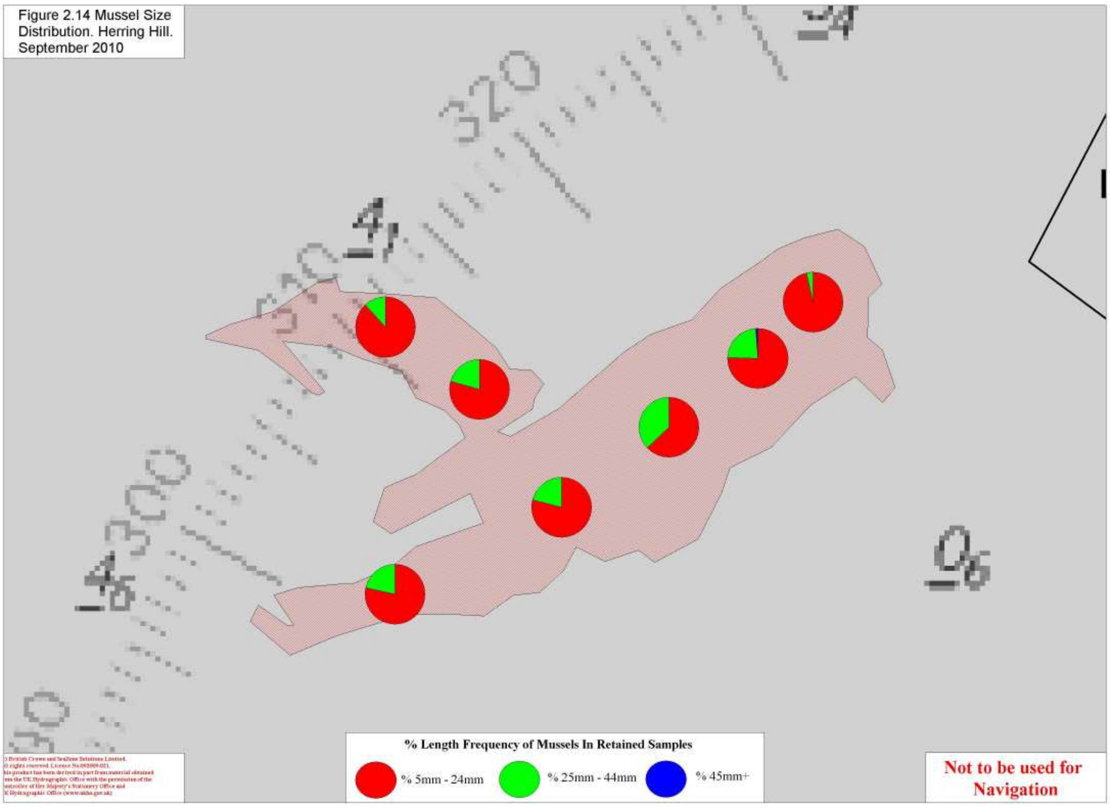
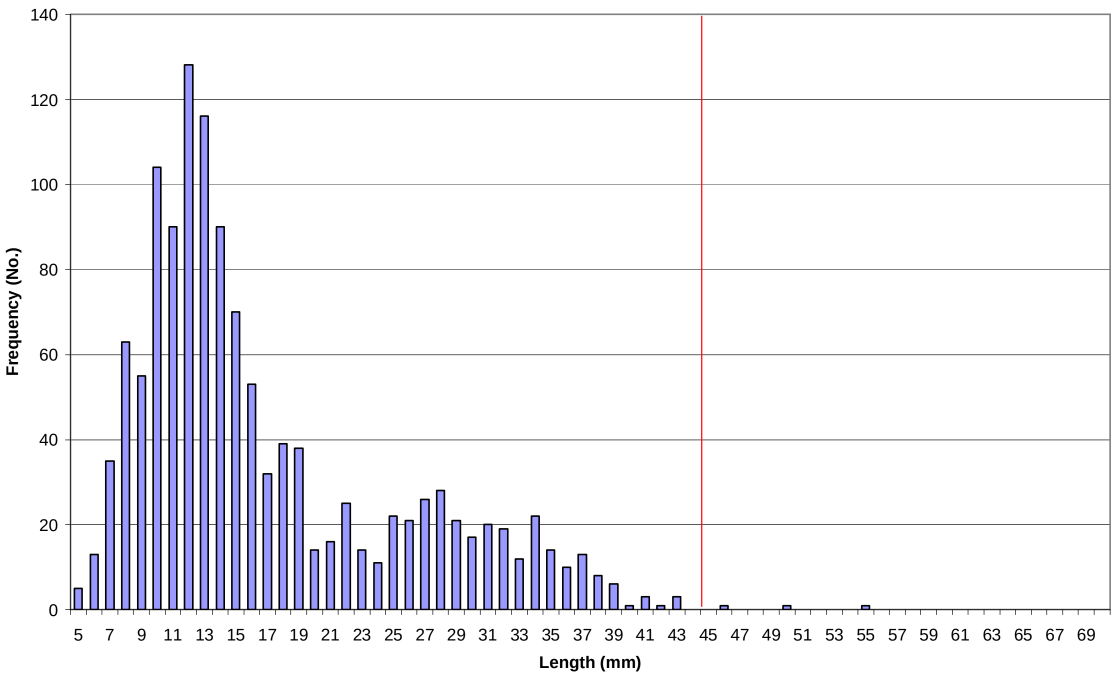


Figure 2.15 Mussel Size Frequency. Herring Hill. September 2010



2.3.12 Main End

- Area: 7.3 hectares
- Coverage: 15%
- Mean Density: 0.44 kg/0.1m^2
- Total Stock: 47 tonnes
- Stock ≥ 45mm: 35 tonnes

The Main End bed was surveyed on November 6th 2010 (Figure 2.16). Samples were collected from every third "hit", producing 16 samples from three transects. Figure 2.17 shows the mussel size frequency within the population taken from these samples.

The mussels on this bed are the remnants of a large settlement of spat that settled in this region in 2001. These were considered vulnerable to storm damage at the time, so were opened for relaying in 2002 before they were lost to natural causes. Following relaying, a small bed remained along the edge of a large run that has remained fairly stable since 2002, even though two dredged cockle fisheries have occurred in the vicinity since then. This bed has received little new settlement since 2001, however, so the population is ageing, and as mortality occurs the mussel patches are becoming sparse. Since 2008 most of the remaining population has been situated, submerged, in the bottom of the run.

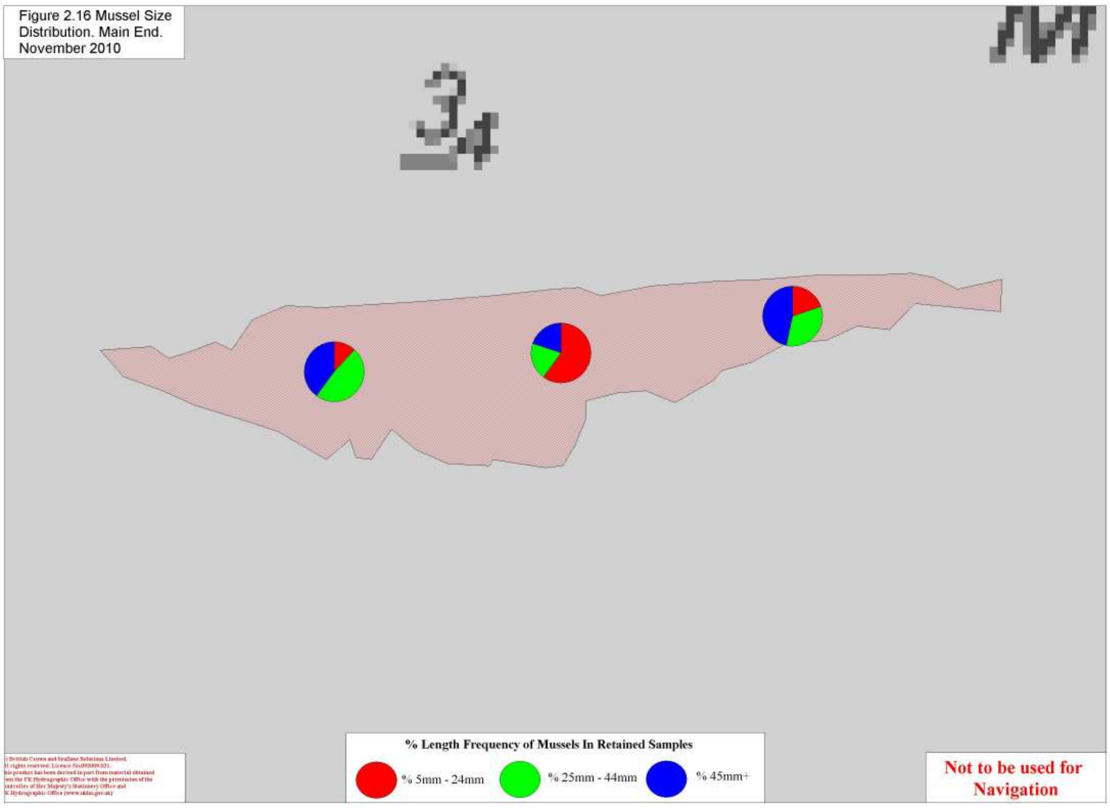
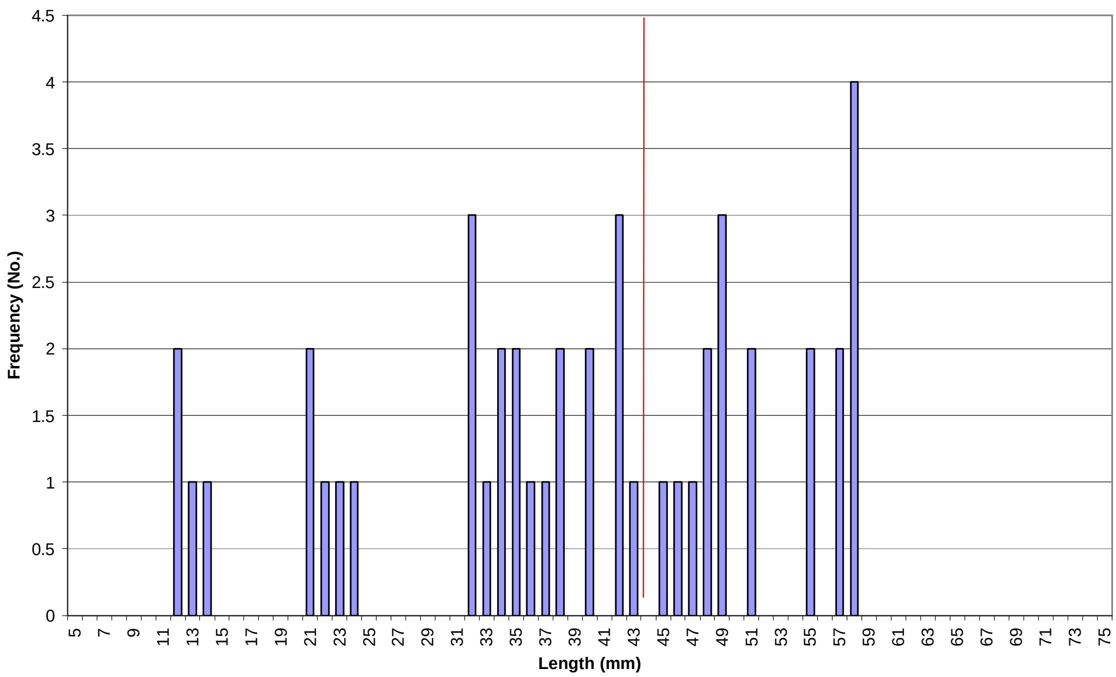


Figure 2.16 Mussel Size Distribution. Main End. November 2010

Similar to most of the other beds surveyed during 2010, mussel mortality was found to be high. The area of the bed was little changed, but the coverage was found to have declined from 28% in 2009 to 15% and the mean mussel density from 1.02 kg/0.1m^2 to 0.44 kg/0.1m^2. From these figures the mussel biomass on this bed was calculated to 47 tonnes, 78% less than the 214 tonnes reported in 2009. Of these 35 tonnes were found to have attained marketable size.

Figure 2.17 Mussel Size Frequency. Main End. November 2010



2.3.13 Holbeach

- Area: 10.2 hectares
- Coverage: 39%
- Mean Density: 0.83 kg/0.1m^2
- Total Stock: 325 tonnes
- Stock ≥ 45mm: 11 tonnes

The Holbeach bed was surveyed on October 9th 2010 (Figure 2.18). Samples were collected from every fifth "hit", generating 46 samples from four transects. Figure 2.19 shows the mussel size frequency within the population taken from these samples.

Similar to the Main End bed, this bed was established following an exceptional settlement in 2001 and subsequently opened to relaying in 2002. Unlike Main End, however, the Holbeach bed has benefited from moderate settlements of spat in recent years that have kept it rejuvenated. Like most of the other beds, evidence of mussel mortality was seen during the 2010 survey, but the effects were not quite as severe as on some of the beds. The area of the bed was found to be fairly consistent with the previous year, increasing slightly from 9.9 hectares to 10.2 hectares. The coverage was found to have fallen from 47% to 39%, while the mean density had decreased by a lesser extent from 0.89 kg/0.1m^2 to 0.83 kg/0.1m^2. Together these changes mean the biomass of mussels on the bed has declined from 411 tonnes to 325 tonnes, an overall reduction of 21%. Of these, the stock of marketable sized mussels had decreased from 33 tonnes to 11 tonnes.

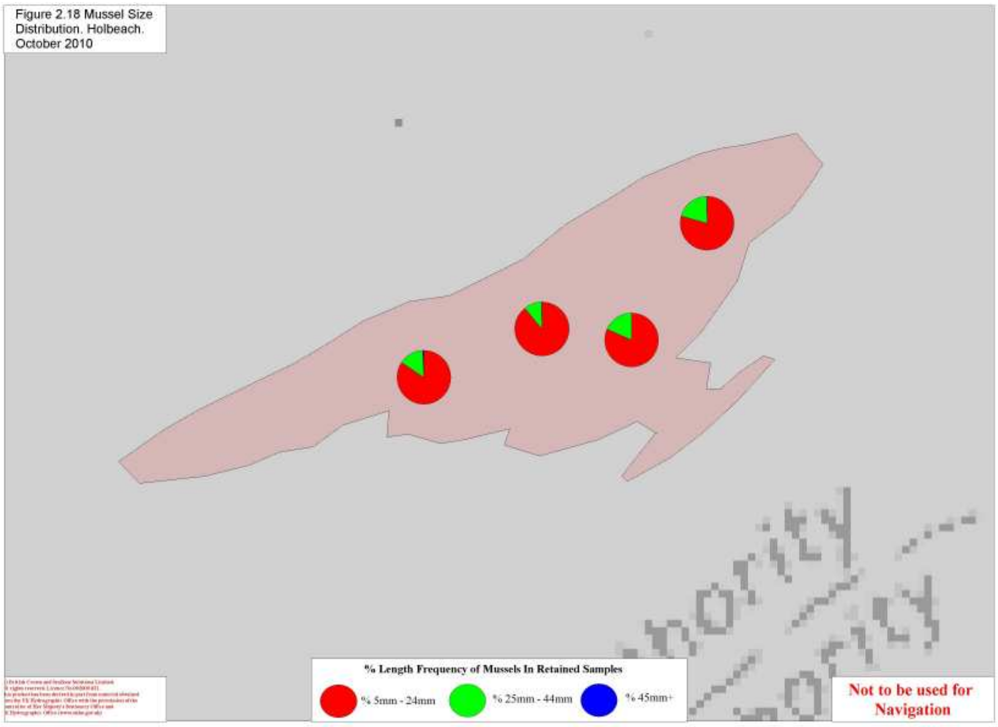
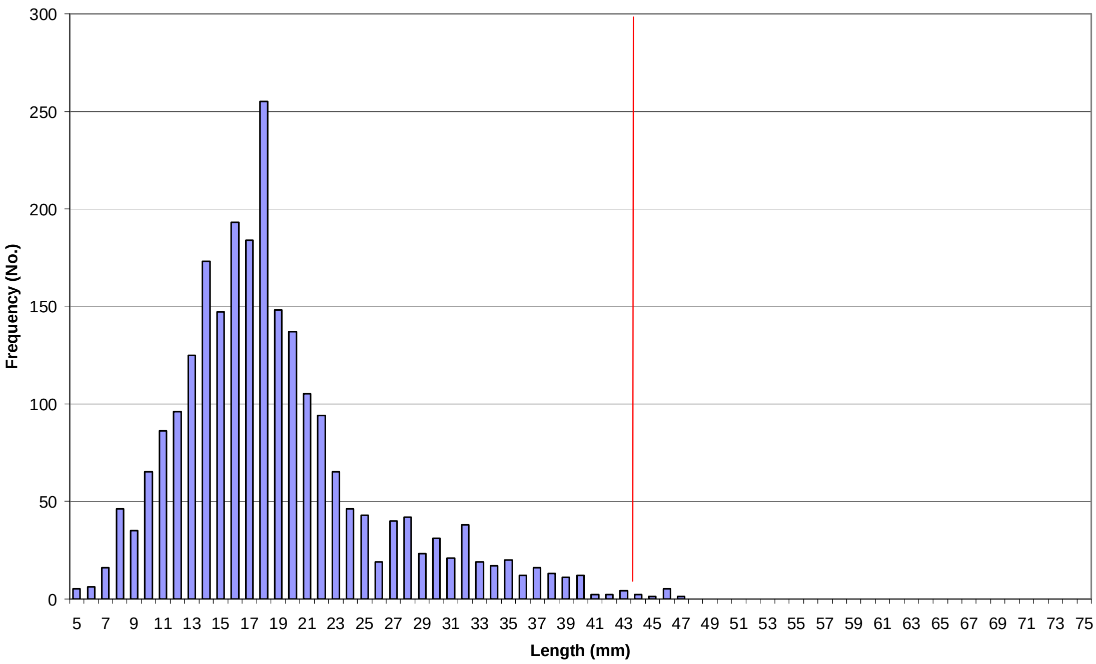


Figure 2.19 Mussel Size Frequency. Holbeach. October 2010



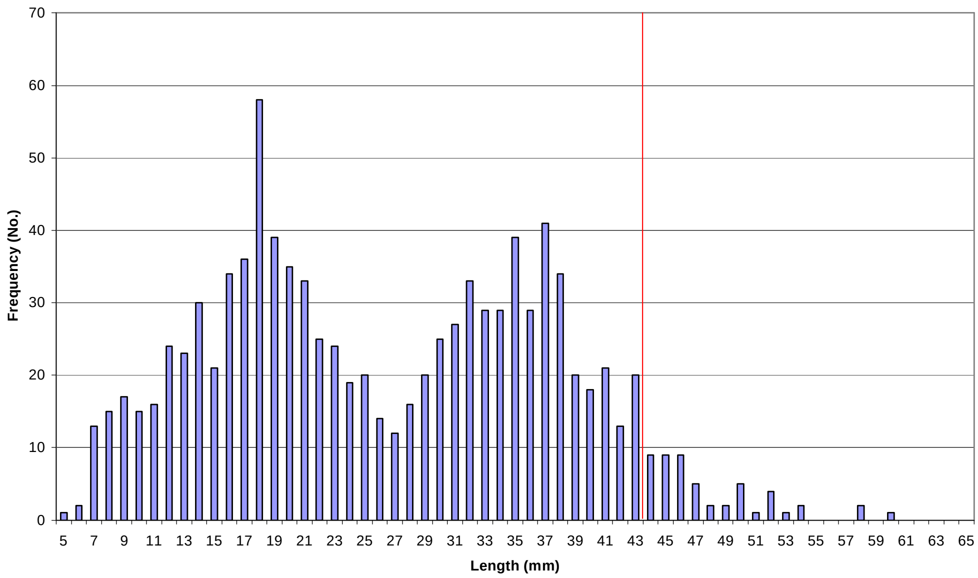
2.3.14 Trial Bank

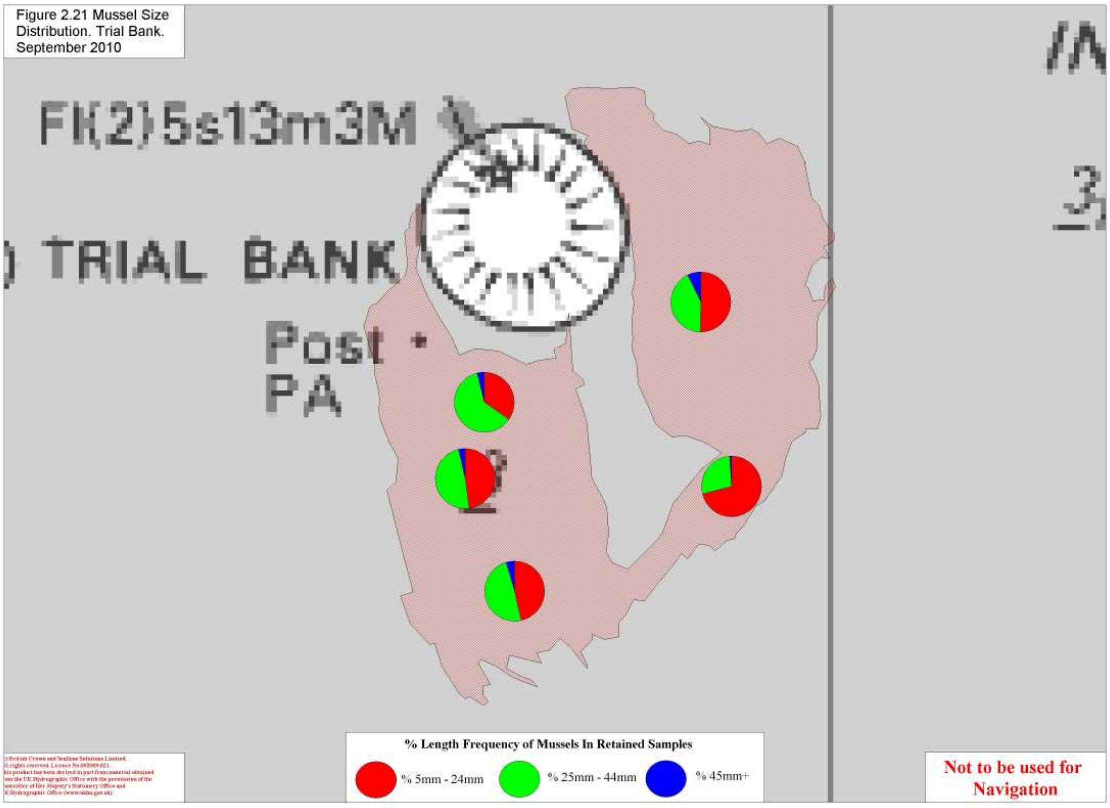
- Area: 27.5 hectares
- Coverage: 25%
- Mean Density: 1.05 kg/0.1m^2
- Total Stock: 709 tonnes
- Stock ≥ 45mm: 133 tonnes

The Trial Bank mussel bed was surveyed on September 27th 2010 (Figure 2.21). Samples were collected from every fourth "hit", producing 46 samples from five transects. Figure 2.20 shows the mussel size frequency within the population taken from these samples.

Having benefited from moderate settlements of spat in recent years this bed had increased in biomass, enabling it to be opened to the 2010 relaying fishery. Several vessels targeted these stocks at the start of the relaying season, removing approximately 200 tonnes before the bed was closed. When surveyed in 2010, most of the fishing activity was found to have occurred on the western half of the bed, leaving the eastern half virtually untouched. At 27.5 hectares, there had been little change to the area of the bed since the previous survey, although the perimeter of the bed had changed slightly. Considering there had been a fishery since the previous survey, the coverage had only decreased slightly from 27% to 25%, while the mean density had changed little from 1.10 kg/0.1m^2 to 1.05 kg/0.1m^2. From these figures the mussel biomass on this bed was calculated to be 709 tonnes, less than 100 tonnes lower than the previous year's figure of 805 tonnes. Although growth of juvenile mussels on this bed had undoubtedly compensated for some of the fishery losses, the 12% reduction in mussel biomass between surveys was significantly lower than that seen on most of the other intertidal beds. Although samples dissected by ESFJC officers from this bed found *M. intestinalis* to be present, there was little evidence that mortalities had occurred.

Figure 2.20 Mussel Size Frequency. Trial Bank. September 2010

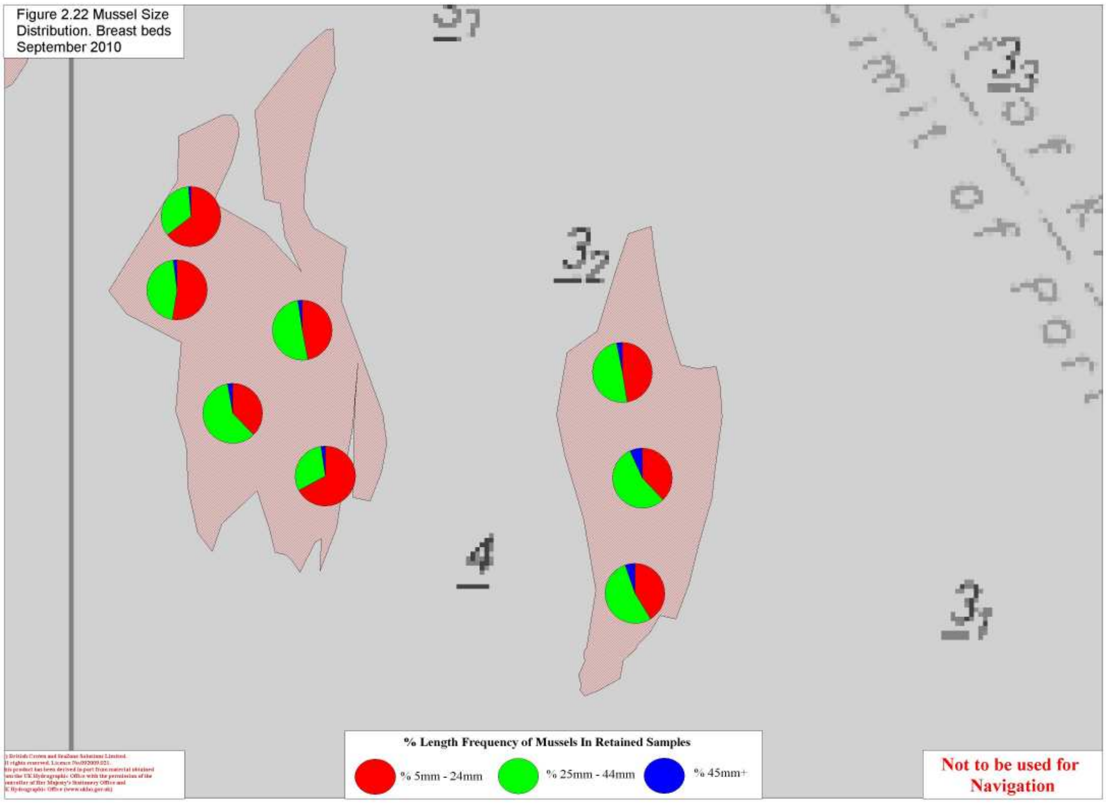




2.3.15 Breast Sand

In 2001 a good settlement of spat created three discrete mussel beds on the Breast sand, which for survey purposes were surveyed and reported separately (Figure 2.22). Over time the West bed has slowly extended towards the Middle bed until both gradually merged into one single bed, the border between them marked by a run that had originally delineated the western edge of the Middle bed. During that period, disparate fishing effort over these beds had caused the Middle bed to become much reduced in both area and stock, until only the western edge of the bed remained. Although in recent years the Middle bed had become an extension of the West bed, to maintain reporting consistency, the two continued to be surveyed separately. In 2009, however, the run delineating the border between the two beds was found to have disappeared, making individual surveys of these two beds difficult. Since 2009, therefore, both beds have been surveyed together in the field, with MapInfo GIS being used during the data analysis process to recreate the old border between the two beds.

All three of these beds were opened during the 2010 relaying fishery, during which period several vessels took the opportunity to exploit these stocks. Survey results show the losses on all three beds greatly exceed what was harvested, however, indicating additional mussel mortality had been high on these beds.



2.3.16 West Breast & Middle Breast

- **West Breast**
- Area: 15.2 hectares
- Coverage: 19%
- Mean Density: 0.93 kg/0.1m^2
- Total Stock: 268 tonnes
- Stock ≥ 45mm: 29 tonnes

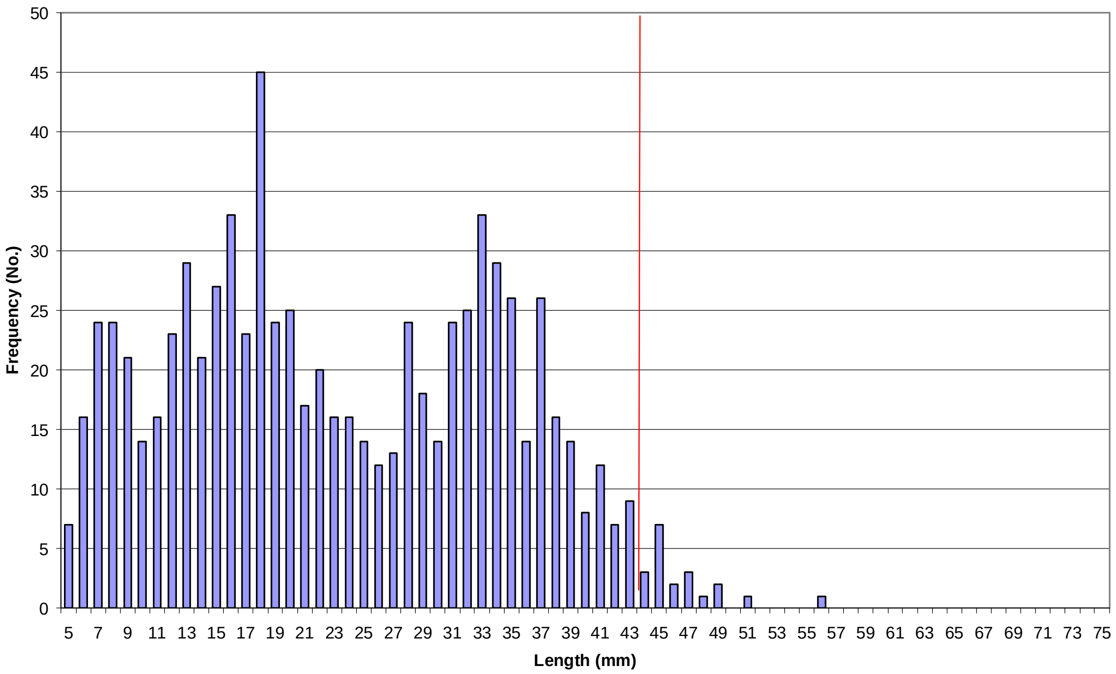
- **Mid Breast**
- Area: 4.1 hectares
- Coverage: 19%
- Mean Density: 0.93 kg/0.1m^2
- Total Stock: 72 tonnes
- Stock ≥ 45mm: 8 tonnes

These two beds were surveyed together on September 24th 2010. Samples were collected from every fourth "hit", producing 32 samples from five transects. Figure 2.23 shows the mussel size frequency within the population taken from these samples.

The West bed was found to have changed little from the previous year, while the Middle bed had increased slightly from 3.6 hectares to 4.1 hectares. Having been fished and suffered additional natural mortality between surveys, the mussel coverage was found to have decreased from 34% to 19%, while the mean density had declined from 1.35 kg/0.1m^2 to 0.93 kg/0.1m^2. From these figures the mussel biomass on the West Breast bed was calculated to be 268 tonnes, 62% less than the 703 tonnes recorded in 2009. The stock on the Middle Breast bed was calculated to be 72 tonnes, 56% less than the

165 tonnes present in 2009. Of these stocks, 29 tonnes on the West bed and 8 tonnes on the Middle bed were found to have attained marketable size.

Figure 2.23 Mussel Size Frequency. West/Mid Breast. September 2010



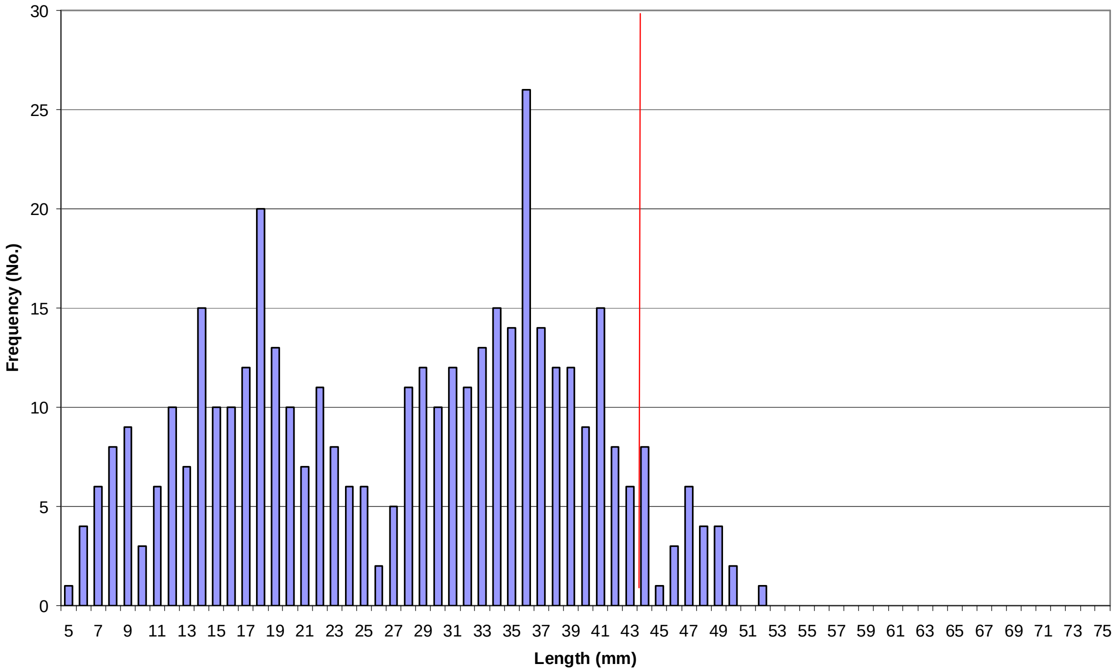
2.3.17 East Breast

- Area: 11.7 hectares
- Coverage: 22%
- Mean Density: 0.92 kg/0.1m^2
- Total Stock: 237 tonnes
- Stock ≥ 45mm: 42 tonnes

The East Breast bed was surveyed on September 26th 2010. Samples were taken from every fourth "hit", producing 24 samples from three transects. Figure 2.24 shows the mussel size frequency within the population taken from these samples.

Mussels washed out of the bed, possibly during the relaying fishery, had caused the bed to increase slightly in area from 10.6 hectares in 2009 to 11.7 hectares. The effects of the fishery and additional mussel mortality, however, had caused the mussel coverage to decline from 38% to 22% and the mean density from 1.16 kg/0.1m^2 to 0.92 kg/0.1m^2. From these figures the mussel biomass on the East Breast bed was calculated to be 237 tonnes, 49% lower than the 461 tonnes recorded in 2009. During the same period the biomass of marketable sized mussels had declined from 69 tonnes to 42 tonnes

Figure 2.24 Mussel Size Frequency. East Breast. September 2010



2.3.18 East Scotsman's Sled

- Area: 25.3 hectares
- Coverage: 21%
- Mean Density: 0.56 kg/0.1m^2
- Total Stock: 299 tonnes
- Stock ≥ 45mm: 78 tonnes

This bed was surveyed on October 7th 2010 (Figure 2.25). Samples were collected from every fourth "hit", producing 49 samples from seven transects. Figure 2.26 shows the mussel size frequency within the population taken from these samples.

Although, at 25.3 hectares, the area of the bed was similar to the 25.0 hectares recorded in 2009, erosion had occurred along the western edge of the bed, while mussels had washed out of the bed onto previously bare areas along the eastern edge. There was no evidence that any re-colonisation had occurred on the ground to the north west of the bed, where 25 hectares had been lost following the 2006/07 fishery. This bed had not been opened to the 2010 relaying fishery, but gaping shells indicated that mussel mortality had occurred recently. This was reflected in the coverage that had declined from 29% to 21%, and the mean mussel density that had been reduced from 0.88 kg/0.1m^2 to 0.56 kg/0.1m^2. From these figures the mussel biomass on this bed was calculated to be 299 tonnes, a 53% reduction from the 637 tonnes recorded in 2009. Of these, 78 tonnes were found to have attained marketable size, a reduction from the 241 tonnes recorded after the previous survey.

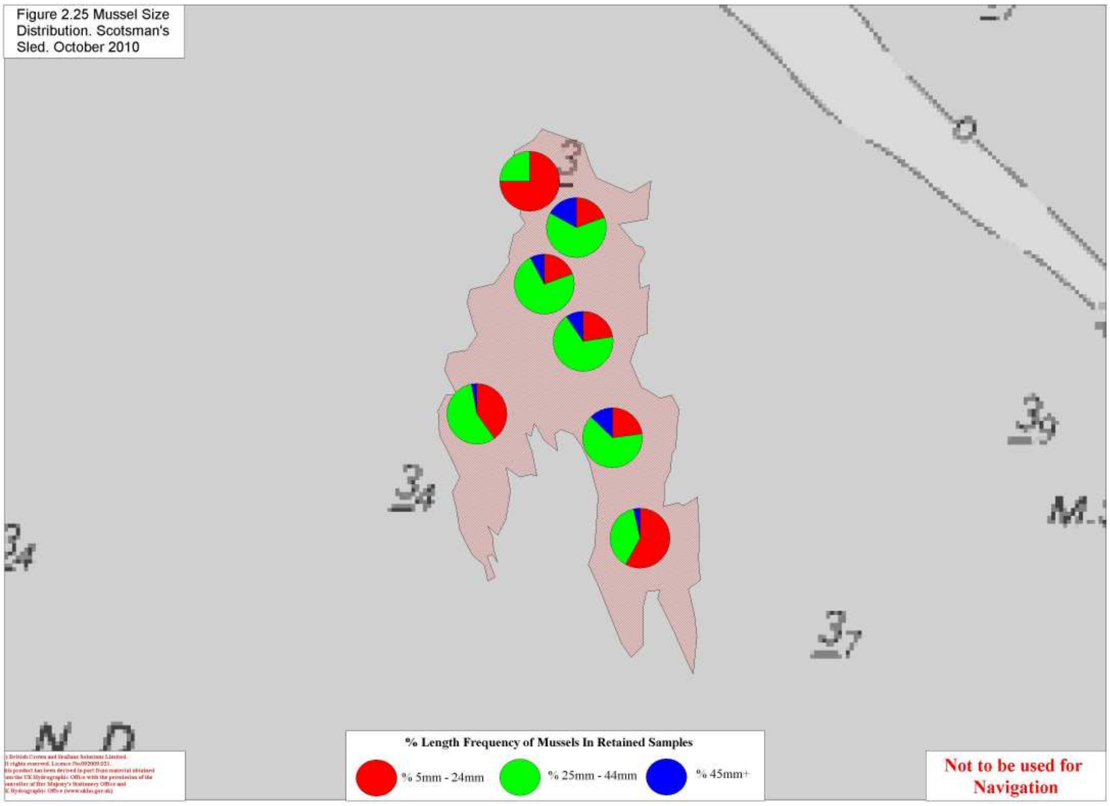
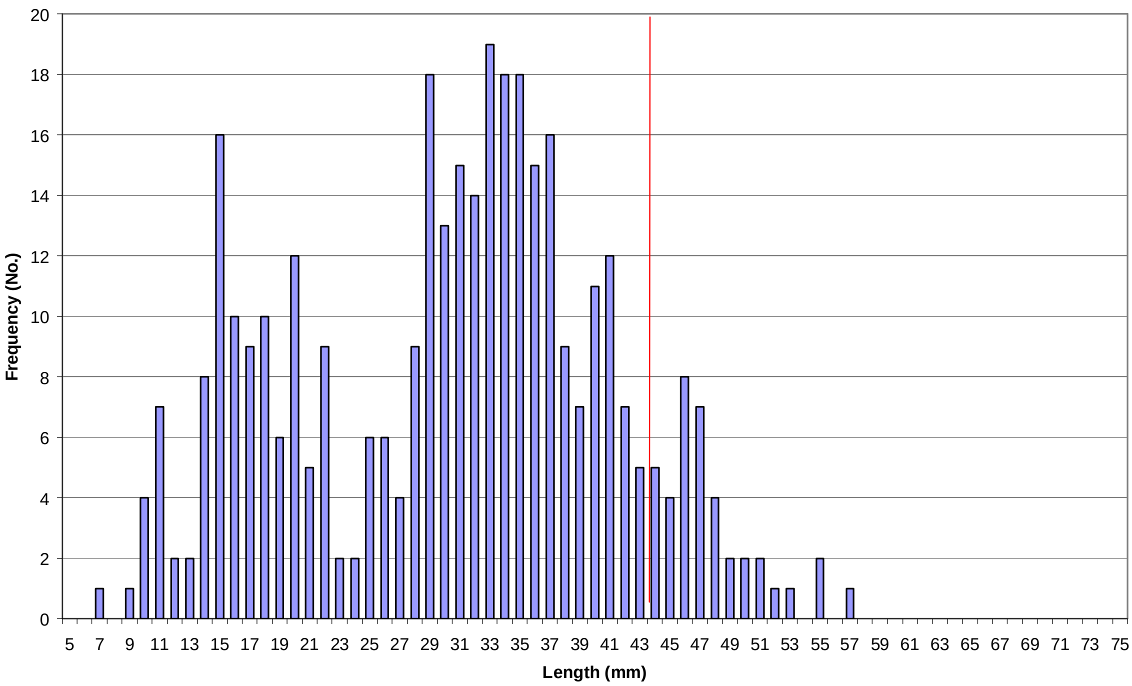


Figure 2.25 Mussel Size Distribution. Scotsman's Sled. October 2010

Figure 2.26 Mussel Size Frequency. East Scotsman's Sled. October 2010

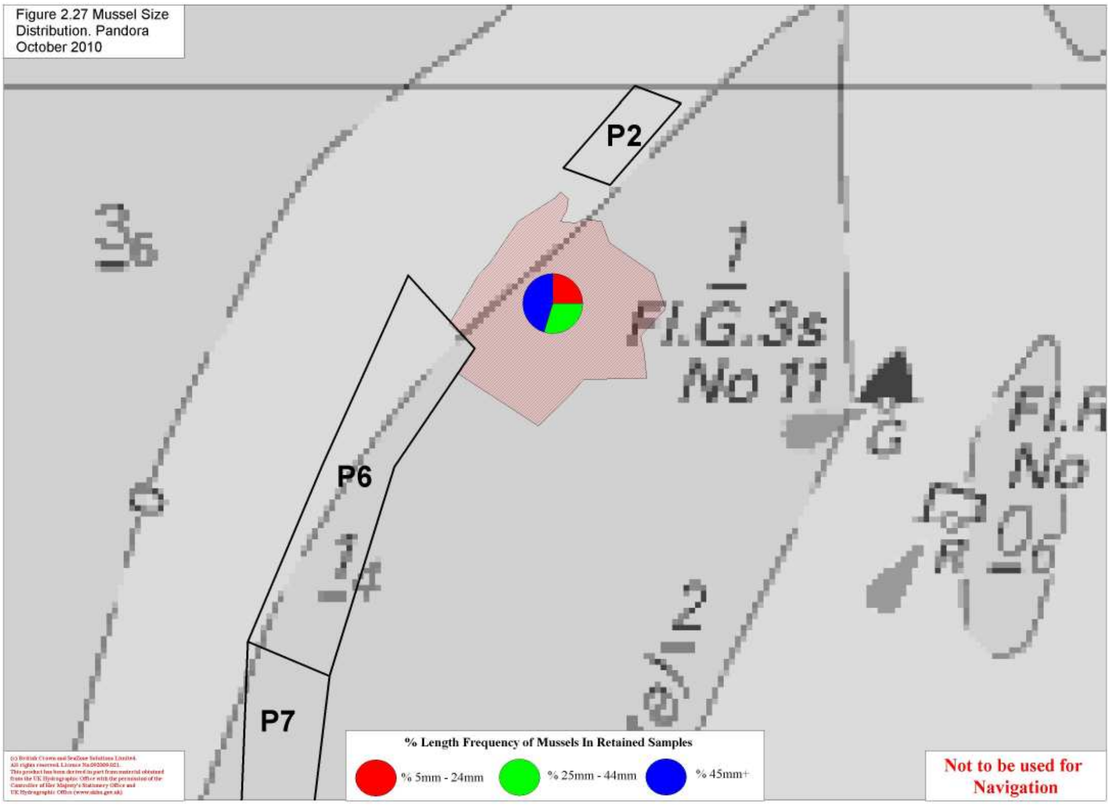


2.3.19 Pandora

- Area: 5.1 hectares
- Coverage: 33%
- Mean Density: 0.78 kg/0.1m^2
- Total Stock: 130 tonnes
- Stock ≥ 45mm: 107 tonnes

The Pandora bed was surveyed on October 21st 2010. Samples were collected from every fifth "hit", producing nine samples from one transect.

The mussels on the Pandora bed are predominantly from the 2001 year-class cohort, which though having grown rapidly in size, have been declining in numbers due to lack of recruitment. Originally the bed extended further southwards, adjacent to the mussel lays, P6 and P7 (Figure 2.27). In recent years, however, mussel coverage within the patches had become so sparse, this southern area ceased to be classified as part of the mussel bed. When surveyed in 2010, mussels from the adjacent lays were found to have encroached onto this ground.



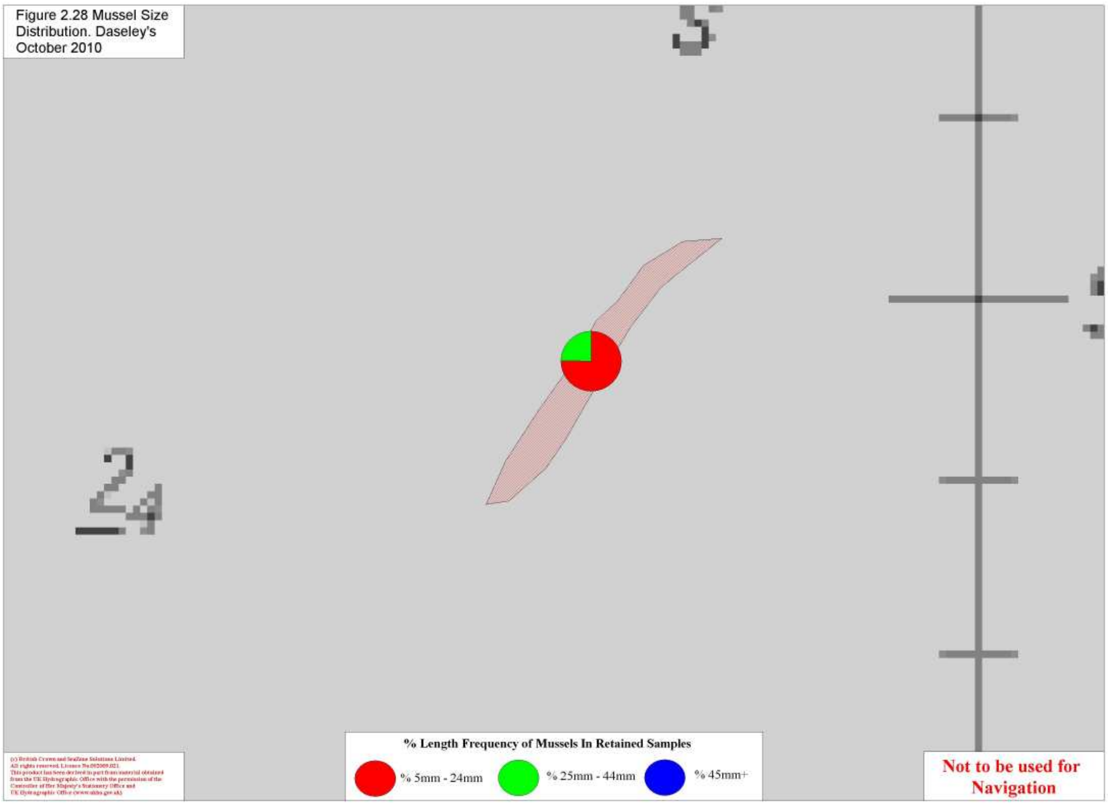
The area of the remaining part of the bed was found to have increased from 3.4 hectares in 2009 to 5.1 hectares. In part this was due to clumps of mussels washing onto the bed from the adjacent lay, and partially due to the low mussel densities and high shell content along the eastern side of the bed making it difficult for surveyors to assess the actual extent of the bed. Within this area the coverage, at 33%, was the same as in 2009, while the mean density had increased slightly from 0.74 kg/0.1m^2 to 0.78 kg/0.1m^2. These figures indicate the mussel biomass on this bed has increased from 84 tonnes in 2009 to 130 tonnes, while the biomass that had attained marketable size had increased from 70 tonnes to 107 tonnes. Most of this change can be attributed to the influx and growth of mussels that have been drifting into the bed from the neighbouring lays, rather than any new recruitment. Because of this influx, coupled with the high levels of dead shell that has been present on this bed for several years, it is difficult to determine whether this bed has been affected at all by the mussel mortality witnessed elsewhere in the Wash.

2.3.20 Daseley's

- Area: 1.1 hectares
- Coverage: 30%
- Mean Density: 0.90 kg/0.1m^2
- Total Stock: 30 tonnes
- Stock ≥ 45mm: 0 tonnes

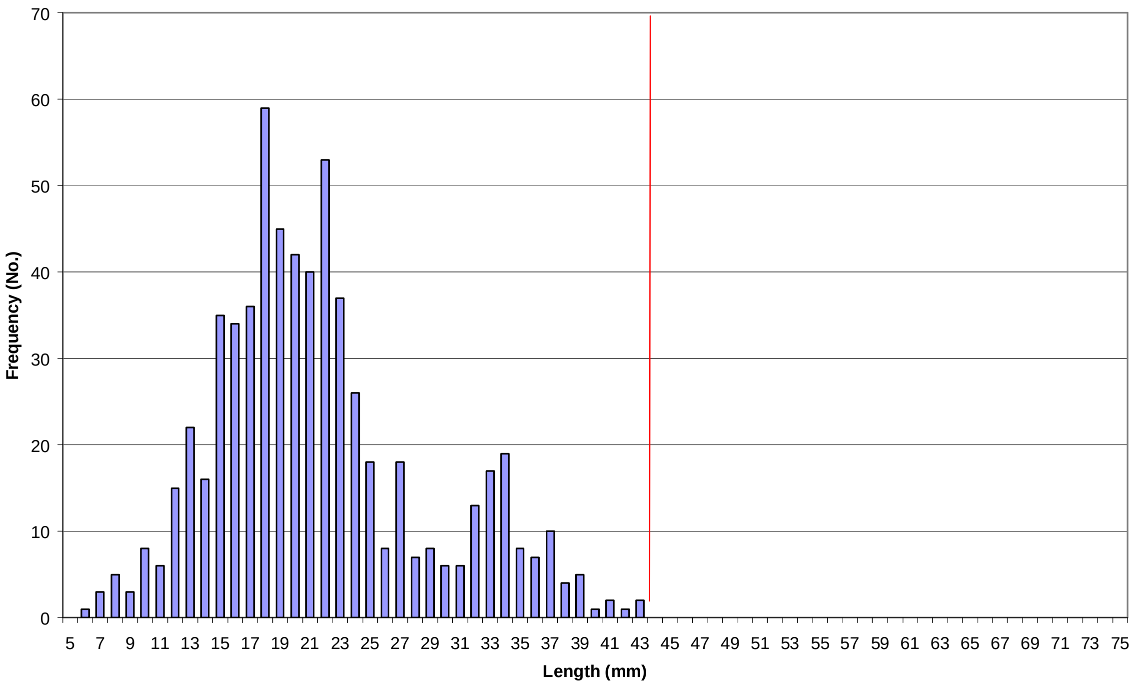
The Daseley's bed was surveyed on October 20th 2010 (Figure 2.28). Samples were collected from every third "hit", producing 15 samples from one transect. Figure 2.29 shows the mussel size frequency within the population taken from these samples.

Figure 2.28 Mussel Size Distribution. Daseley's October 2010



During the 2009 surveys dense patches of mussel seed were found to have settled at this location in a run bottom. At the time, however, the seed was determined to be too small and fragile to risk conducting a survey on. Having grown sufficiently, it was surveyed in 2010. The area of the bed, a long narrow strip following the run, was found to be 1.1 hectares. Within the bed, the coverage was found to be 30% and mean density 0.90 kg/0.1m^2. From these figures the mussel biomass was calculated to be 30 tonnes, none of which had attained marketable size.

Figure 2.29 Mussel Size Frequency. Daseley's. October 2010

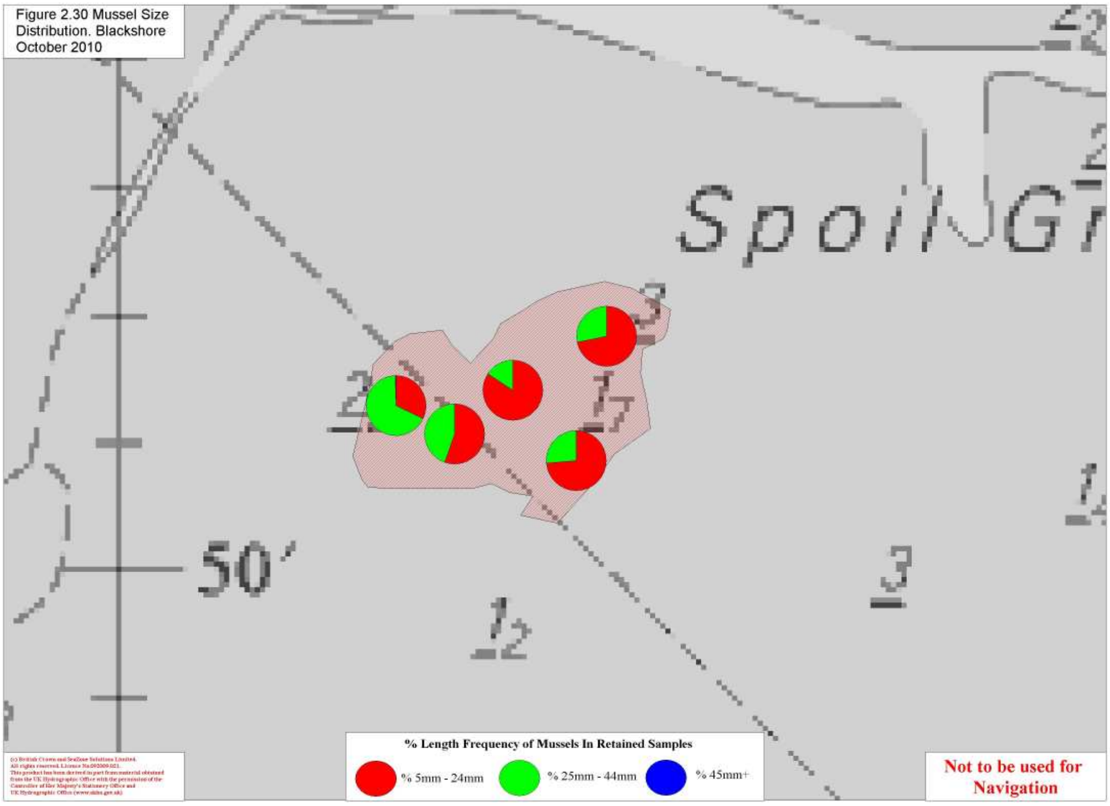


2.3.21 Blackshore

- Area: 10.2 hectares
- Coverage: 23%
- Mean Density: 0.84 kg/0.1m^2
- Total Stock: 197 tonnes
- Stock ≥ 45mm: 1 tonne

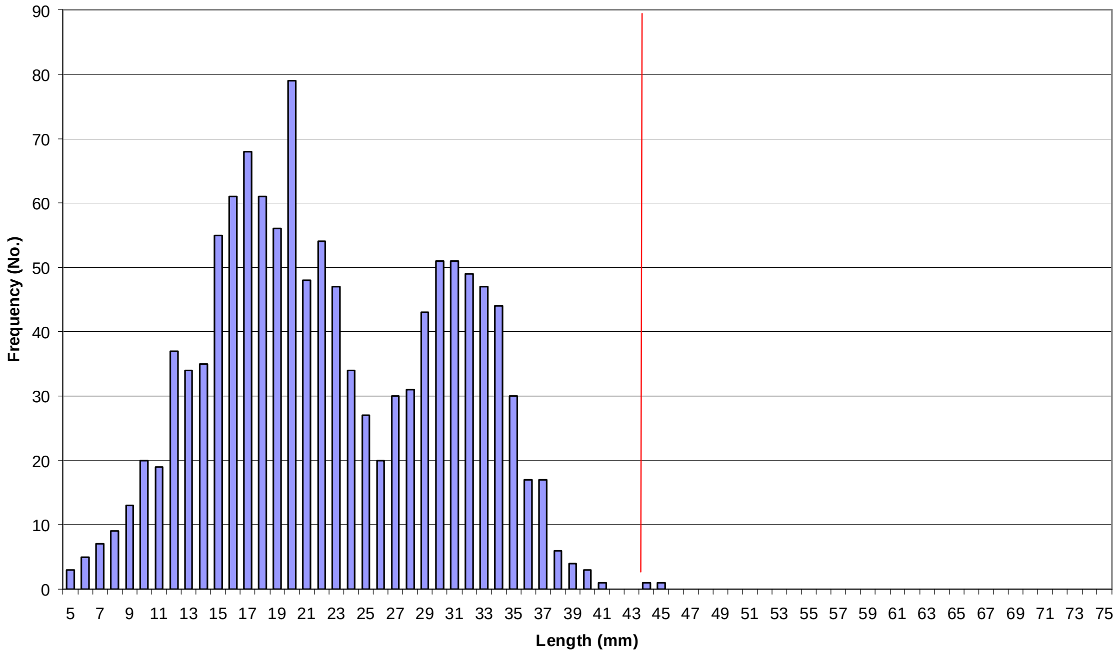
This is a recently settled bed, the presence of which was first noticed when two of the grab samples taken at this location during the 2010 spring cockle surveys were found to contain clumps of mussel seed. The opportunity was taken on August 24th 2010 to visit this area, during which a bed of one year-old seed was found, attached to a low density of older mussels. Other work commitments that day meant it was not possible to conduct a full survey but the opportunity was taken to map the perimeter (Figure 2.30). From this, the area of the bed was found to be 10.2 hectares. Having determined there were sufficient stocks on the bed, a survey was conducted on October 6th. During this samples were collected from every fourth "hit", producing 39 samples from five transects. Figure 2.31 shows the mussel size frequency within the population taken from these samples.

Figure 2.30 Mussel Size Distribution. Blackshore October 2010



The coverage of the bed was found to be 23% and the mean density within the mussel patches was 0.84 kg/0.1m^2. From these figures the biomass of mussels in the bed was calculated to be 197 tonnes of which 1 tonne was found to have attained marketable size.

Figure 2.31 Mussel Size Frequency. Blackshore. October 2010

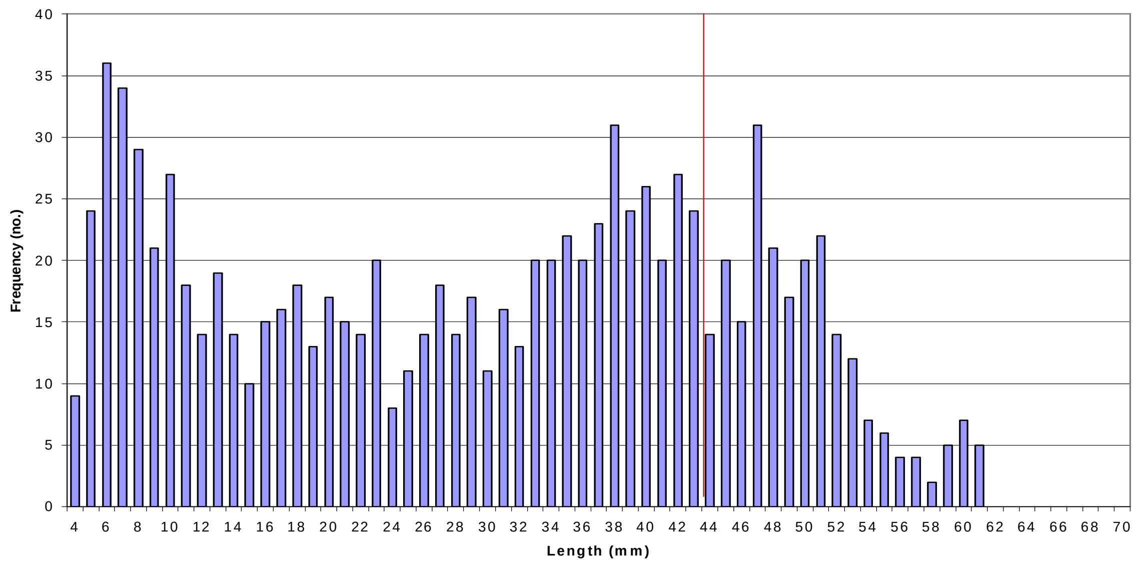


2.3.22 Welland Bank

- Area: 1.8 hectares
- Coverage: 80%
- Mean Density: 2.75 kg/0.1m^2
- Total Stock: 402 tonnes
- Stock ≥ 45mm: 238 tonnes

Historically the rocks forming the north-west bank of the River Welland training wall have supported mussels. This wall is completely immersed during high water periods, and consequently in places mussels are found attached to the rocks on both sides of the wall. Although it is only possible to hand work these stocks, in some years over twenty vessels have exploited the mussels found there. Because of the nature of the wall, it is not possible to measure the perimeter of the stocks in the usual manner. Instead an area of coverage is calculated by measuring the width of the band that the mussels are growing along, and multiplying this figure by the distance which the mussels maintain this width. The coverage and mean density are measured using a similar method to that used on the intertidal beds, but as it is not possible to walk transects along the wall, a series of samples are tested at distances along the wall. As the best coverage of mussels on this wall is found at the lower extremities, the survey is preferably conducted at low water on the largest possible tide.

Figure 2.32 Mussel Size Frequency. Welland Bank. September 2010



This year the survey on the Welland Bank was conducted on September 10th 2010, on an 8.5m tide. Although mussels were growing thickly on the wall in places, the coverage was found to have decreased from 89% in 2009 to 80% and the mean density from 3.01 kg/0.1m^2 to 2.75 kg/0.1m^2. From these figures the mussel biomass was calculated to be 402 tonnes, 20 less than the 502 tonnes recorded to be present in 2009. Of these, 238 tonnes were found to be of marketable size compared to 285 tonnes the previous year.

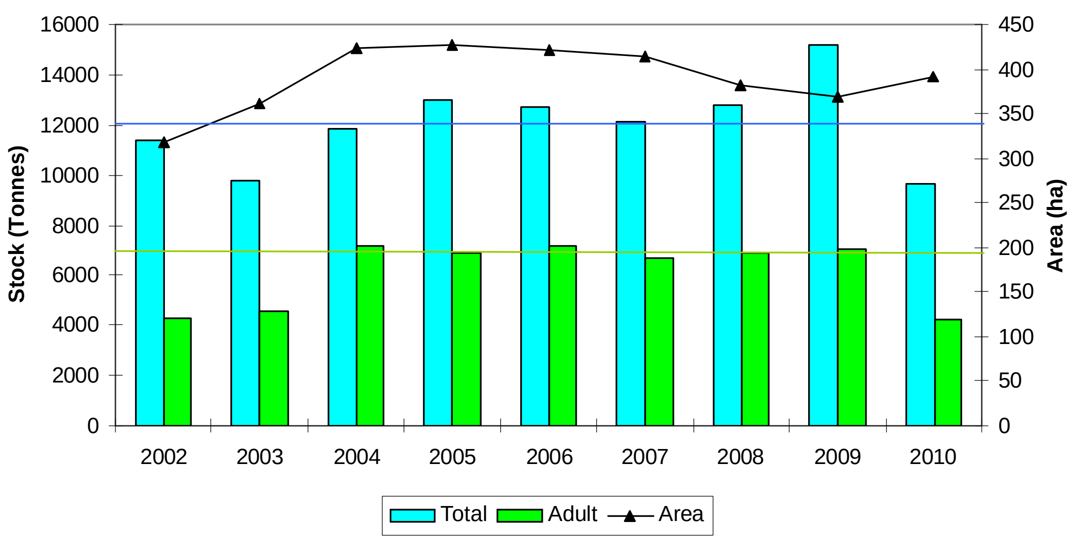
Table 2.1 - Summary of The Wash intertidal mussel stocks following the 2010 autumn mussel surveys

	2010							2009	
BED	**AREA (ha)**	**COVERAGE (%)**	**DENSITY (kg/0.1m^2)**	**TOTAL STOCK (Tonnes)**	**STOCK >≥45MM (Tonnes)**	**% >≥45MM**	**Tonnes/ha**	**TOTAL STOCK (Tonnes)**	**% CHANGE**
Mare Tail North	55.9	42	0.73	1685	370	22.0	30.1	1509	11.7
Mare Tail South	26.1	30	0.65	503	25	5.0	19.3	863	-41.7
Mare Tail East	9.8	22	0.58	126	69	54.8	12.9	174	-27.6
Shellridge	13.9	31	0.38	166	29	17.5	11.9	208	-20.2
Toft	47.0	33	1.51	2357	1904	80.8	50.1	2774	-15.0
Roger	3.1	39	0.46	55	32	58.2	17.7	140	-60.7
Gat, West	48.0	33	0.73	1164	756	64.9	24.3	2943	-60.4
Gat, Mid	25.9	32	0.77	634	375	59.1	24.5	1575	-59.7
Gat, East	19.3	34	0.58	387	214	55.3	20.1	1086	-64.4
Main End	7.3	15	0.44	47	35	74.5	6.4	214	-78.0
Holbeach	10.2	39	0.83	325	11	3.4	31.9	411	-20.9
Herring Hill	25.0	27	0.34	235	8	3.4	9.4	436	-46.1
Trial Bank	27.5	25	1.05	709	133	18.8	25.8	805	-11.9
Breast, West	15.2	19	0.93	268	29	10.8	17.6	703	-61.9
Breast Centre	4.1	19	0.93	72	8	11.1	17.6	165	-56.4
Breast, East	11.7	22	0.92	237	42	17.7	20.3	461	-48.6
Scotsman's Sled, East	25.3	21	0.56	299	78	26.1	11.8	637	-53.1
Daseley's	1.1	30	0.90	30	0	0.0	27.3	0	
Blackshore	10.2	23	0.84	197	1	0.5	19.3	0	
Pandora	5.1	33	0.78	130	107	82.3	25.5	84	54.8
TOTAL	**391.7**			**9626**	**4226**	**43.9**	**24.6**	**15188**	-36.6
Welland Bank	1.8	80	2.75	402	238	59.2	264.2	502	-19.9

2.4 Discussion

After heavy fishery exploitation caused the intertidal mussel stocks in the Wash to collapse during the 1990s, draconian management measures had to be implemented in order to facilitate a recovery during the 2000s. By 2004 the stocks had recovered to pre-1990 levels, enabling the strict closures to be relaxed somewhat, but with few wishing to see stocks collapse again, measures were taken to prevent future over-exploitation. Following lengthy consultation with stakeholders, Natural England published a series of Conservation Objectives for the Wash in 2007. Later the same year, following consultation with the industry and Natural England, the Committee signed off a number of management policies aimed at meeting the Conservation Objectives. Under these Conservation Objectives it was agreed that the total mussel biomass on the regulated intertidal beds should not fall below 12,000 tonnes, or the adult stocks below 7,000 tonnes (Figure 2.33). Although several large mussel fisheries were able to operate on the intertidal beds between 2004 and 2009, it was possible to maintain the stocks above these objectives.

Figure 2.33 Intertidal Mussel Stocks in The Wash



With stock levels in 2009 at their highest level since before their collapse in the mid-1980s, it was possible to open several of the intertidal beds to a relaying fishery of 1000 tonnes during the summer of 2010. Unfortunately, when the beds were surveyed in the autumn, the stocks were found to have fallen 37%, from 15,188 tonnes in 2009 to 9,626 tonnes, greatly exceeding the anticipated losses following the fishery. Excluding two new beds that had been surveyed for the first time in 2010, all but two of the intertidal beds were found to have declined in stock, some by amounts exceeding 60%. Strangely, the worse effected beds appeared to have been those that had not been disturbed by the 2010 fishery, including 61% losses from the Gat beds. On several of the beds where high losses had been reported, high incidences of gaping shells indicated there had been recent heavy mussel mortality, not just affecting old mussels, but also juveniles. On October 13th 2010, a sample of mussels collected from the Mid Gat was delivered to CEFAS's pathology laboratory at Weymouth to be tested for the presence of any potentially harmful pathogens that could be responsible for the deaths. The results of the pathology tests showed relatively high numbers of the parasitic copepod, *Mytilicola intestinalis* to be present in the intestines of the mussels. Having been alerted to the presence of *M. intestinalis*, ESFJC officers subsequently tested mussel samples from four other beds to determine how widespread the parasite had become in the Wash (Table 2.2). These tests showed that *M. intestinalis* was present on all of the beds samples, infecting between 54% and 70% of the mussels. The average number of *M. intestinalis* found to be present in infected mussels varied between 1.9/mussel (range 1-8/mussel) on the Trial Bank bed to 5.1/mussel (range 1-11/mussel) on Mare Tail.

Table 2.2 Proportion of mussels from four beds found to be infected with M. intestinalis *and the average number of* M. intestinalis *found in the infected mussels.*

Mussel bed	Infection rate (%)	Mean number *M. intestinalis*/infected mussel
Trial Bank	70	1.9
Mare Tail	54	5.1
Tofts	60	4.0
Herring Hill	69	3.5

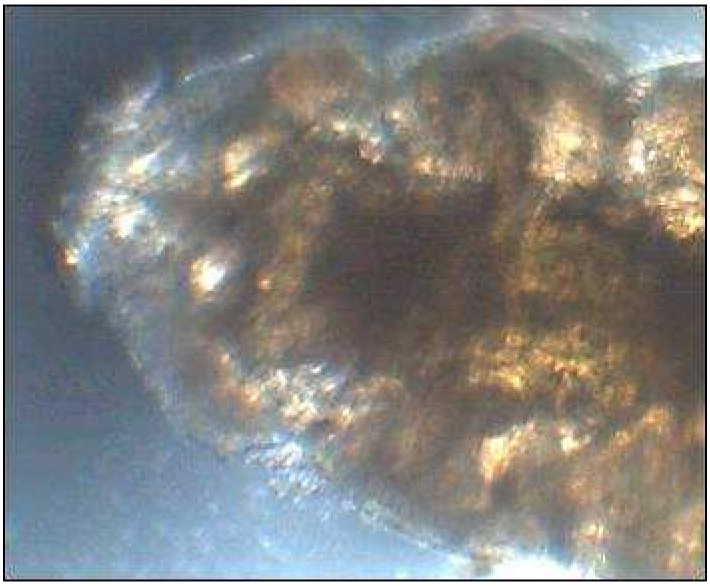


Figure 2.34 Microscope image of the anterior of *M. intestinalis* specimen taken from Trial Bank mussel bed (x40)

Although the sampling confirmed that *M. intestinalis* infection was widespread across the intertidal beds in the Wash, it is difficult to determine whether it is directly responsible for the high mortality witnessed during the surveys. *M. intestinalis* is relatively large (females grow up to 9mm in length and males up to 4.5mm), and may cause physical harm to the host's intestinal epithelium tissue as it moves about (Moore et al., 1977), but there is considerable controversy about how harmful the species might actually be to its host. Between 1949 and 1951 an epidemic of *M. intestinalis* was observed along the North Sea coast that coincided with massive mortality among mussel populations (Korringa, 1968). At the time the parasite was blamed for the deaths, but doubts have since been raised as to whether it was the causal agent in the mortality or had spread coincidentally. As other studies have found that the parasite, at worse, reduces the meat quality of the mussels, it is likely that if it was responsible for the 1949-1951 North Sea mortality, and those in the Wash during 2010, it would have been in combination with other environmental factors. Although *M. intestinalis* has only recently been identified as being present in the Wash intertidal mussels, its presence could explain the poor growth rates and meat yields that Wash mussels have exhibited in recent years.

Whether *M. intestinalis* was causal or not, it is both frustrating and worrying that after working closely with the industry and Natural England in recent years to help the stocks recover from their decline in the 1990s, this mortality has reduced the stocks back to their lowest level since 2001. With only moderate spatfalls in 2009 and 2010, it could take several years before the 12,000 tonnes Conservation Objective is once more achieved, and with it, the prospect of future fisheries.

2.5 Titchwell Marsh Mussel Bed

2.5.1 Introduction

Titchwell Marsh is a RSPB maintained nature reserve on the North Norfolk coast, close to the village of Titchwell and approximately five miles east of Hunstanton. The reserve contains a number of habitats including reedbeds, marshland, fresh water and brackish lagoons and sandy beach. Together these habitats attract a diversity of bird species including nationally important numbers of avocets, bearded tits, bitterns and marsh harriers. It is also an internationally important site for wintering waders and ducks. Whereas the reedbeds and lagoons are managed, the beach area, which includes saltmarsh, shingle and sand dunes is maintained naturally. This area provides suitable habitats for brent geese, wigeon, little terns, red shank and high tide roosts for other wader species, while offshore large numbers of common scoter, eider and long tailed ducks gather in winter.

In 2009 a number of local fishermen approached Eastern Sea Fisheries Joint Committee, requesting permission to fish a natural bed of seed mussels that had settled in the eulittoral zone of the beach. Initially it was unclear who would be responsible for managing a fishery within a nature reserve maintained by the RSPB. Consultation with the Crown Estate landowners, however, confirmed that because the Joint Committee would need to relax Byelaw 4 (minimum size of mussels) and authorise the fishing activity under Byelaw 2(b), allowing the removal of mussels for the purpose of stocking, the responsibility for the management and enforcement of the fishery was that of the Joint Committee. As this activity was considered a new plan or project, the Joint Committee was required to submit an Appropriate Assessment to Natural England prior to the fishery being opened. As part of this process officers conducted a stock assessment on 11th September 2009, from which the mussel biomass was estimated to be approximately 420 tonnes. These covered an area of 4.6 hectares and were mostly of a size range between 12 to 25mm length, although older individuals were present up to a size of 53mm. Figure 2.35 shows the extent of the mussel bed at the time of this survey. Due to the exposure of the site to the sea and the accretion of mussel mud and pseudo-faeces beneath the mussels, they were considered vulnerable to being washed away over winter if they were not fished. Erosion of parts of the bed was already evident at the time of the survey.

To avoid bird disturbance, and because the mussel was relatively small, a small-scale handworked fishery was considered the most appropriate fishery for this site. This would most likely be limited to three individual workers, who would approach the bed from the sea using small tenders. The mussels were attached to an area of exposed neolithic peat, however, and concerns were raised that this feature could potentially be irreversibly damaged by the fishing activity. Before an agreed working practice to avoid damage could be agreed with the industry, the mussels were washed away over the winter. A subsequent survey was conducted on 3rd March 2010, during which ESFJC officers were accompanied by the senior Titchwell Marsh RSPB site warden and a local Natural England officer.

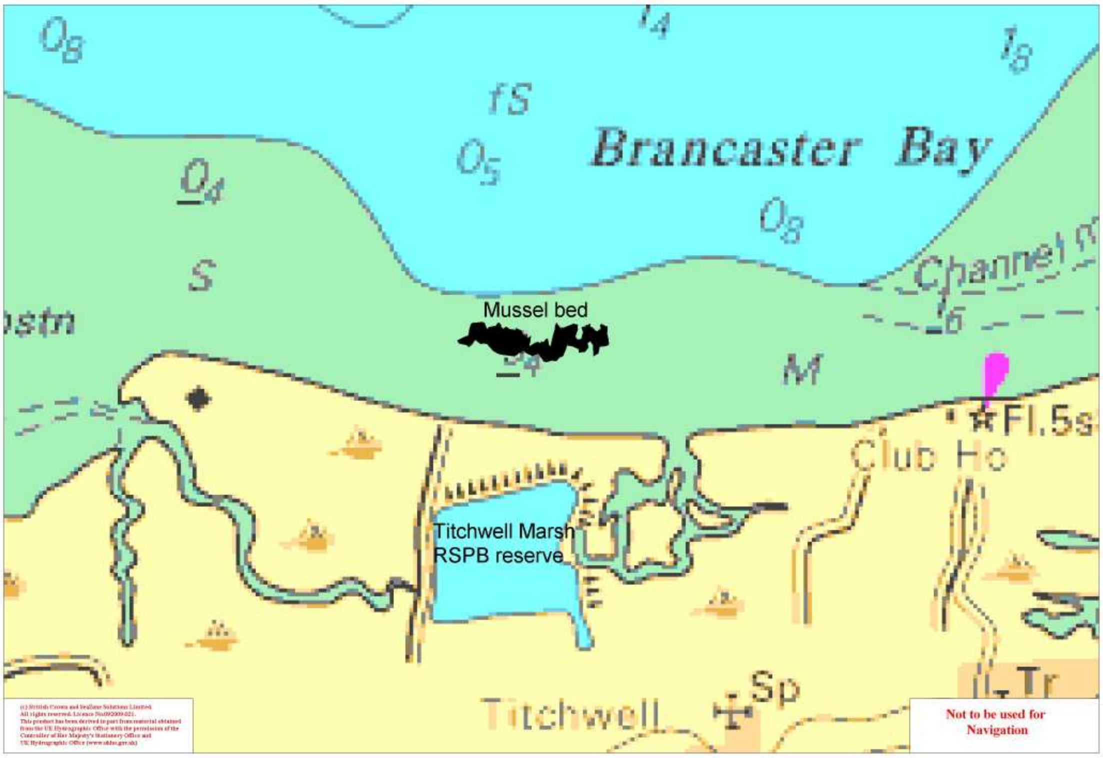


Figure 2.35 Chart showing the position of the mussel bed at Titchwell Marsh in September 2009

2.5.2 Titchwell Marsh Mussel Survey – March 2010

The survey conducted on 3rd March 2010 comprised two parts; a survey of the mussel stocks and a habitat survey of the surrounding area. The methodology for the mussel survey was identical to that used to survey intertidal mussel stocks in the Wash (see section 2.2).

This survey confirmed there had been a significant loss of stock since the September survey, when approximately 420 tonnes had been present. Of the 4.6 hectares covered with mussels in September, only one small core area remained in March, covering 0.26 hectares (figure 2.36). In addition to this core area, other small clumps were scattered across the site, attached to raised peat beds. Although some of these areas did not fully dry, and so were not measured at the time of the March survey, their combined area was estimated to be approximately equivalent to that of the core area. Within the core area of the bed, the mussel coverage was found to be 44%, slightly lower than the 51% recorded in September. As the majority of the mussels had washed away, however, the mean density of mussels within the patches, was found to have fallen from 1.81Kg/0.1m^2 to 0.38Kg/0.1m^2. From these figures the total biomass of mussels within the core area was calculated to be 4 tonnes, plus a similar unmeasured quantity scattered over other areas of raised peat beds. The majority of these were found to have a size range between 21-31mm, approximately 7mm larger than when surveyed in September (figure 2.37). Most of the mussels remaining within the site were found to be firmly attached to the substrate with numerous byssal threads. This, and the absence of mussel mud and pseudo-faeces indicated the area was subject to erosion from wave action, the most likely cause of the loss of mussels from this site over the winter period. This is a common phenomenon when mussels settle in exposed locations, such as this one, often resulting in a situation in which ephemeral beds settle in summer and are washed away the following winter. The exposure of the Titchwell site suggests that any mussels settling in this area are likely to be ephemeral in nature.

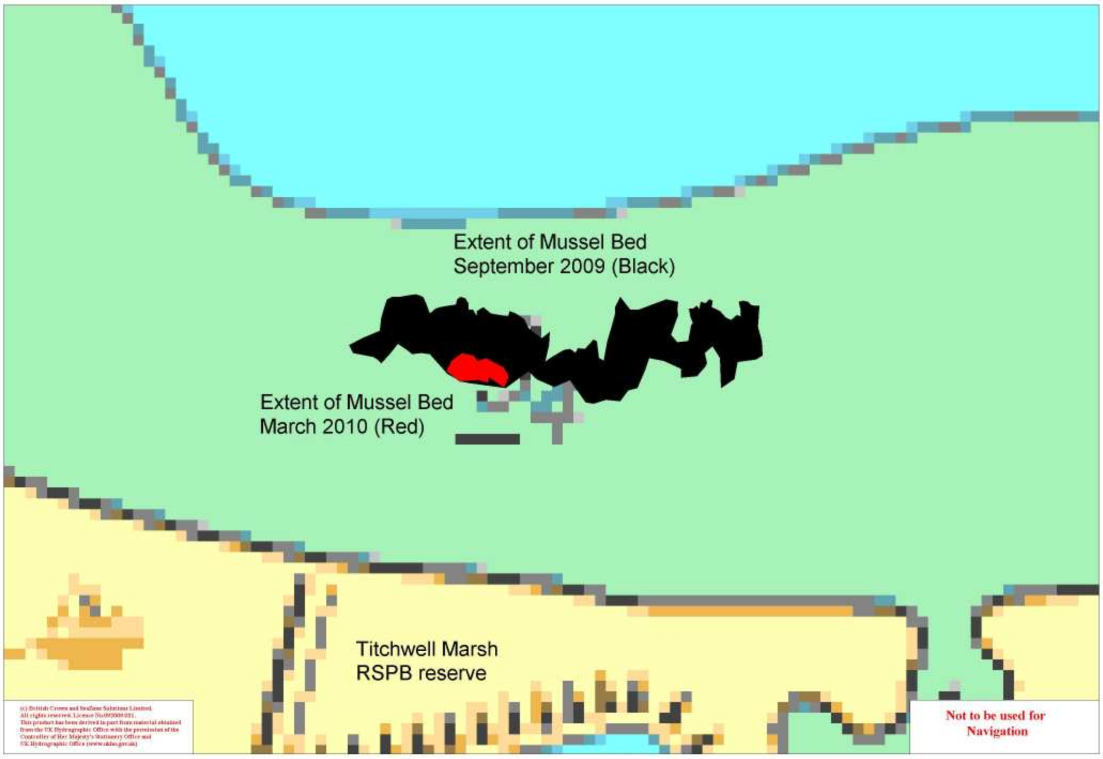


Figure 2.36 Chart showing the extent of the Titchwell Marsh mussel bed in March 2010 (Red) compared to September 2009 (Black)

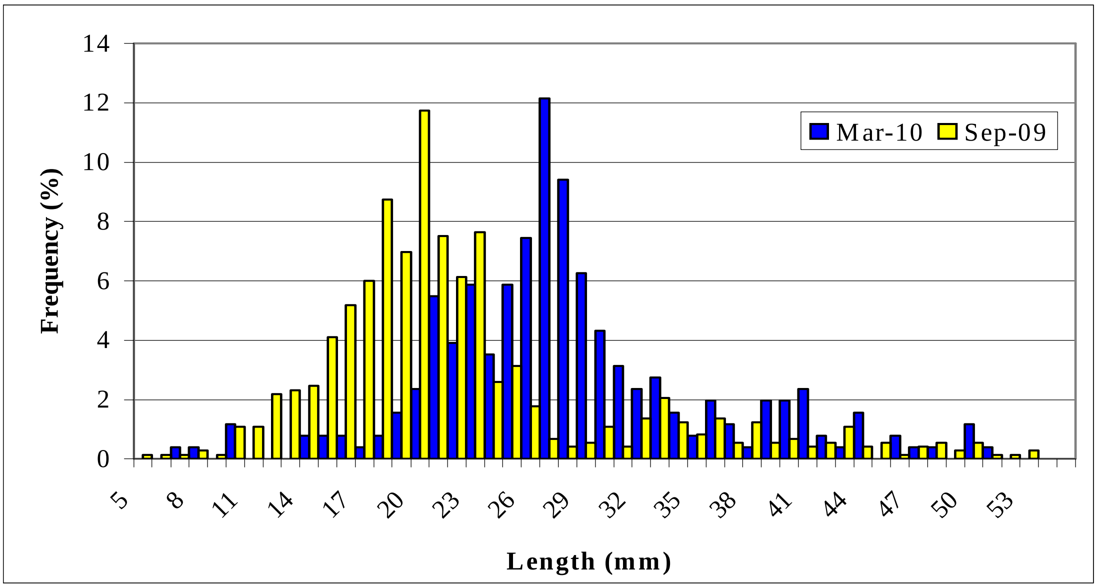


Figure 2.37 Graph showing the population size frequency of the Titchwell Marsh mussels in September 2009 (Yellow) and March 2010 (Blue).

2.5.3 Habitat Survey

For the habitat survey, a methodology developed by Seafish as a standard sampling operating procedure for basic intertidal habitat mapping was used. Designed for use by shellfish farm developers, this procedure incorporates many of the guidelines used by the Marine Nature Conservation Review (MNCR) and Joint Nature Conservation Committee (JNCC) for their own habitat mapping surveys. Using this procedure, the positions of the habitats being mapped were plotted using a portable GPS and described in terms of substratum type and main habitat features. Photographs were taken of each habitat for future reference and descriptive purposes. Figure 2.38 shows the positions of six photographic viewpoints used in this report.

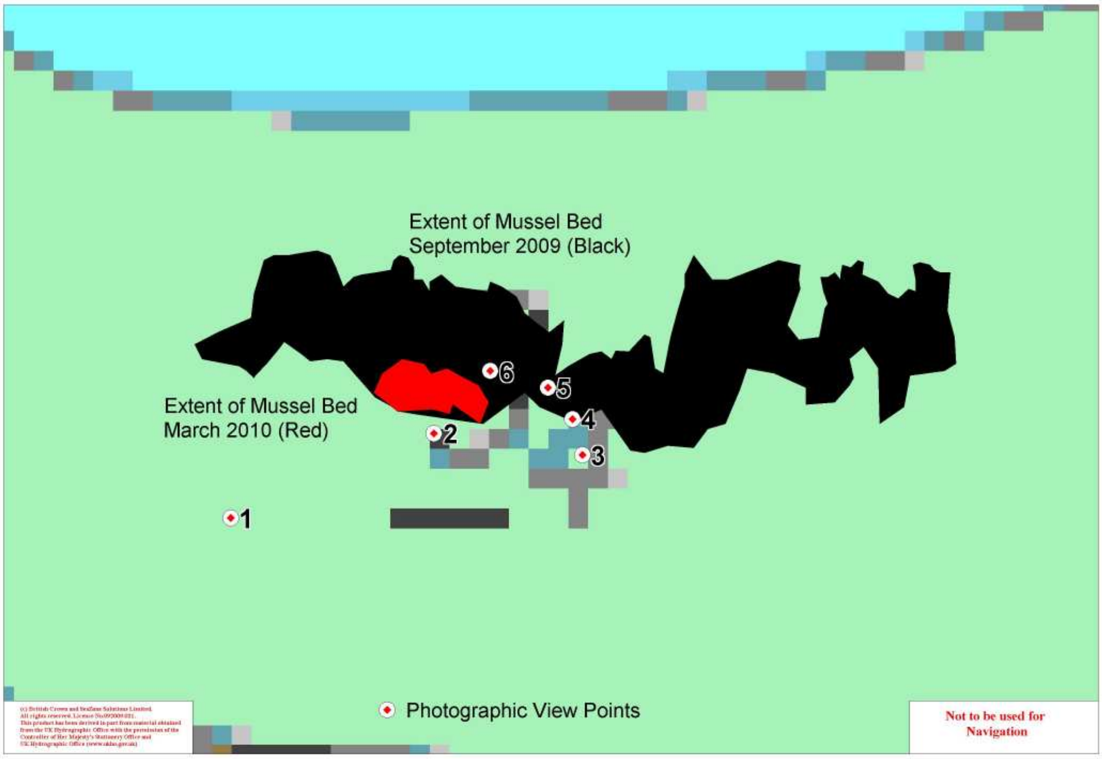


Figure 2.38 Chart showing the extent of the mussel bed in September 2009 (Black) and March 2010 (Red) and the positions of the photograph view sites described in the text.

2.5.3.1 Photographic View Point 1 – Sandy Beach

Along this section of coast, the primary habitat occupying the high and midshore regions between the outer seawall and the sea is sandy beach. In this area, which is fully exposed to the sea, the substrate was found to be mainly fine sand with occasional shells and pieces of gravel. Photographic View Point 1 was situated on the strandline, where large numbers of razorclam (*Ensis* spp) shells had been deposited by the tide (figures 2.39). The area below the strandline was found to have low sand ripples, while above the strandline the ground was mostly flat. Low numbers of lugworm, *Arenicola marina*, casts were found to be present in the mid and lowshore regions of the beach in densities <1cast/0.01m^2.

Close to this position, above the strandline, the remains of a World War II observation tower was present, while below the strandline at this point, some concrete blocks were also visible. Tidal action around these blocks had scoured a shallow pool in the sand.

2.5.3.2 Photographic View Points 2, 4, 5 and 6 – Exposed Neolithic Peat

In places along the lower shore the substrate is composed of exposed peat from the Neolithic period. This is either flush with the surface of the sediment (figure 2.40), or where more exposed, is present in raised beds (figure 2.41). It is on these peat beds that the mussels were attached when surveyed in September 2009 (figure 2.42), and on which the remaining mussel patches were still found in March 2010 (figure 2.43). In September 2009, when the mussels had been more numerous, a layer of fine sediment had been accreted beneath them to a depth of several centimetres. This appeared to have been washed away when surveyed in March, along with the majority of the mussels. The remaining mussels were found to be tightly attached to the underlying substratum with numerous byssal threads.

In addition to the mussels, numerous piddocks were found to have burrowed into the surface of the peat (figure 2.44). In places these were present in densities of approximately 1000/m^2.

Separating the raised peat beds were sandy gullies and pools of standing water (figure 2.45). The substratum in these areas was found to be composed of fine sand or silt, sometimes forming a thin surface veneer over clay. These pools were found to support low densities of both lugworms, *Arenicola marina*, and sand mason worms, *Lanice conchilega*. These were both present in densities of approximately 0.1/m^2.

2.5.3.3 Photographic View Point 3 – Mesolithic Clay

On the lower shore close to the peat beds, a small area of Mesolithic clay was found (figure 2.46). Mixed in with the clay throughout this area were small fragments of decomposing wood. In places the clay was covered with a thin surface veneer of fine sand. The area had either a flat profile, or in places contained shallow gullies and low ripples.

Figure 2.39 Photograph taken at viewpoint 1, looking west. Photograph shows area of sandy beach between the outer seawall and the sea. In foreground are razor clam shells deposited in the strandline.

Figure 2.40 Photograph taken at viewpoint 2, showing an area of exposed peat.

Figure 2.41 Photograph taken at viewpoint 5, looking north. Photograph shows raised peat beds emerging from the sea.

Figure 2.42 Photograph taken in September 2009 from a position close to viewpoint 4, showing mussels on the peat beds and the accreted layer of sediment beneath them.

Figure 2.43 Photograph taken at viewpoint 4, showing patches of mussels attached to areas of exposed peat.

Figure 2.44 Photograph taken at viewpoint 2, showing piddocks that have burrowed into the peat.

Figure 2.45 Photograph taken at viewpoint 6, looking north-west. Photograph shows exposed raised peat beds separated by areas of fine sand and pools of standing water.

Figure 2.46 Photograph taken at viewpoint 3, looking south. Photograph shows area of clay with shallow gullies.

2.5.4 Titchwell Marsh Mussel Survey – September 2010

In August 2010 ESFJC received reports from members of the fishing industry that there had been another settlement of seed on this bed. As a consequence of this report, officers conducted a further survey on this bed on September 8th 2010, using the same method as described for the survey conducted in March. This survey found the mussel coverage was greater than when surveyed in March, the extent being similar to that reported following the September 2009 survey (figure 2.47). Unlike in 2009, however, the bed was found to be broken up into five discrete patches of mussels, each of which were surveyed individually (figure 2.48) and their stocks described in table 2.3.

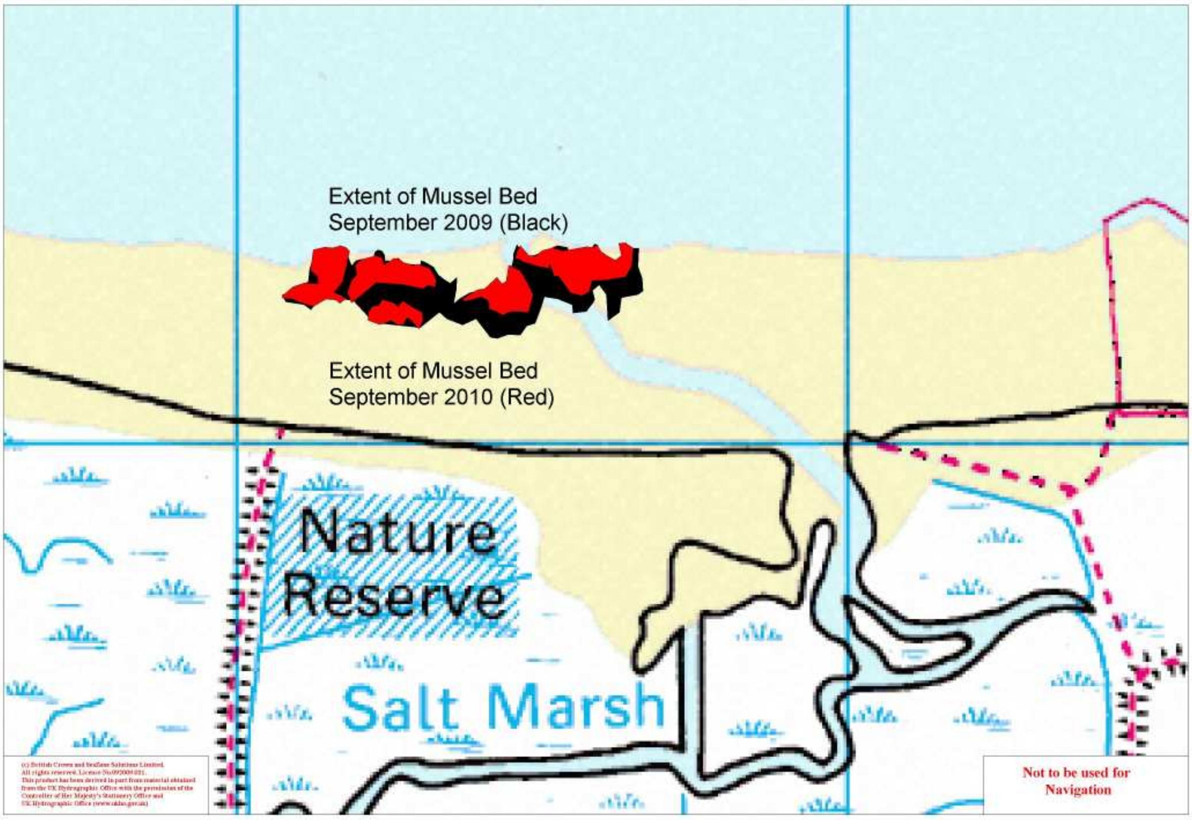


Figure 2.47 Chart showing the extent of the Titchwell Marsh mussel bed in September 2010 (Red) compared to September 2009 (Black)

The survey found that the combined area covered by the five patches of mussels was 2.7 hectares, compared to 0.26 hectares in March. The mussel coverage within these patches was found to vary from 37% to 51%, averaging 41.5% over the site as a whole. Although this is slightly lower than the 44% recorded in March, the mean density of mussels within the patches was found during the same period to have increased from 3.8kg/m^2 to 13.23 kg/m^2. From these figures the total mussel biomass was calculated to be 146 tonnes.

Figure 2.49 shows the aggregated length frequency distribution for the Titchwell bed as a whole. This shows a clear bimodal distribution, indicating two year-classes of mussel, with modal lengths of approximately 18mm and 40mm for years one and two respectively. Most of the mussels were found to be smaller than the 50mm minimum landing size for this part of the District, with only 7 tonnes of the 146 tonnes on the bed having achieved 50mm width.

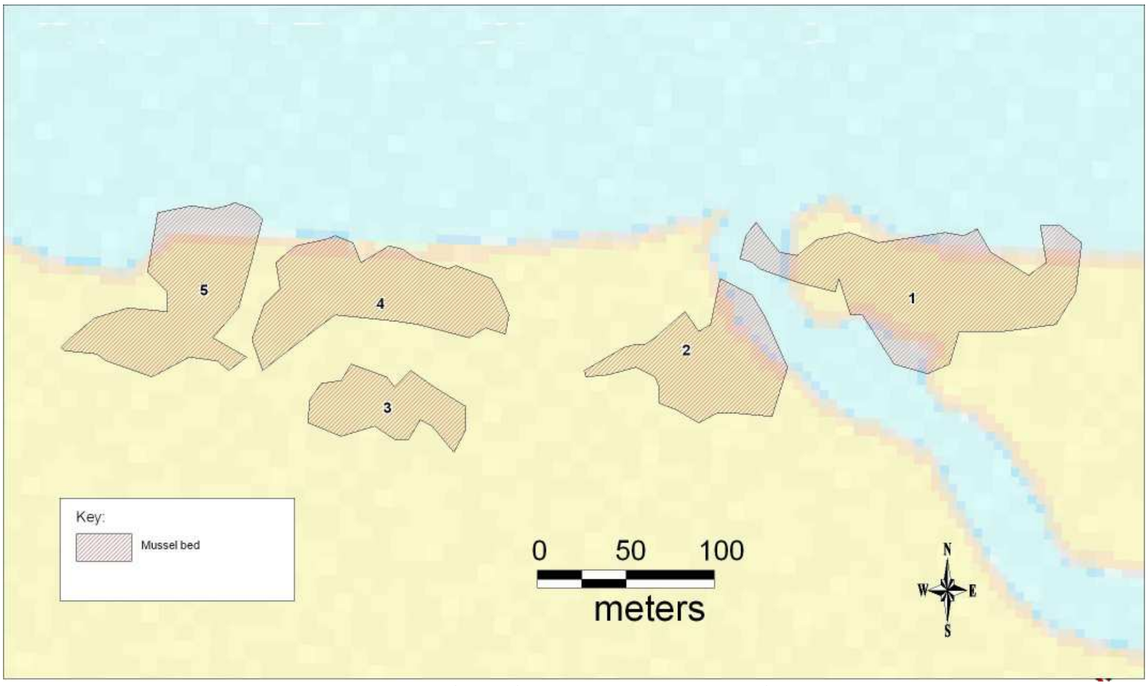


Figure 2.48 Chart showing the extent of the five discrete patches of mussels surveyed at Titchwell Marsh in September 2010

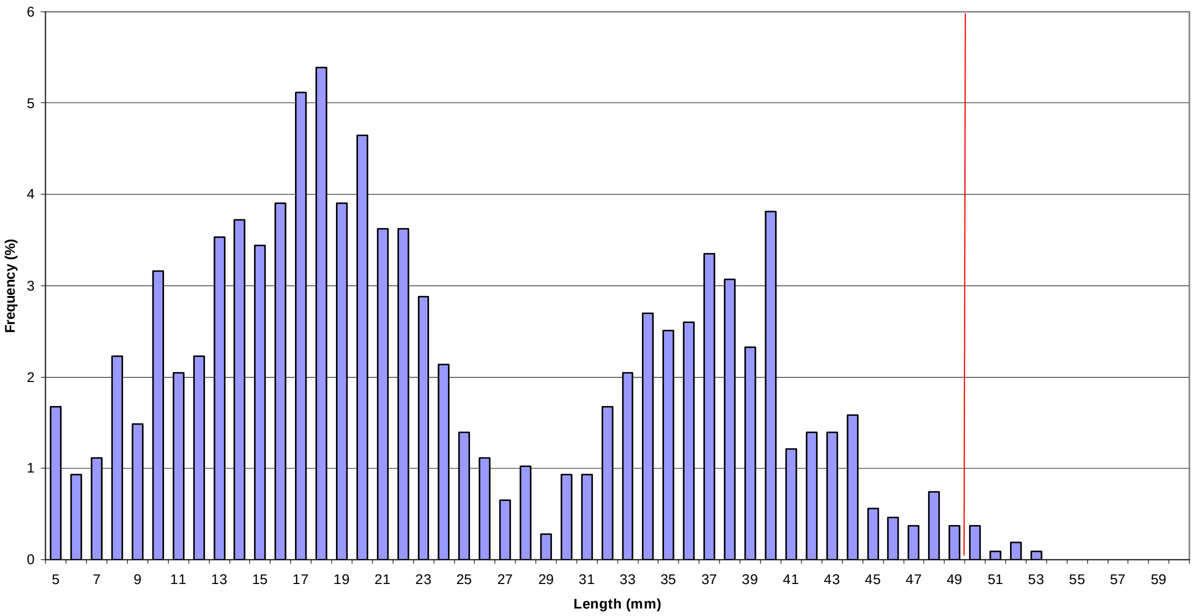


Figure 2.49 Graph showing the population size frequency of the Titchwell Marsh mussels in September 2010

Table 2.3 Summary statistics describing the mussels in each of the five areas shown in figure 2.48

Mussel Patch	Area (ha)	Coverage (%)	Mussel Density (kg/m^2)	Mussel Biomass (Tonnes)	Mussels <30mm (%)	Mussels 30-49mm (%)	Mussels $\geq$50mm (%)
1	0.83	38	12.16	38	71.3	28.3	0.4
2	0.45	48	14.82	32	70.8	28.3	0.9
3	0.26	51	17.13	22	68.4	31.6	0.0
4	0.56	39	13.08	28	61.7	37.7	0.6
5	0.56	37	9.23	19	27.9	67.7	4.4

Table 2.3 shows the variation in mussel coverage, patch density and size composition between the five areas shown in figure 2.48. Although several factors may influence the growth rates of individual mussels, thus making age determinations from size alone unreliable, figure 2.49 shows a clear bimodal distribution in which mussels under 30mm in length are likely to be year-0 and those between 30mm and 49mm are likely to be year-1. The small population that has attained the minimum landing size of 50mm are likely to be survivors of older cohorts. From table 2.3, it can be seen that in mussel patches 1-4 the populations contain high proportions of individuals that are less than 30mm in length, and as such are likely to be from the year-0 cohort. At mussel patch 5, the highest proportion is represented by individuals ranging in size between 30mm and 49mm, likely to be from the year-1 cohort. It appears, therefore, that patches 1-4 received a better settlement of juveniles during 2010 than patch 5. This is supported by the lower mussel coverage and mean patch density recorded at site 5 than the other four. This site also contains the majority of the mussels that were found to have attained the minimum landing size of 50mm.

It can also be seen from table 3 that mussel patch 3 has the highest mussel coverage and mean patch density. This patch is the same area that was surveyed in March 2010 and identified in figure 2.36. During the March survey this patch was estimated to support 4 tonnes of mussels, the size distribution of which was mainly 21-31mm. A similar quantity of mussels was reported as being sparsely scattered over a wider area. As these mussels were attached to the raised peat beds, their distribution if mapped would probably not have been dissimilar to those mapped in September 2010. Although the spatial distribution has remained similar between the two surveys, the figures indicate the mussel biomass had increased significantly.

2.5.5 Discussion

ESFJC has conducted three surveys on a mussel bed at this site in September 2009, March 2010 and September 2010. The initial survey found the mussel biomass to be approximately 420 tonnes, most of which were attached to a layer of pseudo-faeces above raised beds of exposed Neolithic peat. By March only a sparse coverage of mussels remained at the site, mainly concentrated into one core area. Although other patches of mussels were evident at the time of this survey, they did not fully dry so their full extent was not mapped. These patches only had a very sparse coverage, however, so the total mussel biomass was estimated to be less than 10 tonnes. Due to the exposed nature of the site, and the quantity of pseudo-faeces that was found in September to have accreted beneath the mussels, the missing mussels are thought to have washed away during the winter. The survey conducted in September 2010 found there had been a fresh settlement on the bed since the previous survey. The spatial distribution of the bed was found to be similar to that of the previous year, but whereas the coverage in 2009 had been fairly continuous across the site, in 2010 it was limited to five areas of exposed raised peat that were separated by regions of bare sand. This recruitment, combined with the growth of the existing mussels, meant the mussel biomass had increased significantly to an estimated 146 tonnes. These surveys, and anecdotal evidence from fishermen, suggest mussels regularly settle on this area of exposed peat, but that the beds tend to be ephemeral in nature, with the majority of the stocks being lost each winter. Although the population size frequency charts indicate mussel growth in the area is rapid, with individuals attaining the 50mm minimum landing size by their third year, the ephemeral nature of the bed makes the area more valuable as a seed resource.

Although ESFJC generally opens ephemeral beds to exploitation, the location of this bed is highly sensitive. Not only is Titchwell Marsh a RSPB maintained nature reserve, internationally important for wintering waders and ducks, the mussels are attached to a small area of exposed Neolithic peat. Because this peat is relatively soft and fragile, there are concerns that fishing activity could potentially cause irreversible damage to the feature. When surveyed in March the mussels were found to be firmly attached to the substratum with numerous byssal threads. Under such conditions, even a handworked fishery would be damaging. At times when there is a deep layer of protective pseudo-faeces between the mussels and the peat, however, as was the case when surveyed in September 2009, carefully managed fishing activity would be far less disturbing. The timing of such a fishery would be critical, however, as the layer of pseudo-faeces that was protecting the peat would also increase the likelihood of the mussels being washed away during storms.

2.6 Sublittoral Mussels

2.6.1 Introduction

Faced with limited access to the public mussel beds, and frequent poor quality of the stocks therein, the lays of the several fishery are an important part of both The Wash and North Norfolk Coast mussel fisheries. By providing the fishermen with a place in which they can grow good quality mussels, they have given the fishery a stability that would not otherwise be possible. Although some members of the industry import mussel seed from other sites around Britain to relay onto their lays, the cost of this investment is often prohibitive. If they can be found, therefore, sublittoral beds of mussel seed can provide an alternative, less expensive, resource for fishermen wishing to stock their lays. By conducting annual RoxAnn™ Acoustic Ground Discrimination System (ADGS) surveys, Eastern Sea Fisheries have successfully identified several such beds since commencing these surveys in 1993. In 2007 extensive areas of sublittoral seed were discovered to have settled off the Lincolnshire coast between Skegness and Ingoldmells (Jessop, Woo, Torrice. 2007). During the year, fishermen from King's Lynn and Boston relayed approximately 10,000 tonnes of seed from this area onto their lays. Surveys conducted in 2008 found there had been another settlement in this area, with approximately 12,000 tonnes of seed setting into two discrete areas (Jessop, Woo & Harwood, 2008). With their lays already stocked from the previous year, and a market for seed available in the Netherlands, several fishermen took the opportunity to harvest the available seed for export.

In January 2011 ESFJC identified a small bed of mussel seed along the Lincolnshire Coast while conducting *Sabellaria* surveys. A stock assessment was conducted on this bed in February, during which the mussel biomass was estimated to be between 300-600 tonnes. Unfortunately, as the mussels were very small at the time of the survey and were being heavily predated by starfish, it is unlikely many will survive to a size large enough to be successfully relayed.

Also in February, members of the industry notified ESFJC of another bed of sublittoral seed they had identified north of Mundesley on the North Norfolk Coast. A stock assessment was conducted on this bed later that month, during which the stock was estimated to be 22,000 tonnes. Unfortunately, the bed was found to straddle the ESFJC 3-mile limit, the inside area of which was protected by ESFJC byelaw 15 – Towed Gear Restriction for Bivalve Molluscs, prohibiting dredging within the area. Further, although 7,000 tonnes of the mussels were situated outside of the 3-mile limit, the substrate they were attached to was found to be exposed chalk. Although this type of feature is not currently protected, it is one of the interest features of the new Marine Conservation Zones (MCZs) being proposed for this area. In order to minimise potential damage to the feature, therefore, ESFJC imposed a gear restriction on the fishery, ensuring round bars were used in place of blades on the dredges. By the time of writing 16 vessels had applied to fish these stocks, which were opened on March 1st 2011.

2.6.2 Method

RoxAnn^{TM} AGDS tracks were conducted along the Lincolnshire Coast in September 2010 as part of the *Sabellaria* survey programme. When the track data were interpolated to create a model showing the relative hardness of the seabed, an area to the west of the Inner Dowsing wind farm was found to be much softer than the surrounding area, indicating something might be growing there. During the ground truthing of the track data, this area was found to support a bed of mussel seed. Shortly after this bed had been identified, fishermen notified ESFJC of another bed they had identified north of Mundesley on the Norfolk Coast.

Once identified, stock assessments were conducted on both the beds using similar methodologies. Day grab samples were collected from stations within the bed, gradually expanding outward from cardinal points until the edges of the bed were found and mapped. Mussels collected in these samples were measured and weighed and a record made of the substrate. Following grab sampling, ROV video camera drops were conducted in order to ascertain the coverage of the mussels, and in the case of the Norfolk Coast bed, determine whether any elevated chalk reefs were present. The extent of the beds, taken from the grab records, were plotted using MapInfo software, from which their areas could be calculated. The sample weights recorded from the grab records were then used in conjunction with the area of the beds to calculate the mussel biomass within each bed.

2.6.3 Results

The Lincolnshire Coast bed was surveyed on February 8th 2011. Roughly 3.75km in length, the bed was found to cover an area of 170 hectares (figure 2.50). The mussels within the bed were found to be small, ranging between 8-20mm in length, too small for viable relaying operations. Because of their small size, the density of mussels within the bed was also found to be low, ranging between 0.5 tonnes/hectare and 17 tonnes/hectare. Disparity between the mussel densities through the site made a determination of the total biomass difficult, but the stock was estimated to be between 300 tonnes and 600 tonnes. Both the grab samples and video footage found starfish to be present on the bed in large numbers (80-130 starfish/m^2). In some samples over half of the mussels had already been eaten, indicating the bed might not survive long enough for the mussels to grow to size sufficient to be successfully relayed.

A stock assessment was conducted on the Norfolk Coast bed on February 14th 2011. This bed was found to be approximately 4.25km in length and cover an area of 413 hectares (figure 2.51). The size ranges of the mussels varied between stations within the site, but overall were between 20-45mm in length. The mean density of mussels within this bed was found to be 53 tonnes/hectare (range - 1.5 tonnes/hectare and 122.5 tonnes/hectare). From these figures the total mussel biomass was calculated to be 22,000 tonnes.

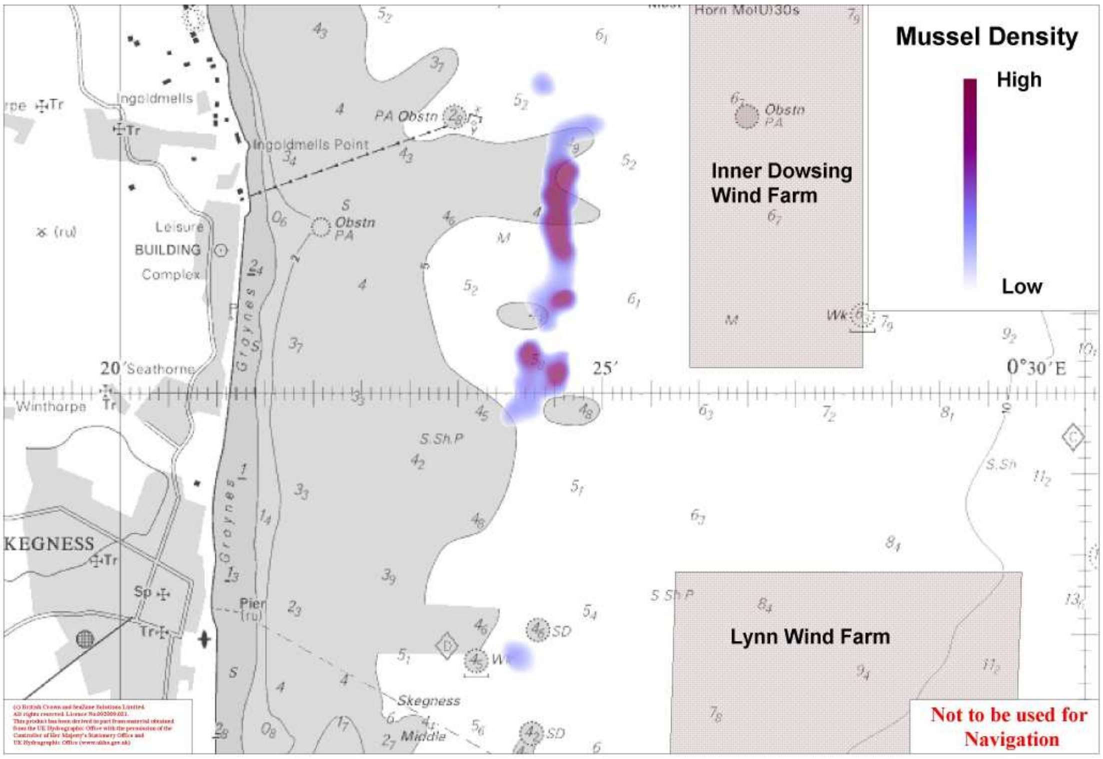


Figure 2.50 Chart showing the distribution of the sublittoral mussels identified on the Lincolnshire Coast to the west of the Inner Dowsing wind farm.

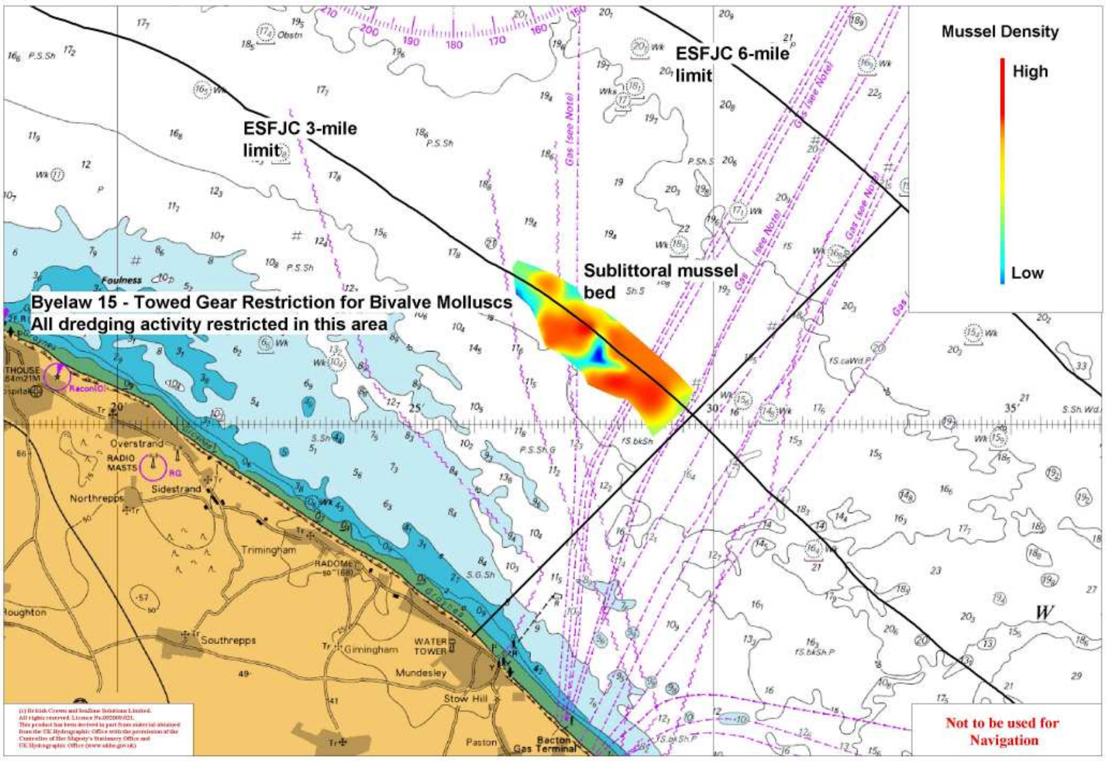


Figure 2.51 Chart showing the distribution of sublittoral mussels identified on the Norfolk Coast to the north of Mundesley.

2.6.4 Discussion

Two beds of sublittoral mussel seed were identified in February 2011. One bed, situated along the Lincolnshire Coast to the west of the Inner Dowsing wind farm (figure 2.50), was in an area that had already been successfully exploited by fishermen from Boston and King's Lynn over the past four years. Although the small size of the mussels within the bed indicated it had been a recent settlement, grab and video footage found large numbers of starfish were already preying on the stocks. The rate of predation indicated that the mussels within this bed might not reach a viable size for successful relaying before being eaten.

The other bed, brought to ESFJC's attention by members of the fishing industry, was situated approximately 3 miles off the Norfolk Coast north of Mundesley (figure 2.51). Although it had not been exploited in the past, anecdotal evidence from North Norfolk crab and lobster fishermen indicated mussel settlement in this area was a common occurrence. The stock assessment conducted on February 14th 2011, however, did not indicate this was an old established bed. Unlike on established beds, few old shells or barnacle-encrusted mussels were found. Instead the mussels ranged in size between 20-45mm, and appeared to represent two year-class cohorts.

Although this bed was estimated to support 22,000 tonnes of mussels, 15,000 tonnes were located within the ESFJC 3-mile limit, placing them within an area in which dredging is prohibited. Although 7,000 tonnes were situated outside of this no-dredge zone, the bed was found have settled on an escarpment of exposed chalk, a feature likely to be protected by the Marine Conservation Zone proposed for this area of the coast. To minimise the risk of causing damage to the chalk, ESFJC imposed a gear restriction on vessels wishing to fish these stocks, ensuring round bars were used on the front of their dredges rather than blades. Of further concern were the numerous pipelines shown in figure 2.51 to be traversing the bed, bringing gas and oil from Europe and the North Sea. It is unclear whether these pipelines are entrenched or sitting on the seabed, but the Maritime and Coastguard Agency (MCA) highlighted serious safety concerns regarding fishing in the area. Notwithstanding the dangers, at the time of writing, application shave been made for 16 vessels to fish these stocks.

3.0 WASH COCKLE STOCKS

3.1 Summary

The annual spring cockle surveys were conducted between April 26th and May 28th 2010. As had been the case in 2009, these were one month later than usual in order to minimise the delay between the completion of the surveys and the commencement of the fishery. During the surveys 1,259 sample stations from 22 sands were surveyed. These included 17 stations on the previously unsurveyed Whiting Shoal sand, where a small bed of cockles had been found by the industry prior to the surveys.

From the surveys the total cockle stock was calculated to be 16,256 tonnes, of which 6,803 tonnes were of marketable size (≥14mm width). These figures are significantly lower than those found in 2009, when following the spring survey the total stock was reported to be 22,419 tonnes, of which 8,395 tonnes had been of marketable size. Apart from approximately 1,400 tonnes that had been harvested during the year by the handworked fishery, most of the losses can be attributed to the atypical mortality that was first noticed to be occurring in the Wash in 2008. This condition, although only appearing to affect relatively low numbers of cockles daily, accounted for approximately 14,000 tonnes of lost stock in 2008 and a further 6,000 tonnes in 2009. As a consequence of these losses, in the space of just three years the cockle stocks in the Wash have gone from their second highest recorded biomass to a situation where it has been difficult for the industry to find patches of adult cockles dense enough to fish. The cause of the mortality, which seems to affect mainly adult cockles as they attain marketable size, is still unknown. Samples sent to CEFAS for analysis, however, were found to contain three species of haplosporidian protozoa, although it is not known whether these parasites are causal factors in the mortality. Unfortunately, following the 2010 surveys, further mortality appeared to be occurring on several of the beds.

As the mortality had mainly affected the larger, faster growing cockles, the prospects for a dredge fishery during 2010 were poor. Although the level of adult stocks would provide a Total Allowable Catch (TAC) exceeding 2,000 tonnes, it was difficult identifying specific beds that would support such a fishery without having a large impact on juvenile stocks. Of the 6,803 tonnes of adult cockles identified, only 3,595 tonnes were present in densities greater than 1.5 tonnes/hectare. Of these, only 1,779 tonnes were present in pockets not dominated by juvenile stocks. Although it was proposed opening Black Buoy Sand (The Dills), Holbeach, Inner Westmark Knock, Whiting Shoal and the Thief beds to the dredge fishery, consultation with the industry revealed mixed feelings towards the proposals. At a Wash Management Sub-Committee meeting, held on June 23rd, it was decided to open the 2010 fishery to handworking only, with an available TAC of 2,081 tonnes. During the course of the season 29 vessels participated in this fishery, exhausting the TAC by December. Towards the end of the season, concerns were raised that some fishermen were landing juvenile cockles. When checked, although a proportion of the cockles were found to be <14mm width, they were from the 2008 year-class cohort, harvested from the Herring Hill sand where growth is traditionally slow due to the elevation.

A second series of cockle surveys were conducted between November 25th and December 10th 2010, during which four beds were surveyed. Although poor weather conditions prevented this series of surveys being more extensive, successful settlements of spat were found on Inner Westmark Knock and Wrangle.

3.2 Method

Samples were collected at regular intervals on a predetermined grid. 1,074 of these were collected at high water using a $0.1m^2$ Day grab deployed from the research vessel, *ESF Three Counties*, and 185 using a $0.1m^2$ quadrat during low water foot surveys. This is fewer foot samples than usual, mainly as a consequence of difficulties experienced this year in accessing the Holbeach Range from shore during weekend periods.

The samples were washed over a 3mm mesh washing table, allowing any cockles present in the sample to be separated from the surrounding sediment. A note was made of the sediment type at each station and the cockles retained in labelled bags for later analysis. At low water the retained samples were individually measured by length and width. These cockles were separated into three groups: those of width equal or greater than 16mm, those of width 14 to 15mm and those smaller than 14mm. These were further separated into age classes and weighed. Due to the sensitivity of the scales used (200g/0.01g), the weighing of these samples could only take place ashore or once the vessel was aground.

The data acquired from these surveys was transferred to a GIS database from which charts of the beds showing cockle densities could be created. The minimum density used to determine the extent of the coverage on the bed was 10 cockles/m^2. The tonnage of stock on the bed was calculated by multiplying the mean weight of the samples to attain a weight per hectare, this figure was applied to the area of coverage. The tonnage of fishable stock was determined by using the mean weight of those individuals having reached a width of 14mm or greater.

At each site additional environmental data were also recorded. This included information concerning the sediment type, and the presence of the polychaete, *Lanice conchilega* and the bivalve mollusc, *Macoma balthica*. At those sites visited on foot, the numbers of *Arenicola marina* casts were also recorded. The findings of this information are reported in Section 8.

3.3 Spring Survey Results

The 2010 spring survey results revealed there had been a significant loss of cockle stocks from most of the intertidal beds compared to the same period in 2009. Even on the Dills sand, which had supported a high proportion of the 2009 handwork fishery, losses greatly exceeded fishery landings. Most of these losses have been attributed to an unexplained mortality that killed an estimated 14,000 tonnes of cockles in 2008 and a further 6,000 tonnes during 2009. Having mainly affected the faster growing adult cockles, the traditional fishing grounds have suffered the greatest impact from this mortality, leaving the remaining marketable cockles either in low-density patches dominated by juvenile stocks, or situated on high, silty ground. Two exceptions were found on the southern side of the Thief Sand and on Whiting Shoal/Hull Sand, where dense populations of 2008 year-class cockles were found.

3.3.1 Boston Main

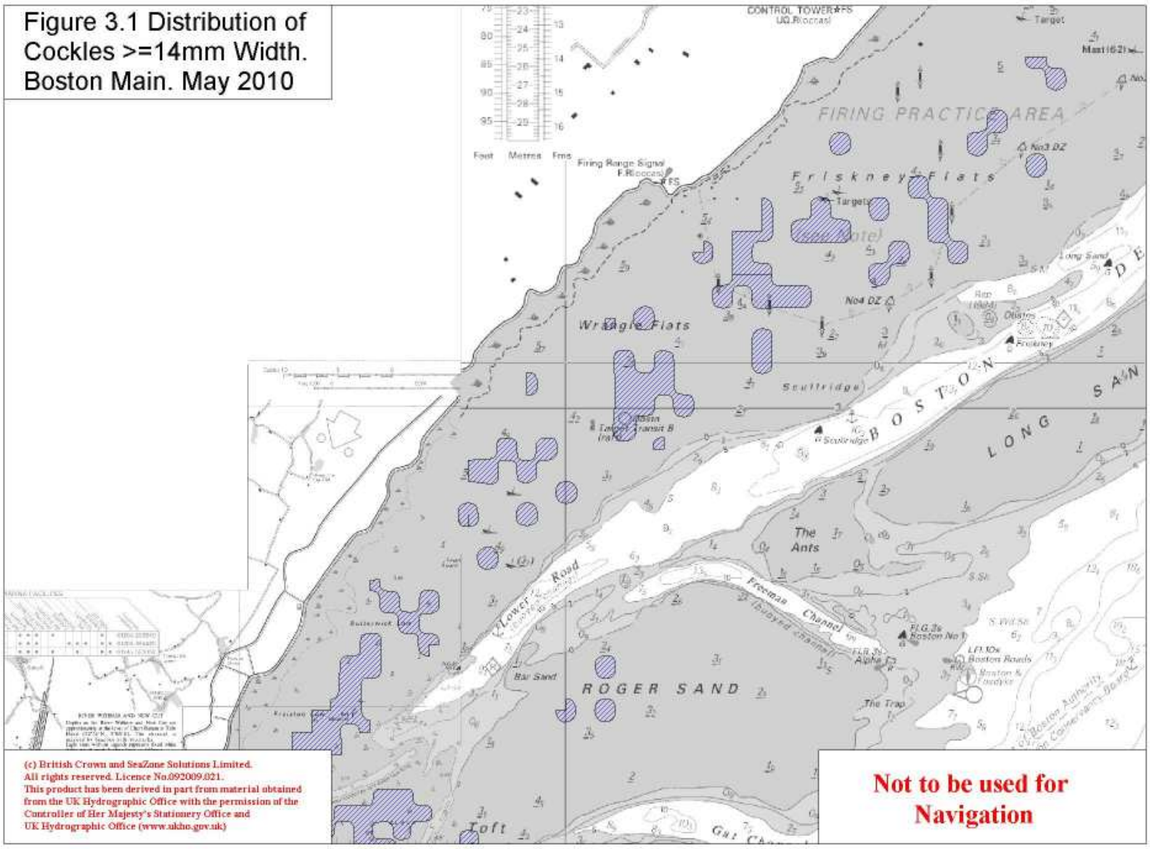
Figures 3.1 and 3.2 show the adult and juvenile cockle distributions found at Boston Main during the spring surveys. These stocks were found to have declined from 2,046 tonnes in 2009 to 1,083 tonnes. Whereas the initial population crash, which had reduced the stocks from 11,040 tonnes in 2008, had occurred mainly on Friskney and Wrangle, this recent decline had also had a heavy impact on Butterwick. Spread sparsely over a large area, these stocks were unable to support either a dredge or handwork fishery.

3.3.2 Butterwick Low

81 stations at Butterwick Low were visited during the spring surveys on April 28th 2010. 30 of these were sampled using a quadrat at low water, and the remaining 51 using a Day Grab over the high water period. As has been the case since 2004, samples were taken above 4.0m drying height to the edge of the green marsh.

The survey found that there had been a successful settlement of spat in this area during 2009, which combined with significant losses among the adult population, had changed the population structure of this bed. In the traditionally surveyed areas (those below 4.0m drying height), cockles of marketable size ($\geq$14mm width) were found at seven stations, covering an area of 63 hectares. Within the extended zone, covering the higher stations, cockles of this size range were found to be present in 15 samples, covering 153 hectares. Although overall the area covered by marketable stocks had decreased from 341 hectares in 2009 to 216 hectares, most of this loss had occurred from the lower parts of the bed where mortality had been more prevalent. At the higher sites, where cockle growth had been slower, the area occupied by marketable sized cockles had increased, mainly as a result of 2008 year-class cockles attaining 14mm width since the previous survey. Within the traditionally surveyed area the mean

Figure 3.1 Distribution of Cockles >=14mm Width. Boston Main. May 2010



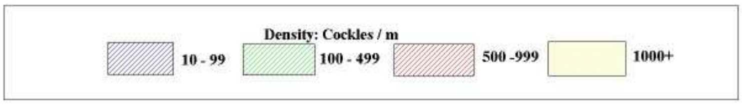
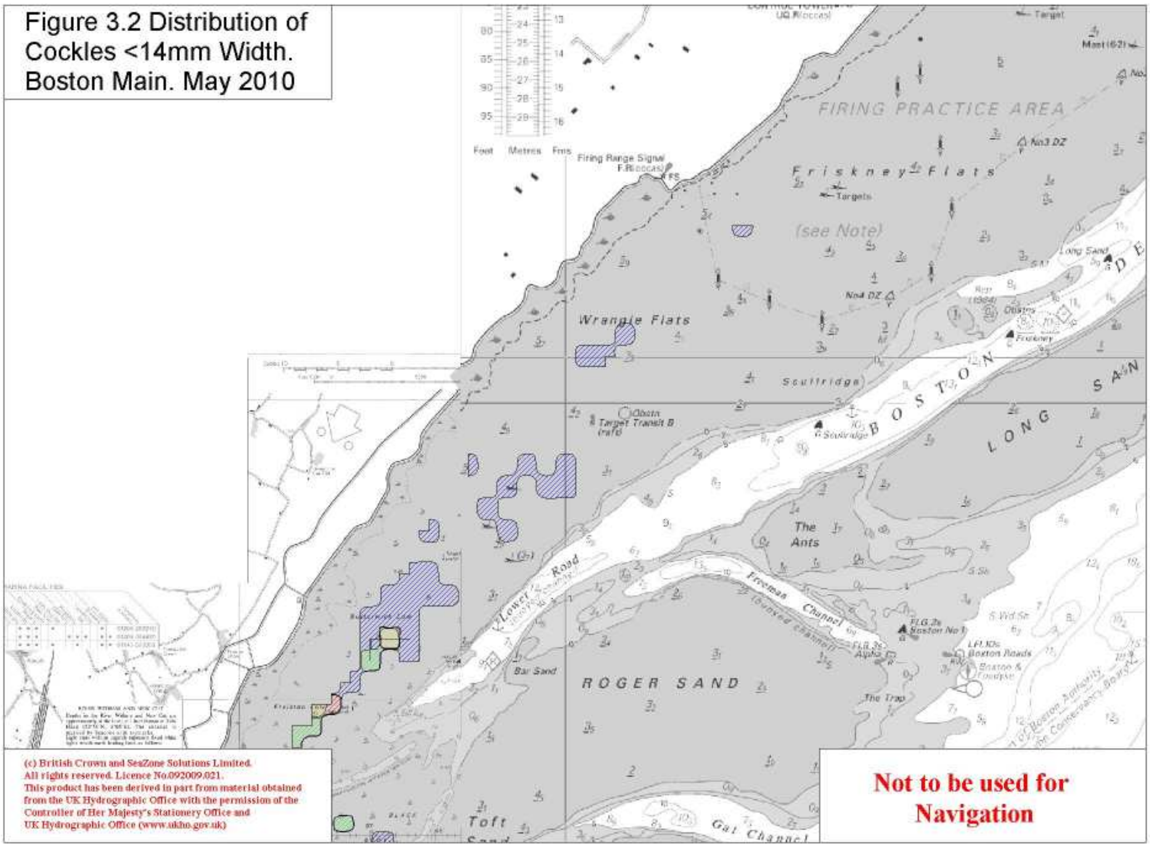
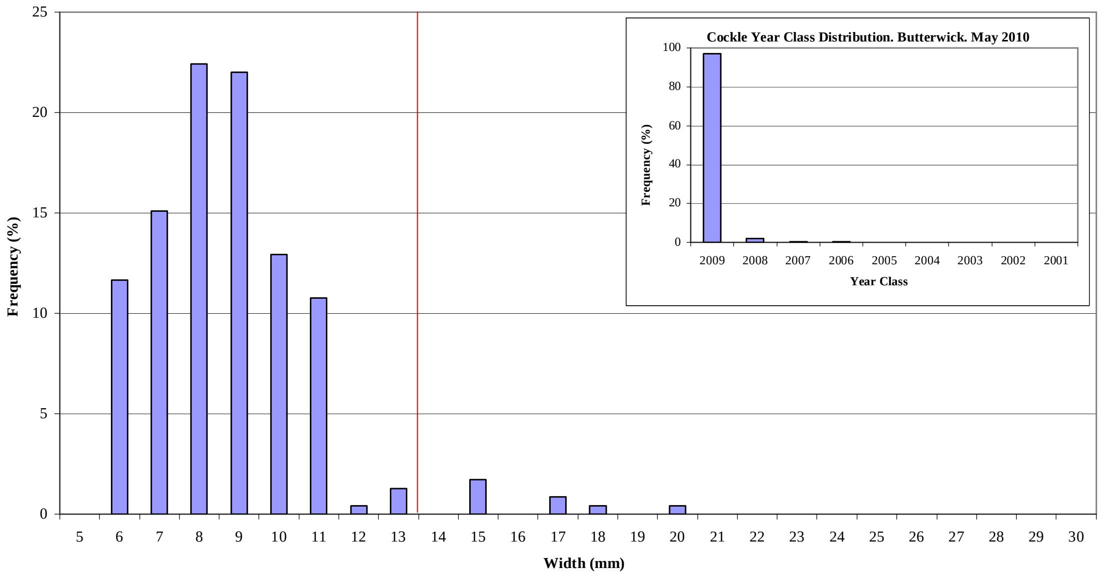


Figure 3.2 Distribution of Cockles <14mm Width. Boston Main. May 2010



cockle density was found to be 11.43 cockles/m^2 (range 10 – 20/m^2), a reduction from the 29.33 cockles/m^2 (range 10 – 150/m^2) recorded in 2009. At 0.51 tonnes/hectare, the mean weight had also decreased from the 1.84 tonnes/hectare reported the previous year. Within the extended zone, recruitment of juveniles during the year into this population group meant the mean density of marketable sized cockles had increased slightly from 18.18 cockles/m^2 (range 10 – 50/m^2) to 21.33 cockles/m^2 (range 10 – 90/m^2). Because the average size of these cockles was smaller than the previous year, however, the mean weight of these stocks had decreased from 0.91 tonnes/hectare to 0.80 tonnes/hectare. From these figures the stock of marketable cockles within the traditionally surveyed area was found to be 37 tonnes, a 91% loss from the 419 tonnes recorded to be present in 2009. During the same period, the marketable stock at the higher sites was found to have increased slightly from 103 tonnes to 122 tonnes.

Figure 3.3 Cockle Size Frequency. Butterwick. May 2010



Smaller cockles (<14mm width) were found to be present at 11 stations within the traditionally surveyed region, covering an area of 105 hectares, and at a further 13 stations in the extended region, covering 149 hectares. Both of these are increases in coverage to the previous year in which 97 hectares of the lower ground and 124 hectares of the higher ground had supported juvenile stocks. Within the traditionally surveyed area the settlement of spat during 2009 meant the mean density of smaller cockles had increased from 31.0 cockles/m^2 (range 10 – 70/m^2) to 207.3 cockles/m^2 (range 10 – 2,000/m^2), while the mean weight had increased from 0.44 tonnes/hectare to 1.23 tonnes/hectare. Within the extended zone, however, where there had been less settlement combined with existing small cockles growing to marketable size, the mean density of small cockles was found to have declined from 452.7 cockles/m^2 (range 10 – 2,400/m^2) to 257.7 cockles/m^2 (range 10 – 1,600/m^2) and the mean weight from 3.14 tonnes/hectare to 2.28 tonnes/hectare. From these figures the biomass of juvenile cockles within the traditionally surveyed area was calculated to be 129 tonnes, 200% higher than the 43 tonnes recorded in 2009. During the same period the stock of smaller cockles within the extended zone had declined slightly from 389 tonnes to 339 tonnes.

The total stock of cockles in Butterwick was calculated to be 627 tonnes, of which 461 tonnes were located in the extended area. This is a significant decline from the 954 tonnes recorded to be present in 2009, and shows a worrying trend of decline that has seen cockle stocks in this area fall from 1,921 tonnes in 2008 and 4,126 tonnes in 2007. Figure 3.3 shows the population size structure of the cockles found at Butterwick in May.

3.3.3 Wrangle Flats

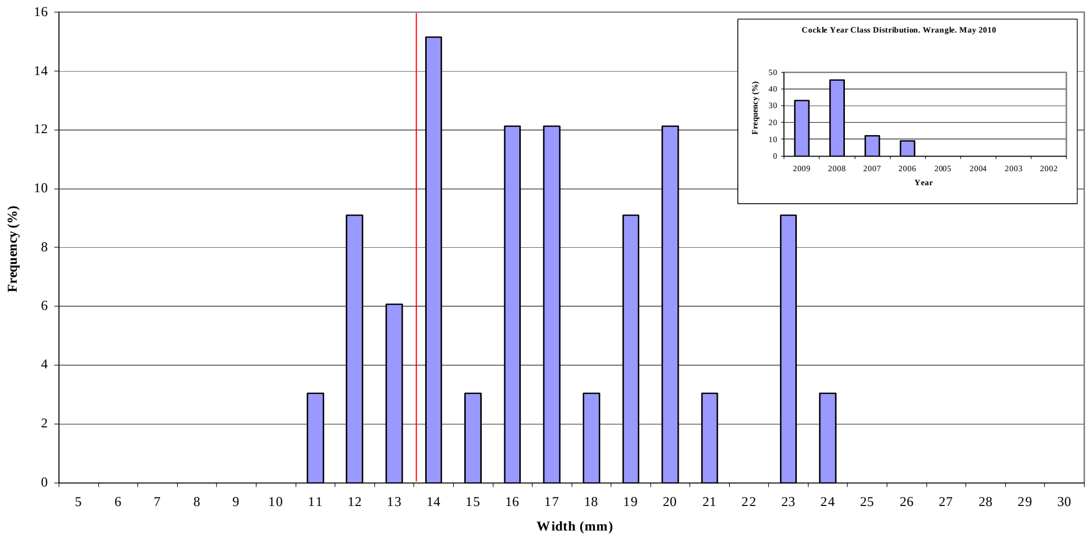
120 sites on Wrangle were sampled during the spring surveys, covering an area that extended as far as the green marsh. All of the stations were sampled on April 26th 2010, 48 on foot during the low water period and 72 using a Day grab over high water.

The atypical mortality that had killed many cockles in Wrangle during 2008 appeared to have continued during 2009, leaving only low densities of marketable stocks remaining. Within the traditionally surveyed area 18 stations, covering 194 hectares, were found to contain marketable sized cockles, a decline from the 242 hectares recorded in 2009. Similarly, in the extended zone, where three stations were found to contain marketable sized cockles, the coverage had declined from 60 hectares to 38 hectares. The mean density of marketable cockles within the traditionally surveyed area had decreased slightly from 17.92 cockles/m^2 (range 10 – 50/m^2) to 15.00 cockles/m^2 (range 10 – 50/m^2), as had the mean weight, from 1.19 tonnes/hectare to 0.94 tonnes/hectare. Within the extended zone the mean density of marketable sized cockles had decreased from 14.00 cockles/m^2 (range 10 – 20/m^2) to 10.00 cockles/m^2 (range 10 – 10/m^2), and the mean weight from 0.78 tonnes/hectare to 0.45 tonnes/hectare. From these figures the biomass of marketable sized cockles within the traditionally surveyed region of Wrangle was calculated to be 182 tonnes, a 37% reduction from the 288 tonnes recorded in 2009. Similarly, the stock in the extended zone was found to have declined from 76 tonnes to 33 tonnes.

There had been a small settlement of spat in Wrangle during 2009, but this was insufficient to compensate natural mortality or replace juveniles that had grown and been recruited into the population of marketable sized cockles. As a consequence the area within the traditionally surveyed region that supported small cockles had declined from 17 stations covering 177 hectares in 2009 to six stations covering 47 hectares. The mean density of these cockles was found to have declined slightly from 11.76 cockles/m^2 (range 10 – 30/m^2) to 10.00 cockles/m^2 (range 10 – 10/m^2) and the mean weight from 0.26 tonnes/hectare to 0.21 tonnes/hectare. Similarly, declines in the extended region meant the area of coverage had decreased from five sites covering 60 hectares to three sites covering 38 hectares. Within this region the mean density of small cockles had remained the same at 10.00 cockles/m^2 (range 10 - 10/m^2), while the mean weight had increased slightly from 0.24 tonnes/hectare to 0.28 tonnes/hectare. From these figures the biomass of small cockles in the traditionally surveyed regions of Wrangle was calculated to be 10 tonnes, a 78% decline from the previous year. Within the extended zone, the biomass was calculated to be 11 tonnes, slightly less than the 14 tonnes recorded in 2009.

The total cockle biomass within Wrangle was estimated to be 236 tonnes, of which 44 tonnes were situated in the extended zone. This is a significant decline from the 424 tonnes recorded in 2009, and shows the problems that have reduced the stocks in this area from 5,443 tonnes in 2008 and 8,277 tonnes in 2007 are not over. Figure 3.4 shows the population size structure of the cockles found at Wrangle when surveyed in May.

Figure 3.4 Cockle Size Frequency. Wrangle. May 2010



3.3.4 Friskney

180 survey stations were sampled in Friskney during the spring surveys, extending to the edge of the green marsh and north-east into the Swatchway. 23 of these were sampled on foot on April 27th 2010 and the rest using a Day grab at high water on April 27th and 28th.

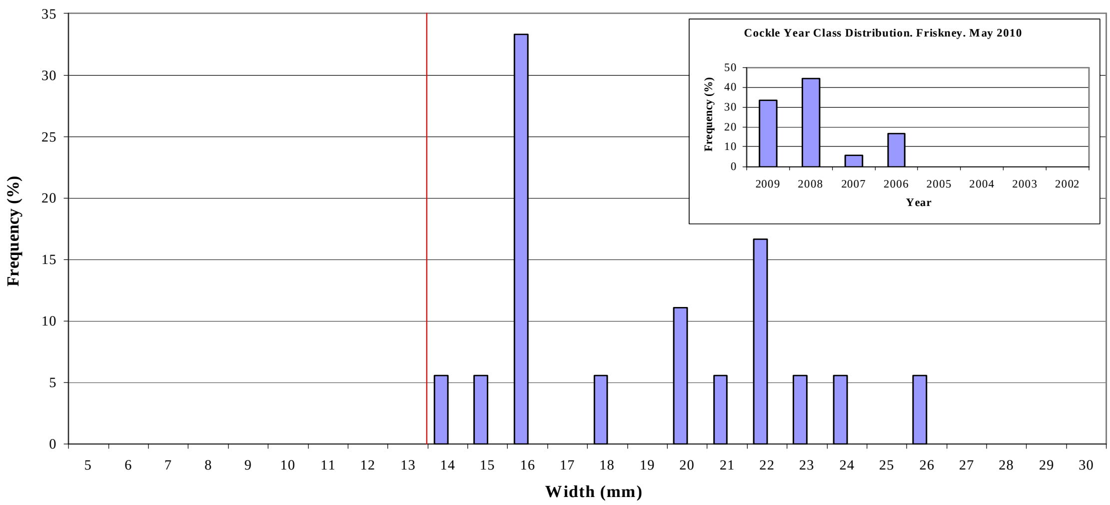
There had been a light settlement of spat in this region during 2009, but this had not compensated for natural mortality that had occurred in the region. Marketable sized cockles were found at 15 of the survey stations within the area traditionally surveyed zone, covering 129 hectares. This was a large reduction from the 285 hectares supporting cockles of this size range in 2009. Within this area the mean density of marketable sized cockles was found to have declined from 16.77 cockles/m^2 (range 10 - 40/m^2) to 12.00 cockles/m^2 (range 10 - 20/m^2), and the mean weight from 0.97 tonnes/hectare to 0.92 tonnes/hectare. Twelve stations covering 146 hectares were found to support marketable sized cockles within the extended zone, a reduction from the 24 stations covering 305 hectares reported in 2009.

Within this area their mean density was found to have declined from 14.58 cockles/m^2 (range 10 - 40/m^2) to 12.50 cockles/m^2 (range 10 - 40/m^2), and their mean weight from 1.06 tonnes/hectare to 0.69 tonnes/hectare. From these figures the traditionally surveyed region of Friskney was calculated to support a marketable sized cockle biomass of 119 tonnes, 57% lower than in 2009. The extended region was calculated to support a marketable stock of 100 tonnes, 69% lower than the previous year.

Although there had been a light settlement of spat in this area following the 2009 surveys, growth had been rapid and by the time of the 2010 survey, most individuals had attained 14mm width. As a consequence, only one station was found to support small cockles in Friskney, representing an area of 6 hectares in the extended zone. With a mean density of 10 cockles/m^2 and a mean weight of 0.11 tonnes/hectare, this equated to a biomass of 0.6 tonnes, a reduction from the 67 tonnes present in 2009.

The total stock on Friskney was found to be 220, a significant reduction from the 668 tonnes recorded in 2009. Figure 3.5 shows the population size structure of the cockles found at Friskney in May.

Figure 3.5 Cockle Size Frequency. Friskney. May 2010



3.3.5 Herring Hill

Until 2009 the Herring Hill survey had incorporated sites from both the Herring Sand and the southern parts of the Black Buoy Sand. After significant cockle stocks were found to be present on the northern part of Black Buoy Sand in 2009, however, additional survey stations were added and the survey split into separate Herring Hill and Black Buoy Sand surveys. The Herring Hill survey was conducted on May 27th and 28th, during which 55 stations were sampled at high water using a Day grab. Figures 3.6 and 3.7 show the distribution of adult and juvenile cockles found at the time of this survey, while figure 3.8 shows the population size frequency.

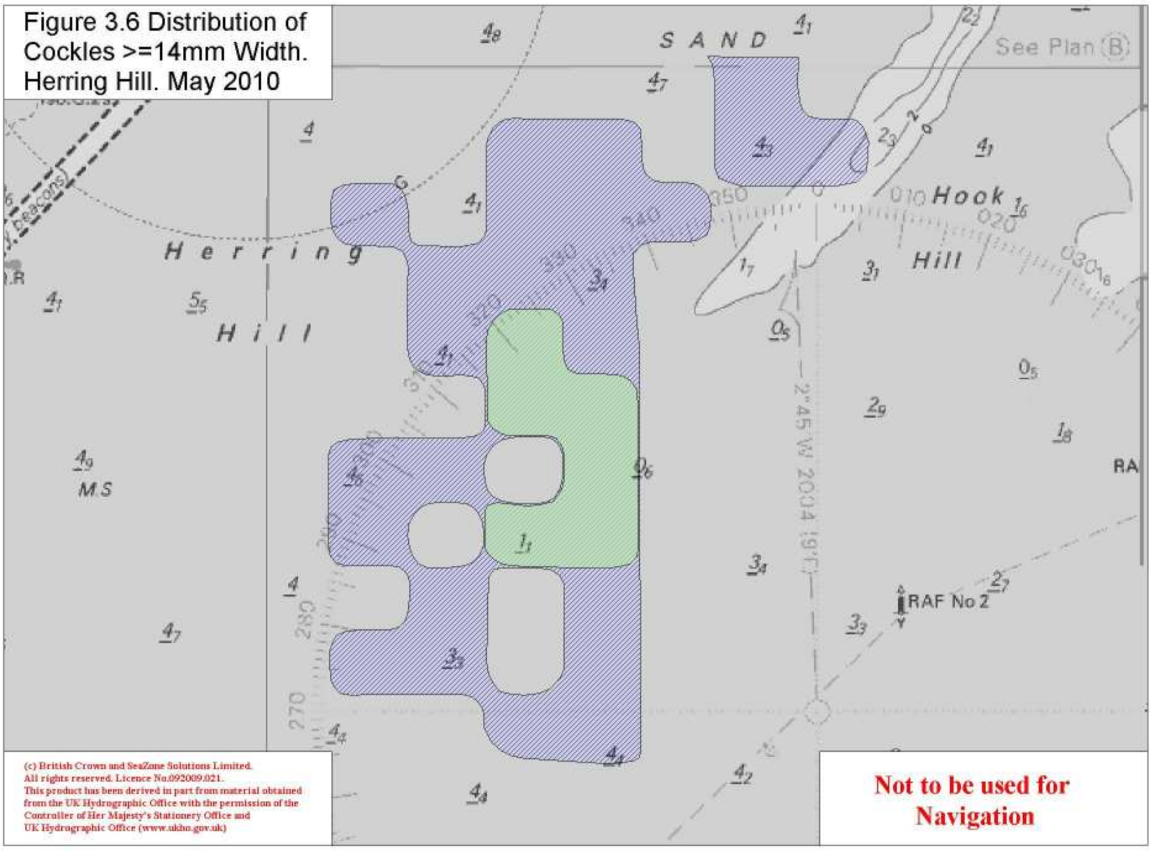
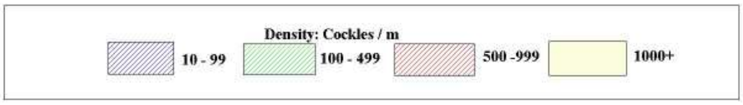


Figure 3.6 Distribution of Cockles >=14mm Width. Herring Hill. May 2010
S A N D
Herring
Hill
Hook
Hill
See Plan B
RAF No 2
(c) British Crown and SeaZone Solutions Limited. All rights reserved. Licence No.092009.021. This product has been derived in part from material obtained from the UK Hydrographic Office with the permission of the Controller of Her Majesty's Stationery Office and UK Hydrographic Office (www.ukho.gov.uk)
Not to be used for Navigation


Density: Cockles / m
10 - 99
100 - 499
500 -999
1000+

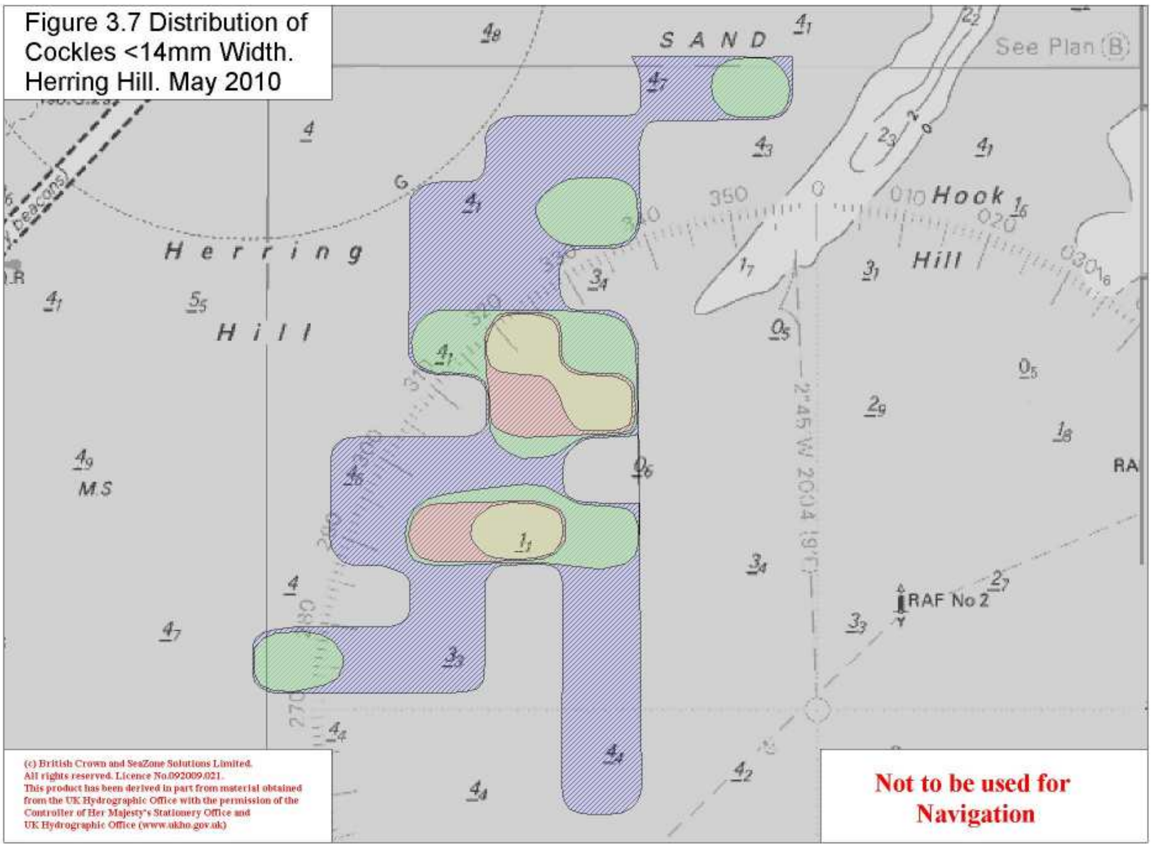


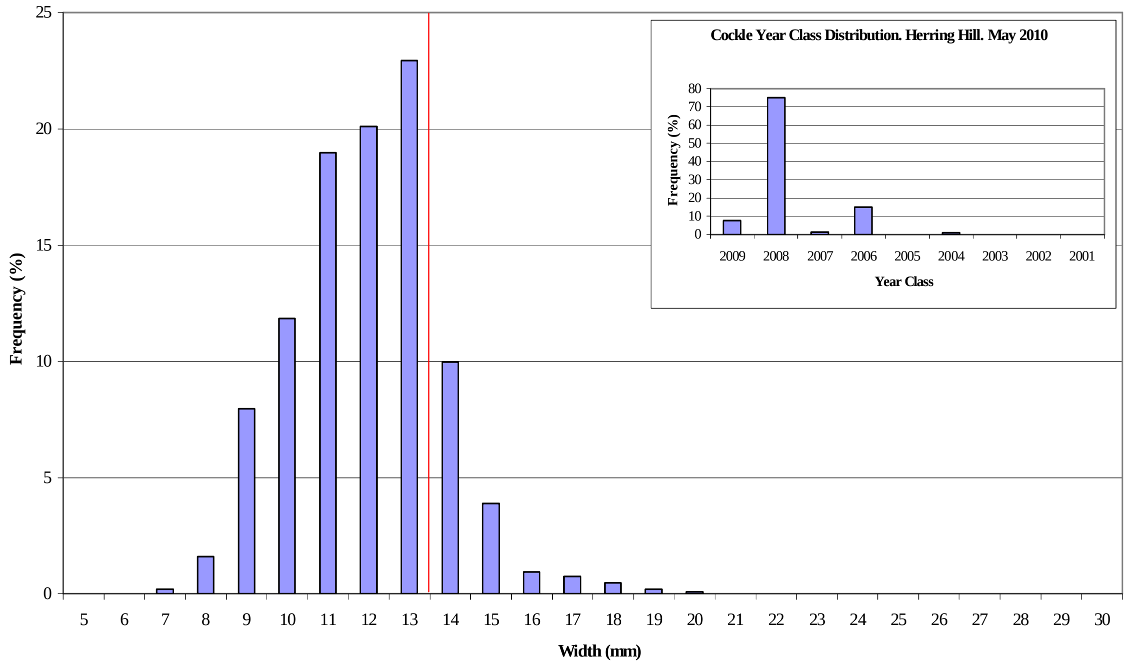
Figure 3.7 Distribution of Cockles <14mm Width. Herring Hill. May 2010
S A N D
Herring
Hill
Hook
Hill
See Plan B
RAF No 2
(c) British Crown and SeaZone Solutions Limited. All rights reserved. Licence No.092009.021. This product has been derived in part from material obtained from the UK Hydrographic Office with the permission of the Controller of Her Majesty's Stationery Office and UK Hydrographic Office (www.ukho.gov.uk)
Not to be used for Navigation

Although there had been a light settlement following the 2009 surveys, the cockle stocks on this bed were found to be dominated by the 2008 year-class cohort. Although most of these were still smaller than 14mm width, some had grown and recruited into the marketable size range group. As a consequence the area supporting marketable sized cockles on this bed had grown from 20 stations covering 167 hectares in 2009 to 30 stations covering 283 hectares in 2010. Within this area the mean density of marketable sized cockles was found to have increased from 26.00 cockles/m^2 (range 10 – 130/m^2) to 57.33 cockles/m^2 (range 10 – 310/m^2), and the mean weight from 1.01 tonnes/hectare to 1.98 tonnes/hectare. From these figures the biomass of marketable sized cockles on this bed was calculated to be 559 tonnes, a significant increase on the 168 tonnes recorded in 2009.

Cockles smaller than 14mm width were found at 29 stations, covering 271 hectares. This is a reduction from the 45 sites covering 396 hectares recorded in 2009. Because of a combination of mortality and some of the smaller cockles growing and recruiting into the marketable population, the mean density of small cockles on this bed was found to have declined from 624.1 cockles/m^2 (range 10 – 6,690/m^2) to 270.3 cockles/m^2 (range 10 – 2,080/m^2). As these cockle were generally larger than they were in 2009, however, the mean weight was found to have increased during the same period from 4.35 tonnes/hectare to from 5.44 tonnes/hectare. From these figures the biomass of small cockles on Herring Hill was calculated to be 1,472 tonnes, 15% lower than the 1,724 tonnes recorded in 2009.

The total cockle biomass on Herring Hill was calculated to be 2,031 tonnes, a 7% increase on the 1,892 tonnes recorded in 2009.

Figure 3.8 Cockle Size Frequency. Herring Hill. May 2010



3.3.6 Black Buoy Sand

Prior to 2009 the southern parts of Black Buoy Sand had been surveyed as part of the Herring Hill survey, while the northern parts of this bed had remained outside of the spring survey area. Following the discovery, in 2009, of dense patches of 2006 year-class cockles on the northern part of Black Buoy Sand, in an area known locally as the Dills Sand, additional sites were added to the survey programme to cover the whole of the Black Buoy Sand. The 2009 survey estimated over 3,400 tonnes of cockles were present on this sand, which subsequently supported a high proportion of the 2009 handwork fishery. Monitoring of this bed throughout the fishery, however, indicated the cockles were dying as the season progressed. When resurveyed in November 2009, it was found that the stock had fallen to 523 tonnes, the decline almost double what could be attributed to fishing effort alone.

The 2010 spring survey was conducted on May 27th and 28th 2010, during which 34 stations were surveyed over high water using a Day grab. Figure 3.9 shows the population size frequency at the time of the survey.

During this survey 17 stations covering an area of 160 hectares were found to support cockles of marketable size (figure 3.10). Although this is not a large decline from the 179 hectares recorded after the spring surveys in 2009, the mean density was found to have fallen from 369.75 cockles/m^2 (range 10 – 2,515/m^2) to 34.12 cockles/m^2 (range 10 – 120/m^2), and the mean weight from 12.76 tonnes/hectare to 1.82 tonnes/hectare. From these figures the biomass of marketable sized cockles on this bed was found to be 291 tonnes, an 87% reduction from the 2,280 tonnes recorded in 2009.

Figure 3.9 Cockle Size Frequency. Black Buoy. May 2010

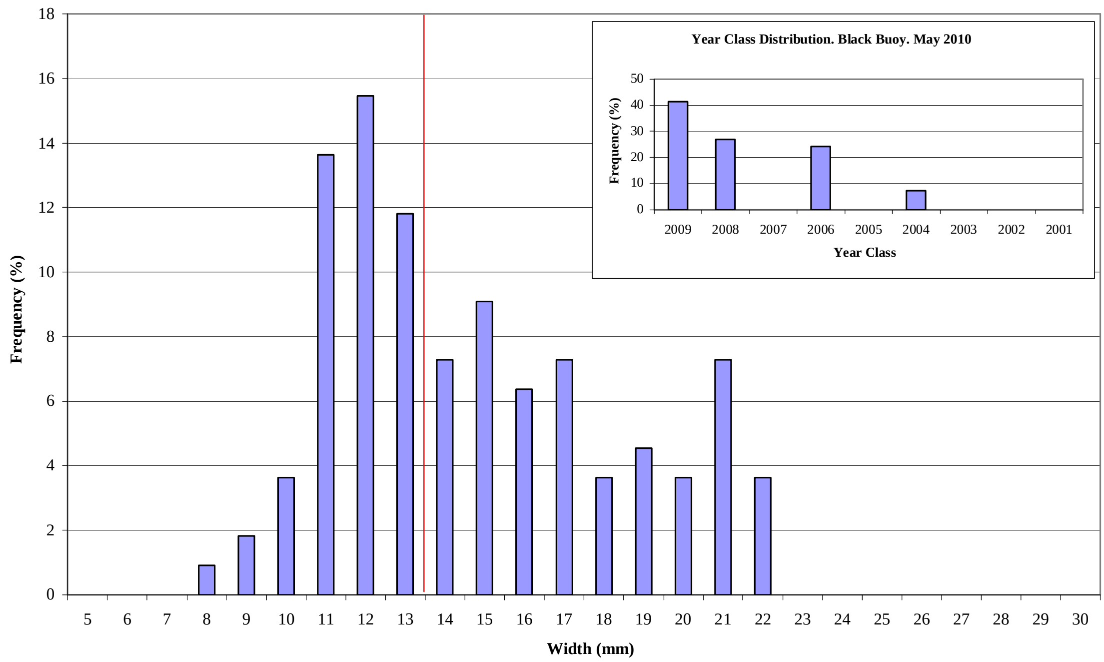
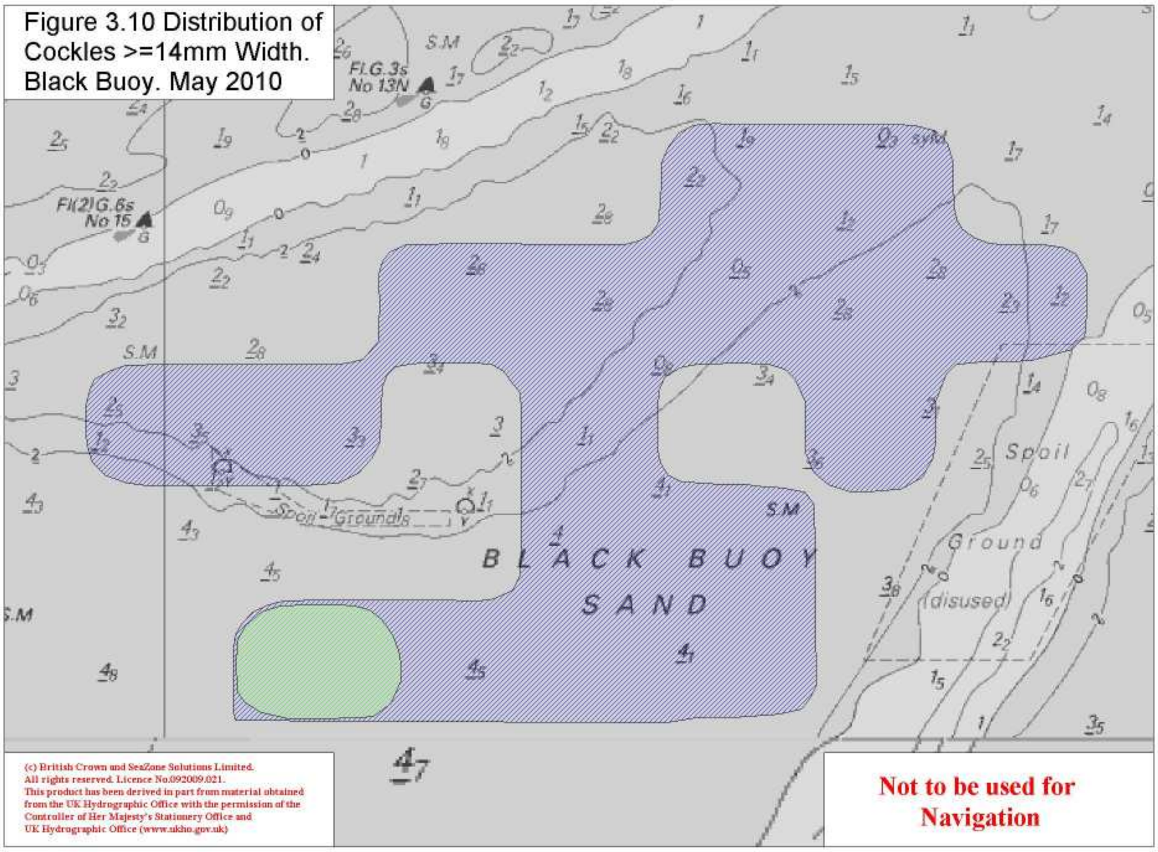


Figure 3.10 Distribution of Cockles >=14mm Width. Black Buoy. May 2010



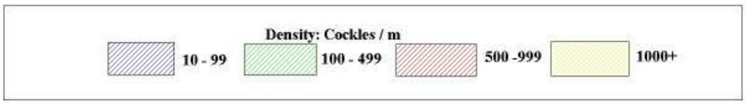
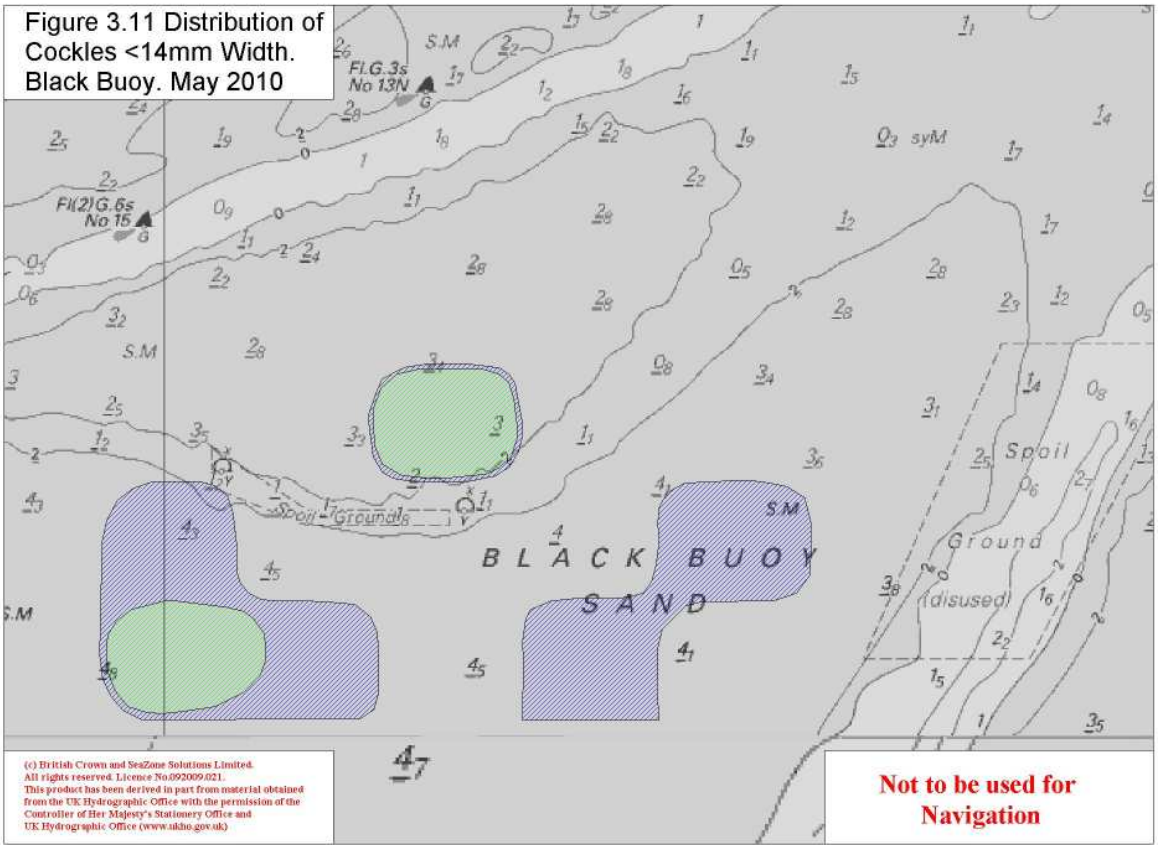


Figure 3.11 Distribution of Cockles <14mm Width. Black Buoy. May 2010



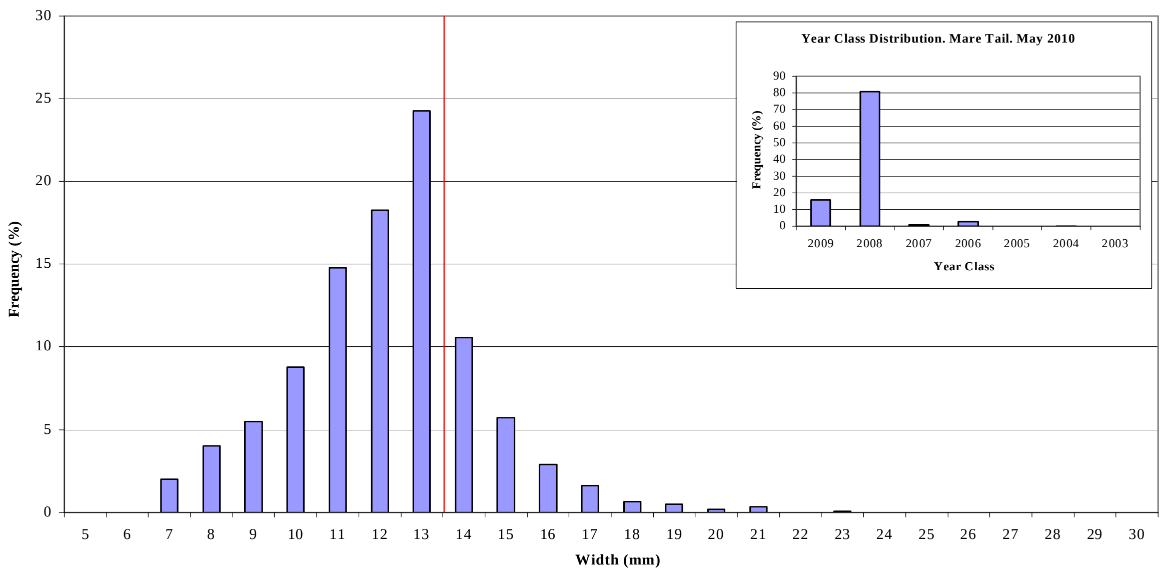
Although there had been a small settlement of spat following the 2009 surveys, this had settled mainly in the southern part of the bed, and did little to replace mortality that had occurred during the year, or to compensate for cockles that had grown and been recruited into the marketable population. As a consequence, the area supporting small cockles on this bed had decreased from 15 sample sites covering 139 hectares in 2009 to six stations covering 54 hectares (figure 3.11). Their mean density was found to have declined from 325.67 cockles/m^2 (range 10 – 2,200/m^2) to 88.33 cockles/m^2 (range 20 – 170/m^2), and their mean weight from 8.24 tonnes/hectare to 1.42 tonnes/hectare. From these figures it was calculated that the biomass of small cockles on this bed had fallen 93%, from 1,142 tonnes in May 2009 to just 77 tonnes.

3.3.7 Mare Tail

Mare Tail was surveyed on May 17th 2010, during which 62 stations were sampled using a Day grab over the high water periods. The previous survey had found this bed to be dominated by dense patches of 2008 year-class cockles. As expected, mortality had been high during the past year with many of the individuals having "ridged out" as they had grown and competed for space. Some of this cohort, having attained 14mm width, had been recruited into the marketable population. Figure 3.12 shows the population size frequency at the time of the survey.

Marketable sized cockles were found to be present at 32 stations covering 308 hectares, a good increase on the 24 stations covering 208 hectares recorded in 2009 (figure 3.13). These were found to have a mean density of 87.19 cockles/m^2 (range 10 – 540/m^2) and a mean weight of 3.60 tonnes/hectare, both significant increases on the 39.16 cockles/m^2 (range 10 – 320/m^2) and 2.00 tonnes/hectare recorded the previous year. From these figures the biomass of marketable sized cockles on this bed was found to have increased from 417 tonnes in 2009 to 1,108 tonnes.

Figure 3.12 Cockle Size Frequency. Mare Tail. May 2010



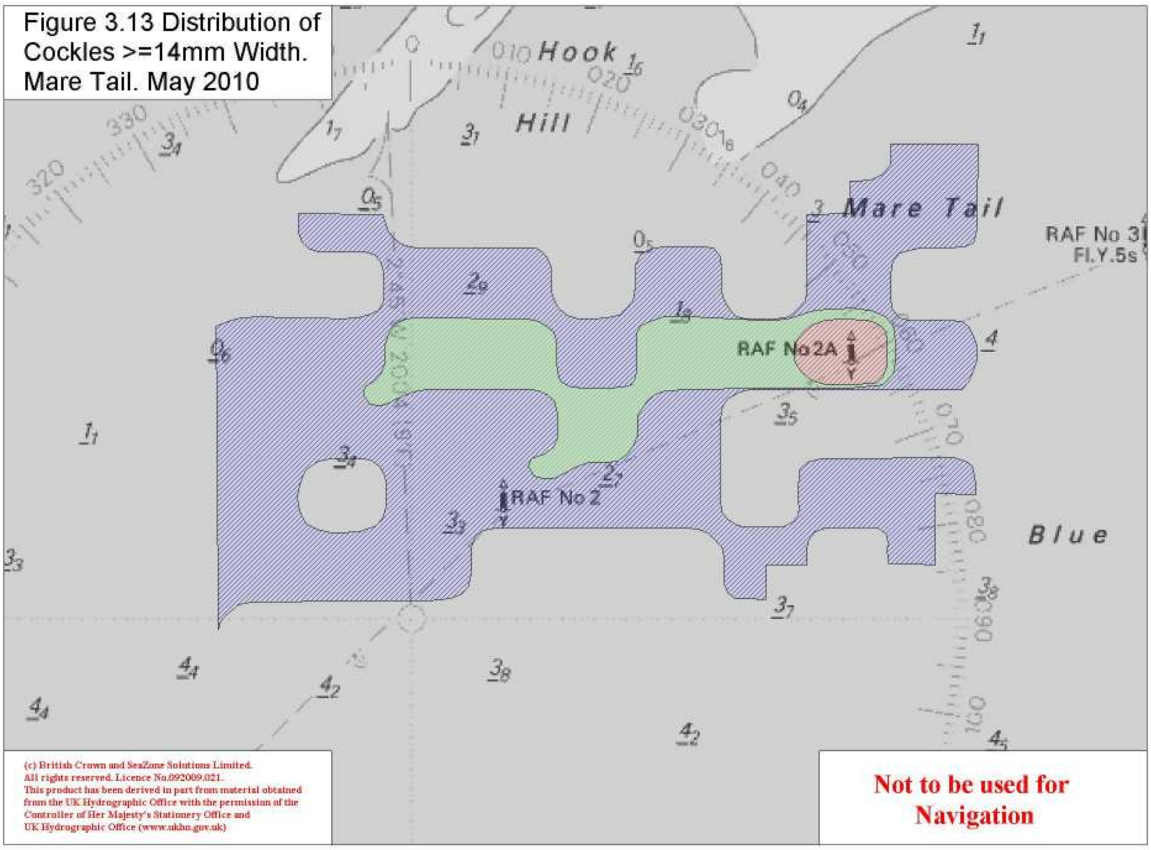
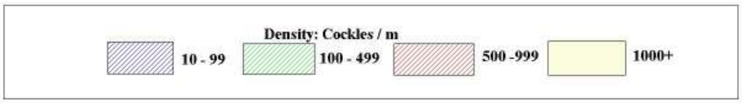


Figure 3.13 Distribution of Cockles >=14mm Width. Mare Tail. May 2010



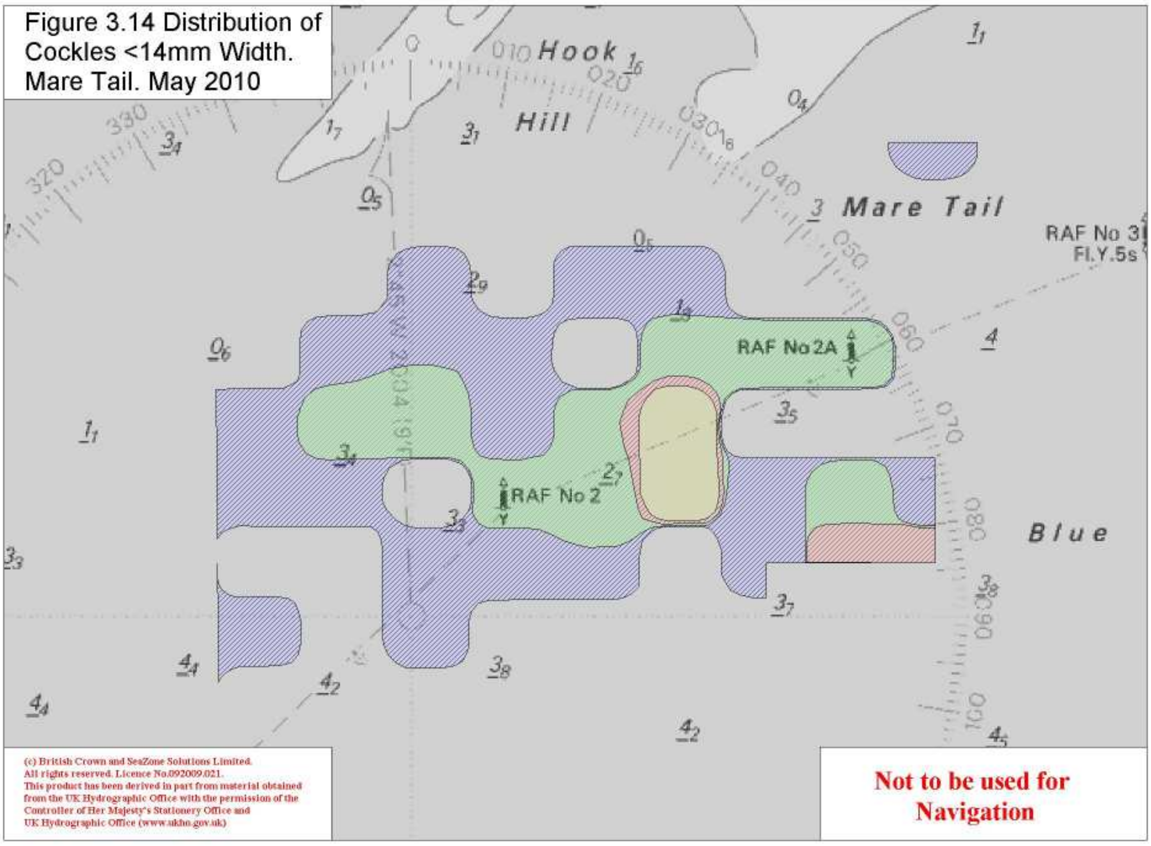


Figure 3.14 Distribution of Cockles <14mm Width. Mare Tail. May 2010

Cockles smaller than 14mm width were found to be present at 28 of the survey stations, covering an area of 275 hectares(figure 3.14), a significant decline from the 44 stations covering 427 hectares recorded in 2009. These small cockles had a mean density of 254.21 cockles/m^2 (range 10 – 5,610/m^2) and a mean weight 6.72 tonnes/hectare, both less than the 1,568.90 cockles/m^2 (range 10 – 5,610/m^2) and 9.02 tonnes/hectare recorded the previous year. From these figures the biomass of small cockles on this bed was calculated to be 1,845 tonnes, less than half of the 3,853 tonnes recorded in 2009.

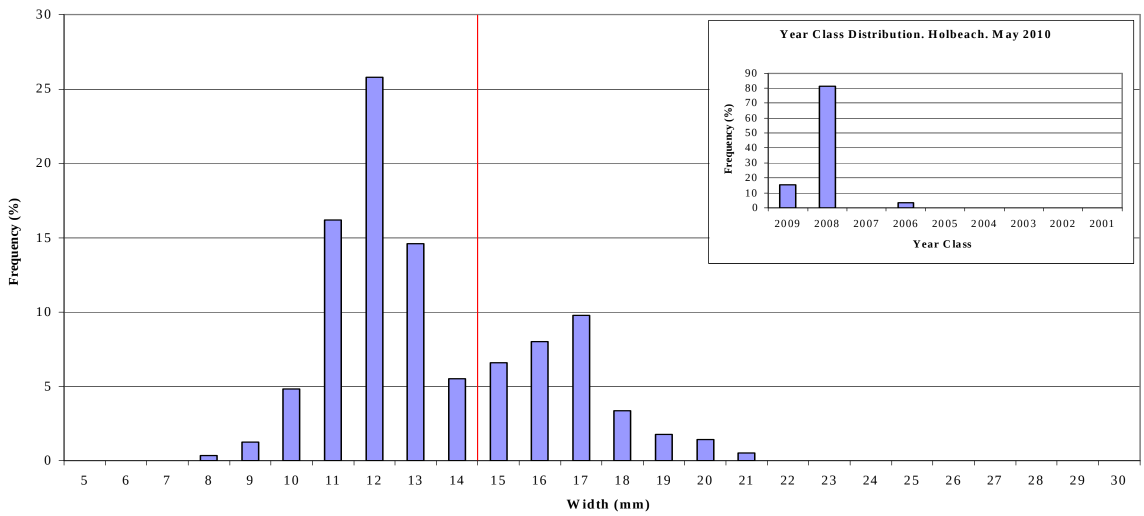
Overall, growth through the year had not been sufficient to compensate for natural losses and the total cockle stock on this bed was found to have declined 31% from 4,270 tonnes to 2,953 tonnes.

3.3.8 Holbeach Range

The cockles in Holbeach Range were surveyed on April 30th and May 17th and 18th 2010, during which 155 stations were sampled over high water periods using a Day grab. Usually a high proportion of the sites on this sand are surveyed on foot, but difficulties were experienced this year while attempting to access the sand through the Holbeach RAF base. This meant the higher sites (those above 4.0m drying height) and those close to the bombing targets were not sampled for safety reasons. Past survey data, however, indicates few cockle stocks are situated in the unsurveyed regions, and those that are tend to be slow growing, small individuals. Figure 3.15 shows the population size frequency at the time of the survey.

64 stations, covering an area of 574 hectares, were found to support marketable sized cockles (figure 3.16), a similar coverage to the 580 hectares recorded the previous year. Within this area the mean density of 31.88 cockles/m^2 (range 10 – 170/m^2) and the mean weight of 1.65 tonnes/hectare were also both similar to the figures of 30.87 cockles/m^2 (range 10 – 150/m^2) and 1.70 tonnes/hectare recorded in 2009. From these figures the biomass of marketable sized cockles on this bed was calculated to be 947 tonnes, a slight reduction to the 987 tonnes recorded the previous year. Although the figures for the marketable sized cockles suggest there had been little change occurring on this bed, some mortality had

Figure 3.15 Cockle Size Frequency. Holbeach. May 2010



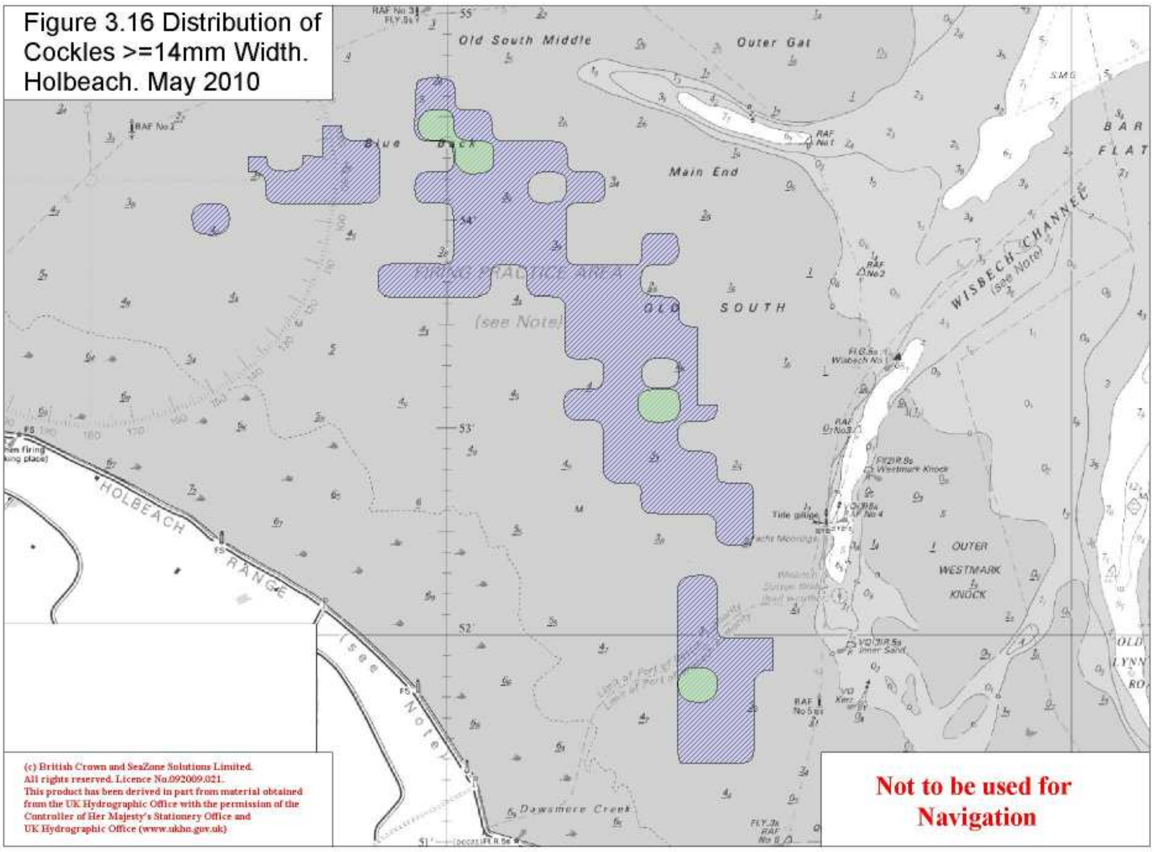


Figure 3.16 Distribution of Cockles >=14mm Width. Holbeach. May 2010

Density: Cockles / m

10 - 99	100 - 499	500 - 999	1000+

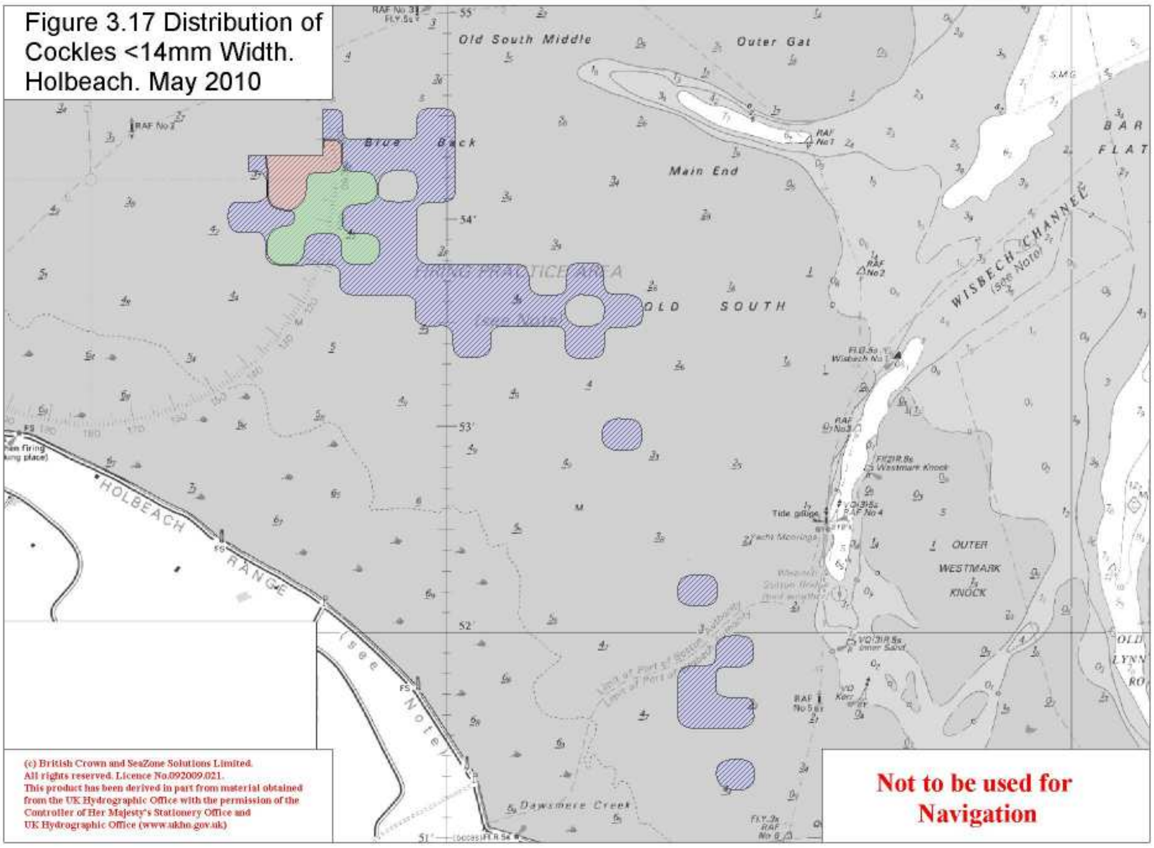


Figure 3.17 Distribution of Cockles <14mm Width. Holbeach. May 2010

occurred during the year, but this had been matched with recruitment of some of the 2008 year-class cohort that had grown to marketable size.

Settlement of new spat within Holbeach had been poor during 2009, so cockles from the 2008 year-class cohort that had grown to marketable size had not been replaced with a new cohort of juveniles. As a consequence the area supporting cockles smaller than 14mm width had fallen from 76 stations covering 603 hectares, to 41 stations covering 365 stations (figure 3.17). Within this area the mean density had fallen from 169.61 cockles/m^2 (range 10 – 2,500/m^2) to 86.34 cockles/m^2 (range 10 – 780/m^2), but because the individuals were larger, the mean weight of 1.65 tonnes/hectare was virtually unchanged at 1.63 tonnes/hectare. From these figures the biomass of small cockles in Holbeach was calculated to be 594 tonnes, a 40% reduction to the 997 tonnes recorded in 2009.

Together, the total biomass of cockles in Holbeach was found to be 1,541 tonnes, 22% less than the 1,983 tonnes recorded in 2009.

3.3.9 Roger/Toft

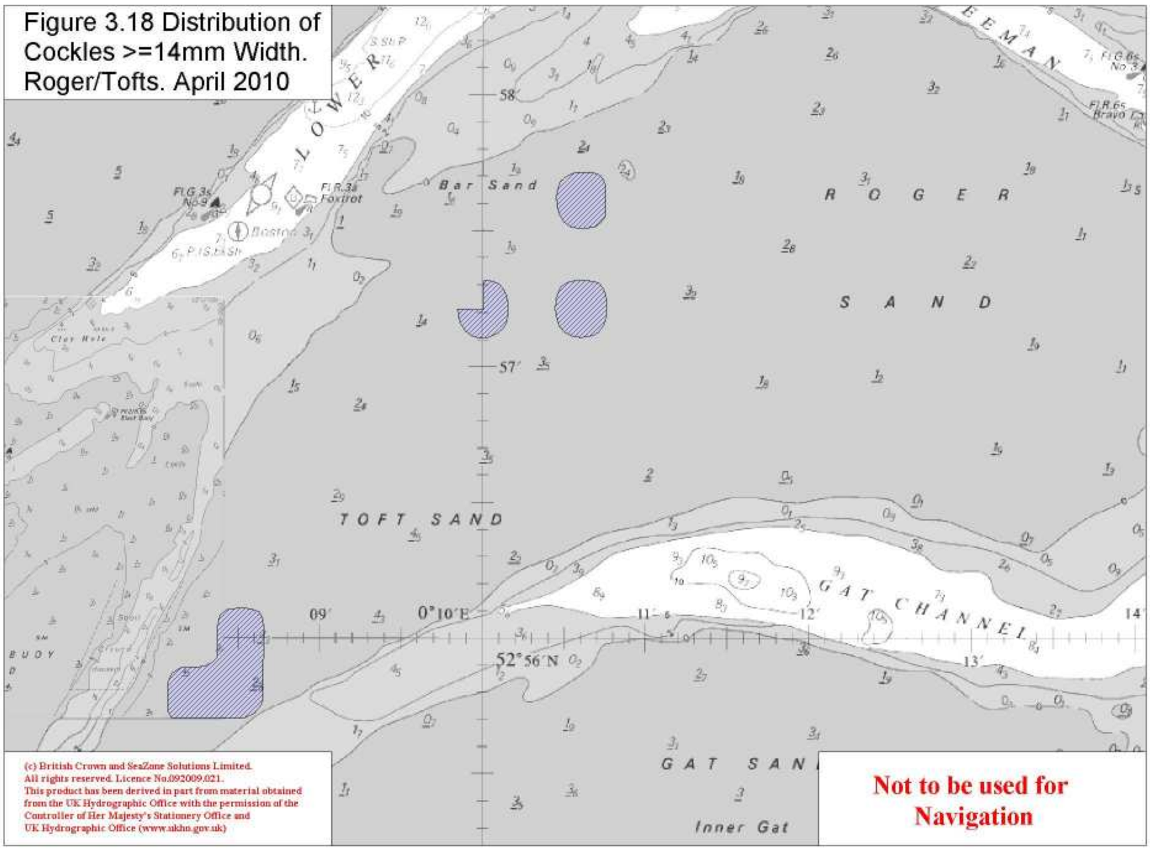
This sand was surveyed on April 29th 2010, during which 81 stations were sampled using a Day grab over high water.

There has been little recruitment on this bed since 2006, so the population was mainly composed of large 4 year-old cockles. The survey found there had been a high mortality on this bed since the 2009 spring survey, leaving just sparse patches of cockles remaining. These were found in six of the stations, covering an area of 65 hectares (figure 3.18). This coverage had declined from eight stations covering 83 hectares in 2009. Although through the year small cockles had grown and recruited into this population, the mean density of marketable sized cockles on this bed was found to have decreased from 111.25 cockles/m^2 (range 10 – 470/m^2) to 16.67 cockles/m^2 (range 10 – 40/m^2). Similarly, the mean weight had also fallen from 4.80 tonnes/hectare to 1.22 tonnes/hectare. From these figures the biomass of marketable sized cockles on this bed was calculated to be 79 tonnes, an 80% reduction from the 397 tonnes recorded the previous year.

Although the 2009 survey had found 317 tonnes of small cockles to be present on this sand, with a mean density of 198.00 cockles/m^2 (range 10 – 480/m^2), these had all either died or attained marketable size during the year. The 2010 survey found no small cockles remaining on this sand, meaning the 79 tonnes of marketable sized cockles represented the whole cockle population (figure 3.18). This is an 89% reduction from the total stock of 714 tonnes that had been recorded in 2009.

Figure 3.20 shows the population size frequency at the time of the survey.

Figure 3.18 Distribution of Cockles >=14mm Width. Roger/Tofts. April 2010



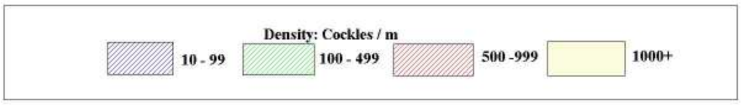


Figure 3.19 Distribution of Cockles <14mm Width. Roger/Tofts. April 2010

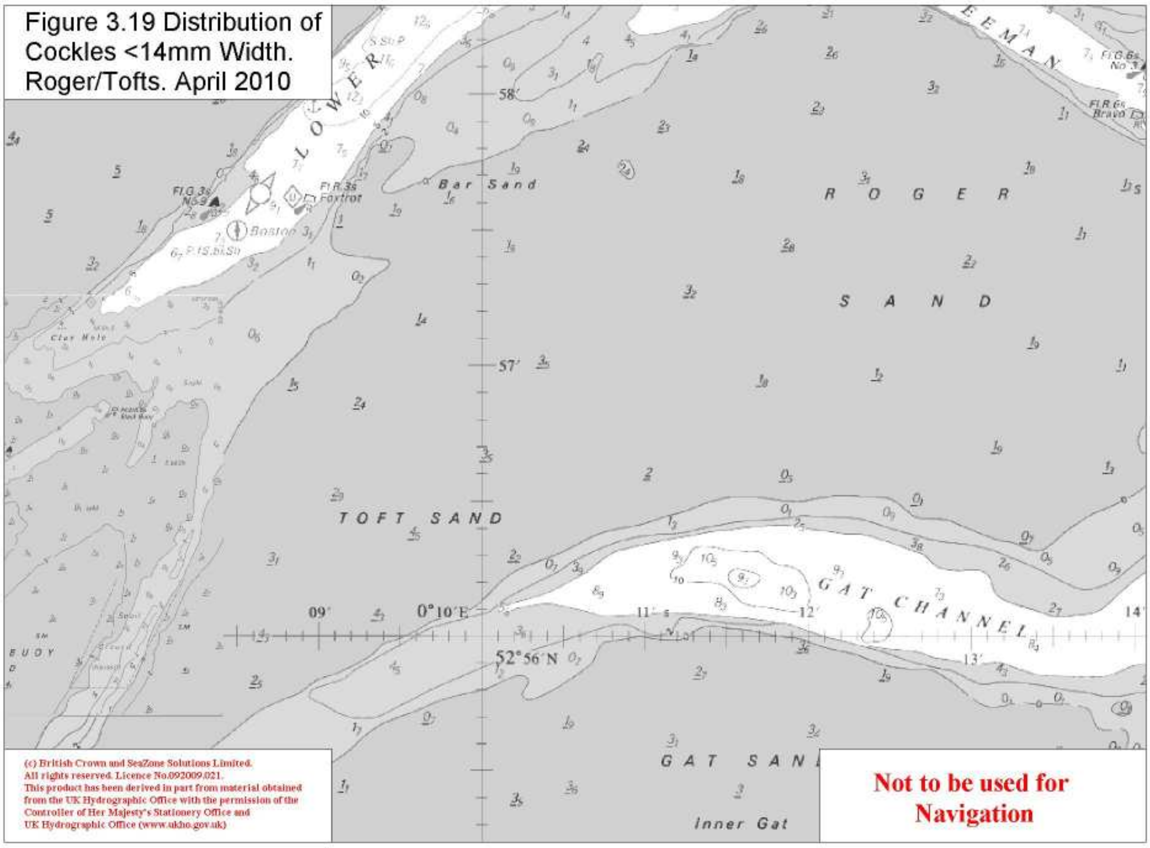
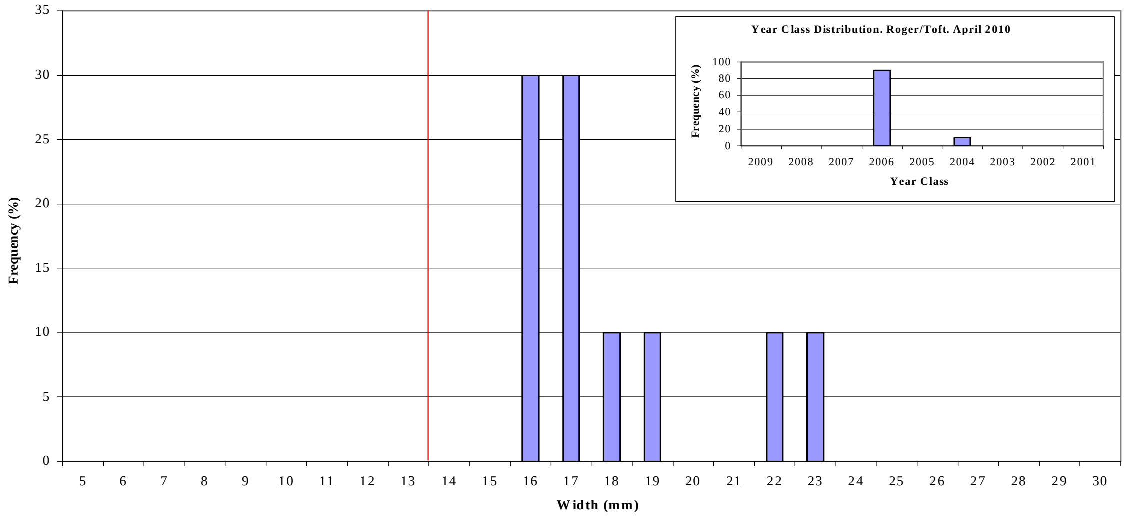


Figure 3.20 Cockle Size Frequency. Roger/Toft. April 2010



3.3.10 Gat Sand

The Gat sand was surveyed on April 29th 2010, during which 20 samples were collected on foot at low water and 45 using a Day grab over high water. Although this bed had supported 2,139 tonnes of cockles in 2008, high mortality had reduced this population to just 58 tonnes by 2009. The 2010 survey found the mortality had continued further, leaving the sand virtually bare of cockles, only a single individual being found throughout the 65 survey sites. This individual, from the 2008 year-class cohort, was 21mm width and weighed 11.25g. Scaled up, the site represented an area of 8 hectares in which approximately 9 tonnes of cockles were calculated to be present (figure 3.21).

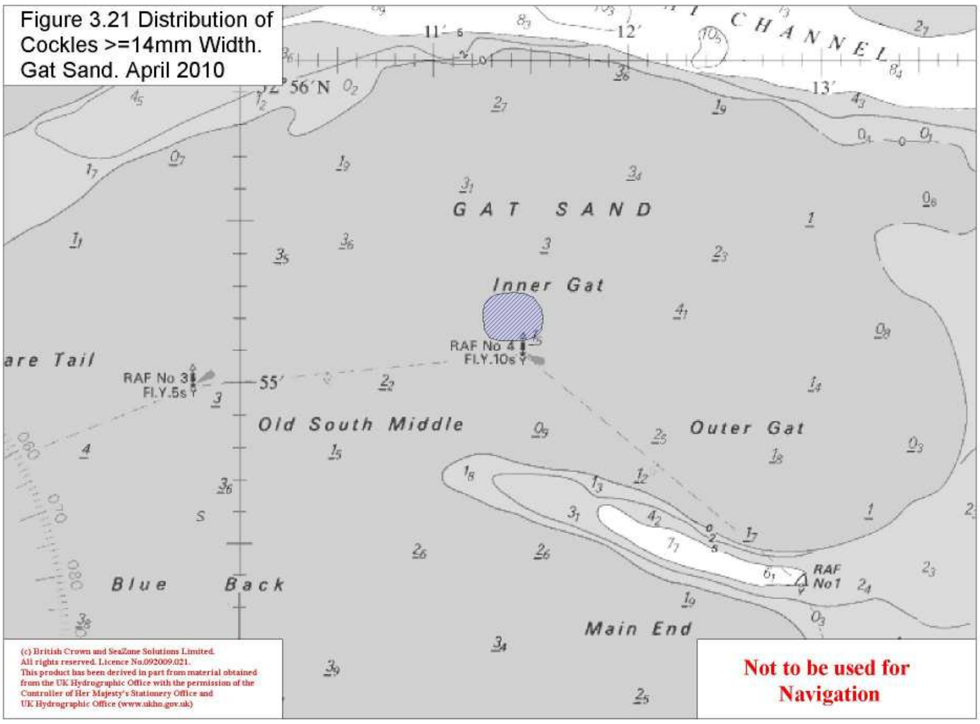


Figure 3.21 Distribution of Cockles >=14mm Width. Gat Sand. April 2010

3.3.11 Inner Westmark Knock

During the 2010 surveys 28 stations on the Inner Westmark Knock sand were sampled on May 12th 2010 using a Day grab over high water, and 15 were sampled on foot at low water the following day.

The survey found that there had been a light settlement of spat on this bed following the 2009 survey, but that the population was still dominated by cockles from the 2008 year-class cohort. These were predominantly 12-16mm in width so contributed to both the marketable sized and small cockle population groups. Figure 3.22 shows the size frequency of the population at the time of the survey. There had been a heavy mortality on this bed between surveys and high numbers of moribund cockles were witnessed on this bed in the month following the survey.

Ten stations, covering an area of 138 hectares, were found to contain cockles of marketable size (figure 3.23), a reduction from the 18 stations, covering 209 hectares, recorded in 2009. The mean density within this area was found to be 73.00 cockles/m^2 (range 10 – 270/m^2), a slight decline from the 83.33 cockles/m^2 (range 10 – 330/m^2) recorded the previous year. During the same period the mean weight was also found to have declined from 3.65 tonnes/hectare to 3.18 tonnes/hectare. From these figures the biomass of marketable sized cockles on this sand was calculated to be 439 tonnes, 42% fewer than the 762 tonnes recorded the previous year.

Smaller cockles were found to be present at ten stations, covering an area of 137 hectares (figure 3.24), compared to 19 stations, covering an area of 235 hectares, in 2009. The mean density of these cockles was found to have fallen from 313.16 cockles/m^2 (range 10 – 2,030/m^2) in 2009 to 60.00 cockles/m^2 (range 10 – 170/m^2), while during the same period the mean weight had fallen from 4.68 tonnes/hectare to 1.14 tonnes/hectare. From these figures the biomass of small cockles on this sand was calculated to be 156 tonnes, an 86% reduction from the 1,099 tonnes recorded the previous year.

Figure 3.22 Cockle Size Frequency. Inner Westmark Knock. May 2010

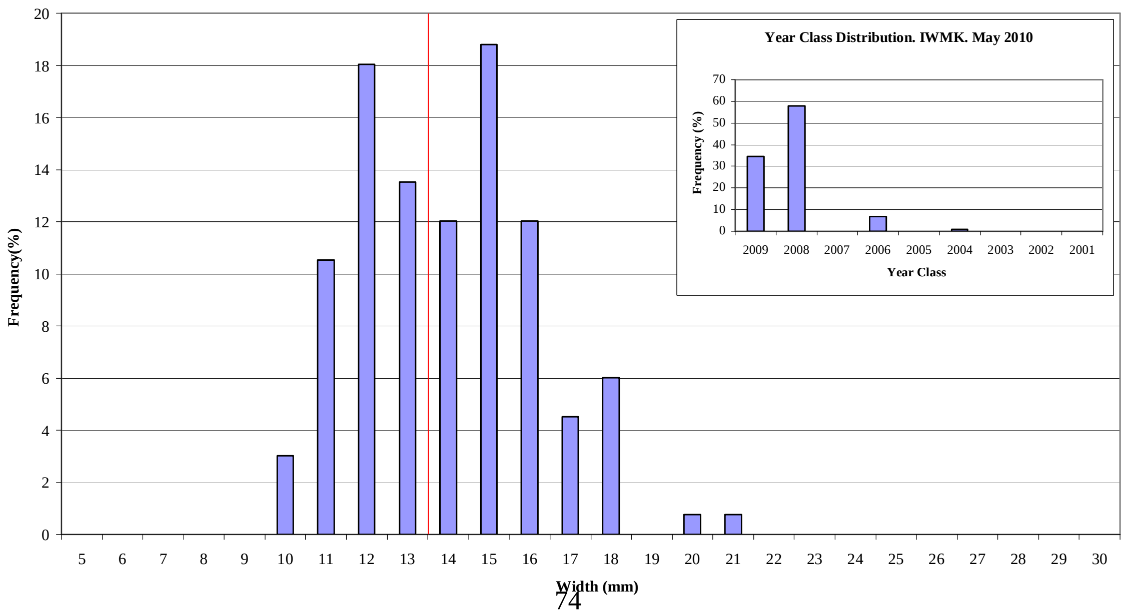
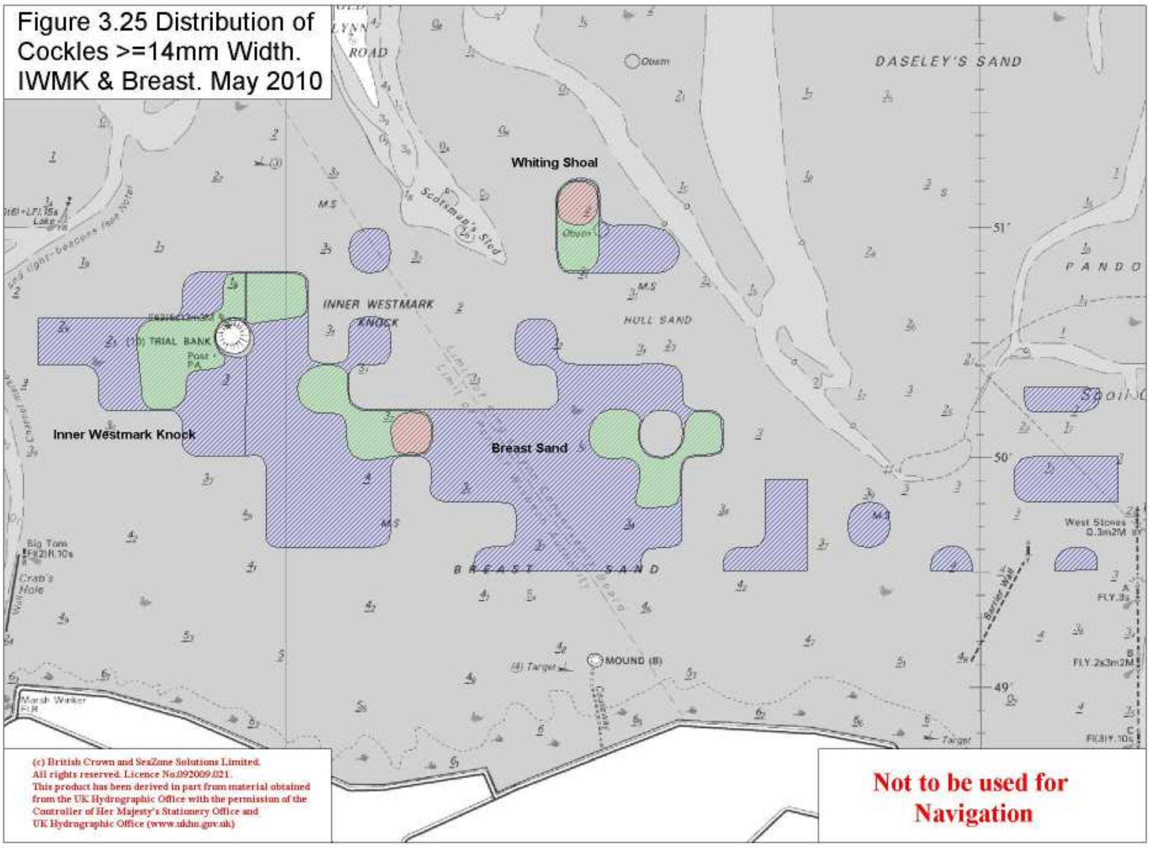


Figure 3.25 Distribution of Cockles >=14mm Width. IWMK & Breast. May 2010



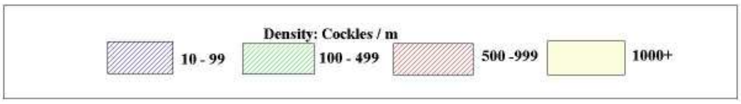
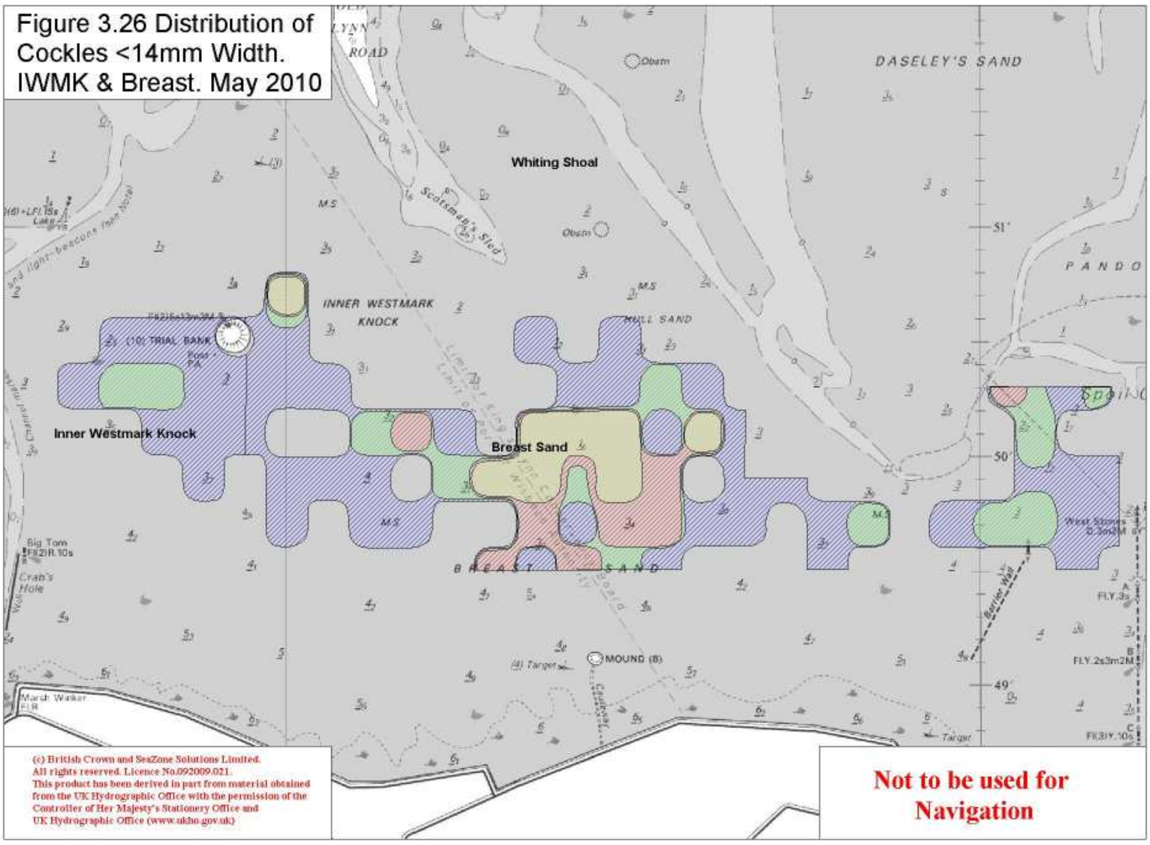


Figure 3.26 Distribution of Cockles <14mm Width. IWMK & Breast. May 2010

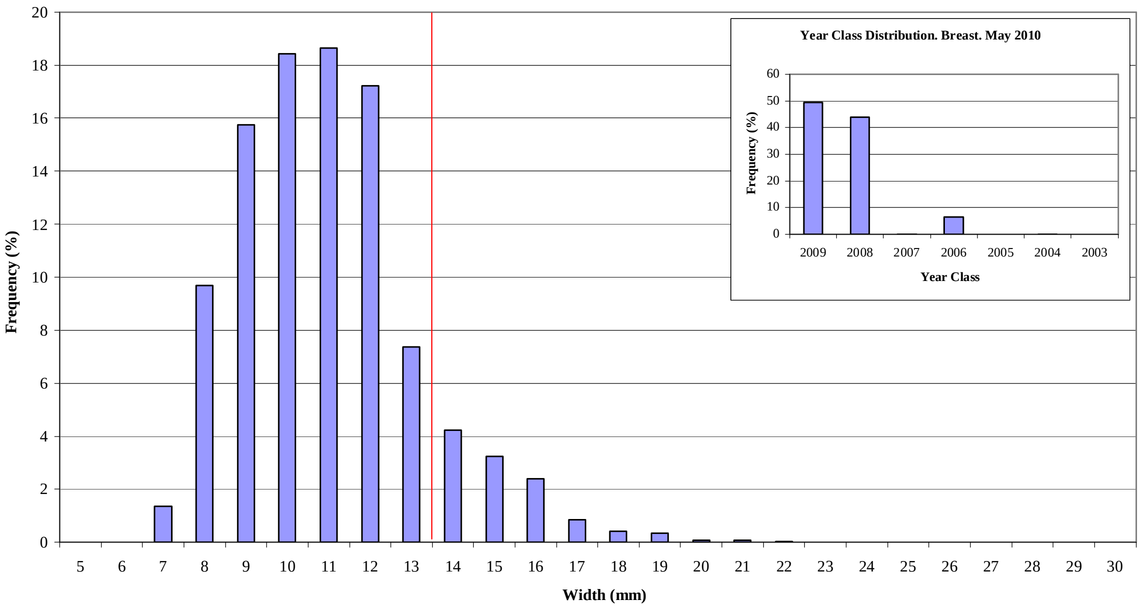


The total stock on Inner Westmark Knock was found to be 595 tonnes, a 68% reduction from the 1,861 tonnes recorded in 2009. This reflects a continuing decline from when the total stock was 2,849 tonnes in 2008.

3.3.12 Breast Sand

128 stations were visited on the Breast Sand during the 2010 surveys, 33 being sampled at low water on foot on May 13th and 14th and 95 with a Day grab at high water on May 12th and 13th. The survey found there had been a moderate settlement of spat on the sand during 2009, but the stocks were still dominated by the 2008 year-class cohort. Few of this latter cohort had attained 14mm width, so the population of marketable sized cockles was mainly represented by older cockles from the 2006 year-class cohort. Figure 3.27 shows the population size frequency at the time of the survey. These marketable sized cockles were found to be present at 56 sites, covering an area of 592 hectares. This coverage had increased from 2009, when 43 stations covering 494 hectares supported marketable stocks. Although the mean density of these cockles was found to have increased slightly from 61.16 cockles/m^2 (range 10 – 370/m^2) in 2009 to 65.18 cockles/m^2 (range 10 – 860/m^2), the mean weight had decreased slightly during the same period from 2.75 tonnes/hectare to 2.62 tonnes/hectare. From these figures the biomass of marketable sized cockles on the Breast Sand was calculated to be 1,548 tonnes, a 14% improvement on the 1,362 recorded in 2009.

Figure 3.27 Cockle Size Frequency. Breast. May 2010



The 2009 settlement assisted the coverage of cockles smaller than 14mm width to increase from 51 stations covering 571 hectares recorded in 2009 to 62 stations covering an area of 681 hectares. Within this area, however, high mortality among the dense patches of the 2008 year-class meant the mean density had decreased from 1,838.2 cockles/m^2 (range 10 – 19,070/m^2) to 455.48 cockles/m^2 (range 10

– 5,480/m^2). During the same period the mean weight had decreased by a smaller extent from 7.13 tonnes/hectare to 6.41 tonnes/hectare. From these figures the biomass of small cockles on this sand was calculated to be 4,368 tonnes, an improvement on the 4,069 tonnes recorded in 2009.

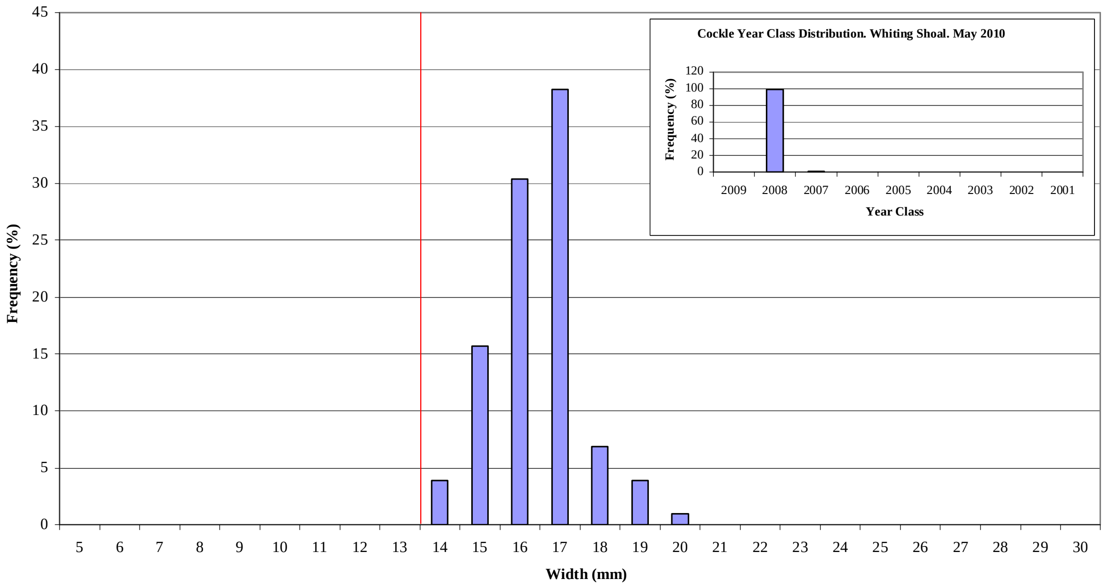
The total cockle stock on the Breast Sand was found to be 5,916 tonnes, a 95 increase on the 5,431 tonnes recorded the previous year.

3.3.13 Whiting Shoal/Hull Sand

Previous surveys had not extended onto this sand. In March 2010, however, fishermen found a dense patch of marketable sized cockles in this area and began harvesting them. A survey was, therefore, conducted on May 27th, during which 17 survey stations were sampled using a Day grab over high water.

The cockles on this bed were found to be predominantly from the 2008 year-class cohort, all of which had attained 14mm width Figure 3.28). Four of the stations, covering an area of 48 hectares, were found to support these cockles. These had a mean density of 255.00 cockles/m^2 (range 10 – 840/m^2), and a mean weight of 11.90 tonnes/hectare. From these figures the biomass of cockles on this bed was calculated be 572 tonnes, of which 458 tonnes were calculated to have reached a size of 16mm width. Some fishermen who had been working on this bed felt this figure had been over-estimated. If so, a likely cause of error would be the relatively small size of the bed combined with the high density of cockles found at one of the stations. Ideally, on small patches like this, the sampling resolution would be increased to improve the survey accuracy. Time constraints, however, meant this was not an option for this survey.

Figure 3.28 Cockle Size Frequency. Whiting Shoal. May 2010



3.3.14 Daseley's

Daseley's sand was surveyed on May 13th and 14th 2010, during which 84 stations were sampled using a Day grab over high water.

Marketable sized cockles were found to be present at 38 of the survey stations, covering an area of 422 hectares (figure 3.30). This was a good increase on the 22 stations covering 239 hectares recorded in 2009, mainly as a result of a proportion of the 2008 year-class cohort attaining 14mm width and recruiting into this population group. Although these additional cockles had helped the mean density increase from 15.45 cockles/m^2 (range 10 – 30/m^2) to 20.26 cockles/m^2 (range 10 – 60/m^2), their smaller size meant their mean weight had decreased from 1.20 tonnes/hectare to 0.87 tonnes/hectare. From these figures, the biomass of marketable sized cockles on Daseley's was calculated to be 367 tonnes, a 28% increase on the 287 tonnes recorded the previous year.

Although there had been a low settlement of spat on this sand during 2009, the area supporting small cockles was found to have decreased from 35 stations covering 383 hectares to 31 stations covering 342 hectares (figure 3.31). Within this area the mean density was found to have declined from 132.57 cockles/m^2 (range 10 –2,750/m^2) to 57.10 cockles/m^2 (range 10 –870/m^2), although during the same period the mean weight had increased from 0.61 tonnes/hectare to 0.97 tonnes/hectare. From these figures the biomass of small cockles on this sand was calculated to have increased 41% from 235 tonnes in 2009 to 332 tonnes.

With growth more than compensating for mortality and the addition of a light settlement of juveniles in 2009, the total biomass of cockles on Daseley's was found to have increased 34% from 522 tonnes in 2009 to 699 tonnes. Figure 3.29 shows the size structure of the population at the time of the survey.

Figure 3.29 Cockle Size Frequency. Daseley's. May 2010

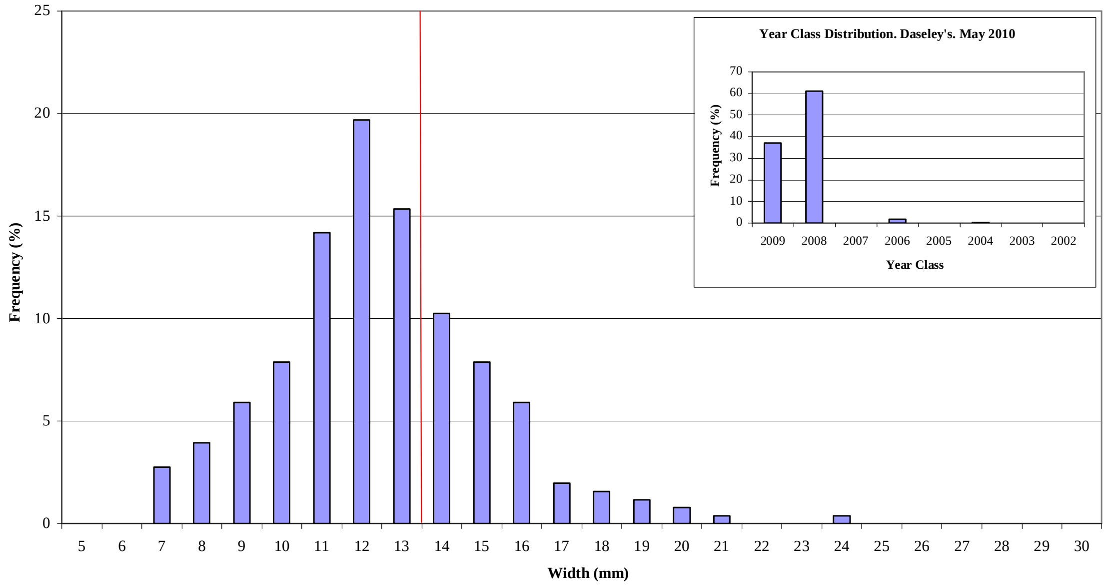
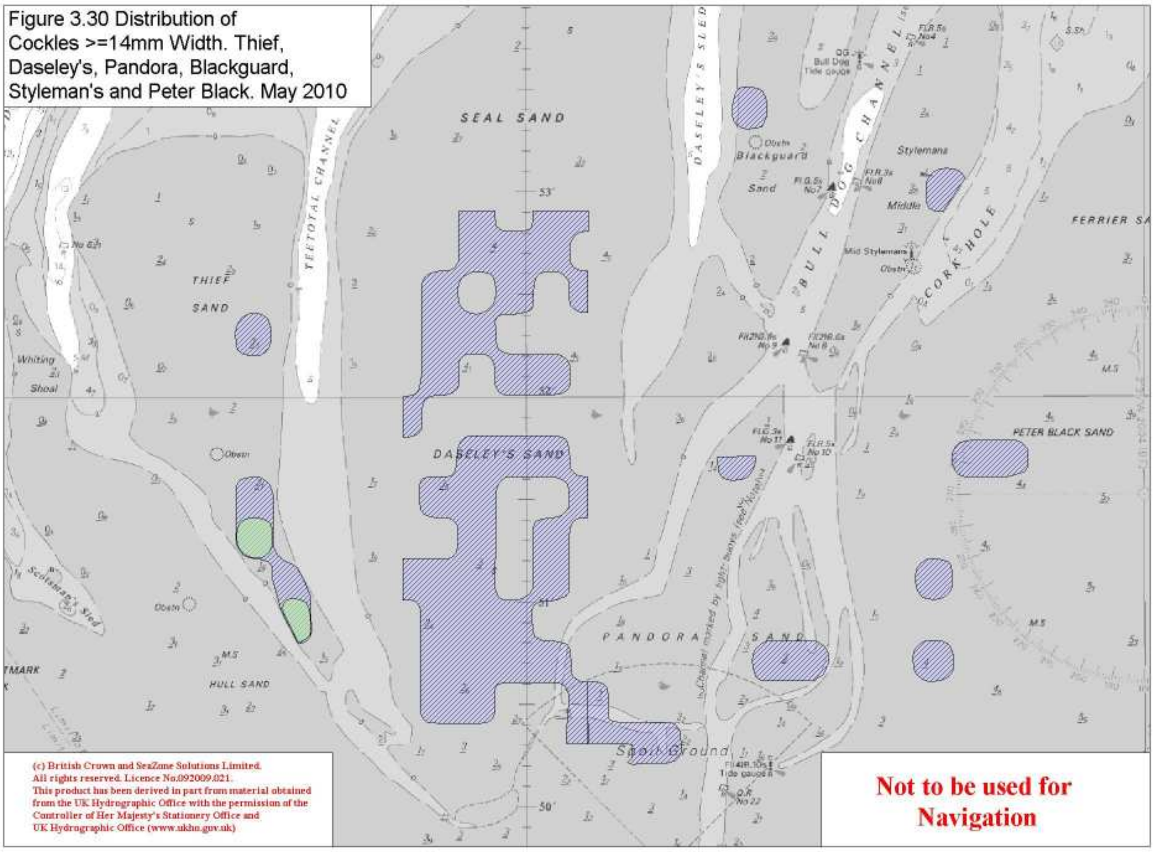


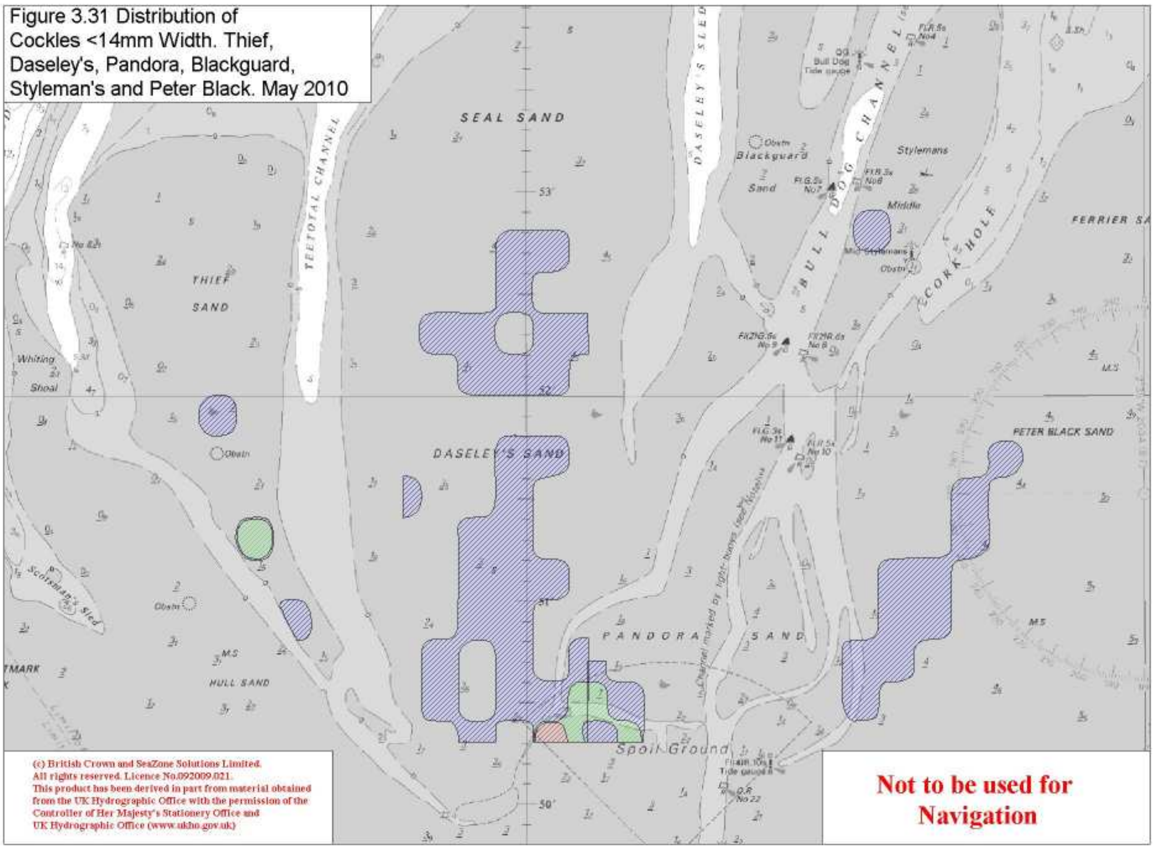
Figure 3.30 Distribution of Cockles >=14mm Width. Thief, Daseley's, Pandora, Blackguard, Styleman's and Peter Black. May 2010



Density: Cockles / m

10 - 99	100 - 499	500 -999	1000+

Figure 3.31 Distribution of Cockles <14mm Width. Thief, Daseley's, Pandora, Blackguard, Styleman's and Peter Black. May 2010

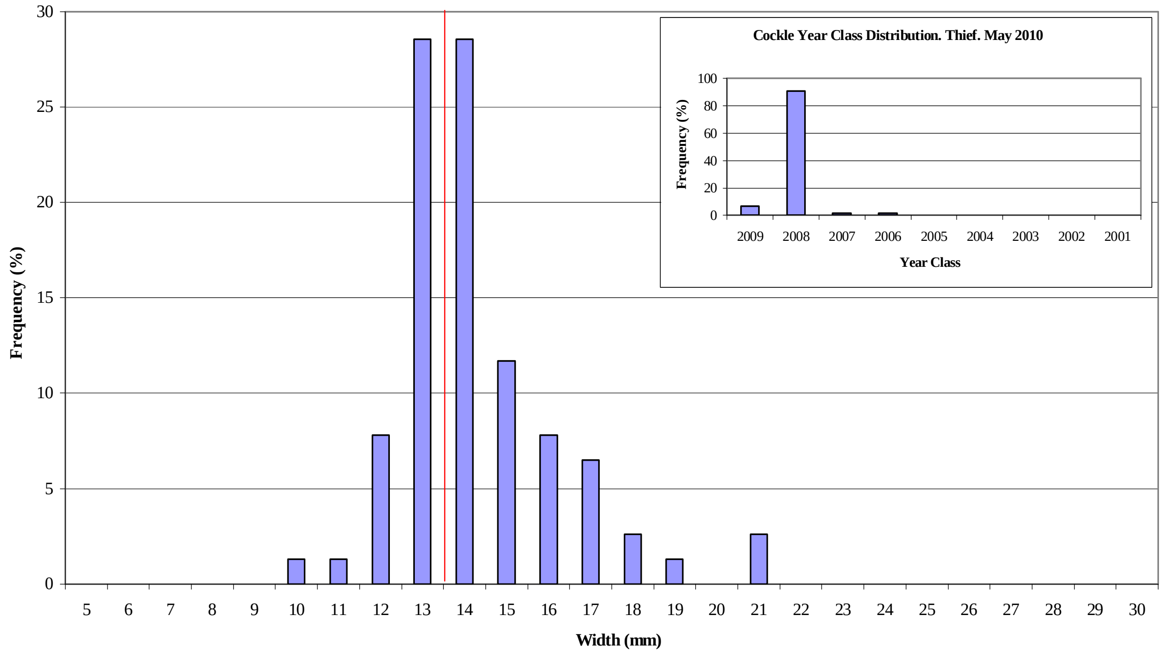


3.3.15 Thief Sand

27 stations on the Thief Sand were surveyed on May 14th using a Day grab over high water. Following this survey, however, it became apparent that further stocks were present on this sand to the south of the survey area. Four additional stations were sampled with a Day grab on May 26th in order to incorporate these stocks. The cockles on this bed were found to be predominantly of the 2008 year-class cohort, approximately half of which had attained 14mm width. Figure 3.32 shows the size frequency of the population at the time of the survey.

Five stations covering an area of 52 hectares were found to support marketable sized cockles. These had a mean density of 92.00 cockles/m^2 (range 10 – 260/m^2) which was an improvement on the 22.5 cockles/m^2 (range 10 – 60/m^2) recorded the previous year. During the same period the mean weight was found to have increased from 2.61 tonnes/hectare to 4.01 tonnes/hectare. From these figures the biomass of marketable sized cockles on this bed was calculated to be 209 tonnes. Although this is a good improvement on the 104 tonnes recorded the previous year, it is nevertheless thought to be an under-estimation of the true biomass. An assessment of the stocks conducted after the surveys were completed found a dense patch of cockles situated between the additional four sample stations. Although the additional four stations had all recorded cockles as being present, none reflected the high densities found to be present within the patch. Unfortunately, time constraints meant it was not possible to conduct a higher resolution survey in this area, that would have more accurately determined the cockle biomass in this area. Landing return data from the fishery showed that at least 430 tonnes of cockles were harvested from this bed following the survey.

Figure 3.32 Cockle Size Distribution. Thief. May 2010



3.3.16 Styleman's, Blackguard and Pandora

Pandora was surveyed on May 13th 2010, during which 35 stations were sampled over high water using a Day grab. The survey found that there had been a light settlement of spat during 2009 on the southern part of the bed, but that stocks on this bed were sparse.

Five stations covering an area of 59 hectares were found to support cockles of marketable size. This is an improvement on 2009, when two stations covering 26 hectares were found to support marketable cockles. As had been the case during the 2009 surveys, only one cockle was found in each of the samples, producing a mean density for the area of 10 cockles/m^2. As these had a smaller average size than the previous year, the mean weight was found to have decreased from 0.85 tonnes/hectare to 0.58 tonnes/hectare. From these figures the biomass of marketable sized cockles on this bed was calculated to have increased from 22 tonnes to 34 tonnes. Two stations covering 31 hectares were found to support smaller cockles, a slight improvement on the 27 hectares recorded in 2009. The mean density of these smaller cockles was found to have increased from 10 cockles/m^2 to 90.0 cockles/m^2 (range 10 – 170/m^2) and the mean weight from 0.03 tonnes/hectare to 0.84 tonnes/hectare. The biomass of these smaller cockles was calculated to have increased from 1 tonne in 2009 to 26 tonnes.

Blackguard Sand was surveyed on May 26th 2010, during which 23 stations were sampled over high water using a Day grab. Just one station, covering 10 hectares, was found to contain cockles, both of which were of marketable size. These represented a stock of 25 tonnes, compared to 7 tonnes in 2009.

Styleman's Sand was also surveyed on May 26th 2010, during which 7 stations were sampled over high water using a Day grab and the remaining 16 stations on foot at low water. Just two cockles were found during this survey, representing marketable stocks of 7 tonnes and 1 tonnes of smaller cockles. These figures compare with 32 tonnes of marketable cockles in 2009 and 1 tonnes of smaller cockles.

3.3.17 Peter Black

Peter Black Sand was surveyed on May 26th 2010, during which 42 stations were surveyed at high water using a Day grab. The survey found there had been a light settlement of spat during 2009 on this sand, but that the stock levels overall were sparse. Figure 3.33 shows the population size structure at the time of the survey.

16 stations covering 43 hectares were found to support marketable sized cockles, a similar coverage to the previous year. Changes to the population structure, however, meant that while the mean density of 10.00 cockles/m^2 (range 10 – 10/m^2) was similar to the previous year's figure of 13.33 cockles/m^2 (range 10 – 20/m^2), the mean weight had declined from 1.06 tonnes/hectare to 0.38 tonnes/hectare.

From these figures it was calculated that the biomass of marketable sized cockles on this bed had declined from 47 tonnes to 16 tonnes.

As a result of the spatfall, the coverage of smaller cockles had increased from 4 stations covering 27 hectares in 2009 to 10 stations covering 119 hectares. These cockles only had a sparse coverage, however, so their mean density of 17.0 cockles/m^2 (range 10 – 40/m^2) was slightly lower than the 20.0 cockles/m^2 (range 10 – 50/m^2) recorded in 2009. During the same period their mean weight was found to have increased slightly from 0.11 tonnes/hectare to 0.13 tonnes/hectare. From these figures the biomass of small cockles on Peter Black Sand was calculated to be 16 tonnes compared to 3 tonnes the previous year.

At 32 tonnes, the total cockle stock on Peter Black was found to have declined 36% from the 50 tonnes recorded in 2009. This itself was a decline from 99 tonnes recorded in 2008.

Figure 3.33 Cockle Size Distribution. Peter Black. May 2010

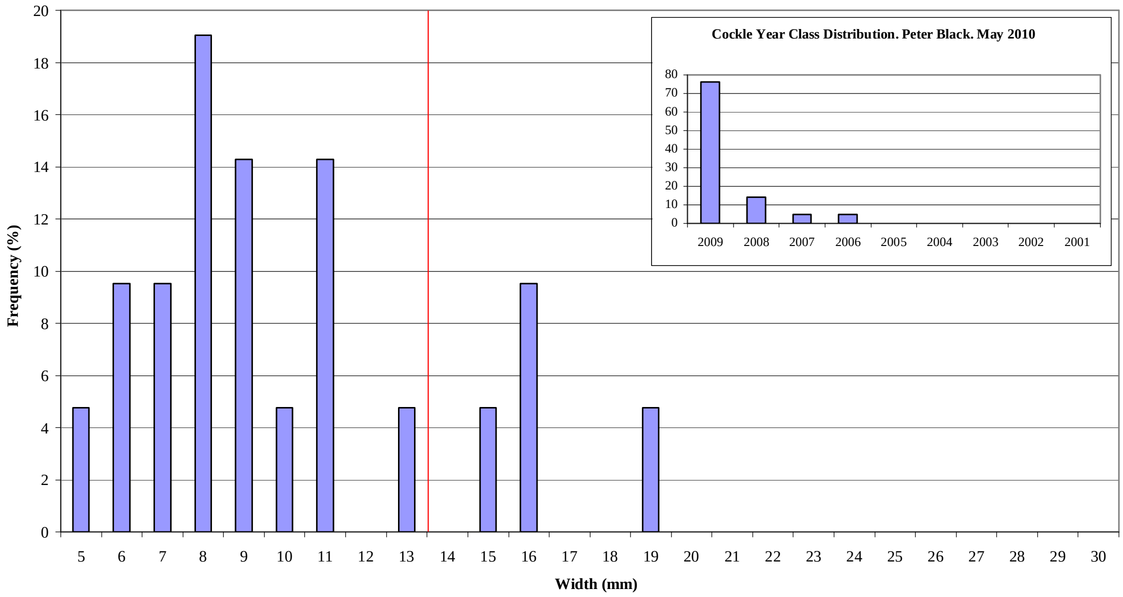


Table 3.1 and figures 3.34 and 3.35 summarise the stocks found during the spring surveys.

Table 3.1 Summary of cockle stocks on the Wash intertidal beds. Spring 2010

	ADULT				JUVENILES					
SAND	**Area (ha)**	**Mean Density (no/m^2)**	**Mean Weight (t/ha)**	**Biomass (t)**	**Area (ha)**	**Mean Density (no/m^2)**	**Mean Weight (t/ha)**	**Biomass (t)**	**Total Biomass (t)**	**%Adult**
Butterwick	63	11.43	0.59	37	105	207.27	1.23	129	166	22
Wrangle	194	15.00	0.94	182	47	10.00	0.21	10	192	95
Friskney	129	12.00	0.92	119	0	0.00	0.00	0	119	100
Butterwick Ext	153	21.33	0.80	122	149	257.69	2.28	339	461	26
Wrangle Ext	73	10.00	0.45	33	38	10.00	0.28	11	44	75
Friskney Ext	146	12.50	0.69	100	6	10.00	0.01	1	101	99
Boston Main Total	757			593	345			490	1083	55
Roger/Toft	65	16.67	1.22	79	0	0.00	0.00	0	79	100
Gat	8	10.00	1.13	9	0	0.00	0.00	0	9	100
Longsand									0	0
Herring Hill	283	57.33	1.98	559	271	270.30	5.44	1472	2031	28
Black Buoy	160	34.12	1.82	291	54	88.33	1.42	77	368	79
Mare Tail	308	87.19	3.60	1108	275	254.21	6.72	1845	2953	38
Holbeach	574	31.88	1.65	947	365	86.34	1.63	594	1541	61
IWMK	138	73.00	3.18	439	137	60.00	1.14	156	595	74
Breast	592	65.18	2.62	1548	681	455.48	6.41	4368	5916	26
IWMK/Breast Total	730			1987	818			4524	6511	31
Thief	52	92.00	4.01	209	29	100.00	2.59	76	285	73
Whiting Shoal	48	255.00	11.90	572	0	0.00	0.00	0	572	
Daseley's	422	20.26	0.87	367	342	57.10	0.97	332	699	53
Styleman's	10	10.00	0.76	7	11	10.00	0.09	1	8	88
Pandora	59	10.00	0.58	34	31	90.00	0.84	26	60	57
Blackguard	10	20.00	2.43	25	0	0.00	0.00	0	25	100
Peter Black	43	10.00	0.38	16	119	17.00	0.13	16	32	50
TOTAL	**3528**			**6803**	**2658**			**9453**	**16256**	**42**

Figure 3.34 Distribution of Cockles >=14mm Width. The Wash. May 2010

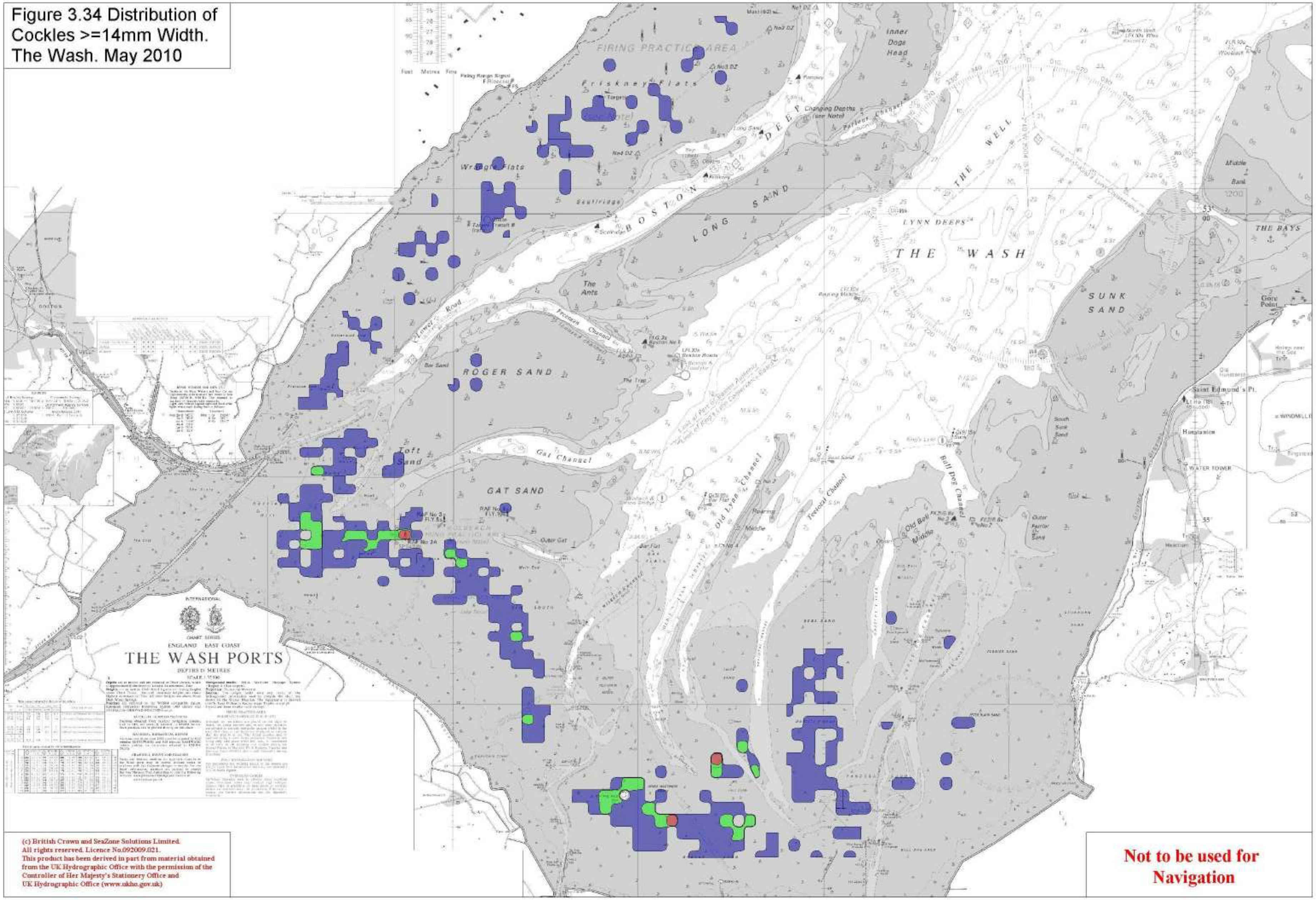
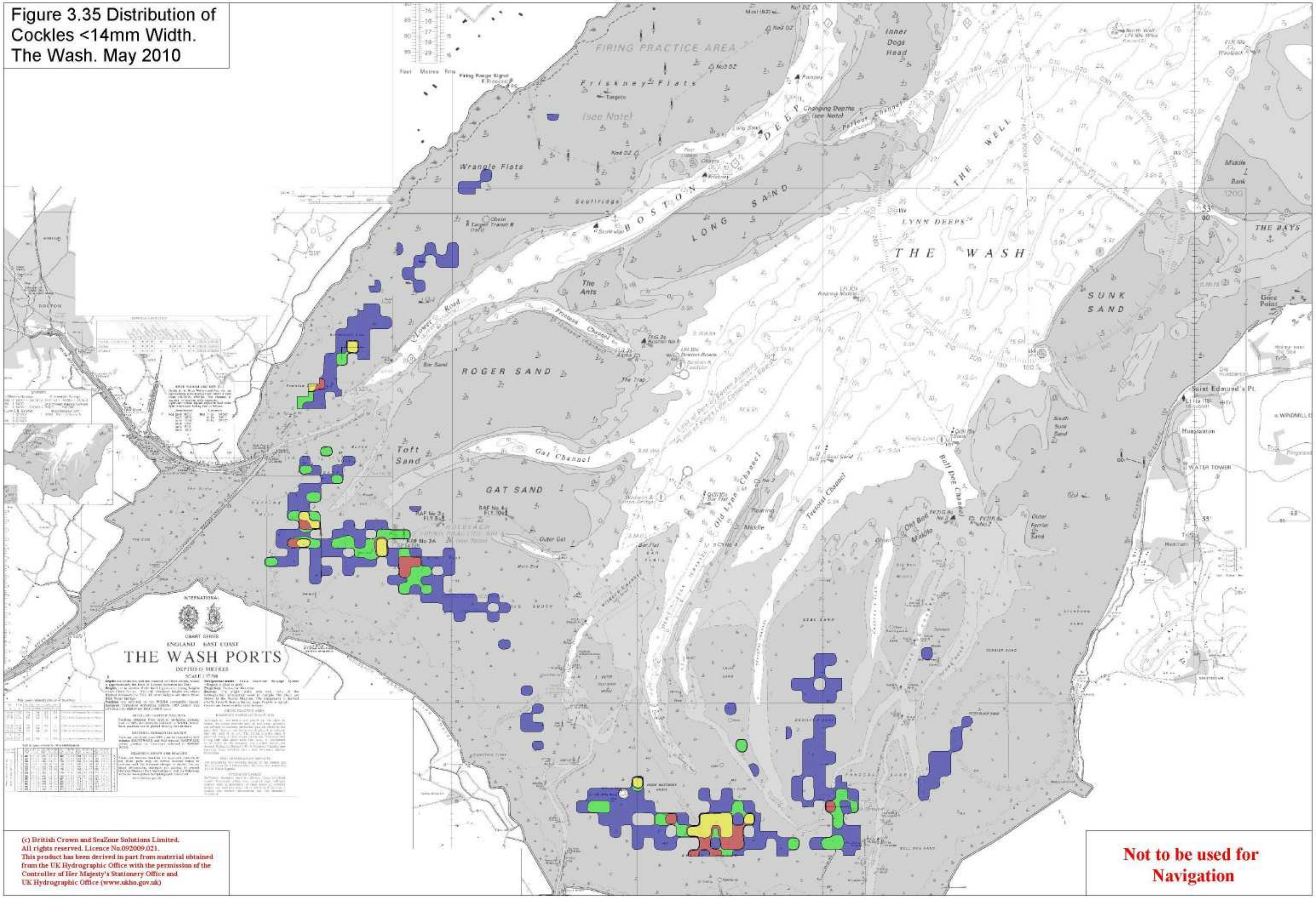


Figure 3.35 Distribution of
Cockles <14mm Width.
The Wash. May 2010



3.4 Autumn Survey Results

The autumn cockle surveys are conducted in order to ascertain the distribution of any spatfall that may have occurred during the summer months and to provide an insight into the health of the stocks on beds that have been fished subsequent to the spring surveys. Because of the time of year that these surveys are conducted, poor weather often limits the number of survey days that are available. The extent of the autumn surveys, therefore, tends to be less exhaustive than the spring surveys, usually providing a snapshot of the stocks from four or five beds. Poor weather conditions limited the 2010 autumn surveys to five days at sea, during which surveys were completed on the Inner Westmark Knock, Wrangle and Black Buoy sands. In addition, the western side of Holbeach was also surveyed. These surveys indicated there had been a significant reduction in cockle stocks on the Inner Westmark Knock sand and smaller losses on Wrangle and Black Buoy. None of these beds had been heavily exploited during the 2010 cockle fishery, but moribund cockles from the 2008 year-class cohort had been witnessed on Inner Westmark Knock in June suggesting the bed was suffering high mortalities. The surveys also found there had been a good settlement of spat on Wrangle and Inner Westmark Knock, but only poor settlement on Black Buoy and Holbeach.

3.4.1 Wrangle

Wrangle was surveyed on December 8th and 9th 2010, during which period 82 stations were sampled at high water using a Day grab and a further 25 stations on foot at low water. These surveys found there had been a decline in the numbers of older cockles present on this sand since the spring survey, but there had been a successful settlement of spat. Figure 3.39 shows the size frequency of the population at the time of the winter survey compared to that of spring..

15 stations, covering an area of 177 hectares, were found to support cockles of marketable size (figure 3.36), a reduction from the 194 hectares recorded in April. Within this area the mean density of marketable sized cockles was found to be 12.0 cockles/m^2 (range 10 – 20/m^2), a decline from the 15.00 cockles/m^2 (range 10 – 50/m^2) recorded in spring. The mean weight of these cockles was also found to have declined during this period from 0.94 tonnes/hectare to be 0.83 tonnes/hectare. From these figures the biomass of marketable sized cockles on Wrangle was found to be 146 tonnes, compared to 182 tonnes in April.

Excluding the new 2010 year-class cohort, cockles smaller than 14mm width were found to be present at 9 of the stations, covering an area of 110 hectares (figure 3.37). These were found to have a mean density of 13.33 cockles/m^2 (range 10 – 20/m^2) and a mean weight of 0.25 tonnes/hectare. All three of these parameters are slightly higher than those recorded following the April surveys. Although it is possible that small cockles may have washed into this site from adjacent beds, this increase is more likely due to an artefact in the survey design, whereby the survey resolution combined with low stock densities have made it difficult to accurately assess the stock biomass. Even taking possible inaccuracies into account, however, the estimated biomasses of 10 tonnes in April and 28 tonnes in December shows the stocks of small cockles on this bed are very low.

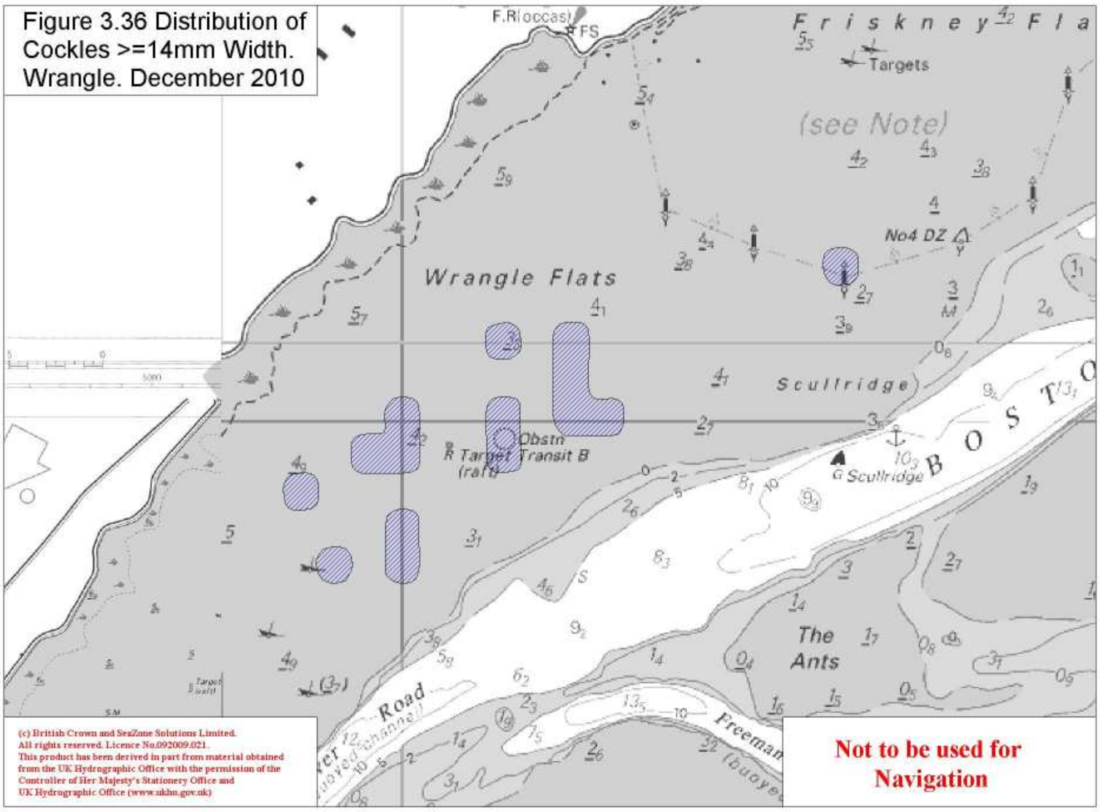
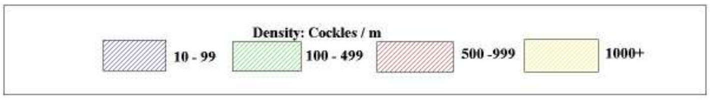


Figure 3.36 Distribution of Cockles >=14mm Width. Wrangle. December 2010



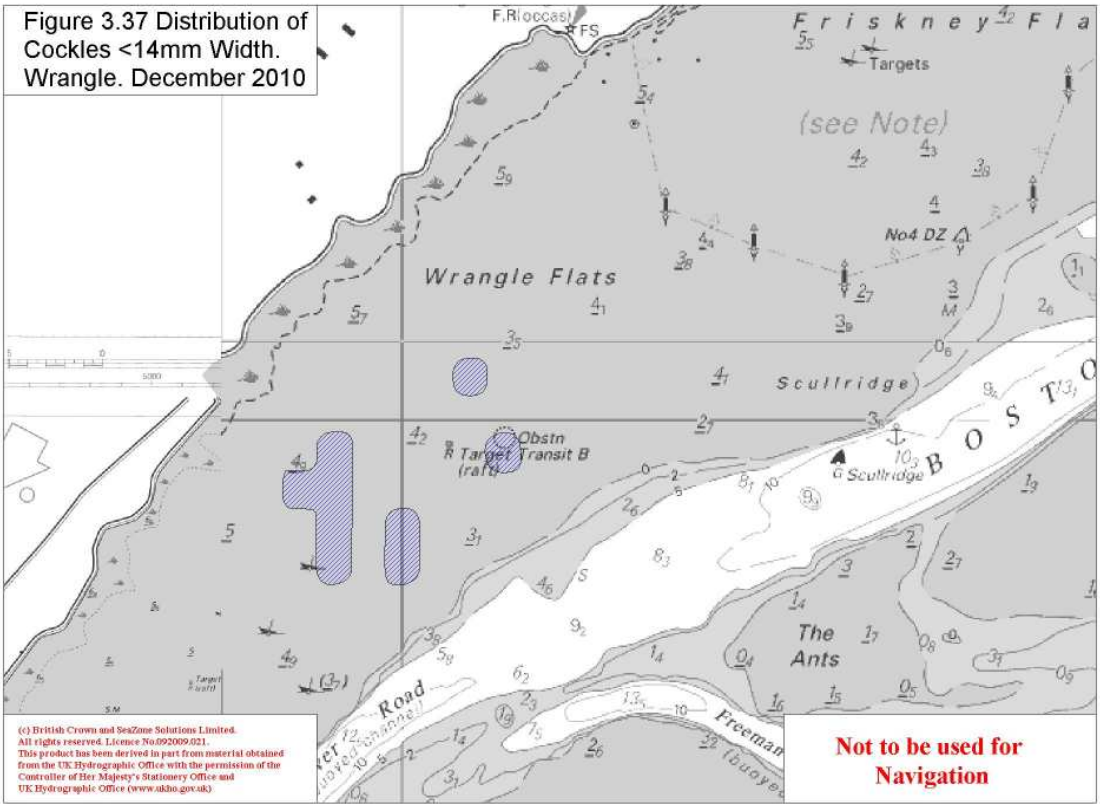


Figure 3.37 Distribution of Cockles <14mm Width. Wrangle. December 2010

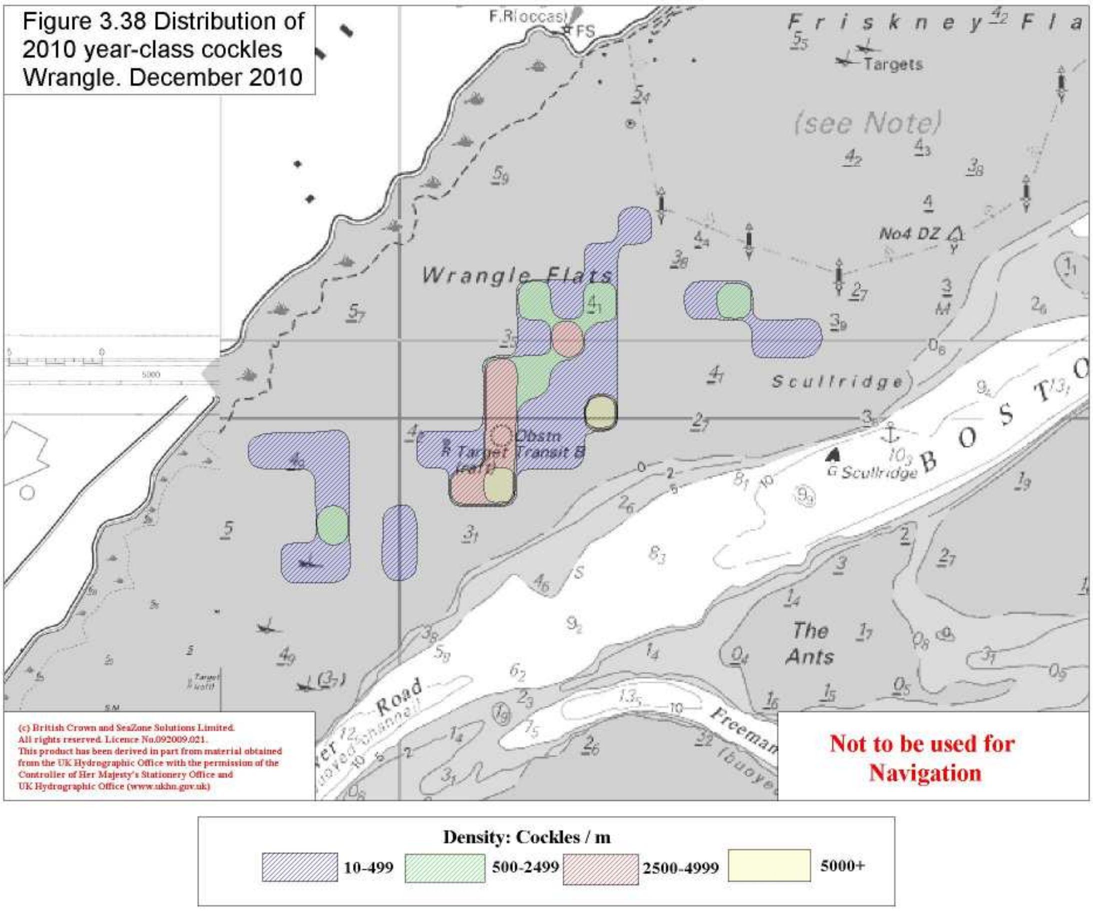
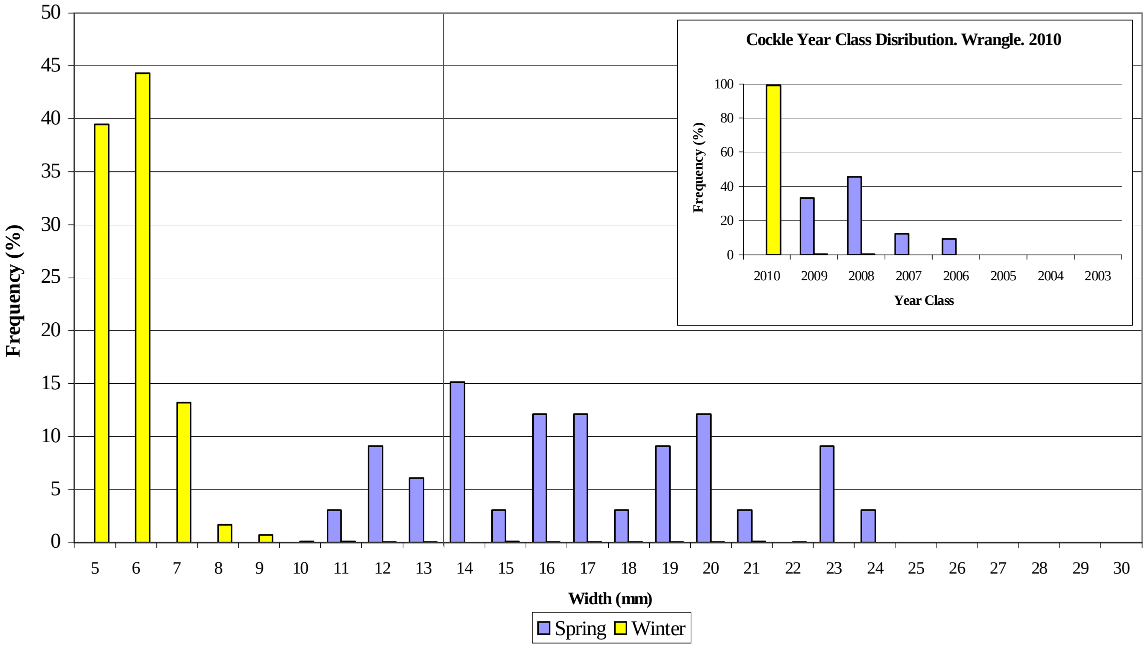


Figure 3.38 Distribution of 2010 year-class cockles Wrangle. December 2010

34 of the stations, covering 445 hectares, were found to have benefited from the 2010 spatfall (figure 3.38). The mean density of these juveniles was found to be 1,121 cockles/m^2 (range 10 – 11,240/m^2), with a mean weight of 2.26 tonnes/hectare. From these figures the biomass of 2010 year-class spat was calculated to be 1,184 tonnes.

Figure 3.39 Cockle Size Frequency. Wrangle. 2010



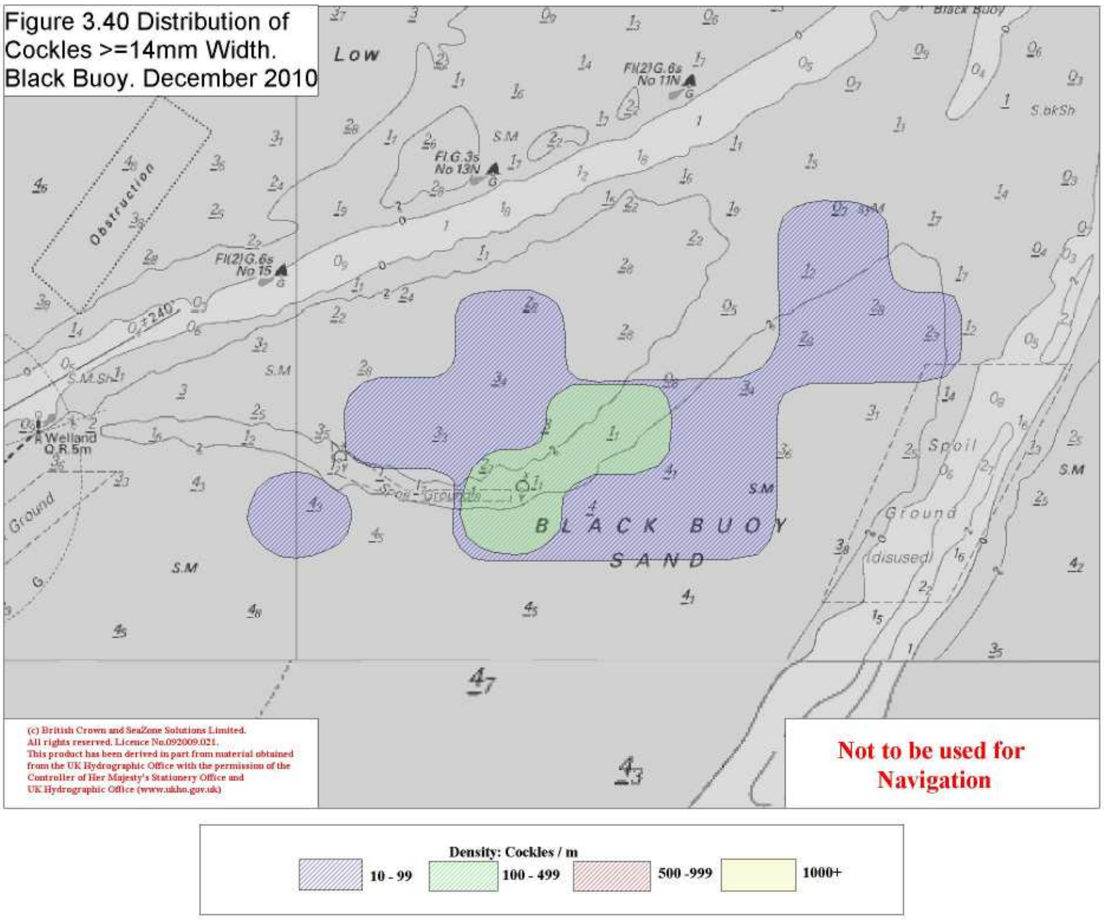
3.4.2 Black Buoy

On December 9th 2010 28 stations were surveyed on the northern parts of Black Buoy Sand (including the Dills Sand), using a Day grab over high water. Because the primary objective of this survey was to determine whether there had been a successful spatfall on the Dills sand, the coverage of this survey was not as extensive as that conducted in spring. For this reason the data from this survey should not be compared directly with the data from the previous survey.

During this survey 12 stations, covering 108 hectares, were found to support cockles of a marketable size (figure 3.40). These were found to have a mean density of 40.00 cockles/m^2 (range 10 – 130/m^2) and a mean weight of 2.79 tonnes/hectare. From these figures the biomass of marketable sized cockles on this bed was calculated to be 299 tonnes.

Apart from three stations that had benefited from a light settlement of spat during 2010, none of the stations surveyed were found to support cockles smaller than 14mm width. The three stations on which recruitment had occurred covered 28 hectares (figure 3.41), had a mean density of 263.3 cockles/m^2 (range 10 – 730/m^2) and a mean weight of 0.59 tonnes/hectare. From these figures the biomass of 2010 year-class spat on this bed was calculated to be 16 tonnes.

Figure 3.40 Distribution of Cockles >=14mm Width. Black Buoy. December 2010



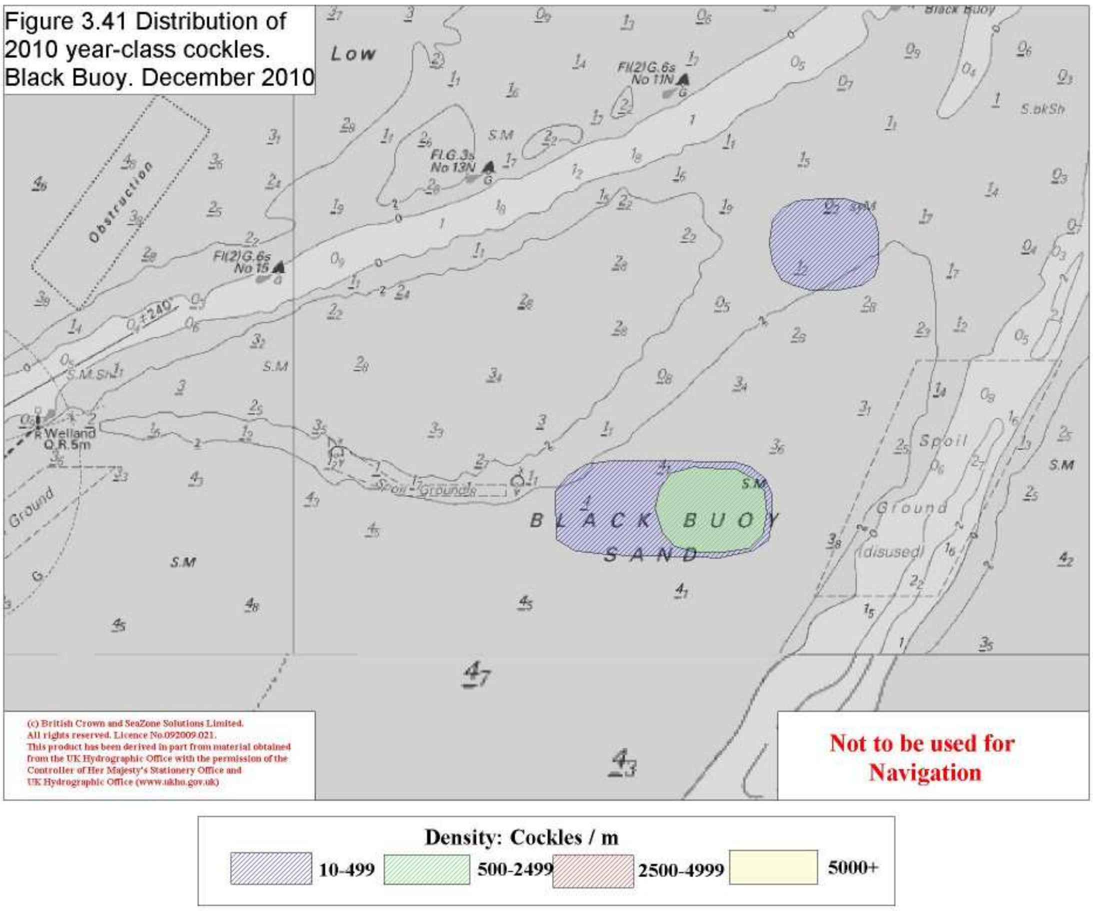
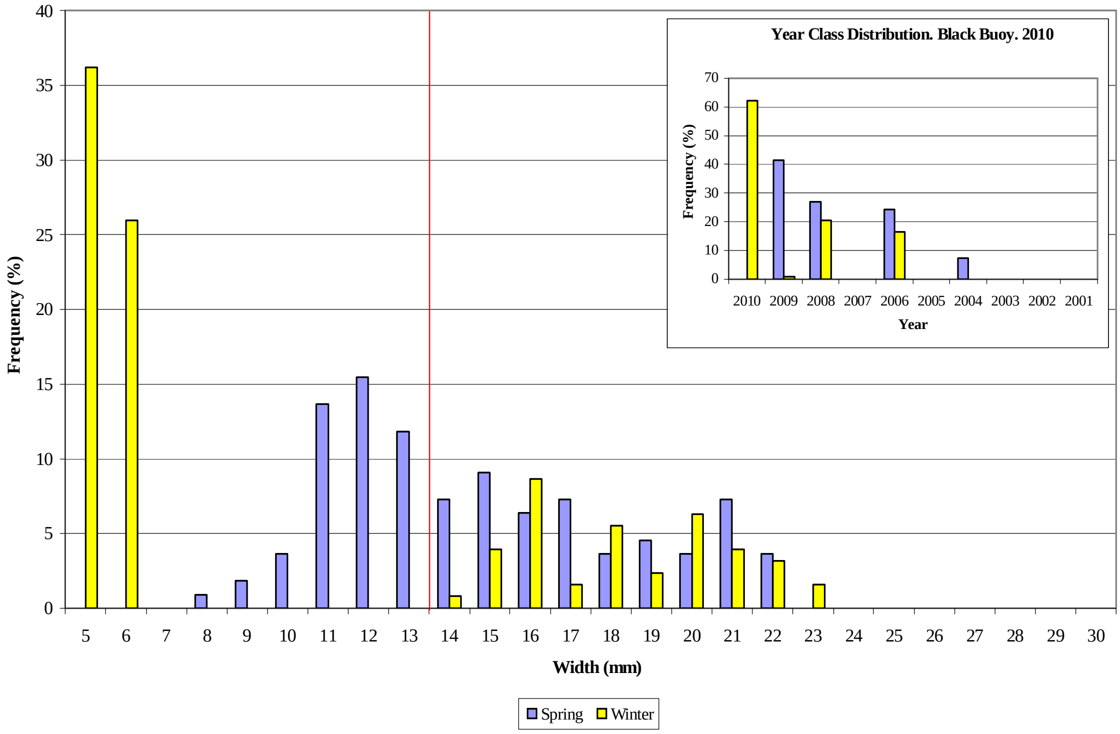


Figure 3.41 Distribution of 2010 year-class cockles. Black Buoy. December 2010

Figure 3.42 compares the size frequency of the population at the time of the spring and winter surveys.

Figure 3.42 Cockle Size Frequency. Black Buoy. 2010



3.4.3 Holbeach

The western side of Holbeach was surveyed on November 25th and 26th and December 10th 2010, during which 72 stations were sampled using a Day grab over high water. Because the survey was not as extensive as the one conducted in summer, the results are not directly comparable.

Within the area surveyed 27 stations, covering 242 hectares, were found to support cockles of marketable size (figure 3.44). These were found to have a mean density of 33.70 cockles/m^2 (range 10 – 120/m^2) and a mean weight of 1.48 tonnes/hectare. From these figures the biomass of marketable sized cockles within this part of the bed was calculated to be 357 tonnes.

Excluding 2010 year-class spat, 19 stations were found to support cockles smaller than 14mm width. These covered an area of 157 hectares (figure 3.45), had a mean density of 51.58 cockles/m^2 (range 10 – 300/m^2) and a mean weight of 1.06 tonnes/hectare. From these figures their biomass was calculated to be 165 tonnes.

29 stations, covering 238 hectares, were found to have benefited from a settlement of spat during 2010 (figure 3.46). Although this had settled in moderate densities at some sites, over most of the area the density was low. Overall, their mean density was found to be 418.97 cockles/m^2 (range 10 – 4,570/m^2) and their mean weight, 0.63 tonnes/hectare. From these figures the biomass of 2010 year-class spat in this area was calculated to be 150 tonnes.

Figure 3.43 shows the population size frequency at the time of the spring and winter surveys.

3.43 Cockle Size Frequency. Holbeach. 2010

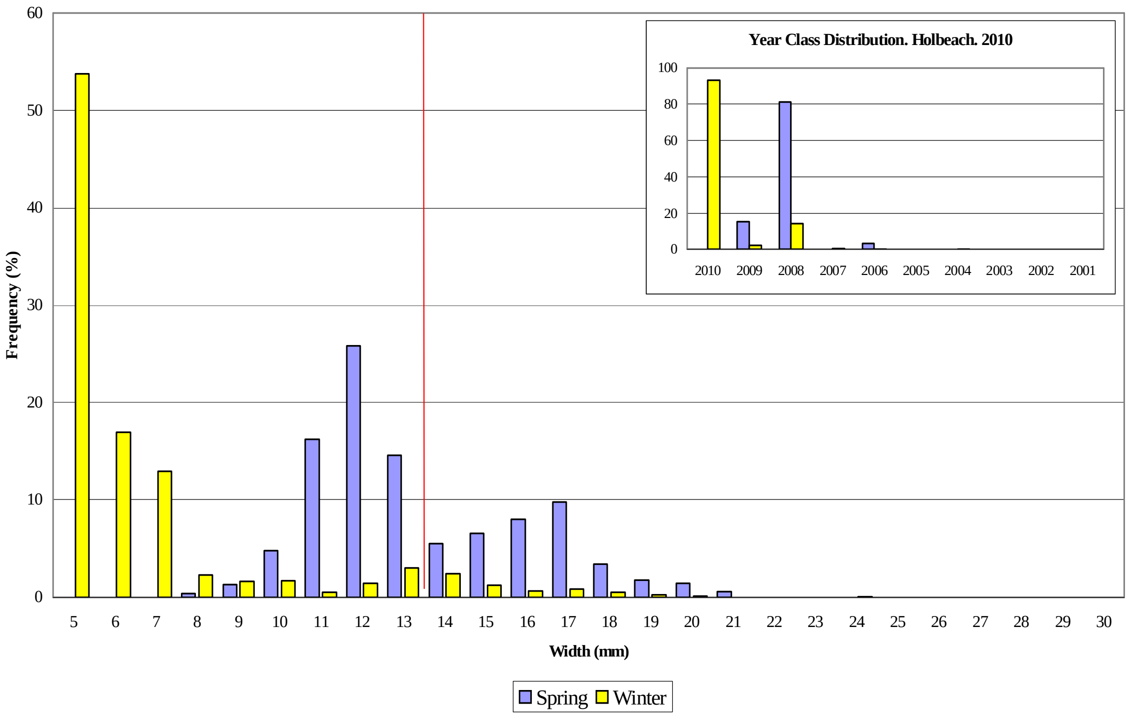
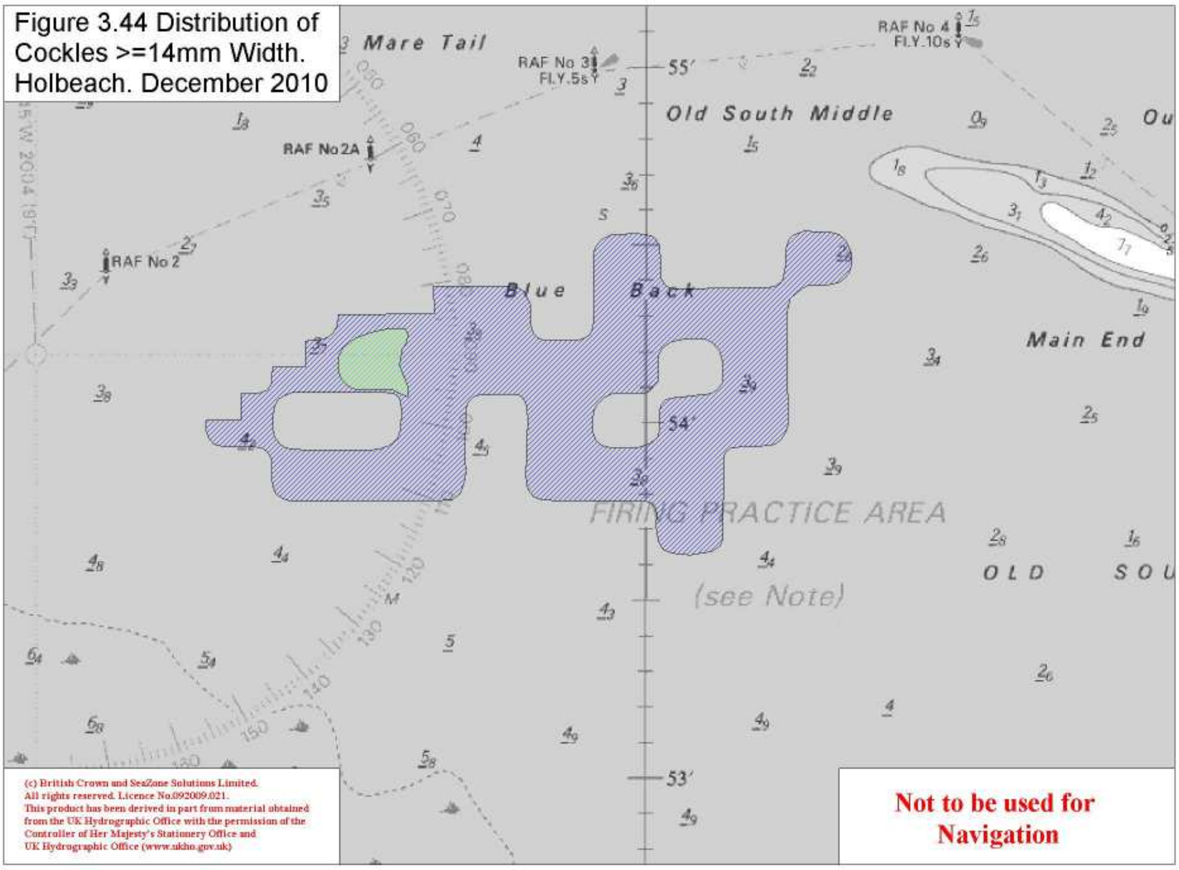


Figure 3.44 Distribution of Cockles >=14mm Width. Holbeach. December 2010



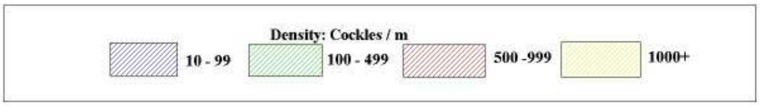
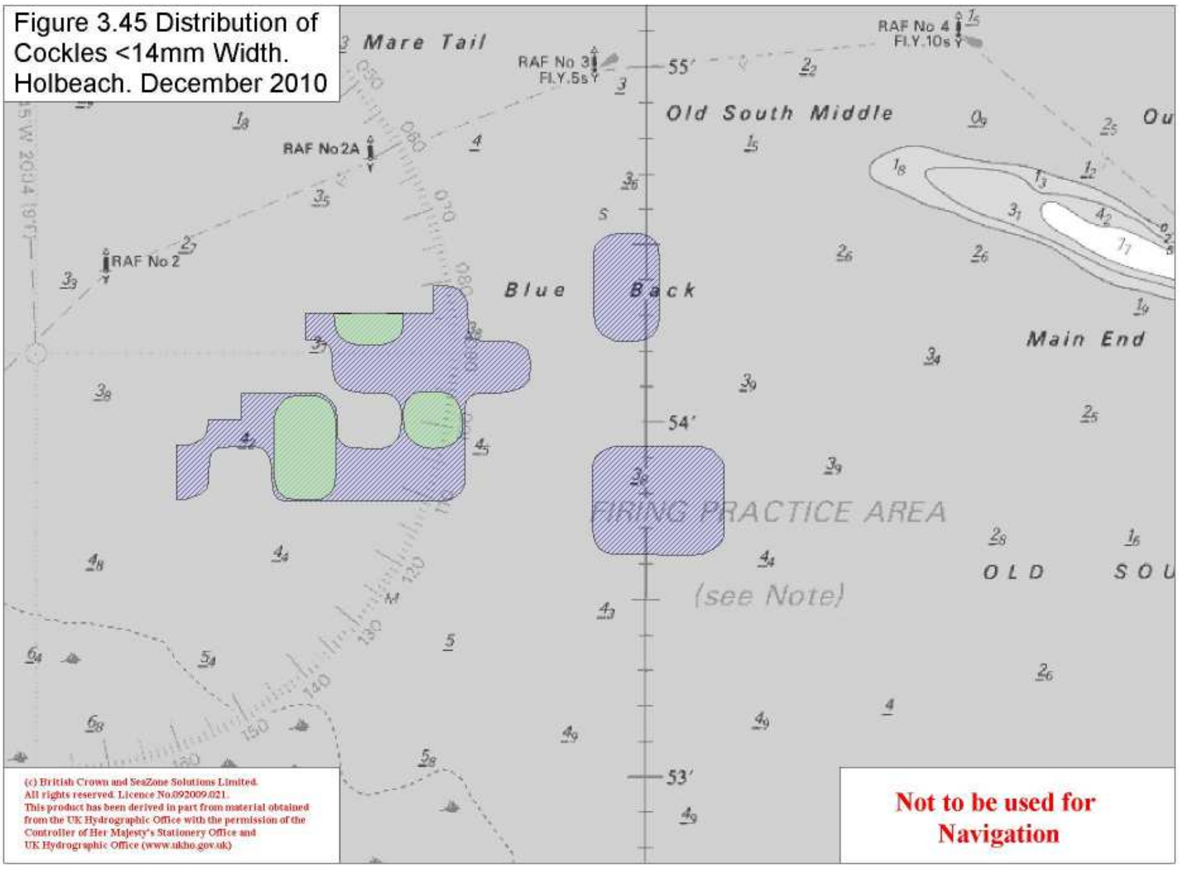


Figure 3.45 Distribution of Cockles <14mm Width. Holbeach. December 2010



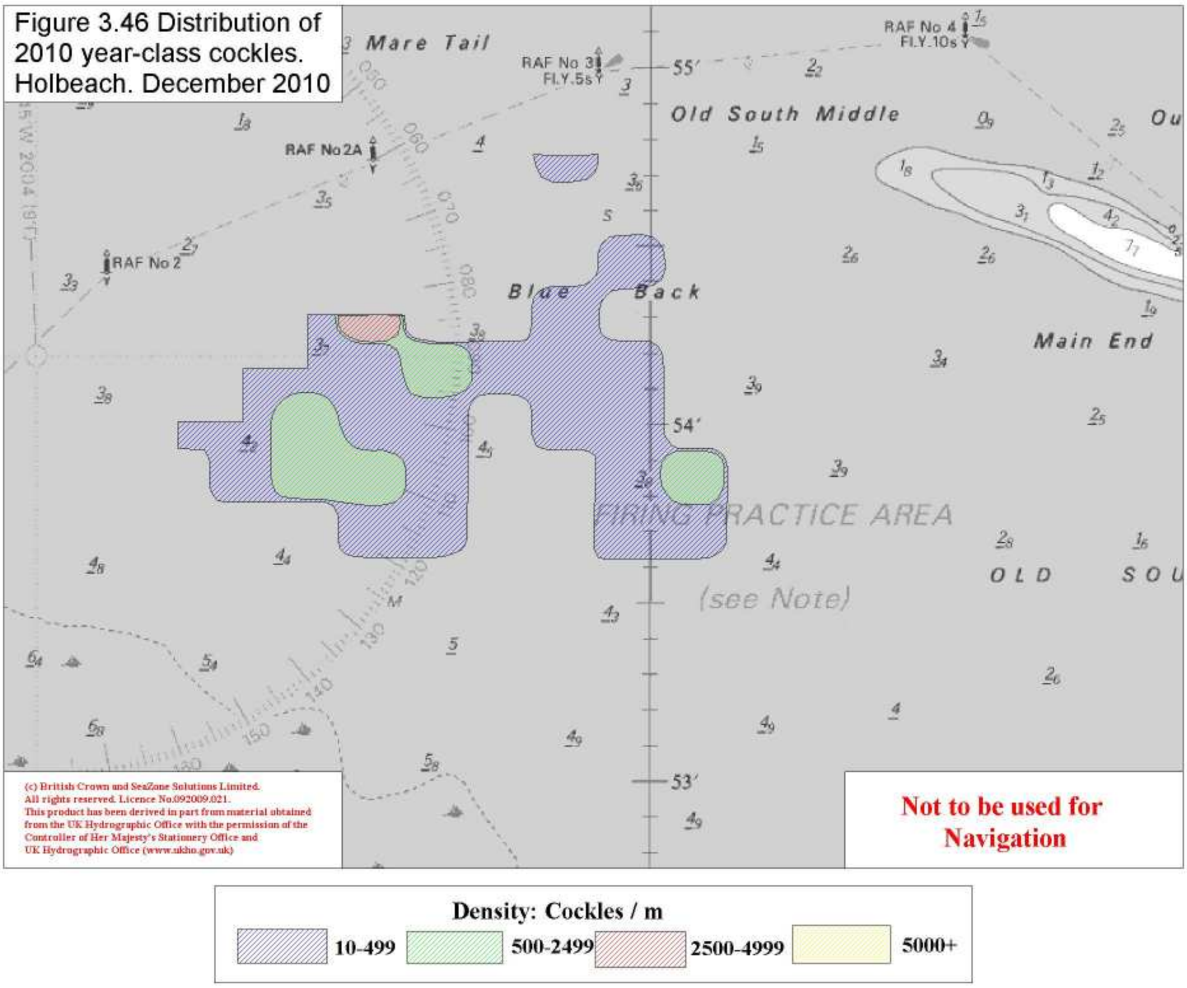


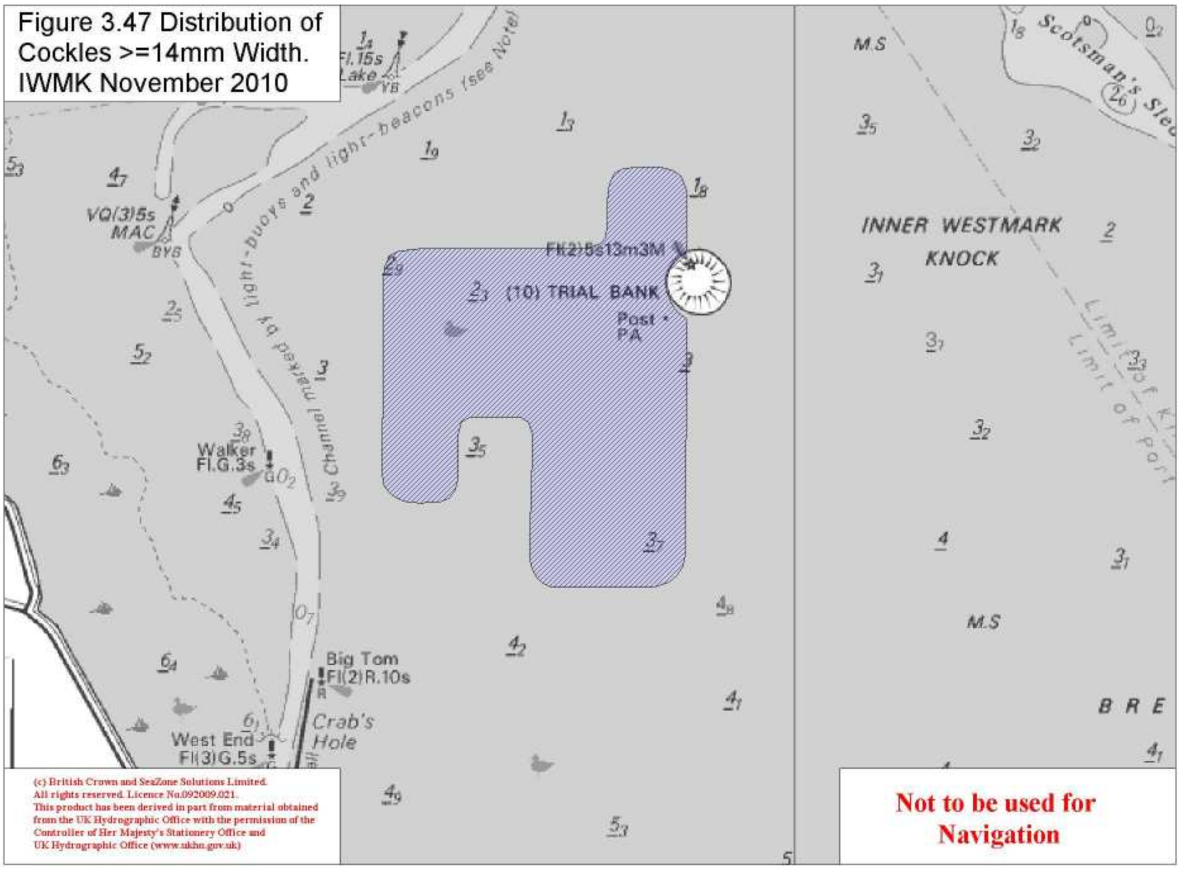
Figure 3.46 Distribution of 2010 year-class cockles. Holbeach. December 2010

3.4.4 Inner Westmark Knock

The Inner Westmark Knock sand was surveyed on November 25th 2010, during which 33 stations were sampled over high water using a Day grab. Although this bed had not been exploited heavily during the 2010 fishery, the survey found there had been a high cockle mortality since the spring survey. The survey also found there had been a good settlement of spat during 2010. Figure 3.50 shows the cockle size frequencies at the time of the spring and winter surveys.

14 stations, covering an area of 176 hectares, were found to contain cockles of marketable size (figure 3.47). This is an improvement on the 138 hectares recorded in May, and was possibly caused by slower growing cockles on the higher parts of the bed recruiting into this population between surveys. Although the coverage of marketable sized cockles had increased, high mortality meant their mean density had decreased during the same period from 73.00 cockles/m^2 (range 10 – 270/m^2) to 32.86 cockles/m^2 (range 10 –70/m^2). Likewise the mean weight of this population had decreased from 3.18 tonnes/hectare in May to 1.63 tonnes/hectare. From these figures the biomass of marketable sized cockles on this bed was calculated to have declined from 439 tonnes in May to 287 tonnes.

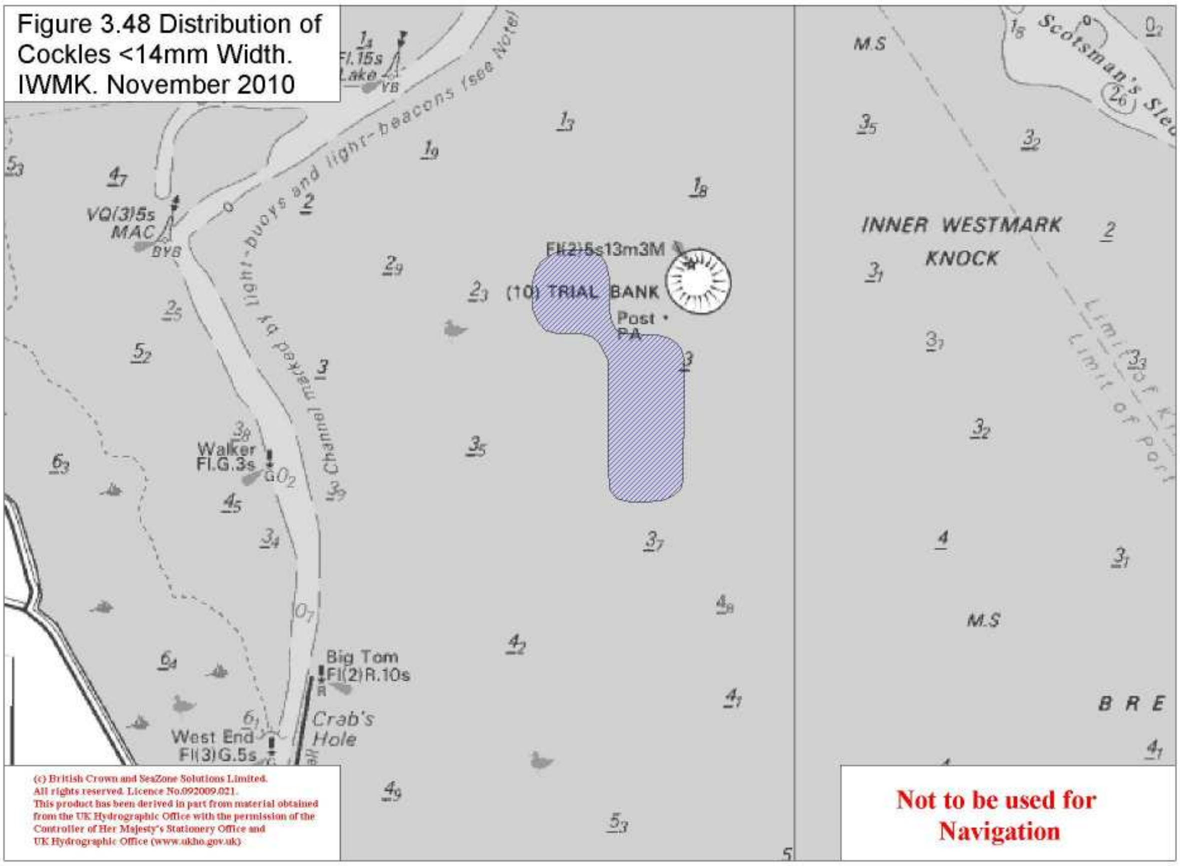
Figure 3.47 Distribution of Cockles >=14mm Width. IWMK November 2010



Density: Cockles / m

10 - 99 | 100 - 499 | 500 -999 | 1000+

Figure 3.48 Distribution of Cockles <14mm Width. IWMK. November 2010



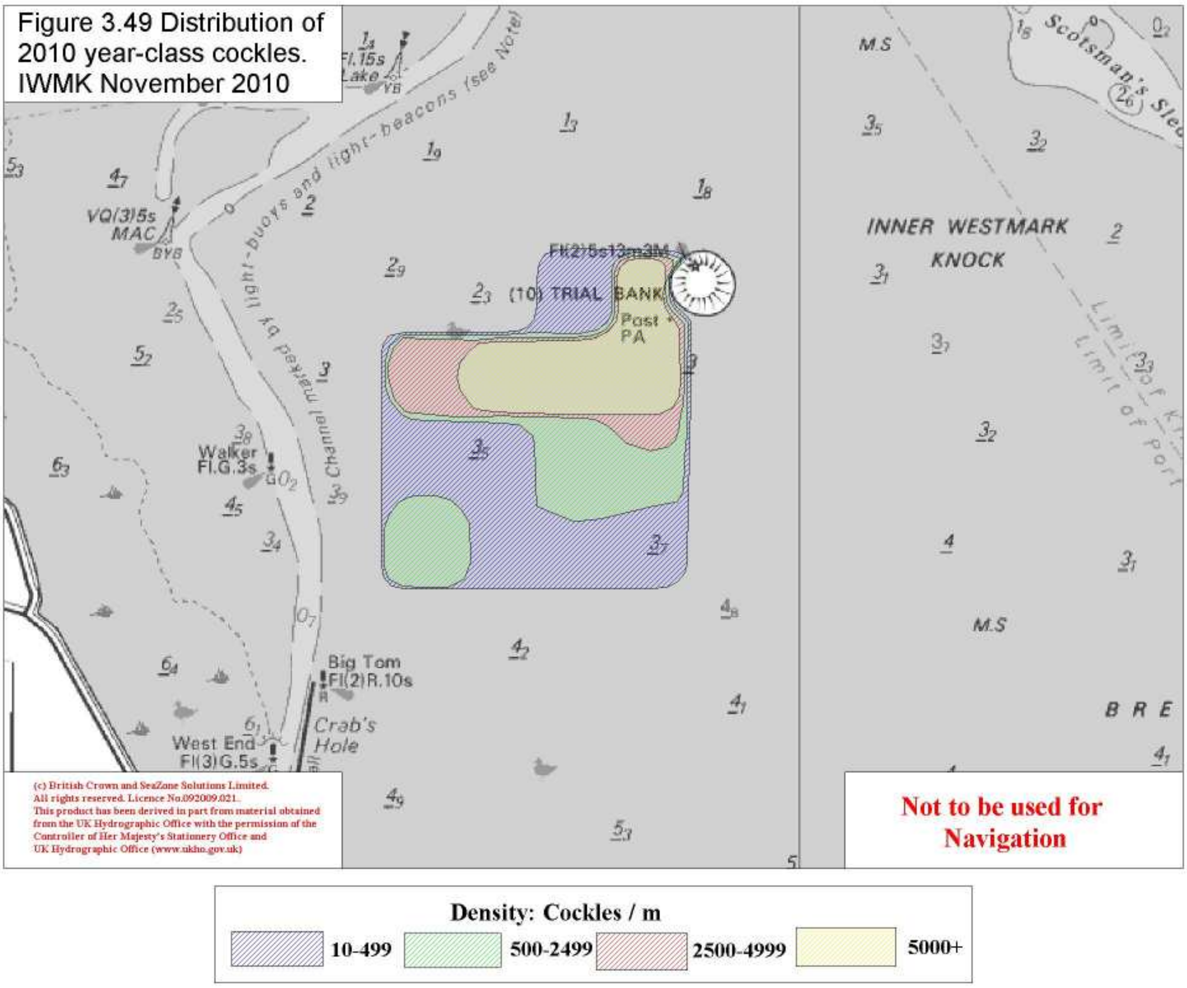
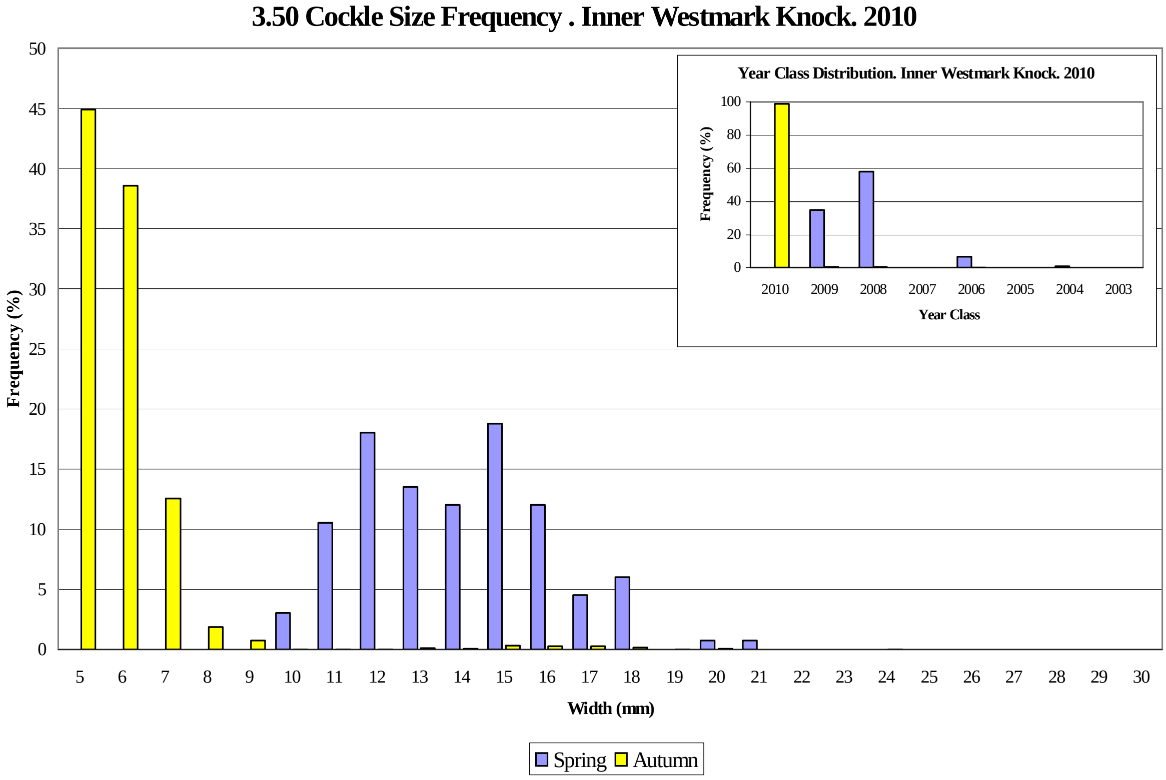


Figure 3.49 Distribution of 2010 year-class cockles. IWMK November 2010
INNER WESTMARK KNOCK
TRIAL BANK
Walker Fl.G.3s
Big Tom Fl(2)R.10s
Crab's Hole
West End Fl(3)G.5s
(c) British Crown and SeaZone Solutions Limited. All rights reserved. Licence No.092009.021. This product has been derived in part from material obtained from the UK Hydrographic Office with the permission of the Controller of Her Majesty's Stationery Office and UK Hydrographic Office (www.ukho.gov.uk)
Not to be used for Navigation
Density: Cockles / m
10-499
500-2499
2500-4999
5000+


3.50 Cockle Size Frequency . Inner Westmark Knock. 2010
Frequency (%)
Width (mm)
Spring
Autumn
Year Class Distribution. Inner Westmark Knock. 2010
Year Class

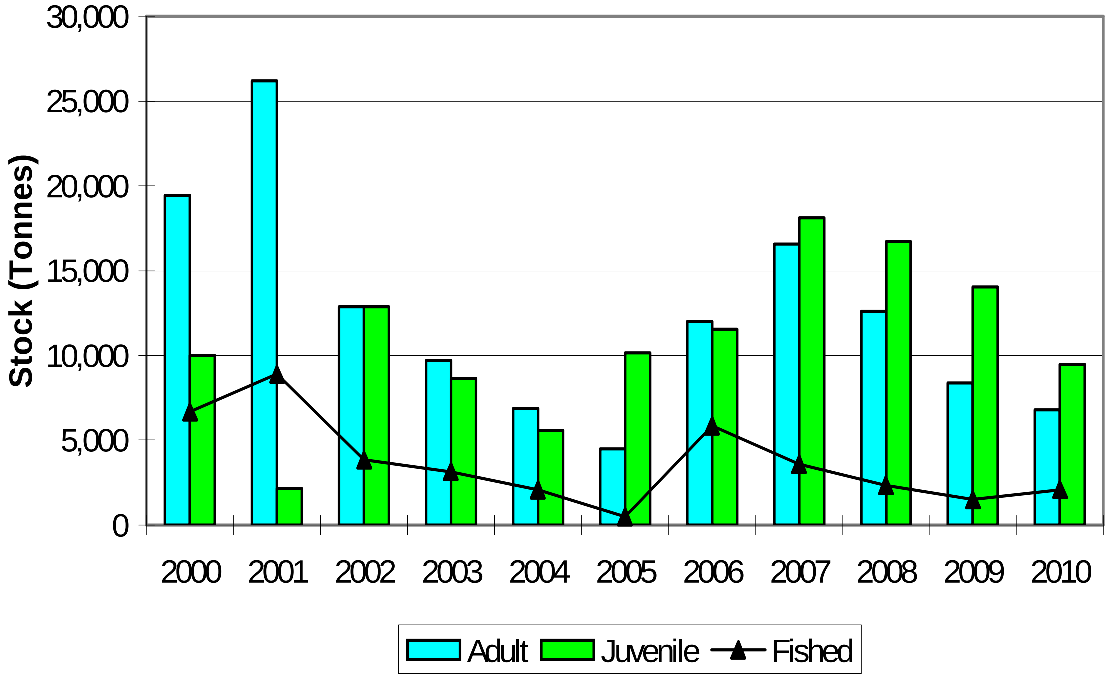
Because a high proportion of the cockles that had been recorded as being smaller than 14mm width in May had either died or grown to marketable size between surveys, the remaining population of small cockles on this bed was greatly reduced. Just three sites, covering 37 hectares, supported these (figure 3.48) compared to 137 hectares in May. At 26.67 cockles/m^2 (range 10 – 270/m^2), their mean density had declined from 60.00 cockles/m^2 (range 10 – 170/m^2), while their mean weight had fallen from 1.14 tonnes/hectare to 0.54 tonnes/hectare. From these figures the biomass of small cockles on this bed was found to have declined from 156 tonnes in May to 20 tonnes.

The bed was found to have benefited from a good settlement of spat during 2010. 14 stations, covering 177 hectares, were found to support these juveniles (figure 3.49). With a mean density of 2,864 cockles/m^2 (range 20 – 11,200/m^2) and a mean weight of 5.74 tonnes/hectare, their biomass was calculated to be 1,017 tonnes.

3.5 Discussion

Figure 3.51 shows the biomass of intertidal cockle stocks in the Wash since 2000. Although the 2010 spring surveys included two small cockle beds that had not been included in previous surveys, the total cockle biomass was found to have declined from 22,419 tonnes to 16,256 tonnes. Although cockle populations do tend to naturally fluctuate in a roughly cyclic pattern, the cause of the recent decline is of particular concern. Not only has the unexplained mortality event caused the stocks to fall from a recent peak of 34,694 tonnes in 2007 to a level below the ten-year average of 23,197 tonnes, but indications are it is still ongoing.

Figure 3.51 Intertidal cockle stocks in The Wash between 2000-2010 and the size of the respective annual fisheries



This mortality, which was first noticed in the Wash in 2008, has accounted for the loss of approximately 25,000 tonnes of cockles. Samples of moribund cockles from the Wash were examined by CEFAS for pathogens in June. These tests found three species of haplosporidian protozoa to be present in the samples, generally concentrated in areas of inflammation or lesions in the cockle flesh (M.Gubbins, CEFAS, Pers. comm). It has not been determined, however, whether these parasites are causal factors in the mortality or are just opportunistically taking advantage of weakened cockles that have been stressed by some other environmental factor. As of yet, the cause of the mortality is still unknown, therefore.

Because the mortality appears to have predominantly affected the larger, faster growing cockles, the result has been the reduction in density of the marketable sized stocks, most noticeably from the sands that support the fastest growth. After three years of mortality, the remaining marketable stocks are now concentrated on the higher beds where growth tends to be slower. Because cockles from these areas may take four or five years to attain marketable size, such beds generally support several year-class cohorts, making opening a fishery difficult without disturbing juvenile stocks. Although the level of adult stock was sufficient to provide a Total Allowable Catch (TAC) exceeding 2,000 tonnes, it was not possible to identify specific beds that could support such a fishery in 2010 without having a large impact on juvenile stocks. Of the 6,803 tonnes of marketable sized cockles identified during the spring surveys, only 3,595 tonnes were present in densities greater than 1.5 tonnes/hectare (this density facilitates a catch rate of approximately 0.75 tonnes/hour with an hydraulic suction dredge). Of these, only 1,779 tonnes were present in pockets not dominated by juvenile stocks (see figures 3.52 and 3.53). Of these marketable stocks, 1,785 tonnes were concentrated across five beds. 1,064 tonnes of these were found to be present in areas that were not dominated by juvenile stocks (see table 3.2).

Table 3.2 The biomass of marketable sized cockles, the biomass of marketable sized cockles beyond 1.5 t/ha and the percentage biomass of cockles that have attained 14mm width on five beds following the 2010 spring surveys

Sand	**Marketable Stocks (tonnes)**	**Marketable Stocks above 1.5t/ha (tonnes)**	**% Adult**
Black Buoy (Dills)	147	60	88
Holbeach	702	310	92
Inner Westmark Knock	303	205	73
Whiting Shoal	572	447	100
Thief	61	42	91
Total	**1,785**	**1,064**	**90**

Although it was proposed opening these five beds to the dredge fishery, consultation with the industry revealed mixed feelings towards the proposals. With views within the industry strongly divided as to whether a dredge fishery should proceed, the Wash Management Sub-Committee decided on June 23rd to open the 2010 fishery to handworking only. During the season 29 vessels participated in this fishery, exhausting the 2,081 tonnes TAC by December 2010.

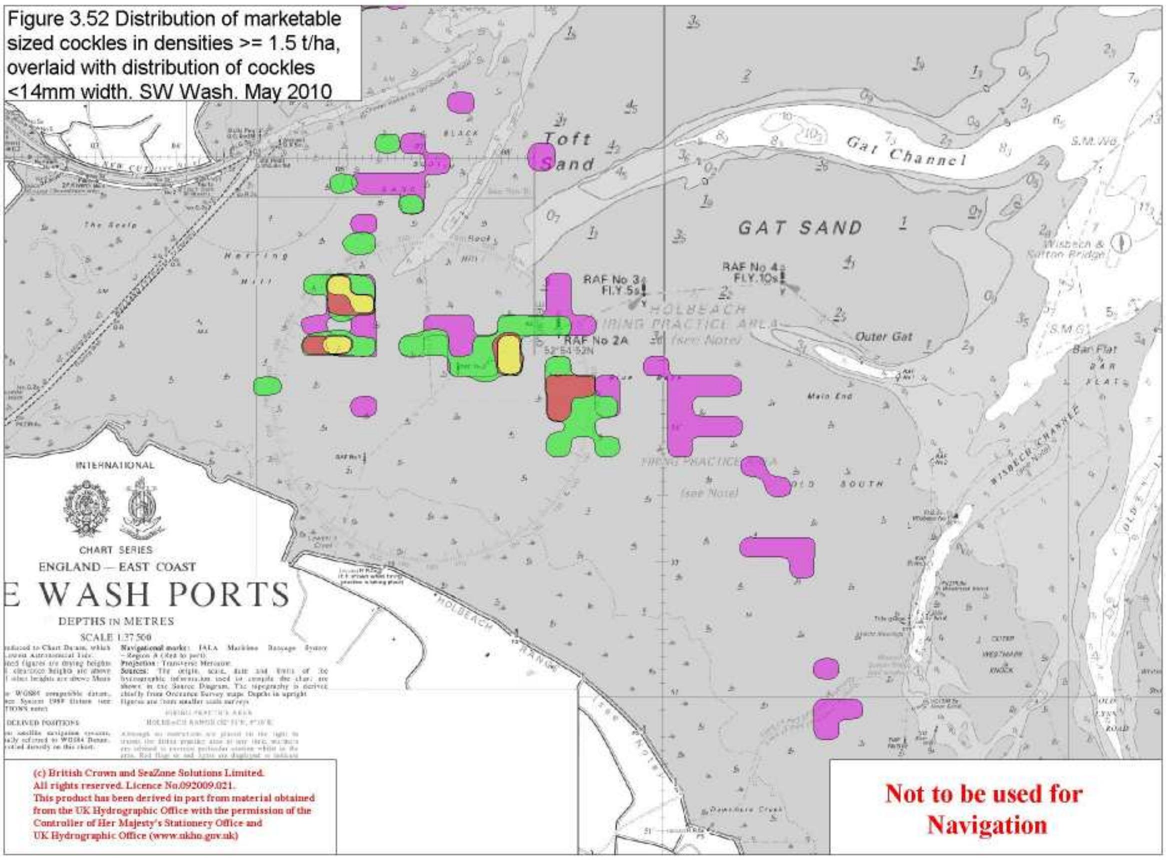
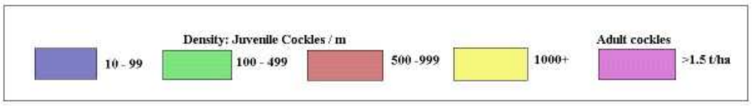


Figure 3.52 Distribution of marketable sized cockles in densities >= 1.5 t/ha, overlaid with distribution of cockles <14mm width. SW Wash. May 2010



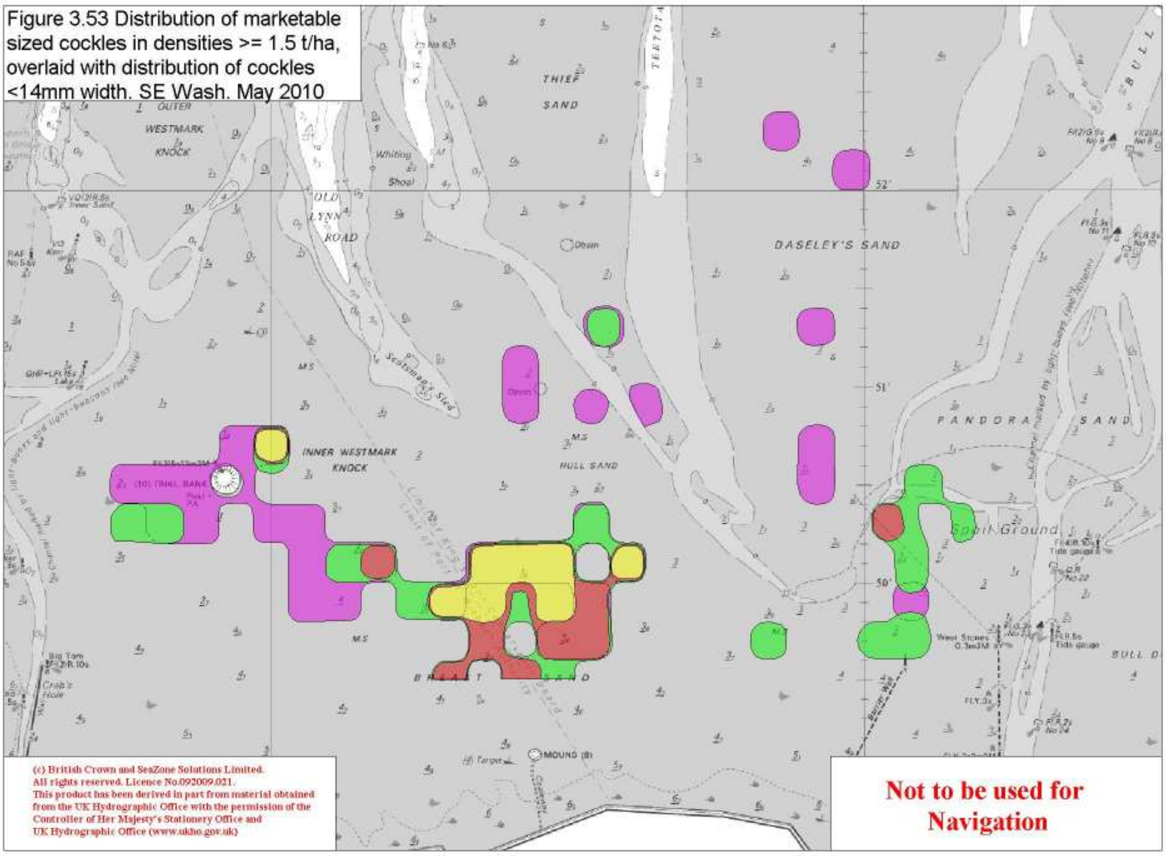


Figure 3.53 Distribution of marketable sized cockles in densities >= 1.5 t/ha, overlaid with distribution of cockles <14mm width. SE Wash. May 2010

3.6 Effects of the Cockle Fishery on Benthic Organisms and Sediment

3.6.1 Introduction

Cockle and mussel fishing are two of the main fisheries currently carried out in the Wash. These are regulated under the Wash Fishery Order (1992) by the Eastern Sea Fisheries Joint Committee (ESFJC), which will become the Eastern Inshore Fisheries and Conservation Authority (EIFCA) in April 2011. The common practices for the cockle fishery are hand working and, when stock levels are favourable, hydraulic suction dredging.

During the 1970's in particular, a common method for hand working cockles referred to as "blowing out" was widely used. Concerns were raised during that period, however, over the amount of damage the practice may have been causing to both the cockle stocks and the seabed. "Blowing out" was achieved by securing the vessel to the seabed with a large "ploughing" anchor and then steaming in progressively tighter circles as the tide fell. Because the vessels were anchored, large amounts of power could be directed against the seabed for prolonged periods. This created sufficient energy to not only remove the top layer of sediment, but to also push the cockles several metres towards the centre of the circle. As each circle was completed, the anchor line would be shortened by several metres prior to the start of the next circle. By doing this, the cockles "blown back" from each preceding ring would be gradually pushed back towards the anchor, where they could easily be harvested at low tide from a single large heap. When perfected, this method could effectively remove almost all of the cockles from an area of 50m radius and create deep rings in the seabed. An unfortunate consequence of this activity was that piles of unharvested and displaced cockles would sometimes be left to die, while the rings created would take several months to recover (ESFJC 2009).

The practice of "blowing out" ceased in 1986 with the advent of hydraulic suction dredging as the predominant method of harvesting cockles. Furthermore, "blowing out" became restricted under Regulation 1 of the Wash Fishery Order 1992, under which no anchors or any other anchoring equipment can be used by vessels engaged in the handwork cockle fishery.

In 2005, when hand working once more became a viable option for harvesting cockles, care was taken by managers and fishermen not to recreate the historical problems associated with "blowing out". Although nowadays boats propellers are still being used to remove the upper layer of sediment from above the cockles in order to make them easier to harvest, the rings created are smaller and cause less disturbance to the seabed than those in the 1970's. For the purposes of this report this method will be referred to as "prop washing". Observations made during the past years of the hand worked fishery have found minimal disturbance to the seabed, with only shallow rings being evident and recovery occurring within a few days (ESFJC 2009). Figures 3.54 and 3.55 show fishing boats at low tide in the Wash engaged in the handwork cockle fishery.

Figure 3.54: Cockle fishing boats at low tide.

Figure 3.55: Bag containing collected cockles.

As far as the author is aware, no peer reviewed studies on the effects of prop washing on macrobenthic communities have been conducted. This is likely to be due to the prop washing method for cockles being limited to the Wash area. However, a similar method referred to as “clam kicking” is carried out in the North Carolina clam fishery. Clam kicking was first tried in the early 1940’s and is a mechanical form of harvest involving the modification of boat engines in such a way as to direct the propeller wash downwards into the sediment. The powerful propeller wash dislodges the clams from the seabed and suspends them in the water plume, which then allows a heavily chained trawl towed 15 feet (4.6 meters) behind the boat to gather the clams (Guthrie and Lewis 1982). A study conducted by Petersen *et al.* (1987) showed that this clam kicking did not affect abundance and species composition of the macrobenthic communities, an outcome which the authors attributed to the marine organisms’ capacity of rapid recolonization and their short lifespan.

Studies on the effects of cockle fishery using other methods of fishing have also been conducted. Short-term and long-term decreases of non-target organisms following cockle suction dredging were detected in several experiments (Hall & Harding 1997, Kaiser et al. 2001, Hiddink 2003). The impacts of this reduction in macrobenthic communities, however, are unclear, with some authors stating that the overall effects on populations are probably low (Hall & Harding 1997), while others indicate that the effects of cockle fisheries on benthic communities persist even one year after the disturbance occurred (Hiddink 2003).

With a lack of information of the prop washing effects on the seabed and its communities, it was ESFJC’s aim to ascertain whether the current practice of “prop washing” is damaging to the benthic community. In partnership with Natural England a three-month survey was conducted in an area of the Wash where “prop washing” was practiced during the cockle season. The aims of the study were to firstly establish whether prop washing was causing any changes to the macrofaunal organisms and the sediment properties composition and secondly to determine whether and how fast the benthos recovered from the disturbance, if such changes were observed in the first place.

3.6.2 Methods

3.6.2.1 Sample Collection

To select a suitable survey location, a representative area of the Wash had to be selected that had not been fished for several years and was largely undisturbed. In addition, sufficient one-off cockle fishing activity had to take place in the area, with no subsequent fishing in order for the rings to recover from the activity. Five impact rings, i.e., rings created by prop washing, were selected between the Breast and Hull Sand at the south-eastern end of the Wash and marked with bamboo stakes (Figure 3.56). In addition to the impact sites, five control sites were selected, where no cockle fishing had taken place. The closest control site was at least 80 metres apart from the nearest impact ring. Coordinates of all sites were recorded using a hand held GPS. At each ring, three sites were chosen at random distances apart along the ring where one benthic and one sediment sample were taken. Benthic macrofaunal and sediment samples were collected using a 102mm and 36mm diameter corer, respectively, to a depth of 150 mm. The contents of each core were then transferred into separate labelled plastic bags. The biological samples were sieved at 0.5 mm and fixed in formaldehyde solution the day after sampling. Benthic samples were sent to Unicomarine for species identification and biomass determination, while particle size analysis was conducted on the sediment samples by the Plymouth Marine Laboratory. Samples were collected one day after fishing was completed (Day 1), and then one week (Week 1), one month (Month 1), and three months (Month 3) after fishing (Table 3.3).

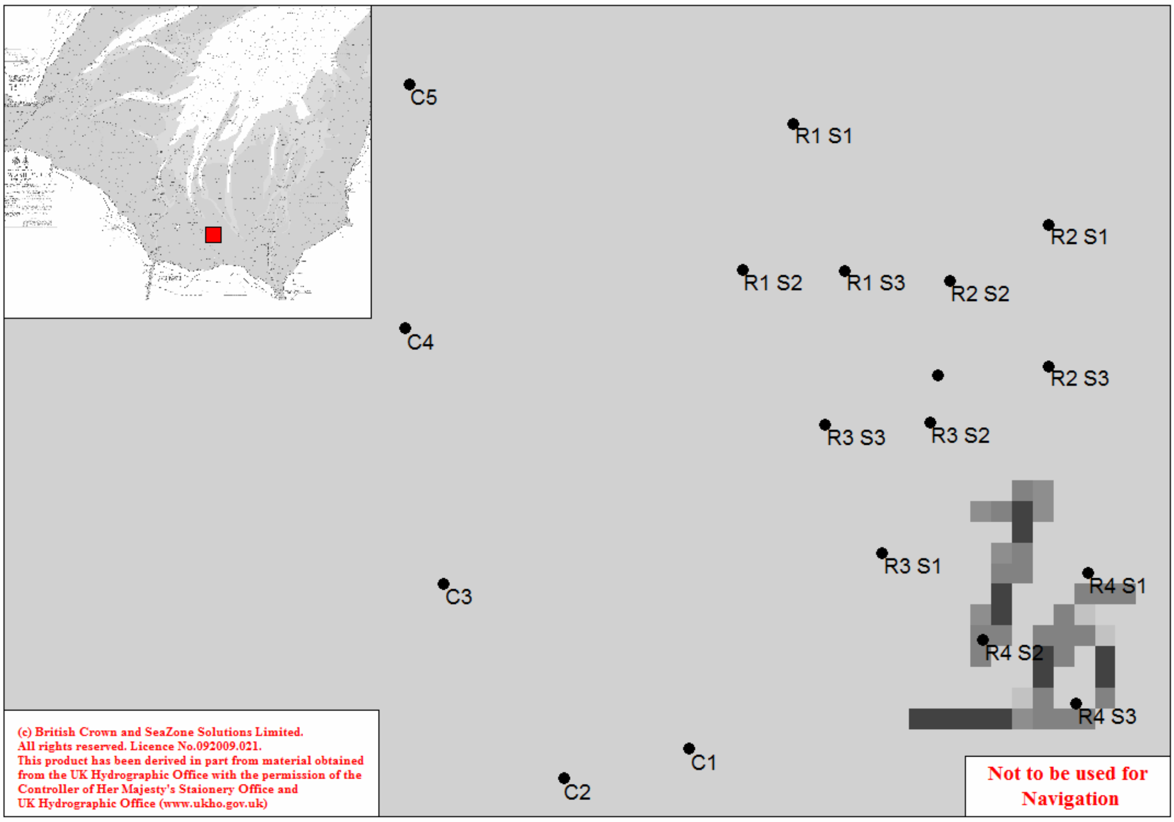


Figure 3.56: Sampling location in the Wash (inset chart) with control (C1 - C5) and fished ring sites (R = Ring numbers and S = Site numbers).

Table 3.3: Schedule of sampling events at ring and impact sites in the Wash.

Sampling Events	Sampling Dates
Day 1	29 July 2010
Week 1	4 August 2010
Month 1	25 August 2010
Month 3	5 November 2010

3.6.2.2 Sample Processing

In accordance with the Unicomarine procedural guidelines (Worsfold et al. 2010) all countable macrofauna and examples of sessile taxa (including plants) were removed from the sample and picked into pots containing 70% industrial methylated spirit. Bryozoans and barnacles were preserved dry after fixation in formaldehyde. For most material, organisms were identified to species level. Colonial organisms such as plants or hydroids and bryozoans were recorded in the abundance as unit occurrence (i.e., 1) due to the inherent difficulties in their quantification. For quality control purposes and to allow future taxonomic comparisons to be made, a reference collection of each taxon found was made and will be kept at Unicomarine, along with the remaining extracted fauna, which are stored at Unicomarine. To determine biomass per site, animals identified in the course of the benthic analysis were, after dry-blotting, sorted into taxonomic groups and weighed. Weights were recorded in grams.

Particle sizes analysis was conducted by the Plymouth Marine Laboratory. Each sediment sample was separated into >2 mm and <2 mm fractions by wet-sieving and then oven dried at 105 °C. The <2 mm fraction was treated with 6% hydrogen peroxide to remove the organic content, and dried. For the laser particle size analysis, water was added to the sediment and the material was loaded into a Malvern Long-bed Mastersizer X (Procedural description for PSA analysis can be provided upon request). Replicates for each sample and lens ranges filtered were averaged and then extended with sieving data fractions calculated at half phi intervals.

3.6.2.3 Univariate and Multivariate Data Analysis

Pie charts of the sediment data were created in MapInfo 8.5 to graphically represent the changes in particle size over time and among sites. For each site, the number of benthic organisms (i.e., species abundance) and number of species (i.e., species richness) were determined and relevant graphs were produced. Additionally, the Shannon-Wiener diversity index was calculated, which is a mathematical measure of species diversity in a community. Shannon-Wiener diversity H' was calculated as follows:

$H' = -(p_i \times \log[p_i])$, where p_i = the proportion of the total sample belonging to the *i*th genus

Diversity indices provide more information about community composition than species richness alone, as they also take the relative abundances of different species into account.

Multivariate analyses were performed in Minitab version 15. Principal component analysis (PCA) and cluster analysis was conducted on the square root transformed combined sediment and macrofaunal data. Principal component analysis is an exploratory technique that takes a set of correlated variables, in our case species and sediment composition at the different sites over time, and defines new variables that are linear combinations of the initial variables. PCA returns new variables, the principal components or axes that summarise the information contained in the original full set of variables (USEPA 2010). The model also indicates which of the original variables are most strongly correlated with the new variables, or axes. The results of the analysis are typically plotted using the first and second axes (USEPA 2010). In addition, cluster analysis was carried out on the data using complete linkages and Euclidean distance measures. The main purpose of this analysis was to organise samples into groups according to their similarities. The similarity matrix data is subjected to the cluster analysis with results presented as a dendrogram. The dendrogram displays those sites as groups that are most similar to each other.

3.6.3 Results

3.6.3.1 Univariate Analysis of Sediment and Macrofaunal Data

Figures 3.57 to 3.60 show the outline of ring 3 throughout the survey period as an example of the visual changes undergoing a fished site over time. The depth of the rings created by prop washing was estimated to range from 2 – 15 cm on Day 1.

Figure 3.57: Ring 3 at Day 1.

Figure 3.58: Ring 3 at Week 1.

Figure 3.59: Ring 3 at Month 1.

Figure 3.60: Ring 3 at Month 3.

Based on the GRADISTAT classification system of Blott & Pye (2001) the sediment in the sampled area of the Wash during the survey period was largely characterised by gravelly to muddy sands (Figure 3.61). The coarsest sediment types on all sampling occasions were found in rings 3 and 4, where at least two of the three replicates contained over 80% sand (0.063 - 2 mm). Similarly with the control sites, at least one of the sites was composed of over 80% sand on all sampling occasions. The finest sediments were found at ring 5, site 3 on Day 1, Week 1 and Month 3, where the silt (0.001953 - 0.0625 mm) contents ranged from 59 – 62%, while on Month 1 the finest sediment (60% silt) was found at ring 1, site 2.

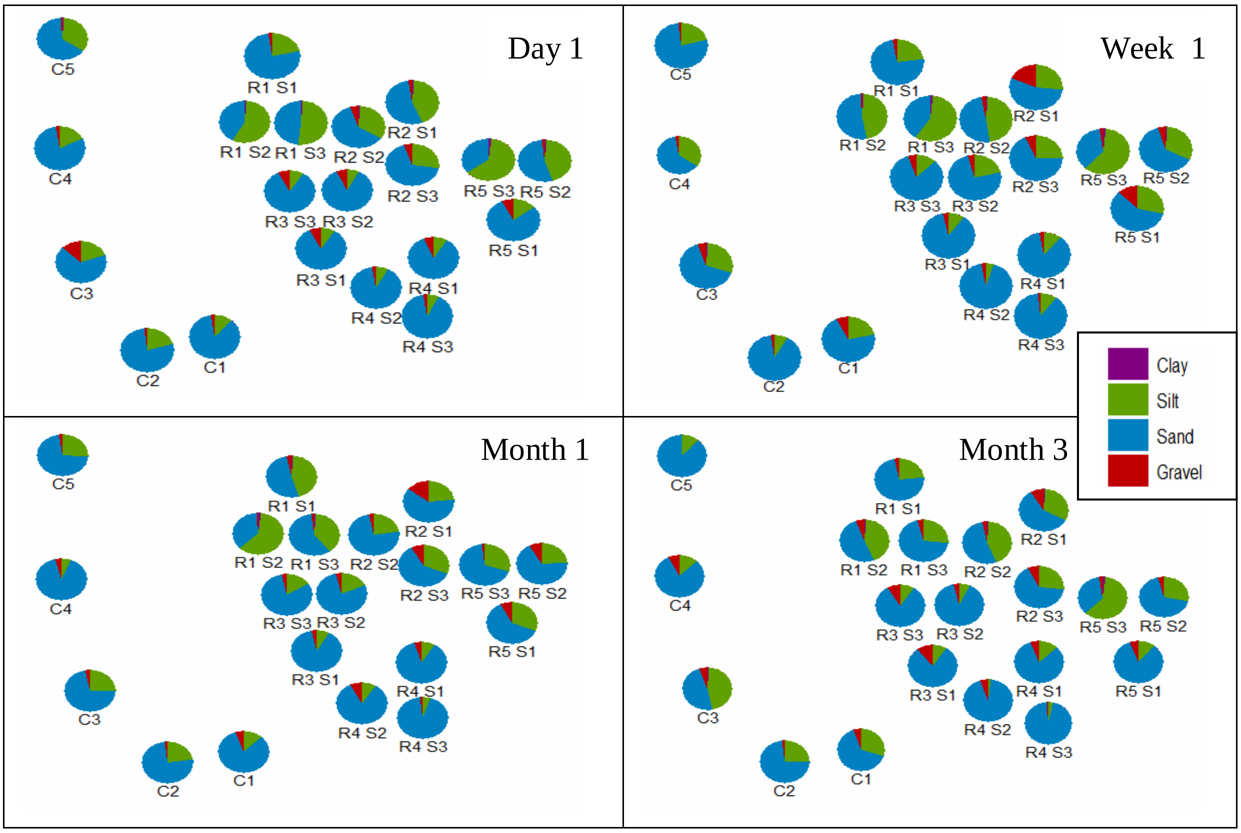


Figure 3.61: Sediment composition at ring and control sites sampled in the Wash from Day 1 (July 2010) to Month 3 (November 2010).

While no obvious temporal changes could be detected at the control and ring sites, spatial differences were observed in sediment composition. Among the ring sites, southern sites largely contained sand, while most northern sites had a high proportion of silt. Among control sites, on the other hand, this north - south differentiation in sediment composition was not observed. The sediment classification results are presented in Appendix A.

Cockle abundances within ring replicates over time were in most cases highly variable, indicating that cockle removal by fishermen using prop washing was not complete (Figure 3.62). One such example was observed at ring 3, replicate 1, where on Day 1 over five cockles were collected in the sample, on Week 1 no cockles and in Month 1 and 3, over 15 cockles were recorded. Abundance of cockles overall was generally higher at the control sites than the ring sites, particularly at controls 1 and 2. However, similarly high numbers were recorded at ring 5 throughout the survey. The highest number of cockles (i.e., 38 individuals) was observed at control 1 during the Month 1 survey and for the ring sites at ring 5 site 1 (Week 1) with 26 cockles. Among the ring sites, highest and most consistent abundance of cockles throughout the survey was observed at ring 5.

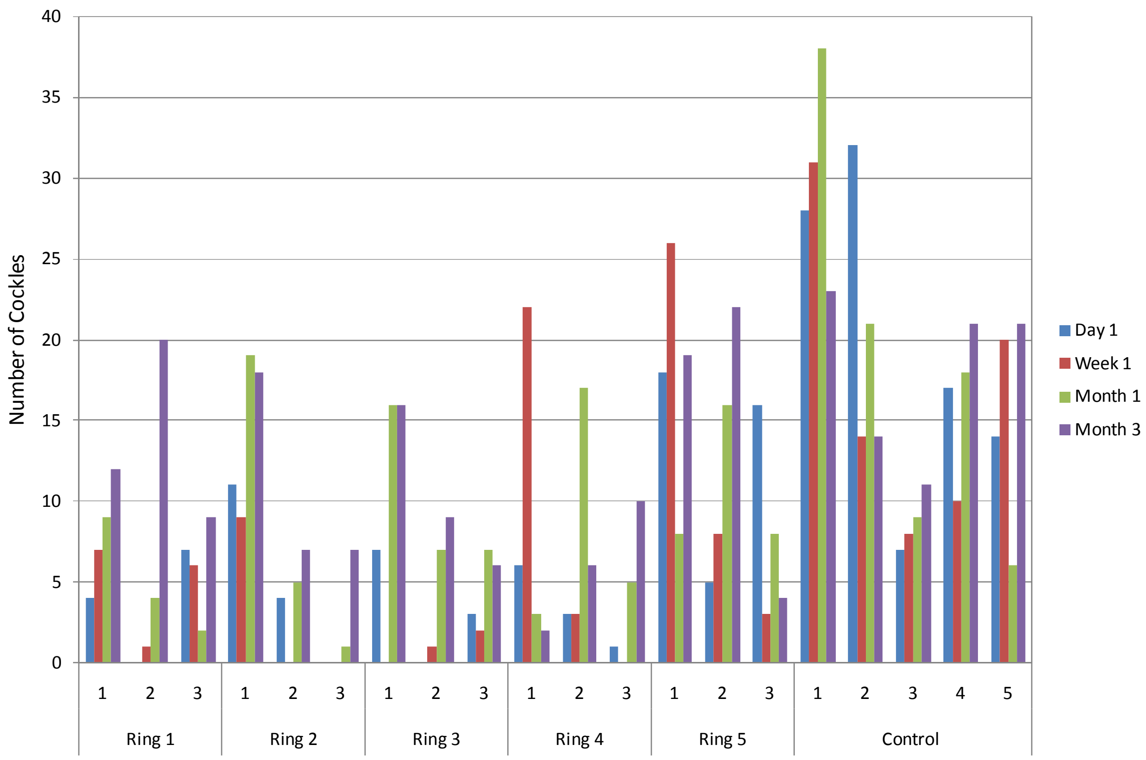


Figure 3.62: Number of cockles collected throughout the survey in the Wash from July to November 2010.

A total of 80 benthic core samples were collected in the Wash over the three-month period from July to November 2010. The samples were sorted and organisms were identified to species level (where possible), enumerated and biomass was established. A complete list of the organisms identified in the benthic samples is shown in Appendix B.

Out of the 1709 g of biomass that was collected throughout the entire survey, molluscs made up most of this biomass with 1693 g. Polychaetes contributed 12 g, crustaceans 2 g, oligochaetes (a subclass of annelid worms) 0.6 g, and nematodes (roundworms) 0.006 g to the biomass.

During the survey, 65 species were collected in the samples, amounting to a total of 6182 organisms. Individual species were occasionally numerous within a sample. Of the quantitative taxa, the cirratulid polychaete *Tharyx* “species A” was the most numerous species in the samples, with a total of 2513 organisms being caught over the entire survey period and across sites. Second most numerous was the polychaete *Tubificoides benedii* (1420 organisms), followed by the cockle *Cerastoderma edule* with 835 organisms. Among all the sites, a dominance of small and motile organisms (i.e., polychaetes and small crustaceans) was observed and a distinctive lack of larger, more sessile organisms.

No clear temporal and spatial trends in macrofaunal abundance (i.e., number of macrofaunal organisms) emerged over the sampling period and between control and ring sites (Figure 3.63). Species abundances at most control sites on Day 1 were, however, higher than at the ring sites 1 to 4. In addition, control sites 1 and 2 displayed consistently high numbers of organisms throughout the survey. Spikes of high species abundances were also apparent at ring sites. One such spike was observed at ring 5 (site 1) on Day 1, which was due to the high numbers of the polychaete *Tubificoides benedii* in the sample. The remaining three survey occasions showed varying levels of abundance across the ring and control sites.

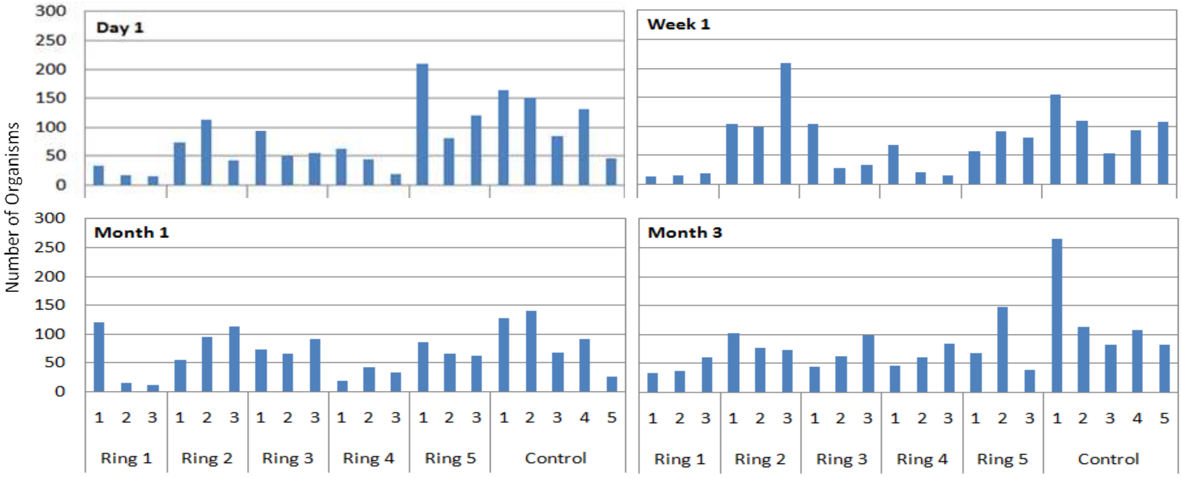


Figure 3.63: Species abundance at ring and control sites in the Wash from July to November 2010.

Species richness and diversity across the sites and survey period were generally low. Species richness per ring was variable and ranged from 3 to 17 species (see Appendix B). In addition, the Shannon-Wiener diversity index (H') was calculated, which takes into account the relative species abundances. Shannon-Wiener diversity index at the various sites was variable and values from 0.58 to 2.17 were obtained. Highest diversities of 2.0 on Day 1 and 2.1 on Month 3 were recorded at ring 1 site 1. At Week 1, the largest H' of 2.1 was calculated at ring 4 site 1 and on Month 1 at ring 3, sites 1 and 2 (diversity of 2.2). With typical values of Shannon-Wiener diversity in marine ecosystems being in the range of 1.5 (low species richness) to 3.5 (high species richness), macrofaunal diversity encountered in the Wash appeared to be on the lower end of the spectrum.

3.6.3.2 Multivariate Analysis of Macrofaunal Communities

Multivariate analyses techniques were utilised to investigate similarities, differences and trends in macrofaunal communities and sediment composition among sites. Analyses were conducted with and without cockles in the dataset to determine the influence this species has on the benthic community. As no considerable difference between the analyses could be determined, cockles were included in the final multivariate analyses.

Figure 3.64 shows the PCA plot of the sediment and macrofauna recorded across the survey sites. Points close together represent sites with similar properties compared to points further apart. Although no distinct clusters were generated, some loose groupings of sites can be observed. Sites 5 and 1 for instance, appear to be grouped in the left and bottom of the plot, respectively. Similarly, a cluster of control sites is present at the top centre of the plot and a fourth cluster with control, ring 3 and 4 sites to the top right of the plot. This indicates that sites within these groups have more similar sediment and macrofaunal properties to each other than to sites further away.

The dendrogram (Figure 3.65) generated using the same data shows the groupings of the different samples according to similarities in sediment and macrofaunal compositions. Due to the distances on the far branches being relatively large in comparison to the near branches, the grouping do not appear to be very effective and the dendrogram should therefore be interpreted with some caution. Nevertheless, two main groups were generated, each with several sub-groups. The clearest groupings were observed for control sites 1 and 2 in purple on the right hand side of the graph, and ring 1 in green in the middle of the graph. These groups are similar to the clusters displayed in the PCA plot. Most other sites are spread across the dendrogram. In summary, both the PCA and cluster analysis revealed only weak clusters indicating that no considerable differences in sediment and macrofaunal communities exist among control and ring sites.

3.6.3 Discussion

The cockle fishing activities observed in the Wash using prop washing created visible rings in the sediment ranging from a depth of 2 – 15 cm. Over the three-month period of the survey, however, the outline of the rings became less visible at most ring sites. Analysis of the benthic core samples revealed that a variable number of cockles were still present in the sediment, indicating that removal of cockles from the sediment using the prop washing method was incomplete at all ring sites. It was beyond the extent of this study to determine the fate of dislodged, non-fished cockles, but previous studies suggested that cockles are capable of reburial into sediment after disturbance. Coffen-Smout & Rees (1999) showed during a study conducted in North Wales that more cockles (*Cerastoderma edule*) were able to reburrow into the sediment within 1 hour of dislodging and handling if they were in shallow wet pools or wet sand, than if they tried to reburrow into drained sand. Cockles unable to reburrow before the incoming tide arrived were found further up-shore in the direction of the tidal flow (Coffen-Smout & Rees, 1999). The prop washing method essentially creates shallow pools, which should facilitate reburrowing of unfished cockles. Observations made in the Wash showed that unfished cockles were often found in shallow pools of water several days after prop washing had taken place (R. Jessop, pers.comm.).

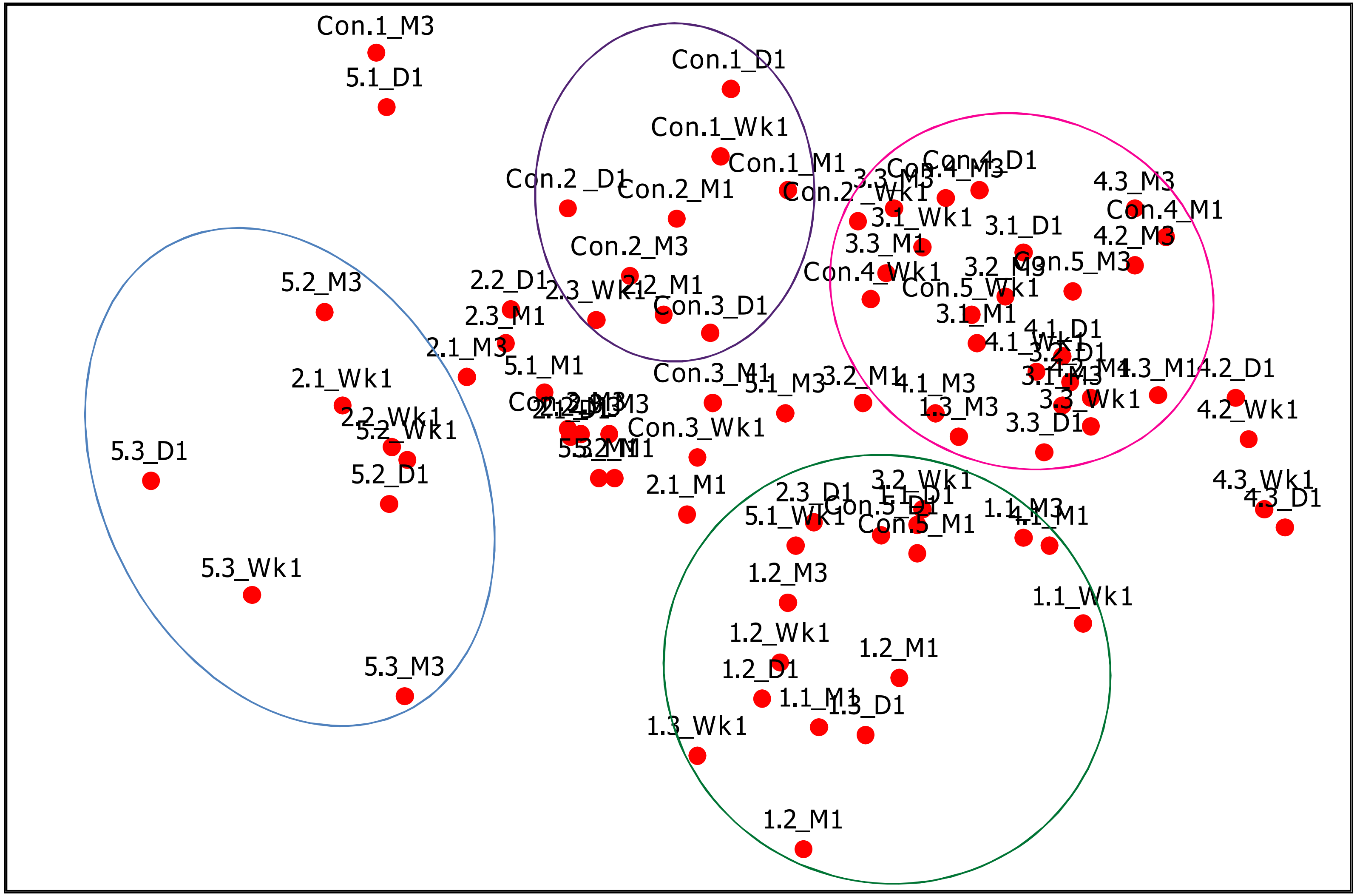


Figure 3.64: PCA ordination of the square root transformed sediment and macrofaunal data collected in the Wash from July to November 2010. (Label description: e.g. 1.1 = Ring 1, Site 1. D1 = Day 1, Wk1 = Week 1, M1 = Month 1 and M3 = Month 3).

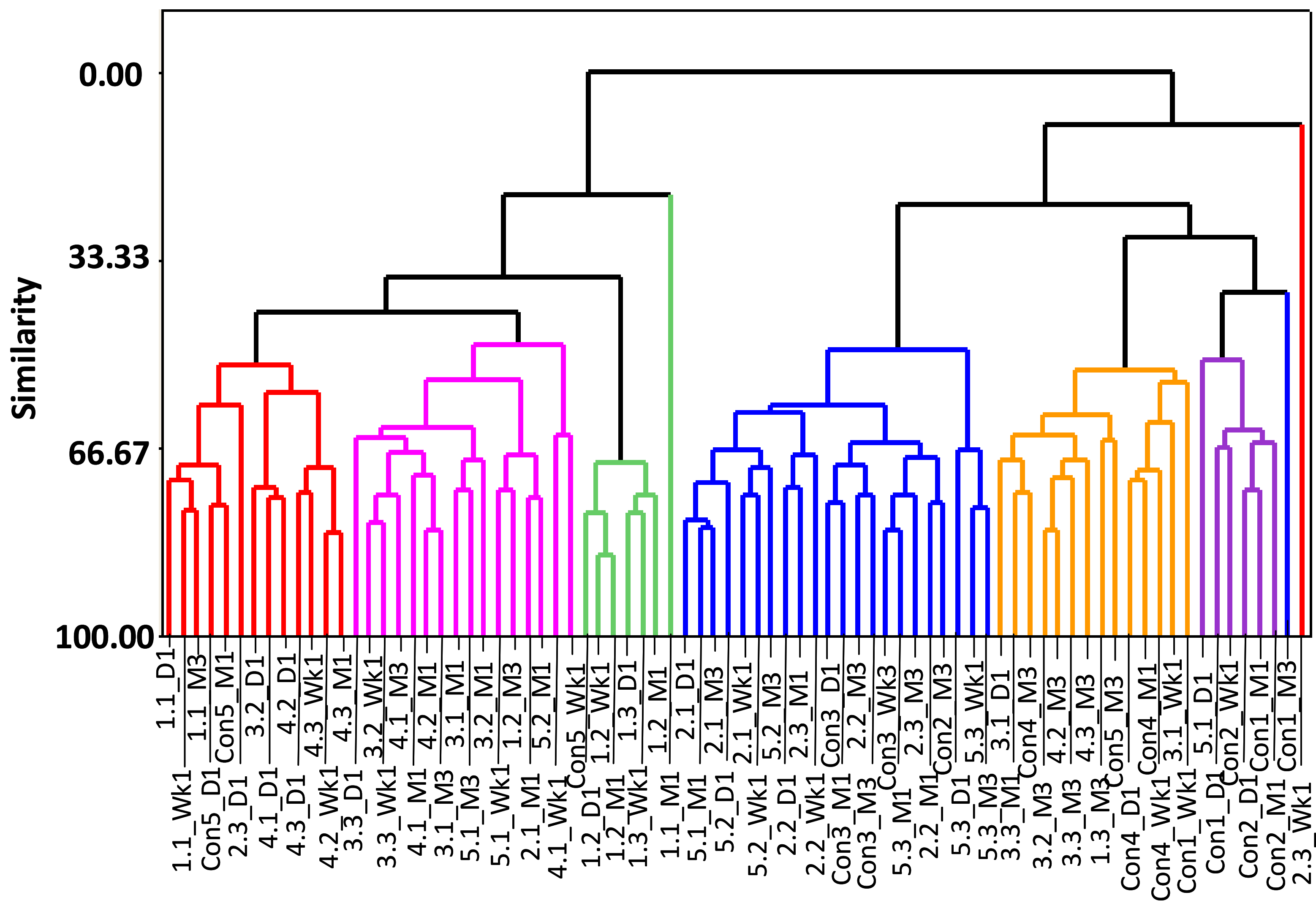


Figure 3.65: Dendrogram of the square root transformed sediment and macrofaunal data collected in the Wash from July to November 2010. (Label description: e.g. 1.1 = Ring 1, Site 1. D1 = Day 1, Wk1 = Week 1, M1 = Month 1 and M3 = Month 3).

Numerically, polychaetes dominated the fauna of all sites sampled during the survey period. Species abundance and richness between control and ring sites was not considerably different with the exception of two control sites (sites 1 and 2) displaying consistently high abundances. Spikes of high numbers of species, however, were also observed across some ring sites. Furthermore, on Day 1 and Week 1 highest species abundances were observed at ring sites and not at control sites. These spikes were in all instances due to one species per site appearing in high numbers; in most cases this was attributable to polychaetes. This small-scale patchiness is characteristic of marine communities, where larvae often settle near conspecific adults (i.e. organisms of the same species), which act as a clue of suitable environmental conditions. The patchy distribution of benthic organisms is unlikely to be the result of small scale differences in sediment composition. Control sites 1 and 2, for instance, displayed consistently higher abundances of organisms compared to other control sites, although the sediment composition of all control sites was similar.

Differences in sediment composition were observed on a spatial rather than temporal scale. A distinct north/ south divide was detected among sites with southern sites being dominated by sand sediments, while northern sites generally had a high proportion of silt. This pattern was absent at control sites. Variations in sediment composition in an estuary or bay usually depend on a number of factors, including sediment bed-load transport, suspended sediment load in the water column and exposure to wave and current actions (Kaiser *et al*. 2001). Finer sediments such as silt are deposited in low-energy sites of low water velocity, while heavier sediments (e.g., sand) settle out of the water column at higher water velocities. It is possible that fine scale hydrodynamic differences among sites exist, and northern sites are dominated by lower water velocities than southern sites. Without any hydrodynamic models, however, it is not possible to determine why these observed spatial differences exist. Sediment composition at the various sites did not change considerably over the sampling period and it is therefore unlikely that prop washing had a significant effect on the seabed properties.

Similarly to the results described in the previous paragraphs, multivariate analyses revealed only weak clusters, and no clear differentiation in sediment and macrofaunal properties between control and ring sites was observed. There is a significant degree of overlap among the sites, including control sites, demonstrating that the changes in macrofaunal structure and sediment composition are likely to be gradual. Given that the same groupings resulted when multivariate analysis was carried out on the data without cockles, it can be assumed that the similarities observed are not attributable to the presence or absence of cockles in the samples.

Looking at the combined results of univariate and multivariate analyses of the macrofaunal communities and sediment properties, no obvious differences between control and ring sites were evident. It is therefore unlikely that prop washing has any significant effects on the benthos in the area sampled in the Wash. As this method of cockle fishing is largely restricted to the area of the Wash, it is not possible to compare these results with other studies on the effects of cockle fishing on benthic communities. Research conducted on other cockle fishing methods revealing an impact on benthic communities highlight a relatively fast recovery of the affected areas, where macrofaunal communities in harvested areas were indistinguishable from adjacent un-harvested areas within 56 day to 3 months after disturbance (Hall & Harding 1997, Kaiser *et al*. 2001).

Although no impacts of prop washing on macrofaunal and sediment properties could be found, it is important to note that effects in other areas of the Wash could be different, as recovery of sediment habitats and associated fauna is largely dependent on sediment type, local environmental conditions and the frequency of harvesting (Kaiser *et al.* 2001). Furthermore, recovery of smaller, motile and opportunistic organisms that are relatively tolerant of habitat disturbances would be shorter than that of larger and relatively sessile organisms such as bivalves (Kaiser *et al.* 2001). Since the area sampled in the Wash showed a paucity of species abundance and diversity and a dominance of smaller organisms, the effects of prop washing on areas with a richer macrofauna containing larger organisms could therefore be quite different.

Appendix A – Sediment Particle Sizes

Site	Site/Collection Date																			
	Day 1																			
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	C1	C2	C3	C4	C5
Medium gravel	0.35	0	0	1.29	3.61	1.84	2.24	1.35	0.68	1.14	0.49	0.46	3.72	0.46	0	0.96	1.26	6.97	1.62	0
Fine gravel	0.68	0.02	0	0.29	0.12	1.03	0.57	1.15	0.56	2.18	0.66	0.81	1.32	0.42	0	0.19	0.03	3.81	0.26	0.12
Very fine gravel	1.57	0.29	0.12	0.55	0.88	2.16	0.61	2.2	0.9	2.53	0.88	0.53	2.39	0.65	0.15	0.72	0.2	2.2	0.22	0.28
Very coarse sand	3.05	0.69	0.62	1.14	2	5.54	3.13	5.28	3.49	4.45	2.42	0.91	4.99	1.33	0.05	1.93	0.54	2.89	0.67	0.61
Coarse sand	13.4	6.22	5.54	9.02	10.8	11.4	18	22.1	18.2	21.5	22.8	19.2	12	3.61	1.24	23.1	17	12.8	14.1	9.5
Medium sand	34.9	16.6	16.3	20.6	23.2	21.5	43.6	42.3	40.5	39.9	54.9	58.4	29.5	9.73	2.27	46.1	40.1	25.2	48.7	29.7
Fine sand	16.9	9.76	13.4	13.9	15.5	17.9	19.6	12.4	17.1	16.7	9.71	11.5	22.9	19.1	11.3	13.5	15.6	17.9	15.5	17.2
Very fine sand	4.52	9.25	12.7	9.45	10	10.4	1.55	1.22	2.54	2.38	0.17	0.24	8.48	19.8	21	1.61	4.23	8.3	0.82	7.26
Very coarse silt	5.17	12.2	10.7	8.68	7.65	6.14	1.8	2.47	3.2	2.07	1.78	2.11	3.02	12.1	15.5	2.71	5.05	3.95	3.83	7.3
Coarse silt	4.4	10.7	9	8.29	5.77	4.95	1.29	1.33	2.64	1.52	1.04	0.96	2.6	8.13	11.1	1.74	3.39	3.19	2.94	6.19
Medium silt	5.65	12.7	11.6	9.58	7.01	6.02	1.67	1.99	3.53	2.01	1.82	1.61	3.27	8.86	13.6	2.53	4.32	4.36	3.9	7.4
Fine silt	5.63	12.6	11.6	9.64	7.54	6.23	1.83	2.2	3.81	2.12	2.11	1.95	3.38	9.04	13.7	2.82	4.71	4.7	4.36	8.06
Very fine silt	3.17	7.29	6.83	6.08	4.8	3.95	1.04	1.28	2.35	1.24	1.18	1.13	2.06	5.54	8.2	1.7	2.9	3.07	2.6	5.14
Clay	0.64	1.63	1.54	1.48	1.16	0.97	0.15	0.22	0.51	0.21	0.13	0.15	0.39	1.3	1.87	0.32	0.65	0.7	0.52	1.23

Site	Site/Collection Date																			
	Week 1																			
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	C1	C2	C3	C4	C5
Medium gravel	0.42	0	0	10.6	0	1.49	0.89	2.38	1.69	0.13	1.39	0.28	0.59	0	0.48	4.95	0.57	3.76	0	0.78
Fine gravel	0.68	0	0.1	0.96	0.14	1.11	0.93	0.7	1.03	0.37	0.38	0.57	3.69	1.11	0.27	1.13	0.64	0.99	0	0.26
Very fine gravel	0.8	0.32	0.15	1.19	0.19	3.68	1.11	0.84	2.2	0.86	0.85	0.32	2.41	0.9	1.09	0.95	0.68	0.61	0.08	0.29
Very coarse sand	2.09	0.81	0.4	2.13	0.8	7.5	3.57	3.36	5.91	2.19	1.35	0.79	3.22	2.02	1.41	2.28	1.47	1.46	0.67	0.68
Coarse sand	17.5	8.83	3.12	5.15	5.37	14.2	22.1	15.5	18.8	21.2	22.4	21.1	8.95	5.64	2.2	16.5	15.9	13.1	14.5	12.8
Medium sand	37.7	21.4	10.5	11.4	15.3	21.5	40.8	31.8	39.6	42.9	60.2	53.2	17.1	14.3	3.74	32.8	61.4	25.8	41	45.9
Fine sand	14.5	12.6	12.3	19.2	15.5	16.1	17.6	16.8	16.2	18	7.97	13.1	18.2	22.4	12.2	14.4	10.7	15.4	15.7	16.4
Very fine sand	2.96	9.05	14.9	16.4	13.2	9.41	2.44	7.07	1.92	2.22	0.18	0.71	12	18.9	17.8	5.07	0.11	8.8	1.91	1.54
Very coarse silt	4.84	9.9	13.2	6.23	9.7	5.55	2.12	5.36	2.68	2.3	1.62	2.55	5.41	8.54	13.4	4.38	1.96	5.84	4.67	4.45
Coarse silt	3.96	8.59	10.4	4.4	8.28	4.36	1.81	3.86	2.07	1.9	0.52	1.31	5.32	5.56	10.7	3.63	1.1	5.01	4.37	3.49
Medium silt	5	10.5	12.5	5.84	10.7	5.23	2.39	4.62	2.73	2.49	1.11	2.13	6.7	6.56	12.9	4.72	1.74	6.91	5.68	4.48
Fine silt	5.41	10.4	12.8	5.96	10.7	5.47	2.53	4.59	2.96	2.47	1.34	2.37	6.38	6.71	13.5	5.12	2.17	7.01	5.76	5.09
Very fine silt	3.4	6.14	7.77	3.81	6.32	3.52	1.44	2.63	1.81	1.38	0.7	1.32	3.91	4.23	8.32	3.28	1.3	4.24	3.31	3.12
Clay	0.76	1.4	1.85	0.94	1.46	0.84	0.23	0.53	0.37	0.22	0.01	0.21	0.86	0.99	1.92	0.76	0.21	0.98	0.67	0.66

Site	Site/Collection Date																			
	Month 1																			
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	C1	C2	C3	C4	C5
Medium gravel	0.09	0	0.16	3.3	0	2.26	0.47	0.44	1.22	1.23	3.95	0.19	1.01	0	1.12	2.11	0.56	1.38	0.81	0
Fine gravel	0.2	0.38	0.51	3.06	0.46	2.46	1.09	1.01	0.64	0.58	1.31	0.51	3.37	1.05	0.32	0.54	0.26	0.72	0.38	0.06
Very fine gravel	0.7	0.25	0.81	3.06	2.06	2.97	1.11	1.82	1.14	1.09	0.59	0.45	2.8	1.55	0.22	0.99	0.3	0.67	0.37	0.32
Very coarse sand	1.69	0.68	1.36	4.84	3.5	4.43	3.49	3.35	2.69	2.71	1.45	0.64	3.11	2.13	0.49	2.23	0.84	1	0.76	1.1
Coarse sand	8.77	4.39	8.79	8.48	12.8	8.57	19	16.8	18.9	17.8	23.7	18.9	8.01	8.32	10.3	23.5	18.5	9.46	20.7	10.7
Medium sand	19.4	10.2	24.3	16.8	32.8	16.8	42.5	33.8	40.7	41.5	47.7	61.9	19.1	19.4	25.7	46.9	38.9	28.9	55.8	34
Fine sand	11.9	9.07	15.3	18.7	18.8	17	21.1	17.6	16.1	21.5	9.66	11.5	18.7	23.1	19.2	9.16	14	23.5	12.8	19
Very fine sand	10.4	13.1	9.23	13.2	6.39	14	2.4	6.2	2	3.34	0.76	0.23	12.6	14.9	12.2	0.64	4	9.49	0.1	6.34
Very coarse silt	9.95	13.1	9.06	5.43	5.03	8.22	1.75	4.33	3.27	1.97	2.56	1.76	7.31	5.44	7.8	2.59	5.17	4.3	1.63	5.91
Coarse silt	8.29	11.1	7.31	3.69	3.87	5.3	1.58	3.23	2.7	1.55	1.34	0.57	5.83	4.05	5.31	1.91	3.74	4.29	0.82	4.74
Medium silt	10.1	13.7	8.52	4.98	4.89	6.3	1.96	4.01	3.69	1.98	2.03	1.14	6.98	5.14	6.08	2.87	4.82	6.01	1.3	5.76
Fine silt	9.7	13.8	8.43	5.23	5.26	6.55	2.09	4.2	4.01	2.09	2.28	1.41	6.56	5.37	6.38	2.99	5.16	6.03	1.53	5.89
Very fine silt	5.64	8.3	5	3.32	3.31	4.12	1.22	2.61	2.44	1.2	1.32	0.76	3.77	3.41	3.98	1.68	3.13	3.57	0.83	3.5
Clay	1.36	1.94	1.18	0.81	0.78	1	0.2	0.59	0.53	0.2	0.22	0.03	0.79	0.75	0.92	0.29	0.67	0.76	0.04	0.8

Site	Site/Collection Date																			
	Month 3																			
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	C1	C2	C3	C4	C5
Medium gravel	1.19	1.4	2.19	4.34	1.14	2.75	5.23	1.01	5.73	2.27	2.33	0.55	2.03	1.38	0.26	0.44	1.07	2.64	4.13	0
Fine gravel	1	0.51	0.9	1.82	0.37	1.68	1.67	1.31	1.46	0.88	0.67	0.28	1.29	1.39	0	0.86	0.03	1.43	2.55	0.06
Very fine gravel	0.72	0.51	0.51	2.3	1.49	2.97	1.32	0.85	1.44	1.04	0.86	0.22	2.34	0.86	0.36	0.63	0.17	1.15	0.36	0.15
Very coarse sand	1.44	1.07	1.09	3.07	2.78	4.77	4.06	3.52	3.68	2.23	1.89	0.54	5.95	2	0.64	0.78	0.49	1.28	1	0.93
Coarse sand	16.9	8.36	15.1	6.05	8.69	12	21.4	23.9	19.8	17.1	25.9	22.5	13.5	6.06	1.49	15.9	13.6	7.04	15.1	13.3
Medium sand	37.1	21.6	35.7	14.5	18.5	20.6	39.2	46.9	42.6	37.8	53.5	58.7	27.7	15.8	2.89	31	35.1	13.3	51	56
Fine sand	14.3	11.2	13.7	19.9	12.5	16.6	13.5	13.4	13.8	19.1	11	13.4	25.5	24.3	10.8	11.4	16.9	14.5	13.2	17.2
Very fine sand	3.68	8.65	3.59	15.2	10.9	11.4	1.84	1.63	1.7	4.57	0.04	0.06	10.2	19.6	20.3	5.8	6.65	12.2	0.19	0.16
Very coarse silt	5.35	10.6	6.53	6.97	11.2	6.78	2.25	2.14	2.6	3	0.29	0.65	2.08	7.57	14.9	6.82	5.94	7.34	2.44	2.37
Coarse silt	4.18	8.42	4.95	5.79	7.95	4.81	1.5	1.05	1.51	2.44	0.15	0.36	2.17	4.93	10.6	5.18	4.37	8.05	2.02	1.9
Medium silt	5.08	9.43	5.61	7.48	8.41	5.46	1.99	1.57	2.07	3.05	0.76	1.03	2.64	6.03	13.2	6.28	5.35	11.5	2.86	2.67
Fine silt	5.21	8.94	5.78	7.19	8.96	5.7	2.11	1.65	2.19	3.04	0.82	1.14	2.6	5.74	13.1	6.4	5.72	11.2	3.06	3.05
Very fine silt	3.1	5.19	3.49	4.3	5.63	3.61	1.22	0.94	1.25	1.8	0.35	0.53	1.64	3.49	7.82	3.92	3.66	6.71	1.76	1.81
Clay	0.72	1.31	0.87	1.08	1.43	0.88	0.23	0.15	0.24	0.38	0	0.04	0.31	0.9	2.03	1.02	0.97	1.7	0.36	0.37

Appendix B – Macrofaunal Species List and Abundance (1 of 2)

Taxon			Site/Collection Date: Day 1																			
			1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	C1	C2	C3	C4	C5
Annelida	Polychaeta	*Ampharete grubei*													2				1			
		Anaitides maculata																				
		Anaitides mucosa	1								1								1	2	3	
		Arenicola marina																				
		Capitella							1													
		Eteone longa (agg)																			1	
		Eumida bahusiensis																				
		Eumida sanguinea																				
		Eunereis longissima					1															
		Galathowenia oculata						1														1
		Glycera tridactyla									1											
		Harmothoe impar							1													
		Hediste diversicolor						1	1		1	1				2			2		1	
		Heterochaeta costata	3																			
		Heteromastus filiformis					3					2							2	2		
		Lanice conchilega		1			1		7	1	1	4	3	2	2			2	2		6	
		Mediomastus fragilis																				
		Microphthalmus		1																		
		Monopylephorus irroratus																				
		Nephtys (juv)																				
		Nephtys hombergii										1	1									1
		Nereididae (juv)																				
		Nereididae (juv)																				
		Notomastus						2														
		Pholoe inornata (sensu petersen)																				
		Pygospio elegans			1												1		1	4		1
		Scalibregma inflatum																				
		Spio martinensis											1							1		
		Tharyx "species A"	1	8	5	38	63	18	52	18	22	18	13	2	55	33	47	63	37	44	91	23
		Tubificoides benedii	7	5		21	34	6	4	6	2	4	1	1	96	34	52	38	62	15	1	1
		Tubificoides pseudogaster (agg)	1				4	7	3	2		3	1	1	1			7	3	5	1	
Arthropoda	Amphipoda	*Crassicorophium crassicorne*																				
	Copepoda	Copepod																				
	Decapoda	*Crangon crangon*									1	1			1							
		Carcinus maenas																				
		Carcinus maenas (juv)					1		3	2		3			2	2		2	1			
	Sessilia	*Balanidae* (juv)																				
		Balanus crenatus	1				1				1					2		2				
		Elminius modestus							6		14											
	Pycnogonida	*Anoplodactylus petiolatus*																				
Plantae	Chlorophyta	*Enteromorpha*	1										1									
		Ulva												1								
	Rhodophyta	*Plocamium cartilagineum*																				
Cnidaria	Hydrozoa	Campanulariidae							1		1											
		Hydrallmania falcata																				
Nemertea		Nemertean sp.																				
Nematoda		Nematode sp.		1		2	1	8	1	13	3	18	17		15		1	14		1	1	
Mollusca	Bivalvia	*Abra prismatica*																				
		Angulus tenuis																				
		Cerastoderma edule	4		7	11	4		7		3	6	3	1	18	5	16	28	32	7	17	14
		Cerastoderma edule (juv)	1											1								1
		Kurtiella bidentata							2	1								1	1			
		Macoma balthica	3		1	2			2	6	3	1	2	2	5	2	4	7	6	2	7	2
		Mya arenaria																				
		Mytilus edulis (juv)	1	1	1				2	1	2		1	8	1	1			1		2	2
		Scrobicularia plana			1																	
		Scrobicularia plana (juv)																				
	Gastropoda	*Hydrobia ulvae*																		1		
	Polyplacophora	*Lepidochitona cinerea*																				
Bryozoa		*Amathia lendigera*																				
		Bugula plumosa													1							
		Electra pilosa													1							
		Eucratea loricata																				
		Flustra foliacea																				
		Scrupocellaria scruposa																				
Species richness (Number of species)			11	6	6	5	10	7	15	9	14	12	11	9	13	8	6	10	14	11	11	9
Abundance (Number of organisms)			24	17	16	74	113	43	93	50	56	62	44	19	200	81	121	164	152	84	131	46
Shannon-Wiener diversity index			2.0	1.4	1.4	1.2	1.2	1.6	1.7	1.7	1.9	2.0	1.8	1.8	1.6	1.3	1.2	1.7	1.6	1.6	1.2	1.4

Taxon			Site/Collection Date: Week 1																			
			1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	C1	C2	C3	C4	C5
Annelida	Polychaeta	*Ampharete grubei*																				
		Anaitides maculata																				
		Anaitides mucosa												1				1				4
		Arenicola marina																				-
		Capitella									1							1			1	
		Eteone longa (agg)																		1	1	
		Eumida bahusiensis																				
		Eumida sanguinea																				
		Eunereis longissima																	1			1
		Galathowenia oculata																				
		Glycera tridactyla															1					
		Harmothoe impar																				
		Hediste diversicolor			1				1				1		1			3				
		Heterochaeta costata																				
		Heteromastus filiformis					1	1								1			2	1	1	
		Lanice conchilega								3	2	6		1	1	2		3	1			15
		Mediomastus fragilis																				
		Microphthalmus																				
		Monopylephorus irroratus																				
		Nephtys (juv)	1										1									
		Nephtys hombergii			1		1					1			1				1			1
		Nereididae (juv)																				
		Nereididae (juv)																				
		Notomastus																				
		Pholoe inornata (sensu petersen)																				
		Pygospio elegans	1					2	1												1	
		Scalibregma inflatum																				-
		Spio martinensis																				
		Tharyx "species A"	2	9	3	29	5	32	91	1	15	12	12	11	1	19	2	82	32	16	69	32
		Tubificoides benedii	1	6	4	64	43	39	5	7	2	7	1		4	54	55	14	38	21	4	6
		Tubificoides pseudogaster (agg)				1	1	6	2	3	4	2		1		1		6		3	1	2
Arthropoda	Amphipoda	*Crassicorophium crassicorne*																				
	Copepoda	Copepod										1										
	Decapoda	*Crangon crangon*																				
		Carcinus maenas																1				
		Carcinus maenas (juv)										1			1	1		3				
	Sessilia	*Balanidae* (juv)																				
		Balanus crenatus			1							1			3				7			
		Elminius modestus			1																	
	Pycnogonida	*Anoplodactylus petiolatus*																				
Plantae	Chlorophyta	*Enteromorpha*						1														1
		Ulva																				
	Rhodophyta	*Plocamium cartilagineum*																				
Cnidaria	Hydrozoa	Campanulariidae										1			1		1					
		Hydrallmania falcata																				
Nemertea		Nemertean sp.																				
Nematoda		Nematode sp.			1			128			4	5	1						3	1	1	
Mollusca	Bivalvia	*Abra prismatica*																				
		Angulus tenuis																			1	
		Cerastoderma edule	7	1	6	9				1	2	22	3		26	8	3	31	14	8	1	2
		Cerastoderma edule (juv)										1										
		Kurtiella bidentata	1															5				2
		Macoma balthica				2	2		2	4	3	4	2	1	8	5		5	1	3	3	4
		Mya arenaria												1								
		Mytilus edulis (juv)			1			1	2			4			1		1		1			19
		Scrobicularia plana																				
		Scrobicularia plana (juv)																				
	Gastropoda	*Hydrobia ulvae*																				
	Polyplacophora	*Lepidochitona cinerea*																				
Bryozoa		*Amathia lendigera*																				
		Bugula plumosa																				
		Electra pilosa																				
		Eucratea loricata																				1
		Flustra foliacea																				
		Scrupocellaria scruposa																				
Species richness (Number of species)			6	3	9	5	6	8	7	6	8	14	7	6	11	8	6	12	11	8	11	13
Abundance (Number of organisms)			13	16	19	105	53	210	104	19	33	68	21	16	48	91	63	155	101	54	84	90
Shannon-Wiener diversity index			1.4	0.9	1.9	1.0	0.9	1.1	0.6	1.6	1.7	2.1	1.4	1.1	1.7	1.2	0.9	1.5	1.7	1.6	1.0	2.0

Appendix B – Macrofaunal Species List and Abundance (2 of 2)

Taxon			Site/Collection Date																																																																																																																
			Month 1																				Month 3																			
			1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	C1	C2	C3	C4	C5	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3	C1	C2	C3	C4	C5
Annelida	Polychaeta	*Ampharete grubei*						1	1						1				1																			1				
		Anaitides maculata																																								1
		Anaitides mucosa							1										3				1					1				3										1
		Arenicola marina								1																																
		Capitella							2		2												1	1	9	2				3	3	5	5	2	1				1	2	2	6
		Eteone longa (agg)									1																															
		Eumida bahusiensis																													1							2				
		Eumida sanguinea									1																															
		Eunereis longissima																	1				1						1													1
		Galathowenia oculata	2																																							
		Glycera tridactyla																													1											1
		Harmothoe impar																																								
		Hediste diversicolor									1			1				1		1							1				1					1						
		Heterochaeta costata																																								
		Heteromastus filiformis	1				1	1					2	1					4			1					1				1							1				
		Lanice conchilega						1	3	6	5	1	1	2	2			5	11		2	1							1			2		1				1	1		3	4
		Mediomastus fragilis						1																																		
		Microphthalmus																																								
		Monopylephorus irroratus								1																																
		Nephtys (juv)														1							1														1					
		Nephtys hombergii			1																	1							1													
		Nereididae (juv)														1																										
		Nereididae (juv)																																								
		Notomastus																																								
		Pholoe inornata (sensu petersen)																																	1							
		Pygospio elegans									1									1			1		5																	
		Scalibregma inflatum				1																																				
		Spio martinensis																																								
		Tharyx "species A"	4		7	1	45	66	21	18	56	3	12	13	4	2	16	37	34	42	69	11	6	7	25	48	36	21	17	36	64	15	36	37	18	49	12	157	39	5	67	33
		Tubificoides benedii	3	1	1	16	27	27	11	13	11	8	5	6	29	23	33	38	42	12		4	2	5	2	3	18	29	3	8	11	13	6	5	17	6	22	54	37	11	8	4
		Tubificoides pseudogaster (agg)				2	9	5	2	5	1		1				1	1	11	2			2		3		5	5	2	5	6	2	5	1	3	2		3	7	3	2	5
Arthropoda	Amphipoda	*Crassicorophium crassicorne*	2																																							
	Copepoda	Copepod																																								
	Decapoda	*Crangon crangon*								2														1			1							1						1		
		Carcinus maenas																							1														1		1	
		Carcinus maenas (juv)	1						1	1		1						1			1												1			1						
	Sessilia	*Balanidae* (juv)																										4										1				
		Balanus crenatus															1		3																							
		Elminius modestus	96	4		2		7	7	2		3	1	1									1		1		3	2	2						5	3		15			1	
	Pycnogonida	*Anoplodactylus petiolatus*														1																										
Plantae	Chlorophyta	*Enteromorpha*	1	1	1	1	1		1	1	1														1	1			1						1	1			1	1	1	1
		Ulva																																								
	Rhodophyta	*Plocamium cartilagineum*		1																																						
Cnidaria	Hydrozoa	Campanulariidae	1	1					1								1																									
		Hydrallmania falcata								1													1																			
Nemertea		Nemertean sp.																																								1
Nematoda		Nematode sp.				1		1					1	2	1	2			1		1				1	1	3				3	3		6		1			2			
Mollusca	Bivalvia	*Abra prismatica*																																					1			
		Angulus tenuis																																								
		Cerastoderma edule	9	4	2	19	5	1	16	7	7	3	17	5	8	16	8	38	21	9	18	6	12	2	9	18	7	7	16	9	6	2	6	1	19	22	4	23	14	11	21	21
		Cerastoderma edule (juv)							1																																	
		Kurtiella bidentata					3		1									1	1								1						1						1			2
		Macoma balthica		2		1	4	1	3	8	1		1	2	3	1	2	4	4		1	2	3	3	2	2	1	5	1	2	1	1		11	1	6		3	7	2	2	1
		Mya arenaria																																								
		Mytilus edulis (juv)	1	1		1		1	1		3		1		2	1			2						1	1						1		1	2	1		2	1			
		Scrobicularia plana												1																												
		Scrobicularia plana (juv)				1																																				
	Gastropoda	*Hydrobia ulvae*																1	1	1																				1		
	Polyplacophora	*Lepidochitona cinerea*										1																														
Bryozoa		*Amathia lendigera*															1		1			1																1				
		Bugula plumosa																					1																			
		Electra pilosa																																								
		Eucratea loricata																																				1				
		Flustra foliacea							1																																	
		Scrupocellaria scruposa								1																																
Species richness (Number of species)			11	8	5	11	8	12	17	13	13	7	10	10	8	9	8	10	16	7	6	8	13	6	12	8	11	8	10	6	11	10	7	10	10	11	4	14	13	9	10	14
Abundance (Number of organisms)			121	15	12	46	95	113	74	67	91	20	42	34	50	48	63	127	141	68	92	27	33	19	60	76	77	74	45	63	98	47	60	66	68	93	39	265	113	37	108	82
Shannon-Wiener diversity index			0.9	1.9	1.2	1.7	1.4	1.3	2.2	2.2	1.5	1.7	1.7	1.9	1.3	1.5	1.3	1.5	2.0	1.2	0.8	1.7	2.1	1.3	1.9	1.3	1.6	1.6	1.6	1.3	1.3	1.9	1.3	1.7	1.7	1.5	1.0	1.3	1.7	1.3	1.3	1.8

4.0 CRUSTACEAN FISHERIES

4.1 Introduction

The fisheries for lobster (*Homarus gammarus*), edible crab (*Cancer pagurus*) and velvet crab (*Necora puber*) are important throughout the ESFJC District, with estimated total landings in 2009 of over 700 tonnes worth nearly £1.9 million pounds (Mander, 2009).

Due to the heavy reliance of many of the District's fishermen on the health of crustacean stocks, care must be taken to ensure that fishing remains sustainable, so that the fisheries – and the communities which depend on them – might continue to be healthy. The need for research into and monitoring of the fisheries was recognised in 1997, when ESFJC lobster stock assessments based on port biosampling and at-sea surveys commenced. In 2003, a decision was made to increase survey effort at sea, and from 2004 some edible crab and velvet crab data started being collected in conjunction with the lobster sampling. From 2007 to 2009, even greater emphasis was been put on crab populations, with more sampling at sea and the commencement of port sampling throughout the year.

In 2010, there was a review of the research program – prompted in part by staff changes and in part by an increasing awareness of the need for more targeted research, in an effort to maximise the use of staff time and committee resources. Additionally, research staff identified a need to liaise more closely with Cefas scientists undertaking biosampling and similar work locally, with a view to coordinating research more effectively between organisations. Therefore, research trips were put on hold awaiting a full review of crustacean research in the District. Port-based biosampling continued, and the results of this will be analysed and presented subsequently along with data from catch returns.

In lieu of research data, it has been possible to focus on reporting on the work that has been done by ESFJC Officers in developing a portable test kit for the detection of scrubbed berried lobsters. Initially trialled in 2005, work on the test has been undertaken in various stages, and until now has not been reported on in a comprehensive fashion. With ESFJC Officers now promoting the use of the kit to other committees, Officers felt it appropriate that a record exist of the background and basis of the testing procedure, for reference by ourselves and others. This report is written to provide that record.

4.2 Background to the stain test

4.2.1 Managing lobster stocks in the context of risk to the spawning stock

The economic importance of the lobster fishery to a local community is easy to understand, but the local dynamics and health of the stock itself are not. Despite the best efforts of fisheries scientists, current data relating to the lobster fishery is not sufficient – if it ever could be – to understand how recruitment to the fishery operates within a local context; nor how the selective removal of a large proportion of the mature population affects the population structure and the ability of that population to sustain itself.

This situation is far from uncommon; fisheries science more often than not operates in a data-poor environment, and this uncertainty is inevitably, unenviably passed to fisheries managers and policy decision-makers. Management must therefore be approached in terms of risk: assessing both the hazard (overfishing of the breeding population to the extent that it cannot replace itself) and the vulnerability (the likelihood that this might happen) of the population to this hazard.

Population collapse would be devastating to the local economy, and previous experience in fisheries management (notably the Grand Banks cod fishery) shows that, once a critical threshold of spawning stock has bottomed out, there is sometimes little that can be done but wait (in this case, for over a decade) for the stocks to recover. This eventual recovery is assuming that the local population crash has not led to a regime shift in the ecosystem, with other species assuming dominance, making it hard for the original species assemblage to re-establish. The vulnerability of the North Norfolk lobster stocks is unknown, but ESFJC data has shown a pronounced drop-off in frequency of animals as soon as the minimum size of 87mm CL is reached. This indicates that the fishery has an effect on the population structure, but it is not clear what the scale of this effect is: specifically, what proportion of the spawning stock is routinely removed from the fishery.

One indication that a spawning stock may be under pressure is the size at which fish mature, with a reduction in mean size suggesting that smaller, early-maturing lobsters are being selected for. This suggests that a majority of mature, sizeable fish do not get the opportunity to recruit to the fishery but are removed before they have reproduced. ESFJC surveys have shown that the mean size of berried female lobsters caught has decreased over the lifetime of survey records. Jessop *et al.* (2007) also shows a decrease in size of the smallest berried female lobsters measured in surveys at sea from 80mm CL in 1997 to 70mm CL in 2007, apparently a steady trend over that decade. As well as implying – as did the size-frequency profile – that the population has been altered by the fishery and is under pressure, a smaller mean size has its own implications, as smaller individuals are less fecund (produce fewer eggs) than larger ones. A spawning stock consisting of predominantly smaller females is less fruitful than one where a larger proportion of lobsters survive to greater maturity.

ESFJC data show an increase in effort, with the number of pots estimated to have increased to over 20,000 (Norfolk Inshore and Offshore) according to recent data (Jessop *et al.*, 2009). This increasing pressure on both the fishery and available space in which to prosecute it is a potential threat to the profitability and viability of the fishery from a commercial perspective, let alone an ecological one. Increased fuel costs raise the stakes – and consequently the risk – even higher.

4.2.2 Existing management

In recognition of this risk to the fishery, Eastern Sea Fisheries Joint Committee has in place a Byelaw prohibiting the removal from the fishery of egg-bearing and soft-shelled lobster and crab (Byelaw 6). This was brought in as a precautionary measure to conserve the spawning stock (at least at the time of spawning), and is applicable throughout the ESFJC District. It is particularly relevant to lobsters, which, unlike crabs, continue to feed and therefore be caught in traps once berried. However, animals taken from outside the District (effectively beyond the 6nm limit) are not afforded the same protection as there is no existing national legislation, and berried lobsters caught further offshore can legally be landed.

This was not always the case: in 1951, the Sea Fish Industry (Crabs and Lobsters) Order did afford egg-bearing females protection, as their landing was prohibited. However, difficulties enforcing the legislation (and detecting scrubbing) led to its being repealed in 1966, and since then no similar legislation has been introduced. In 2005, Defra consulted on a draft Statutory Instrument (SI), The Berried Lobster (Prohibition of Carriage, Landing and Removal of Eggs) Order, but ultimately this was not brought in.

For enforcement purposes it is therefore essential to determine the provenance of a berried lobster, and this creates its own difficulties. But it is also possible for fishermen to remove the eggs from a lobster caught within the District, so that it can be landed without detection. This is known as "scrubbing", as it is often done by literally scrubbing the eggs off with a brush; alternatively, high-pressure deck washes are used. It's unclear how commonplace the practice is, as it is controversial amongst many fishermen – although Officers are aware of it taking place, and with increasing pressure on the fisheries and on the fishermen who make their living from them, the temptation to land more fish to make ends meet becomes more compelling.

4.2.3 The impact of scrubbing

The first sale value of a lobster measuring the minimum size (MLS) of 87mm carapace length (CL) can vary considerably depending on current market prices and on the condition of the lobster, but is likely to be in the order of £5 - £10. Being able to land a (scrubbed) lobster therefore provides a reasonable financial incentive to the individual to remove the eggs. However, there is a resulting cost to the fishery from the loss of potential recruits.

The number of eggs produced by a lobster is a function of size and maturity of the animal, and can average between 10 – 15,000 eggs per female around the MLS, although older animals may carry several times this number. Estimated larval survival through to recruitment is less than 1% (FRS, 2004). In a report to Defra (Vaughan, 2008), ESFJC Officers used lower estimates of 5,000 eggs and a recruitment rate of 0.5% (representing a small female of 87mm CL) to estimate a potential loss to the fishery of 25 lobsters per lobster scrubbed. Using the figures in the FRS report for a mean fecundity of 12,500 and the same moderate 0.5% recruitment rate would suggest an average loss to the fishery of 62 lobsters per lobster scrubbed.

That the mean size at maturity in the local population may be decreasing is of little comfort. Although one could conclude that proportionally fewer recruits are lost per lobster scrubbed (probably closer to the lower estimate of 25), the relative importance of each of those recruits to the fishery would seem to be higher in this context.

4.2.4 Lobster reproductive biology

In order to understand how to detect the removal of berries from a lobster, it is necessary to explain some of the biology of egg production and attachment.

Mating normally occurs between a soft-shelled female and a hard-shelled male; the female can retain the sperm plug (spermatophore) from the male for up to two years before fertilisation. The eggs are extruded onto the tail, where they attach to the lower hairs (setae) of the pleopods. This allows the female to curl her tail around the eggs as a form of protection – an action often observed when berried lobsters are brought up in pots (personal observation). The female incubates the eggs for up to ten months, during which time she constantly tends to them until they hatch, which normally occurs during the summer (MAFF, 1996).

Goudeau *et al.* (1987) examined the mechanism of egg attachment in both European and American lobster, and found that it was similar in both species. Each egg is surrounded by a coating, or "envelope". When extruded and exposed to seawater, the outer layer of this coating swells and becomes sticky, and a second layer forms between the egg and the coating. The outer, sticky layer of the envelope causes the eggs to stick to each other and to the setal hairs on the pleopods. The lobster beats its pleopods as the eggs are extruded, which is likely to cause the attached eggs to twist and further wrap around the setae, after which the egg attachment stalks condense into a tough cementum which is strong enough to secure the egg mass in place for over 12 months.

When the eggs hatch naturally, the outer membrane splits to release the egg inside; the empty casing and attachment stalk remain cemented to the setae (Karlsson and Sisson, 1973). When eggs are scrubbed off, the attachment stalk is snapped, and the membranes (along with the eggs inside) are removed.

4.2.5 Basic description of the test methodology

The test uses a biological stain, haematoxylin, to highlight the presence of cementum on the setal hairs of the pleopod. In a naturally-shed lobster, the empty egg casing is visible along with remaining cementum, creating a messy "wheat-chaff" appearance. Where cementum is present and there are no empty egg sacs, except perhaps some visibly torn remnants, this indicates that the lobster has had the eggs forcibly removed. Inspection of the pleopod under a high-powered microscope will clearly show the additional signs of torn and damaged setal hairs. Crucially, however, the haematoxylin stain has been shown to allow reliable detection of forcible egg removal by eye. The test procedure is as follows:

- Remove a pleopod, ensuring that the long setae at its base are intact, as it is here that the eggs are attached
- Rinse in alcohol to remove any loose debris
- Dip in a solution of 1-2% haematoxylin in alcohol for two minutes to allow stain to develop
- Rinse in alcohol to prevent further staining
- Examine to determine presence of cementum
- (Optional /for evidential purposes: Preserve in formalin or glycerol)
- (Optional /for evidential purposes: Examine under a microscope for presence of damage to setae)

Figures 4.1 to 4.3 show pictures taken under a microscope of pleopods from non-berried, naturally-shed and scrubbed berried lobsters. The "messy" nature of the naturally shed pleopods with the intact egg casing clearly contrasts with the ragged, torn egg casing and cementum on the scrubbed samples. The non-berried lobsters are totally clean and clear of any mess or debris.

4.2.6 History of the origin and development of the test, and its use in the US

The basic test procedure (described above) was documented in *Transactions of the American Fisheries Society* in the seventies (Karlsson and Sisson, 1973 – referred to subsequently in this report as "the Karlsson and Sisson test", or "the test"), and is widely used in fisheries enforcement in the United States. The Massachusetts Division of Marine Fisheries (MDMF) is among the agencies that have used the test extensively in the forensic evaluation of lobster catches in scrubbing investigations, to provide evidence in many successful prosecutions - including one record-breaking case which resulted in a fisherman being fined over $650,000 for 600 scrubbed lobsters in 2004 (Estrella, pers. comm).

The test has proven court-credibility at both a state and federal level in America. Bruce Estrella, Senior Marine Fisheries Biologist, who has over 25 years' experience using the test in forensic investigations for MDMF and for NOAA's National Marine Fisheries Service, reports that he has never been involved in a case where the technique has been challenged or which has not resulted in a successful prosecution. Although the application of the test in the USA is to the American lobster, *Homarus americanus*, there is no significant biological difference between the American and European lobster (*Homarus gammarus*), and the test has been judged equally applicable to the European species (Estrella, pers. comm).

As it became apparent that lobster scrubbing was taking place within the ESFJC District, Officers identified the Karlsson-Sisson test as a potential tool to be used in the enforcement of Byelaw 6. Officers were instructed to find out more about the test, with a view to developing it for use in the UK to support prosecutions for illegal fishing of berried lobster. Research & Fishery Officer (RFO) Kevin Graves entered into correspondence with American scientists (in particular Bruce Estrella) about the test, and in May 2005 Officers began the first local trials.

Figure 4.1 Pleopods from non-berried lobsters

Figure 4.2 Pleopods from naturally-shed lobsters

Figure 4.3 Pleopods from scrubbed berried lobsters

4.3 Initial trials at ESFJC

Several trials of the test took place in 2005 and 2006 so that Officers could become familiar with the test procedure and train themselves to identify positive and negative results confidently and reliably. The test itself is simple, but the logistics of handling and managing the lobsters being tested needed to be considered. The dry runs provided opportunities to hone the planning of enforcement activities around the test. A brief summary of the trials is provided here.

<u>May 2005</u>

Eighteen lobsters were collected during two survey trips (13^{th} and 16^{th}), and on landing were stored in a holding tank. On the morning of the 19^{th}, the nine berried lobsters were scrubbed until the eggs were removed, after which all lobsters were placed in a box under a wet sack for eight hours. Between 17:00 and 19:00 hours, the test was carried out on all eighteen lobsters. Photographs of the “developed” pleopods were taken with a digital camera under a macro setting.

Of the eighteen treated, all nine scrubbed lobsters showed staining and clotting due to the presence of cementum; the non-berried lobsters tested negative.

<u>March 2006</u>

Five berried and five non-berried female lobsters were collected on a survey trip aboard a local fishing vessel. The berried lobsters were scrubbed at approximately 15:35 hours onboard the vessel, and all lobsters were banded (out of sight of the tester) with pre-numbered rubber bands picked in a random order. All ten lobsters were then stored in a fish box under a wet hessian sack until being landed at 22:00 hours.

On landing, pleopods were dissected from all ten lobsters, tested and photographed. A visual assessment of each pleopod was made, and a result recorded against each number. At this point, the record made by the independent officer was consulted, and it was shown that all pleopods had been correctly identified as non-berried or scrubbed respectively.

<u>April 5^{th} and 6^{th} 2006</u>

Seven berried lobsters were scrubbed onboard a fishing vessel during a survey, at approximately 20:00 hours on 5^{th}. These were banded out of sight of the tester along with six non-berried lobsters. A record was made of which band numbers corresponded to each treatment group. As before, the lobsters were kept in a fish box under a wet sack, to reflect how they would normally be stored. At 23:00 hours, the lobsters were landed and placed in a holding tank overnight. The next day between 12:00 and 13:30 hours, the staining test was carried out. Again, all 13 lobsters were correctly identified.

<u>April 19^{th} and 20^{th} 2006</u>

At 1800 hours on 19^{th} April, four berried and three non-berried lobsters were processed as described previously, being landed at 22:00 hours. The following day between 11:00 and 12:00 hours the test was conducted. On this occasion, the assessment for each pleopod was made and committed to directly after testing, rather than when all had been processed. Each of the four scrubbed and three non-berried lobsters was identified correctly using the techniques described.

Throughout the trials, Officers became confident in using the test and in its reliability in correctly identifying scrubbed lobsters in the experimental populations. From first use, the appearance of cementum – highlighted by the haematoxylin stain – was easy to identify and Officers were happy that the test would provide evidence good enough to be used in a prosecution in the UK, in the same way that it already was in the USA.

4.4 Prosecution case

On the 25th of September 2007, King's Lynn Magistrates heard the Master of a commercial fishing vessel plead guilty to removing fifteen egg-bearing lobsters from the fishery on 3rd June 2006, contrary to ESFJC Byelaw 6.

The case was brought against the fisherman by Eastern Sea Fisheries Joint Committee. On inspection of the fisherman's catch upon landing at Brancaster, Fishery Officers used the test to identify potentially "scrubbed" lobsters, having observed a higher ratio of females to male lobsters than expected for the time of year. After a random sample of six lobsters yielded three positive results, all remaining female lobsters (43 in total) were tested and a further twelve tested positive.

The fisherman was fined £2,700 for illegal fishing and partial costs of £2,500 were awarded to ESFJC. Actual legal costs were in the order of £10,000 and the cost of deploying the eleven Fishery Officers and two patrol vessels needed for the operation was an additional £10,000 approx. It is worth noting that, had national legislation been in place, the requirements to enforce it would have been reduced to just one Fishery Officer, as the issue of having to prove the scrubbed animals were caught within the six mile District limit would not have existed.

The original plea entered had been "not guilty", and Officers had been prepared for the test procedure to come under scrutiny in court. Witness statements written by the Officers conducting the test were sent to Bruce Estrella, who provided a letter and witness statement endorsing the procedures followed and the reliability of the results in terms of identifying scrubbed lobsters.

4.5 Development of the method

Further trials

Although the test had already helped to secure a successful prosecution, Officers were keen to undertake a further “double blind” trial (more closely simulating enforcement conditions, with no knowledge of the potential total number of scrubbed lobsters) recording the assessments of several officers, to ensure the robustness of the process, evaluate its accuracy, and highlight the ability with which it can be replicated by anyone.

Officers also wanted to simplify the actual process of testing. In addition to concerns over health and safety (in relation to the transport and storage of the chemicals), the method to date had required at least two Officers to implement due to the number of different stages to the test. By using pre-measured quantities of the chemicals in small vials and a colour-coded sequence for the consecutive stages of the process, it was felt that the test would be simpler, safer and less unwieldy to administer. Safe storage would be provided by a rugged case, which would hold a number of vials along with gloves, forceps and scissors.

Another element that needed addressing was the strength of the stain, haematoxylin. The test as described in Karlsson and Sisson uses a concentration of 1-2% haematoxylin in ethanol (substituted here with industrial ethanol, I.M.S.). Officers had found that the depth of colouration at this concentration was minimal (after the prescribed 2 minutes). This is probably due to the pH at which the stain is kept through the process; in order to produce a dark blue-purple stain, the (insoluble) precipitate haematin must be produced – this only happens under neutral-alkaline conditions (Web 1, 2011). Alcohol can be weakly acidic, which explains the clear reddish colouration of the haematoxylin solution and the weak strength of the stain, which develops and is rinsed in I.M.S. Officers were keen to explore the use of a higher concentration.

October 23rd 2007

Method

Twelve lobsters were sourced from a North Norfolk fisherman, including some (legally landed from the offshore grounds) which were berried. These latter were scrubbed by two Officers who would not be involved in the assessment. All twelve lobsters were marked with evidence tags, and their condition (non-berried or scrubbed) was recorded; the numbers of each were not made known to testers.

First, each of the testers examined the twelve lobsters, and recorded an assessment of non-berried/scrubbed based purely on visual inspection.

Next, three pleopods were dissected from each lobster out of sight of the testers. These were placed in one of 36 numbered jars, selected at random, and the numbers of each jar were recorded against the evidence tag number for that lobster. 180 5ml glass vials were prepared, so that 36 sets of five vials were created, each containing a different chemical distinguished by a particular coloured cap. In each set were two yellow-capped vials containing I.M.S, one purple-capped vial containing the haematoxylin solution, one red-capped vial containing formalin (40%), and one pink-capped vial containing glycerol.

Each pleopod was processed through the test, being transferred between the sequence of vials. At the end, testers assessed the sample and judged whether they believed it was a negative (non-berried) or positive result (scrubbed). Most tests used a concentration of 1.5% haematoxylin in I.M.S. but for some a stronger stain solution was trialled, with three drops of Delafield's haematoxylin added to the 1.5% solution in I.M.S.

Following testing, the lobsters were returned to the sea and the vials containing the pleopods were taken to the University of East Anglia, where images of the pleopods viewed under a high power microscope were recorded. These pictures were later analysed by Officers who were asked to assess whether or not the pleopods came from a scrubbed lobster.

Results

Three Officers assessed the lobsters before removal of the pleopods. Testers 1 and 2 identified all twelve lobsters correctly. Tester 3, the least experience of the three, mis-identified two lobsters, identifying both as scrubbed when they were in fact non-berried.

Two Officers (Testers 1 and 2) analysed 24 pleopods from 12 different lobsters using the 1.5% haematoxylin solution.

Table 4.1 – Test accuracy using 1.5% haematoxylin in I.M.S. solution

Stage 1 - Vial		Stage 2 - Photo		
T1	**T2**	**T1**	**T2**	
1	0	0	0	False +ve
2	4	4	4	False -ve
3	4	4	4	Total False ID
9	8	8	8	Correct ID
11	12	12	12	Correct ID inc false -ve
12	12	12	12	Sampled (n)
75	67	67	67	Accuracy (%)
92	**100**	**100**	**100**	Accuracy inc. false negative (%)

Table 4.1 shows results aggregated per lobster. Four of the lobsters were assessed on the basis of one pleopod only; others are represented by two or three replicates.

After stage 1, the vial test, Tester 1 (T1) had identified nine of twelve lobsters correctly, with two false negatives and one false positive. The false positive was for an assessment based on one pleopod. Tester 2 (T2) identified eight of the twelve correctly, with no false positives. After stage 2, both testers had correctly identified all twelve lobsters.

Table 4.2 – Test accuracy using 1.5% haematoxylin in I.M.S. solution plus Delafield's

Stage 1 - Vial		Stage 2 - Photo		
T1	**T2**	**T1**	**T2**	
0	0	0	0	False +ve
0	1	0	0	False -ve
0	1	0	0	Total False ID
8	7	7	7	Correct ID
8	8	7	7	Correct ID inc false -ve
8	8	7	7	Sampled (n)
100	88	100	100	Accuracy (%)
100	**100**	**100**	**100**	Accuracy inc. false negative (%)

The stronger stain was used for eleven pleopods, which represented eight different lobsters. The identification at the vial stage appeared to be more accurate, with no false positives and far fewer false negatives. As before, by stage 2 there was 100% accuracy in identification.

Conclusions

The trial underscored both the reliability and usefulness of the test, but also the need for several stages to the assessment. Both testers correctly identified all lobsters before the test was started, although this was very soon after scrubbing which is physically stressful to the lobster and may have aided identification. In the field it is likely to be more difficult, and this is where the ability of the test to highlight cementum on the setae becomes valuable. The only false positive identification was reached when a single pleopod was used; the photograph was then used to correct the identification. In fact, the photos under the high-powered microscope were the key to a definitive, accurate assessment, although increasing the strength of the haematoxylin stain was found to improve accuracy of the vial test.

As a result of this trial, the ESFJC test methodology was formalised to include pre-assessment, the use of more than one pleopod (in the case of a positive first result) and a need for photographic evidence to confirm identification. The full method is outlined in Section 4.6.

Haematoxylin strength

Rather than use a combination of different haematoxylin treatments, as in the trial, Officers investigated using an increased concentration of the stain in I.M.S. as this is the closest to the original methodology and does not change the chemistry to the same extent as adding Delafield's would. The solubility of haematoxylin in alcohol limited the maximum concentration to 5%; this was found to produce a clearer result in tests, without any evidence of excessive staining, and is recommended for use in future tests.

Test kit

The use of the vials during the last trial was successful, and so additional vials and coloured caps were ordered. To make a distinction between the initial and post-stain rinse in I.M.S., two different colours were used, with orange for the latter stage. Two briefcase-sized peli cases were ordered, and adapted to hold rows of vials containing the chemicals pre-measured and ready to be used in the test. A crib sheet with clear visual cues was developed to be included in the kit, so that the method could easily be followed through the instructions.

4.6 Description of methodology and evidence requirements

The following process should be followed when using the test in targeted enforcement.

- Track vessel at sea to monitor its position while fishing, to determine that it has stayed inside the District (and that any lobsters caught are therefore subject to ESFJC Byelaw 6)
- On landing, inspect the catch – a check of the male/female ratio often indicates an offence, as the proportion of females is relatively much lower during the berried season
- Talk to fisherman to corroborate where he fished that day; explain the test procedure
- Examine lobsters and select any that, by eye, appear to have been scrubbed; look for limpness, signs of trauma and stray eggs that might have been forced into crevices in the carapace
- If an offence is suspected, caution the fisherman and continue with test. If no offence is initially apparent, continue and test a small, random selection of lobsters
- Proceed with test as per instructions (Figures 4.4, 4.5)
- If possible, place each lobster in seawater after removing pleopod(s), to aid healing
- If an offence is found, caution the fisherman and potentially start interview process
- Seize any suspected scrubbed lobsters, issuing a receipt to the fisherman, and return to sea
- Follow up any positive tests by examining pleopods under high-powered microscope and taking images for evidence, making sure to reference evidence tag numbers to photographs

Note that a positive result from the vial test requires two pleopods, both positive. These would then be examined in greater detail under the microscope. Any negative result or uncertain result is treated as a "clean", legal lobster.

Lobsters that are either in the process of naturally shedding or have recently done so are generally very clearly identifiable as such – due to the messy, wheat-chaff appearance of the setal hairs. These would not be tested; in the event that any appeared to have been scrubbed but had in fact naturally shed, this would be identified under microscopic examination by the fact that the egg casings were still intact and unbroken.

The radar track recorded at sea should be accompanied by a log of observations at regular intervals, describing the movement or activity of the vessel. A note should be made in the patrol vessel's log of the GPS positional accuracy at the time of tracking, and the start and finish times of observations. The Transas system installed on FPV *ESF Protector III* allows radar tracks to be downloaded and transferred so that they can be admitted as evidence and played back in court. Additional observations relating to conditions at the time (e.g. sea state, weather, visibility) should also be recorded in the patrol vessel's log.

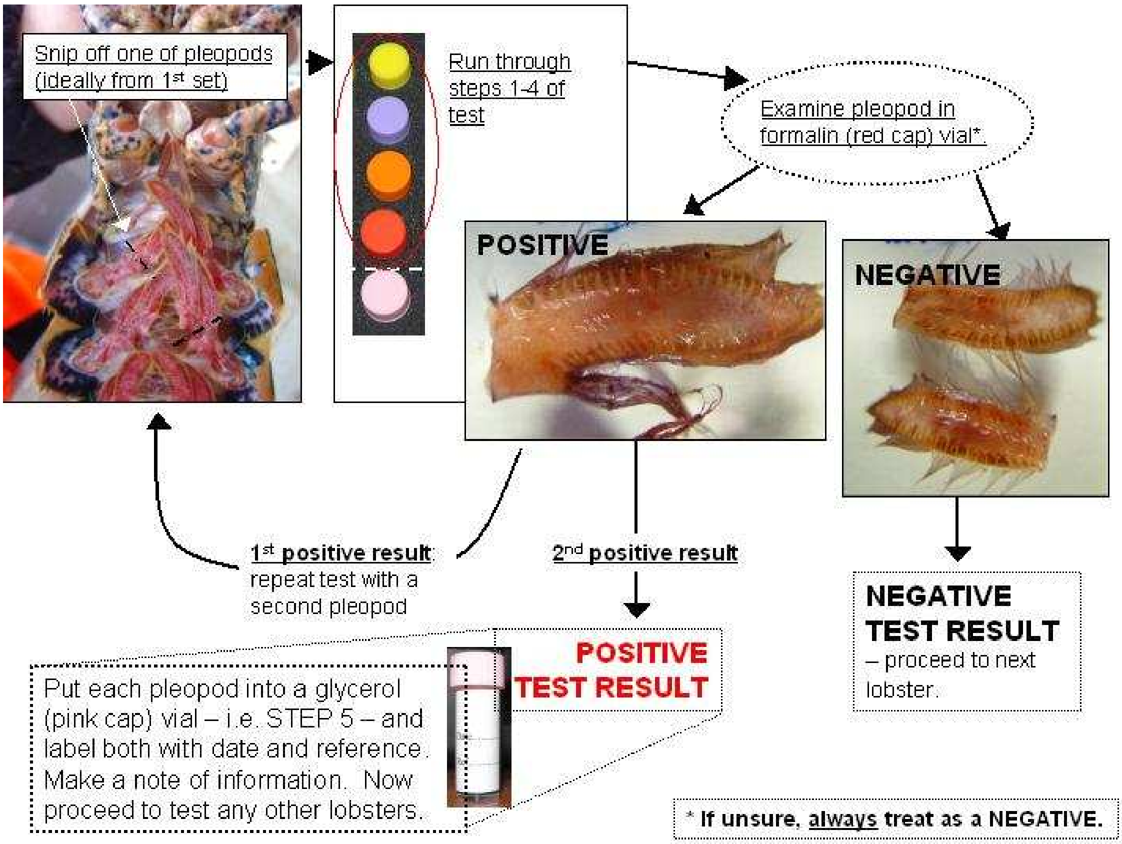


Figure 4.4 Process diagram explaining how to process each lobster using the test kit

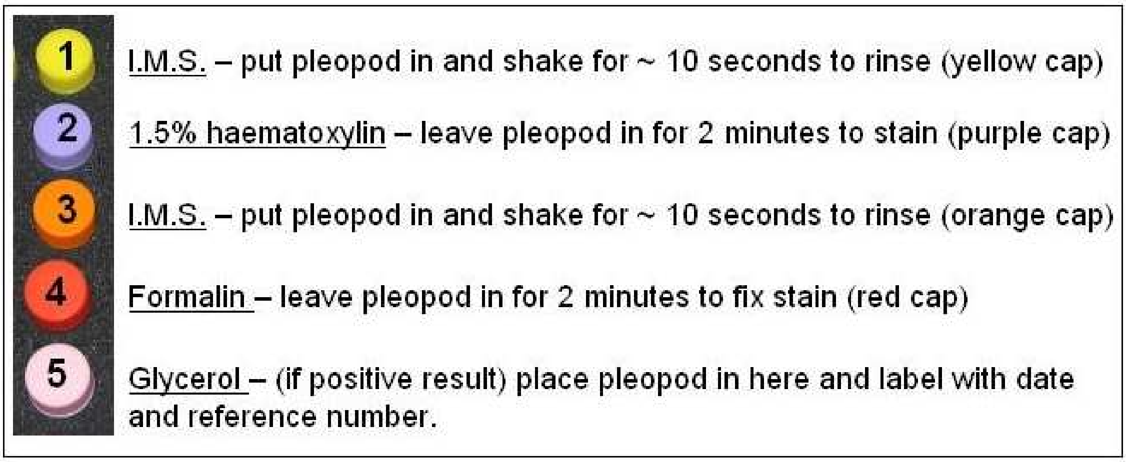


Figure 4.5 Instructions describing each stage of the vial test process (these are now slightly out of date, and are to be amended to read "5% haematoxylin in I.M.S").

4.7 Further trials, training, and promoting the kit

Shellfish Manager's conference 2010

In April 2010, a demonstration of the test was given to delegates at the Shellfish Manager's conference, which was held in King's Lynn. Attendees included SFC Officers, fisheries scientists and representatives from statutory nature conservation groups. Despite some logistical difficulties with demonstrating a somewhat slow process to so many people, there was interest in the test and some good feedback from those who attended.

Introduction to other Districts

After the demonstration in April, ESFJC Officers were asked by a group of three other SFCs to introduce the test to them and provide some training. These were Committees that have lobster fisheries and either currently have or are considering introducing a berried Byelaw. On 15th and 16th June 2010, Research & Assistant Marine Environment Officer Jessica Woo, Deputy Clerk & Fishery Officer Duncan Vaughan and Clerk & Chief Fishery Officer Mat Mander held a workshop in Portland, Dorset for invited Officers from Southern SFC, Devon SFC and Cornwall SFC. Attendees were given a presentation, which explained the origin and development of the test, described the economic and fishery benefits of protecting berried lobsters, and covered some lobster biology as well as talking through the different stages of the test methodology.

Officers then had an opportunity to see practical demonstrations and to use the test themselves. Their assessments were recorded and the results discussed as a group. The trainees' success rate at correctly identifying the lobsters was 96%, with no false positives at all (and most of the false negatives relating to one particular lobster, for which the benefit of the doubt was given). At the end of the workshop, attendees took a written test on the knowledge acquired over the previous two days. Feedback on the test was positive – Officers commented on its simplicity and were able, with a minimum of training, to identify which lobsters had been scrubbed.

Each "delegate" received an information pack to take away which included the PowerPoint presentation slides, a copy of the Karlsson and Sisson technical paper and a guide on procuring and putting together the kit. A certificate of competence was issued to all attendees, who had successfully demonstrated (via the written test and practical exercises) understanding of the principles and methods of the detection of berried lobsters using the Karlsson and Sisson test.

Training at ESFJC

On 1st October 2010, four lobsters were brought to the ESFJC Offices and available Officers had the opportunity to undergo some training and get practical experience of the test using the new kit. After a presentation (the same as that given at the Dorset workshop) and using the instructions, three of the four Officers correctly identified two non-berried, one berried (scrubbed) and one naturally-shed lobster using the procedure; the fourth Officer was given further training and instruction until they better understood the process. Proper, formal training of all Officers is planned for the 2011 season.

Use in enforcement

On 6th October 2010, the full test (including at-sea observations) was used in a targeted enforcement exercise. No offence was found, but it was a good opportunity for all Officers to run through the procedure, and also acted as an effective demonstration of the test to the fishermen. Quite a crowd drew on the quay to watch the test being carried out, and afterwards Officers answered questions from onlookers – both fishermen and members of the public – and explained the reason for the test and how it worked.

4.8 The future of the test

Following from the workshop in June 2010, Southern SFC (now Southern IFCA) and Devon SFC (now Devon and Severn IFCA) have both expressed their intention to adopt the test, and have been procuring the necessary chemicals and kit needed to do so.

The main barrier to the test's widescale use remains the scope of legal protection for berried lobsters. Those Districts where a berried byelaw exists are able to enforce it only if there is sufficient proof that the "positive"-testing lobster was removed from the fishery within the 6nm IFCA limit – the extent of the applicability of the byelaw, and the IFCA's jurisdiction. This need for a resource-intensive approach to enforcement will undoubtedly make the adoption of the Byelaw a less than attractive prospect for other IFCAs.

Currently, there is no national legislation that offers protection to egg-bearing lobsters, although there was a review of existing lobster conservation that considered this in 2006. The Defra consultation examined options such as an increase of minimum landing size (from the current 87mm CL), and the introduction of a maximum landing size to protect the most highly fecund, larger female lobsters. The potential for legislating against the landing of berried lobsters through a statutory instrument had been discounted in an earlier consultation, in part as it was deemed "unenforceable".

Although this may have been the case in 1966, when the Sea Fish Industry (Crabs and Lobsters) Order 1951 was repealed, today this is not quite correct – and certainly the main barrier to the efficacy of the test is the burden of supporting evidence needed (as a result of the 6nm cut-off) rather than the logistics or reliability of the test itself. ESFJC provided Defra with a report (Vaughan, 2008) on the test, documenting our own experiences in implementing and enforcing legislation prohibiting the landing of berrieds. It demonstrated that the existing (byelaw) legislation has proven enforceable, in spite of the extra burden of proof relating to the 6nm issue – which would of course be removed by increasing the scope of the regulation to a national level.

The focus of the argument for (or against) introducing national legislation then becomes one of the benefit of protecting brood stock. Arguably this has, to date, been discussed in a fisheries management context. With limited data on lobster fisheries available it's hard to see how there can be any certainty as to whether or not the measure is likely to deliver commercial benefit – this hasn't, of course, prevented other countries (notably the USA and Canada) from protecting berried lobster. Some scientists do not agree that there is any proven benefit in protecting egg-bearing lobster (Thomas, 1965), although this review – written just before the ban on landing berried lobsters was lifted – was at a time when most lobster fisheries in England and Wales were not heavily exploited. The same paper suggests that the lobster fisheries most likely to benefit from a ban would be the more heavily fished, although this is not quantified. The level of exploitation has certainly increased in the North Norfolk fisheries since that time, although another issue raised – the indirect relationship between egg and larval production and recruitment – is still not well understood.

But it is likely that the biology and ecology of lobster fisheries may never be well understood, regardless of how much data we are able gather, due to the dynamic nature of the environment and the cryptic behaviour of lobsters themselves. Perhaps the most compelling argument for protection is that it is good practice – common sense – to take a precautionary approach to management from both a fisheries management and a conservation perspective.

If it were accepted that a responsible approach is to require egg-bearing lobsters to be returned to the sea, it would seem to follow that the practice of retaining these lobsters and landing them for sale is wrong. The absence of any government stance on the removal from the fishery of berried lobsters, as is the case currently, acts as a tacit endorsement of the activity and places an enormous burden on local fisheries managers seeking to implement conservation measures. It also sends out a message to the fishermen who want to act responsibly that it's not only unnecessary to do so, but also a stance that puts them at a commercial disadvantage. Thankfully, some remain undeterred, and v-notch any berried females they catch before returning them, which ensures that they cannot be landed until the notch has grown out through subsequent moults – allowing that lobster to reproduce.

In light of the confidence Eastern IFCA has in the test, Officers would be keen to see the government give proper consideration to the introduction of national legislation to protect berried lobsters.

5.0 ACOUSTIC GROUND DISCRIMINATION SYSTEM (A.G.D.S) ROXANN^{TM} SURVEYS

5.1 Introduction

ESFJC has been conducting sublittoral seabed surveys since 1993, when RoxAnn^{TM} Acoustic Ground Discrimination System (AGDS) equipment was first fitted aboard the research vessel *ESF Surveyor*. Initially these surveys were conducted in order to identify and map beds of sublittoral mussel seed, but over time increased emphasis has been given to using the equipment to identify and map *Sabellaria spinulosa* reefs.

Sabellaria spinulosa, or Ross worm, is a colonial tubiculus polychaete that occurs subtidally throughout UK waters forming temporally, semi-stable, albeit fragile patches of biogenic reef. The worms live in tubes that they build from sand grains or fine gravel that has been put into suspension by tidal currents or wave action, and on occasions may form structures that rise up to 60cm above the seabed (Jackson and Hiscock, 2006). Because they provide a biogenic structure upon which a range of epibenthic species can become established, these reefs are ecologically important features. Not only have they been designated as a priority habitat under the Uk's Biodiversity Action Plan (BAP), they have also been named as an interest feature of the Wash and North Norfolk Coast Marine Special Area of Conservation (SAC), where their categorisation has been upgraded from a sub-feature of the 'Large Shallow Inlet and Bay' biotope to a 'Reef' feature in their own right.

The greatest anthropogenic impact on *Sabellaria spinulosa* reef is considered to be physical disturbance from fisheries activities, which can cause damage to the erect *Sabellaria spinulosa* reef communities, breaking them into small chunks that are unable to provide habitats for the rich infauna and epifauna associated with this biotope (UK Biodiversity Group, 1999). Although dredging, trawling and potting can all cause damage to the reefs, the location of the identified reefs in the central Wash, corresponding to the SSSI Unit 58, indicates that the greatest impact is likely to be from the beam trawl shrimp fisheries, particularly those targeting the pink shrimp, *Pandalus montagui*. The lack of spatial management or effort restriction on demersal towed fishing activities meant English Nature had identified Unit 58 as being in "unfavourable declining condition". Although the pink shrimp fishery has greatly declined since the late 1980s, the potential for an uncontrolled revival in the fishery means the unfavourable assessment has been maintained.

As the competent authority responsible for the management of fisheries within these sites, ESFJC has a duty to ensure that fishing activities do not damage *Sabellaria* reef features. ESFJC currently has no regulations or byelaws specifically aimed at restricting damage to *Sabellaria* reefs from the fishing industry, but has been consulting with Natural England since 2006 over the creation of one. During that period there has been much discussion to what precisely constitutes a *Sabellaria spinulosa* reef. In many parts of its geographical range *Sabellaria spinulosa* does not form elevated reefs, instead being solitary or spreading laterally to form extensive thin crusts. As surveys indicate the crust form of *Sabellaria* is far more widespread in The Wash than elevated reef, it is important to determine the spatial extent of both forms and to establish core areas for protection. In 2006 Hendrick developed a method of scoring the "reefiness" of a reef, using characteristics including area of coverage, elevation, patchiness, sediment consolidation and biodiversity (Hendrick and Foster-Smith, 2006). Following a Joint Nature Conservation Committee (JNCC) inter-agency workshop in 2007, in which the thresholds suggested by Hendrick were discussed, criteria were established for differentiating between elevated reef and *Sabellaria* crust (Gubbay, 2007). Using these criteria, elevations between 2-5cm were classified as low-grade reef, those between 5-10cm were medium-grade reef and those greater than 10cm were classified as high-grade reef. Elevations lower than 2cm, or less than 10% patchiness cover, were no longer considered to be reef. ESFJC adopted these thresholds in 2009, having originally used thresholds suggested in Hendrick and Foster-Smith, 2006 for the 2007 surveys.

Prior to 2009, the A.G.D.S surveys conducted by ESFJC had been relatively broadscale, aimed at detecting reefs and sublittoral mussel beds over large expanses of seabed. While these surveys had been ideal for maximising the area surveyed in the time available, mapping resolution was low. In order to make confident management decisions that would arise from a potential *Sabellaria* byelaw, greater accuracy was required in the mapping of reefs. This was achieved during the 2009-survey programme, during which the survey area was significantly reduced by concentrating on five discreet areas that previous surveys had identified as supporting *Sabellaria* reef (figure 5.1). Because the survey areas were significantly smaller than those previously surveyed, it was possible to change the survey methodology, giving greater emphasis to the ground truth record during the mapping phase than had previously been attempted. During the 2010 programme, the same five areas were surveyed once again, plus additional areas along the Lincolnshire coast near the Lynn and Inner Dowsing wind farms (figure 5.2).

5.2 Method

The survey programme was divided spatially into two main areas comprising five sites within The Wash (figure 5.1) and four sites along the Lincolnshire coast near the Lynn and Inner Dowsing wind farms (figure 5.2). In order to save time and enable the survey programme to be completed, it was necessary to use slightly different survey methodologies for the two areas.

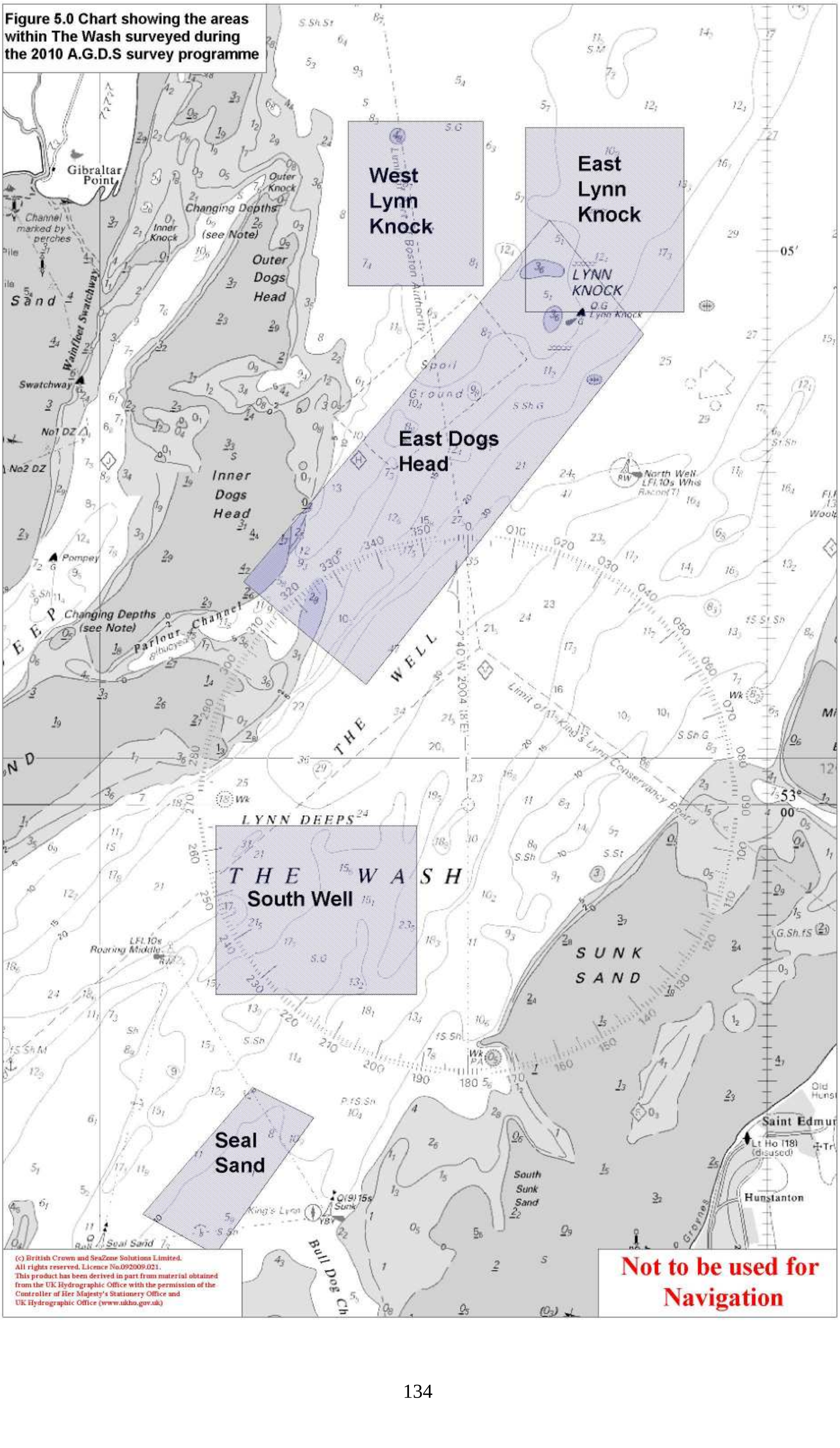
<u>Lincolnshire Coast Sites</u>

At the Lincolnshire coast areas, where there was less knowledge of the positions of reefs than at the Wash sites, a similar survey method was employed as had been applied in 2009 to map the Wash reefs (Jessop, Harwood & Woo, 2009). This comprised conducting RoxAnn™ AGDS tracks, the data from which were then interpolated to create models depicting the hardness and roughness of the seabed within the survey areas. These models were then used to inform the positioning of the semi-stratified ground truth positions. For these Lincolnshire Coast surveys, RoxAnn^{TM} A.G.D.S tracking was conducted using *RV Three Counties* at all of the sites apart from the South West Wind Farm (SWWF) site, which was conducted using *FPV Protector III*. Within each area parallel tracks were conducted at a distance between 150-200 metres apart, except for the SWWF site in which the tracks were between 200-250 metres apart. In order to maximise the signal quality for the AGDS, all tracks were conducted at a speed of approximately 6-8 knots and only on days when the sea-state was relatively calm. Although the RoxAnn^{TM} data is displayed real-time as a coloured track on the vessel's plotter, from which ground-truth sites can be assigned, for these surveys the data were further analysed using MapInfo and Vertical Mapper GIS software prior to assigning ground-truth sites. Using these programs the RoxAnn^{TM} track data were interpolated to create models depicting the hardness and roughness of the seabed within the survey areas. These models of seabed hardness and roughness were then used to predict where reef structures might be located, and thus to inform where to assign ground-truth stations in a semi-stratified manner. Ground-truthing was conducted using a mixture of Day grabs and underwater video camera footage taken from a Remotely Operated Vehicle (ROV). Prior to the 2009 surveys, Natural England had requested that Day grab sampling be kept to a minimum when ground truthing RoxAnn^{TM} data in order to reduce the potentially damaging impact grab sampling can have on reefs. As the 2009 and 2010 surveys required much higher resolution than the earlier broadscale surveys, however, increasing the frequency of grab samples was seen as the only feasible method available for confidently mapping the boundaries of the reef and ascertaining the elevation of the structures. For these surveys the ground-truthing was conducted in three phases. At each survey area Day grabs were used exclusively during phase one, using the pre-determined semi-stratified patterns that had been assigned following analysis of the track data. To minimise seabed disturbance a single sample was collected from each ground-truth station, from which the following details were recorded:

Predominant sediment types	Height range of clumps
Percentage volume of shell	Occupancy of *Sabellaria* tubes (zero, low, moderate or high)
Percentage volume of *Sabellaria* fragments	Presence of faunal turfs
Percentage coverage of *Sabellaria* clumps	Presence of other macro-faunal species present

Data from these grab samples were plotted using MapInfo GIS and interpolated using Vertical Mapper to create models depicting the distribution of sediment types and *Sabellaria* features within each survey area. These models were then used to inform the second phase of ground-truthing, in which further Day grab samples were collected to more precisely chart the extent of the reef features identified in the first phase. Data collected during the second phase were pooled with those data collected during phase one and the Vertical Mapper interpolated models re-created using the additional data. Areas of predicted *Sabellaria* reef were selected from these models as sites for the third phase of ground-truthing, in which the ROV video camera was used to verify the grab data and to estimate the patchiness of the reef.

Figure 5.0 Chart showing the areas within The Wash surveyed during the 2010 A.G.D.S survey programme



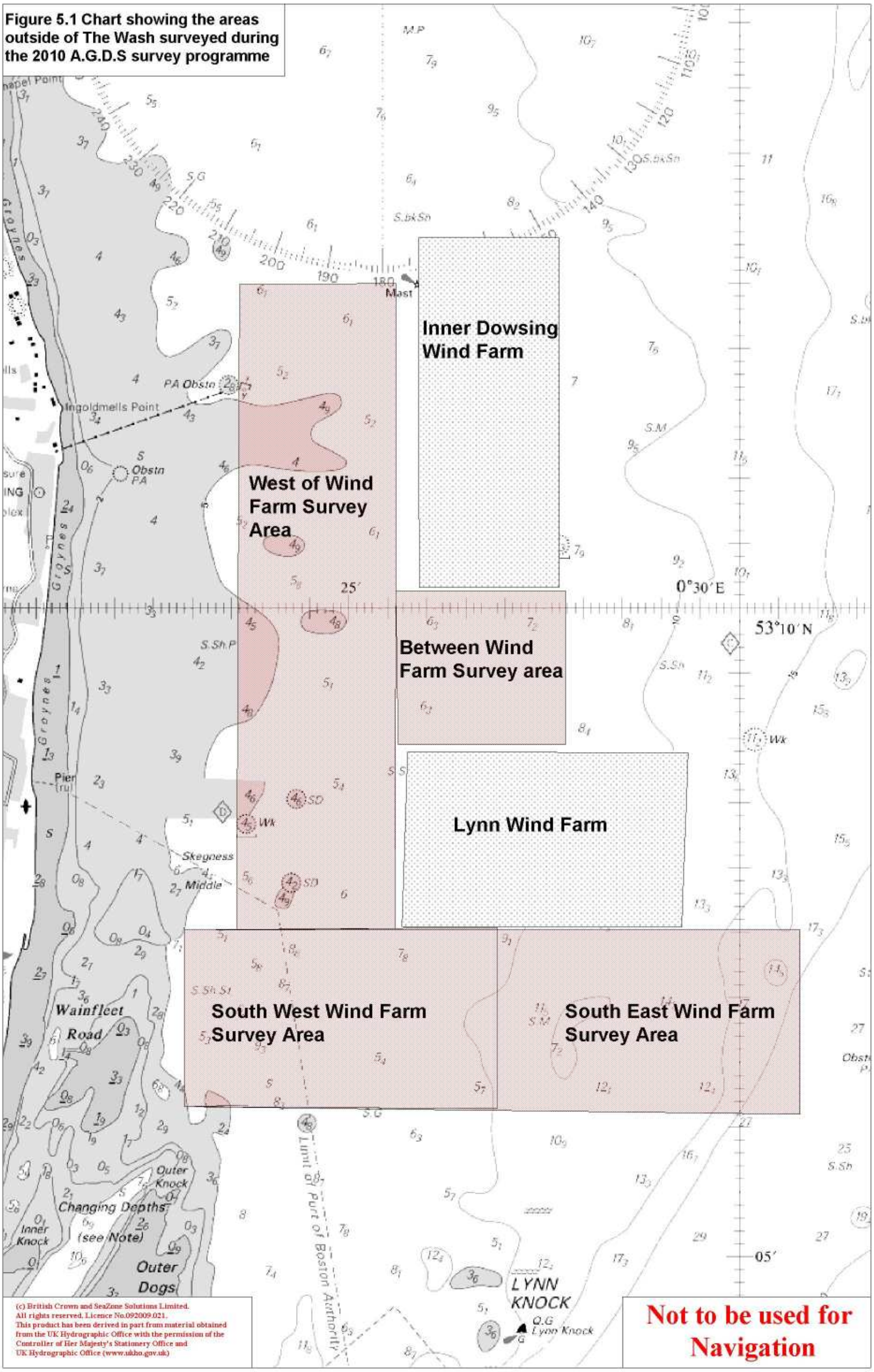


Figure 5.1 Chart showing the areas outside of The Wash surveyed during the 2010 A.G.D.S survey programme
Inner Dowsing Wind Farm
West of Wind Farm Survey Area
Between Wind Farm Survey area
Lynn Wind Farm
South West Wind Farm Survey Area
South East Wind Farm Survey Area
Ingoldmells Point
Skegness Middle
Wainfleet Road
Changing Depths (see Note)
Inner Knock
Outer Knock
Outer Dogs
LYNN KNOCK
Limit of Port of Boston Authority
0°30′E
53°10′N
25′
05′
(c) British Crown and SeaZone Solutions Limited. All rights reserved. Licence No.092009.021. This product has been derived in part from material obtained from the UK Hydrographic Office with the permission of the Controller of Her Majesty's Stationery Office and UK Hydrographic Office (www.ukho.gov.uk)
Not to be used for Navigation

The Wash sites

The 2010 surveys of The Wash sites were conducted in a similar manner to the Lincolnshire Coast areas, except time constraints meant it was not possible to RoxAnn^{TM} track these areas. Whereas interpolated hardness and roughness models derived from track data had been used to inform the semi-stratified positioning of the ground truth stations at the Lincolnshire Coast sites, for The Wash stations, semi-stratified positions were derived from interpolated models of the *Sabellaria* reefs created from the 2009 ground truth data.

Mapping Reef features

For the 2009 surveys, two sets of charts showing the distribution of *Sabellaria* colonies were produced for each site by interpolating the ground-truth data using different thresholds. One set showed the distribution of *Sabellaria* crust and elevated reef using thresholds suggested by Hendrick (Hendrick and Foster-Smith, 2006), which had also been used during ESFJC's 2007 survey programme (Jessop, Woo & Torrice, 2007). The second set of charts were produced to show the distribution of *Sabellaria* colonies in terms of low, medium and high grade reef, using the thresholds suggested in Gubbay (2007). Because the Gubbay (2007) thresholds have become a widely accepted standard, they have been used exclusively during the ESFJC 2010 surveys for mapping reef features. Table 5.1 shows a number of reef scoring thresholds suggested in Gubbay (2007). When mapping reef features, the elevation and patchiness criteria are the ones commonly used. Determining patchiness, however, requires either multiple grabs being taken at each site or clear video footage. As neither of these were practical options for all of the survey sites sampled during the 2009 and 2010 programmes, elevation and sediment consolidation are the criteria that have been used for mapping reef features during these surveys.

Table 5.1 Reef scoring parameters suggested in Gubbay (2007)

Criteria	Not Reef	Low	Medium	High
Elevation (cm) (average tube height)	<2	2-5	5-10	>10
Sediment consolidation (% cover of sediment)	<5	5-10	10-30	>30
Area (m^2)	<25	25-10,000	10,000-1,000,000	>1,000,000
Patchiness (% cover within reef)	<10%	10-20	20-30	>30

5.3 Results

5.3.1 West Lynn Knock

For the first phase of ground truthing of the West Lynn Knock site, 97 sample stations were positioned in a semi-stratified pattern, their locations informed by an interpolated model of *Sabellaria* reef derived from the 2009 survey data (figure 5.2). Of these stations, 23 were positioned in areas predicted from the 2009 model to be medium reef, 43 in areas predicted to be low reef and a further 31 in areas predicted to support no reef. These Phase-1 stations were sampled with a Day grab on July 20th and 21st.

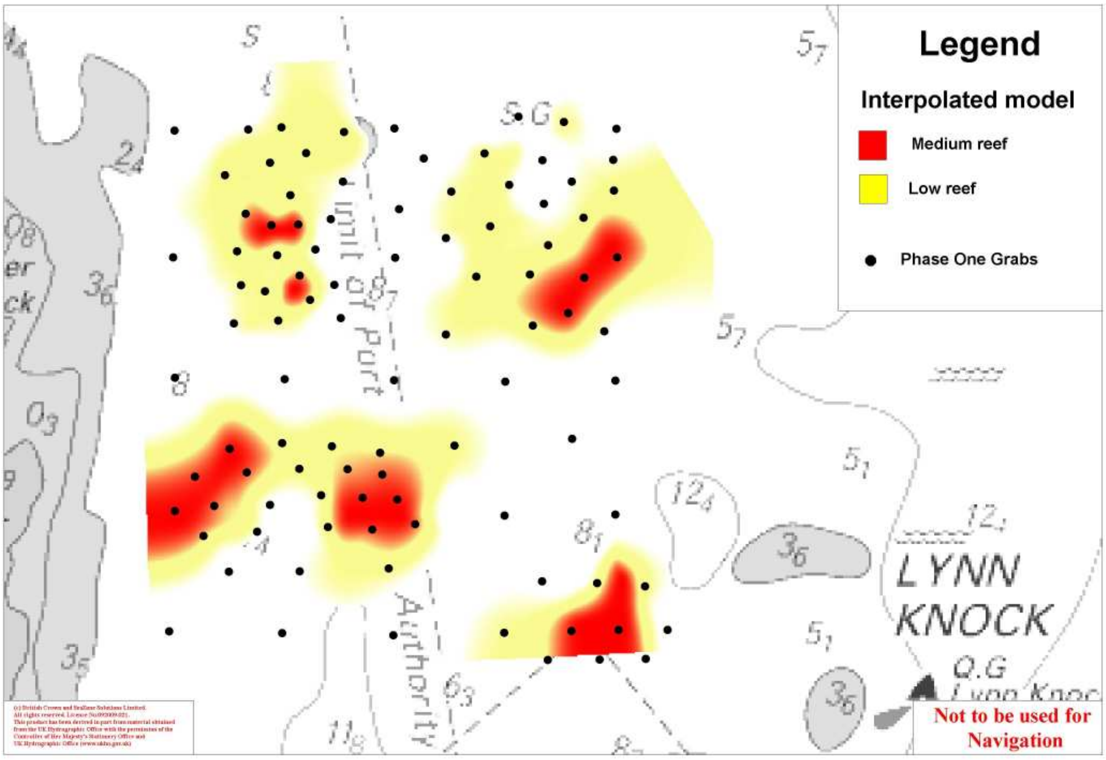


Figure 5.2 Chart showing the positions of the Phase-1 survey stations at West Lynn Knock overlaid with an interpolated model of *Sabellaria spinulosa* reefs derived from the 2009 survey data.

When sampled, 15 of the stations were found to support medium reef, 34 supported low reef and 48 were found not to support any reef. Of the 66 sites in which some form of reef structure had been predicted, 40 (61%) were found to support reef. Of the 31 stations chosen from areas predicted not to support reef, 9 (29%) were found to actually support reef. Although at 61% of the sample stations reef structures had been accurately predicted, predicting the quality of the reef was less accurate. Of the 23 stations predicted to support medium reef, only 5 (22%) were actually found to, while 14 (33%) of the 43 stations predicted to support low reef did. It was not possible during the surveys to determine whether these discrepancies were due to the uneven patchiness of the *Sabellaria* structures within a reef or due to the ephemeral nature of *Sabellaria* reefs.

The data collected from the first phase of sampling were interpolated using Vertical Mapper, from which a model was created showing the predicted distribution of *Sabellaria* reef across the site. Using this model, a further 19 stations were selected in order to map the edges of the identified reef features with more precision. These Phase-2 stations were sampled with a Day grab on July 22nd, their data being pooled with those from Phase-1 and re-interpolated using Vertical Mapper to create a model showing the predicted distribution of *Sabellaria* reef features (figure 5.3).

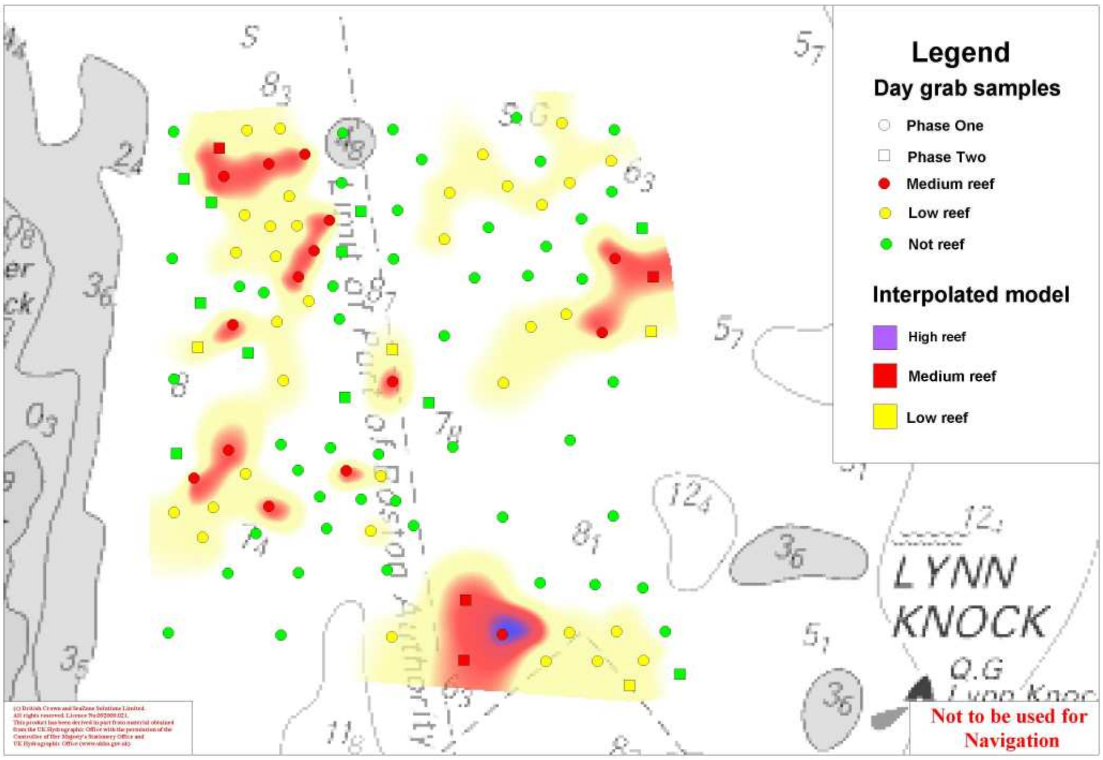


Figure 5.3 Interpolated model from the Day grab data at the West Lynn Knock site (applying thresholds suggested in Gubbay, 2007), showing the predicted distribution of low, medium and high *Sabellaria* reef, overlaid with the positions of the Day grab sample stations (Phases 1& 2).

From figure 5.3 it can be seen that nine discrete patches of medium reef were identified during the 2010 surveys. These have been estimated to cover areas of 12.9 hectares, 5.6 hectares, 2.0 hectares, 7.4 hectares, 1.9 hectares, of 2.0 hectares, 1.0 hectares, 14.5 hectares and 28.5 hectares; an overall area of 75.8 hectares. A 2.3 hectare area within the latter region of medium reef was of sufficient height and coverage to be categorised as high reef. A further 263.7 hectares were found to support low reef. These figures are slight reductions to the 89.1 hectares of medium reef and 272.2 hectares of low reef charted in 2009.

In addition to recording *Sabellaria* data, information about the predominant sediment types found in each Day grab sample was also recorded. At the West Lynn Knock site, these were found to be predominantly mixtures of muddy and sandy gravel, with approximately half of the stations containing pebbles or cobbles. These habitats were generally consistent with the EUNIS classification A5.44 – Circalittoral mixed sediments (JNCC code – SS.SMx.CMx).

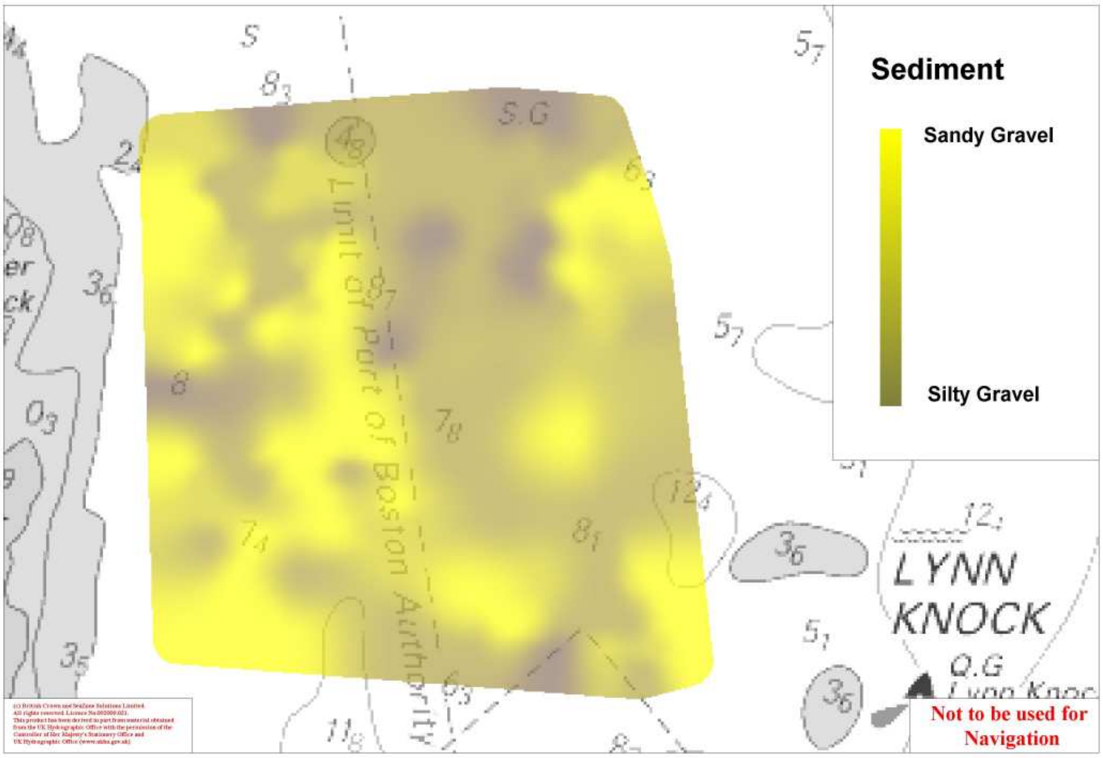


Figure 5.4 Interpolated model from the Day grab data at the West Lynn Knock site showing the distribution of silty and sandy gravel habitats.

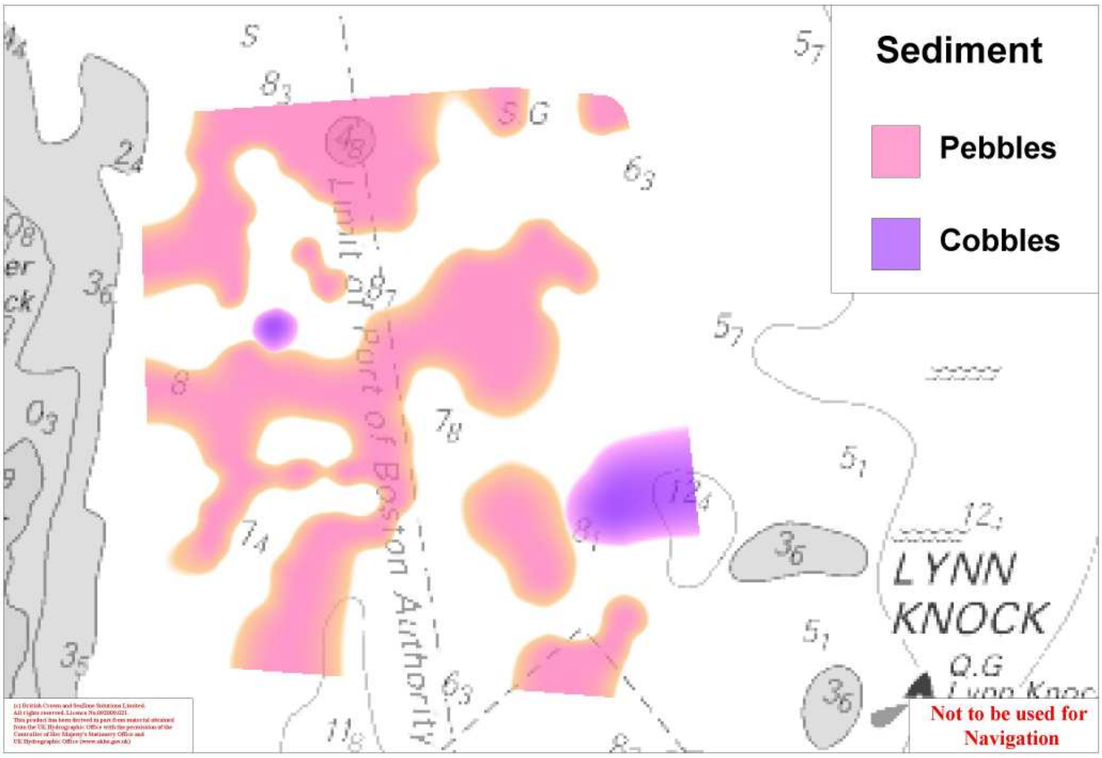


Figure 5.5 Interpolated model from the Day grab data at the West Lynn Knock site showing the distribution of pebble and cobble habitats.

5.3.2 East Lynn Knock

Similar to the West Lynn Knock site, an interpolated model of *Sabellaria* reef, derived from the 2009 survey data, was used to inform the positioning of the sample stations for the first phase of ground truthing at the East Lynn Knock site. 55 stations were positioned in a semi-stratified pattern; 1 situated on an area predicted to support medium reef, 11 on areas predicted to support low reef and 43 on areas predicted to support no reef (figure 5.6). These stations were sampled on July 21st using a Day grab.

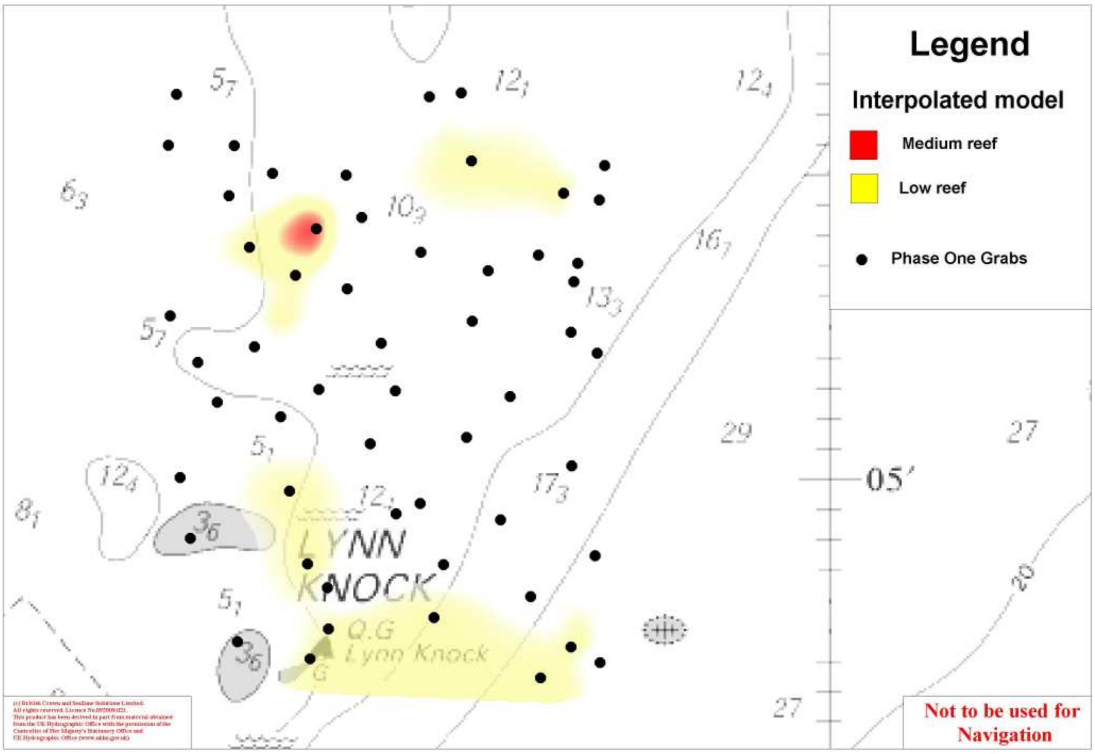


Figure 5.6 Chart showing the positions of the Phase-1 survey stations at East Lynn Knock overlaid with an interpolated model of *Sabellaria spinulosa* reefs derived from the 2009 survey data.

When sampled, 4 of the stations were found to support medium reef, 9 supported low reef and 42 were found not to support any reef. Of the 12 stations that had been positioned on areas predicted to support reef structures, 7 (58%) were found to do so. A further 5 stations situated in areas predicted not to support reef were found to contain reef, including the 2 of the stations found to support medium reef.

The data from this phase of sampling were interpolated using Vertical Mapper, creating a model of the *Sabellaria* distribution within the site, from which a further 5 sample stations were selected in order to map the edges of the identified reef features with more precision. These 5 stations were sampled on July 21st, using a Day grab, their data being pooled with those from Phase-1 and re-interpolated using Vertical Mapper to create a model showing the predicted distribution of *Sabellaria* reef features (figure 5.7).

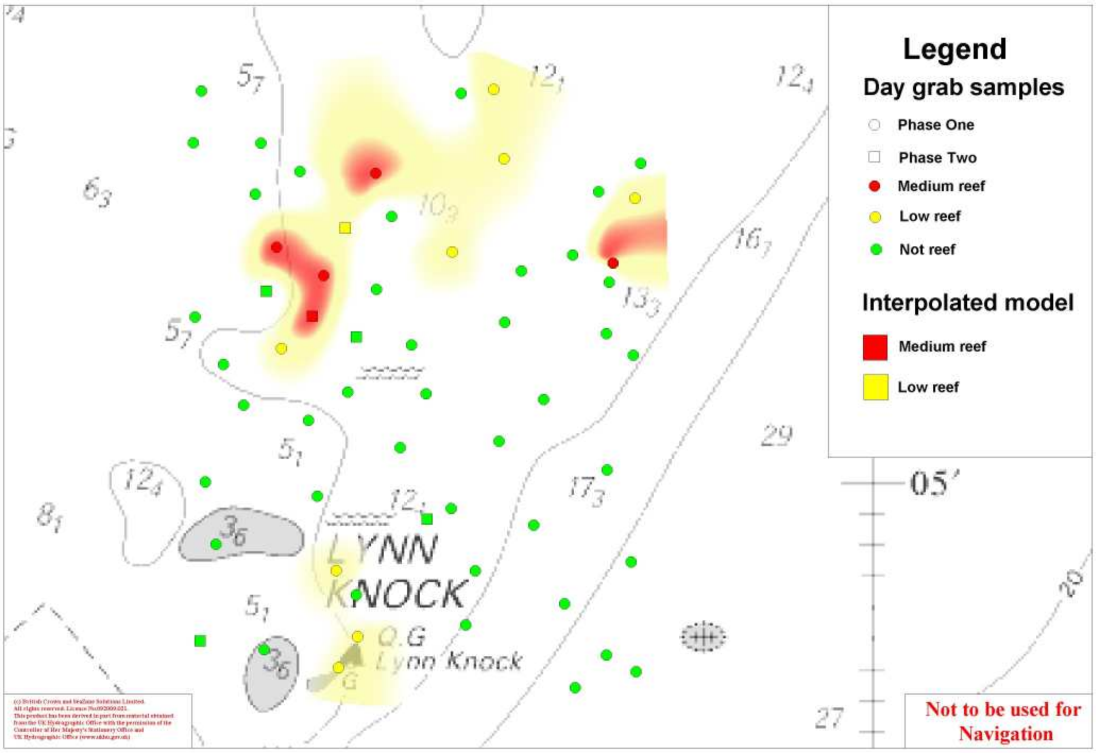


Figure 5.7 Interpolated model from the Day grab data at the East Lynn Knock site (applying thresholds suggested in Gubbay, 2007), showing the predicted distribution of low and medium *Sabellaria* reef, overlaid with the positions of the Day grab sample stations (Phases 1& 2).

The surveys identified three discrete patches of medium reef to be present at the East Lynn Knock site. These have been estimated to cover areas of 15.4 hectares, 8.9 hectares and 8.7 hectares; an overall area of 33.0 hectares. A further 153.1 hectares were found to support low reef. These figures indicate the area of medium reef has significantly increased from 5.8 hectares in 2009, but that the area of low reef has declined 208 hectares. Although these figures do not show a great deal of change in the overall area of *Sabellaria* reef at this site, comparing the reef distribution in 2009 (figure 5.6) with the reef distribution in 2010 (figure 5.7) shows there has been a significant change to the distribution. The extent of the reef in the northern half of the site appears to have increased in area and quality, while the coverage in the southern half has declined.

Additional sediment data collected from each sample station found the substrate across the site to be composed primarily of sandy and silty gravel mixtures or sandy and silty pebble mixtures. These were generally consistent with the EUNIS classification A5.44 – Circalittoral mixed sediments (JNCC code – SS.SMx.CMx). Figures 5.8 to 5.10 show the distribution of these features. 20 of the 60 stations sampled were also found to support a faunal turf composed mainly of hydroids and/or the bryozoan, *Flustra foliacea* (see figure 5.11). This habitat was estimated to cover 344 hectares (approximately 31% of the site) and was consistent with the EUNIS classification A5.444 – *Flustra foliacea* and *Hydrallmania falcata* on tide-swept circalittoral mixed sediment (JNCC code – SS.SMx.CMx.FluHyd).

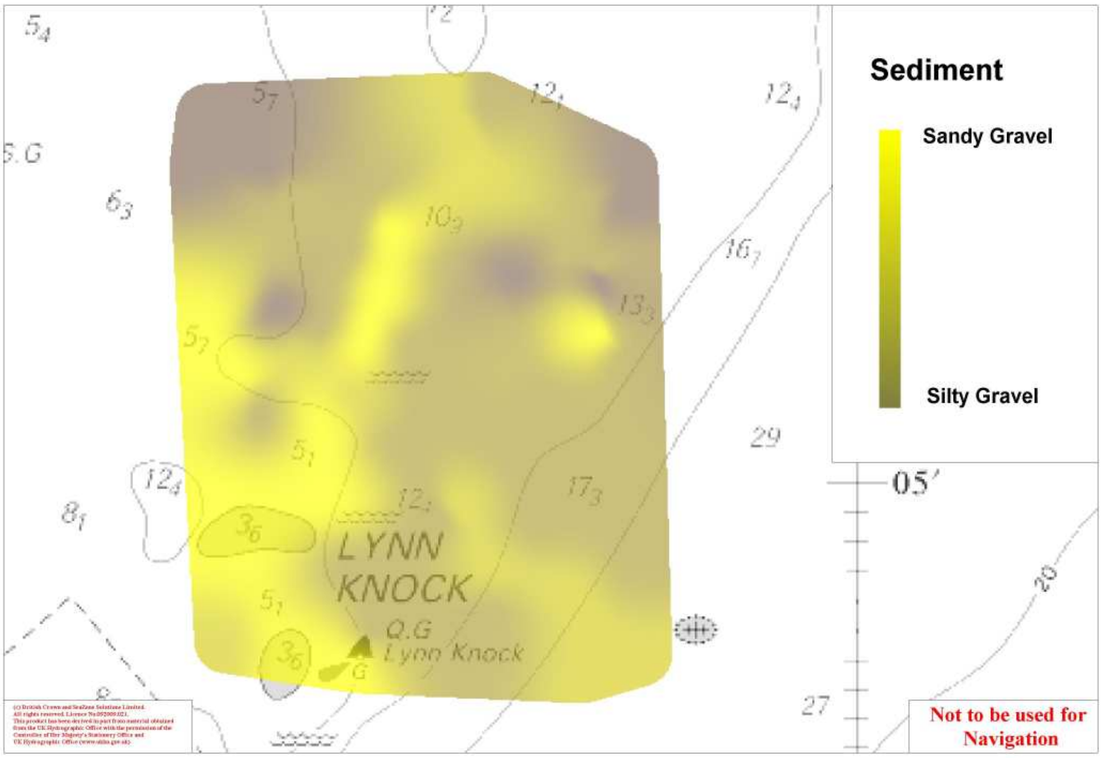


Figure 5.8 Interpolated model from the Day grab data at the East Lynn Knock site showing the distribution of silty and sandy mixed habitats.

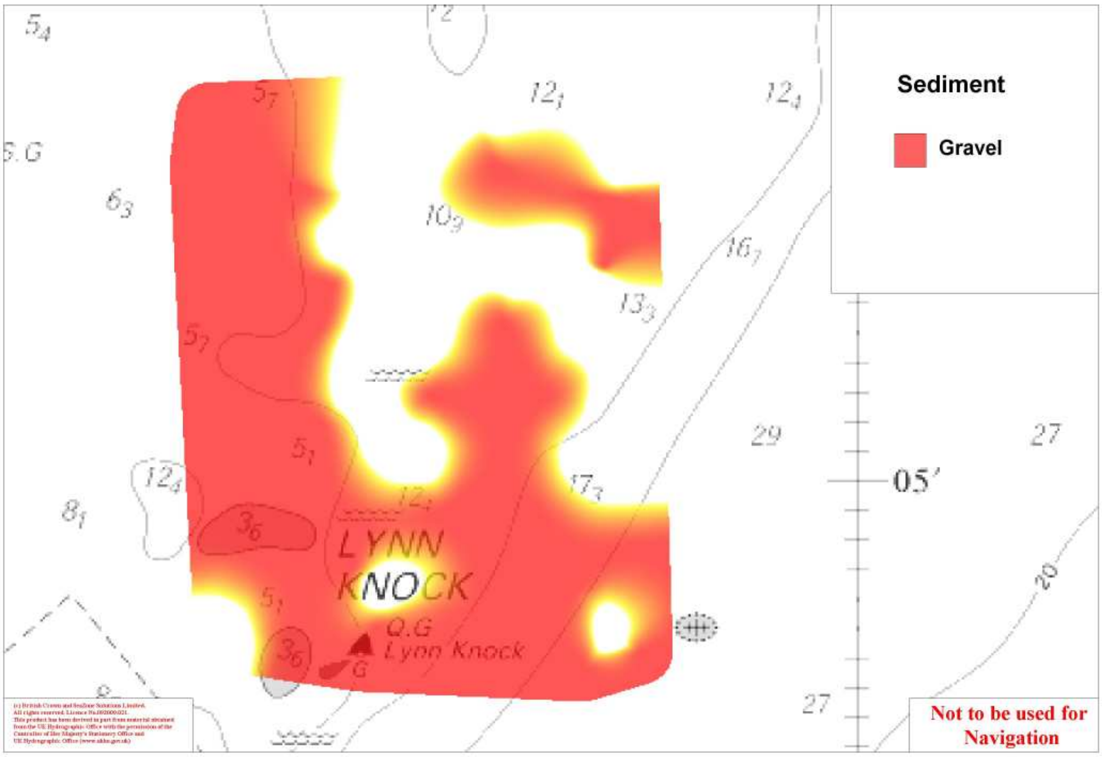


Figure 5.9 Interpolated model from the Day grab data at the East Lynn Knock site showing the distribution of gravel habitats.

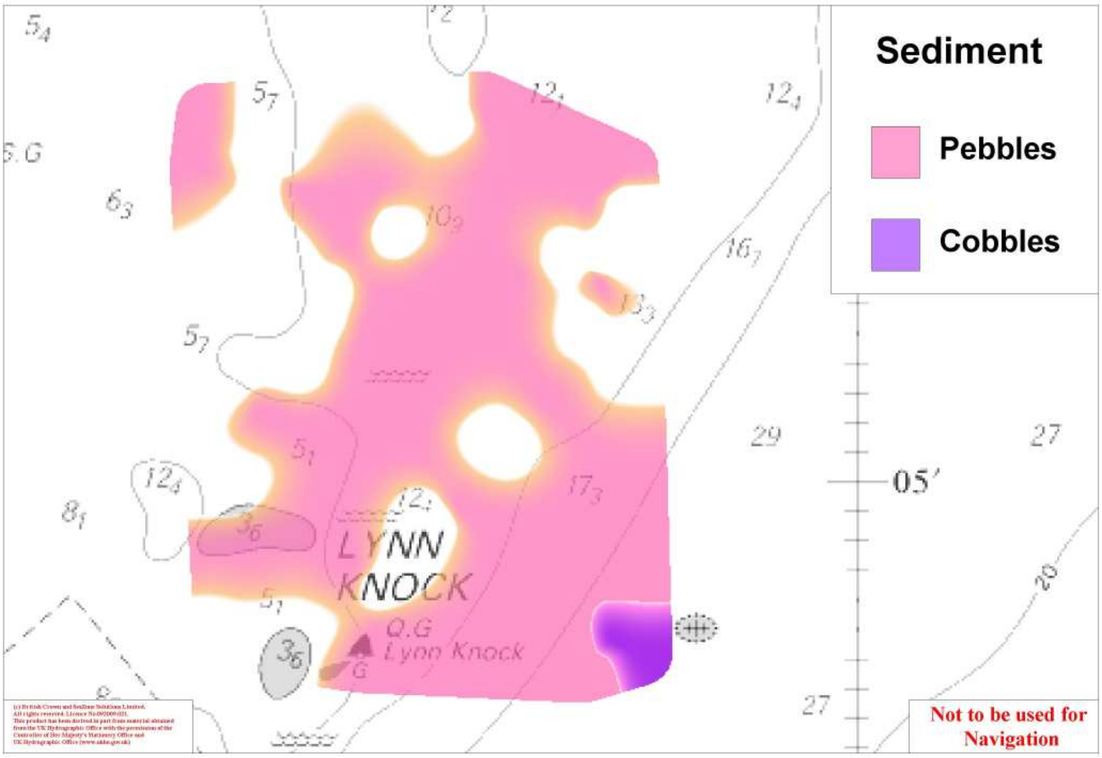


Figure 5.10 Interpolated model from the Day grab data at the East Lynn Knock site showing the distribution of pebble and cobble habitats.

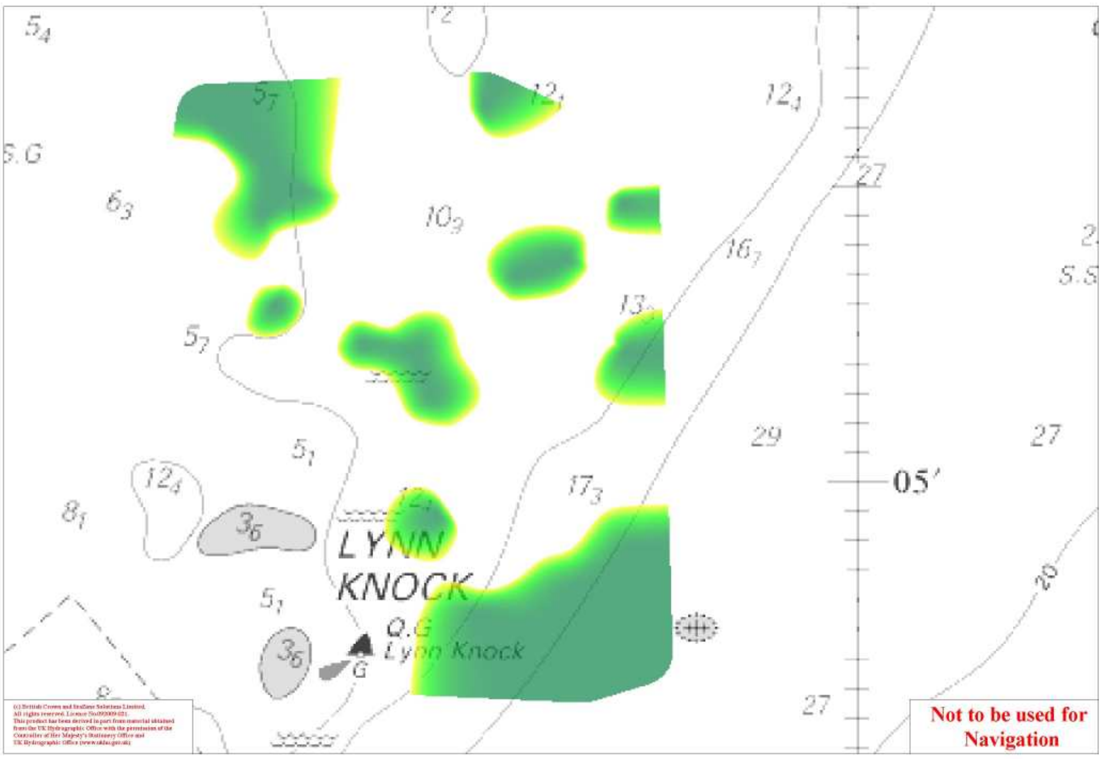


Figure 5.11 Interpolated model from the Day grab data at the East Lynn Knock site showing the distribution of faunal turf.

5.3.3 East Dogs Head

Unlike the other Wash sites monitored during the 2010 survey programme, which had used a semi-stratified sampling pattern for ground truthing, the 78 sample stations at the East Dogs Head site were arranged in a regular grid pattern, with stations 400 metres apart (figure 5.12). These were situated at the same positions as those used during the Phase-1 stage of the 2009 surveys. Of these stations, 2 were in positions that had supported medium reef in 2009, 16 were in areas of low reef and the remaining 60 were in areas that had not supported reef.

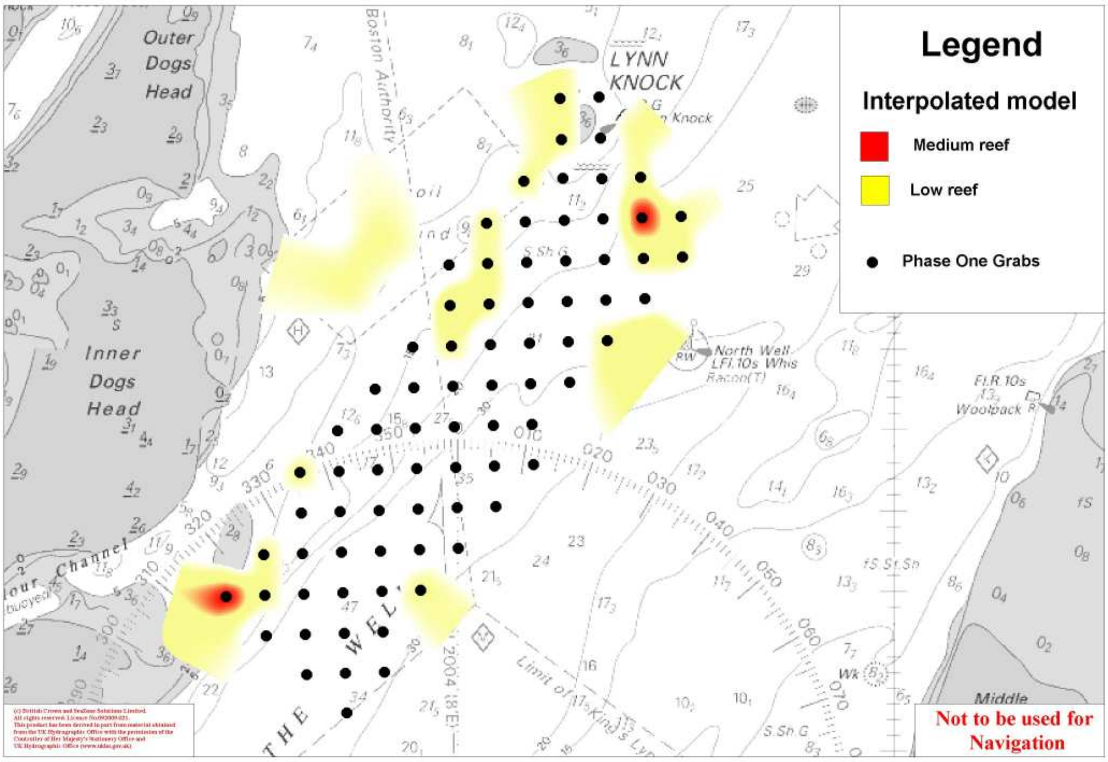


Figure 5.12 Chart showing the positions of the Phase-1 survey stations at the East Dogs Head site, overlaid with an interpolated model of *Sabellaria spinulosa* reefs derived from the 2009 survey data.

When sampled with a Day grab on April 22nd, 4 of the stations were found to support medium reef and 9 of the stations supported low reef. Additionally, with structures up to 12cm in height and a ground consolidation of 50%, 1 station was classed as supporting high reef. This was the only station identified during the 2010-survey programme classified as such. The data from this phase of sampling were interpolated using Vertical Mapper, creating a model of the *Sabellaria* distribution within the site, from which a further 22 sample stations were selected in order to map the edges of the identified reef features with more precision. These stations were sampled on April 23rd with a Day grab, their data being pooled with those from Phase-1 and re-interpolated using Vertical Mapper to create a model showing the predicted distribution of *Sabellaria* reef features (figure 5.13).

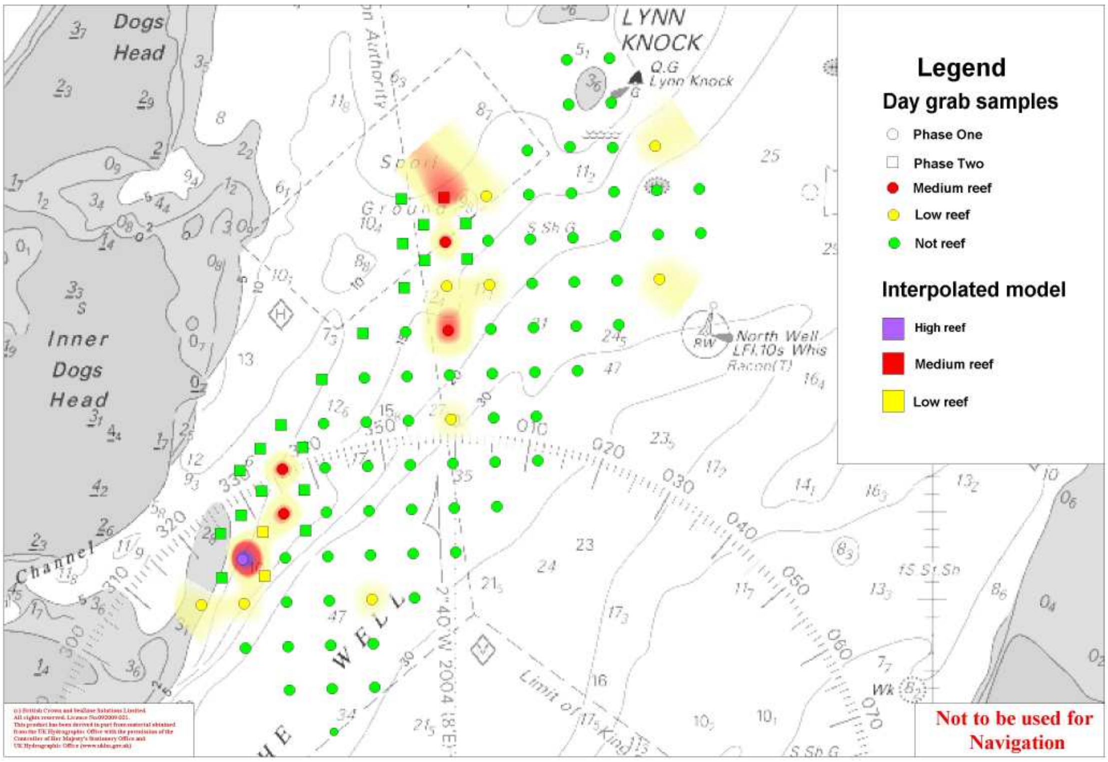


Figure 5.13 Interpolated model from the Day grab data at the East Dogs Head site (applying thresholds suggested in Gubbay, 2007), showing the predicted distribution of low and medium and high *Sabellaria* reef, overlaid with the positions of the Day grab sample stations (Phases 1& 2).

The interpolated model of the ground-truth data indicated that the East Dogshead site supported 1 area of high reef, covering 2.7 hectares. There were 6 areas of medium reef, covering 21.0 hectares, 2.3 hectares, 9.7 hectares, 3.2 hectares, 3.7 hectares and 8.2 hectares; a total area of 48.1 hectares. In addition the site supported 256.8 hectares of low reef. When compared with figures from the 2009 survey, the coverage of high and medium quality reef was found to have increased from 30.2 hectares, but the coverage of low reef had declined from 679 hectares. Comparison of figures 5.12 and 5.13 show that much of this decline had occurred in the north western part of the site, but can be partially attributed to an area to the north west of the site that had supported low reef in 2009, but had fallen outside of the 2010 survey area.

On August 5th three ROV video camera drops were conducted as part of the Phase-3 ground truthing of the East Dogs Head site. Although these were positioned over areas the Day grab surveys had identified as supporting high and medium reef structures, barring the occasional isolated clump of *Sabellaria*, none of the videos found evidence of any significant reef structures. Some of the *Sabellaria* clumps found in the grab samples from these areas had been over 10cm in height. It is unlikely, therefore, that reef of this height would have naturally degraded in the four-month period separating the two surveys. The video footage did show the substrate to be composed of coarse sand, however, so it is possible that if the sand in this area is relatively mobile, the *Sabellaria* structures might be subject to regular burial.

Additional sediment data were also collected from each of the ground-truth stations within the East Dogshead site. These data were interpolated using Vertical Mapper to produce models showing the distribution of the sediment within the site (figures 5.14 & 5.15). Unlike the West and East Lynn Knock sites, in which gravel was a constituent part of the sediment throughout both areas, figure 5.15 shows that gravel is not universally present throughout the Dogshead site, being absent through the central region of the site. In this area the sediment was considered to fall under the EUNIS habitat classifications A5.25 – Circalittoral fine sand (JNCC code – SS.SSa.CFiSa) and A5.26 – Circalittoral muddy sand (JNCC code – SS.SSa.CMuSa).

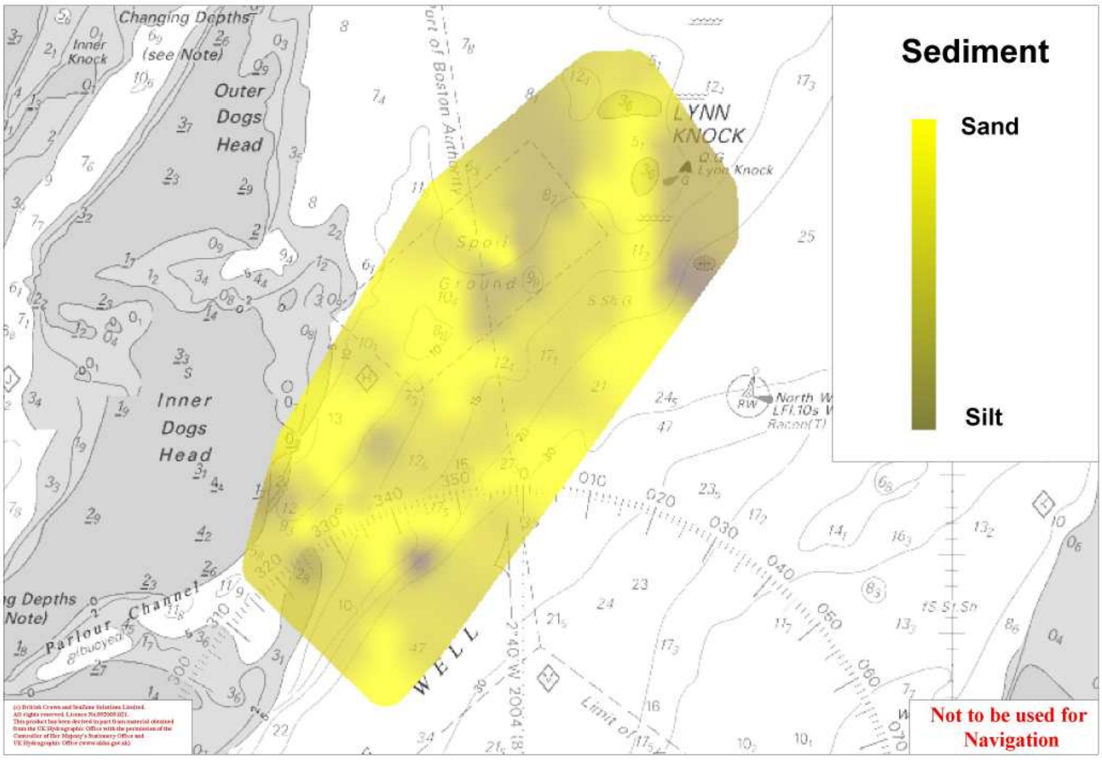


Figure 5.14 Interpolated model from the Day grab data at the East Dogs Head site showing the distribution of sand and silty sediments.

From the interpolated models showing the distribution of the larger sediments, gravel was calculated to be present over 1,391 hectares, representing 61% of the site. Pebbles were calculated to cover 591 hectares (26% of the site) and cobbles 71 hectares (3% of the site). These areas were considered to fall under the EUNIS habitat classification A5.44 – Circalittoral mixed sediments (JNCC code – SS.SMx.CMx).

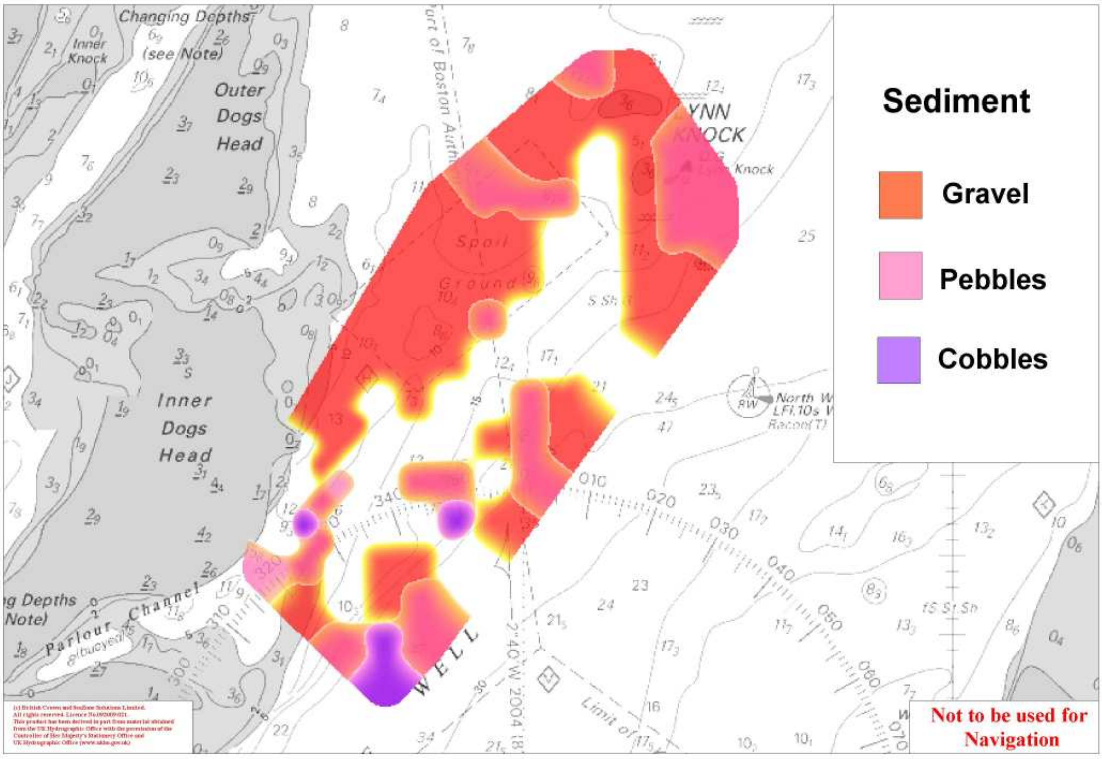


Figure 5.15 Interpolated model from the Day grab data at the East Dogs Head site showing the distribution of gravel, pebble and cobble habitats.

Analysis of the East Dogs Head data found a strong correlation between the distribution of the gravel and pebble sediments and the distribution of Sabellaria reef. Of the 17 stations found to support reef structures, 16 were situated at locations where either gravel, pebbles or cobbles were present.

5.3.4 Seal Sand

49 sample stations were selected in a semi-stratified pattern for the first phase of ground truthing at the Seal Sand site, using a model of *Sabellaria* reef distribution derived from 2009 survey data (figure 5.16). 18 of the sample stations were positioned in locations predicted from the model to have supported reef in 2009, and the 31 stations in areas predicted to not support reef structures. These stations were sampled on August 6th using a Day grab. During this survey 3 stations were found to support medium reef and 3 were found to support low reef. Three of these stations found to support reef were from areas predicted to support reef. As with the other sites, the data from this survey was interpolated using Vertical Mapper in order to create a model showing the distribution of *Sabellaria* reef features. Using this model a further 5 stations were selected in order to map the edges of the identified reef features with more precision. These 5 stations were sampled on August 6th using a Day grab, their data being pooled with those from Phase-1 and re-interpolated using Vertical Mapper to create a model showing the predicted distribution of *Sabellaria* reef features (figure 5.17).

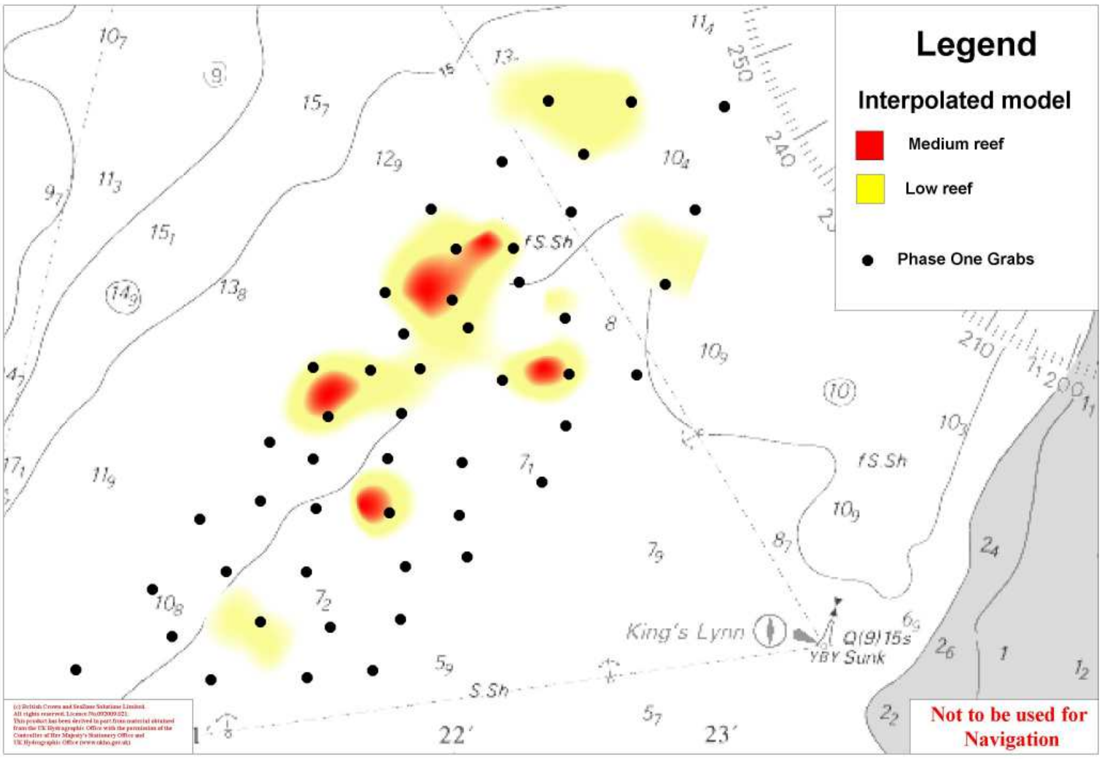


Figure 5.16 Chart showing the positions of the Phase-1 survey stations at the Seal Sand site, overlaid with an interpolated model of *Sabellaria spinulosa* reefs derived from the 2009 survey data.

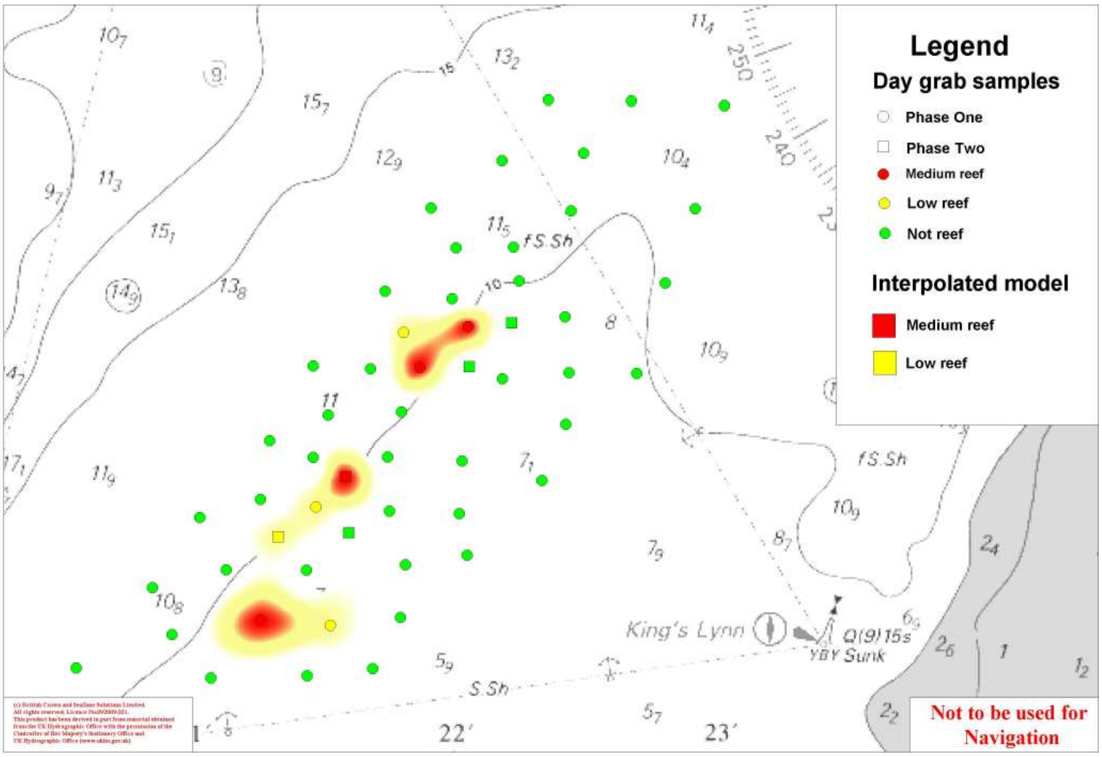


Figure 5.17 Interpolated model from the Day grab data at the Seal Sand site (applying thresholds suggested in Gubbay, 2007), showing the predicted distribution of low and medium *Sabellaria* reef, overlaid with the positions of the Day grab sample stations (Phases 1& 2).

The surveys identified three discrete patches of medium reef to be present at the Seal Sand site. These have been estimated to cover areas of 3.6 hectares, 1.6 hectares and 3.6 hectares; an overall area of 8.8 hectares. A further 29.2 hectares were found to support low reef. These figures indicate the reef has declined at this site since the 2009 survey, when 13.1 hectares supported medium reef and 82.2 hectares supported low reef. This decline could be explained by the low tube occupancy that had been recorded during both the 2009 and 2010 surveys at this site. With few worms occupying and maintaining the tubes, the reef structures are gradually decaying.

Additional sediment data collected from each of the ground-truth stations were interpolated to create models depicting the distribution of sediment in the area (figures 5.18 & 5.19). In the shallower regions on the eastern side of the site, the sediment was found to be composed of a mixture of silty and sandy gravel and pebbles. On the western side of the site, where the water was generally deeper, the sediment was found to be a mixture of silty sands, with less evidence of larger particles being present. Unlike the East Dogs Head site, where there had been a strong correlation between the presence of larger particles and *Sabellaria* structures, at the Seal Sand site the reverse appeared to be the case. Although 57% of the stations contained gravel-sized or larger particles, only 25% of the stations found to contain *Sabellaria* were in these areas.

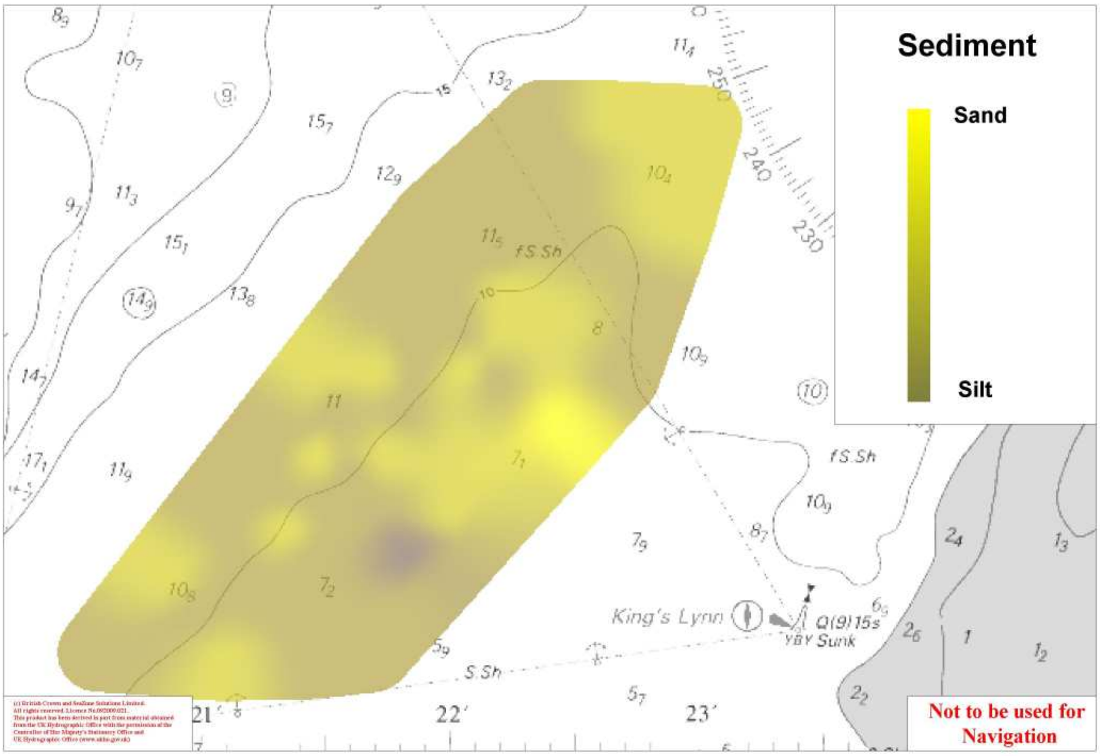


Figure 5.18 Interpolated model from the Day grab data at the Seal Sand site showing the distribution of sand and silty sediments.

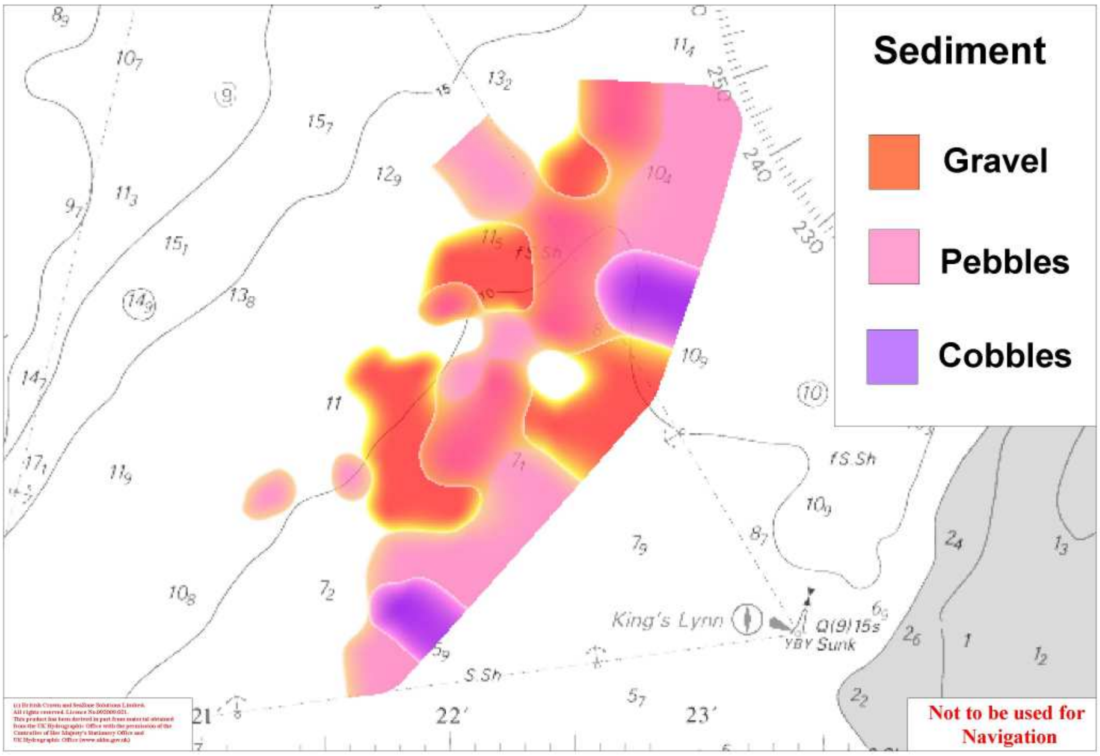


Figure 5.19 Interpolated model from the Day grab data at the Seal Sand site showing the distribution of gravel, pebble and cobble habitats.

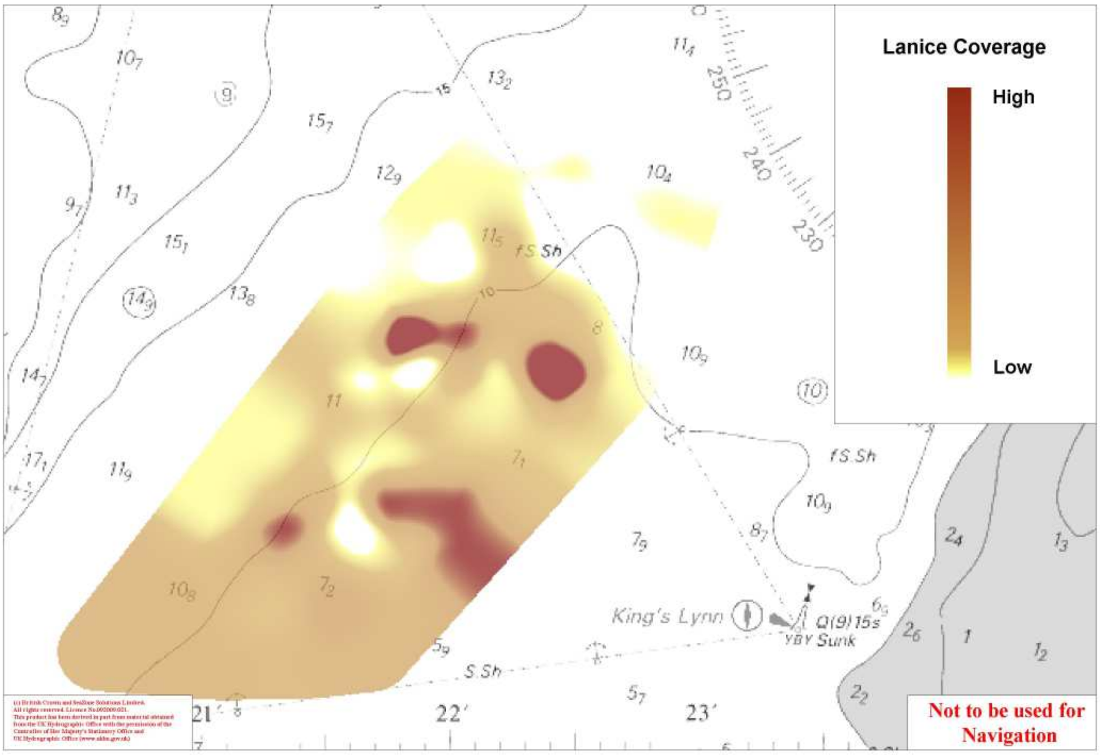


Figure 5.20 Interpolated model from the Day grab data at the Seal Sand site showing the distribution of *Lanice concheliga.*

During the surveys 46 (85%) of the ground truth stations were found to support *Lanice concheliga*. When these data were interpolated, *Lanice concheliga* were found to cover 340 hectares, representing 78% of the area of the site (figure 5.20). These figures indicate that within the Seal Sand site the distribution of *Lanice concheliga* had increased since 2009, when the coverage was estimated to be 246 hectares (57% of the area of the site). The areas conformed with the EUNIS habitat classification A5.137 – Dense (*Lanice concheliga*) and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (JNCC code – SS.SCS.ICS.SLan). Where neither *Lanice concheliga* or larger particles were present, the habitats were classified as either A5.23 - Infralittoral fine sand (JNCC code – SS.SSa.IFiSa) or A5.24 - Infralittoral muddy sand (JNCC code – SS.SSa.IMuSa). In areas where *Lanice concheliga* was not present, but the sediment contained gravel-sized or larger particles, the habitat was classified as A5.43 – Infralittoral mixed sediments (JNCC code – SS.SMx.IMx).

5.3.5 South Well

Because the 2009 survey had identified only a small amount of reef within the South Well site, when it came to assigning ground truth stations for the 2010 survey, a regular grid pattern was used rather than a semi-stratified pattern (figure 5.21). The first phase of ground-truthing, comprised of 49 Day grab samples, was conducted on July 22nd.

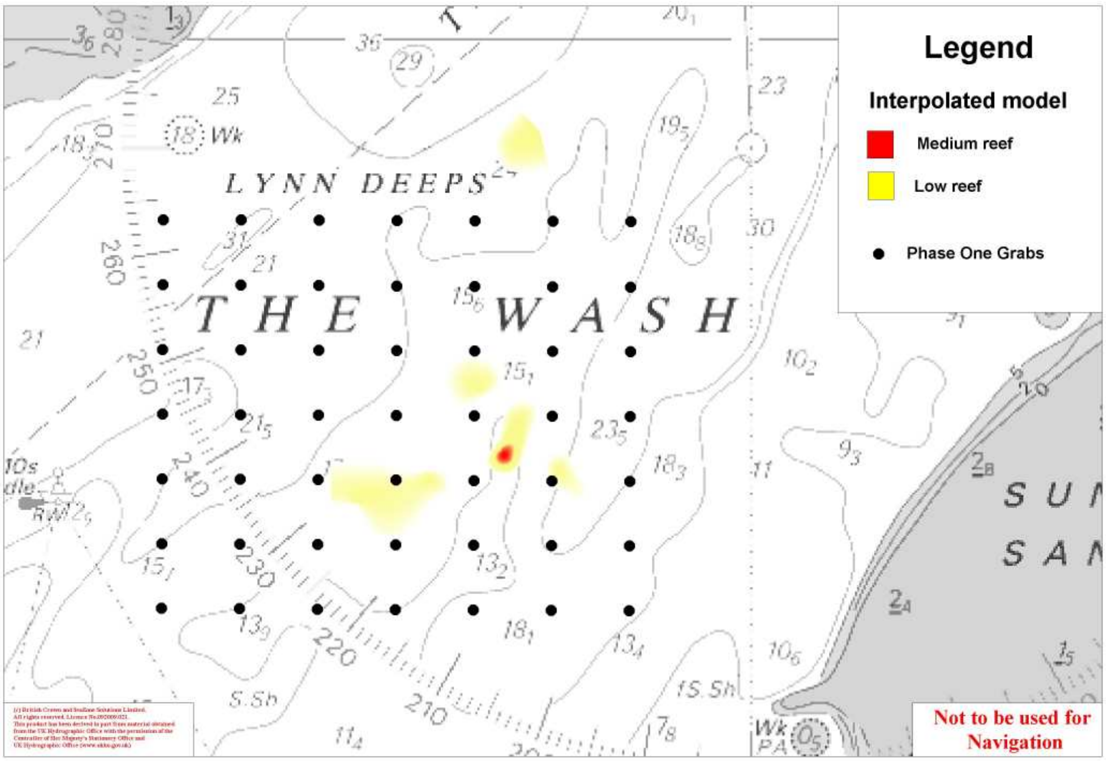


Figure 5.21 Chart showing the positions of the Phase-1 survey stations at the South Well site, overlaid with an interpolated model of *Sabellaria spinulosa* reefs derived from the 2009 survey data.

When sampled, 5 of the stations were found to support medium reef and 3 supported low reef. The data from this phase of sampling were interpolated using Vertical Mapper, from which a model was created showing the predicted distribution of *Sabellaria* reef across the site. This model was then used to inform the positioning of a further 25 sample stations. These Phase-2 stations were sampled with a Day grab on July 30th, their data being pooled with those from Phase-1 and re-interpolated using Vertical Mapper to create a model showing the predicted distribution of *Sabellaria* reef features (figure 5.22).

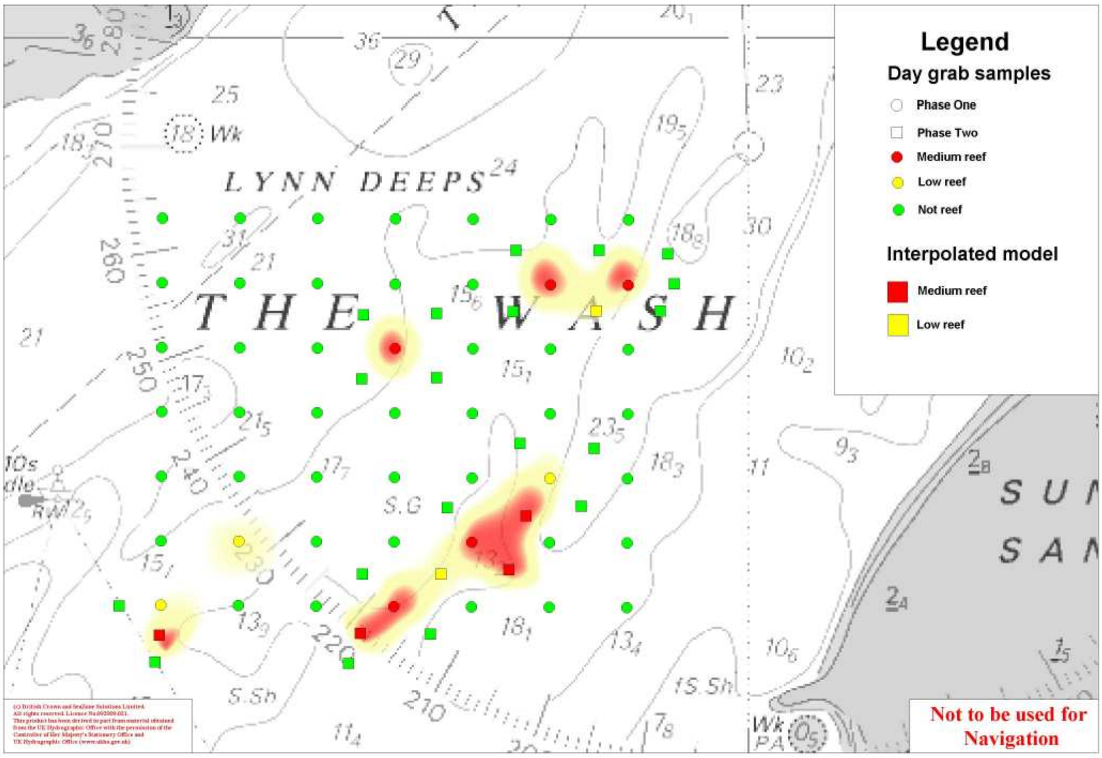


Figure 5.22 Interpolated model from the Day grab data at the South Well site (applying thresholds suggested in Gubbay, 2007), showing the predicted distribution of low and medium *Sabellaria* reef, overlaid with the positions of the Day grab sample stations (Phases 1 & 2).

The interpolated model indicted the South Well site supported six discrete patches of medium reef. These were estimated to cover 4.3 hectares, 5.8 hectares 4.0 hectares, 23.6 hectares 9.5 hectares and 2.1 hectares; a total area of 49.3 hectares. A further 124.7 hectares were found to support low reef. These figures indicate there has been a significant increase to the *Sabellaria* distribution in this area, compared to the 1.2 hectares of medium reef and 51.4 hectares of low reef identified during the 2009 surveys. The data collected during these surveys was also interpolated in order to create models showing the distribution of sediment across the site (figure 5.23 & 5.24). Across most of the area, the substratum was composed of silty or sandy gravel or pebbles, conforming with the EUNIS habitat classification A5.44 – Circalittoral mixed sediments (JNCC code – SS.SMx.CMx). In places along the eastern edge of the site, where larger particles were not present, the habitats were classified as A5.25 – Circalittoral fine sand (JNCC code – SS.SSa.CFiSa) and A5.26 – Circalittoral muddy sand (JNCC code – SS.SSa.CMuSa).

Figure 5.23 Interpolated model from the Day grab data at the South Well site showing the distribution of sand and silty sediments.

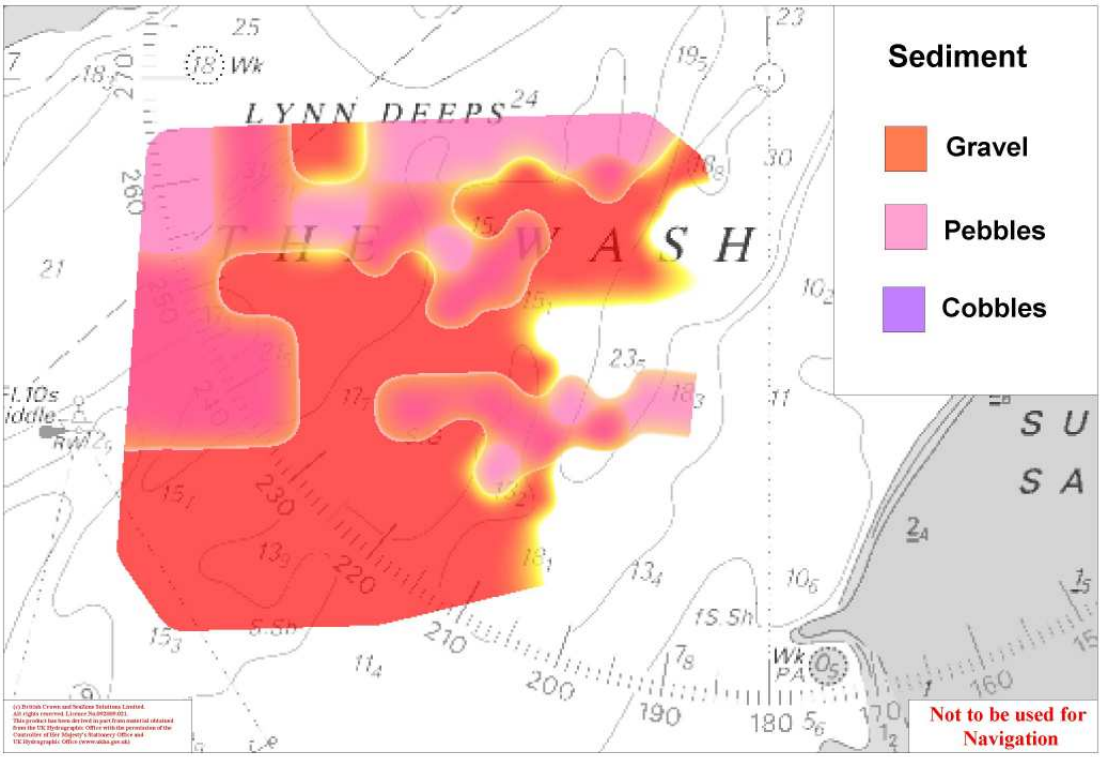


Figure 5.24 Interpolated model from the Day grab data at the South Well site showing the distribution of gravel, pebble and cobble habitats.

9 of the 74 stations sampled during the first two phases of ground truthing were found to support a faunal turf composed mainly of hydroids and/or the bryozoan, *Flustra foliacea* (see figure 5.25). This habitat was estimated to cover 159 hectares (approximately 13% of the site) and was consistent with the EUNIS classification A5.444 – *Flustra foliacea* and *Hydrallmania falcata* on tide-swept circalittoral mixed sediment (JNCC code – SS.SMx.CMx.FluHyd).

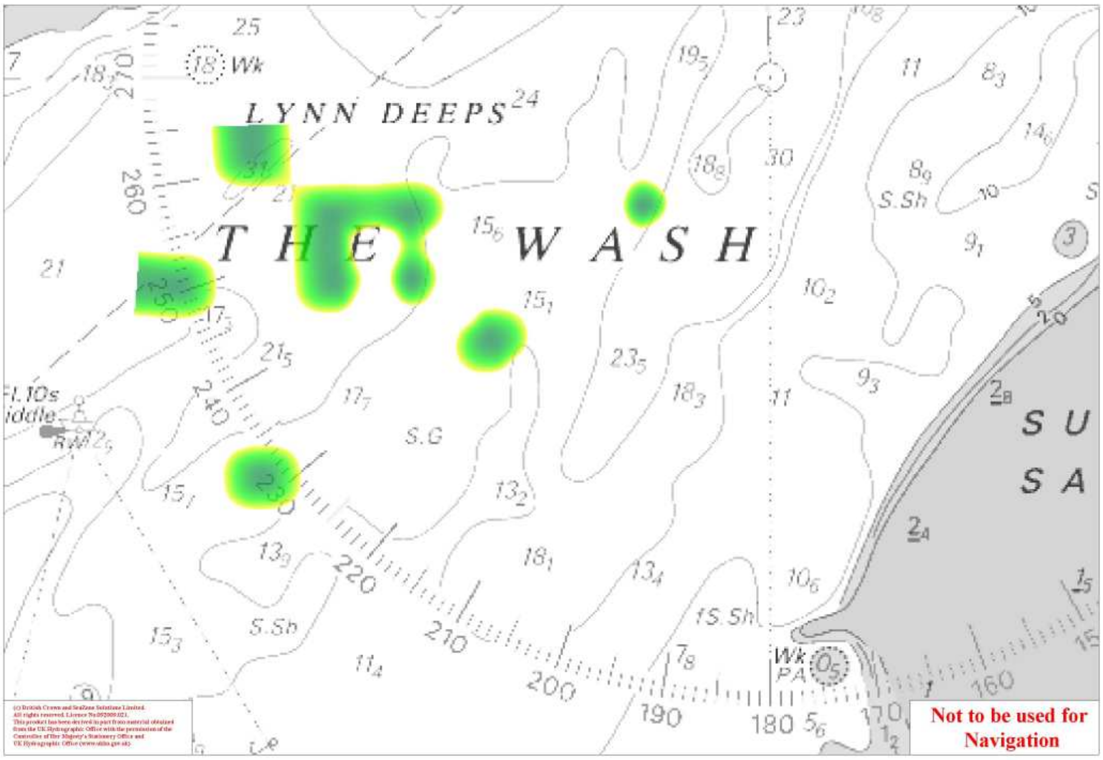


Figure 5.25 Interpolated model from the Day grab data at the South Well site showing the distribution of faunal turf.

5.3.6 West of Wind Farm

A Roxann™ AGDS survey was conducted at this site on September 22nd, during which 14 parallel tracks were carried out. These tracks, spaced approximately 150-200 metres apart, covered a distance of 110km and an area of 2,068 hectares. Electrical interference from an earth fault on one of *RV Three Counties'* engine starter motors had caused the Roxann™ unit to malfunction during the latter half of 2009. This fault had been rectified in time to conduct the 2010 surveys, but although the E2 values representing the hardness of the ground appeared to be discriminating correctly, the E1 values representing the roughness of the ground were returning very low discrimination values. As a consequence, only the E2 – hardness values were used to inform the positioning of the Phase-1 ground truth sample station sites. To inform the positioning of these stations, the track data were interpolated using Vertical Mapper software, in order to create a model showing the relative hardness of the ground.

Positions were then selected that would reflect various fields of hardness values identified by the model (figure 5.26).

The first phase of ground truthing was initially delayed by several months due to poor weather, until it was eventually possible to conduct sampling on January 13th 2011. 80 stations were sampled during this phase, 9 stations from which were found to support low *Sabellaria* reef features. The data from these samples were interpolated using Vertical Mapper, from which a model was created showing the distribution of these features. This model was then used to inform the positioning of a further 12 sample stations, aimed at mapping the edges of the identified reef features with more precision. These additional stations were also sampled on January 13th, their data being pooled with those from Phase-1 and re-interpolated using Vertical Mapper to create a model showing the predicted distribution of *Sabellaria* reef features (figure 5.27).

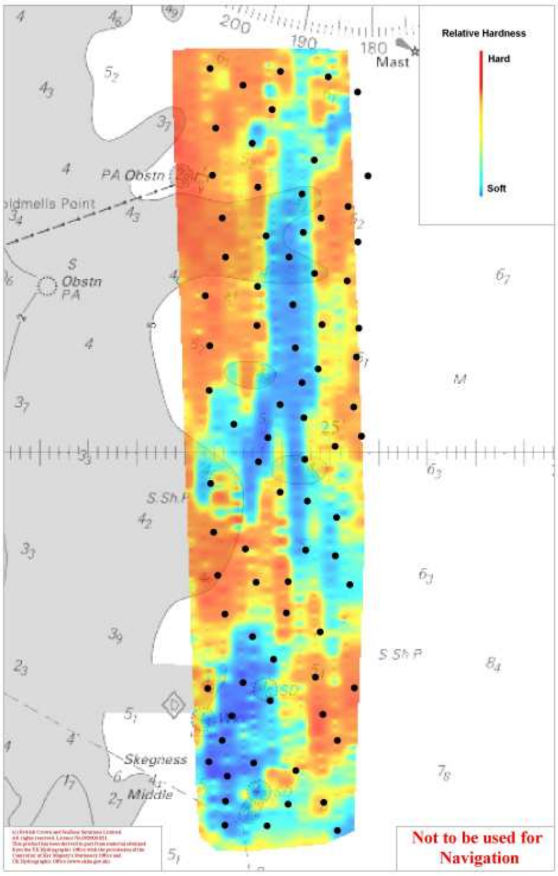


Figure 5.26 Interpolated model of the Roxann track data at the West of Wind Farm site, showing the relative hardness of the ground, overlaid with the Phase-1 ground truth stations.

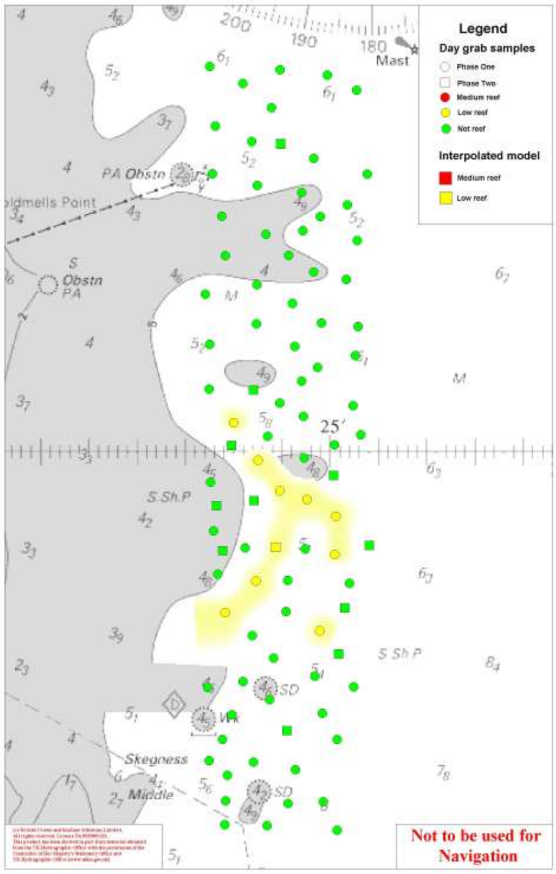


Figure 5.27 Interpolated model from the Day grab data at the South Well site (applying thresholds suggested in Gubbay, 2007), showing the predicted distribution of low and medium *Sabellaria* reef, overlaid with the positions of the Day grab sample stations (Phases 1 & 2).

During the survey of the West of Wind Farm site, no medium reef was identified. The area, however, was found to support 159.6 hectares of low reef, situated mainly in the southern half of the site. In the northern half of the site, in an area that had been predicted from the ground hardness model as potentially supporting reef features, a bed of sublittoral mussel seed was found (see Section 2 – Wash Mussel stocks, figure 2.50).

The sediment data collected from this survey was interpolated using Vertical Mapper, from which models depicting the substratum of the site was created (figures 5.28 & 5.29).

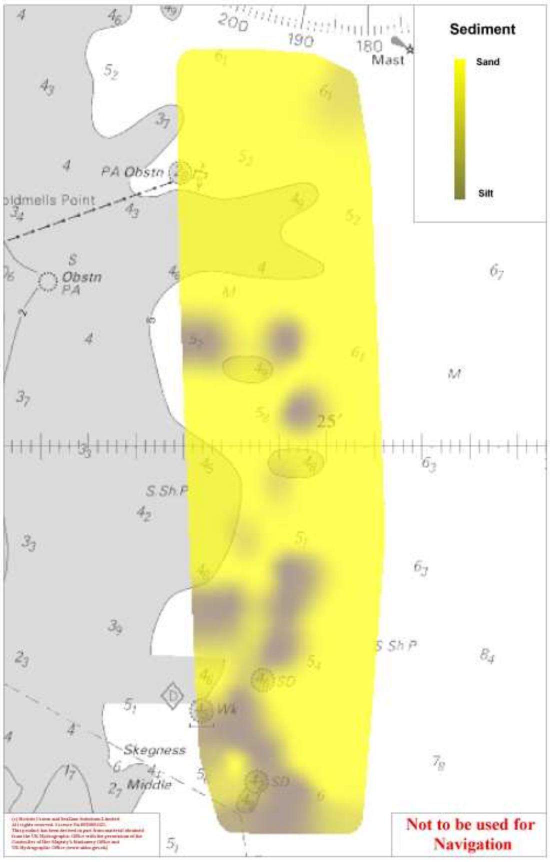


Figure 5.28 Interpolated model from the Day grab data at the West of Wind Farm site showing the distribution of sand and silty sediments

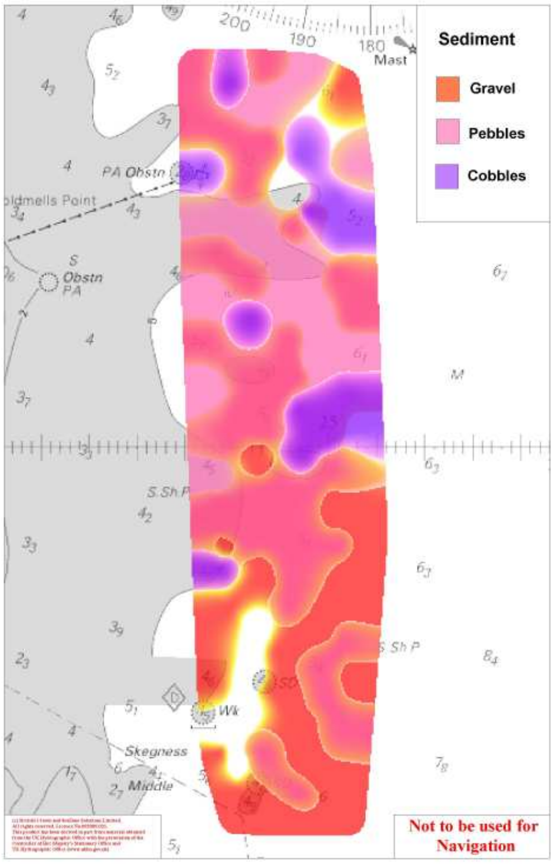


Figure 5.29 Interpolated model from the Day grab data at the West of Wind Farm site showing the distribution of gravel, pebble and cobble habitats.

These models show the substratum within this area to be composed mainly of silty or sandy gravel or pebbles, consistent with the EUNIS habitat classification A5.44 – Circalittoral mixed sediments (JNCC code – SS.SMx.CMx). In places, where the substratum was composed of mainly of larger particles, the habitat was described under the EUNIS classification as being A5.14 Circalittoral coarse sediment (JNCC code – SS.SCS.CCS).

5.3.7 South West of Wind Farm

A Roxann™ AGDS survey was conducted at this site on August 3rd, using the equipment aboard the patrol vessel *Protector III*. During this survey 10 parallel tracks spaced approximately 200-250 metres apart were carried out, covering a distance of 45km. Data collected during this survey were interpolated using Vertical Mapper to create models depicting the hardness and roughness of the ground. The model depicting hardness was then used to inform the semi-stratified positioning of 64 Phase-1 ground truth stations (figure 5.30).

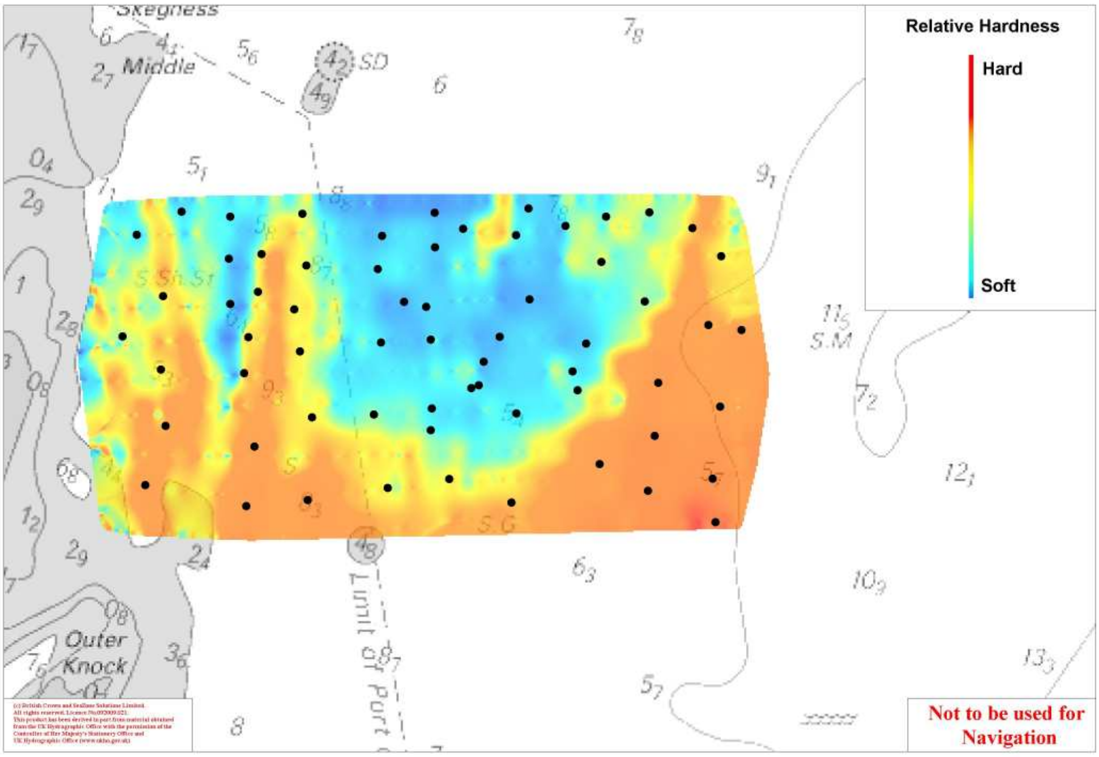


Figure 5.30 Interpolated model of the Roxann track data at the South West of Wind Farm site, showing the relative hardness of the ground, overlaid with the Phase-1 ground truth stations.

These sites were sampled on November 15th, during which 1 station was found to support medium reef and 13 stations were found to support low reef. The data from these samples were interpolated using Vertical Mapper, from which a model was created showing the distribution of these features. This model was then used to inform the positioning of a further 14 sample stations, aimed at mapping the edges of the identified reef features with more precision. These additional stations were sampled on November 16th, the data from which were pooled with those from the Phase-1 sites and re-interpolated using Vertical Mapper to create a model showing the predicted distribution of *Sabellaria* reef features (figure 5.31).

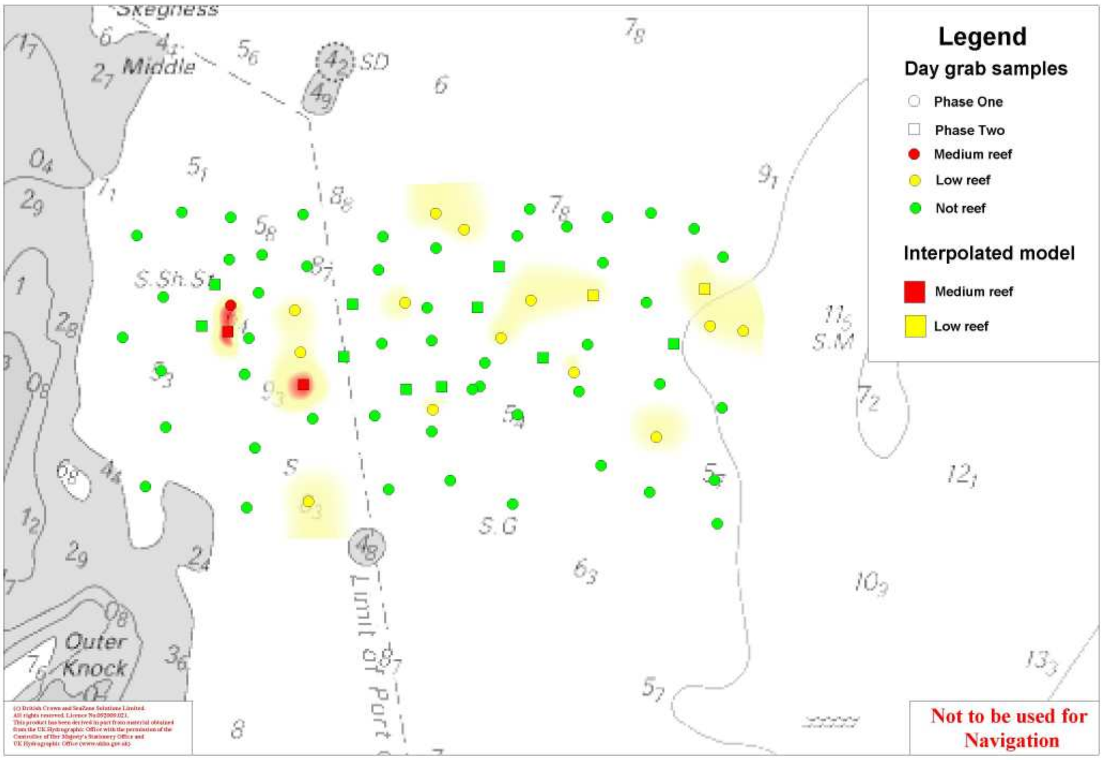


Figure 5.31 Interpolated model from the Day grab data at the South West of Wind Farm site (applying thresholds suggested in Gubbay, 2007), showing the predicted distribution of low and medium *Sabellaria* reef, overlaid with the positions of the Day grab sample stations (Phases 1 & 2).

The interpolated model of the South West of Wind Farm site indicated there were two discrete patches of medium reef within the area. These were estimated to cover 2.9 hectares and 3.2 hectares; a total area of 6.1 hectares. In addition 10 discrete patches of low reef within the area covered a total of 147.1 hectares.

Sediment data collected during the first two phases of ground truthing were also interpolated using Vertical Mapper in order to create models showing the substratum across the site (figures 5.32 & 5.33). These models showed that in most areas the substratum was composed of silty or sandy gravel or pebbles, conforming with the EUNIS habitat classification A5.44 – Circalittoral mixed sediments (JNCC code – SS.SMx.CMx). In some places where gravel-sized and larger particles were not present, the habitats were classified as being either A5.25 – Circalittoral fine sand (JNCC code – SS.SSa.CFiSa) or A5.26 – Circalittoral muddy sand (JNCC code – SS.SSa.CMuSa).

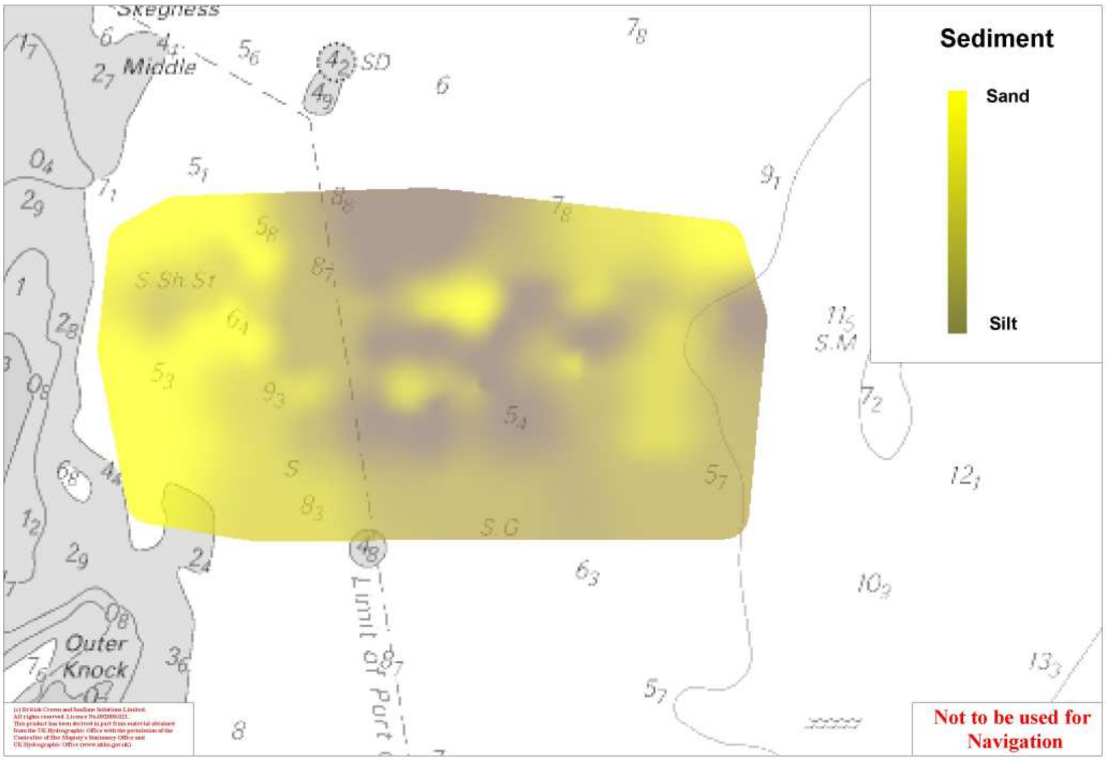


Figure 5.32 Interpolated model from the Day grab data at the South West of Wind Farm site showing the distribution of sand and silty sediments.

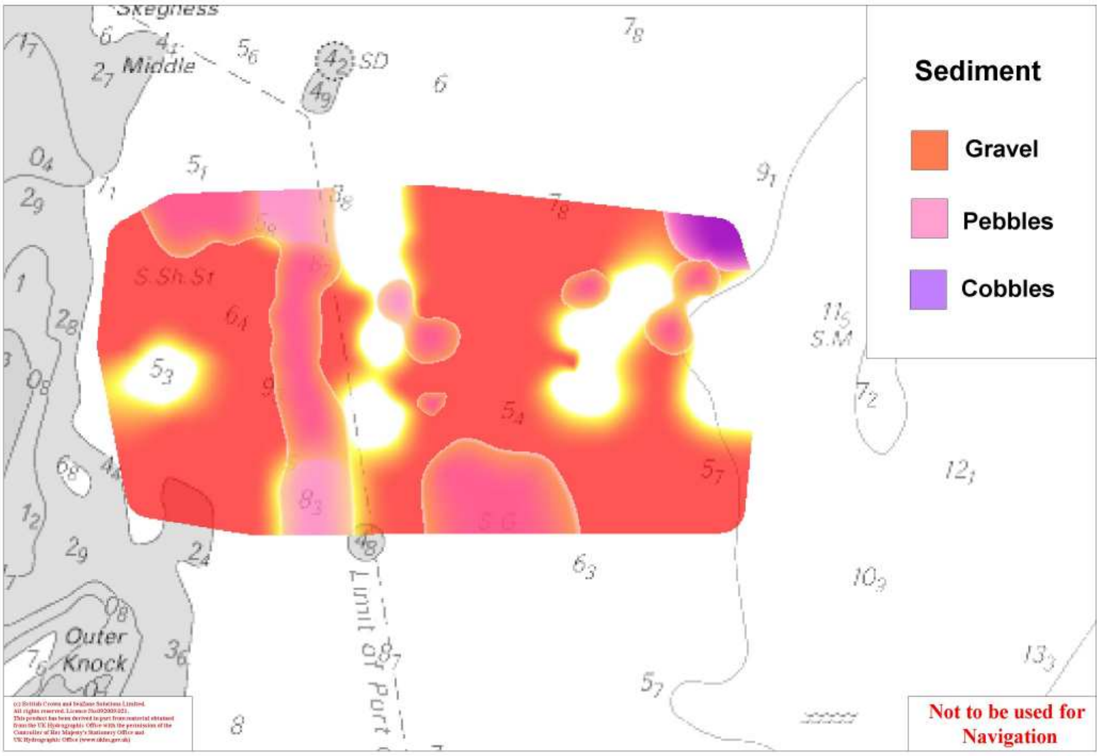


Figure 5.33 Interpolated model from the Day grab data at the South West of Wind Farm site showing the distribution of gravel, pebble and cobble habitats.

5.3.8 South East of Wind Farm

A Roxann™ AGDS survey was conducted at this site on September 21st, using the equipment aboard the research vessel *Three Counties*. During this survey 14 parallel tracks, spaced approximately 150-200 metres apart, were carried out covering a total distance of 60km. Data collected from these tracks were interpolated using Vertical Mapper to create models depicting the hardness and roughness of the ground. The model depicting hardness was then used to inform the semi-stratified positioning of 47 Phase-1 ground truth stations (figure 5.34).

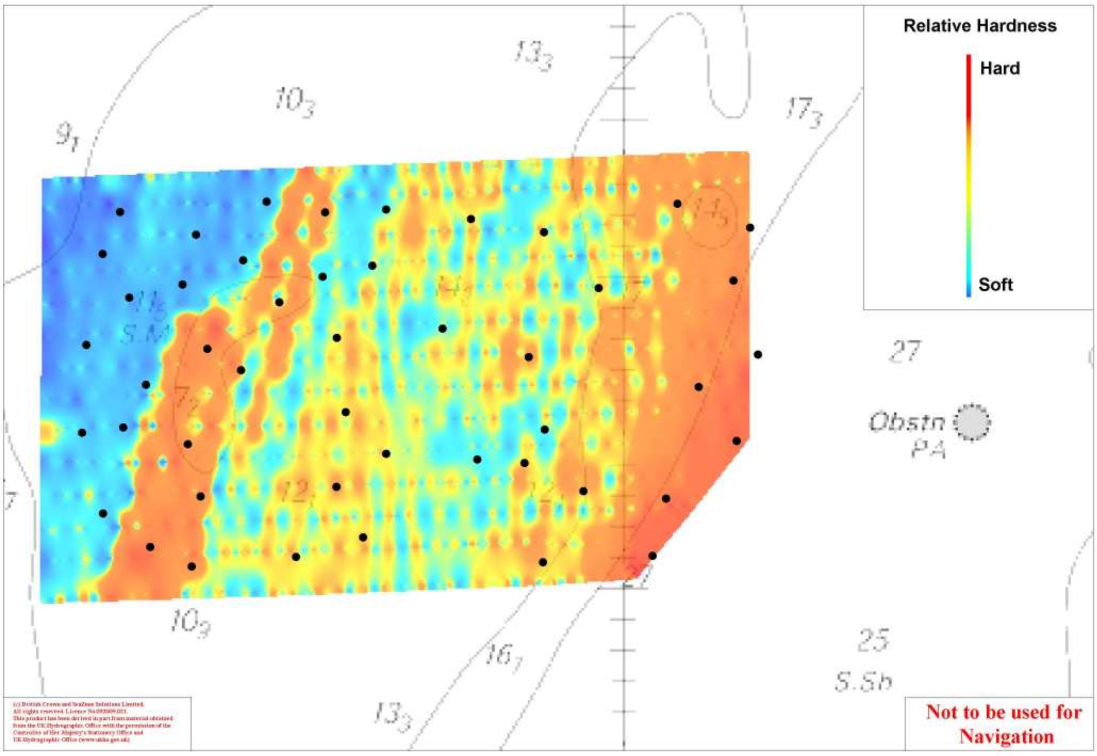


Figure 5.34 Interpolated model of the Roxann track data at the South East of Wind Farm site, showing the relative hardness of the ground, overlaid with the Phase-1 ground truth stations.

Poor weather prevented these stations from being sampled during 2010. When eventually sampled on January 12th 2011, 1 station was found to support medium reef, while 5 more supported low reef. The data from these samples were interpolated using Vertical Mapper, from which a model was created showing the distribution of the reef features. This model was then used to inform the positioning of a further 7 sample stations, aimed at mapping the edges of the identified reef features with more precision. These Phase-2 stations were sampled the following day, their data being pooled with those from the Phase-1 sites and re-interpolated to create a model showing the predicted distribution of *Sabellaria* reef features (figure 5.35).

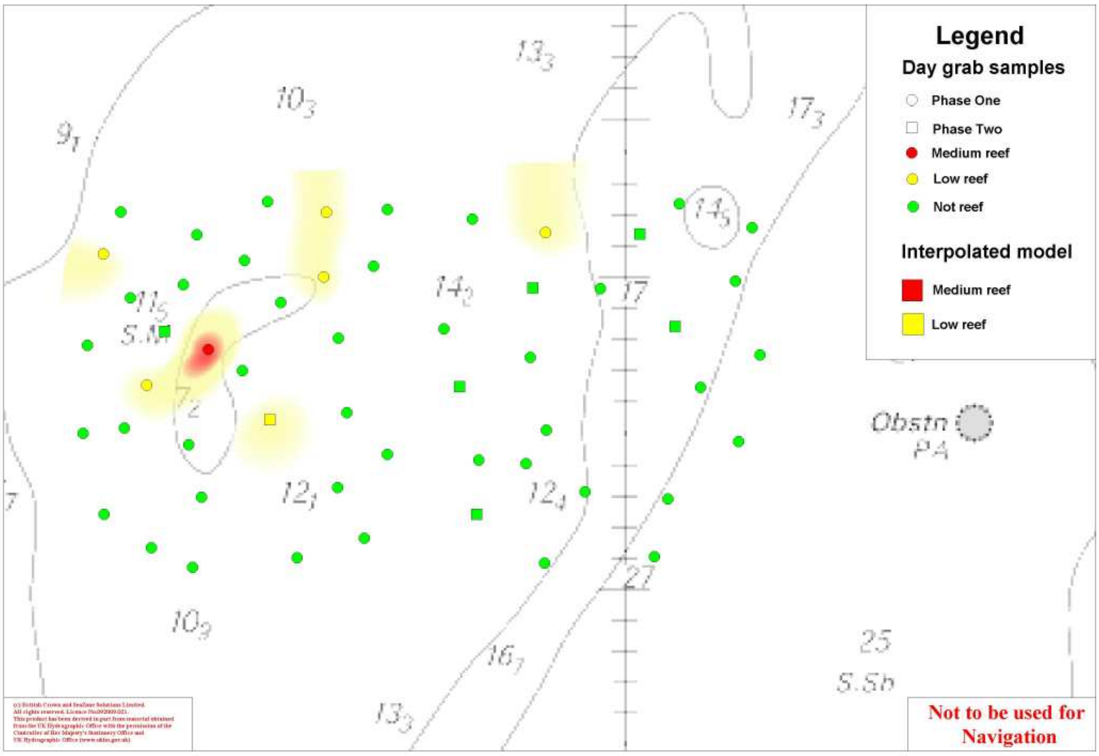


Figure 5.35 Interpolated model from the Day grab data at the South East of Wind Farm site (applying thresholds suggested in Gubbay, 2007), showing the predicted distribution of low and medium *Sabellaria* reef, overlaid with the positions of the Day grab sample stations (Phases 1 & 2).

Using the interpolated model, the South East of Wind Farm site was found to support a single area of medium reef with an estimated area of 4.7 hectares. In addition, 5 discrete areas of low reef were identified, covering a total area of 95.3 hectares.

The interpolated model of indicated there were two discrete patches of medium reef within the area. These were estimated to cover 2.9 hectares and 3.2 hectares; a total area of 6.1 hectares. In addition 10 discrete patches of low reef within the area covered a total of 147.1 hectares.

Sediment data collected during the first two phases of ground truthing were also interpolated using Vertical Mapper in order to create models showing the substratum across the site (figures 5.36 & 5.37). As had been the case with the neighbouring West of Wind Farm site, these models showed that in most areas the substratum was composed of silty or sandy gravel or pebbles, conforming with the EUNIS habitat classification A5.44 – Circalittoral mixed sediments (JNCC code – SS.SMx.CMx). In the north west of the site, where gravel-sized and larger particles were not present, the habitat was classified as being A5.26 – Circalittoral muddy sand (JNCC code – SS.SSa.CMuSa).

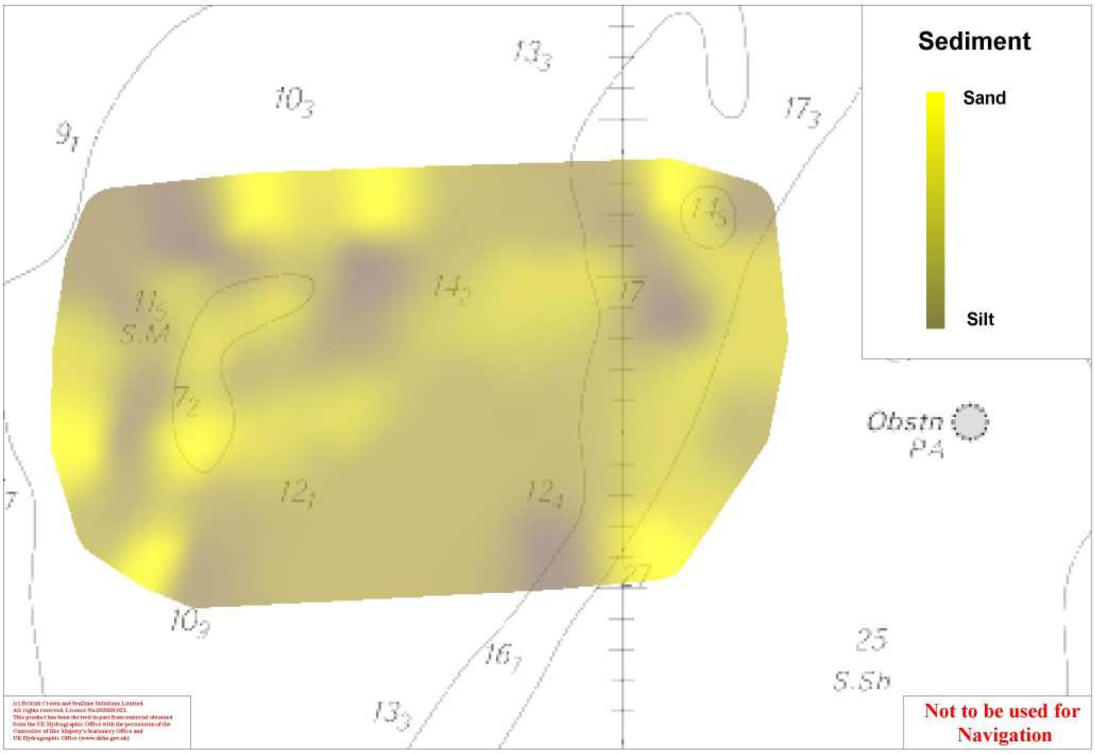


Figure 5.36 Interpolated model from the Day grab data at the South East of Wind Farm site showing the distribution of sand and silty sediments.

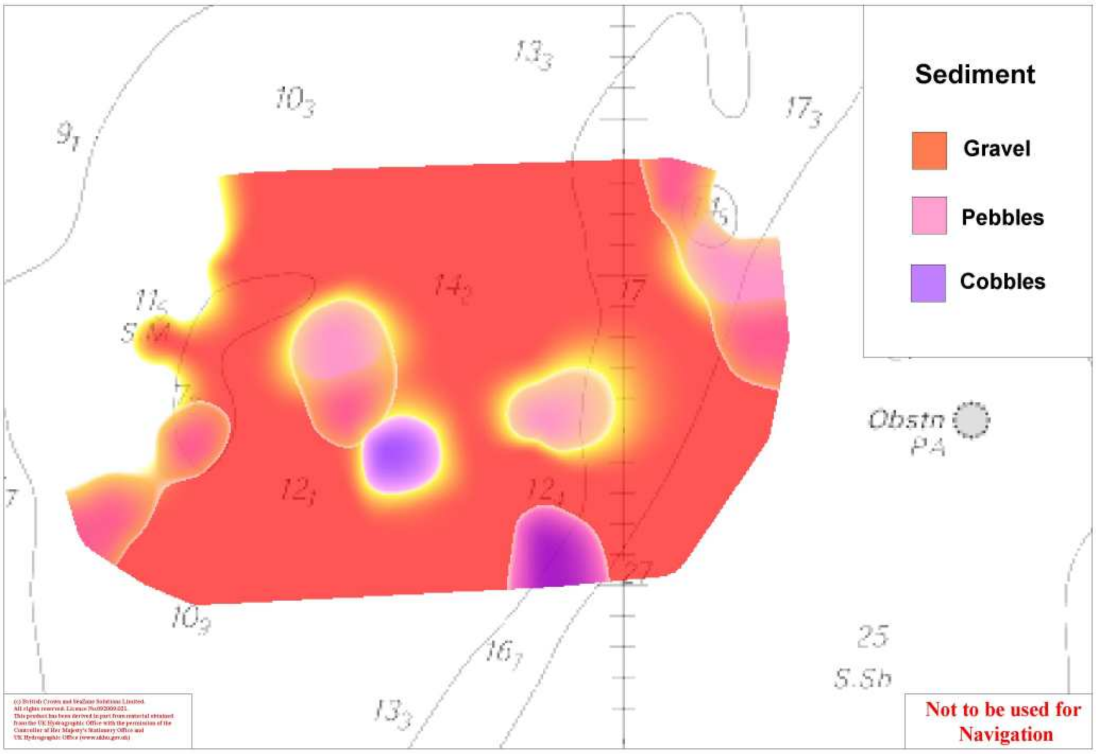


Figure 5.37 Interpolated model from the Day grab data at the South East of Wind Farm site showing the distribution of gravel, pebble and cobble habitats.

5.3.9 Between Wind Farms

26km of Roxann™ AGDS tracks were conducted at this site on September 22nd by the research vessel *Three Counties.* During this survey 10 parallel tracks, spaced 150-200 metres apart were carried out, covering an area of approximately 527 hectares. Data collected during this survey were interpolated using Vertical Mapper from which a model depicting the relative hardness of the ground across the site was created. This model was then used to inform the semi-stratified positioning of 33 Phase-1 ground truth stations (figure 5.38).

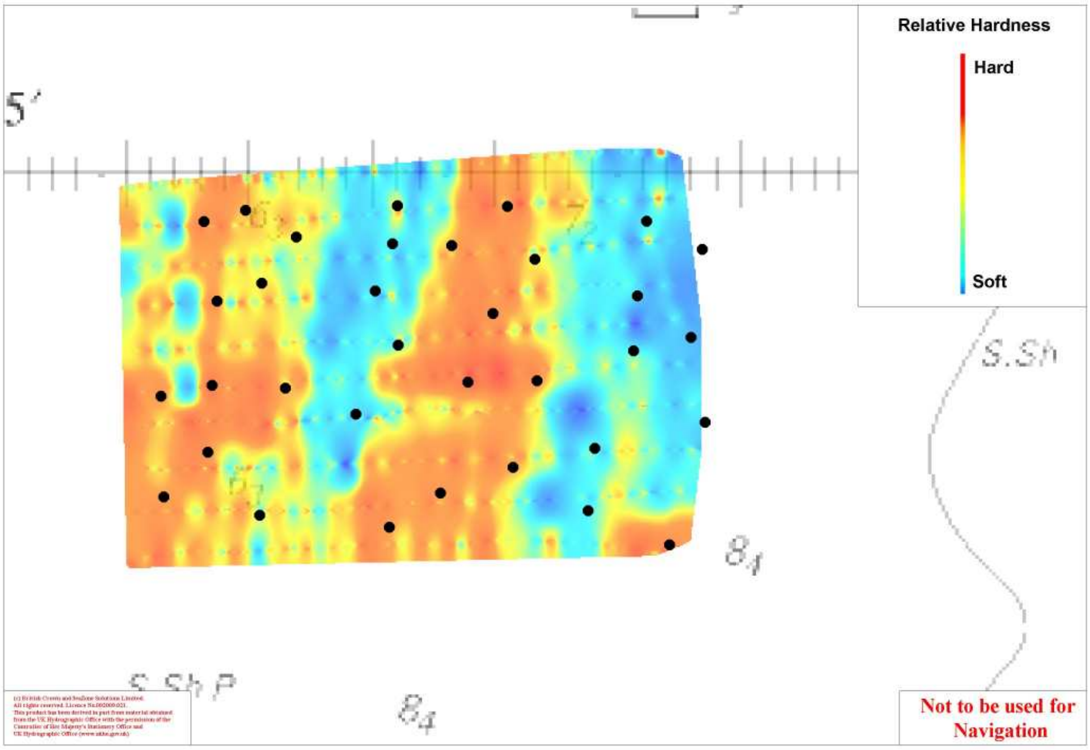


Figure 5.38 Interpolated model of the Roxann track data at Between Wind Farms site, showing the relative hardness of the ground, overlaid with the Phase-1 ground truth stations.

Poor weather delayed the sampling of these stations until February 9th 2011, when only 4 stations were found to support low reef. The data from these samples were interpolated, creating a model depicting the distribution of these features. Limited time availability did not permit an extensive second phase of ground truthing to be conducted at this site, but the model was tested with a further Day grab and ROV video camera drop over one area of identified reef. Data from this additional site was pooled with those from the first phase of ground truthing, and re-interpolated to create a model showing the predicted distribution of *Sabellaria* reef features (figure 5.39). The two areas of low reef identified during this survey were estimated to have a coverage of 36.6 hectares.

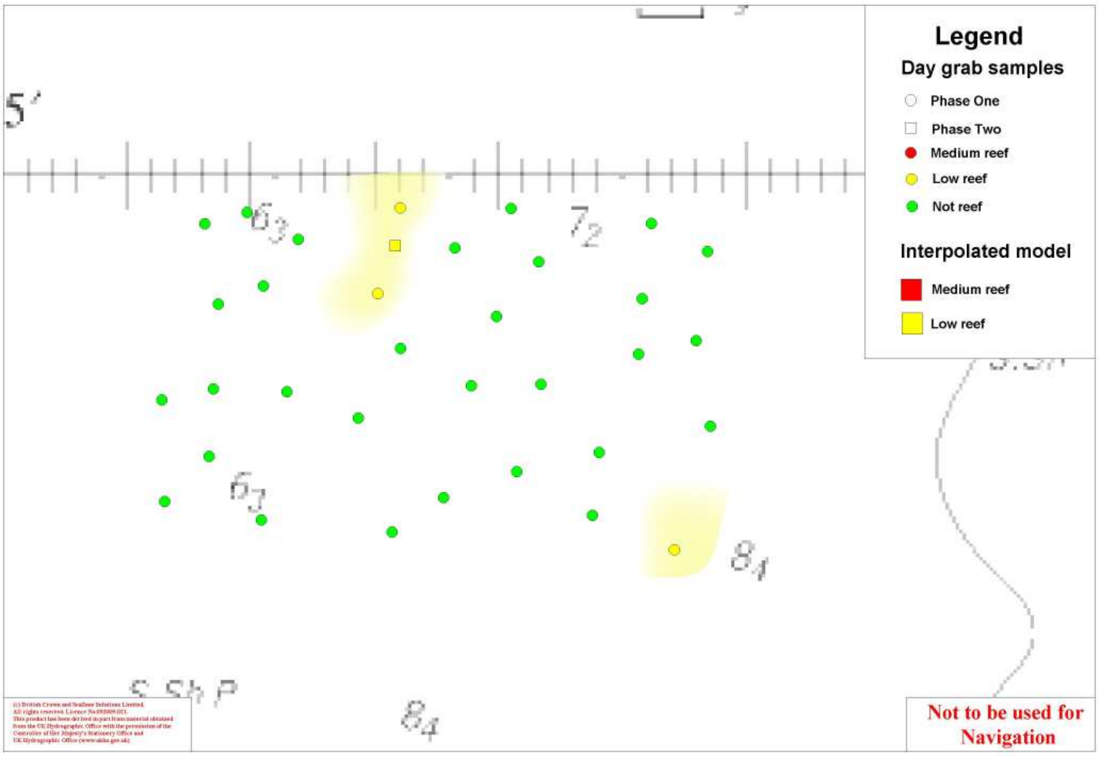


Figure 5.39 Interpolated model from the Day grab data at the Between Wind Farms site (applying thresholds suggested in Gubbay, 2007), showing the predicted distribution of low and medium *Sabellaria* reef, overlaid with the positions of the Day grab sample stations (Phases 1 & 2).

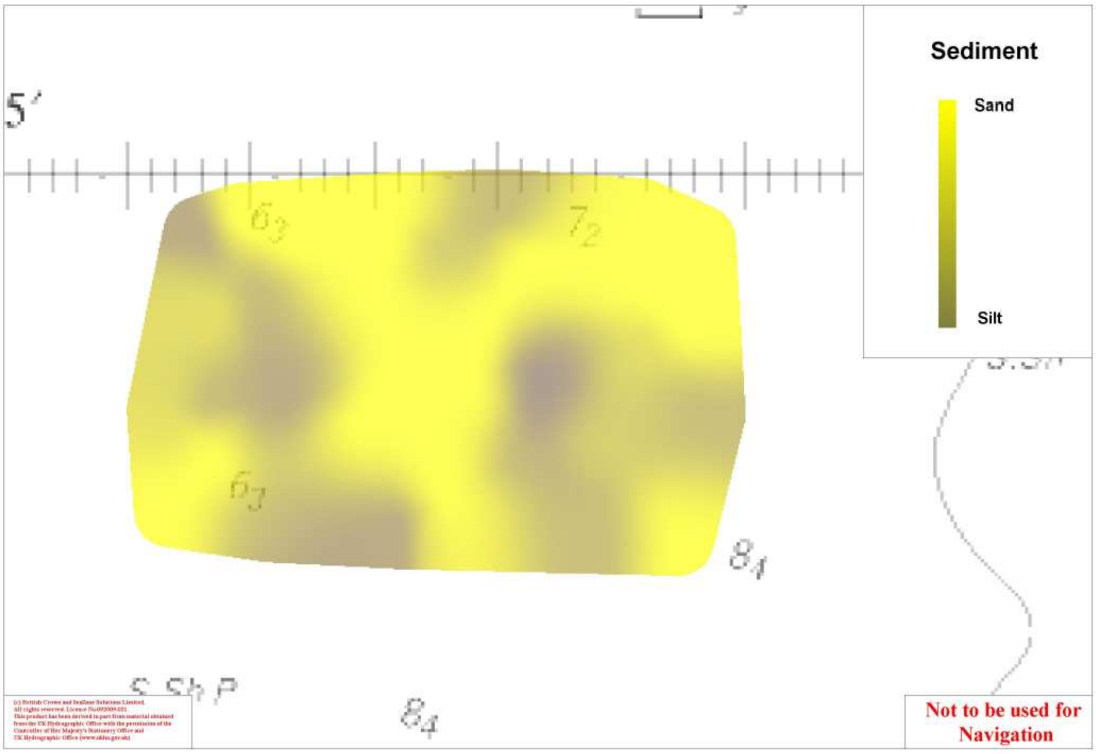


Figure 5.40 Interpolated model from the Day grab data at the South East of Wind Farm site showing the distribution of sand and silty sediments.

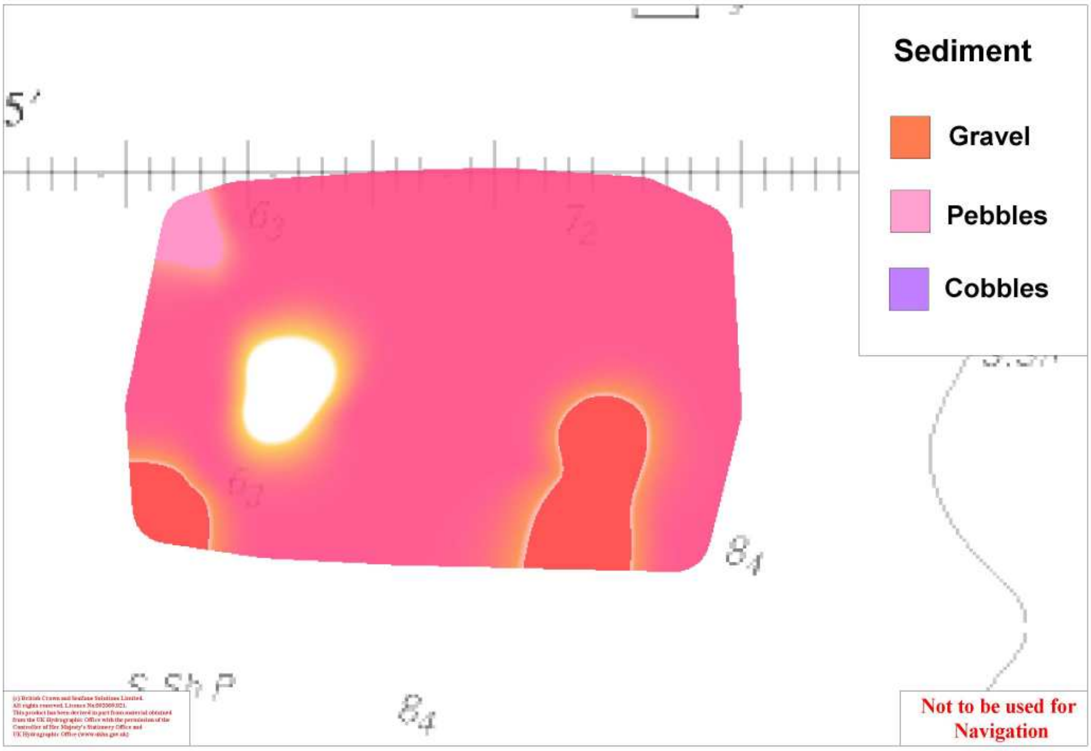


Figure 5.41 Interpolated model from the Day grab data at the South East of Wind Farm site showing the distribution of gravel, pebble and cobble habitats.

As had been the case at the other survey areas, the sediment data collected during ground truthing were interpolated in order to create models showing the substratum across the site (figures 5.40 & 5.41). Similar to the other sites surveyed, the substratum was found to be mainly composed of silty or sandy gravel or pebbles, conforming with the EUNIS habitat classification A5.44 – Circalittoral mixed sediments (JNCC code – SS.SMx.CMx). In some parts of the site, the samples were mostly composed of pebbles and larger particles, many of which were encrusted with keel worm, *Pomatoceros* spp, tubes and encrusting bryozoa. These sites were classified as being A5.141 – (*Pomatoceros triqueter*) with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles (JNCC code – SS.SCS.CCS.PomB).

Once all of the surveys had been completed, the Phase-1 and Phase-2 ground truth data from all of the sites were pooled together and re-interpolated so that the neighbouring sites from each area could interact during the interpolation process. This created a model showing the distribution of *Sabellaria* reef throughout the survey area (figure 5.42). The coverage of reef features throughout the survey areas has been summarised in table 5.2.

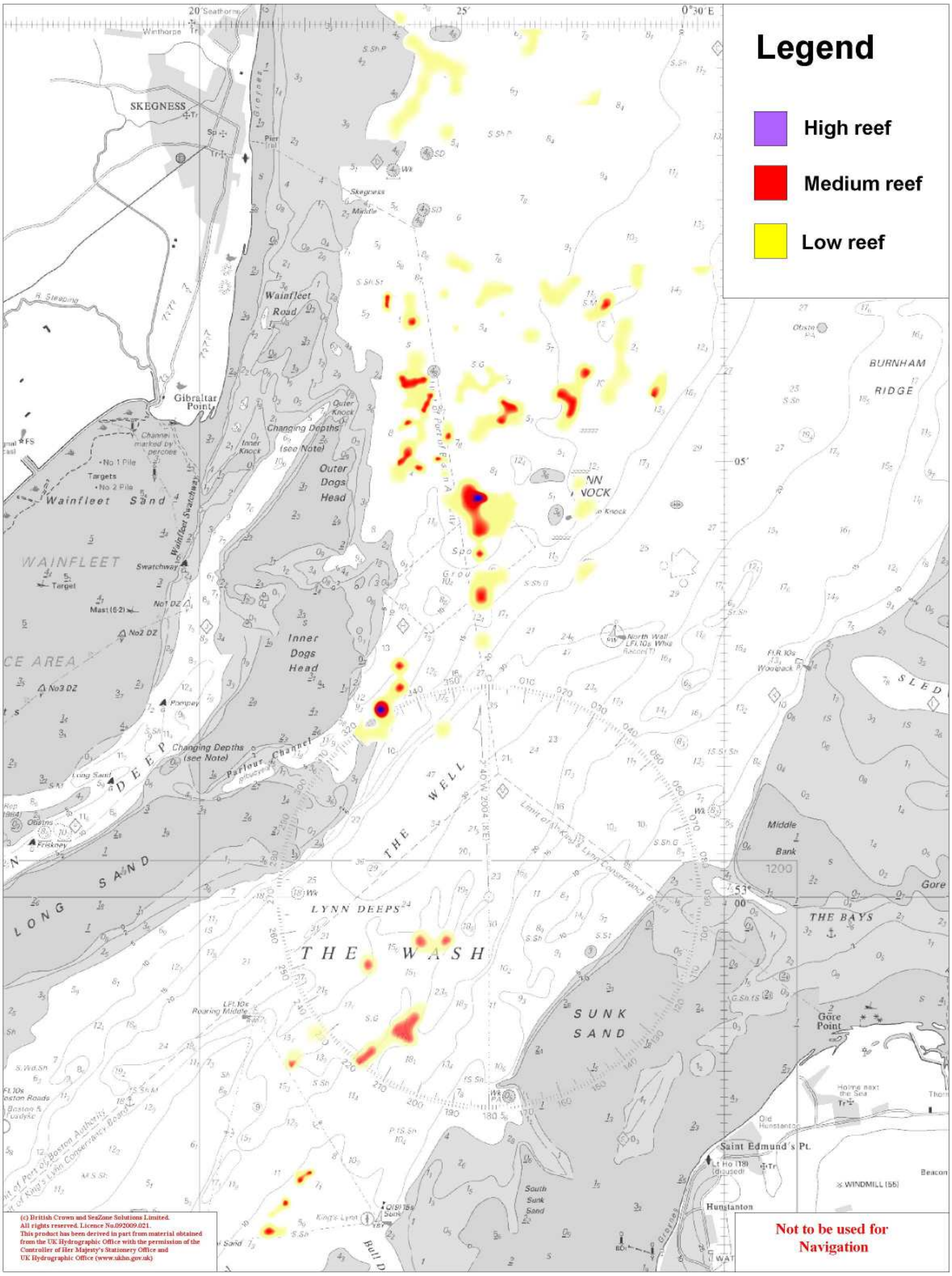


Figure 5.42 Extent of the *Sabellaria spinulosa* reef mapped during the 2010 surveys, using thresholds suggested in Gubbay (2007)

Table 5.2 Summary of the coverage of *Sabellaria* reef structures identified during the 2010 surveys at each of the survey areas

	Area covered by *Sabellaria* reef structures (hectares)		
Location	**High**	**Medium**	**Low**
Wash Sites			
West Lynn Knock	2.3	73.5	263.7
East Lynn Knock		33.0	153.1
East Dogs Head	2.7	48.1	256.8
Seal Sand		8.8	29.2
South Well		49.3	124.7
Total	**5.0**	**212.7**	**827.5**
Lincolnshire Coast			
West of Wind Farms			159.6
South West of Wind Farms		6.1	147.1
South East of Wind Farms		4.7	95.3
Between Wind Farms			36.6
Total		**10.8**	**438.6**

5.4 Discussion

During the 2010 survey programme models depicting Sabellaria reef distribution were created for five areas in the Wash and four areas along the Lincolnshire coast near the Lynn and Inner Dowsing wind farms. Although all of the areas had been mapped during previous broadscale surveys, only those in the Wash had previously been mapped by ESFJC to the same resolution as this series of surveys, whereby the models were created by interpolating intensive ground truth data rather than RoxAnn™ track data.

Figure 5.42 shows the distribution of reef structures identified during these surveys and table 5.2 provides a summary of the spatial extent of reef in each of the survey areas. From this table it can be seen that the sites in the Wash support 5.0 hectares of high reef, 212.7 hectares of medium reef and 827.5 hectares of low reef. Although the total area of reef in this area was found to have decreased from 1,432 hectares in 2009, the quality of the reef appeared to have improved, with greater areas being covered by medium and high reef. These increases were particularly noticeable at the East Lynn Knock, East Dogs Head and South Well sites, while small declines had occurred at the West Lynn Knock and Seal Sand sites. Reduction in area of low reef was found to have occurred at all of the sites except the South Well area, and was particularly noticeable at the East Dogs Head site where the coverage had fallen from 679 hectares to 256.8 hectares (although approximately 100 hectares of this decline can be attributed to a reduction in the area surveyed in the north western part of the site, which had previously supported an area of low reef). There are a number of explanations for these changes:

1. The sample stations used for the Phase-1 ground truthing were selected in semi-stratified patterns that were informed using the 2009 reef distribution models. Although care was taken to ensure sufficient coverage was given to areas that had been predicted as being non-reef areas, higher sampling densities were conducted in areas predicted as supporting reef. On one hand, focusing survey effort towards areas predicted to support reef could explain why the quality of reef appeared to have increased between surveys. This could be because the reef really had developed during the year, or it could be an artefact created by focusing greater attention on reef areas and thus increasing the probability of discovering better quality structures. On the other hand, by biasing sampling towards areas that had formally supported reefs, the chances of detecting reefs elsewhere were reduced. If the reefs are behaving ephemerally, this unbalance in sampling effort could result in an apparent reduction in identified reef coverage throughout the site. Although this sampling methodology could explain some of the changes, it is unlikely to be responsible for all. To reduce such occurrences, widespread sampling had been conducted outside of the stratified areas in regions predicted as supporting no reef in order to provide sampling coverage throughout the survey area. Whenever these samples detected areas of previously unidentified reef, additional Phase-2 stations had been focused around them to further improve the sampling resolution.
2. If the reefs are behaving ephemerally, and the distribution has changed between surveys, using the previous year's survey results to stratify the current year's sampling may not be as effective at detecting reef structures as using models derived from the RoxAnn™ track data. If this was the case, the coverage of Sabellaria would appear reduced in the second survey. As in 1) above, however, because widespread sampling was conducted outside of the stratified areas, this explanation would not account for all of the changes identified.
3. During both the 2009 and 2010 surveys, at many of the survey stations low or zero tube occupancy in the *Sabellaria* clumps was recorded. The ephemeral nature of *Sabellaria spinulosa* reefs is well documented, and the low tube occupancy would suggest there had been a high level of worm mortality in some areas, without whose maintenance the reef structures would erode and fragment over time. Although *Sabellaria* larvae are strongly stimulated to metamorphose and settle on conspecific tubes, whether the latter are living or old, deceased colonies (Wilson, 1970), without the rejuvenation provided by a successful settlement, deceased colonies will eventually disappear. Zero occupancy had been particularly noticeable in 2009 at the Seal Sand site, where many clumps appeared to be eroding or having become anoxic. At this site in particular, and possibly others where low occupancy was recorded, it seems likely that the decline was real rather than an artefact of survey design.

At several of the survey sites, comparison between the 2009 and 2010 models indicated the spatial distribution of the reefs had changed. This was particularly noticeable at the East Lynn Knock site.

Although the overall area occupied by reef structures at this site had only declined from 213.8 hectares in 2009 to 186.1 hectares in 2010, comparing the distribution models from these two years (figures 5.6 and 5.7) indicated there had been significant changes to the reef distribution during that period. Although these results appear to substantiate the ephemeral nature of *Sabellaria* colonies, the apparent changes could be an artefact of the survey methodology. To minimise the disturbance that sampling with a grab causes, only one sample was collected from each station during these surveys. Phase-3 ROV video camera footage taken from areas identified as being reef, however, have frequently found the reef structures to be quite patchy. Grab samples taken from such areas, therefore, may have a low probability of actually detecting reef in those areas two surveys in succession, even if there is little change to the structures themselves. If *Sabellaria* with a low patchiness quality is widespread across the survey area, by using the current methodology there is a high probability that the areas of reef will appear to move between surveys. In such incidences of widespread, low-patchiness reef, the models are likely to chart a lower extent of reef than is actually present, but of a higher quality. These affects could be reduced by taking multiple samples at each station. This, however, would not only significantly increase the disturbance at each station, but due to time constraints would severely limit the spatial coverage currently achieved. Until this compromise between spatial coverage and accuracy can be resolved, possibly by employing other remote sensing techniques such as side scan sonar, care should be taken when interpreting these reef distribution models.

To reduce some of the problems associated with grab sampling, greater emphasis could be given to video footage when modelling the reef features. Unfortunately, the time window in which the ROV video camera can be successfully deployed is narrow, limited to slack water periods. Further, visibility during spring tides tends to be poor. Drop cameras might be a possible solution, but unlike a ROV, they cannot roam. Three ROV video camera drops, conducted as part of the Phase-3 ground truthing of the East Dogs Head site on August 5th, highlighted another problem that might be encountered if relying heavily on video footage for mapping *Sabellaria* reefs. Although the ROV drops were conducted over positions identified by the Day grab surveys as supporting high and medium reef structures, none of the videos showed evidence of any significant reef structures, barring the occasional isolated clump of *Sabellaria*. As some of the *Sabellaria* clumps found in the grab samples from these areas had been over 10cm in height, it is unlikely they would have degraded naturally in the four-month period separating the two surveys. The video footage did show the substrate to be composed of coarse sand, however, so it is possible that if the sand in this area is relatively mobile, the *Sabellaria* structures might be subject to regular smothering. Much of the video footage taken from ESFJC's ROV video camera over the past three years have found reef structures to be partially buried, often with only the tips of the tubes visible. If complete smothering is a regular occurrence, reliance on camera footage rather than grab samples for ground truthing would also have limitations.

The distribution of *Sabellaria* reefs at the Lincolnshire Coast sites appeared sparse compared to the Wash sites, supporting only 10.8 hectares of medium reef and 438.6 hectares of low reef. ESFJC had conducted RoxAnn^{TM} AGDS surveys over the same area in 2008, while looking for beds of sublittoral mussel seed (Jessop, Woo & Harwood, 2008). During these previous surveys the RoxAnn^{TM} equipment had identified widespread areas of ground that was indicative of supporting reef features. Ground truth samples taken at the time with a Day grab had confirmed the presence of *Sabellaria*, but because the surveys were focusing on identifying mussel beds, the ground truthing of identified *Sabellaria* sites was severely restricted. It is difficult to determine from these surveys whether the apparent decline of reef distribution in these areas is real or due to differences in survey methodology. As the 2008 surveys were relatively broadscale, however, and the distribution had been modelled using data derived from the RoxAnn^{TM} tracks, lower confidence should be given to these results than those from the current survey, in which intensive ground truthing had been applied.

Additional sediment data recorded from the ground truth samples indicated across most of the area surveyed there was a high prevalence of substrates composed of silt or sandy gravel and pebbles. These mainly fell into the EUNIS habitat classification A5.44 – Circalittoral mixed sediments (JNCC code – SS.SMx.CMx). Because the light penetration associated with this habitat is too poor for photosynthesis, this habitat is generally dominated by animals, such as bryozoa and hydroids, rather than plants. In the shallow waters of many estuaries the similar habitat, A5.43 – Infralittoral mixed sediments (JNCC code – SS.SMx.IMx) is more commonly found, in which the better light penetration allows plants to dominate. The high turbidity found in the Wash, however, reduces light penetration to levels more often associated with deeper waters.

6.0 STUDY OF THE WASH EMBAYMENT, ENVIRONMENT AND PRODUCTIVITY (SWEEP)

6.1 Introduction

In 2009 a dedicated project was established to Study The Wash Embayment, Environment and Productivity (SWEEP) with a focus on understanding temporal and spatial variations in water quality and primary productivity. That report provided an introduction and setting for the project including the presentation of initial monitoring work conducted during the latter half of 2009 and into 2010.

Original AIMS (as stated in Jessop et al, 2009)

1) **"Long term monitoring** of productivity (chlorophyll) and basic water quality parameters via a dedicated programme. Such information will help identify changes in the availability of food resources for bivalves in The Wash and variability in environmental parameters that are likely to influence physiological processes. These data are valuable in furthering our understanding of the general productivity of the ecosystem, aiding in the maximisation of a productive and sustainable fishery. This work will incorporate collaborative research with other organisations to address other aspects of productivity and water quality."

2010/11 update:

Long-term monitoring has been carried out using the YSI 6820-V2 and the YSI 6600 Multiparameter Water Quality Sondes (note correction to 2009 report which details use of YSI 6920-V2, this is actually 6820-V2 Sonde). The original monitoring research schedule detailed within the 2009 Research Report was completed as fully as was practicably possible. Over 90% of the water sampling activities were completed as planned, with poor weather being the main reason preventing sampling. This provided a wealth of data over an extended period of time, spanning seasonality trends in The Wash. Of particular interest are the chlorophyll levels in The Wash, being an indicator of phytoplankton on which bivalves feed.

As well as ESFJC's own sonde monitoring programme, a water-sampling programme has continued with Cefas investigating plankton abundance. This collaborative work is also important to gain accurate values of salinity and chlorophyll at our sample locations by way of high-end analytical chemistry techniques carried out at Cefas laboratories in Lowestoft. This ensures our data are of high integrity and accuracy.

2) "**Short-term studies** to investigate localised depletion of food resources (chlorophyll) around natural beds and lays. This will primarily begin to help in the assessment of whether specific areas could be deprived of vital food supplies or are less productive than others."

2010/11 update:

This comprises the majority of the data collection programme focussed on in the last year. Attempts to determine an influence of shellfish occupied areas on the surrounding water characteristics at ~1m depths above those locations have been underway, and results are detailed later on in this chapter.

3) "**Additional research** focusing on the collation of other available data required for the study of carrying capacity in The Wash and identification of topics that require further work. This will involve the construction of food webs to help identify sources of competition and predator prey interactions. It will also address other issues such as the hydrodynamics of The Wash and environmental variability which has significant links with primary production and thus the productivity of the ecosystem."

2010/11 update:

In order to calculate a carrying capacity for a dynamic and complex system such as The Wash, an understanding of the role played by biotic organisms of that system is crucial. The construction of comprehensive food webs and associated interactions were an integral part of the original aims of this study, along with the compilation of a comprehensive hydrodynamic model of The Wash embayment. From the outset, it had been identified that elements of the project lay beyond the expertise and scope of ESFJC, most specifically the creation of a hydrodynamic model of The Wash that would detail the water movements over and around the lays. At a workshop held on September 7th 2009 it was determined that the establishment of a fellowship appointment would be essential in order to successfully achieve several of the project's goals. Unfortunately, the funding for this post was not forthcoming and therefore the original aims of the SWEEP project have been duly reviewed and revised within this report.

It is worth noting here, however, that the importance of this project has not lost the interest of stakeholders, but has continued to inspire interest with monitoring thus far yielding excellent results. This is testament to those individuals regularly involved in the periodic sampling trips allowing the project to continue productively during a challenging and changeable year.

6.2 Aim

Following an unexplained high incidence of cockle mortality in 2008, this study originally aimed to address whether the shellfish beds within The Wash have a significant effect on the available food resources and whether this may have a direct influence on the health of cockle stocks. However, with the failure to successfully gain funding for the fellowship appointment that had been identified as being integral to this project, it has become increasingly clear that the original aims of the study are, for the present time, beyond the scope of ESFJC. During 2009/10, therefore, data collection and analysis have focused predominantly on the study of chlorophyll distribution and abundance in various shellfish occupied and non-shellfish occupied areas in The Wash. As detailed in Section 6.14 of the 2009 Research Report (Jessop et al, 2009), chlorophyll is a photosynthetic pigment found in most plants including phytoplankton species and is vital for the production of energy using sunlight. However, some phytoplankton species utilise different pigments to harness a different fraction of the available light spectrum. This makes it somewhat complicated to fully quantify the amount of phytoplankton present purely on chlorophyll readings.

Aim 2 of the 2009 report details the original approach of testing water quality parameters with the YSI Sonde instruments. These parameters are used to assess depletions of phytoplankton as water passes over specific beds and the influence on food supplies of such beds. Specifically, it refers to measuring chlorophyll as a proxy for the abundance of phytoplankton. On this basis, the data collected as part of this research programme have been entered into analyses to test the following hypothesis:

“At water depths of 1m (±10%), chlorophyll levels will be lower above stations where shellfish are present than at those stations where shellfish are not present.”

In addition to the focused analysis on the chlorophyll levels above shellfish and non-shellfish areas, some exploratory analyses will be demonstrated comparing various water-sampling sites in graphical format with discussion.

As the greatest abundance of shellfish at the time of the study were mussels situated on the several fishery lays, high resolution spot sampling programmes were concentrated around two such areas, on the Toft and Scotsman’s Sled lays. Further high resolution spot sampling surveys were conducted on a non-shellfish occupied “control” site at the Ants, while an additional medium resolution programme of sampling was conducted over the North West area of The Wash, which contained a number of wild and farmed shellfish beds, non-occupied areas and several channels.

Independent of this study, questions had also been raised by Natural England concerning the extent to which the mussel lays affected the surrounding ecosystem. By focusing the SWEEP sampling around the lays, therefore, it was aimed to address to both questions.

6.3 Methodology

Sampling areas:

Four key areas, as devised in the initial aims of the SWEEP project, were used for this particular study. The high spatial resolution sites were chosen to provide detailed studies over specific areas. To aid in the spatial monitoring of water quality within The Wash, activities were divided into three principle complementary components: monthly Wash wide surveys (7 stations), high spatial resolution surveys over specific sites (3 sites with between 30 and 35 stations at each) and a more broad scale survey over a wider area (16 stations):

The seven monthly Wash wide surveys are carried out in collaboration with Cefas. Data from these trips are predominantly used to gain laboratory standard calibrations of chlorophyll, nutrient and salinity of surface water values at these sites. The other water sampling sites are devised as follows:

1) High Resolution. Ants - control site with no significant stock of bivalves recorded
2) High Resolution Toft - natural mussel bed and high concentration of cultivated mussel lays
3) High Resolution Scotsman’s - mainly cultivated mussel lays in the south-east region of The Wash
4) Medium Resolution NW Wash - broad scale survey over a wider area

Grids were produced, shown in figure 6.1, covering each of these sites to provide a framework of survey stations. Each high-resolution site covers a different area: Ants (3.35 km^2), Toft (4.36 km^2) and Scotsman’s (3.75 km^2). These sites generally occupy intertidal regions of sands, whilst the medium resolution site, NW Wash, occupies a considerably larger area where sites were selected to provide the greatest range in individual features of the area, including sites set in the river mouth, channels and over shellfish beds. Depths and drying heights will be given relative to chart datum.

Sampling at these stations was conducted at High Water (+/- 2 hours) using a YSI 6820-V2 sonde, taking three measurements at each site at a depth of ~1m. Bi-annual surveys were also conducted in the Rivers Witham/Haven, Welland, Nene and Great Ouse, using the YSI 6820-V2 sonde to take spot measurements at positions shown in figure 6.2.

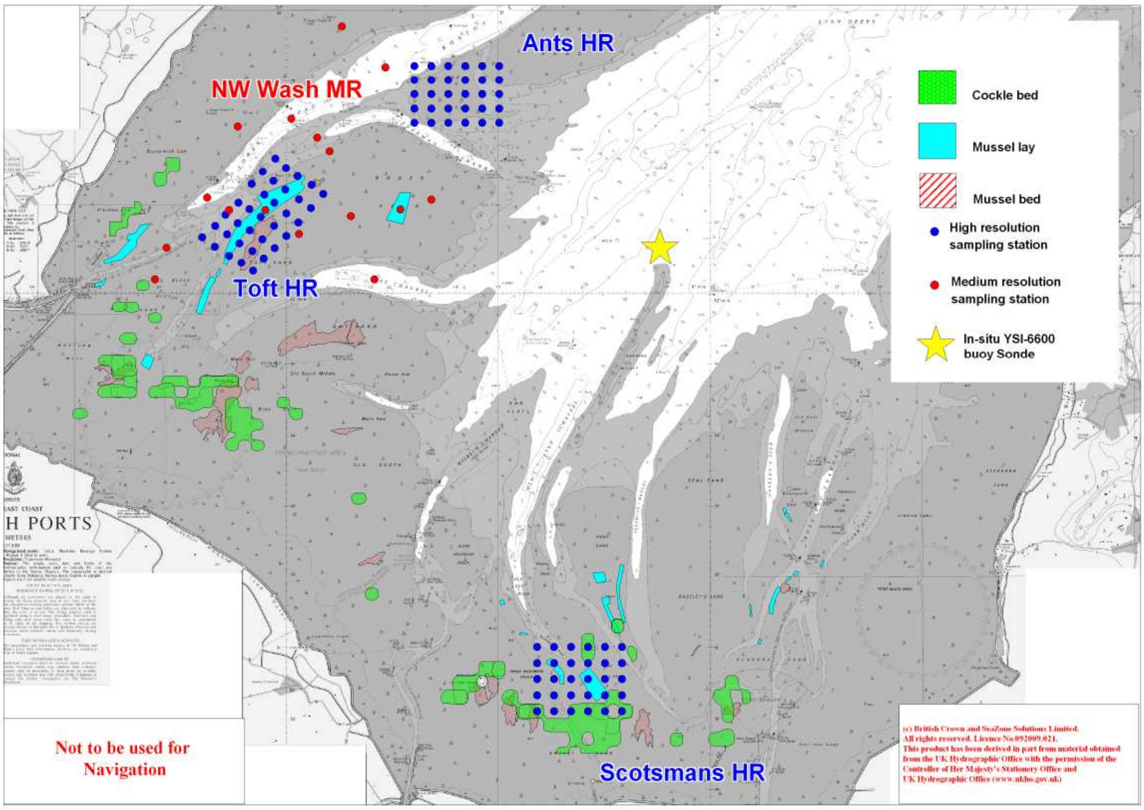


Figure 6.1 Chart showing locations of high and medium resolution sampling sites with positions of various shellfish beds.

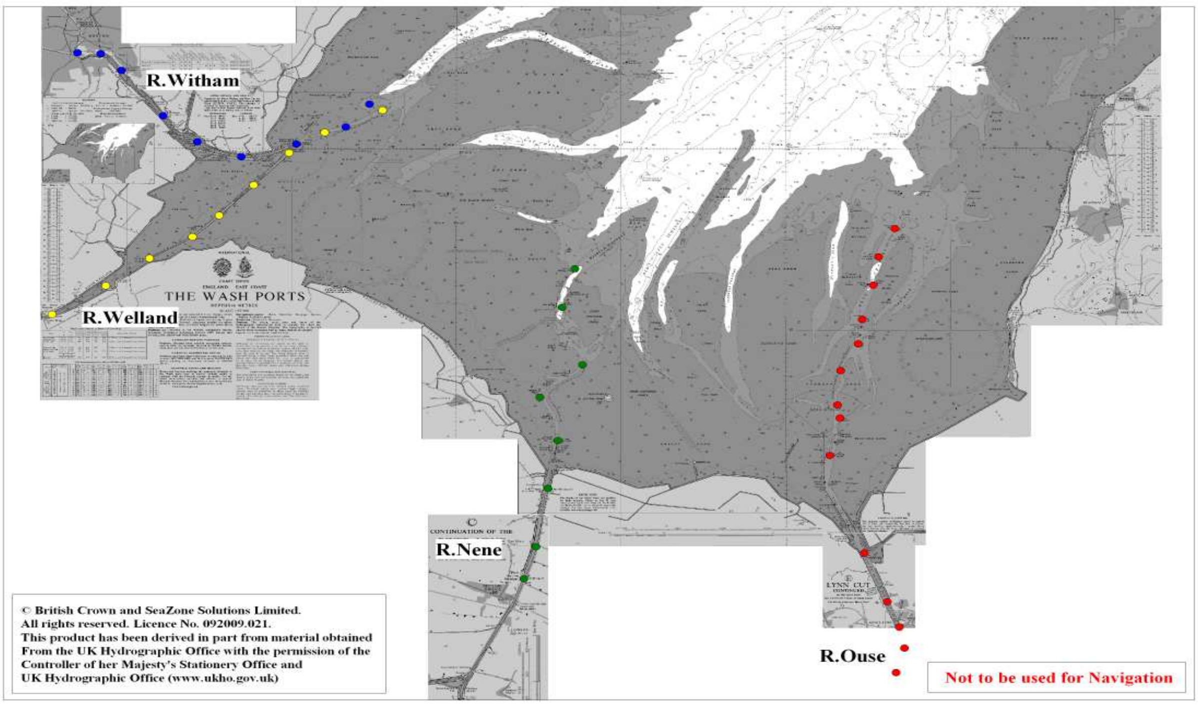


Figure 6.2 Locations of river transect water quality monitoring sites. Red; "Ouse", green; "Nene", yellow; "Welland" and blue; "Witham".

The sonde is capable of measuring chlorophyll in Relative Fluorescence Units (RFU) and provides only an estimation of chlorophyll levels. These readings were correlated with Cefas laboratory analytical chemistry standard readings to ensure they follow a suitably close correlation. Chlorophyll RFU value is, therefore, the parameter used in the data analyses.

Data processing:

Both the YSI 6600 and YSI 6820-V2 Sondes have generated a significant amount of data over the last 18 months, particularly the YSI 6600 that is deployed permanently in-situ in The Wash taking readings at 10 min. intervals. All of these data required re-organising and processing to ensure integrity of the data with which to perform data analyses. The processing included the following manipulation of the data:

For YSI 6820-V2 (spot Sonde data)

i) Revision of the current site coding system to ensure all sites have a unique "Site ID" code against which to match associated information about that sampling site.

ii) Removal of anomalous negative values of turbidity data which often occur when readings are taken prior to the cleaning and stabilising process of the Sonde having completed.

iii) Removal of data at depths that do not lie within 1m±10%.

iv) Calculation of the means of multiple readings taken at each sampling station during each sampling event.

v) Geographical information (decimal latitudes and longitudes) merged with each row of data according to unique "Site ID" code.

vi) Drift corrections applied to the turbidity and salinity readings according to calibrations completed at periodic intervals on all of the spot sonde parameters. Drift corrections, where necessary, were assumed to be linear over time and applied using a linear equation model.

For YSI 6600 (in-situ buoy Sonde data)

i) Revision of the current site coding system to ensure all sites have a unique "Site ID" code against which to match associated information about that sampling site.

ii) Removal of anomalous negative values of turbidity data which often occur when readings are taken prior to the cleaning and stabilizing process of the Sonde having completed.

iv) Calculation of mean daily interval readings for comparison with 10-minute interval data and to allow for easier management of large datasets.

v) Drift corrections applied to readings of turbidity and salinity according to calibrations completed at regular 4–6 week intervals. Drifts were assumed to be linear over time and applied using a linear equation model providing the R^2 value of each equation was ≥ 0.95 indicating a suitable fit. A quadratic equation model and associated processing script has been set up to correct values accordingly should any drift occur which is notably non-linear in nature. Linear and quadratic calibration drift correction processes were devised with the help of T.C. O'Haver (Professor Emeritus, Department of Chemistry and Biochemistry, University of Maryland, US. In email, 6th November 2010).

Data processing was carried out using the programming language R, (R Development Core Team (2010).

Statistical analysis:

The bi-monthly water sampling of the high and medium resolution sites were processed as above to gain accurate readings for each station for both the shellfish and non-shellfish sites. A 2-sample independent t-test was conducted on the chlorophyll data to ascertain if the means of chlorophyll readings at 1m depths were significantly different between stations situated above shellfish and those not.

Other exploratory analysis:

The chlorophyll levels above shellfish and non-shellfish areas data were entered into MapInfo and Contour surfaces were produced to provide a visual representation of spatial variability over survey site, these were interpolated using a simple nearest neighbour function in Vertical Mapper (MapInfo). The figures are displayed by site and discussed later in the chapter.

6.4 Results

Statistical analysis of the data found that chlorophyll RFU readings were slightly greater (M=0.05, SE=0.079) in areas directly above shellfish beds and/or lays than over non-shellfish occupied areas (M=0.02, *SE*=0.04). This difference however, was not significant $t\,(817) = -0.37$, $p > 0.05$ and had a very small-sized effect, $r = 0.013$.

Figures 6.3 to 6.10 display levels of chlorophyll over each of the inshore sites, Scotsman's Sled, Ants, Tofts and NW Wash. Figures 6.3 to 6.6 have used survey-specific scales to best examine intra-site differences. Seasonal trends and inter-site comparison of the four sites have been depicted in figures 6.7 to 6.10 applying a single scale.

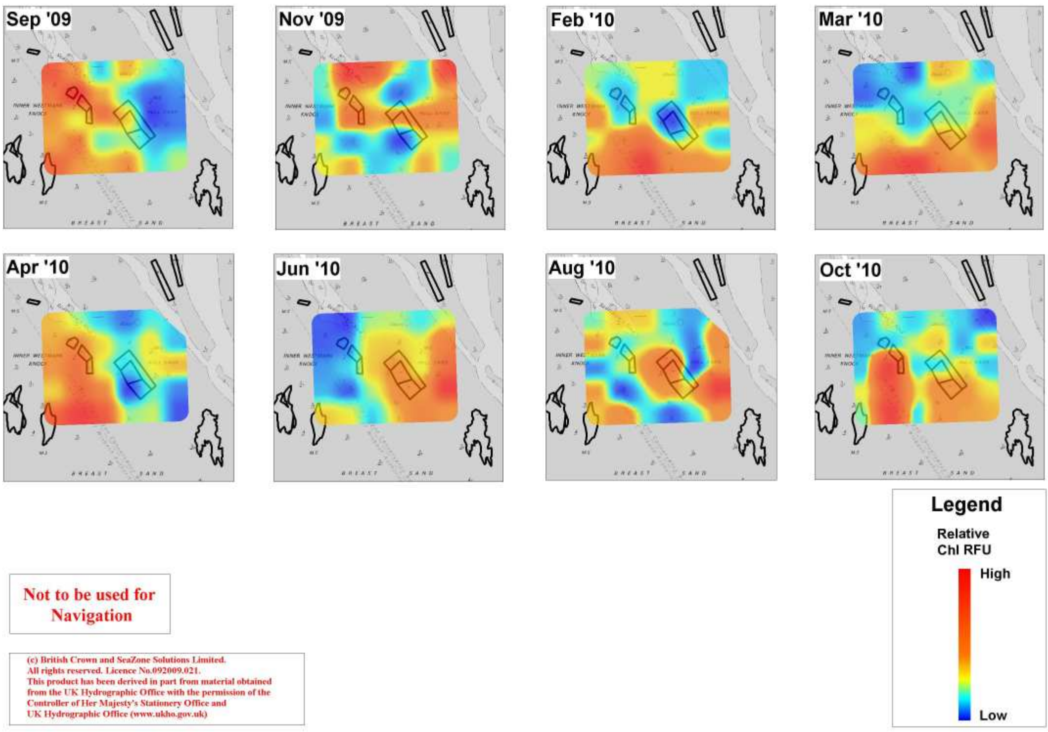


Figure 6.3 Mean chlorophyll levels over Scotman's sampling site. Darkened outlines show position of mussel beds and lays.

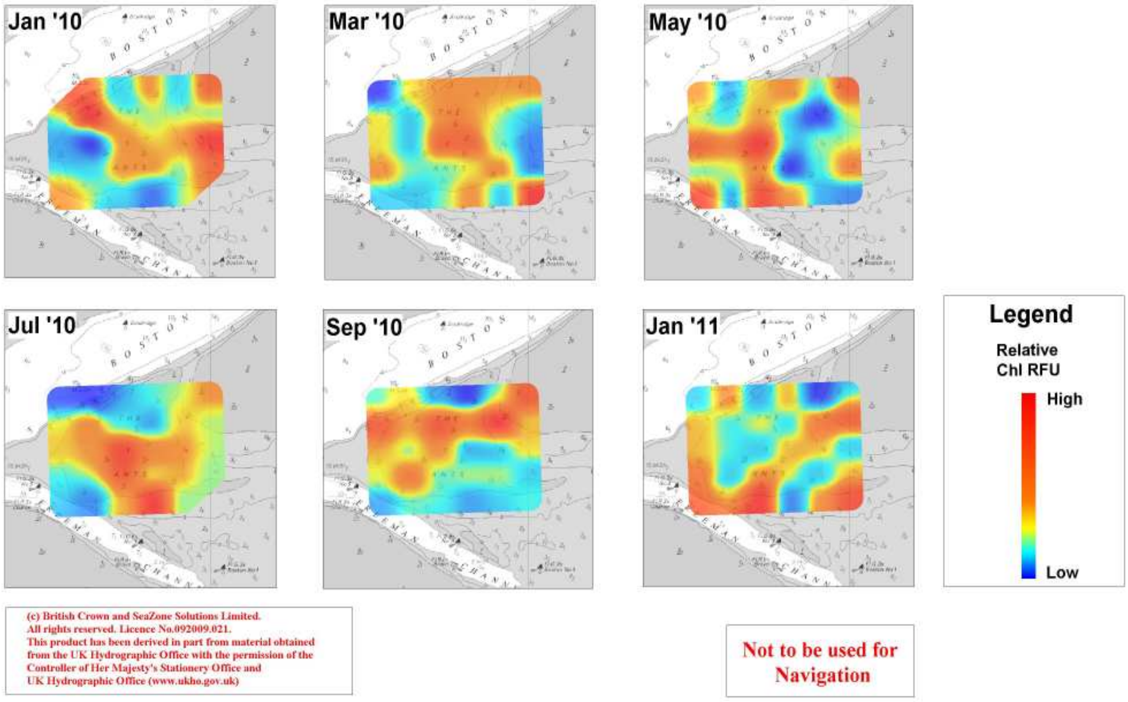


Figure 6.4 Mean chlorophyll levels over Ants sampling site; control site containing no shellfish.

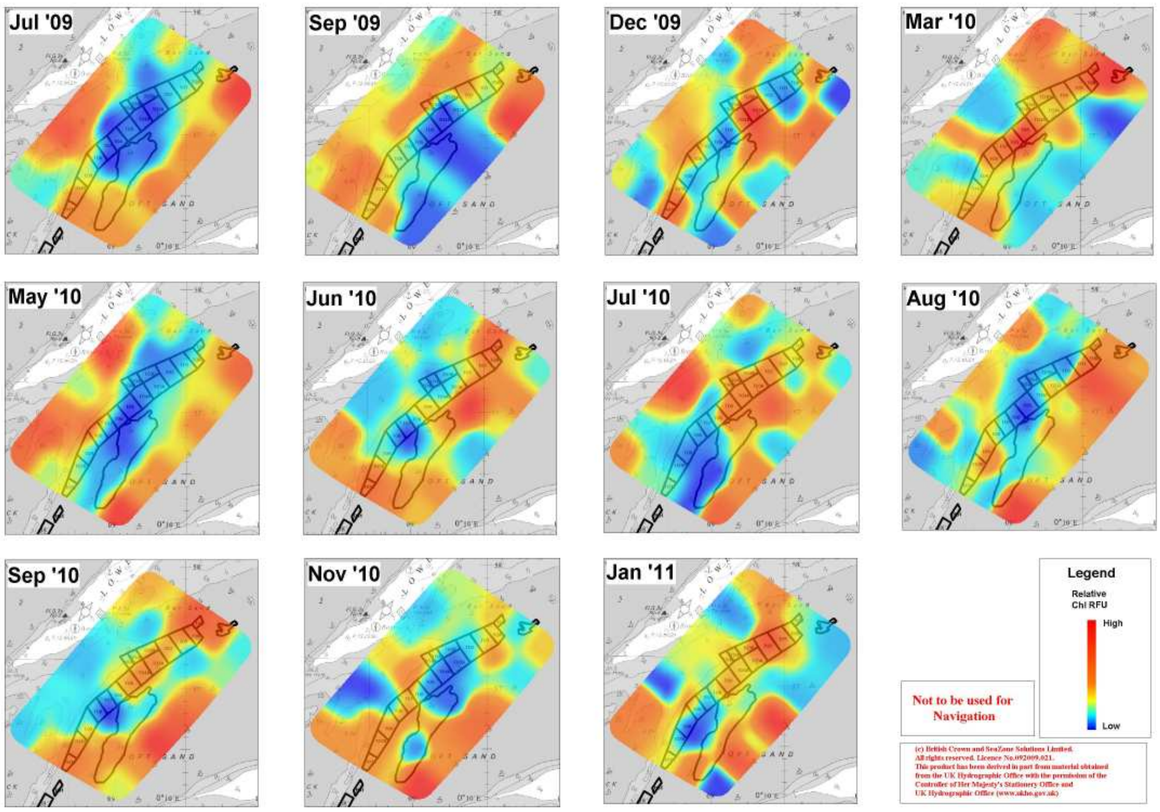


Figure 6.5 Mean chlorophyll levels over Tofts sampling site. Darkened outlines show position of mussel beds and lays.

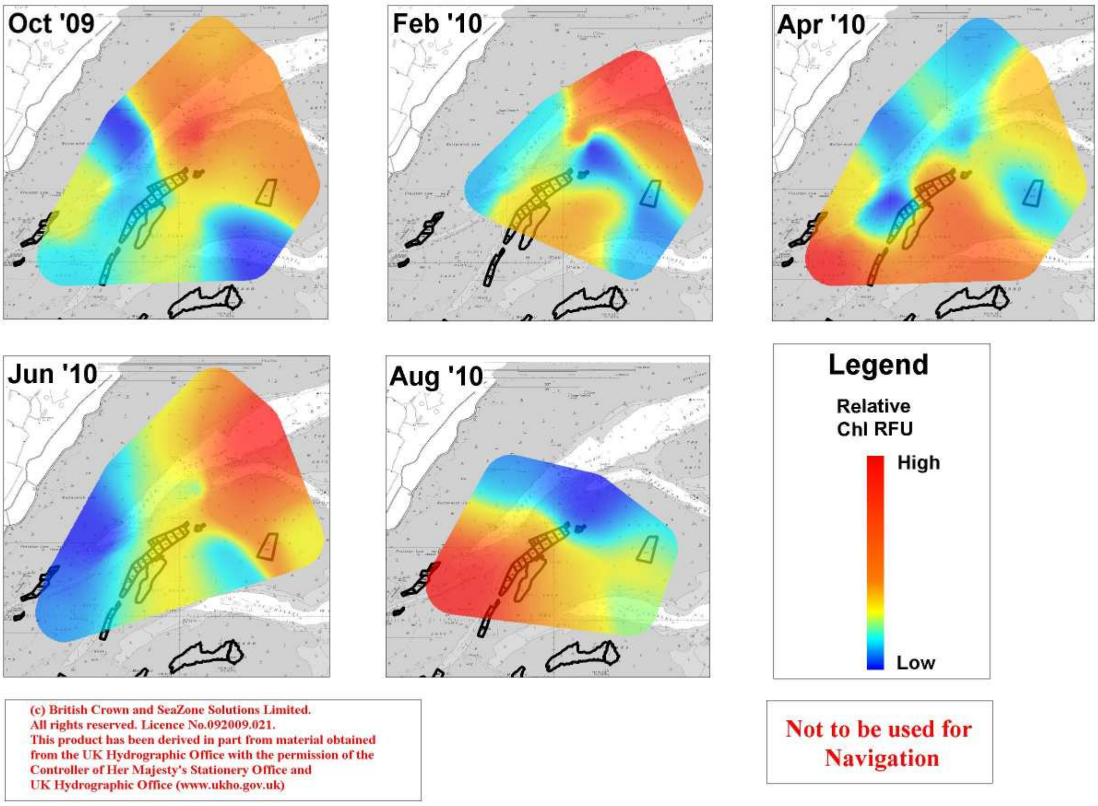


Figure 6.6 Mean chlorophyll levels over NW Wash sampling site. Darkened outlines show position of mussel beds and lays.

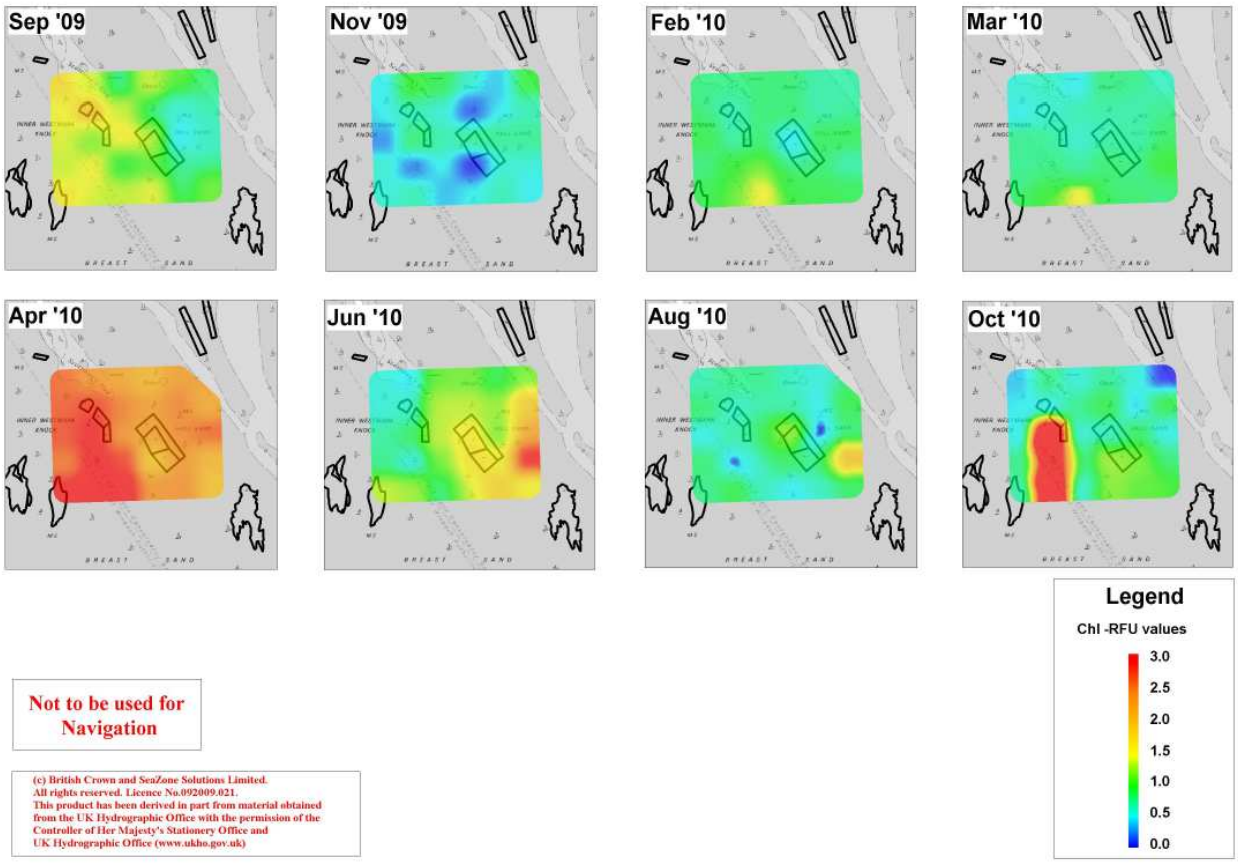


Figure 6.7 Relative mean chlorophyll levels over Scotsman's Sled sampling site. Darkened outlines show position of mussel beds and lays.

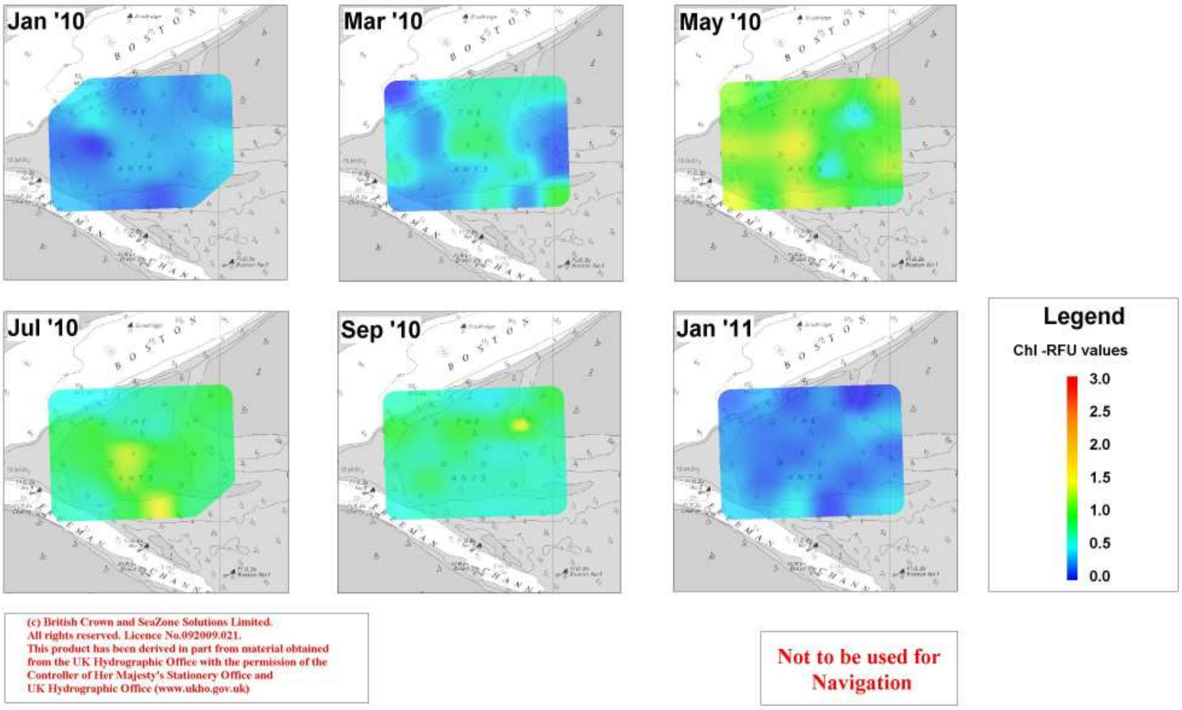


Figure 6.8 Relative mean chlorophyll levels over the Ants sampling site; control site containing no shellfish.

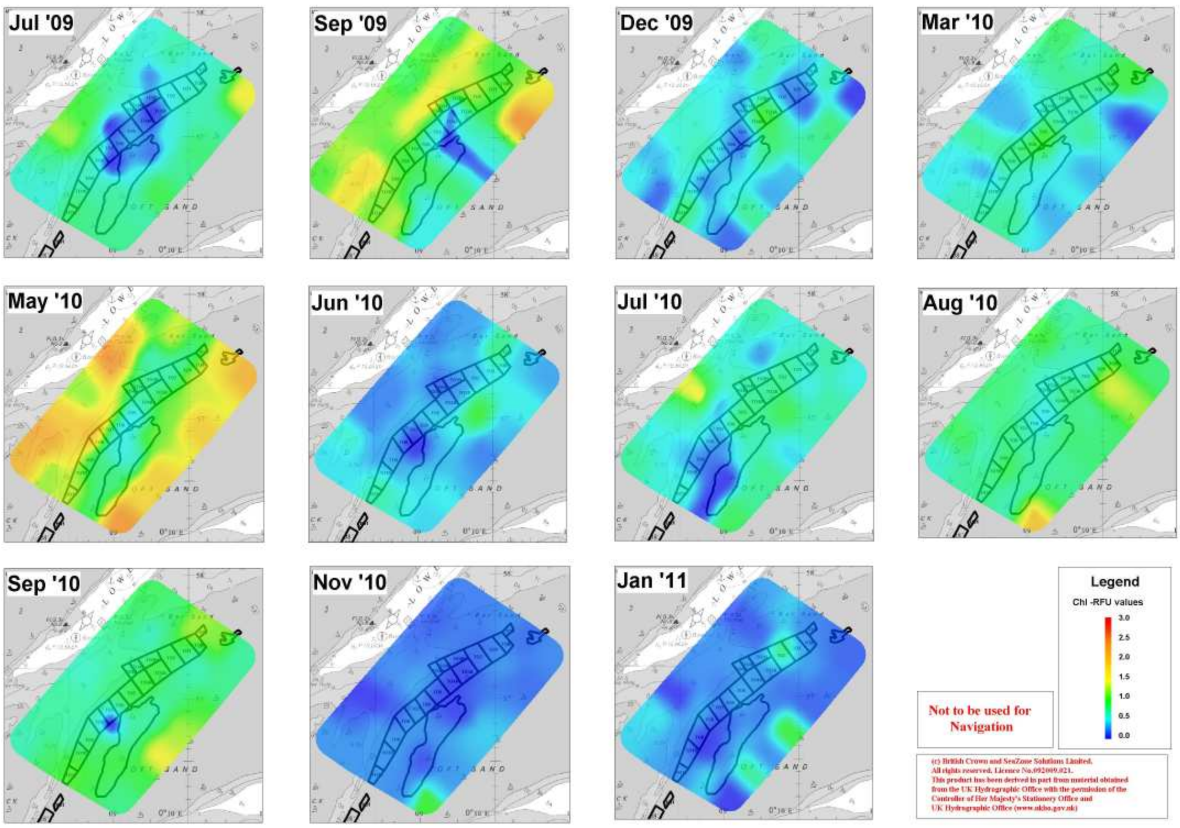


Figure 6.9 Relative mean chlorophyll levels over the Tofts sampling site. Darkened outlines show position of mussel beds and lays.

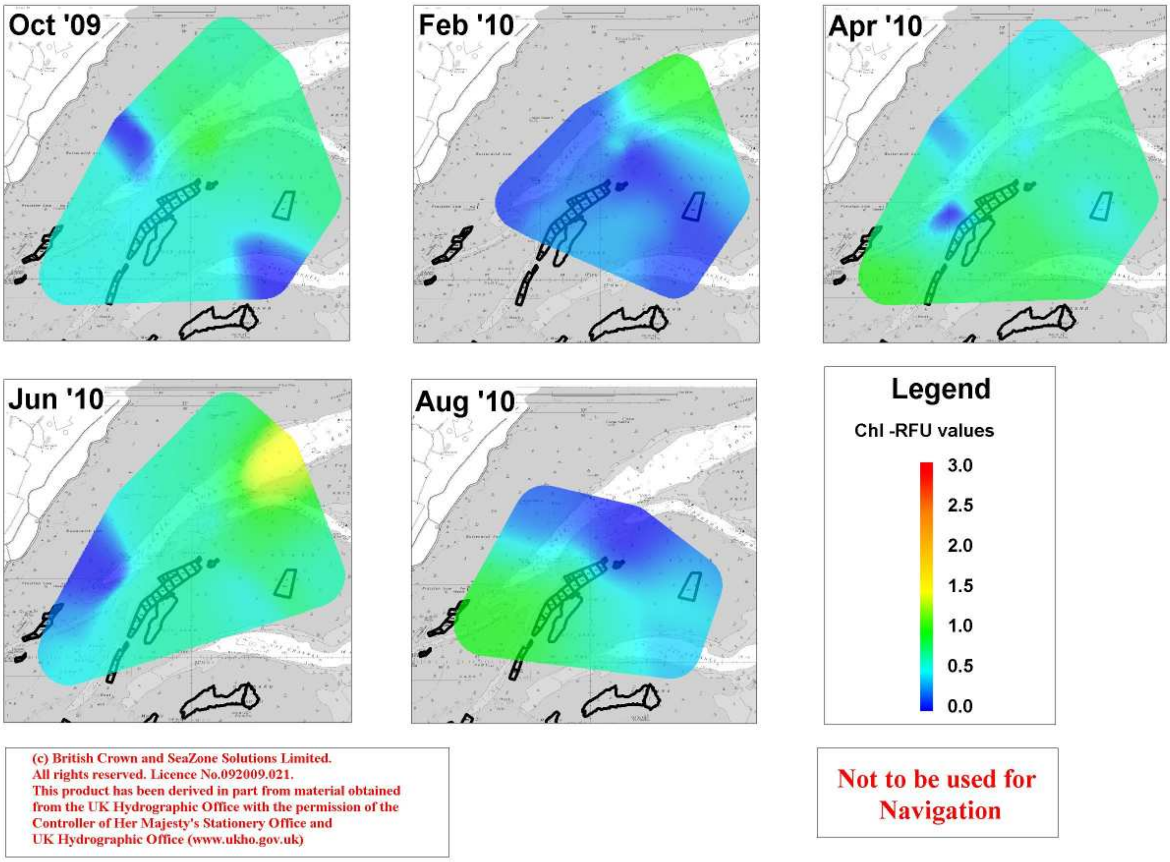


Figure 6.10 Mean chlorophyll levels over NW Wash sampling site. Darkened outlines show position of mussel beds and lays

Figures 6.3 to 6.6 show there to be variation in chlorophyll levels at all of the sites, while figures 6.7 to 6.10 show seasonal variation with higher levels of chlorophyll in the summer months than during the winter months. It can be clearly seen from the above figures, however, that the variation is not consistent at any of the sites, and therefore, fails to provide consistent evidence that the shellfish beds are influencing the levels of chlorophyll at ~1m depth.

Figure 6.11 shows the mean chlorophyll levels found during the spot sampling surveys between August 2009 and February 2011, showing clear peaks in chlorophyll levels at three of the four sites between April and June 2010. Figure 6.12 shows this same data combined with that taken from the buoy sonde. In this figure a large spike in chlorophyll levels at the buoy site between May and June 2010. As the spot sampling surveys fell either side of this bloom, similar spikes were not detected at the spot sampling sites.

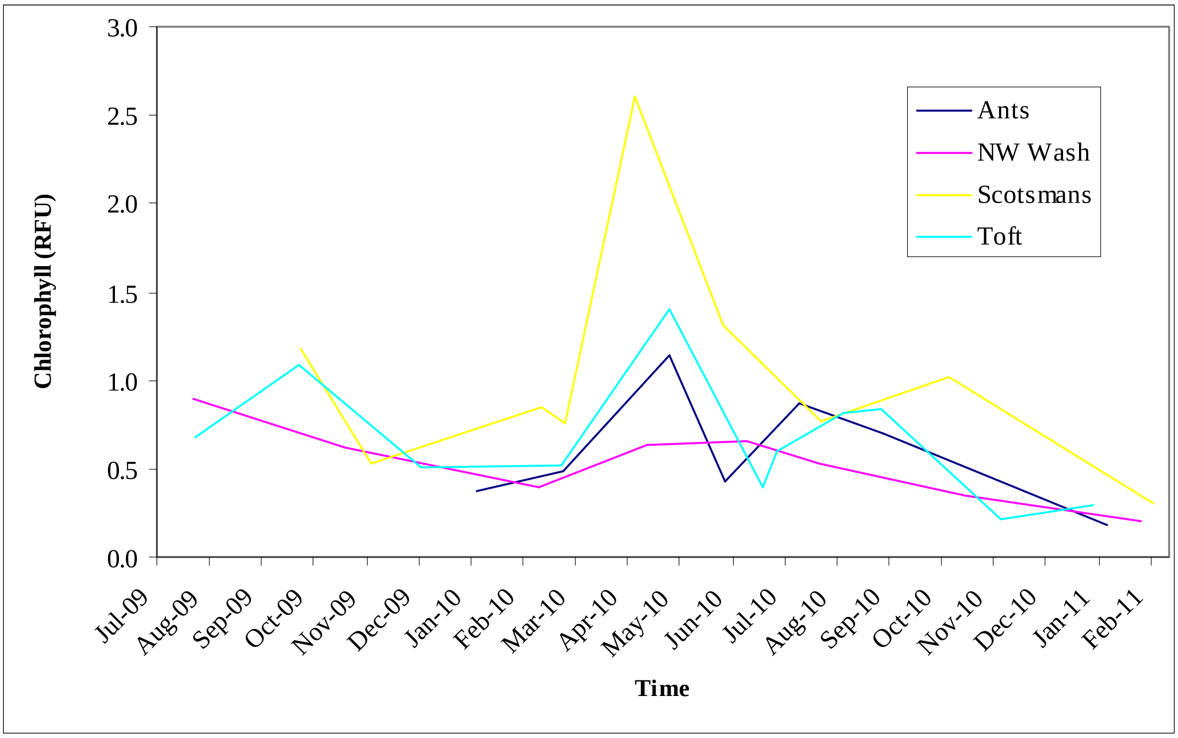


Figure 6.11 Mean chlorophyll levels over the three high- and one medium-resolution spot sampling sites.

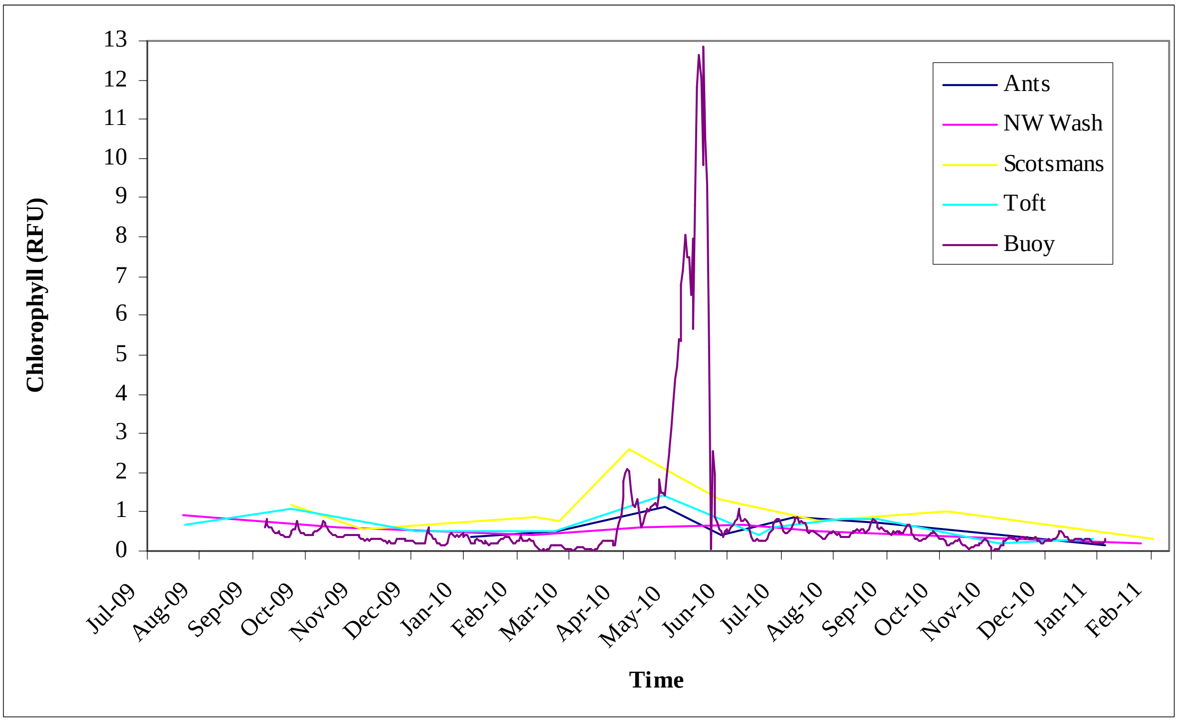


Figure 6.12 Mean chlorophyll levels at the four spot sampling sites and at the in-situ buoy.

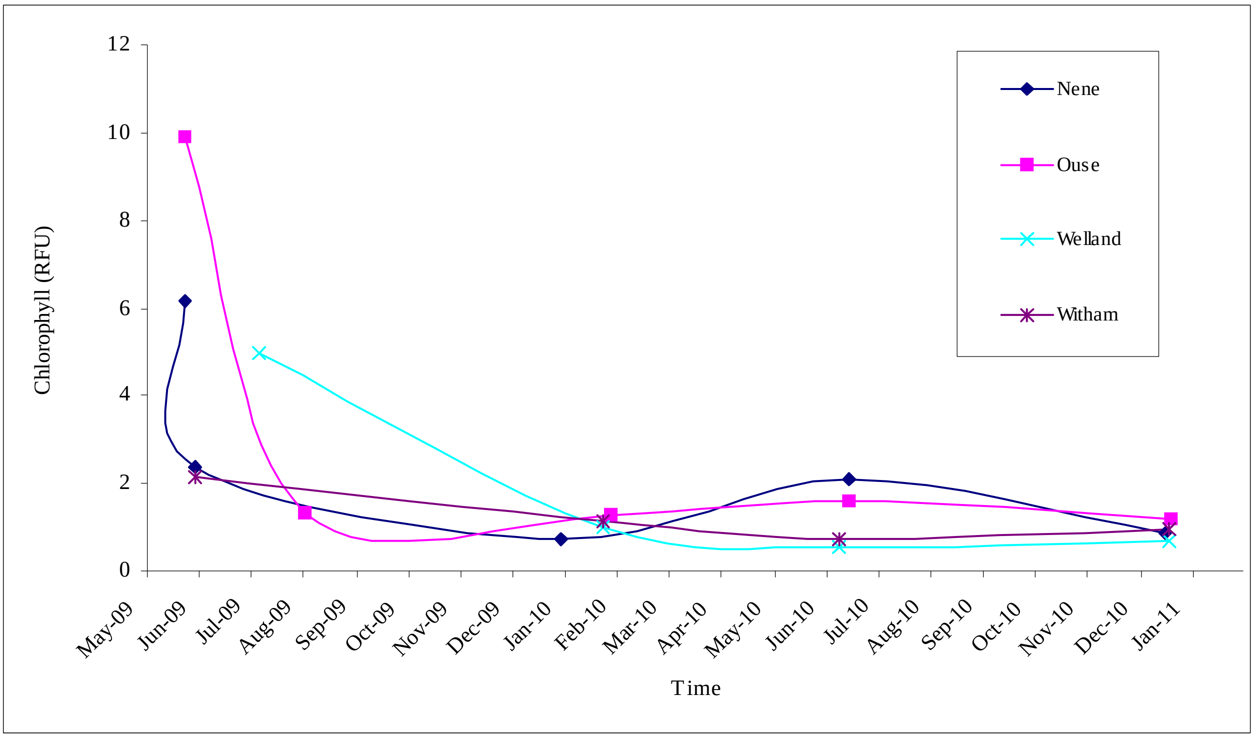


Figure 6.13. Chlorophyll levels of the four river profiles flowing into The Wash. Daily means are used for each river profile.

6.5 Discussion

The statistical analysis shows there to be no significant difference between chlorophyll RFU levels measured at a depth of 1m±10% above shellfish and non-shellfish occupied areas. Interpolated models of the chlorophyll RFU values (figures 3-6) illustrate visually, the lack of correlation between chlorophyll RFU levels and location of mussels. In figures 6-9, where the scale has been adjusted to allow seasonal as well as intra-site comparison, seasonal variations can be seen, but again, no correlation between areas of low chlorophyll levels and the location of shellfish beds are visually apparent. It is important not to infer any cause-effect relationship from this analysis, but rather to explore possible reasons as to why our hypothesis is rejected and to critically analyse our survey design.

At the outset of this study it was assumed that depletion of chlorophyll by shellfish in the shallow, mixed waters above the lays would be of sufficient a magnitude to be detectable at the upper reaches of the water column, specifically at a depth of 1m from the surface of the water. Analysis of data collected over the past 18 months, however, suggests shellfish extraction of chlorophyll is not sufficient to be measurable at a depth of ~1m from the surface applying the methodology used in this study. Below are a number of factors that could explain the failure of the study to demonstrate what impact the shellfish might be having closer to the seabed.

1. Although the depths of the lays are between $\underline{0}_5$ and $\underline{3}_2$ m, the depths over the whole of the high-resolution sites range between 10 and $\underline{4}_5$ m. Slightly greater variation is found at the medium resolution site, where the depth of the stations varies between 11_7 and $\underline{3}_5$ m. With the sonde measurements being taken at high water ($\pm$ 1 hour), at a depth of ~1m, the height above the seabed at which the measurements were taken would have varied considerably. Even if mixing were to cause a measurable dilution of chlorophyll levels in the

upper water column, the lack of standardised heights between stations would likely have had a significant impact on those effects.

2. The spot sampling regime was conducted at high water (+/- 1hr). During the sampling period, therefore, the state of the tide would include ebb, flow and slack tidal conditions. Without an accurate hydrodynamic model to assess the water currents, it is difficult to determine to what extent these water movements would have influenced the results from this study.

3. Mixing of the water might not be sufficient to detect depletion of chlorophyll in the upper water column above the lays. This would be particularly problematic at sites where the water was deepest, or on calm days when there was little wave action to help mix the water.

It is likely therefore, that devising a discrete surveying design in which maintaining a fixed height above the seabed or one where continuous readings are being taken throughout the water column would be preferential to one aimed at maintaining a fixed depth below sea surface level. Fluctuations in chlorophyll level could then be interpreted more reliably as being linked to an effect of the shellfish presence or absence. In addition, although the ‘Ants’ site represents a shellfish-free control area, whilst monitoring shellfish occupied areas it would be useful to extend measurements across adjacent non-shellfish occupied areas to ascertain a possible effect zone.

Figure 6.11 shows similar trends between mean chlorophyll levels at the four sampling sites especially amongst the higher resolution sites. It is unclear why the medium resolution site shows weaker correlation than the other sites but could be an artifact of surveying at lower resolutions, where this site has fewer stations situated in a wider variety of depths such as in channels and at the mouth of the river. The three high-resolution sites showed a marked increase in chlorophyll levels in late spring/early summer, but failed to detect the dramatic increase in chlorophyll levels detected by the in-situ buoy sonde in May, indicative of a plankton bloom (figure 6.12). As monthly spot sample surveys at these sites were conducted one week prior to the in-situ buoy Sonde detecting this bloom and again one week after the chlorophyll levels had declined, it seems probable that the bloom was merely undetected at the high resolution sites rather than absent. Similarly, in figure 6.13, the chlorophyll RFU values measured in the River Ouse and the River Nene can be seen to peak in 2009 at a similar time of year as the plankton bloom occurred in 2010. However, these increased levels were not apparent in 2010, possibly due to the fact that these profiles are only conducted once in the winter and once during the summer months and may have missed the window when the bloom was present.

Water samples collected each month throughout the programme were analysed by Cefas using a flow cytometer to measure the size, shape and pigment content of cells. This analysis found that at the time of the May 2010 bloom, diversity had significantly reduced from what it had been in the April, and was dominated by a single large group of cells that were not present in any great quantities in April. Although these cells were not identified, they were thought to be a species of Phaeocystis (K. Owen, Cefas. Pers com). Phaeocystis species are flagellated single cells (5 µm) that form spherical colonies, surrounded by mucus-filled membranes. When colonies rupture or are broken down, the mucus is released. In addition to being “whipped” by the wind into a sticky foam, this mucus serves as an attachment for bacteria and other cells and particles. It is thought that the peak detected by the in-situ buoy Sonde in May might have been caused by a biofilm of mucus created by Phaeocystis, with an aggregation of cells and pigments embedded within it. Unfortunately, research results suggest that Phaeocystis species have an inhibitory effect on the filtration activity of mussels (Prins, 1994) potentially clogging the gills of filter feeders with polysacharide mucus (Pieters, 1980).

6.6 Aims of SWEEP 2011/12

The initial study was unable to confidently demonstrate what impacts shellfish beds were having on chlorophyll levels by measuring chlorophyll values at a depth of ~1m from the surface. To enable us to confidently attribute a change in chlorophyll levels to shellfish, and to ascertain the extent of any impact, the methodology will need to include measurements taken closer to the seabed. Research into the effective filtration zones for mussels have found that during mid ebb-tide, mussels were capable of filtering the water within 7cm of the seabed, removing approximately 20% of the seston flux within that region (Muschenheim & Newell, 1992). In a study at a mussel farm, this effect on chlorophyll levels was found to be detectable at ~1m distance from the mussels (Cranford et al., 2008).

In order to successfully measure the impacts the mussels are having on chlorophyll levels in the Wash, therefore, measurements should be taken at least within 1m of the seabed, preferably closer. Two such studies are planned to coincide with the anticipated plankton bloom in 2011. Similar to the current programme of high-resolution spot sampling, one will take static measurements over shellfish and non-shellfish areas, but within 10cm of the seabed rather than ~1m from the water surface. The other survey design involves drifting with the tide creating transects that extend through both shellfish and non-shellfish areas. Using two sondes, this study will attempt to take a series of measurements within 1m of the seabed whilst simultaneously taking vertical measurements through the water column. These survey designs are planned to be tested during the anticipated plankton bloom around April/May 2011.

7.0 SUFFOLK RIVERS SURVEYS

7.1 Introduction

Surveys were conducted in the two Suffolk rivers, Stour and Orwell, between March 15th-18th using the research vessel, *Three Counties*. Surveys in these rivers are usually conducted on alternate years, but following the discovery of relatively high numbers of Manila clams, *Tapes philippinarum*, in March 2009, a further survey was conducted in 2010. In addition to studying the distribution of the clam population, the programme included surveying the intertidal cockle, *Cerastoderma edule*, stocks along the intertidal banks of the rivers and monitoring two colonies of peacock worm, *Sabella pavonina*, that had been identified during previous surveys. The opportunity was also taken during this period to survey a population of native oysters, *Ostrea edulis*, in the Holbrook Bay area of the River Stour, using a commercial vessel.

7.2 Intertidal Cockle Survey

7.2.1 Method

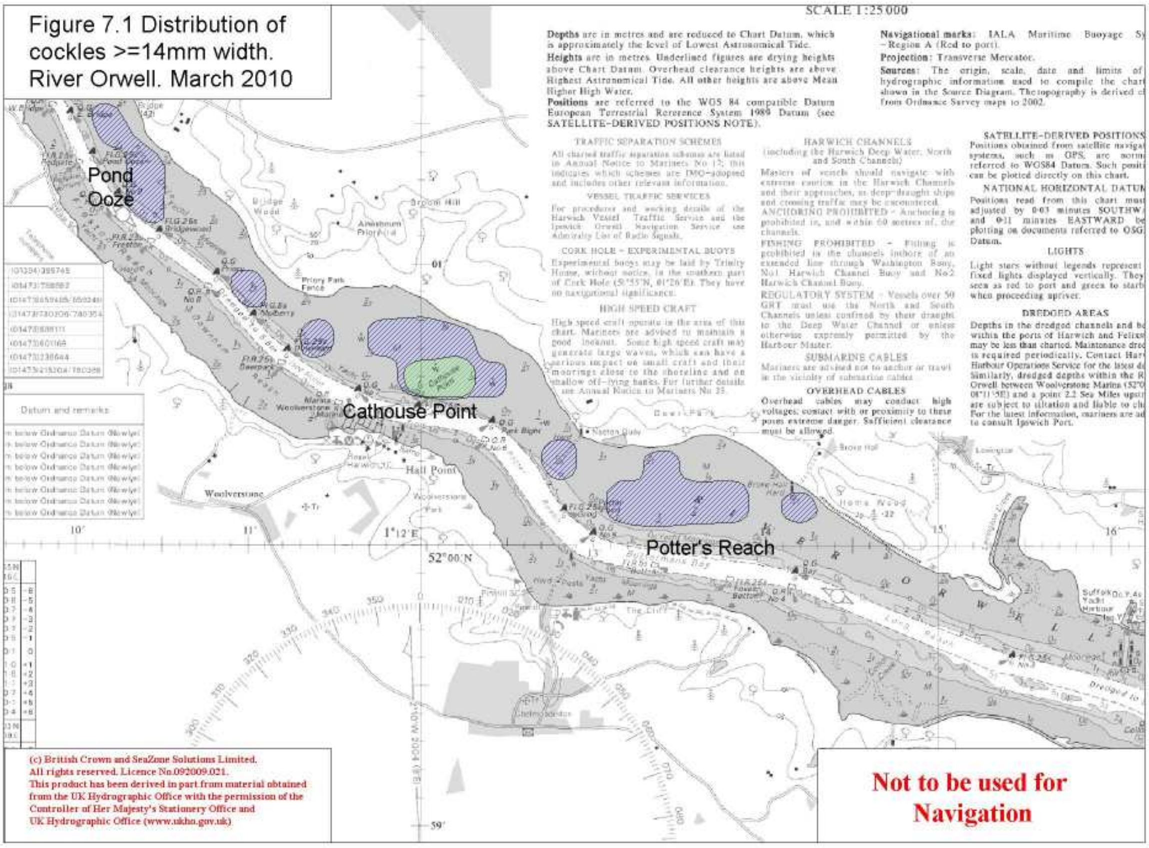
The cockle surveys were conducted using a similar methodology to those conducted in the Wash, in that samples were collected from stations approximately 250 meters apart along a regular, pre-determined grid. These were collected at high water using a Day grab. At each station the type of substrate was recorded prior to the sample being washed over a 3mm screen. Any cockles found within the samples were stored in labelled bags for later analysis, in which they were measured, categorised into age groups and weighed. This data was then further analysed using MapInfo GIS software to estimate the distribution of the stocks over the beds. The presence of other macro-fauna present in the samples was also recorded.

7.2.2 Results

7.2.2.1 River Orwell

Cockle surveys were conducted on the intertidal banks of the River Orwell on March 15th and 18th. These were limited to the northern bank of the river, in an area extending from the Orwell Bridge to Levington Creek. A total of 44 stations were surveyed in this area. Previous surveys have found cockles along this bank to be present in three discreet patches located at Pond Ooze, Cathouse Point and an area between Potter Point and Long Reach. Of the recent surveys conducted along this stretch of the river, the 2003 survey showed the highest cockle levels, when the stock was estimated to be 1,141 tonnes. In contrast, the 2009 survey found the stock had fallen to a ten-year low of 465 tonnes. The results from the 2010 survey indicated the stocks had continued to decline further.

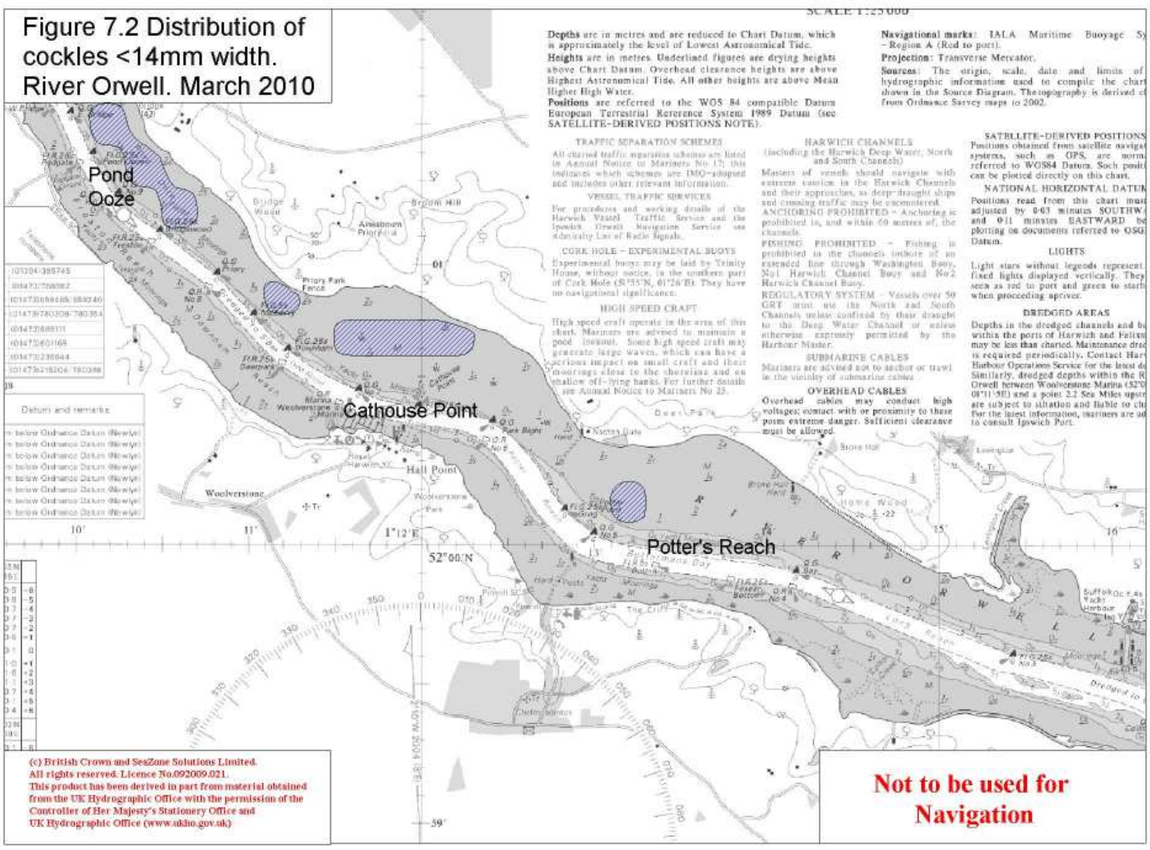
Figure 7.1 Distribution of cockles >=14mm width. River Orwell. March 2010



Density: Cockles / m

10 - 99 | 100 - 499 | 500 -999 | 1000+

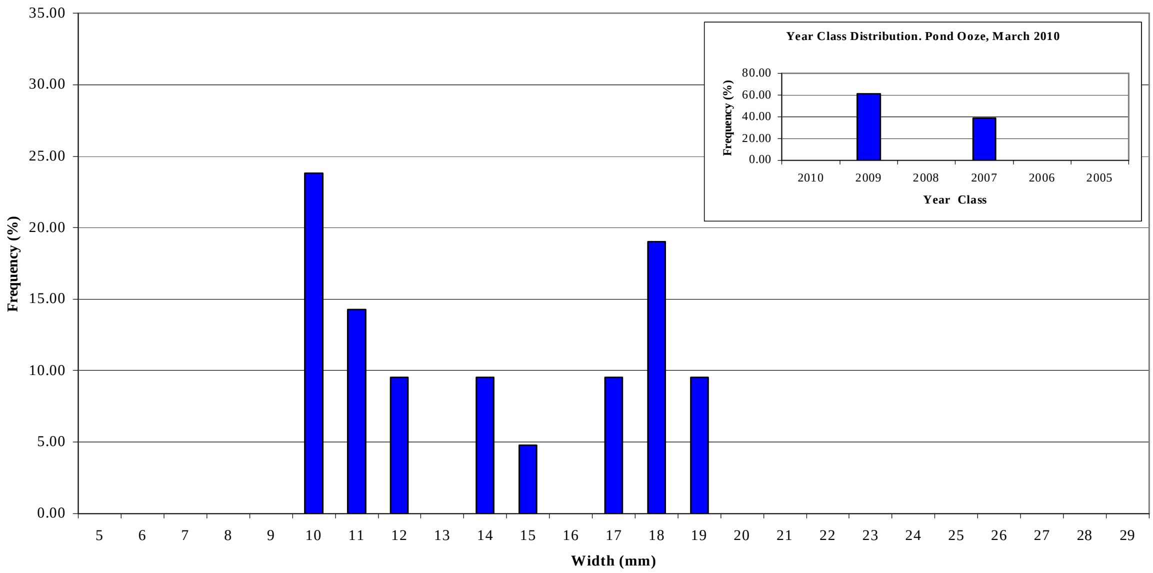
Figure 7.2 Distribution of cockles <14mm width. River Orwell. March 2010



Figures 7.1 and 7.2 show the distribution of cockles found along the north bank of the River Orwell during the surveys.

At Pond Ooze, four of the ten survey stations were found to harbour cockles of marketable size ($\geq$14mm width). These covered an area of 21.6 hectares, a reduction from the 30.3 hectares recorded in 2009 and considerably less than the 73 hectares recorded following the 2003 survey. The mean density of these market-sized cockles was found to be 27.5 cockles/m^2 (range 10 – 50/m^2) compared to 40 cockles/m^2 (range 10 – 90/m^2) the previous year. This appears to be the result of the loss of older cockles from the population. When surveyed in 2009, the population was composed of a mixture of 2006 and 2007 year-class individuals, of which the majority of the 2007 cohort were still below marketable size. Figure 7.3, however, shows the 2006 cohort to be no longer present in this area by the time of the 2010 survey, the marketable-size population being represented by a smaller 2007 cohort. Although individually these had a slightly higher mean weight than the 2006 cohort (5.8g compared to 4.3g), this was not sufficient to compensate for the loss of numbers. As a consequence the mean cockle biomass had decreased slightly from 1.73 tonnes/hectare to 1.59 tonnes/hectare. From these figures the stock of market-sized cockles in this region was calculated to be 34 tonnes, a reduction from the 52 tonnes calculated to be present in 2009. In 2003 this area had supported 603 tonnes of market-sized cockles. Figure 7.3 shows the size distribution of the cockles found at Pond Ooze.

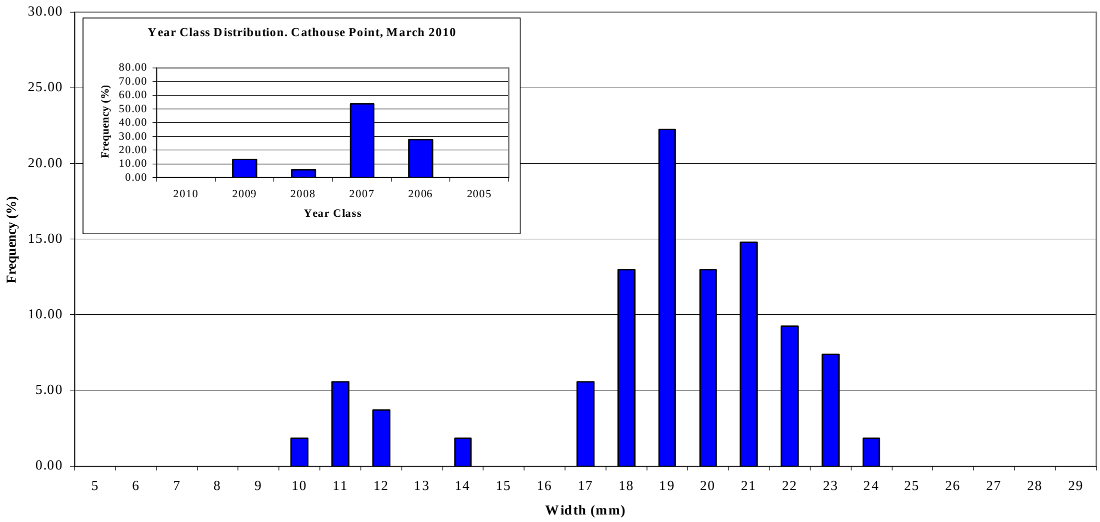
Figure 7.3 - Cockle Size Distribution. Pond Ooze. March 2010



Smaller sized cockles, represented by a settlement of 2009 year-class individuals, were found to be present at four of the survey stations, covering an area of 23.0 hectares. Although this is a slight increase on the 19.5 hectares recorded in 2009, the mean density of small cockles within this area was found to have decreased from 126.7 cockles/m^2 (range 10 – 350/m^2) to 25.0 cockles/m^2 (range 10 – 30/m^2). As the population in 2009 was composed of two year old cockles from the 2007 year-class cohort, their mean size was greater than that of the 2009 year-class, one year old, cockles that were representing the population in 2010 (2.8g compared to 1.5g). As a consequence of these changes, the mean biomass had decreased by 89%, from 3.50 tonnes/hectare to 0.39 tonnes/hectare. The stock of smaller cockles was calculated to have decreased from 68 tonnes in 2009 to 9 tonnes in 2010.

Between Cathouse Point and Potter Point 7 of the 13 survey stations were found to contain marketable sized cockles. These covered an estimated area of 44.2 hectares, slightly more than the 38.3 hectares recorded in 2009. The mean density of these cockles was found to be 68.57 cockles/m^2 (range 10 – 210), similar to the 70.0 cockles/m^2 (range 10 – 210) present the previous year. Although the densities are similar, the population structure had changed somewhat. In 2009 the population of market-size cockles consisted mainly of 2006 year-class individuals, plus some older individuals from the 2004 and 2005 year-class cohorts. The results from the 2010 survey show these older cockles have disappeared from the population, the market-size population comprising 2006 and 2007 year-class cockles (figure 7.4). Even though these older cockles had been lost from the population, individually, the mean cockle weights were found to have increased from 6.0g in 2009 to 8.7g in 2010, helping the mean cockle biomass increase from 4.20 tonnes/hectare to 5.96 tonnes/hectare. From these figures the stock of marketable sized cockles was calculated to be 263 tonnes, an increase on the 161 tonnes recorded in 2009, but lower than the 311 tonnes recorded in 2007 and 300 tonnes recorded in 2003. Figure 7.4 shows the size distribution of cockles found at Cathouse Point during the surveys.

Figure 7.4 - Cockle Size Distribution. Cathouse Point. March 2010

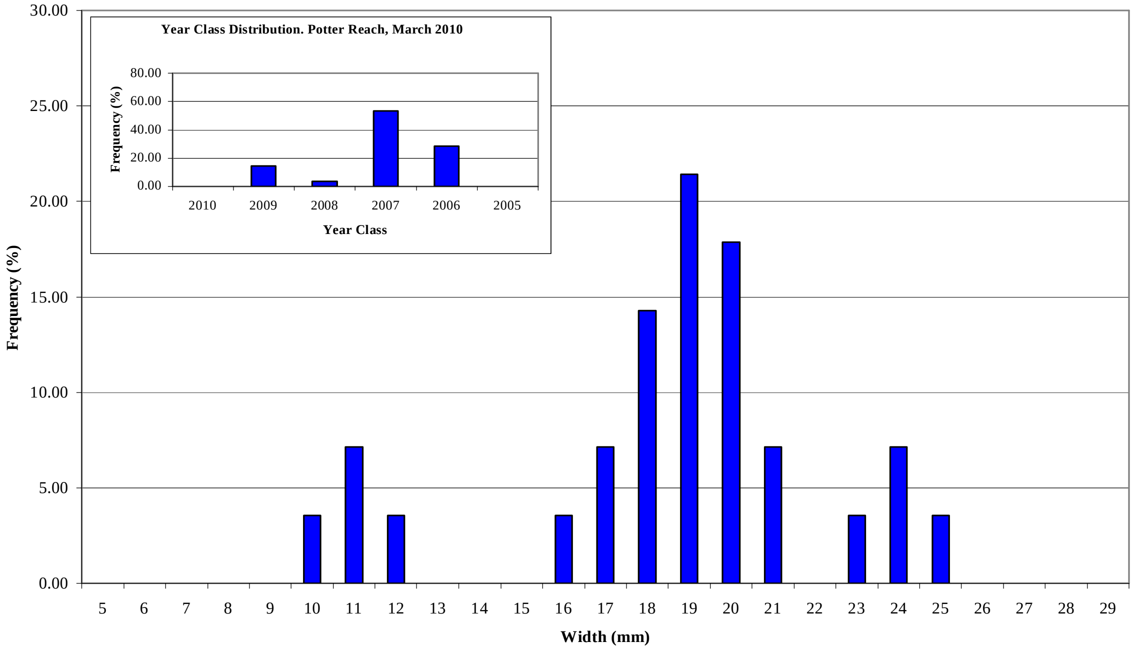


Four of the survey stations, covering an area of 20.5 hectares, were also found to support low numbers of smaller cockles. This is a reduction to the 35.8 hectares supporting smaller cockles in 2009 and the 46 hectares recorded in 2007. Consisting of members of the 2008 and 2009 year-class cohorts, these had a mean density of 15.0 cockles/m^2 (range 10 – 30). This is a reduction from the previous year when the population, consisting of members of the 2007 year-class cohort, had a mean density of 28.6

cockles/m^2 (range 10 – 90). Because at the time of the 2009 survey the population had been predominantly older than the 2010 population, the mean weight of the individuals had been almost double (2.7g in 2009 compared to 1.4g in 2010). These changes meant the mean biomass had decreased from 0.76 tonnes/hectare in 2009 to 0.20 tonnes/hectare in 2010. The stock of smaller cockles in this area was found to have decreased from 27 tonnes to 4 tonnes.

Between Potter Point and Long Reach, seven of the 21 survey stations were found to harbour marketable sized cockles. These covered an area of approximately 34.1 hectares, slightly more than the 32.9 hectares recorded in 2009 and similar to the 35 hectares recorded in 2007. Although the area of coverage was similar to the two previous surveys, the mean density of these cockles was found to have decreased from 81.7 cockles/m^2 (range 10 – 340) in 2009 to 34.29 cockles/m^2 (range 10 – 80). This is of a similar density to 2007, when 30 cockles/m^2 (range 10 – 110) had been present. In 2009 the cockle population in this stretch of the river was composed of marketable sized 2006 year-class cockles, and a larger number of 2007 year-class cockles, approximately half of which had attained marketable size. Although by 2009 all of the 2007 year-class cohort were found to have attained market size, the reduction in the mean density of marketable sized cockles from 81.7 cockles/m^2 to 34.29 cockles/m^2 shows there had been a significant mortality among these two cohorts between the two surveys. As these cockles had grown well, however, from a mean weight of 4.8g in 2009 to 8.9g in 2010, despite the large reduction in density, the mean biomass had only decreased from 3.9 tonnes/hectare to 3.1 tonnes/hectare. It was calculated from these figures that 104 tonnes of marketable sized cockles were present at this site, 26 tonnes less than had been recorded in 2009. Figure 7.5 shows the size distribution of cockles found at Potter Reach during these surveys.

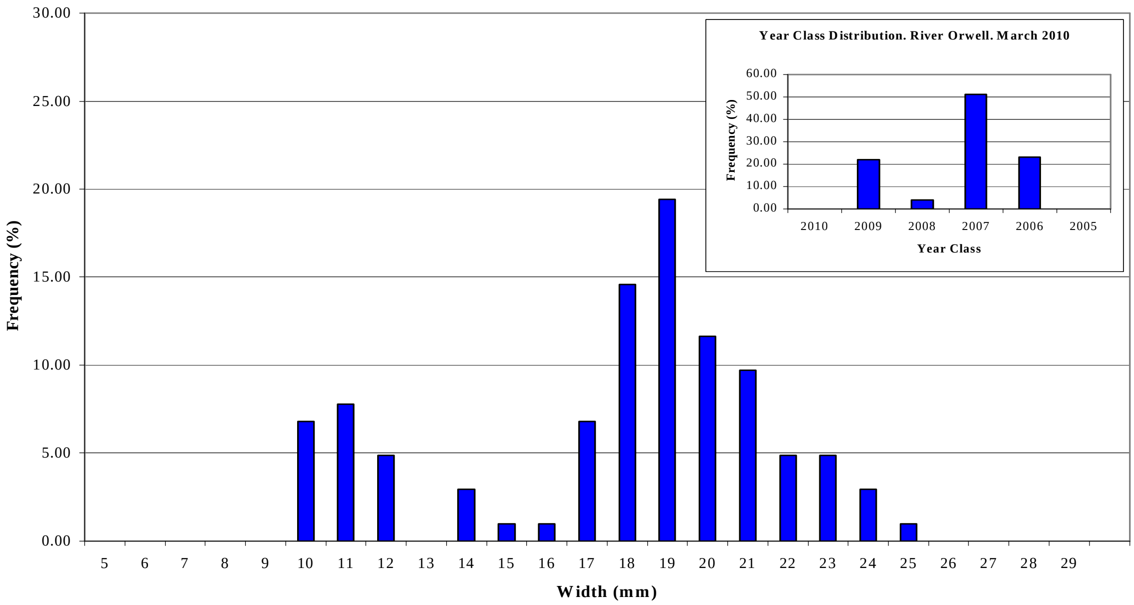
Figure 7.5 - Cockle Size Distribution. Potter Reach. March 2010



Just one site, covering 5.3 hectares, was found to support smaller cockles, a reduction from the 14.1 hectares recorded in 2009. This fall was caused by poor recruitment in 2009 combined with the 2007 year-class cockles that formed this population in 2009 growing to marketable size. At 10 cockles/m^2, the mean density had fallen from 66.7 cockles/m^2, while the mean biomass had decreased from 1.9 tonnes/hectare to 0.73 tonnes/hectare. Applying these figures, the stock of small cockles in this area of the river was found to have decreased from 27 tonnes in 2009 to 4 tonnes.

Combining the three areas, this stretch of the River Orwell was found to support 401 tonnes of marketable sized cockles and a further 25 tonnes of smaller cockles. Although the stock of marketable sized cockles has increased from 343 tonnes in 2009, the stock of smaller cockles has fallen during the same period from 122 tonnes. Together, this means the total stock in this area has declined from 465 tonnes to 426 tonnes, the lowest level since ESFJC began conducting surveys in this river in the 1990s. Figure 7.6 shows the combined size distribution of the cockles found on the River Orwell during these surveys.

Figure 7.6 - Cockle Size Distribution. River Orwell. March 2010



River Stour – Holbrook Bay

Cockle surveys were conducted in the Holbrook Bay area of the River Stour on March 16th and 17th, during which samples were collected from 74 stations using a Day grab deployed from the research vessel, *Three Counties.* 13 of these stations, covering an area of 75.2 hectares, were found to support marketable-sized cockles (figure 7.7), an increase to the 54 hectares recorded in 2009. These were found to have a mean density of 17.69 cockles/m^2 (range 10 - 50), a slight increase on the 16.36 cockles/m^2 (range 10 - 40) recorded the previous year. The mean biomass of these cockle was found to be 1.41 tonnes/hectare, a slight reduction to the 1.68 tonnes/hectare recorded in 2009.

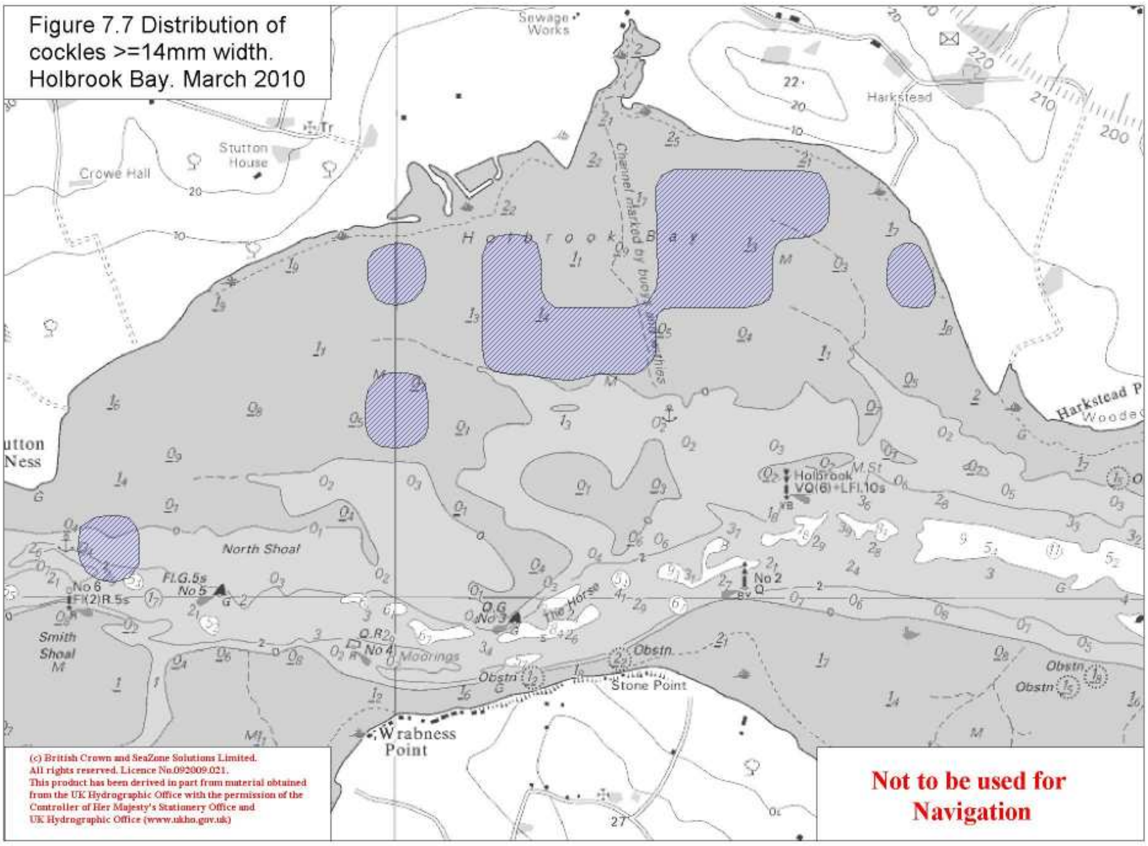
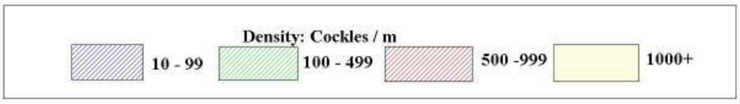


Figure 7.7 Distribution of cockles >=14mm width. Holbrook Bay. March 2010



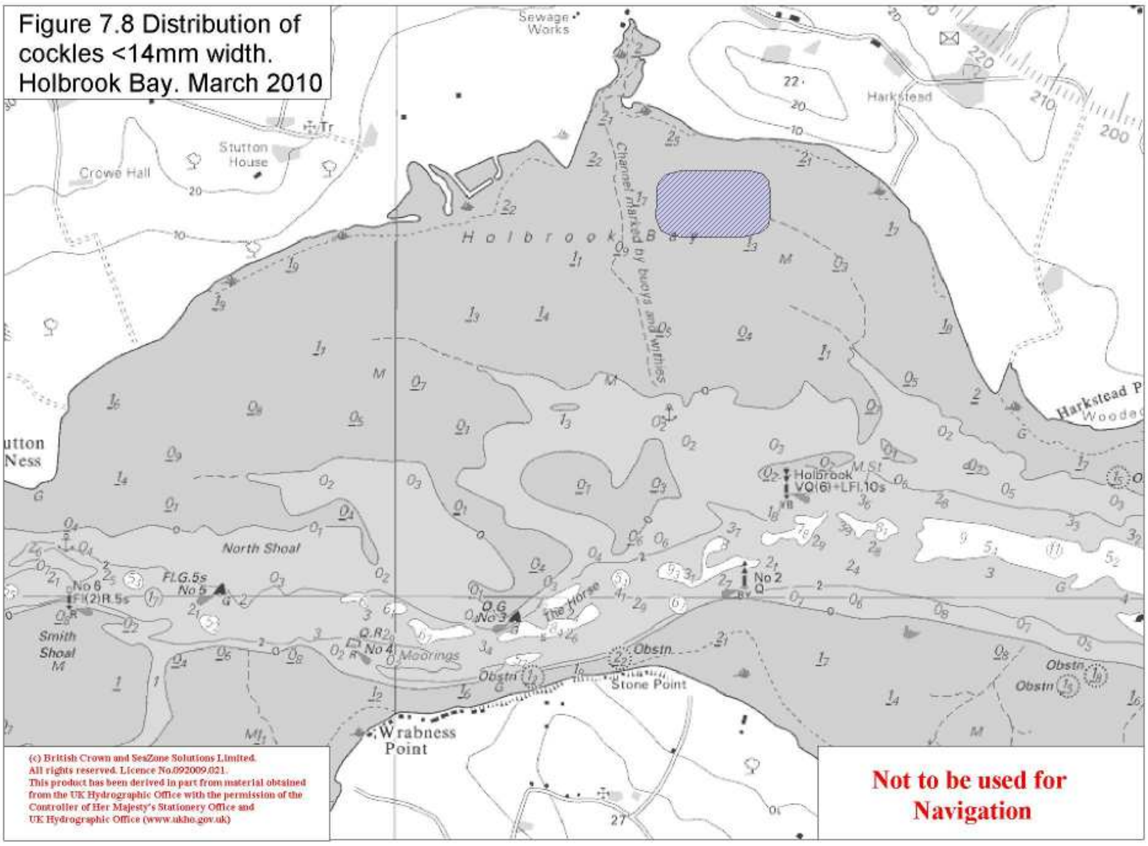


Figure 7.8 Distribution of cockles <14mm width. Holbrook Bay. March 2010

From these figures the stock of marketable sized cockles was calculated to be 106 tonnes, a slight increase to the 91 tonnes recorded in 2009.

Smaller cockles were found to be present at two sites, covering an area of 11 hectares (figure 7.8). Similar to 2009, these were present in low densities of 10 cockles/m^2, with a mean biomass of 0.16 tonnes/hectare. These equated to a stock of less than 2 tonnes.

In 2009 the cockle population was found to contain individuals from all cohorts ranging from year-1 to year-6. When surveyed in 2010, however, no individuals from the 2003-2005 cohorts were found, the population being represented by the 2006, 2007 and 2008 cohorts. Although the growth of these three cohorts has compensated for the loss of older cockles from the population, the absence of any year-1 cockles could mean the population will decline in 2011. Figure 7.9 shows the size distribution of the cockle found at Holbrook Bay during these surveys.

Figure 7.9 - Cockle Width Distribution. Holbrook Bay. March 2010

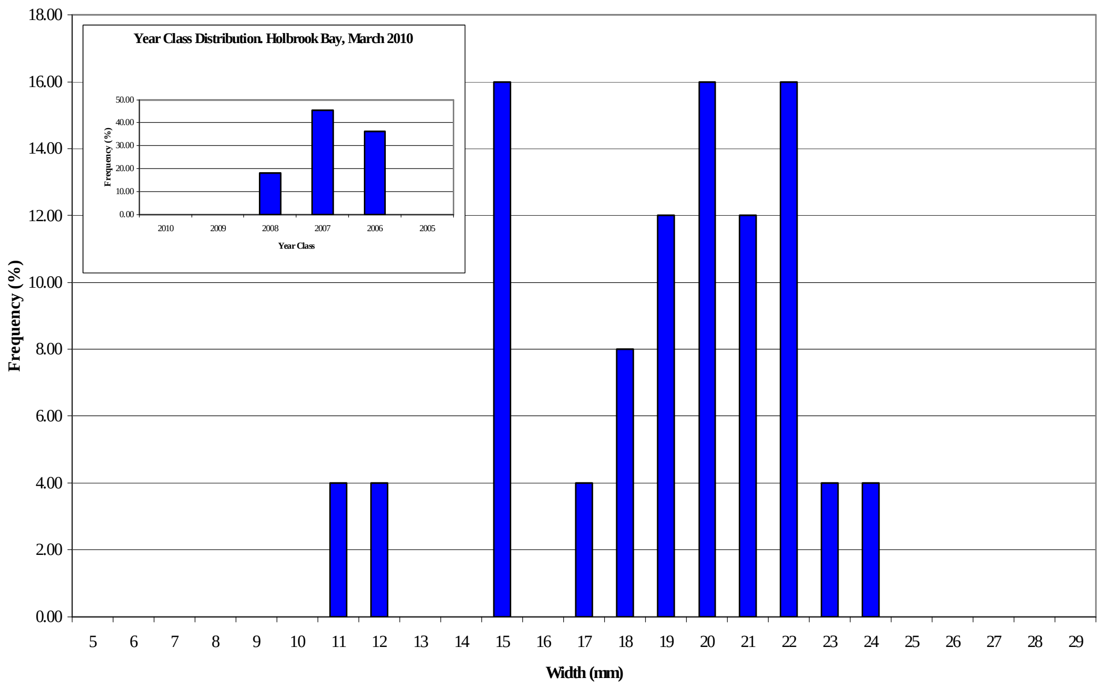


Table 7.1 summarises the cockle stocks found at each of the survey areas during the past five surveys.

Table 7.1 Biomass of cockles at three sites on the River Orwell and at Holbrook Bay on the River Stour during 2001, 2003, 2007, 2009 and 2010

	ADULT					JUVENILE				
Site	**Biomass (Tonnes)**					**Biomass (Tonnes)**				
	2001	**2003**	**2007**	**2009**	**2010**	**2001**	**2003**	**2007**	**2009**	**2010**
Pond Ooze	<10	603	57	52	34	0	32	40	68	9
Cathouse Pt	314	300	311	161	263	0	38	31	27	4
Potter each	632	159	86	130	104	0	9	1	27	4
Total	**946**	**1062**	**455**	**343**	**401**	**0**	**79**	**72**	**122**	**17**
Holbrook	138	77	23	91	106	0	3	2.5	2	2

7.2.4 Discussion

The 2010 survey found there had been a slight increase in the adult cockle stocks on the northern bank of the River Orwell between the Orwell Bridge and Levington Creek since the previous survey in 2009. The current stock levels are still much lower than when surveyed in 2001 and 2003, however. ESFJC only began surveying these stocks in 1997, so it is difficult to determine from the short data record whether the cockle stocks have declined in recent years or whether the high stocks found in 2001 and 2003 were themselves above average for the area following exceptional settlements in 1997 and 2000. Cockle populations do widely fluctuate naturally, and this can be seen from the survey record to have occurred in the stock levels at Pond Ooze and Potter Reach, where stocks have on occasions increased significantly following exceptional spatfalls. As the peaks in the stock levels have generally been influenced by single strong year-class cohorts, however, the stock levels have plunged once that cohort has aged and died. In contrast, the population at Cathouse Point appears to have remained more stable. Since 2007 there has not been a strong settlement along this northern bank of the River Orwell, so stocks are likely to decrease as the cockles from older cohorts die.

Throughout the survey period, the data show the cockle stocks at Holbrook Bay on the River Stour to be lower than those in the River Orwell. Unlike the River Orwell stocks, however, which have declined during the past decade, the Holbrook Bay stocks have shown a recovery following low stock levels in 2007.

7.3 Native Oyster Survey

7.3.1 Introduction

A survey conducted by ESFJC in 2001 revealed a bed of native oyster, *Ostrea edulis*, to be present around the Gallister's Creek area of Holbrook Bay on the River Stour. These are thought to be the remnants of what was once, historically, an oyster farm located in this same area. An application to dredge for these oysters was submitted to the Committee in 2002, but until a complete stock assessment could be completed, the area was temporarily closed to shellfish fishing. A stock assessment was conducted in February 2004, in which the oyster population was estimated to be between 11.5 and 17.3 tonnes (Jessop, Lowry, Graves, 2003). This was considered too small to support a sustainable commercially viable fishery so the temporary closure was kept in place. In 2005, a further survey found the oysters to be suffering from an unidentified abnormal shell condition, and the stock had fallen to between 6.5 and 10.8 tonnes (Jessop, Graves, 2005). Subsequent surveys have been conducted annually, the results from which have shown the stocks to fluctuate but fail to reach the levels recorded in 2004. The survey conducted in March 2010 estimated the stocks to be between 3.7 and 6.2 tonnes. During this survey, tows were also conducted for the first time on the south side of the River Stour, near Copperas Bay. An additional stock of between 2.1 and 3.6 tonnes were estimated to be present in this area.

7.3.2 Method

Surveys were conducted from a commercial fishing vessel, towing a commercial oyster dredge over areas the oysters were known from previous surveys to be present. Tows varied in length between 29 and 246 metres, with care being taken not to extend the tow lengths beyond the holding capacity of the dredge. For tows in which the dredge was considered to have been fishing inefficiently, or had totally filled with mud, the tow was classed as void and the data discarded. Positions were recorded using a portable GPS at the start and end of each tow, and these data were later analysed using MapInfo™ GIS to determine the precise length of each tow. All oysters caught were measured and individually weighed aboard the vessel.

7.3.3 Results

A total of 124 tows were conducted over a two-day period, 39 of which were located in the previously unsurveyed areas of the river near Copperas Bay (figure 7.10). Of these tows, eight were discarded for fishing inefficiently or for filling with mud, five of which were from the usual Holbrook Bay survey area and three from near Copperas Bay. Of the 80 valid tows conducted at the Holbrook Bay sites, 30 were found to contain live oysters (range 1 – 5 oysters/tow). These were found to be present in

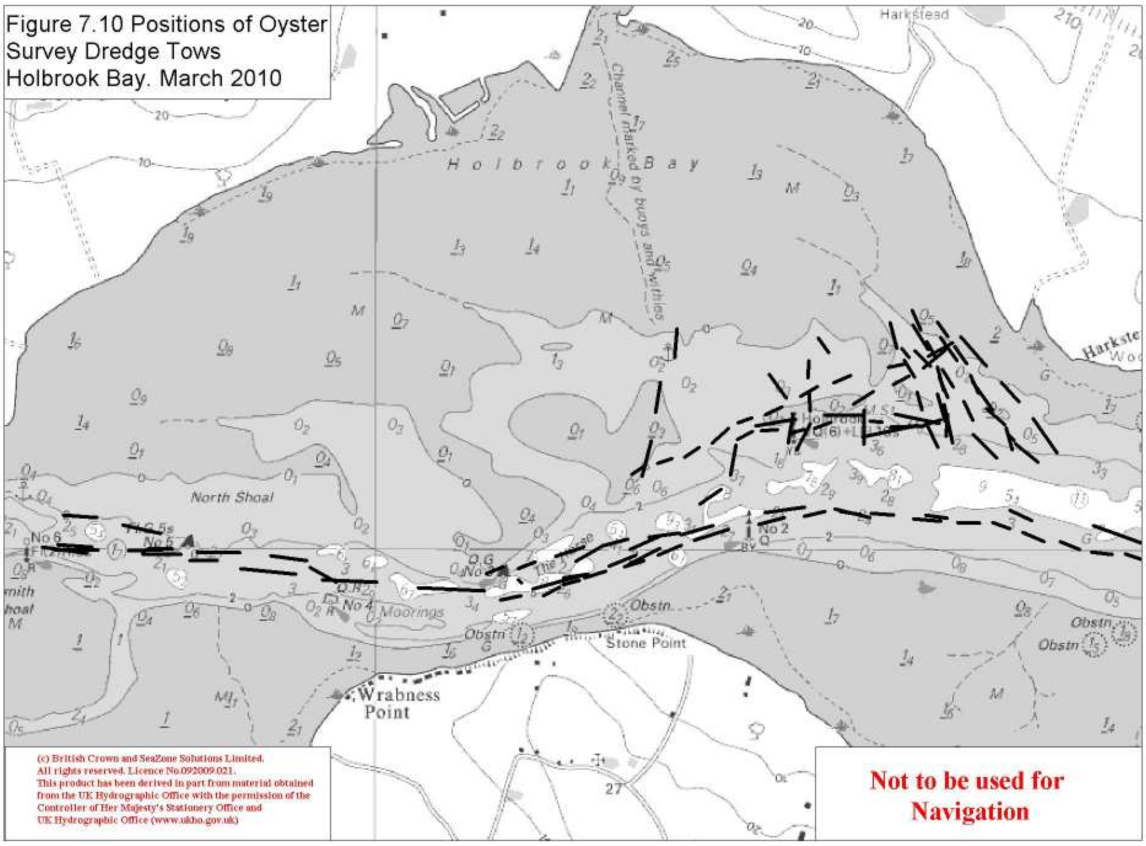
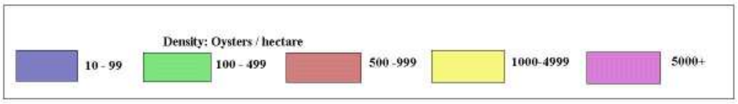


Figure 7.10 Positions of Oyster Survey Dredge Tows Holbrook Bay. March 2010



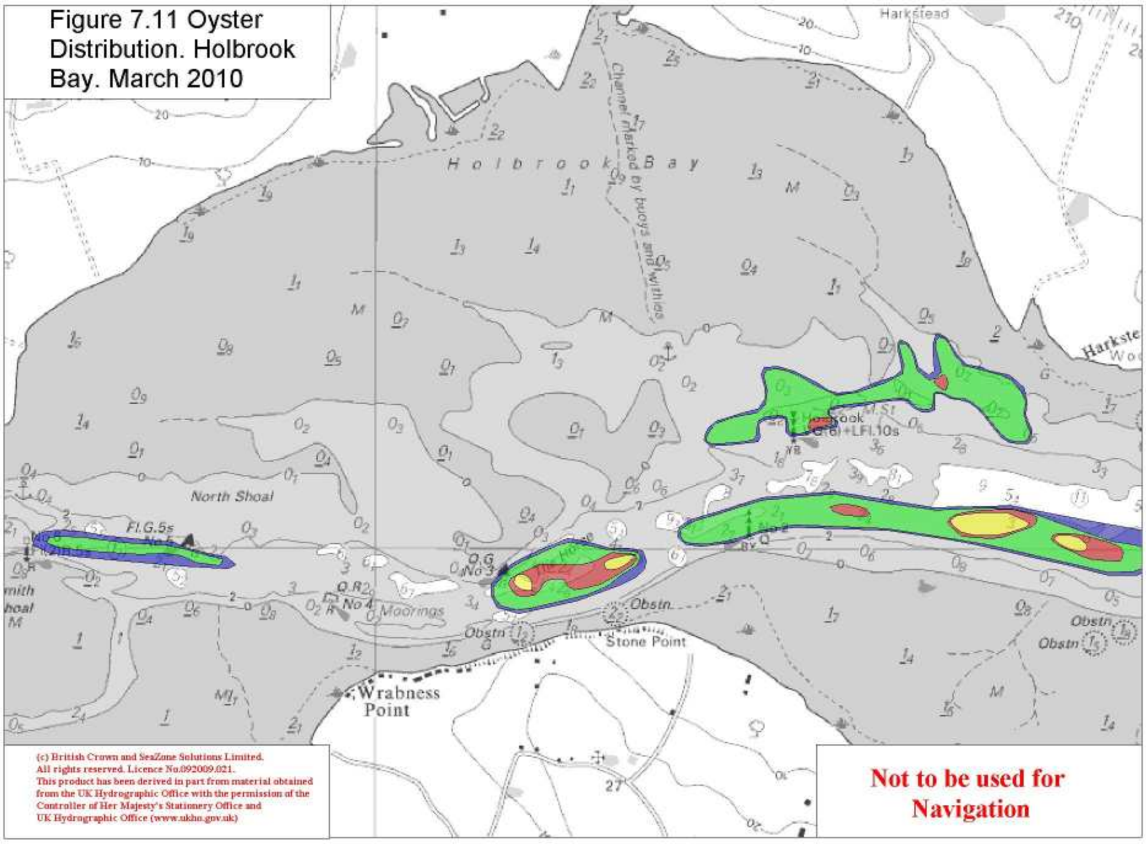


Figure 7.11 Oyster Distribution. Holbrook Bay. March 2010

densities between 0.66 oysters/100m^2 and 6.84 oysters/100m^2. Of the 36 valid tows conducted near Copperas Bay, 31 were found to contain live oysters (range 1 – 13 oysters/tow). These were found to be present in densities between 0.53 oysters/100m^2 and 46.78 oysters/100m^2.

The dredge tow data was analysed using MapInfo™ GIS, from which a distribution chart of the oyster beds was created (figure 7.11). From this chart it was estimated that 4.1 hectares of the Holbrook Bay site supported oyster densities in excess of 5 oysters/100m^2, while a further 29.6 hectares supported lower densities. Assuming a 100% catch efficiency of the dredge, the high-density region was estimated to contain 639kg of oysters, while a further 603kg were calculated to be present in lower densities. At best, under ideal conditions, these dredges are thought to be no more than 30% efficient, however, with an average efficiency of only 20% more likely. When this error is taken into account, a more accurate estimate of the stock would place between 1,917kg and 3,195kg of oysters in the higher density regions and between 1,810kg and 3,017kg in the low-density regions. The total oyster stock in the area of Holbrook Bay was, therefore, estimated to be between 3,727kg and 6,212kg.

At the Copperas Bay site, 4.3 hectares were estimated to support oyster densities in excess of 5 oysters/100m^2, while a further 19.9 hectares supported lower densities. Assuming 100% catch efficiency, the high-density region was estimated to contain 341kg of oysters, while a further 372kg were calculated to be present in lower densities. Taking into account the same dredge inefficiencies as at the Holbrook Bay site, the actual oyster stock in this area was estimated to be between 1,023kg and 1,705kg in the high-density region, and between 1,117kg and 1,862kg in the low-density region. The total oyster stock in the Copperas Bay area was estimated to be between 2,140kg and 3,566kg.

The oysters in the River Stour were located predominantly on ground composed of gravel and cobbles over muddy sand. There is a rich biodiversity at the site, with Slipper Limpet, *Crepidula fornicata*, being the predominant species. Tunicates are also abundant, frequently attaching themselves to the oysters in large numbers. Other species seen to be present were the Shore Crab, *Carcinus maenas*, Mussel, *Mytilus edulis,* Manila Clam, *Tapes philippinarum,* Periwinkle, *Littorina littorea*, Hydroids, Anemones, Polychaeta, Brittle Stars, Spider Crab and Sea Mites.

7.3.4 Discussion

Table 7.2 shows the estimated oyster stocks present in Holbrook Bay between 2004 and 2010. Following the initial survey, in which the stock levels were at their highest recorded level during the seven-year period, they appeared to suffer a significant decline between 2004 and 2006 from which subsequent recovery has been negligible. Although the reason for this decline could not be positively determined, the 2005 survey found many of the oysters were exhibiting an abnormal shell condition in which the outer edge of their upper valve was soft and sponge-like rather than hard. Samples of these oysters were forwarded to CEFAS for tests, but the results failed to identify any pathogenic cause for the condition (Jessop, Graves, 2005). This condition was found to still be present in the oysters at the time of the 2006 survey, in which the stocks were found to have declined further. In surveys conducted subsequent to 2006, incidence of the condition was greatly reduced with only occasional oysters showing signs of being affected. The 2007 survey found the stock had recovered slightly, back to 2005 levels, but the 2008 survey found there had been another decline. The results from the 2009 survey showed the stocks to be at their lowest level since surveys began in 2004. This survey, however, had been conducted in very poor weather conditions, so it is likely that the dredge was fishing ineffectively. Although this makes direct comparison between the 2009 surveys and the previous ones difficult, the oyster stock nevertheless appears low even if poor dredge efficiency is taken into account. The latest survey, conducted in 2010, found the stock levels to be similar to those recorded in 2008. At roughly a third of the biomass present in 2004, the stock appears to be slow in recovering from whatever had caused the decline in 2005-2006.

Table 7.2 – Estimated biomass of native oysters present in Holbrook Bay between 2004 and 2010, the mean weight of individual oysters and the proportion of Year-0 juveniles

Year	Total Oyster Stock (tonnes)	Mean Weight (g)	Proportion Year-0 (%)
2004	11.55 – 17.33	149.43	15.1
2005	6.47 – 10.80	160.88	13.8
2006	3.33 – 5.00	124.14	23.7
2007	6.63 – 11.05	136.25	18.2
2008	3.48 – 5.80	132.45	18.6
2009	1.9 – 3.2 (*1)	205.42	9.2
2010	3.73 – 6.21 (*2)	124.13 (*2)	32.7 (*2)

*1 - Survey results likely to have been influenced by poor weather

*2 – Data does not include stock found at Copperas Bay

Table 7.2 also shows the mean weight of individual oysters sampled during each survey and the proportion of the population that were year-0 juveniles. As would be expected, there is a strong correlation between these two variables, as high levels of small juvenile oysters will naturally reduce the mean weight of the population. A high proportion of juveniles does not necessarily indicate a successful settlement, however, as a high mortality among older individuals can also influence these figures. This is probably the case in 2006, where the abnormal shell condition appeared common in large oysters but was almost absent in smaller individuals. If the condition was terminal and larger individuals were being removed from the population at a higher rate than smaller individuals, there would be a bias towards a higher proportion of juveniles within the population and a reduced mean weight. Under such circumstances, it is also likely that the population biomass would also decrease, as was seen in 2005 and 2006. In contrast, the population biomass appears stable between 2008 and 2010, indicating the elevated proportion of juveniles witnessed in 2010 is most likely due to a successful settlement having occurred between the 2009 and 2010 surveys.

During the 2010 survey additional tows were conducted on the southern side of the river near Copperas Bay. This area falls within Kent and Essex Sea Fisheries Committee's district, and as such had not been surveyed by ESFJC before. The survey found an estimated 2.1 – 3.6 tonnes of oysters to be present in this area, their sizes indicating the bed was only a few years old. These oysters appeared to have settled on a gravel bank that contained little mud. The Holbrook Bay beds were situated on similar substratum in 2004, but several of these areas have becoming muddier during the period that the surveys have been conducted. This change could have had a deleterious impact on the oyster population that typically cements itself to the substratum. Unable to migrate, adults could become smothered by silt and die, while smothering of suitable substrata could restrict larval settlement.

7.4 Manila Clam Survey

7.4.1 Introduction

Between 1993 and 1996 Eastern Sea Fisheries Joint Committee conducted a number of small-scale surveys in some of the Suffolk rivers including the Blythe, Debbin, Alde and Ore, in order to improve its knowledge of the species inhabiting those areas. In 1997 a larger survey was conducted in the Stour and Orwell rivers using the research vessel *ESF Surveyor*, primarily to determine what shellfish stocks might be present along the banks and in the bays of those rivers. The beds of the two rivers were also surveyed at that time using RoxAnn^{TM} Acoustic Ground Discrimination Survey (AGDS) equipment in conjunction with beam trawl and Day grab sampling. During the 1997 survey significant stocks of edible cockles (*Cerastoderma edule*) were identified to be present along the banks of both rivers. These surveys were subsequently repeated in 2001, 2003, 2007 and 2009, over which period the cockle stocks appeared to be declining in numbers. During the 2009 survey, a significant number of Manila clams (*Tapes philippinarum*) were found to be present in both rivers (Jessop, *et. al.* 2009.) These are a non-native species of clam that had been introduced into Poole Harbour in 1998 for aquaculture. At that time UK waters were thought to be too cold for *T. philippinarum* to successfully breed but by 1994 the Poole Harbour population were found to have naturalised (Jensen, *et. al*. 2004), becoming the northernmost naturalised population of this clam in Europe. Although they are not known to have been intentionally introduced into the Stour and Orwell rivers, it is possible that larvae could have been introduced in ballast water from shipping. A further survey was conducted in 2010 to determine whether significant numbers of *T. philippinarum* were still present in the rivers, and if so, whether the population appeared sufficient to support a sustainable fishery.

7.4.2 Method

Sample stations were arranged at regular intervals on predetermined grids, situated along the northern bank of the River Orwell between Pond Ooze and Levington (figure 7.4.1) and covering the Holbrook Bay area of the River Stour (figure 7.4.2). These same stations had been used during all of the previous surveys between 1997 and 2009 in order to survey the cockle stocks.

At each of the stations a sample covering an area of 0.1m^2 was collected using a Day grab deployed from the research vessel during the high water period. These samples were washed over a 3mm mesh washing table, allowing any shellfish present in the sample to be separated from the surrounding sediment. A note was made of the sediment type at each station and any shellfish present in the sample were retained. During analysis, the retained samples were individually measured by length and width to the nearest 1mm, and in the case of *T. philippinarum,* individually weighed using electronic scales capable of measuring between 0.01g to 200g.

The data acquired from these surveys were transferred to a MapInfo GIS database. Vertical Mapper software was then used to create Nearest Neighbour interpolated models of *T. philippinarum* distribution within the two rivers. The total biomass of *T. philippinarum* was calculated by multiplying the area of clam coverage by the mean weight of the samples.

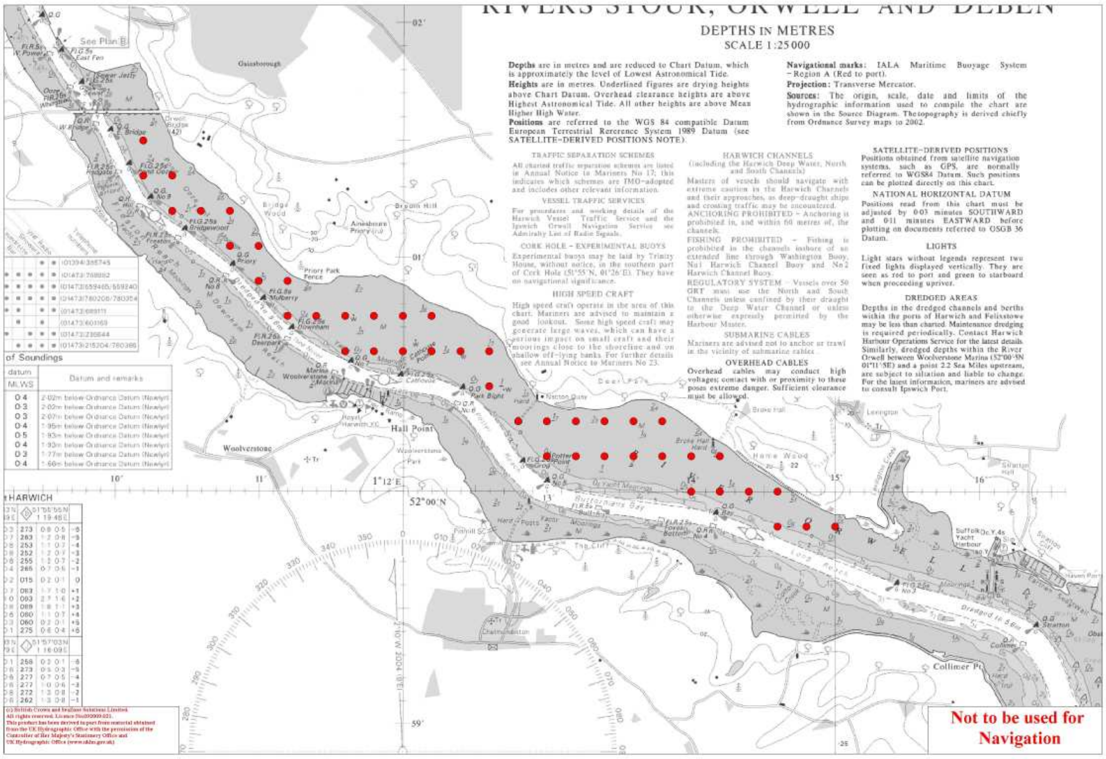


Figure 7.4.1. Chart showing the positions of the sample stations on the River Orwell surveyed by ESFJC between 1997 and 2010.

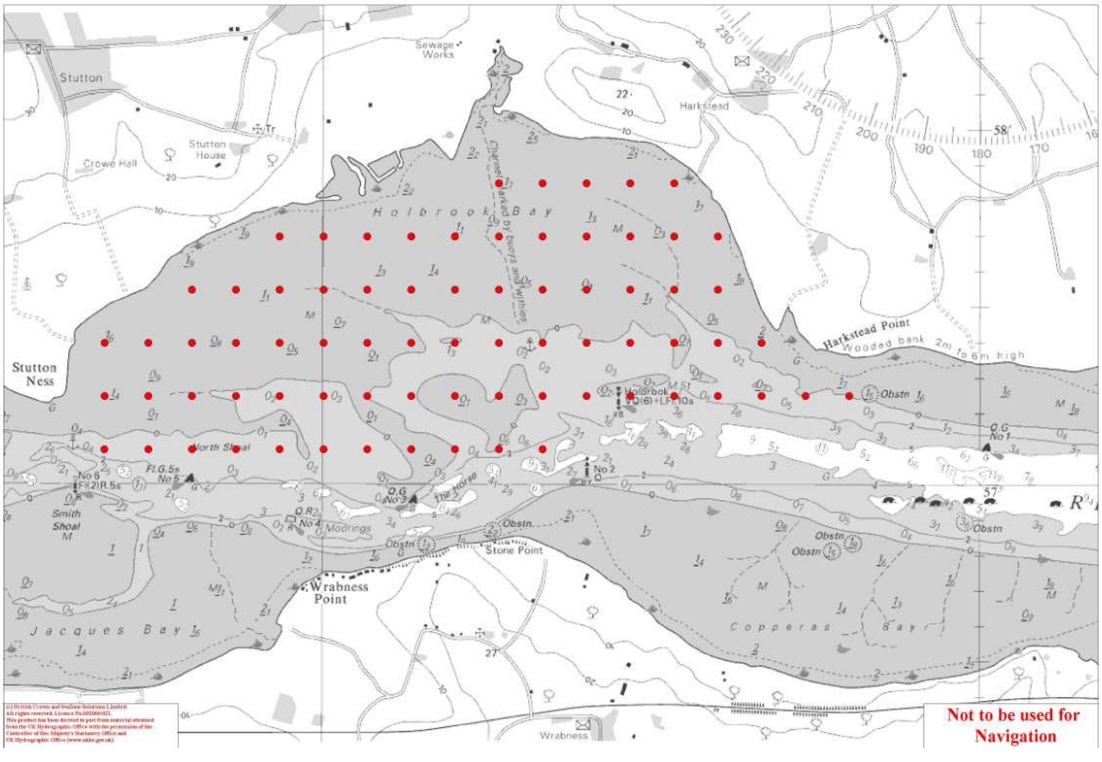


Figure 7.4.2. Chart showing the positions of the sample stations at Holbrook Bay in the River Stour surveyed by ESFJC between 1997 and 2010.

7.4.3 Distribution of *T. philippinarum* in the River Orwell

During the 2009 survey, nine of the 44 survey stations in the River Orwell were found to support *T. philippinarum*. From these data, an interpolated model of *T. philippinarum* distribution was created (figure 7.4.3). Analysis of this modelled distribution identified the clams were present in an area covering 51 hectares. Within this area their mean density was found to be 11 clams/m^2 (range 10-20 clams/m^2), with a mean biomass of 2.76 t/ha. Individually, these clams had a mean weight of 24.8g (range 6.6 - 54.2g). The total biomass of *T. philippinarum* within the survey area was estimated to be 150 tonnes (+/- 70 tonnes at a 95% confidence interval) .

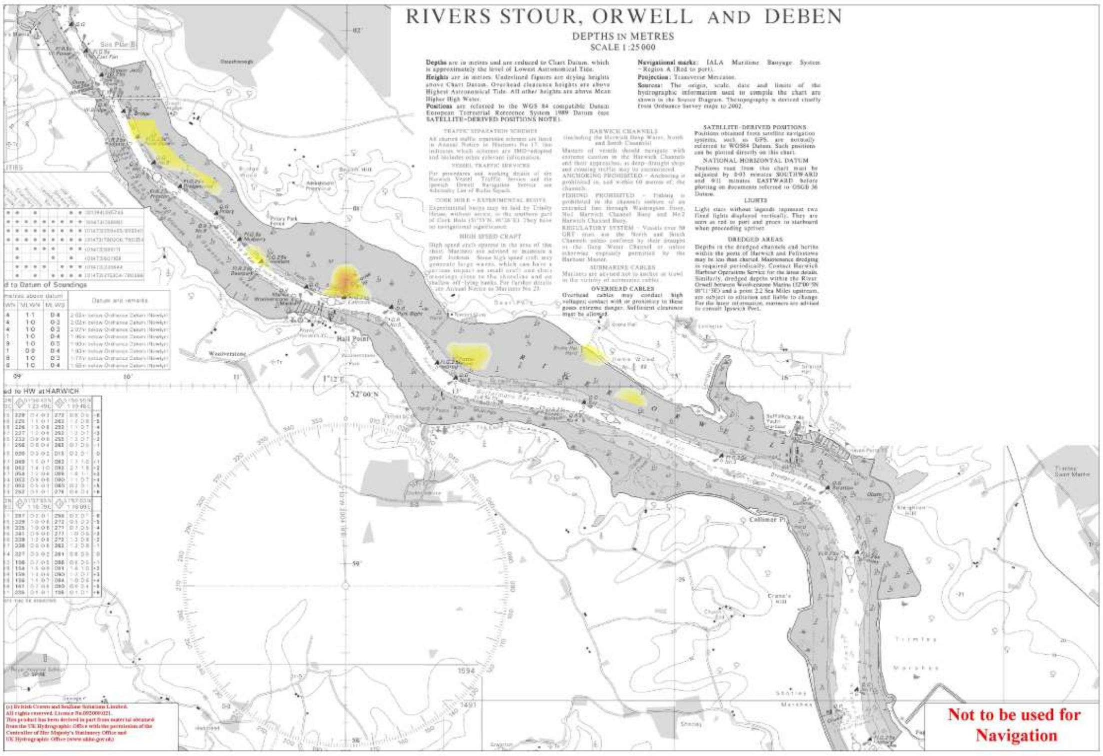


Figure 7.4.3. Distribution of *T. philippinarum* in the surveyed areas of the River Orwell in March 2009.

When resurveyed in 2010, seven of the 44 survey stations were found to support *T. philippinarum*. These data were used to create an interpolated model of clam distribution (figure 7.4.4), analysis of which identified the clams to be present in an area covering 50 hectares. Within this area the mean density was found to be 20 clams/m^2 (range 10-40 clams/m^2), slightly higher than had been found in 2009. At 2.86 t/ha, their mean biomass had also increased, but by a lesser extent than their mean density. Individually, the mean weight of the clams had decreased from 24.8g (range 6.6 - 54.2g) to 14.3g (range 4.13g – 47.0g), indicating that: 1) there had either been a loss of larger clams from the population, or, 2) there had been an increase in the recruitment of juveniles. Figure 7.4.5, which shows the size distributions of *T. philippinarum* in this river for each year indicates that both scenarios may have occurred, there being an increase in the number of clams below 34mm in length and a decrease in numbers over 45mm in length. The overall biomass of *T. philippinarum* within the survey area was estimated to be 142 tonnes (+/- 81 tonnes at a 95% confidence interval), a similar range to that found the previous year.

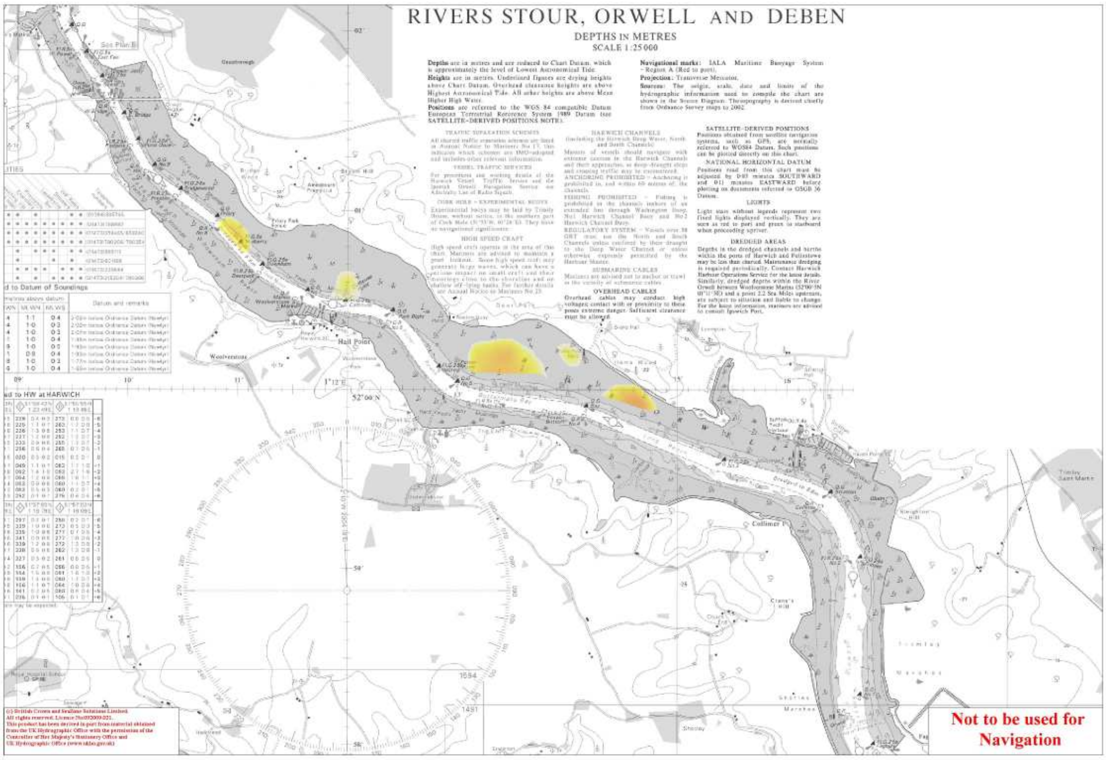


Figure 7.4.4. Distribution of *T. philippinarum* in the surveyed areas of the River Orwell in March 2010.

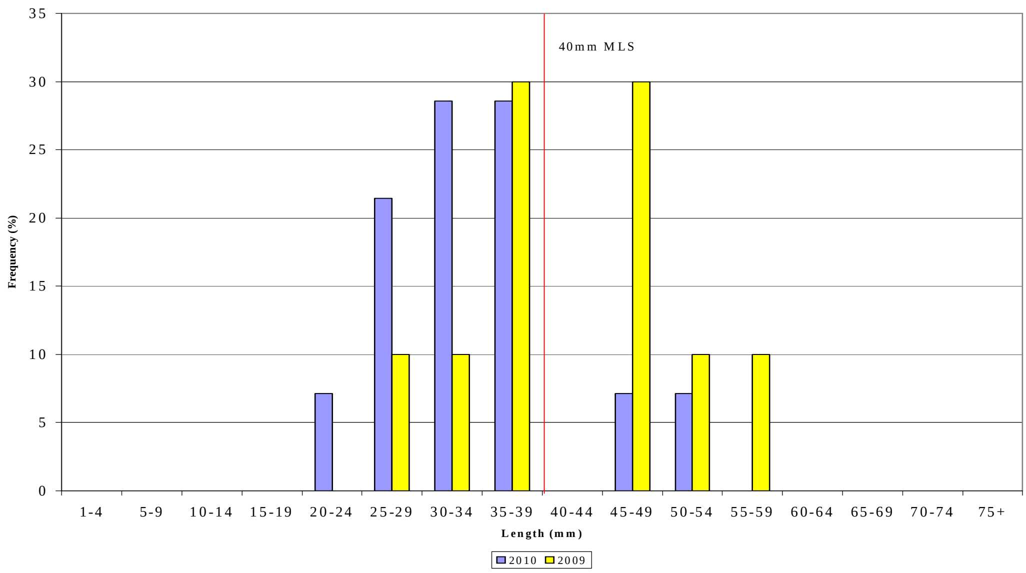


Figure 7.4.5. Graph showing the size distribution of *T. philippinarum* within the surveyed area of the River Orwell in 2009 (yellow) and 2010 (blue).

7.4.4 Distribution of *T. philippinarum* in the River Stour

During the 2009 survey, ten of the 74 survey stations sampled in the Holbrook Bay area of the River Stour were found to support *T. philippinarum*. Data from this survey was used to create an interpolated model of the clam distribution (figure 7.4.6). Analysis of this model identified *T. philippinarum* to be present in an area of 65 hectares. Within this area their mean density was found to be 15 clams/m^2 (range 10-30 clams/m^2), with a mean biomass of 3.48 t/ha. From these figures their biomass was calculated to be 226 tonnes (+/- 126 tonnes at a 95% confidence interval). The mean weight of individual clams was found to be 23.2g (range 2.1 – 55.5g).

Figure 7.4.6. Distribution of *T. philippinarum* in the Holbrook Bay area of the River Stour in March 2009.

When resurveyed in 2010, eleven of the 74 stations were found to support *T. philippinarum*. Figure 7.4.7 shows an interpolated model of the distribution of clams taken from these data. Analysis of this model identified *T. philippinarum* to be present in an area of 74 hectares. Within this area their mean density was found to be 15 clams/m^2 (range 10-30 clams/m^2), with a mean biomass of 3.11 t/ha. From these figures, their total biomass was calculated to be 230 tonnes (+/- 78 tonnes at a 95% confidence interval), a similar figure to the previous year. Individually, the clams had a mean weight of 20.1g (4.4 – 42.4g), slightly lower than in 2009. Figure 7.4.8 shows the size distribution of the clams sampled during the 2009 and 2010 surveys. Unlike the population from the River Orwell, which had shown a marked difference in size structure between the two surveys, the population in Holbrook Bay showed less change.

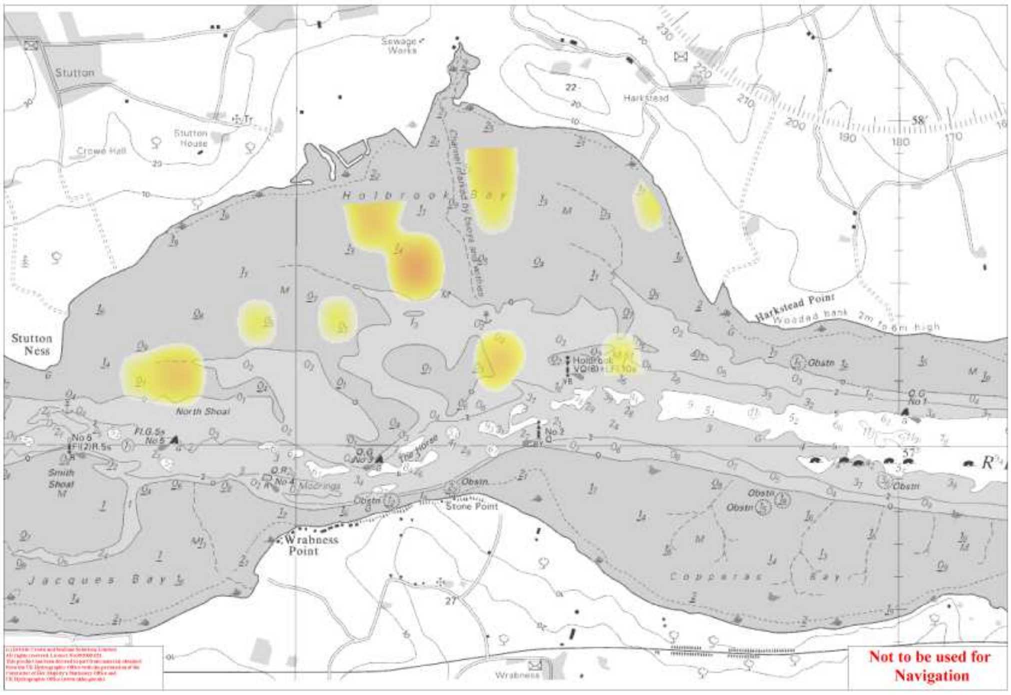


Figure 7.4.7. Distribution of *T. philippinarum* in the Holbrook Bay area of the River Stour in March 2010.

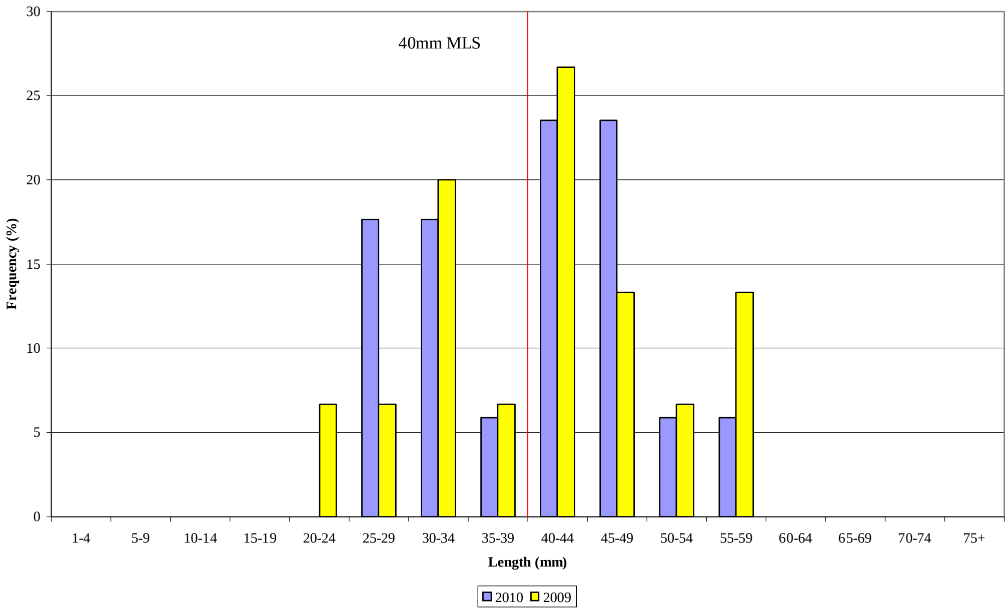


Figure 7.4.8. Graph showing the size distribution of *T. philippinarum* within the surveyed area of Holbrook Bay on the River Stour in 2009 (yellow) and 2010 (blue).

Although the overall stock levels had remained reasonably consistent between the 2009 and 2010 surveys, the actual distribution of clams had significantly changed in both rivers. At the River Orwell sites, nine of the 44 stations had supported clams in 2009 and seven in 2010. Of these, however, only three were found to have supported clams during both surveys. Similarly at Holbrook Bay, only two of the ten stations supporting clams in 2009 were among the eleven stations found to support clams in 2010. Although it is possible that the distribution of clams had changed during the course of the year, it is more likely that these disparities are actually an artefact caused by the low density of clams in the area. Even if the clam distribution being sampled had a homogeneous coverage across the survey area, the distribution would appear patchy when sampled with a $0.1m^2$ grab if the density was lower than 10 clams/m^2.

Between the two surveys conducted in the Holbrook Bay area of the River Stour, 14% of the total stations were found to support *T. philippinarum*. Of these 19% were found to support clams during both surveys. Assuming the distribution had not changed significantly between the two surveys, these figures would suggest the clams are present in average densities of approximately 2 clams/m^2, in patches covering approximately 70% of the survey stations. Between the two surveys in the River Orwell, 18% of the total stations were found to support *T. philippinarum*, of which 37% were found to support clams during both surveys. If the disparity was due to density rather than an actual change in distribution, these figures would suggest the clams in this river are present in average densities of 3-4 clams/m^2 in patches covering approximately 50% of the survey stations.

7.4.5 Additional data collected from dredge survey

During the same period in which the 2010 grab survey was conducted in Holbrook Bay, a dredge survey was also conducted nearby in the river channel and the deeper parts of the bay. Although the dredge survey was aimed at assessing the stock of a small bed of native oysters (*Ostrea edulis),* known to be present in that part of the river, low numbers of *T. phillipinarum* were found among the samples and their details recorded. This information can be seen in figure 7.4.9.

Eleven of the 124 tows conducted during the oyster survey were found to contain *T. phillipinarum.* Numbers were only low, however, ranging between 1 - 3 clams per tow. Taking into account the area covered by these tows, these figures equated to densities of just 54 - 366/clams/ha. Considering the results of the Holbrook Bay grab survey estimated average densities to be 2 clams/m^2, equating to 20,000 clams/ha, the numbers found in the dredge samples are extremely low. As the dredge samples were collected in deeper water than the grab samples, it is possible that the disparity between the two sets of results reflects a real change in the distribution of the clams between two areas. There are, however, a number of dredge tows that overlap areas in which clams were found in the grab samples. As clams were either absent or only present in low numbers in these overlapping dredge tows, it seems probable that the dredge was inefficient at catching the clams. Designed to catch oysters attached to the substratum, rather than clams buried in the sediment, the dredge was only light, with a shallow blade. It is likely, therefore, that the only clams being caught were those that were unburied on the surface. As such, the samples collected during the dredge survey should not be used to provide information concerning the density of *T. phillipinarum* in those areas. They do, however, provide evidence that the distribution of the clams is not just limited to the shallow regions of the bay, but extend further into the river channel.

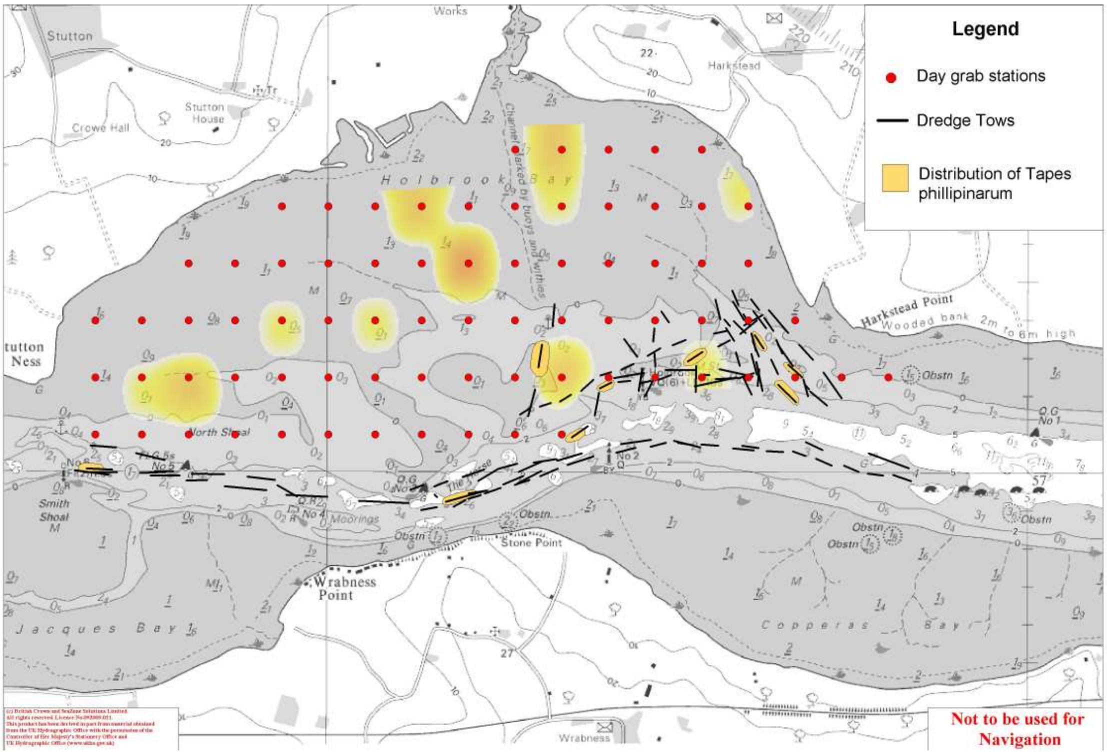


Figure 7.4.9. Chart showing the positions of the dredge tows (black lines) conducted during the 2010 survey compared to the grab stations (red dots), and overlaid with the distribution of *T. phillipinarum* as modelled using the data from both surveys.

7.4.6 Conclusion

The surveys conducted in 2009 estimated 150 (+/- 70) tonnes of *T. phillipinarum* to be present within the survey area of the River Orwell and 226 (+/- 126) tonnes within the survey area of the River Stour (Holbrook Bay). When further surveys were conducted in 2010, taking samples from the same stations, the stock estimates were similar with 142 (+/- 81) tonnes estimated to be present in the River Orwell and 230 (+/- 78) tonnes in the River Stour. Additional data taken from a dredge survey, although unsuitable for estimating densities or biomass, showed the coverage of *T. phillipinarum* was not limited to the extent of the grab surveys. It is possible, therefore, that significant stocks may be present in the two rivers outside of the surveyed areas.

The distribution of the clams within the survey areas was found to be patchy, with maximum densities ranging between 10 to 40 clams/m^2. Disparities between the 2009 and 2010 survey results, however, suggest that either the distribution had changed between surveys, or that the average densities across the survey areas are below 10 clams/m^2. If the latter is the case, analysis of the Day grab data would suggest the clams in the Holbrook Bay area of the River Stour are spread thinly (2 clams/m^2) across approximately 70% of the survey area, with small localised patches of higher density. Similarly, in the River Orwell, the clams would be present over approximately half of the survey area in densities of 3-4 clams/m^2, with some localised regions of higher density. In Poole Harbour, where there is an established fishery for *T. phillipinarum*, densities range between 25 - 50 clams/m^2, of which 3 - 7 clams/m^2 are above the minimum landing size (MLS) of 35mm (Pengelly, *pers com*, 2010). At these densities the local fishermen are able to harvest approximately 300kg/day using pump scoop dredges or 1,000kg/day with heavier box dredges. At 25 - 50 clams/m^2 the average densities are significantly higher than those found in either the Rivers Stour or Orwell. Presumably as a result of larger clams having been harvested, however, the proportion of clams above the 30mm MLS in Poole Harbour (approximately 12-14%) is much lower than in the Stour (65-67%) or the Orwell (43-80%). In terms of these harvestable stocks, the average densities in Poole Harbour are likely to be approximately four to five times higher than in the Stour and Orwell rivers. At these densities, fishing with a box dredge in the Stour or Orwell would yield approximately 200-250kg/day. While the value of the clams would make this commercially viable, strict management measures would be required if the fishery were to remain sustainable. Even in the absence of a fishery, the clam densities in the Stour and Orwell are lower than in Poole Harbour. If harvestable sized clams were removed at this stage, with only low densities of juvenile clams to replace them in subsequent years, recruitment to the harvestable population would be poor. It is unlikely that at the current densities, a large-scale fishery could be sustained for more than one or two years before the population crashed. From the surveys conducted in the past ten years, however, it appears the clams are relatively new to these rivers, and their current density level is a recent occurrence. Anecdotal evidence suggests that once naturalised, populations of *T. phillipinarum* can rapidly colonise suitable habitats. If this proves to be the case, and the densities do increase, the stocks in the two rivers could potentially support a larger fishery in the future.

Stock levels aside, developing a new fishery in these rivers could be problematic. The site has several environmental designations including being a Special Protected Area (SPA), European Marine Site (EMS), a Site of Special Scientific Interest (SSSI) and a Ramsar site. Consideration of environmental features would need to be rigorously addressed before any fishery could be consented. Should consent be given, the high numbers of Slipper Limpets (*Crepidula fornicata)* present in the Holbrook Bay area of the River Stour could also prove problematic, both for the successful growth of the clams and during harvesting.

7.5 Distribution of Peacock Worm, *Sabella pavonina*

7.5.1 Introduction

The Peacock worm, *Sabella pavonina,* is a sessile, filter-feeding polychaete worm that grows up to 30cm in length and lives in slender, leathery tubes protruding from the seabed, from which they extend their delicate feathery fans to feed. During the surveys conducted in 2003, ESFJC mapped the extent of two large colonies of *Sabella pavonina* that had been detected using the Roxann™ Acoustic Ground Discrimination System (AGDS) aboard the research vessel *Three Counties.* One colony, covering approximately 85 hectares was situated in the River Stour between Copperas Bay and Holbrook Bay, and the other, covering 35 hectares was located in the River Orwell near Levington Creek (Jessop, Lowry & Graves, 2003). A subsequent survey conducted in 2007 found the River Stour colony had deteriorated badly, with video footage showing numerous damaged and unoccupied tubes with large barren patches of muddy ground between the clumps (Jessop, Woo, & Torrice, 2007). Further video footage taken during a survey in 2009 found healthy tubes were re-colonising some of the ground, but the extent of the colony was still only 33 hectares (Jessop, Harwood & Woo, 2009). Both colonies were monitored once more during the 2010 surveys to ascertain whether there had been further deterioration or recovery of these features.

7.5.2 Method

The beds of the rivers were surveyed using Roxann™ AGDS as the research vessel, *Three Counties*, conducted a number of parallel tracks, approximately 30 meters apart. Data collected from this survey provided information on the "hardness" and "roughness" of the seabed beneath the vessel, displayed "real-time" as a series of coloured tracks on the vessel's plotter. As colonies of organisms such as mussels, *Sabellaria* and *Sabella* frequently display distinct hardness/roughness signatures, their presence could be predicted using the Roxann™ AGDS equipment. Sites identified by the Roxann™ equipment as potentially supporting such colonies were then ground-truthed using a Day grab to collect samples in a semi-stratified pattern. These data were then interpolated using Vertical Mapper™ GIS software in order to create models predicting the distribution of the *Sabella* colonies.

7.5.3 Results

Figure 7.5.1 is an interpolated model depicting the predicted distribution of *Sabella pavonina* in the River Orwell, close to the Levington marina. Video footage of this colony showed it to be in a healthy condition with high densities of worms present. Samples taken by Day grab found the worms to be present in numbers as high as 1,600 tubes/m^2. The area covered by this colony was calculated to be 29 hectares, which though lower than the 35 hectares recorded in 2003 is a slight improvement on the 28 hectares recorded in 2009. Although the total area had only changed by one hectare between the two

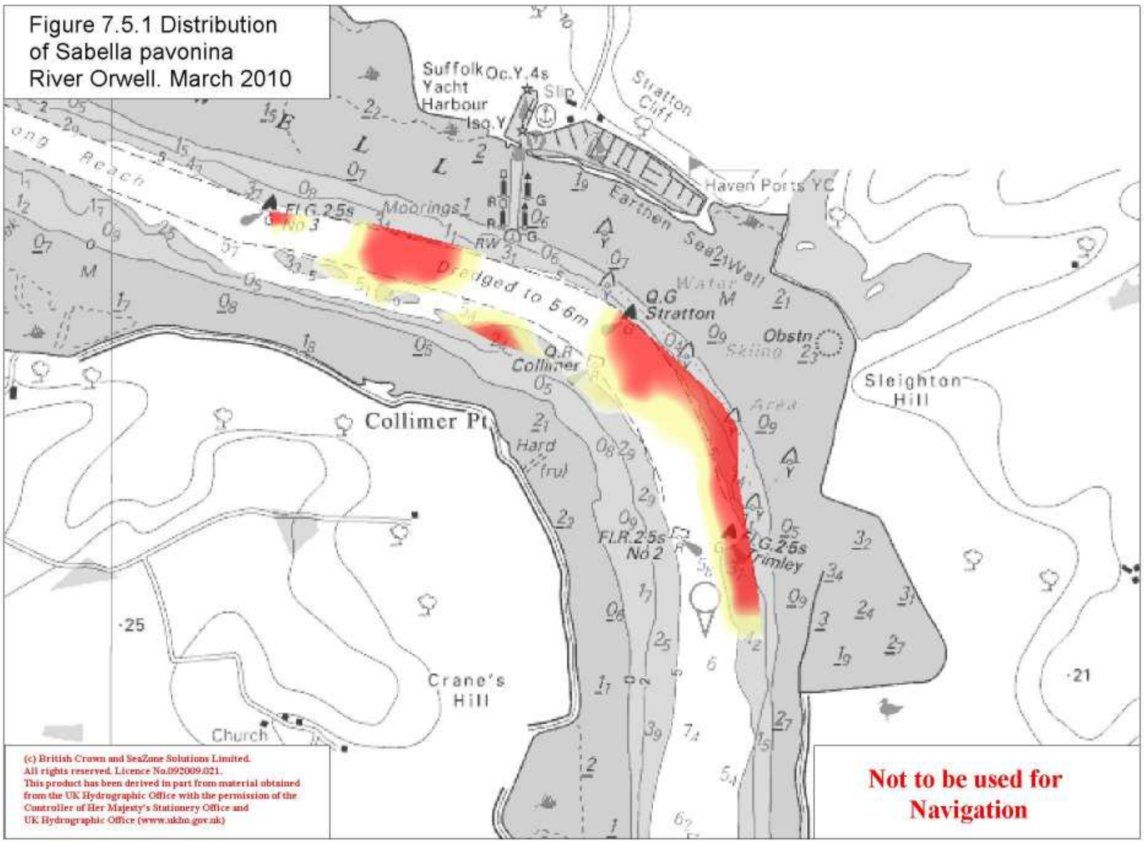


Figure 7.5.1 Distribution of Sabella pavonina River Orwell. March 2010

Distribution Sabella pavonina

Low Density	High Density

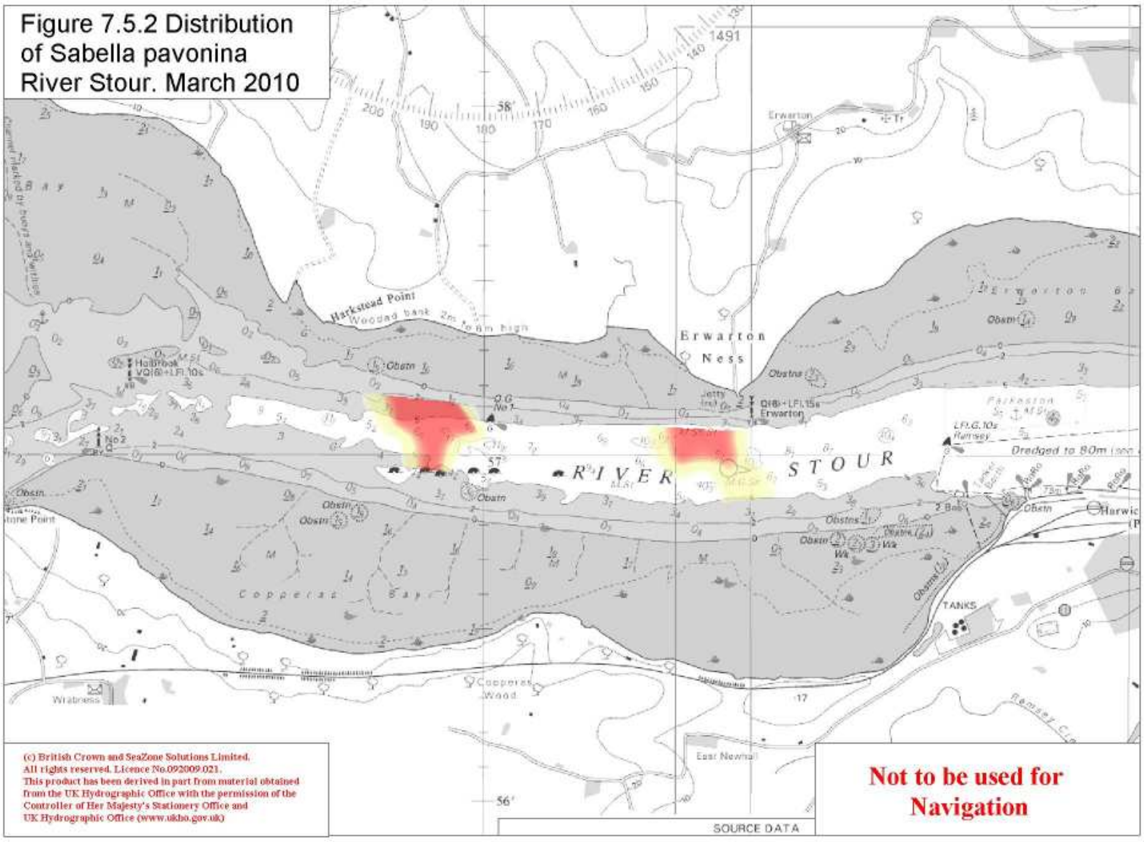


Figure 7.5.2 Distribution of Sabella pavonina River Stour. March 2010

surveys, the distribution of the colony was found to have changed more significantly. Although the colony extended further across the river than in 2009, a 5 hectares patch had been lost adjacent to the entrance to Levington marina.

Figure 7.5.2 shows the predicted distribution of *Sabella pavonina* in the River Stour, in which two discrete colonies were found. Covering approximately 17 hectares each, the distribution of these two colonies is very similar to that mapped in 2009. The density of tubes in these colonies was found to range between 70 and 500 tubes/m^2.

7.5.4 Discussion

Although *Sabella pavonina* colonies have not been classified as reef structures, in many ways they conform to the description given to reefs. As such, their raised tubes help collect sediment, create firm anchorage for other sessile marine organisms and provide shelter for numerous other species. ESFJC has been monitoring two such colonies in the rivers Stour and Orwell since 2003, and has been aware of their presence since earlier surveys conducted in 1997 and 2001. In 2007 the colony in the River Stour was found to have badly deteriorated, possibly as a result of sediment replacement activities that had been occurring in the river prior to the survey. After three years the colony is gradually recovering, but the extent of the colony and the density of worm tubes within it are still much lower than prior to the decline.

In the River Orwell, the 2010 survey found the *Sabella* colony had extended further across the river than was mapped in 2009, but a 5 hectares patch had disappeared from the area adjacent to the entrance of the Levington marina. Being sessile and partially buried within the substratum, this species is vulnerable to activities that disturb the seabed. Both the river channel and the entrance to Levington marina are occasionally dredged, which could explain the changes in distribution to the *Sabella* colony within this area.

8.0 DISTRIBUTION OF *ARENICOLA MARINA*, *LANICE CONCHILEGA* AND *MACOMA BALTHICA* ON THE TIDAL FLATS OF THE WASH

8.1 Introduction

The intertidal sandflats and mudflats of the Wash are often numerically dominated by infaunal organisms of the polychaete and bivalve groups. Of particular interest for the current survey were the burrowing polychaetes, the lugworm (*Arenicola marina*) and sandmason worm (*Lanice conchilega*), and the infaunal bivalve *Macoma balthica*, which occupy the same habitats as the cockle (*Cerastoderma edule*) and could therefore be affected by hydraulic suction dredging.

Lanice conchilega, which is found along all European coasts, is considered to be a habitat structuring organism that plays a major role in benthic ecosystems by stabilizing the sediments and providing a habitat for sessile organisms (Hoey *et al.* 2008, Callaway *et al.* 2010). On the other hand, the bioturbating polychaete *Arenicola marina* is a sediment destabiliser that is common in intertidal sandy sediments along northwest European coasts (Volkenborn *et al.* 2009). The Baltic tellin (*Macoma balthica*) is a dominant member of many estuaries and tidal flat communities around the North Atlantic and lives a few centimetres below the surface of muddy and sandy sediments.

These three invertebrates provide valuable resources to predators, in particular wading birds such as knots, bar-tailed godwits, grey plovers and curlews (Goss-Custard *et al.* 1977). *Arenicola marina* is also preyed upon by the flatfishes plaice and flounder, which feed on the tail tips of this organism as it defecates (de Vlas 1979). This worm is also much prized as bait among both commercial and private anglers.

Concerns were raised that hydraulic suction dredging for cockles could have deleterious impacts on the associated invertebrate population. In this fishing method, a water jet is directed towards the seabed, which disturbs the upper layer of the seabed and its contents to such an extent that it is suspended in the seawater (Ens *et al.* 2004). The mixture of water, sediment, cockles and other organisms is then guided into the dredge by a metal blade at the underside of the dredge. The dredge is a cage with bars spaced about 14 mm apart (in the Wash cockle fishery), so any organism smaller than 14mm is immediately discarded. Anything over 14mm is pumped on board, where a rotating sieve separates cockles from bycatch (Ens *et al.* 2004).

Hydraulic suction dredging has been operating in the Wash for most years since 1986, and this century, only in 2005, 2009 and 2010 were all the beds closed to this fishing method. As hydraulic suction dredging creates considerable disturbance to the surface of the seabed, monitoring of the three invertebrates *Arenicola marina, Lanice conchilega* and *Macoma balthica* was incorporated into the 2007 annual spring cockle monitoring. The aim of this monitoring programme was to determine the distribution and density of these invertebrates and assess any changes over time.

8.2. Methodology and Results

Infaunal invertebrate data was collected as part of the annual 2010 spring cockle surveys, which were conducted between April 26th and May 28th 2010. Densities of the two polychaetes *Arenicola marina* and *Lanice conchilega* were recorded, as well as numbers of the infaunal bivalve *Macoma balthica*. ESFJC officers sampled 1,259 stations covering 19 areas of sandbank (Figure 8.1). The stations were arranged in a regular grid pattern at approximately 350 meters apart. Of these stations, 185 were visited on foot during low water periods, while the remaining 1074 stations were sampled at high water by deploying a Day grab from the research vessel *ESF Three Counties.* Detailed descriptions of the sampling methodologies for each invertebrate will be provided in the following paragraphs.

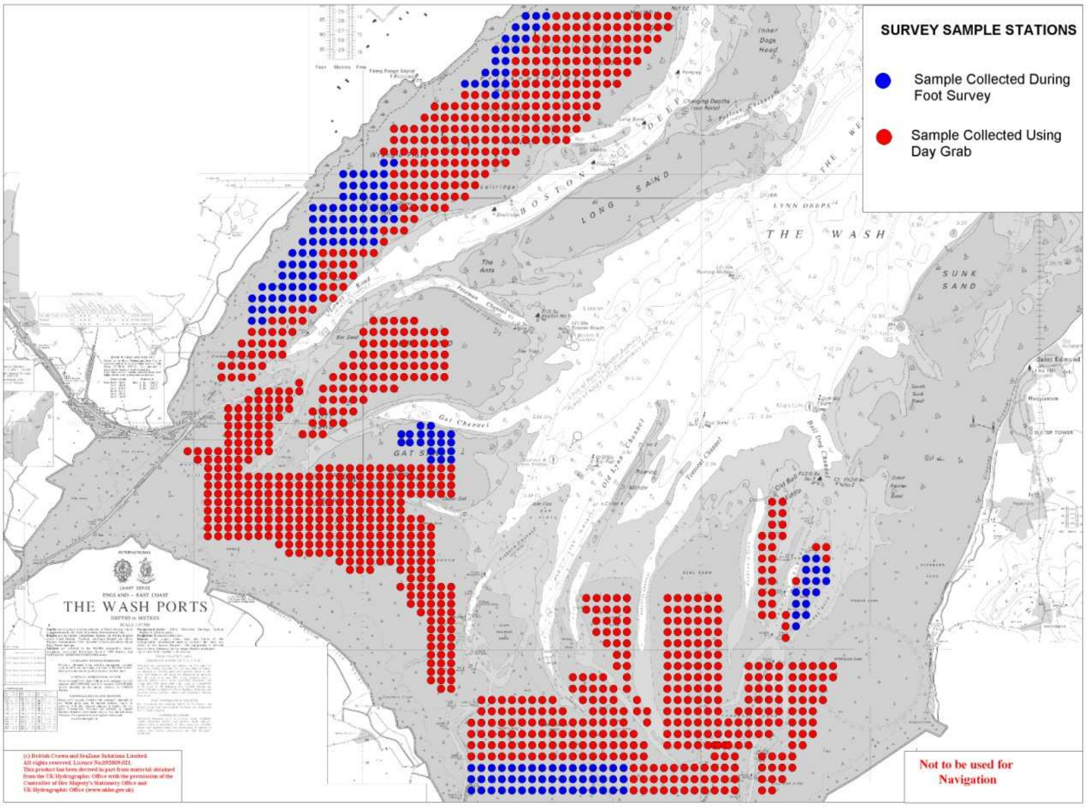


Figure 8.1 Stations in the Wash sampled between April and May 2010 as part of the annual cockle surveys.

8.2.1 Lugworm (*Arenicola marina*)

At low water *Arenicola marina* casts are readily visible (Figure 8.2) and provide a good indication of the presence of the worms. At each sample station visited during the foot surveys, three 0.1m^2 quadrats were randomly deployed and the number of *Arenicola* casts present in each was recorded. Day grab was unsuitable for the collection of *Arenicola* density data due to the fragility of the casts. Using the Vertical Mapper™ software, the data were then spatially interpolated using natural neighbour to create models depicting the distribution of *Arenicola* over the survey area. The graduated scale in these models uses the densities shown in Table 8.1.

Figure 8.2: Casts produced by the polychaete *Arenicola marina* in the Wash at low tide.

Table 8.1: Scale used to represent *Arenicola marina* density within the survey areas.

***Arenicola marina* Density/m^2**	**Density Scale in Models**
0	Absent
1 - 10	Low
11 - 50	Moderate
> 51	High

During the 2010 surveys, fewer stations were sampled on foot than during the 2009 survey, which restricted the collection of *Arenicola* density data. This was mainly due to better accessibility of some cockle beds during high water, particularly in the Friskney area, and suitable weather conditions allowing for Day grabbing to take place during high water. Due to this limited availability of data, no reliable spatial interpolation models could be constructed for *Arenicola* for 2010.

8.2.2 Sand mason worm (*Lanice conchilega*)

Tubes constructed by the sand mason worm *Lanice conchilega* are readily visible at low water (Figure 8.3) and can be used to determine this species' presence. At each site visited on foot, three quadrats (0.1 m^2 per quadrat) were deployed, and the presence or absence of *L. conchilega* tubes was recorded for each. The density of *Lanice* at each site was determined by how many of the three quadrats the tubes were present in (see Table 8.2).

As *L. conchilega* tubes are sufficiently resilient to survive collection with a Day grab (0.1 m^2), it was also possible to record data on their distribution from sites sampled using Day grabs. Due to time constraints, however, samples were restricted to one grab per site. Densities were classified as either absent, when no *Lanice* were found in the grab, or moderate, when one or several *Lanice* were found in the single grab sample. Using the Vertical Mapper^{TM} software, the data were spatially interpolated using natural neighbour to create models depicting the distribution of *L. conchilega* over the survey area.

Figure 8.3 Tube of the polychaete *Lanice conchilega* at low tide in the Wash**.**

Table 8.2: Scale used to represent *Lanice conchilega* density within the survey areas.

Number of Quadrats per Sampling Site containing *Lanice* Tubes	Density Scale in Models
0	Absent
1	Low
2	Moderate
3	High

Figures 8.4 to 8.6 show the distribution of *Lanice* within the survey sites across the Wash. Densities of this polychaete in 2010 ranged from low to moderate in most areas, and only sites in the Boston Main supported high densities. Compared to previous years, a notable difference was observed in the southwest area of the Wash, where in 2009 high densities of *Lanice* were recorded at most sites where *Lanice* were recorded as being present, but a subsequent decrease to moderate densities was observed in the 2010 survey. The same can be observed in Figure 8.7, which shows in addition a slight increase of sites with moderate densities between 2009 and 2010. Inner Westmark Knock indicates an overall reduction in *Lanice* densities from 2008 to 2009 and 2010. Similarly on the Roger Sand, sites of high densities of *Lanice* decreased between 2009 and 2010. At all three areas of the Wash, *Lanice* was occupying similar areas in the 2010 survey to the 2009 and 2008 surveys (Jessop *et al.* 2008, 2009).

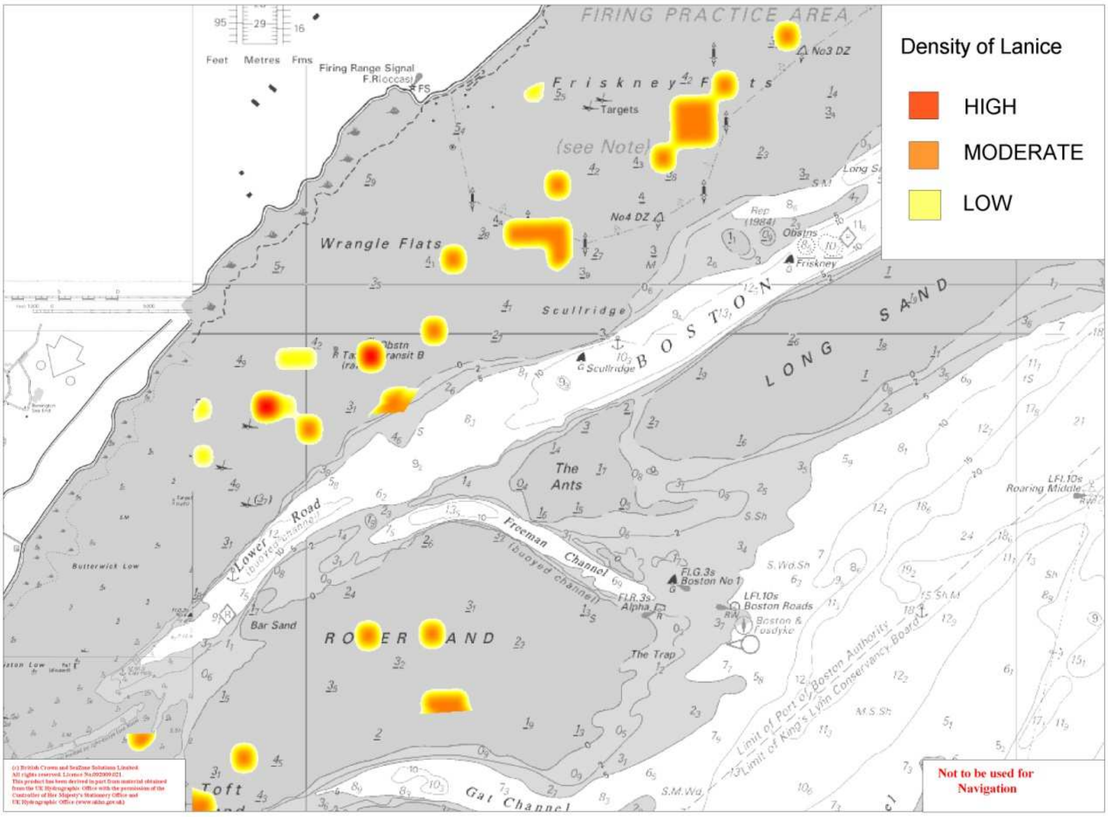


Figure 8.4 Distribution of *Lanice conchilega* within the survey sites of the Boston Main and Roger areas sampled between April and May 2010**.**

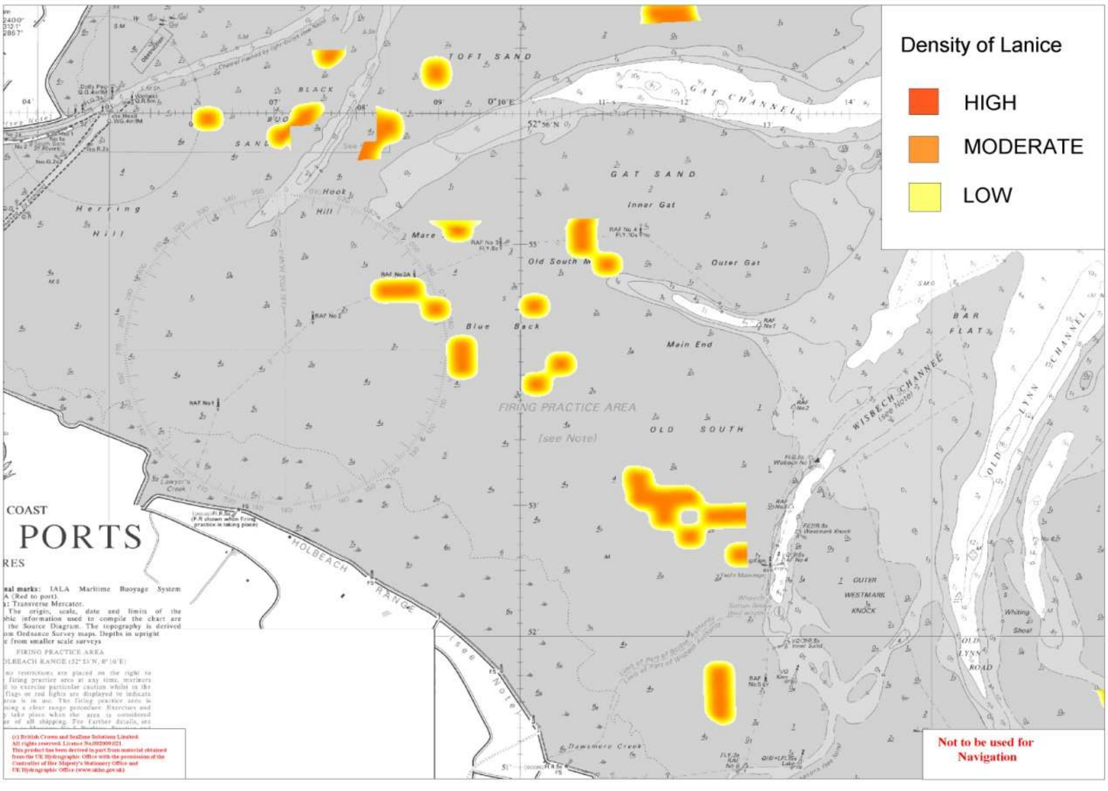


Figure 8.5 Distribution of *Lanice conchilega* within the survey sites at the southwest Wash area sampled between April and May 2010.

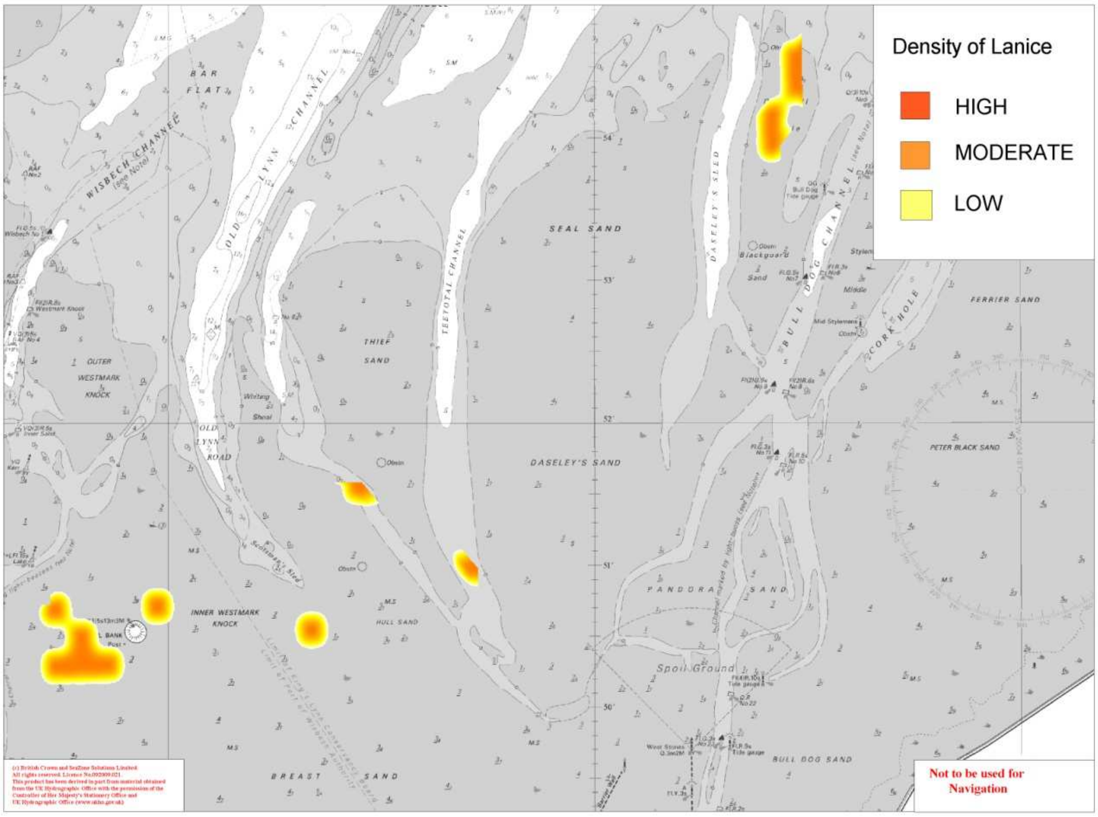


Figure 8.6 Distribution of *Lanice conchilega* within the survey sites at the southeast Wash area sampled between April and May 2010.

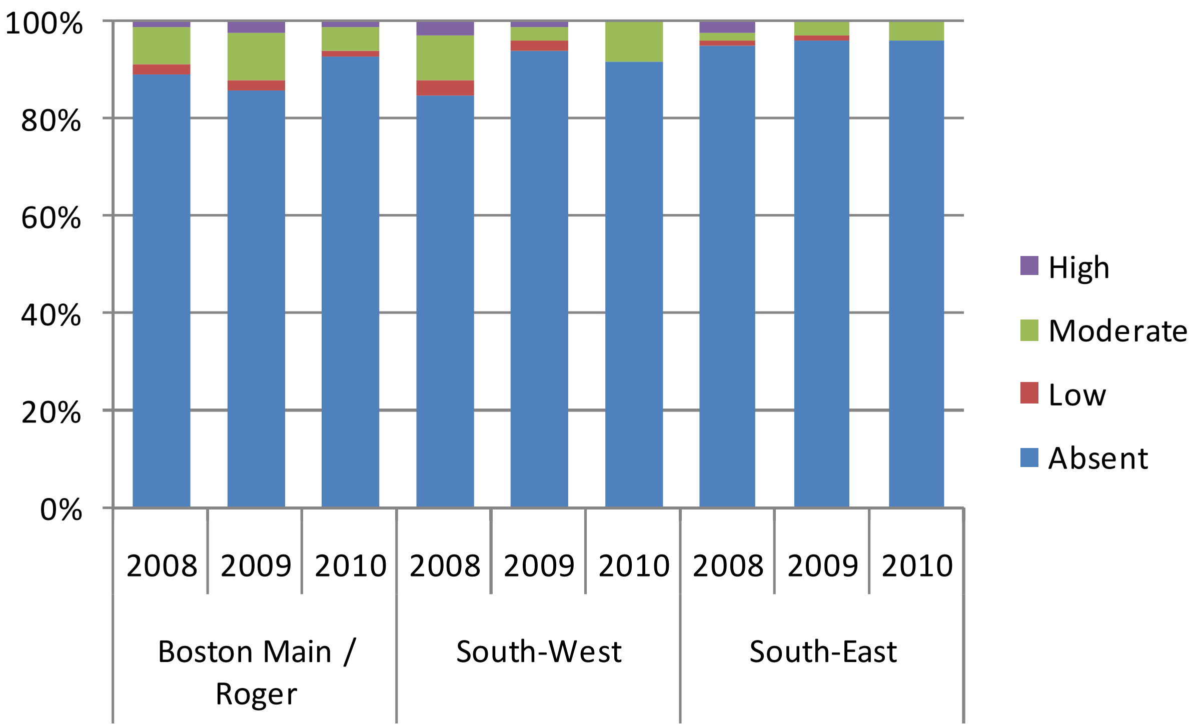


Figure 8.7 Percentage of survey sites supporting each density category of *Lanice conchilega* tubes in the areas of the Wash sampled during the 2008 to 2010 surveys**.**

8.2.3 Baltic tellin (*Macoma balthica*)

To collect data on the infaunal bivalve *Macoma balthica* one sample was collected per site with either a quadrat (0.1 m^2), if a foot survey was conducted at that particular site, or a Day grab (0.1 m^2). The number of *Macoma* present in each sample was recorded and density was established. Using Vertical Mapper™ software, the data were spatially interpolated to create models depicting the distribution of *M. balthica* over the survey area. The graduated scale used in these models to represent *Macoma* density is shown in Table 8.3.

Table 8.3: Densities of *Macoma balthica* found at each sampling station and density scale used in the models.

***Macoma* Density/m^2**	**Density Scale in Models**
0	Absent
1 - 10	Low
11 - 50	Moderate
>51	High

The sites occupied by *M. balthica* in the 2010 survey (Figures 8.8 to 8.10) were similar to those in 2009, where this species was generally found at the sheltered high shore habitats. In the Boston Main and Roger area, however, patches of *Macoma* were found on Roger Sand in 2008, but were absent at this site in the following two surveys. Conversely, on the southwest and southeast sites of the Wash, higher numbers of *Macoma* were observed in 2009 and 2010 between Herring Hill and Mare Tail than during the 2008 survey. This increase is also apparent in Figure 8.11, which indicates the percentage of sites supporting each density category. Sites of high density increased in 2010 and reached 9% at the southwest Wash and 13% at the southeast Wash. Density categories of *Macoma* in the Boston Main and Roger areas, however, have not changed considerably over the last three years.

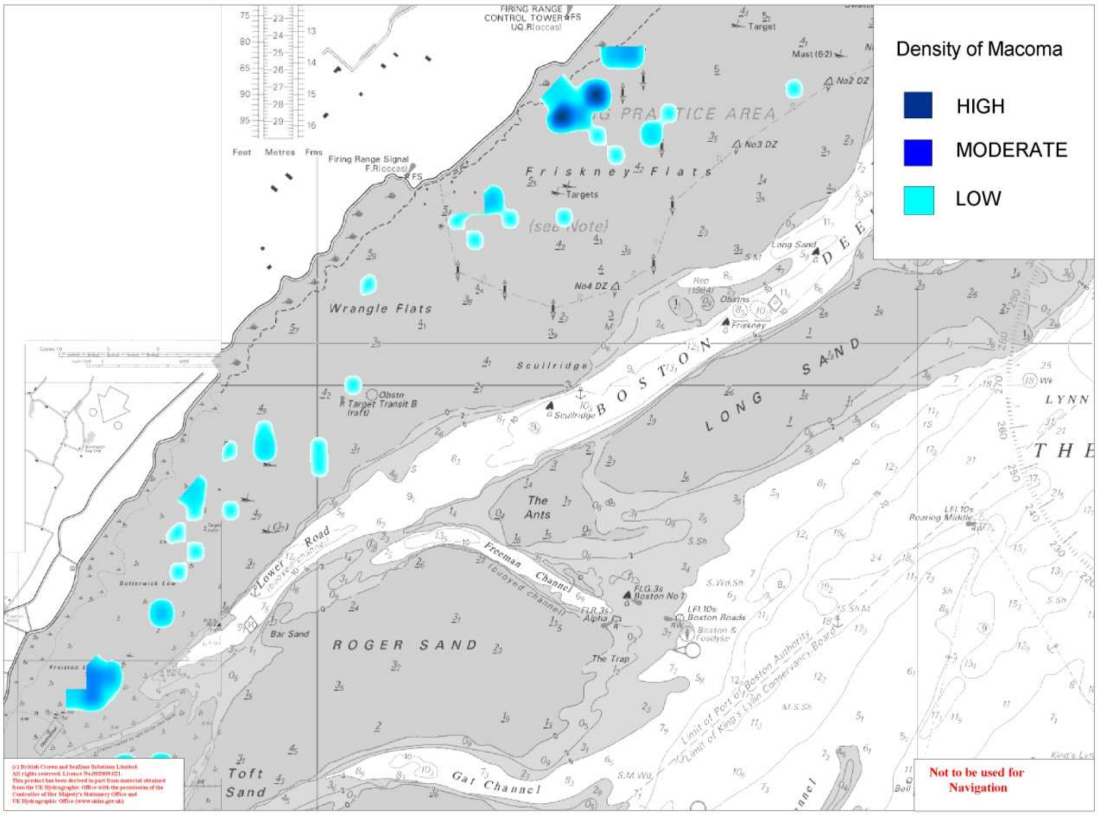


Figure 8.8 Distribution of *Macoma balthica* within the survey sites of the Boston Main and Roger areas sampled between April and May 2010**.**

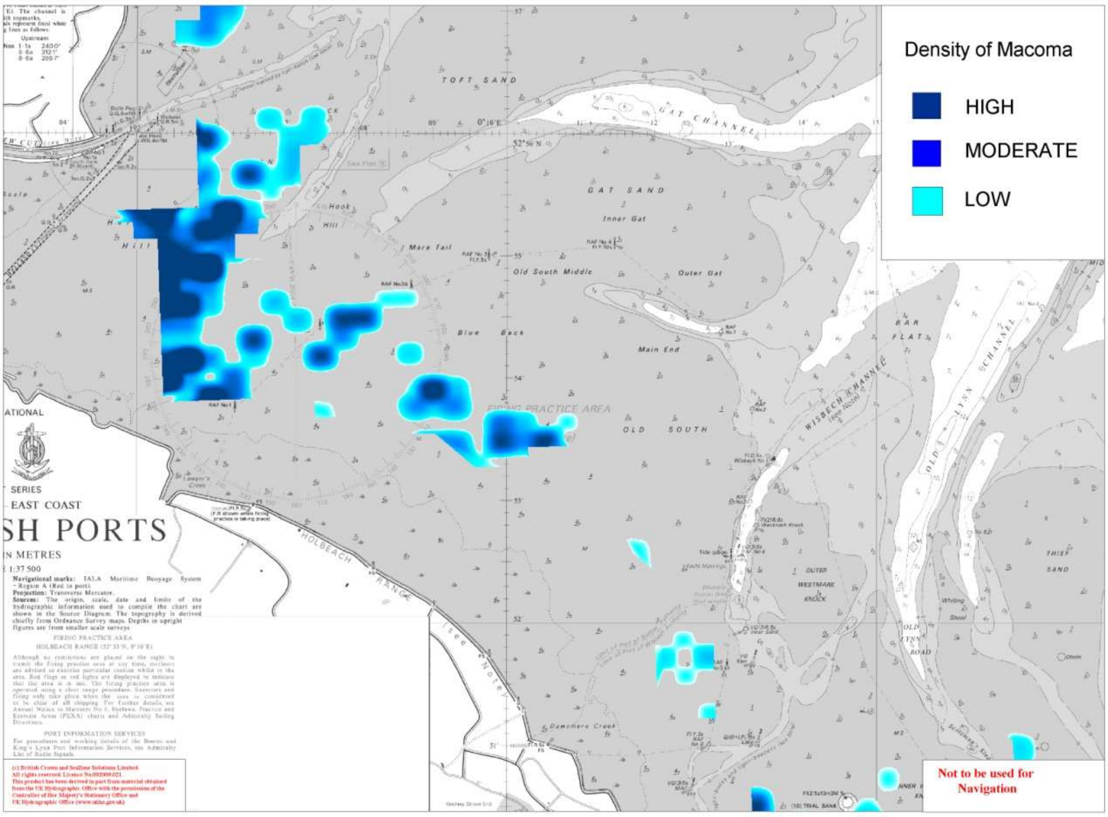


Figure 8.9 Distribution of *Macoma balthica* within the survey sites of the southwest Wash area sampled between April and May 2010.

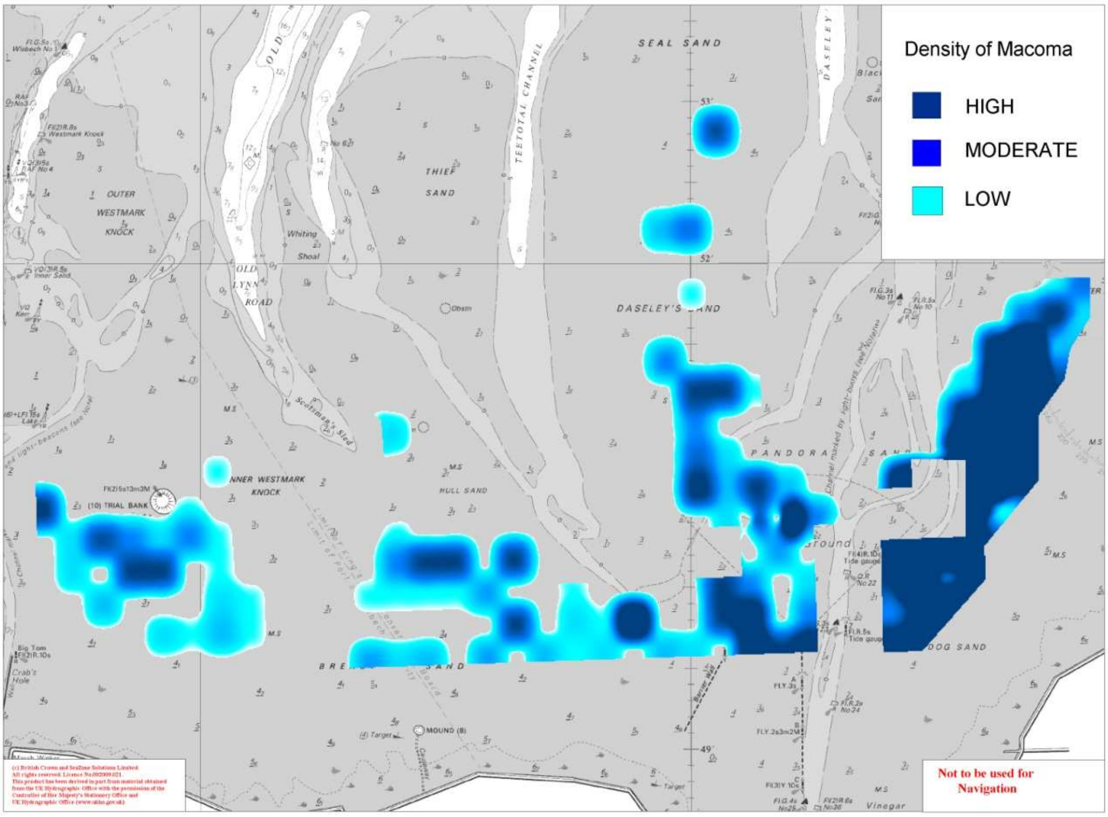


Figure 8.10 Distribution of *Macoma balthica* within the survey sites of the southeast Wash area sampled between April and May 2010.

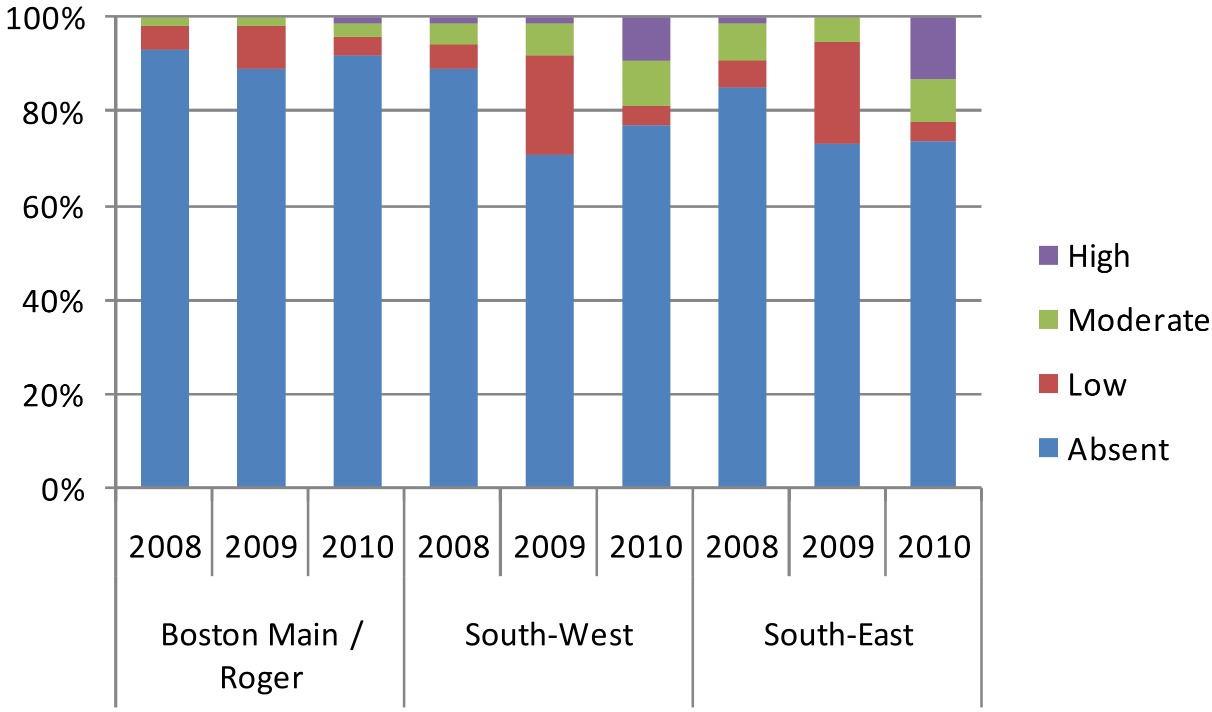


Figure 8.11 Percentage of survey sites supporting each density category of *Macoma balthica* in the areas of the Wash sampled during the 2008 to 2010 surveys.

8.2.4 Sediment

During the foot surveys and day grab sampling, notes on the sediment types encountered were recorded. The scale used to classify the sediment at each site has been used at ESFJC since 2006 and categories range from sand (coarsest) to anoxic clay (finest sediment type). Using Vertical Mapper^{TM} software, the data were spatially interpolated to create models depicting the sediment distribution over the survey area (Figure 8.12).

Sand was the predominant sediment type in the 2010 survey along the Boston Main and Rogers area and at the lower shores of the southwest Wash. The seabed in the southeast Wash was composed of finer sediments such as silt along the higher shore and of sand at the lower shore. Compared to the 2009 survey results, an increase in silt was observed between Herring Hill and Mare Tail in the 2010 survey. Another change in sediment type was observed near the Breast Sand, where anoxic clay has largely been replaced with silt and sand on anoxic clay.

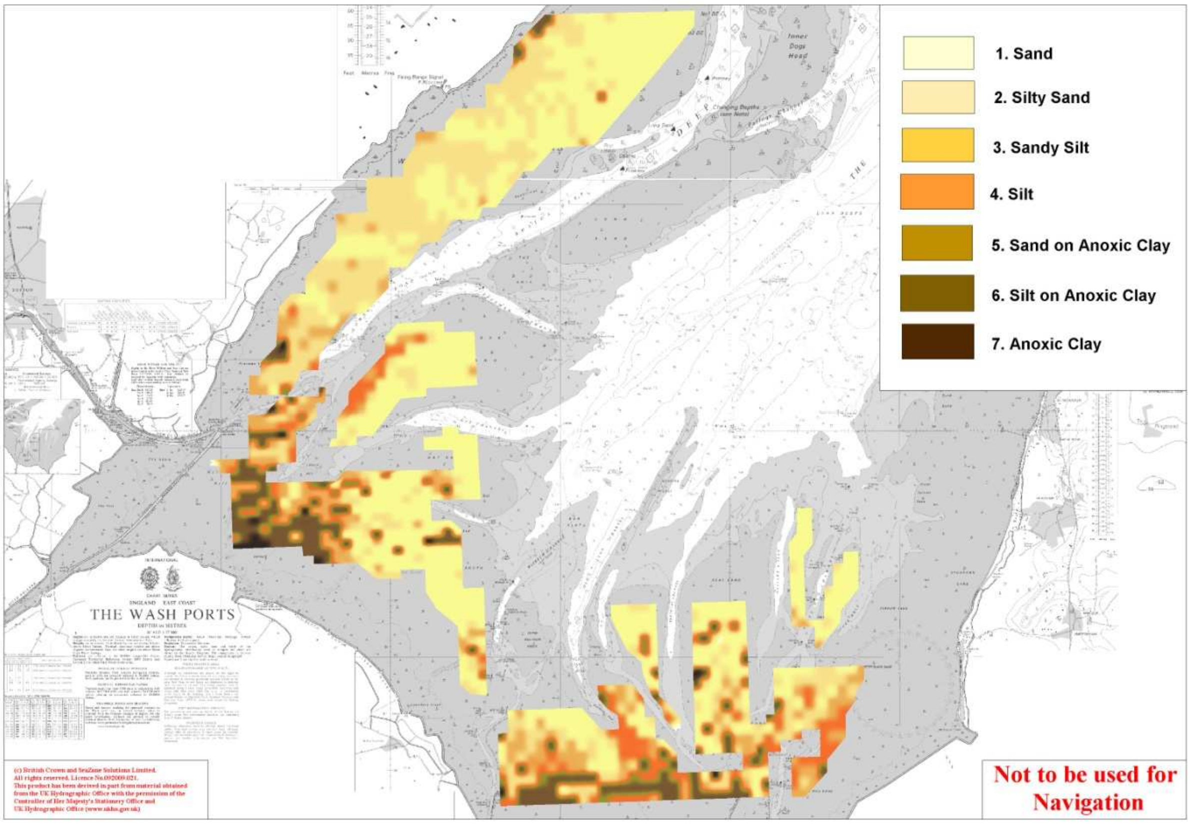


Figure 8.12 Sediment distribution in the areas of the Wash surveyed during April and May 2010.

8.3 Discussion

Density data of the three invertebrates, the lugworm *Arenicola marina*, the sandmason worm *Lanice conchilega* and the Baltic tellin *Macoma balthica*, was collected as part of the annual cockle surveys in the Wash during April and May 2010. The information was used to produce distribution models for the sampled areas of the Wash, which was then compared with data collected over the past four years.

Similar to previous years, *Macoma balthica* has been found predominantly along the higher shore and in areas of fine sediment. *Lanice conchilega*, on the other hand, was distributed at the lower shores that were dominated by coarser sediment. In the past, *Arenicola marina* was found from the upper to lower shore regions, but due to the limited number of samples taken during the 2010 survey, it was not possible to determine whether similar habitats were occupied by this species in 2010.

An overall reduction in *Lanice conchilega* densities was observed from the 2009 to the 2010 survey across most of the areas sampled in the Wash, but the sites occupied by this polychaete showed little change during the same period. No suction dredging for cockles has taken place in the Wash in 2009 and 2010 and this reduction was thus unlikely to be caused by the cockle fishery. *Lanice conchilega* is considered to be a temperature sensitive polychaete (Beukema 1992) and it is therefore possible that the reduced density is a result of the cold winter in 2009/2010, when the lowest temperatures were recorded since the winter of 1995/1996. Similar results were observed in the Wadden Sea, where lower abundances and higher-than-average mortalities of *L. conchilega* coincided with colder winters, while higher numbers of this species were recorded during mild winters (Beukema 1992).

Macoma balthica, on the other hand, showed increased densities in the southwest and southeast Wash in the 2010 survey, but no change was observed in the Boston Main and Roger areas. Unlike *L. conchilega*, *M. balthica* is positively influenced by cold winter temperatures. It was shown that *M. balthica* densities were higher in the year following a cold winter, which was thought to be due to a reduction in predators (Beukema *et al.* 1998). This may explain the higher abundances of *M. balthica* observed in the southwest and southeast areas of the Wash during the 2010 surveys. Since *M. balthica* was included in the invertebrate surveys in 2007, this bivalve has been found predominantly in areas of fine sediment. This is in line with other reports indicating this species' preference for fine sediment with high mud content (Desroy *et al*. 2002, Gofas 2011).

Since no hydraulic suction dredging has taken place in the Wash for the past two years, no impacts on associated invertebrate communities were expected. The data collected during April and May 2010 and the results presented in this report confirm this. Monitoring of densities and distribution of the three invertebrates was conducted nonetheless, since a long term data set will be valuable if hydraulic suction dredging will recur in future years.

9.0 BACTERIOLOGICAL AND BIOTOXIN SAMPLING 2010/11

9.1 Introduction

Shellfish harvesting areas are required to be classified by the competent authority, the Food Standards Agency (FSA) to ensure food safety and public health in accordance with EC regulations 852/2004; 853/2004 and 854/2004. The analytical approach is two-pronged and includes bacteriological analyses of shellfish meats (for the purposes of bed classification) and biotoxin analyses by means of both meat and water analyses.

Bacteriological Sampling- Bed Classification

Bed classification involves initial desktop and coastline studies to ascertain the degree of potential pollutant sources in and around a shellfish production area. Potential sources of contaminant include farmland, treatment plants and boats. Outlets near and into rivers and streams facilitate the transport of faecal coliforms onto shellfish beds where the degree and rate of deposition is affected by a host of physical and environmental factors such as bathymetry of the seabed, seasonality, wind and rainfall.

Based on this information, sanitary surveys are devised to optimise sampling representation and aim to quantify the presence of *Escherichia Coli*, as a proxy of the concentration of faecal coliforms in a shellfish sample. Other viruses such as Norovirus are also tested for, allowing for a more rapid response to outbreaks especially during very cold weather when shellfish filter-feeding, and therefore the purging of such contaminants, is at a minimum.

Under the current scheme, Local Action Groups and Local Action Plans provide an immediate and responsive mechanism for the investigation of *E. coli* sample results exceeding regulatory levels. There are government targets that aim to improve water quality in shellfish harvesting areas under the Shellfish Waters Directive (scheduled to be superseded by the Water Framework Directive in 2013). There has been significant investment in the improvement of sewage systems, although very few shellfish harvesting areas currently achieve an A-grade classification. Ultimately, water quality is one of the most important concerns for the shellfish industry and can cause significant issues for producers.

The testing procedure in the ESFJC district uses samples of *Cerastoderma edule* (common edible cockle), *Mytilus edulis* (blue mussel), *Ostrea edulis* (native or flat oyster), *Crassostrea gigas* (pacific oyster) and at times has included *Ensis directus* (razor clam). Samples are collected monthly by a number of organisations including the ESFJC on behalf of Local Councils. ESFJC itself is currently responsible for collecting *C.edule* and *M.edulis* only.

`**Table 1.** Classification criteria for harvesting areas (Cefas Protocol for the Classification of Shellfish Harvesting Areas – England and Wales, 2009)

Class	Microbiological standard	Treatment level
A	All samples contain <300 faecal coliforms or < 230 *E.coli* / 100g of flesh.	None required (direct human consumption).
B	90% samples must not exceed 6,000 faecal coliforms or 4,600 *E.coli* / 100g of mollusc flesh. 10% of samples must not exceed 46,000 *E.coli* / 100g of flesh.	Depurate (using approved methodology), relayed in an approved Class A relaying area or heat treated by approved methods before being sold for human consumption.
C	All samples must not exceed 60,000 faecal coliforms or 46,000 *E. coli* / 100g of mollusc flesh.	Must be relayed (minimum of 2 months) to meet Class A or B, or be heat treated.
D	Do not conform to at least class C.	Prohibited.

Biotoxin Sampling

C.edule, *M.edulis* and water samples are collected by ESFJC as part of this sampling regime on a monthly basis. Meats are used in the testing of Amnesic Shellfish Poisoning (ASP) associated with *Pseudo nitzchia*, Diarrhetic Shellfish Poisoning (DSP) caused by *Dinophysis spp*. and *Prorocentrum lima*, and Paralytic Shellfish Poisoning (PSP) caused by *Alexandrium spp*. Unusually high biotoxin concentrations can often be triggered by plankton blooms where an influx of phytoplankton to a system may bring with it toxic algal species. The presence of these may cause a temporary increase in the detection of toxic species associated with ASP, DSP and PSP. Although the occurrence of one, is not necessarily preceded by the other, they can give an indication as to whether a toxic event may be imminent in results. The plankton data is analysed from water samples collected concurrently with the meat samples on behalf of Cefas and analysed by the Cefas plankton laboratories in Lowestoft.

Table 2. Action levels of flesh and water toxic algae levels and methods of analysis. (Accreditation to ISO 17025).

	Flesh	**Method of analysis**	**Water**	**Method of analysis**
ASP	20µg/g flesh	High Performance Liquid Chromatography (HPLC)	Producing algae: 150,000 cells/L	Utermöhl method (Light microscopy and electron microscopy)
DSP	Presence	Mouse Biological Assay (MBA) and Liquid Chromatography Mass Spectrometry (LC-MS)	Producing algae: 100 cells/L	
PSP	80µg/g/100g flesh	MBA and HPLC for screen and quantitation	Producing algae: Presence (40cells/L)	

The HPA has recently approved the use of a chemical method, High Performance Liquid Chromatography (HPLC), as a quantitative assay for the testing of PSP toxins in mussels, cockles, razor clams and hard clams. It is envisaged that in time such chemical methods will replace the bioassay involving live mice.

Based on the current programme of monitoring, Table 3 outlines the current sample requirements from each site in The Wash from which Officers collect organisms. Figure 1 depicts the locations of these sampling sites. During site visits, water quality readings are taken using data sondes (as described in Section 6 of this document). Such concurrent data collection provides water quality parameter details utilised by Cefas and contribute to the SWEEP study that is being conducted by the ESFJC (See Section 6 of this document).

Table 3. Current bacteriological sampling requirements for The Wash

Sample type	**Area**	**Zone**	**Species**
EHO	Friskney / Wrangle	1	*Cockle*
	North Lays / Witham Bank	1	*Mussel*
	Mare Tail	2	*Mussel*
	Breast	3	*Cockle*
	Breast	3	*Mussel*
	Stylemans	4	*Mussel*
	Training Wall	5	*Mussel*
	Welland Wall	6	*Mussel*
Biotoxin	Friskney / Wrangle	1	*Cockle*
	Mare Tail	2	*Mussel*
	Breast	3	*Cockle*
Water	Friskney / Wrangle	1	
	Mare Tail	2	
	Breast	3	
	Heacham South	4	

9.2 Methodology & Analysis

Samples described in Table 3 and Figure 1 were collected and delivered to the Centre for Environmental, Fisheries and Aquaculture Science (Cefas) using temperature controlled biotherm boxes. Bacteriological and Biotoxin analyses are conducted by the Cefas under contract of the FSA. Details of the methodologies used at Cefas laboratories together with results can be found at the following websites:

Shellfish classification results (*E.Coli* numbers in detail) and maps including maps of zones (Cefas website):
http://www.cefas.co.uk/our-science/animal-health-and-food-safety/food-safety/classifying-shellfish-harvesting.aspx

For the classification ratings of shellfish beds see (Food Standards Agency website):
http://food.gov.uk/multimedia/pdfs/shellclassew201011e.pdf

For biotoxin results (ASP, DSP and PSP) see (Food Standards Agency Website):
http://food.gov.uk/foodindustry/farmingfood/shellfish/ewbiotoxin/

Figure 1 depicts the locations of sampling sites. During site visits, water quality readings are taken using YSI data sondes (as described in Section 6). Such concurrent data collection provides water quality parameter details utilised by Cefas and contribute to the SWEEP study that is being conducted by the ESFJC (See Section 6 of this document).

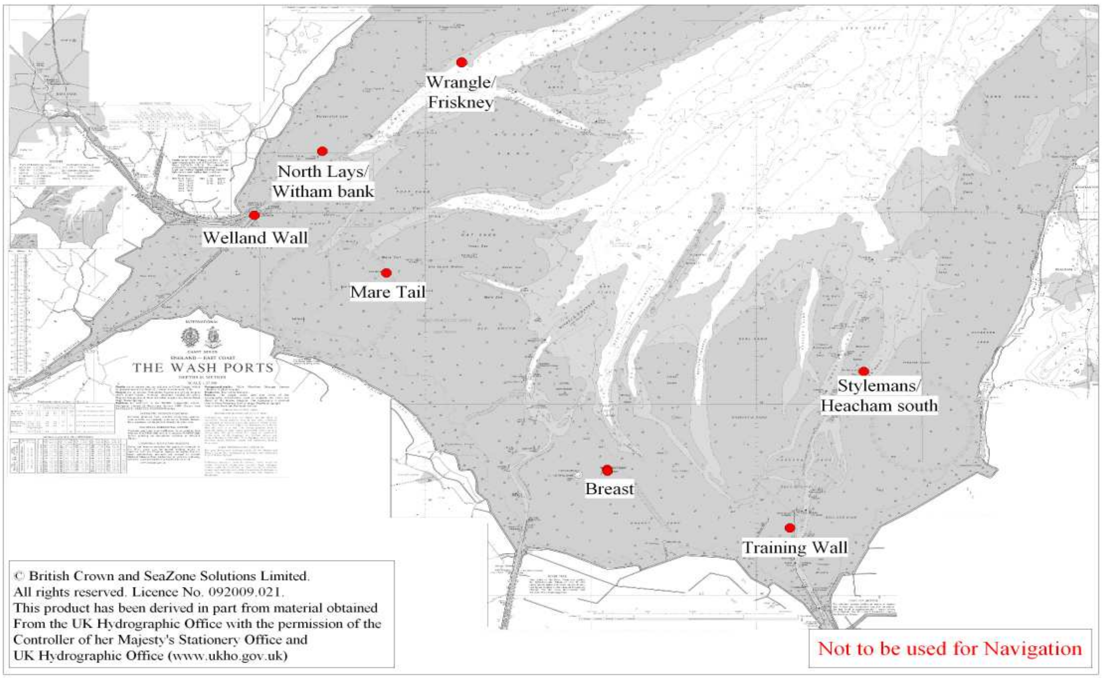


Figure 1 Bacteriological, Biotoxin and water sampling sites (2010)

9.3 Results and Discussion

Table 4 reports the classification results of bivalve production areas in the ESFJC district during the periods 2009-10. Classifications are effective from the 1st of September until 31st of August of the following year. The latest classifications (2009-10) for those sites in which ESFJC collect samples are all of a B-grade standard (Table 4), meaning the shellfish are required to undergo depuration or other suitable treatment by producers prior to consumption. The majority of the areas have achieved a long-term status, in that they have 5 years of compliance data. Since a sanitary survey in 2010, Bednames for Blakeney were changed as follows: Well-The Pool (previously Bob Halls Sands)-cockles are no longer classified; Simpool Head (formerly Simpool)-name change and Southside (formerly Morston Strand)-name change. These bed classification results are generally good, but the aim would be to achieve waters with an A-grade classification for all production areas within the Eastern Sea Fisheries district.

There have been no incidences of biotoxin meat or water samples containing toxic algae species above what is regarded as safe throughout 2009-10.

Table 4. *Classification of bivalve mollusc production areas in the ESFJC district, 1st September 2010 to the 1st September 2011*

2010	The Wash - Boston												
Zone	Zone 1 North			Zone 1 South	Zone 2 East								
Bed name	Butterwick	Wrangle	Friskney	Witham Bank/ North Lays	Maretail	Tofts Ridge	Tofts South	Gat Sand	Toft Lays	Herring Hill	Black Buoy	Holbeach (formerly Nene)	Welland Wall
C.edule	B	B	B		B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	
C.gigas													
M.edulis				B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B
O.edulis													

2010	The Wash - King's Lynn											
Zone	Zone 3					Zone 5	Zone 4 North		Zone 4 South			
Bed name	Thief	Breast Sand	Breast Sand (IWMK)	Daseleys	Scotsman's Sled	Training Wall	Heacham	Hunstanton	Ferrier Sand	Pandora	Stylemans	South Daseleys
C.edule	B-LT	B-LT	B-LT	B-LT			B-LT		B-LT	B-LT	B-LT	B-LT
C.gigas												
M.edulis	B-LT	B-LT		B-LT	B-LT	B-LT		B-LT	B-LT	B-LT	B-LT	B-LT
O.edulis												

2010	Brancaster			Blakeney		River Alde	Butley
Zone							
Bed name	Brancaster	Thornham	Burnham Overy Staither	Simpool Head	Southside	Home Reach	Creek
C.edule	B-LT						
C.gigas	B-LT	B-LT			B-LT	B-LT	B-LT
M.edulis	B-LT		B	B-LT			
O.edulis							

Notes

Cerastoderma edule = Common edible cockle
Mytilus spp. = Mytilus edulis. (blue mussel)
Ostrea edulis = Native or Flat Oyster
Crassostrea gigas = Pacific Oyster
LT = Long-term classification applies

There are many factors which can influence the levels of microbiological contamination in mollusc flesh including environmental conditions, time of year and the quality and quantity of faecal contamination discharged into local coastal area. Sources of contamination include human and animal sources of pollution that can occur as point source inputs (e.g. discharges, outfalls and cracked pipes) or more generally as diffuse pollution (e.g. agricultural runoff). Although there have been many improvements in recent years, the identification and prevention of contamination from such sources is clearly difficult and represents an ongoing challenge.

10.0 ACKNOWLEDGEMENTS

The Research team would like to thank all those who have assisted in the production of the Committee's 2010 Research Report, including;

- The Masters and crews of the Committee's vessels and the shore based officers for their invaluable assistance in the collection of data.
- All at ESFJC office, in particular Dawn Reeve and Jodi Hammond for their efforts in printing and final production of this report.
- Former ESFJC Research Officer, Andrew Harwood, for his help and enthusiasm in instigating the Study of the Wash Embayment Environment and Productivity (SWEEP) project.
- Dave Palmer and the shellfish team of CEFAS for their continued support and advice.
- Dave Sivyer, Veronique Creach, Naomi Greenwood and Katy Owen from CEFAS, for their advice towards the SWEEP project sampling regime and their continued support with water sampling and analyses.
- Mike Gubbins and the CEFAS Fish Health Inspectorate team for assistance in analysing shellfish samples for potential pathogens
- Martin Dyer and everyone at Unicomarine for analysing the cockle propeller wash core samples and processing the data.
- Natural England who contributed financially to the acquisition of the YSI water quality data sondes and in-situ buoy system, and for their support of the SWEEP project since its inception
- Jan Light of the Conchological Society of GB and Ireland, for assistance in classifying bivalve species.
- Stuart Tyler, for the use of his vessel and assistance in collecting the Holbrook Bay oyster data.
- Fishermen throughout the District for their continued support and advice with projects.

11.0 References

Beukema, J.J. (1992) Expected changes in the Wadden Sea benthos in a warmer world: Lessons from periods with mild winters. *Netherlands Journal of Sea Research* 30, 73-79.

Beukema, J.J., Honkoop, P.J.C., Dekker, R. (1998) Original reference not seen, cited by Widdows & Brinsley (2002). Recruitment in *Macoma balthica* after mild and cold winters and its control by egg production and shrimp predation. *Hydrobiologia* 375/376, 23-34.

Blott, S.J., Pye, K. (2001) GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms* 26, 1237-1248.

Callaway, R., Desroy, N., Dubois, S.F., Fournier, J., Frost, M., Godet, L., Hendrick, V.J., Rabaut, M. (2010) Ephemeral bio-engineers or reef-building polychaetes: how stable are aggregations of the tube worm *Lanice conchilega* (Pallas, 1766)? *Integrative and Comparative Biology* 50(2), 237-250.

Coffen-Smout, S.S., Rees, E.I.S. (1999) Burrowing behaviour and dispersion of cockles *Cerastoderma edule* L. following simulated fishing disturbance. *Fisheries Research* 40, 65–72.

Cranford, P.J., Li, W.K.W., Strand, O., Strohmeier, T. *(2008) Phytoplankton depletion by mussel aquaculture: high resolution mapping, ecosystem modeling and potential indicators of ecological carrying capacity. International Council for the Exploration of the Seas (ICES). Theme H: Ecological Carrying Capacity in Shellfish Aquaculture. ICES CM 2008/H:12.*

Desroy, N., Warembourg, C., Dewarumez, J.M., Dauvin, J.C. (2002) Macrobenthic resources of the shallow soft-bottom sediment in the eastern English Channel and southern North Sea. *ICES Journal of Marine Science* 60, 120-131.

de Vlas, J. (1979) Secondary production by tail regeneration in a tidal flat population of lugworms (*Arenicola marina*), cropped by flatfish. *Netherlands Journal of Sea Research* 13 (3/4), 362-393.

Ens, B.J., Smaal, A.C., de Vlas, J. (2004) The effects of shellfish fishery on the ecosystems of the Dutch Wadden Sea and Oosterschelde; Final report on the second phase of the scientific evaluation of the Dutch shellfish fishery policy (EVA II). Wageningen, Alterra, Alterra-rapport 1011, RIVO-rapport C056/04, RIKZ-rapport RKZ/2004.031, 212 blz.

FRS (2004) *Lobsters and Crabs Information leaflet FM16*. Fisheries Research Services, Aberdeen. [Accessed online at http://www.frs-scotland.gov.uk/Uploads/Documents/FM16LobstersCrabs.pdf on 5/3/2008.]

Gofas, S. (2011) *Macoma balthica* (Linnaeus, 1758). Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=141579 on 2011-03-10.

Goss-Custard, J.D., Jones, R.E., Newbery, P.E. (1977) The ecology of the Wash. I. Distribution and diet of wading birds (Charadrii). *Journal of Applied Ecology* 14(3), 681-700.

Goudeau, M; Talbot, P; Harper, R (1987) Mechanism of egg attachment stalk formation in the lobster, Homarus. *Gamete Research* 18:4, pp279-289.

Gubbay. S., (2007) Defining and managing *Sabellaria spinulosa* reefs: report of an inter-agency workshop 1-2 May, 2007. Joint Nature Conservation Committee Report No. 405. 22pp. JNCC, Peterborough. ISSN 0963-8091.

Guthrie, J.F., Lewis, C.W. (1982) The clam-kicking fishery of North Carolina. *Marine Fisheries Review* 44(1), 16-21.

Hall, S.J., Harding, M.J.C. (1997) Physical disturbance and marine benthic communities: The effects of mechanical harvesting of cockles on non-target benthic infauna. *Journal of Applied Ecology* 34(2), 497-517.

Hendrick,V,J., Foster-Smith, R.L., (2006) *Sabellaria spinulosa* reef: a scoring system for evaluating 'reefiness' in the context of the Habitats Directive. *Journal of the Marine Biological Association 86*, 665-677.

Hiddink, J.G. (2003) Effects of suction-dredging for cockles on non-target fauna in the Wadden Sea. *Journal of Sea Research* 50, 315-323.

Hoey, G.V., Guilini, K., Rabaut, M., Vincx, M., Degraer, S. (2008) Ecological implications of the presence of the tube-building polychaete *Lanice conchilega* on soft-bottom benthic ecosystems. *Marine Biology* 154, 1009-1019.

Jackson, A., Hiscock, K., (2006) Web Page: *Sabellaria spinulosa*. Ross worm. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: http://www.marlin.ac.uk/species/Sabellariaspinulosa.htm

Jensen, A.C., Humphreys, J., Caldow, R.W.G., Grisley, C., Dyrynda, P.E.J., 2004. Naturalization of the Manila clam (*Tapes philippinarum*), an alien species, and establishment of a clam fishery within

Poole Harbour, Dorset. *Journal of the Marine Biological Association of the United Kingdom* 84, 1069-1073.

Jessop, R.W., Graves, K.M., (2005) Eastern Sea Fisheries Joint Committee Research Report 2005. ESFJC, King's Lynn.

Jessop, R.W., Harwood, A.J.P., Woo, J.R., (2009) Eastern Sea Fisheries District Research Report 2009. Eastern Sea Fisheries Joint Committee. King's Lynn.

Jessop, R.W., Woo, J.R., Harwood, A.J.P., (2008) Eastern Sea Fisheries District Research Report 2008. Eastern Sea Fisheries Joint Committee. King's Lynn.

Jessop, R.W., Woo, J.R., Torrice, L., (2007) Eastern Sea Fisheries District Research Report 2007. King's Lynn. Eastern Sea Fisheries Joint Committee: King's Lynn.

Kaiser, M.J., Broad, G., Hall, S.J. (2001) Disturbance of intertidal soft-sediment benthic communities by cockle hand raking. *Journal of Sea Research* 45, 119-130.

Karlsson, J and Sisson, R (1973) A technique for the detection of brushed lobsters by staining the cement of the swimmerets. *Transactions of the American Fisheries Society* 102:847-848.

Korringa, P. (1968) On the ecology and distribution of the parasitic copepod *Mytilicola intestinalis* Steuer. *Bijdragen tot de Dierkunde* 38, 47-57.

MAFF (1996) *The lobster: its biology and fishery*. Laboratory leaflet, MAFF Directorate of Fisheries Research, Lowestoft. 19pp.

Mander, M (2009) *Eastern Sea Fisheries Joint Committee Annual Report 2009*. ESFJC, King's Lynn.

Moore, M.N., Lowe, D.M. and Gee, J.M. (1977) Histopathological effects induced in *Mytilus edulis* by *Mytilicola intestinalis* and the histochemistry of the copepod intestinal cells. *Journal du Conseil International pour l'Exploration de la Mer* 38(1), 6-11.

O'Haver, T.C. (2010) *Pers. Comm. 6th November 2010. Professor Emeritus, Department of Chemistry and Biochemistry, University of Maryland, US.*

Pengelly, S., (2010) Environment and Fisheries Officer, Southern Sea Fisheries District Committee. Personal comment concerning densities of *Tapes phillipinarum* in Poole Harbour, Dorset, UK.

Petersen, C.H., Summerson, H.C., Fegley, S.R. (1987) Ecological consequences of mechanical harvesting of clams. *Fishery Bulletin* 85(2), 281-298.

Pieters, H., Kluytmans, J.H., Zandee, D.I., Cadee, G.C. (1980) Tissue composition and reproduction of *Mytilus edulis* in relation to food availability. *Netherlands Journal of Sea Research* 14, 349-361.

Prins, T.C., Dankers, N., Smaal, A.C. (1994) Seasonal variation in the filtration rates of a semi-natural mussel bed in relation to seston composition. *Journal of Experimental Marine Biology and Ecology* 176, 69-86

***R Development Core Team** (2010). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org*

Thomas, HJ (1965) The Protection of Berried Lobsters. *Scottish Fisheries Bulletin* 23. 3pp.

US Environmental Protection Agency (2010) Principal Component Analysis. Accessed from http://www.epa.gov/bioiweb1/statprimer/pca.html on the 10th of January 2011.

Vaughan, D (2008) *Synopsis of work conducted to develop a test to identify lobsters (*Homarus gammarus*) that have had their eggs scrubbed illegally*. Report to Jonathon Shaw MP. Eastern Sea Fisheries Joint Committee.

Volkenborn, N., Robertson, D.M., Reise, K. (2009) Sediment destabilizing and stabilizing bio-engineers on tidal flats: cascading effects of experimental exclusion. *Helgol□nder Marine Research* 63, 27-35.

Web 1 (2011) Haematoxylin Eosin (H&E) staining. Available online at: http://protocolsonline.com/histology/haematoxylin-eosin-he-staining/ [Accessed April 2011].

Wilson, D.P., (1970). The larvae of *Sabellaria spinulosa* and their settlement behaviour. *Journal of the Marine Biological Association of the United Kingdom* 50, 33-52.

Worsfold, T., Hall, D., Ashelby, C. (2010) Unicomarine Procedural Guidelines and Quality Control Systems, Version 5.0. March 2010.