Eastern IFCA
Inshore Fisheries and Conservation Authority

RESEARCH REPORT 2016

WFO MUSSEL STOCK ASSESSMENT

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2016 WFO MUSSEL SURVEY

CONTENTS

Introduction

The intertidal mussel stocks in The Wash have traditionally provided a valuable resource for the local fishing industry; either being harvested directly for market or relayed from poor-growing beds within the regulated fishery to leased lay ground within the several fishery. These stocks also provide an important habitat for invertebrate communities and an essential food resource for the internationally important communities of birds that reside or over-winter in the Wash. Despite their importance to both fishermen and wildlife communities, heavy fishing activity coupled with low recruitment resulted in a crash in the stocks in the 1990s. Following this decline draconian fishery management measures were introduced but recovery was slow until an exceptional spatfall in 2001 rejuvenated several of the beds and helped new ones to develop. Following the recovery of the stocks from this crash, an increasing awareness of the mussel beds as an important environmental resource led to a comprehensive review of the management measures for shellfish in the Wash being conducted. This review resulted in a set of shellfish management policies being agreed between the Authority, Natural England and fishing industry in 2008. These policies have subsequently formed the framework guiding the management measures for the Wash mussel and cockle fisheries.

Adhering to the management policies helped to stabilise the mussel stocks above their 12,000 tonnes Conservation Objective target and by 2009 they had reached 15,188 tonnes. An unexpected crash between 2009 and 2010, however, caused the stocks to decline to 9,626 tonnes. Cefas attributed the cause of this die-off to an unusually high abundance of the parasitic copepod, *Mytilicola intestinalis*. Although there was sufficient recovery in stock biomass over the following three years to achieve the Conservation Objective target once more, there was increasing concern over the health of the beds. Since then recruitment has tended to be poor and mortality high. Some of the decline can be attributed to an ageing mussel population, particularly on those beds that first settled in 2001 and have since received little subsequent settlement. Of greater concern, however, have been the recent high levels of mortality observed among younger mussels that are typically 2 or 3 years old. In several cases these die-offs have resulted in the sudden decline of beds that had previously appeared to be in good states of health. Initially this was most noticeable in the sharp decline of the Gat beds, but since 2012 the surveys have found most of the beds to be in a state of steady decline. The reason

for this decline is currently not known. The *Mytilicola intestinalis* parasite, which was considered a causal factor in the 2010 die-off, is still present in the stocks. Most literature, however, suggests this parasite does not kill its host. The decline is not thought to be the result of fishing activity either. There has been little fishing activity on the beds in recent years and none during 2015. The presence of dead young mussels on many of the beds is also not indicative of fishing impacts.

In recent years recruitment has also been poor. Although a widespread settlement in 2001 helped to rejuvenate many of the beds and established several new ones, such events are rare in the Wash. Usually, the majority of settlement tends to occur within existing beds. This is possibly due to the physical matrix of living and dead shells bound by byssus threads found within a healthy mussel bed, providing favourable conditions for attracting settlement and affording protection for seed. As the inter-tidal beds have declined, however, their densities have fallen below levels at which these raised matrices tend to form, potentially reducing further their potential to attract seed. Observations have found that when mussel seed does settle outside of existing mussel beds in the Wash, it is usually in areas where cockle shells have accumulated on the surface. In 2014 the Authority began a research project to study whether laying a culch of cockle shells could be used as a method of encouraging the settlement of mussel seed. It was hoped that if successful, this could be used as a method of rejuvenating mussel beds.

This report documents the results of the 2016 mussel surveys and includes an update on the results from the mussel regeneration project.

Method

The intertidal mussel surveys in the Wash are conducted during the daytime low periods of spring tides. These tides allow vessel access the higher beds while allowing lower beds to become fully exposed. For most of the surveys, the beds are accessed by drying the research vessel out close to the bed, taking care to use safe anchor sites selected prior to the survey.

To determine the biomass of mussels within a bed, the area of the bed is multiplied by the mean biomass of the mussels within the bed. Because the mussels in the Wash tend to have patchy distributions, the mean biomass is determined by multiplying the mean mussel density within the patches with the mean percentage coverage of the patches.

To determine the area of the bed, one member of the survey team walks around the perimeter of the bed, close to the edge of the mussels, entering waypoints into a handheld GPS at each change of direction. Determining the edge of the bed can be subjective at times as not all beds have clearly defined edges. In such cases, experience is required to maintain consistency in what is included within the bed perimeter. The waypoints gained from the survey are transferred to a Geographic Information System (GIS), MapInfo, from which the perimeter of the bed can be plotted and its area determined.

To measure the mean density and coverage of the mussels within the bed, the Authority uses a procedure demonstrated by the Dutch marine consultants, MarinX, during the 2004 mussel surveys (van Stralen & Bol, 2004). The survey is conducted in transects that zig-zag across the bed, taking care that the transect lines offer equal bias to all parts of the bed. On small beds this can be determined by eye at the time of the survey, but for larger beds this can be difficult. For larger beds gridded charts taken from the previous year's survey are used to assign an even coverage of transect lines (see figure 1).

As the survey team walk along the transect lines, the coverage of mussels is determined using an 11cm ring attached to a pole. Every three paces the ring is placed on the ground and the presence ("hit") or absence ("miss") of mussels within the ring recorded. Randomisation is achieved by placing the ring down to one side, outside of the field of vision of the user. In order to calculate patch density, samples

of mussels are taken from within some of the rings that were determined to be "hits". Prior to commencing the survey it is determined how many of the "hits" will be taken as samples. This is a compromise between accuracy and how many mussels can be carried/measured. Depending on the size of the bed, how good the coverage looks and how many small mussels appear to be in the bed, sampling may occur as often as 1 sample from 2 hits to 1 sample from 7 hits. For most of the beds in the Wash samples are collected from either 1 in 4 or 1 in 5 hits.

When a sample is collected it is taken from within the ring that produced the "hit" determination using a corer of the same diameter as the sampling ring. This is gently twisted into the ground to a depth of approximately 8cm (it is important to twist the corer rather than pushing it into the ground, as any mussels that are partially in/out will then tip either in or out of the corer rather than just being pushed down into the mud). All the mussels within the corer are then placed into a 5 litre container, enabling numerous small random samples to be collected from throughout the bed.

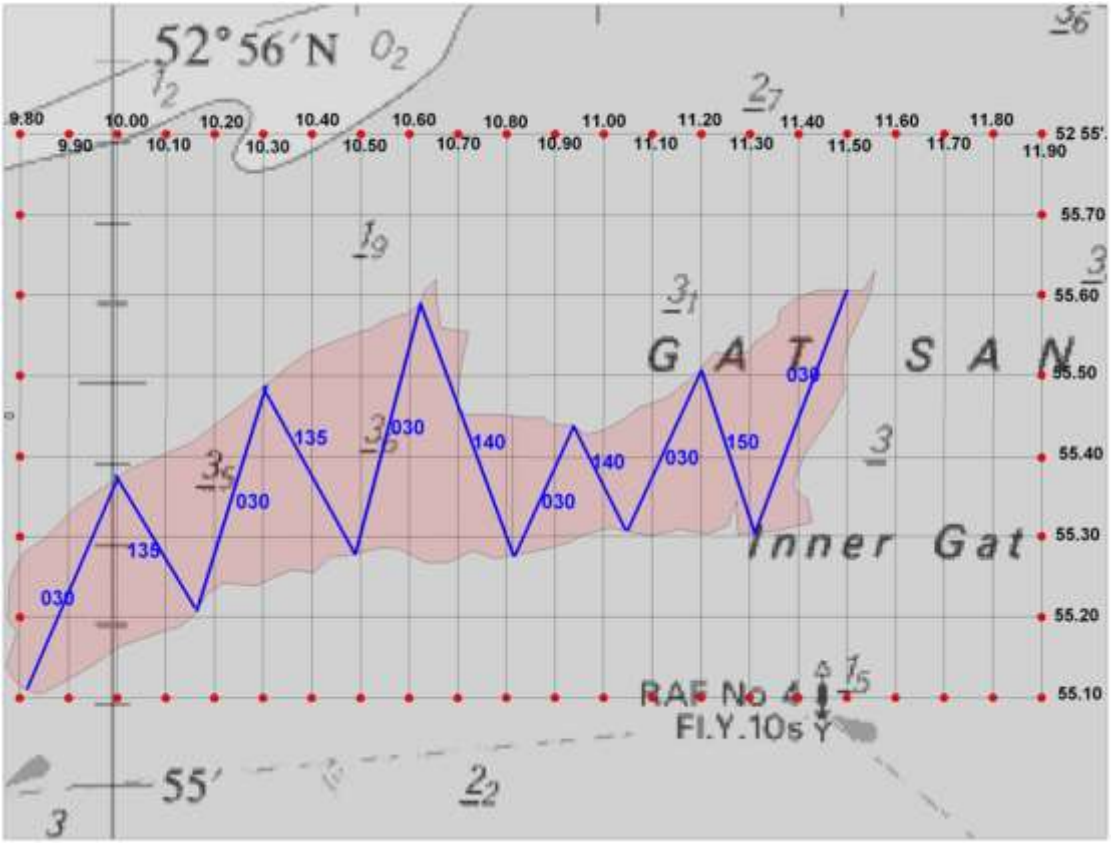

Figure 1 – Chart showing the area of a mussel bed, the transect lines to be surveyed, their bearings and an overlaid grid showing the latitude and longitude

For the surveys in the Wash, samples are divided into groups that have been collected from transects that are 150 hit/miss determinations in length. These are washed using a 0.5mm sieve and placed in labelled bags. On returning to the research vessel the live mussels are separated from the debris in each sample. The length of each mussel is determined, and the samples divided into those mussels that are of marketable size (≥45mm) and those that are smaller. Since 2012 the number and weight of mussels ≥25mm length have also recorded as this size range is favoured by oystercatchers.

In addition to determining the biomass of mussels within the bed, the size distribution of the population is obtained from the length measurements of mussels in the retained samples.

Results

The 2016 surveys commenced on September 17th and were completed on October 18th. During this period 17 areas of mussel bed were surveyed. Further surveys on three small patches of mussels on the Mare Tail sand were planned for later in October, but poor weather prevented these from being conducted. In addition to these inter-tidal beds, the mussels on the Welland Bank were also surveyed.

The surveys found that although the beds still appeared to be in a vulnerable condition following several years of decline, most of them had benefitted from a moderate settlement of seed since the previous year. In addition to settling within existing beds, in some areas seed was found to have settled among patches ridged out cockles that bordered mussel beds. Two such areas, adjacent to the South Mare Tail and Toft beds, are highlighted in blue on the chart in figure 2. Similarly, the Blackshore bed was found to have resettled after losing 95% of its stock during the previous three years.

The surveys also found that natural mortality was less evident than in recent years, when high proportions of the 2 and 3 year-old mussels had died. The reduction in mortality this year is possibly due to the population supporting lower levels of these vulnerable cohorts this year following poor spatfalls between 2012 and 2014. This reduction in mortality, coupled with recruitment and growth, has helped the overall mussel biomass to increase from 9,376 tonnes to 12,002 tonnes[1]. Table 1 summarises the stocks found on each bed surveyed, while the chart in figure 3 highlights the changes in mussel biomass on the beds between the 2015 and 2016 surveys.

[1] This figure does not include three small beds that we were unable to survey this year. Previous survey results indicate these beds would support a combined stock of approximately 120 tonnes.

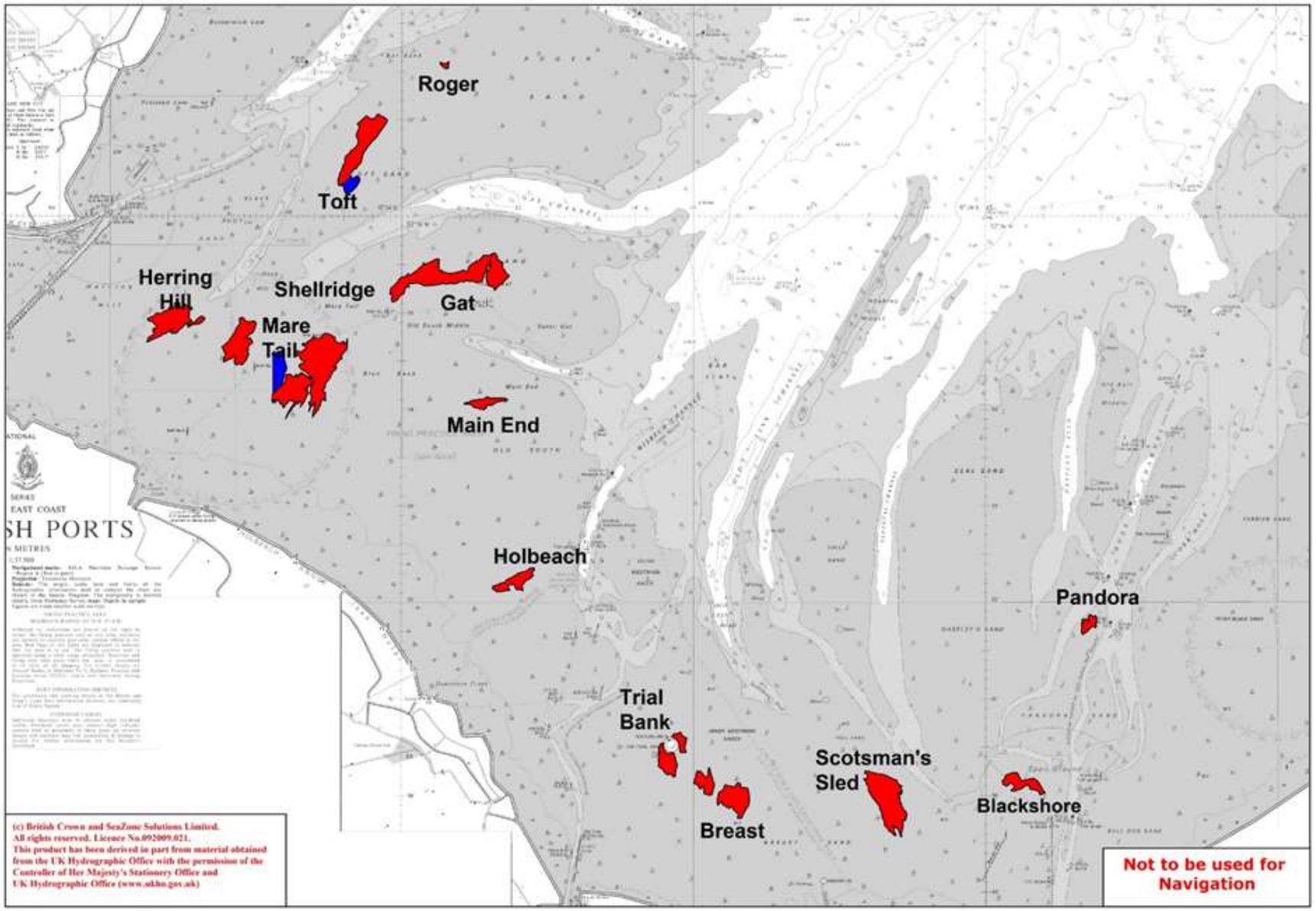

Figure 2 - Distribution of intertidal mussel beds surveyed during 2016

Table 1 – Summary of the mussel stocks on individual beds at the time of the 2016 surveys

	2016							2015	
BED	**AREA (ha)**	**COVERAGE (%)**	**DENSITY (kg/0.1m)**	**TOTAL STOCK (tonnes)**	**STOCK >45MM (tonnes)**	**% ≥45MM (%)**	**BED DENSITY (Tonnes/ha**	**TOTAL STOCK**	**% CHANGE**
Mare Tail North	68	37	0.86	2190	1187	54.2	32.2	1969	11.2
Mare Tail South	30.6	34	0.7	718	173	24.1	23.5	632	13.6
Mare Tail South (ext)	15	27	0.13	53	0	0.0	3.5	0	-
Mare Tail East	Unsurveyed							79	-
Mare Tail West	31.6	41	0.33	435	87	20.0	13.8	239	82.0
Shellridge	Unsurveyed							0	-
Toft	40.8	37	1.4	2148	1936	90.1	52.6	1428	50.4
Toft Ext	6.7	46	0.22	69	27	39.1	10.3	0	-
Roger	1.4	32	0.69	31	23	74.2	22.1	31	0.0
Gat, West	35.3	42	0.73	1095	681	62.2	31.0	828	32.2
Gat, Mid	21.5	37	0.63	496	325	65.5	23.1	225	120.4
Gat, East	17.1	45	0.71	549	355	64.7	32.1	373	47.2
Main End	8.98	31	0.64	179	121	67.6	19.9	55	225.5
Holbeach	14.6	52	0.34	254	57	22.4	17.4	280	-9.3
Herring Hill	34.6	35	0.85	1014	338	33.3	29.3	748	35.6
East Herring Hill	Unsurveyed							41	-
Trial bank	19.6	32	1.01	635	193	30.4	32.4	695	-8.6
Breast, West	11.6	24	1.12	308	145	47.1	26.6	259	18.9
Breast, East	25.4	30	1.13	853	390	45.7	33.6	804	6.1
Scotsman's Sled, East	53.1	19	0.59	584	180	30.8	11.0	518	12.7
Blackshore	15	23	0.57	202	13	6.4	13.5	50	304.0
Pandora	6.6	28	1.01	189	144	76.2	28.6	122	54.9
TOTAL	**457**			**12002**	**6375**	**53.1**	**26.2**	**9376**	28.0
Welland Bank	2.5	75	2.38	438	345	78.8	264.2	442	-0.9

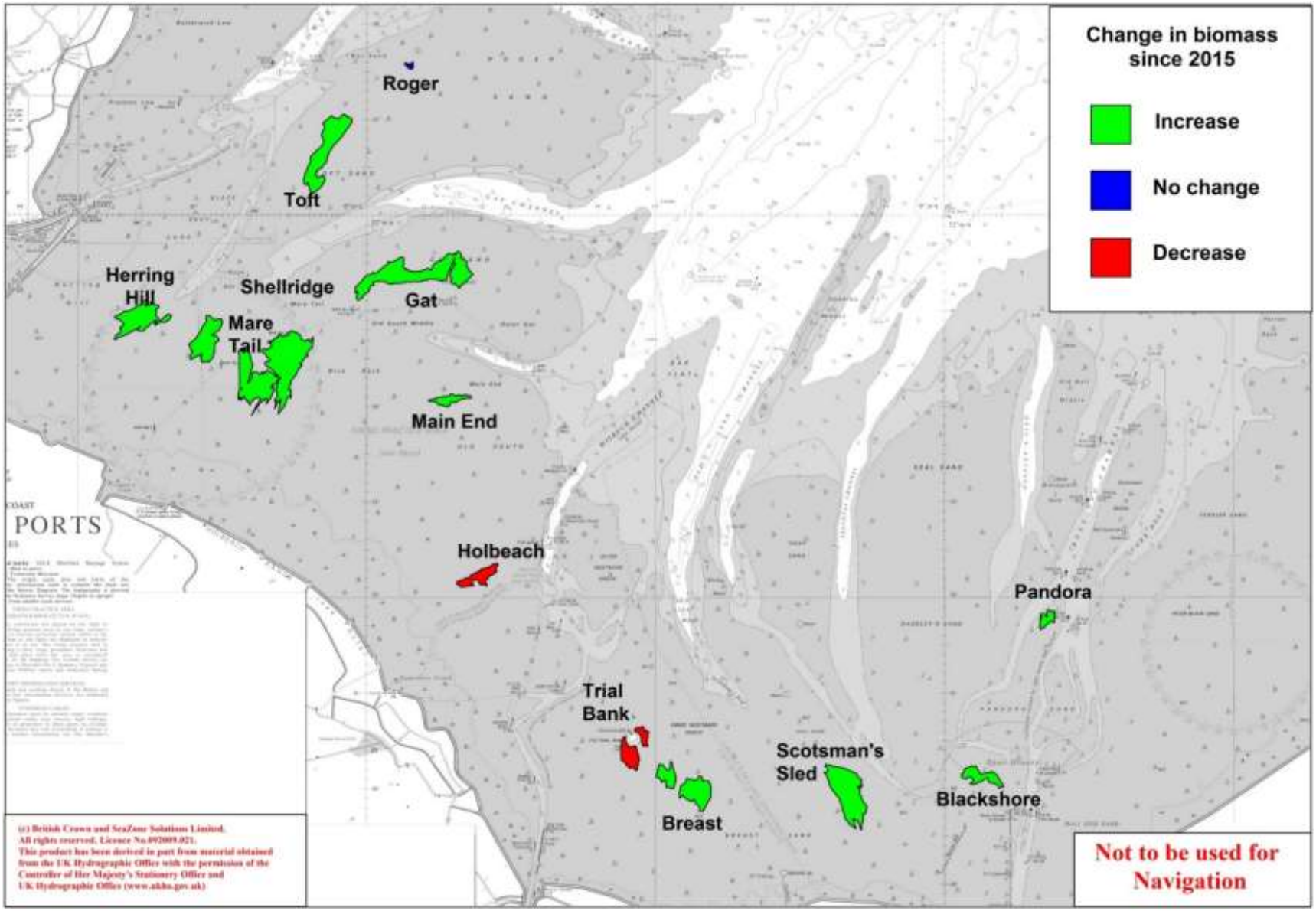

Figure 3 – Chart highlighting the changes in mussel biomass to individual beds between the 2015 and 2016 surveys

Mare Tail Beds

Mare Tail supports a conglomeration of mussel beds that are either short distances apart or separated by creeks. For survey purposes, these beds are monitored as individual entities and include the North, South, West and East Mare Tail beds. Unfortunately, due to poor weather conditions, it was not possible to survey the East Mare Tail bed during the 2016 survey programme. Figure 4 shows the distribution of the Mare Tail beds surveyed in 2016.

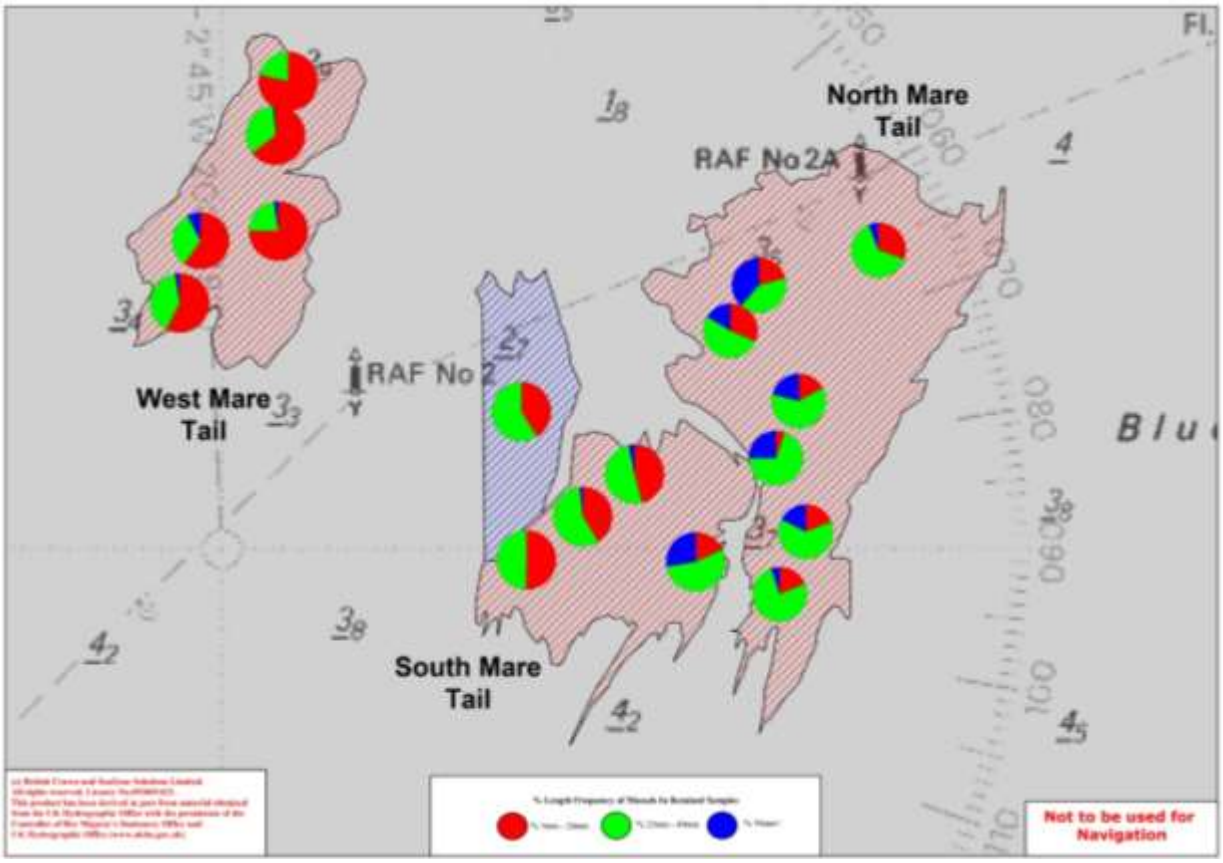

Figure 4 - Mussel size distributions on the Mare Tail mussel beds – October 2016

Until 2015 the Shellridge bed was also situated to the north of this area, but following several years of declining stocks it had deteriorated to a level no longer warranting surveying.

North Mare Tail

- Area: 68.0 hectares
- Coverage: 37%
- Mean Density: 0.86 kg/0.1m^2
- Total Stock: 2,190 tonnes
- Stock ≥ 45mm: 1,187 tonnes

The North Mare Tail bed was surveyed on September 18th, during which samples were collected from every fifth "hit", producing 78 samples from seven transects. Figure 5 shows the mussel size frequency within the population taken from these samples.

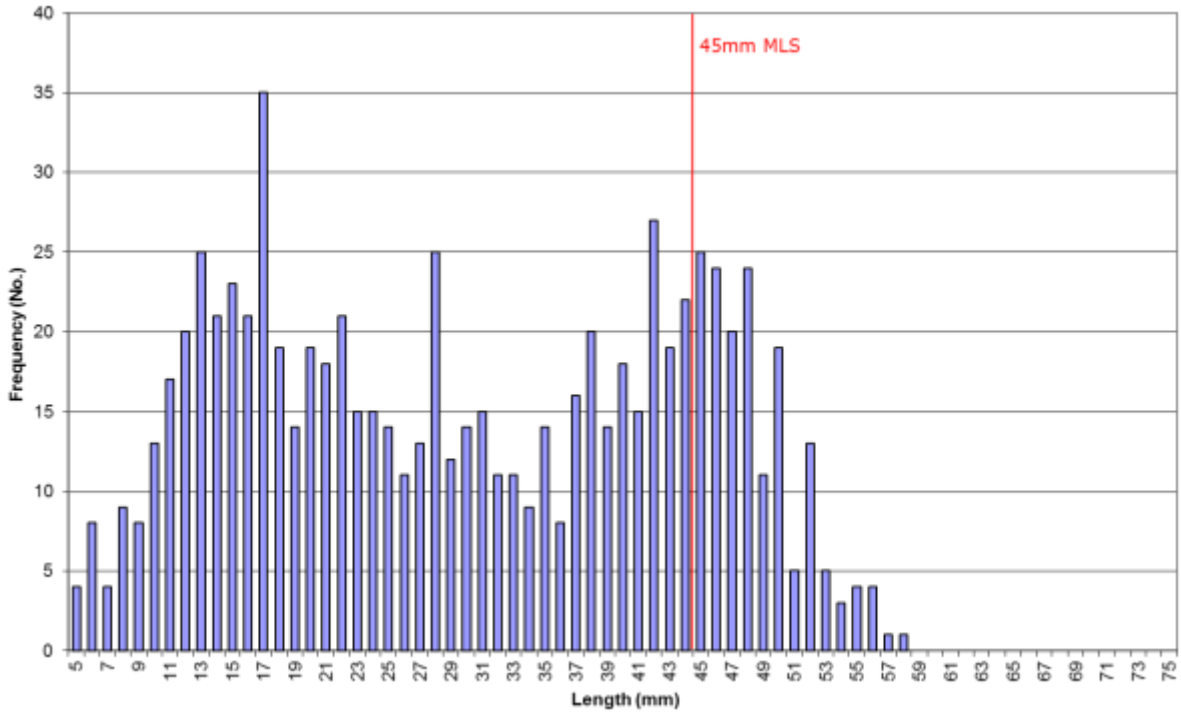

Figure 5 - Mussel size frequency on North Mare Tail - October 2016

During the past decade, this bed has been one of the largest and most stable areas of mussel bed in the Wash. Although it has supported several dredge fisheries during this period, it has tended to attract regular settlements of seed that have facilitated its recovery. Like many of the beds, however, in recent years it has been subject to die-offs of young mussels that have caused a deterioration of the bed. The 2016 survey found there had been a light settlement on and around the northern parts of this bed that had helped it to increase in area from 62.0 hectares to 68.0 hectares. Evidence of this settlement can be seen in figure 5. Within the bed the coverage was found to have increased slightly from 36% to 37%, while the mean density of the mussel patches had

declined slightly from 0.87 kg/0.1m^2 to 0.86 kg/0.1m^2. From these figures, the mussel biomass on the bed was calculated to have increased from 1,969 tonnes in 2015 to 2,190 tonnes. The biomass of mussels that had attained 45mm was also found to have increased from 1,030 tonnes to 1,187 tonnes.

South Mare Tail

- Area: 30.6 hectares
- Coverage: 34%
- Mean Density: 0.70 kg/0.1m^2
- Total Stock: 718 tonnes
- Stock ≥ 45mm: 173 tonnes

The South Mare Tail bed was surveyed on October 16th. Samples were taken from every fourth "hit", producing 50 samples from four transects. A further transect was conducted in an area to the north of the bed, where mussel seed had settled among washed out cockle shells situated in gullies. This additional transect produced a further 8 samples. Figure 6 shows the mussel size frequency within the population taken from the combined five transects.

Excluding the area that was found to have recently settled with seed, the area of the bed was found to have declined from 31.4 hectares to 30.6 hectares. Within the bed, the coverage was found to have increased from 32% to 34% and the mean density from 0.63 kg/0.1m^2 to 0.70 kg/0.1m^2. From these figures, the total biomass of mussels in the bed was calculated to have increased from 632 tonnes to 718 tonnes. Mortality of larger mussels, however, meant the biomass of ≥45mm mussels had declined from 197 tonnes to 173 tonnes.

The area that had settled with seed was found to cover 15 hectares and support a further 53 tonnes of small mussels.

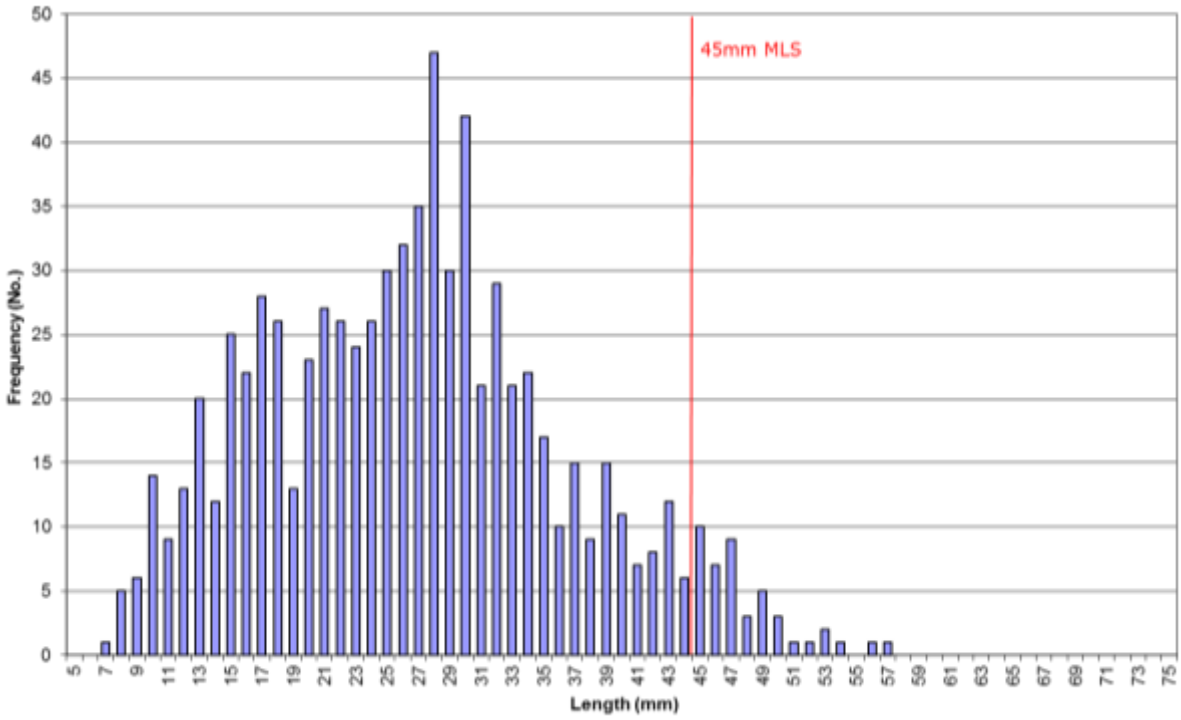

Figure 6 - Mussel size frequency on South Mare Tail - October 2016

West Mare Tail

- Area: 31.6 hectares
- Coverage: 41%
- Mean Density: 0.33kg/0.1m^2
- Total Stock: 435 tonnes
- Stock ≥ 45mm: 87 tonnes

The East Mare Tail bed was surveyed on September 21st. Samples were collected from every fourth "hit", resulting in 77 samples being taken from five transects. Figure 7 shows the size distribution of the mussels collected from the samples.

This bed was first identified and surveyed in 2014, having been thought to have first settled in 2013. Fresh settlements in both 2015 and 2016 have helped the bed to grow in area from 17.2 hectares to 31 6 hectares. Within the bed the coverage of mussels was found to have increased from 32% to 41%, but the mean density had declined from 0.51kg/0.1m^2 to 0.33kg/0.1m^2. From these figures, the total mussel biomass within the bed was calculated to have increased from 239 tonnes to 435 tonnes. Of these, 87 tonnes had reached 45mm.

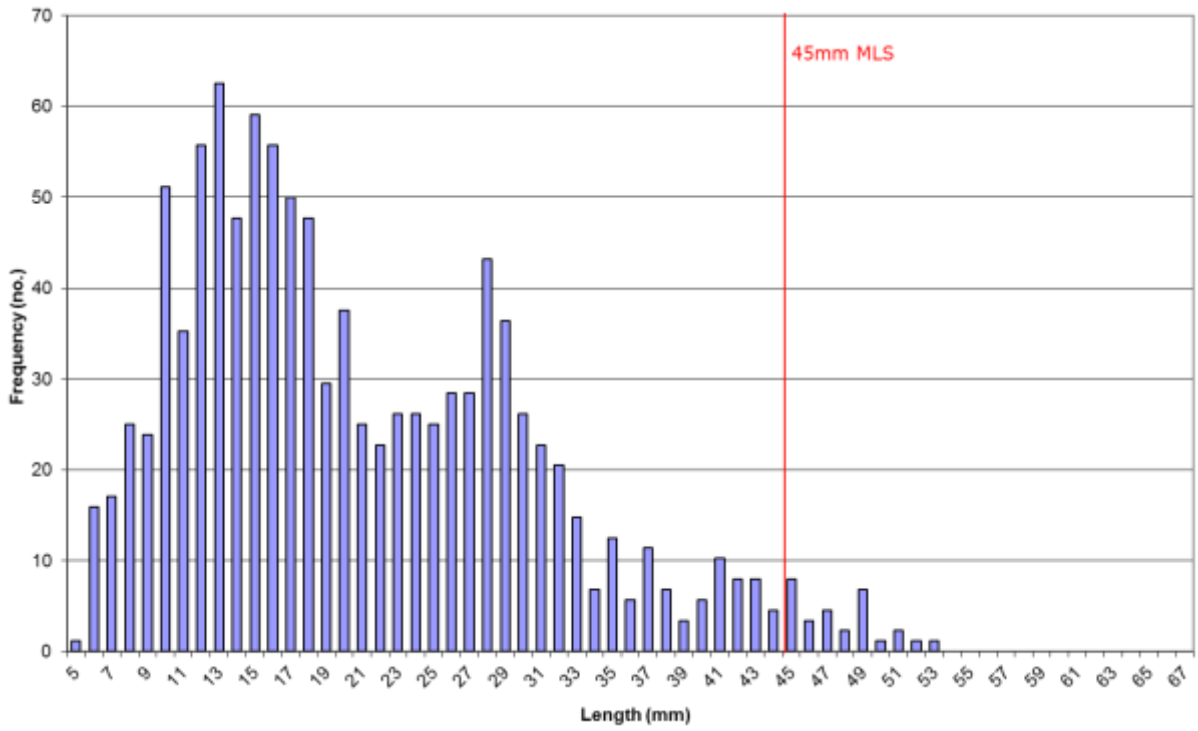

Figure 7 - Mussel size frequency on West Mare Tail – September 2016

The Gat Beds

The Gat sand supports an extensive area of mussels that for survey purposes is divided into three beds (see figure 8). Following overfishing throughout the Wash in the late 1980s, the Gat became one of the few inter-tidal beds that still supported significant quantities of mussels. As such they were viewed as being particularly important by both the fishing industry and conservationists alike. Barring some heavy poaching that occurred on them between 2000 and 2002, they were closed to fishing between 1993 and 2006. This long closure helped them to mature and develop some important biogenic reef features, particularly along the exposed northern fringes of the bed. When they were eventually opened to a dredge fishery in 2006, and subsequent hand-worked fisheries between 2007 and 2010, the northern edges of the bed remained closed in order to protect these biogenic reef features. Although fisheries on these beds have been restricted and closely managed, they have suffered significant declines since 2010, during which period the beds declined from a total stock of 5,604 tonnes in 2009 to a low of 1,246 tonnes in 2014. Observations made during the annual surveys during that period suggest this decline was due to poor recruitment, coupled with high mortalities among the populations of 3 year-old mussels. These beds now support a declining population of ageing mussels that are thinly distributed. Although there have been light settlements on these beds during 2015 and 2016, they are still in poor condition.

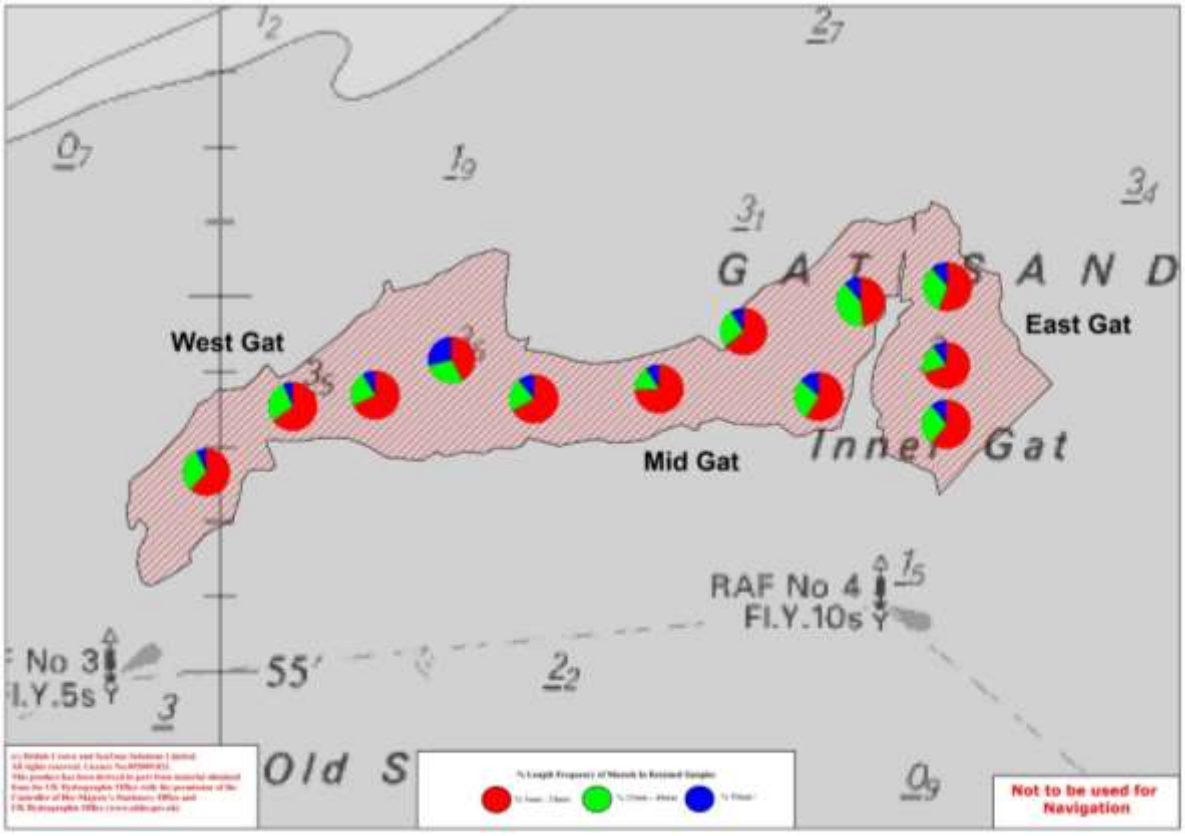

Figure 8 - Mussel size distributions on the Gat mussel beds – September 2016

West Gat

- Area: 35.3 hectares
- Coverage: 42%
- Mean Density: 0.73kg/0.1m^2
- Total Stock: 1,095 tonnes
- Stock ≥ 45mm: 618 tonnes

The West Gat bed was surveyed on September 29th. Samples were taken from every fifth "hit", producing 63 samples from five transects. Figure 9 shows the size frequency of mussels found in the samples taken during this survey.

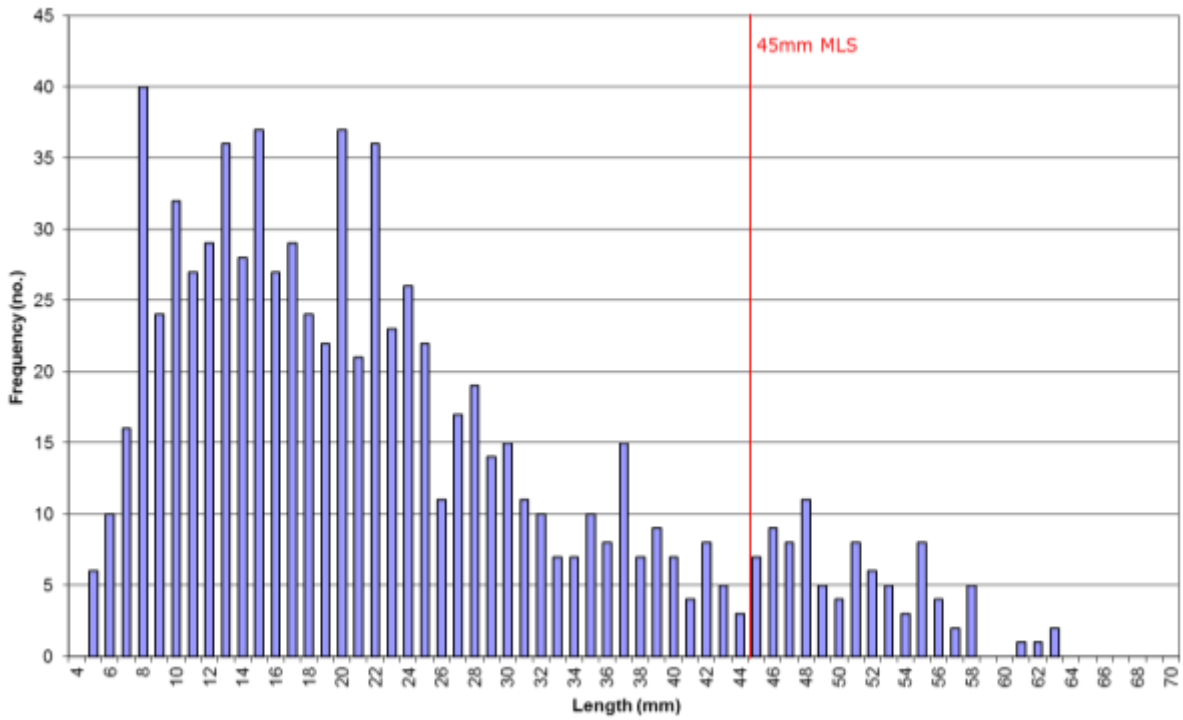

Figure 9 - Mussel size frequency on West Gat – September 2016

Recent surveys had observed that due to the declining populations of mussels on this bed, large areas were becoming thinly covered and beginning to erode. This was particularly noticeable during the 2015 survey, when the western and southern edges of the bed had fragmented and eroded away, causing 8 hectares of the bed to be lost. The 2016 survey found there had been no further erosion along the edges of the bed, but there were no signs of recovery in those areas either. There had been a settlement within the bed, however, that had thickened the mussels up a little. While the area of the bed, at 35.3 hectares, remained similar to the previous year, the mussel coverage had increased from 35% to 42% and the mean density from 0.68kg/0.1m^2 to 0.73kg/0.1m^2. From these figures, the total mussel biomass on this bed was calculated to have increased from 828 tonnes to 1,095 tonnes, while those that had reached 45mm had increased from 513 tonnes to 618 tonnes.

Mid Gat

- Area: 21.5 hectares
- Coverage: 37%
- Mean Density: 0.63kg/0.1m^2
- Total Stock: 496 tonnes
- Stock ≥ 45mm: 325 tonnes

The Mid Gat was surveyed on September 29th. Samples were collected from every fourth "hit", producing 44 samples from four transects. Figure 10 shows the size frequency of the mussels collected in these samples.

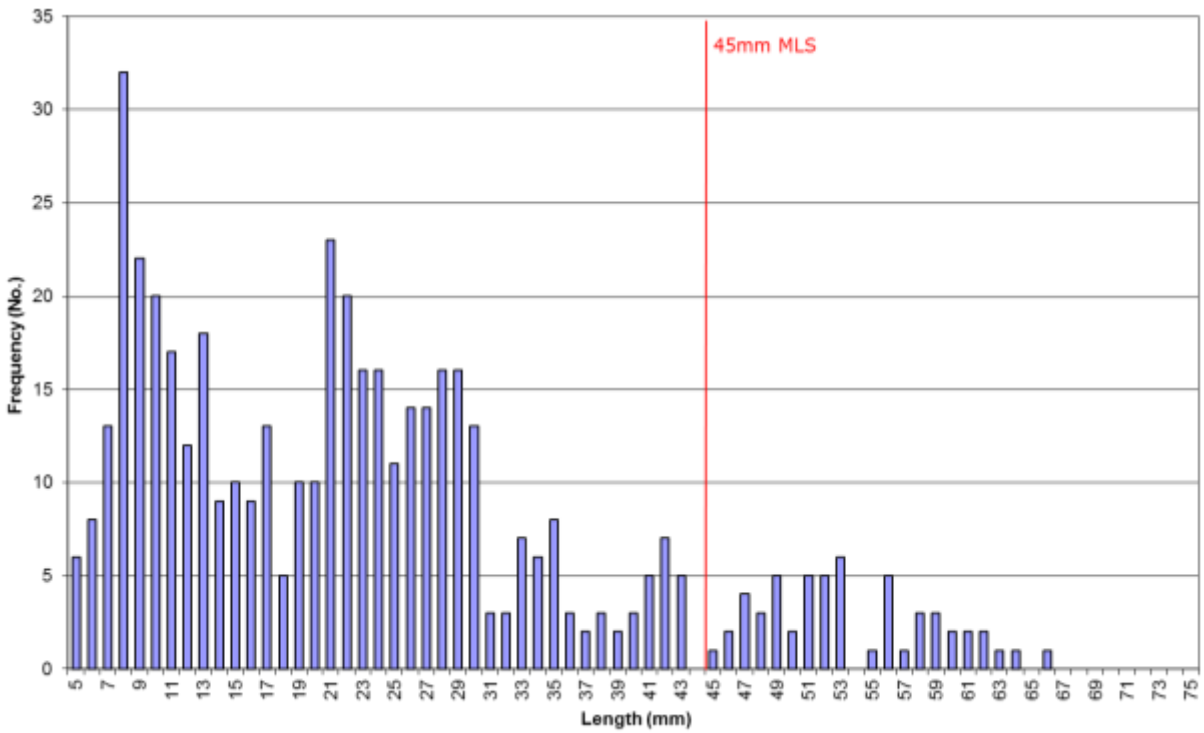

Figure 10 - Mussel size frequency on Mid Gat – September 2016

The survey found that although the area of the bed had declined from 26.6 hectares to 21.5 hectares, the loss of some formally very sparse areas, combined with a light settlement within the bed, had helped the mussel coverage increase from 22% to 37% and the mean density from 0.39kg/0.1m^2 to 0.63kg/0.1m^2. From these figures, the total biomass of mussels on the bed was calculated to have increased from 225 tonnes to 496 tonnes. Of these, 325 tonnes were found to have attained harvestable size compared to 190 tonnes the previous year.

East Gat

- Area: 17.1 hectares
- Coverage: 45%
- Mean Density: 0.71kg/0.1m^2
- Total Stock: 549 tonnes
- Stock ≥ 45mm: 355 tonnes

The East Gat was surveyed on October 5th. Samples were taken from every fourth "hit", producing 51 samples from three transects. Figure 11 shows the size frequency of the mussels collected in these samples.

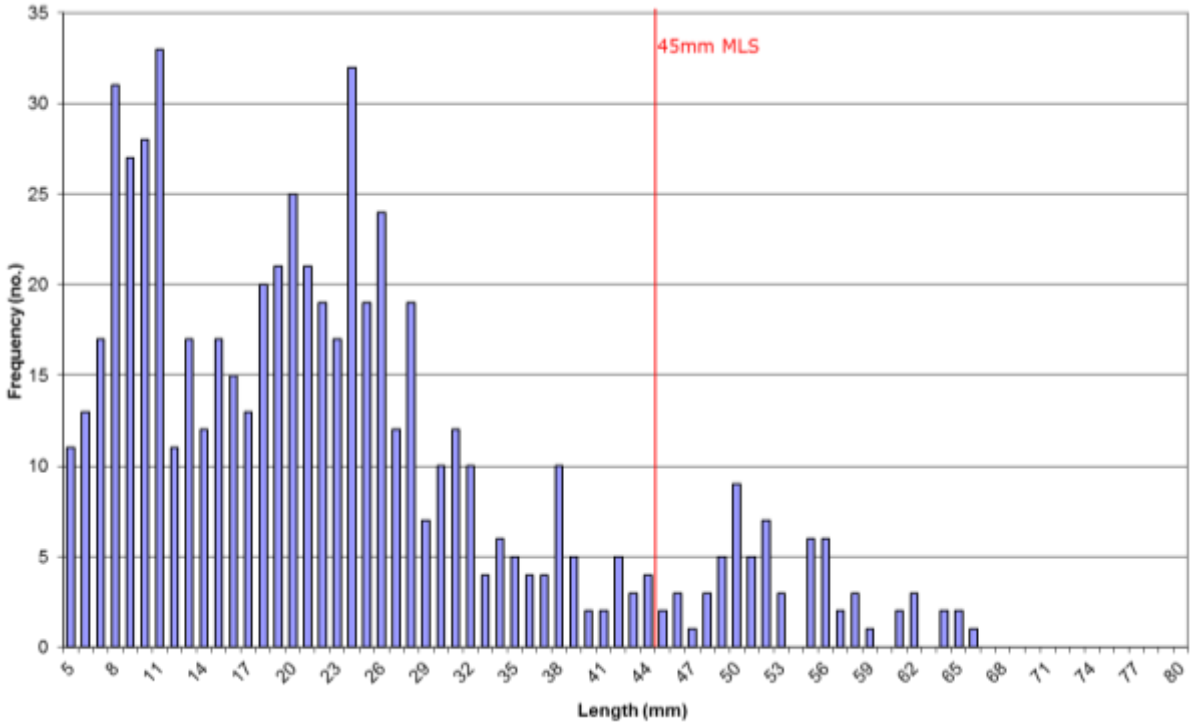

Figure 11 - Mussel size frequency on East Gat – October 2016

The area of this bed was found to have increased slightly from 16.9 hectares to 17.1 hectares. Within the bed, light settlements of seed from 2015 and 2016 recruitment helped the coverage increase from 40% to 45% and the mean coverage from 0.55kg/0.1m^2 to 0.71kg/0.1m^2. From these figures, the total mussel biomass on the bed was calculated to have increased from 373 tonnes to 549 tonnes. Of these, 355 tonnes had attained 45mm compared to 307 tonnes the previous year.

Tofts

- Area: 40.8 hectares
- Coverage: 37%
- Mean Density: 1.40 kg/0.1m^2
- Total Stock: 2,148 tonnes
- Stock ≥ 45mm: 1,936 tonnes

Because of the size of this bed, the perimeter was surveyed on October 7th and transects conducted using two teams on October 18th. Samples were taken from every sixth "hit", producing 67 samples from seven transects. Figure 12 shows the mussel size distribution over the bed, while figure 13 shows the size frequency of the mussels in the samples.

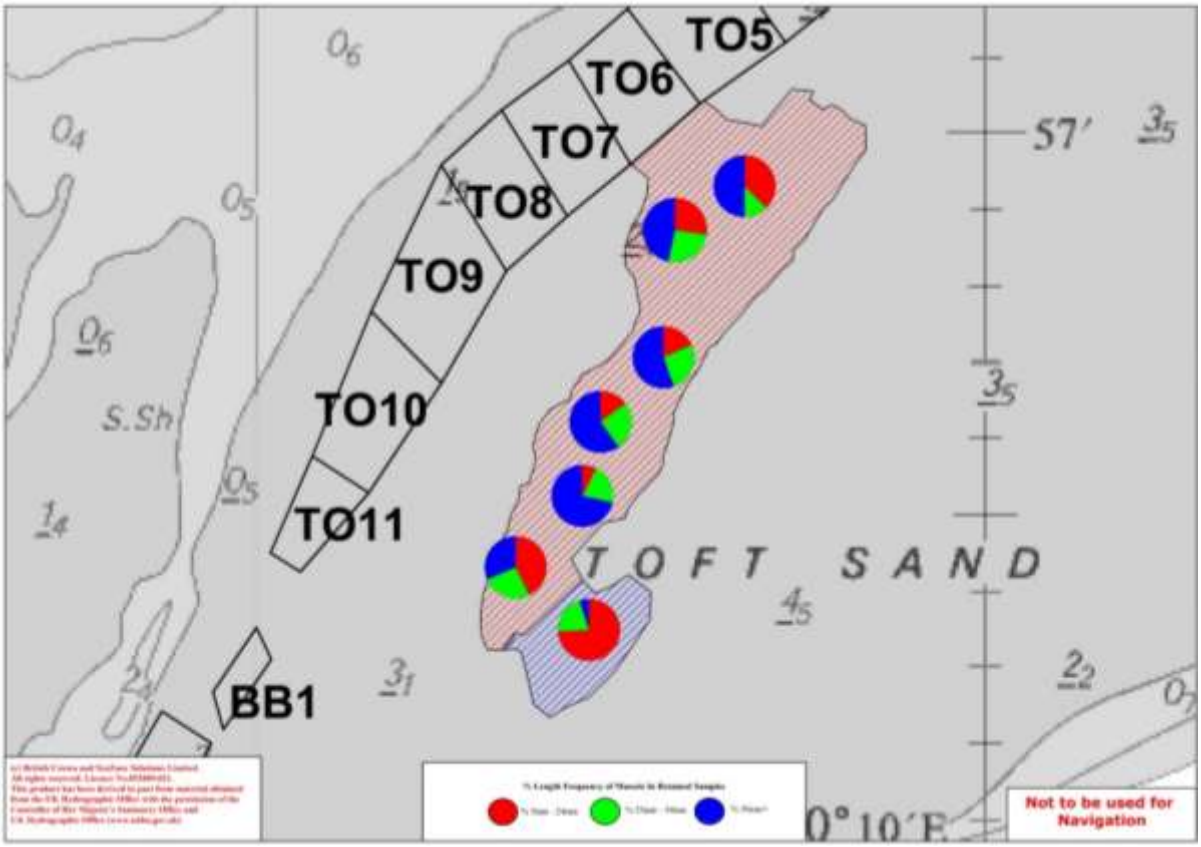

Figure 12 - Mussel size distributions on the Toft mussel bed – October 2016

The survey found there had a been a moderate settlement of seed within this bed, plus among ridged out cockle shells in the area adjacent to the south-eastern edge of the bed (marked in blue in figure 12). Excluding this latter area, which was surveyed separately, the bed was found to have increased in size from 40.0 hectares to 40.8 hectares. Growth of existing mussels combined with recruitment within this area had enabled the mussel

coverage to increase from 31% to 37% and the mean density from 1.14 kg/0.1m^2 to 1.40 kg/0.1m^2. From these figures, the total biomass of mussels in the bed was estimated to have increased from 1,428 tonnes to 2,148 tonnes. Of these, 1,936 tonnes had reached 45mm compared to 1,305 tonnes the previous year.

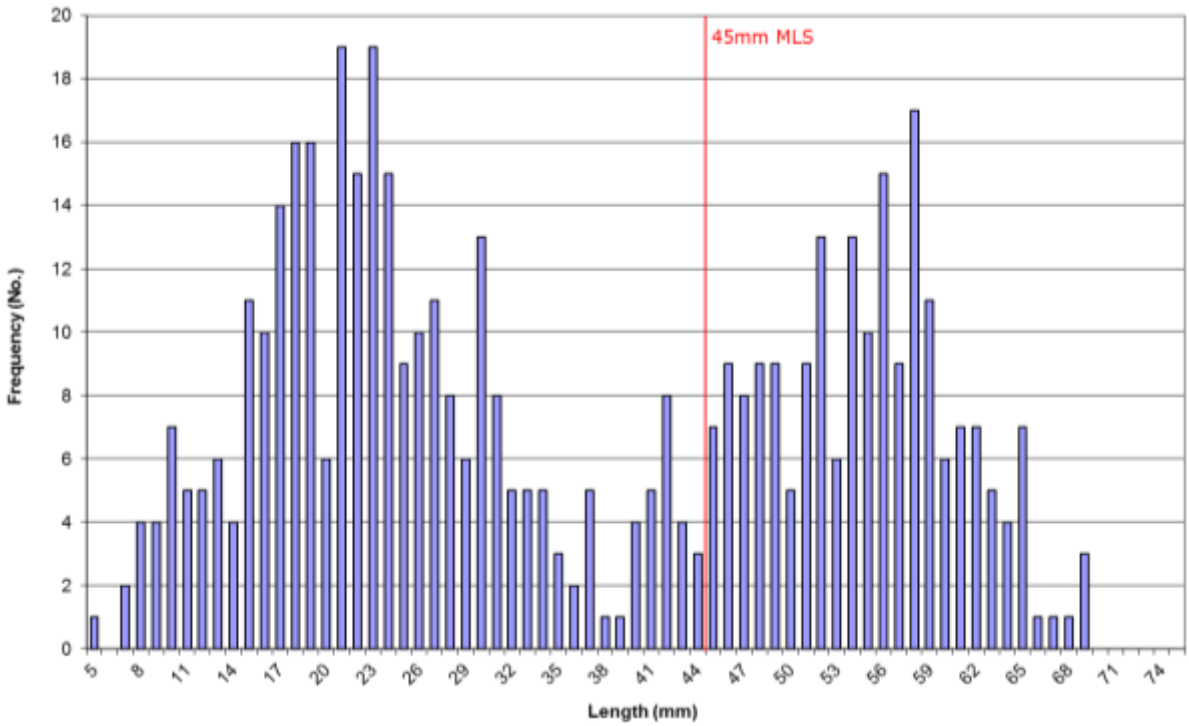

Figure 13 - Mussel size frequency on the Tofts – October 2016

6.7 hectares outside of the existing mussel bed had attracted a settlement of seed. These had a coverage of 46% and a mean density of 0.22 kg/0.1m^2. This equated to a total stock of 69 tonnes, of which 27 tonnes had reached 45mm. These larger mussels were not thought to be from the 2016 settlement, but rather older mussels that had either washed out of the main bed, or had settled in low densities in previous years.

Roger

- Area: 1.4 hectares
- Coverage: 32%
- Mean Density: 0.69 kg/0.1m^2
- Total Stock: 31 tonnes
- Stock ≥ 45mm: 23 tonnes

This small bed was surveyed on October 7th. Samples were collected from every third "hit", producing 13 samples from a single transect. Figure 14 shows the mussel size distribution on this bed while figure 15 shows the size frequency within the population.

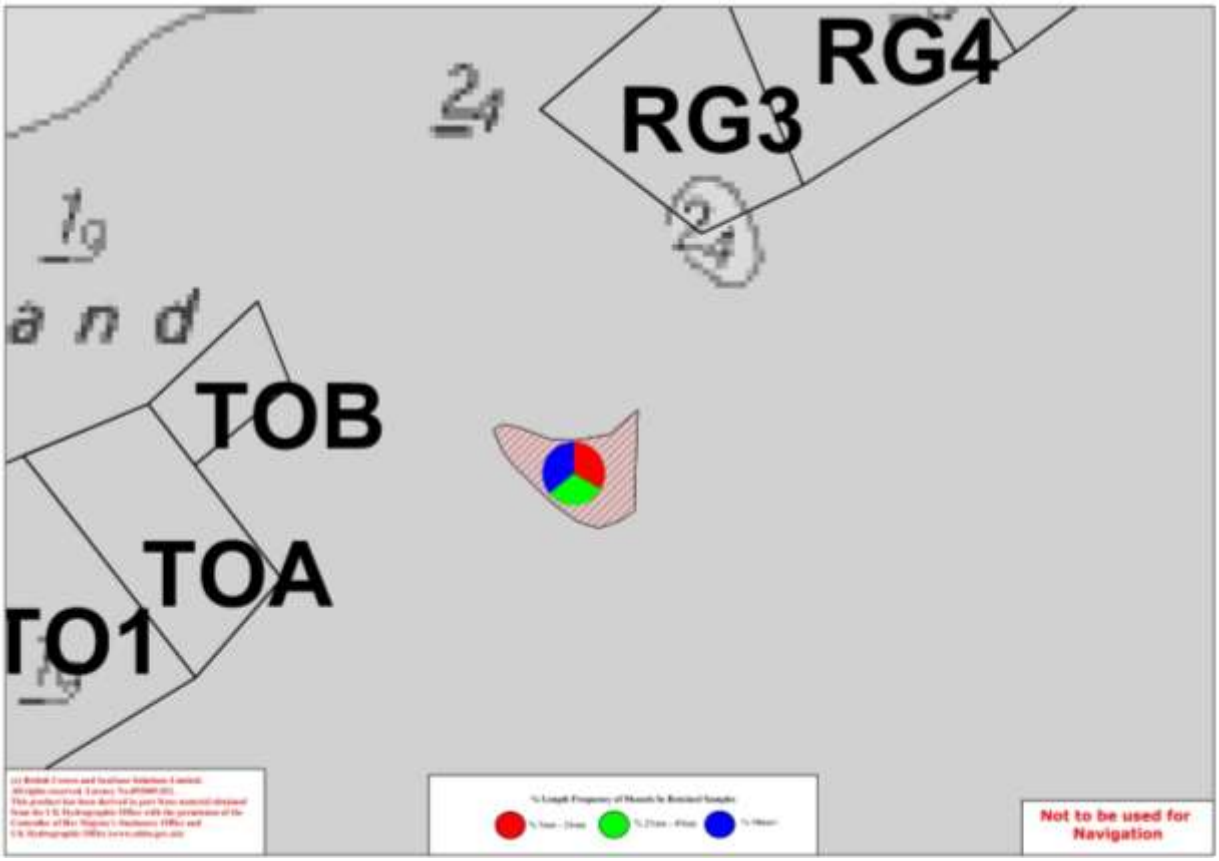

Figure 14 - Mussel size distribution on the Roger mussel bed – October 2016

The survey found there had been only minor changes since the previous survey. The area and mean density remained the same at 1.4 hectares and at 0.69 kg/0.1m^2, while the coverage had declined slightly from 33% to 32%. The total mussel biomass remained the same at 31 tonnes, but the biomass of those that had attained 45mm had declined from 27 tonnes to 23 tonnes.

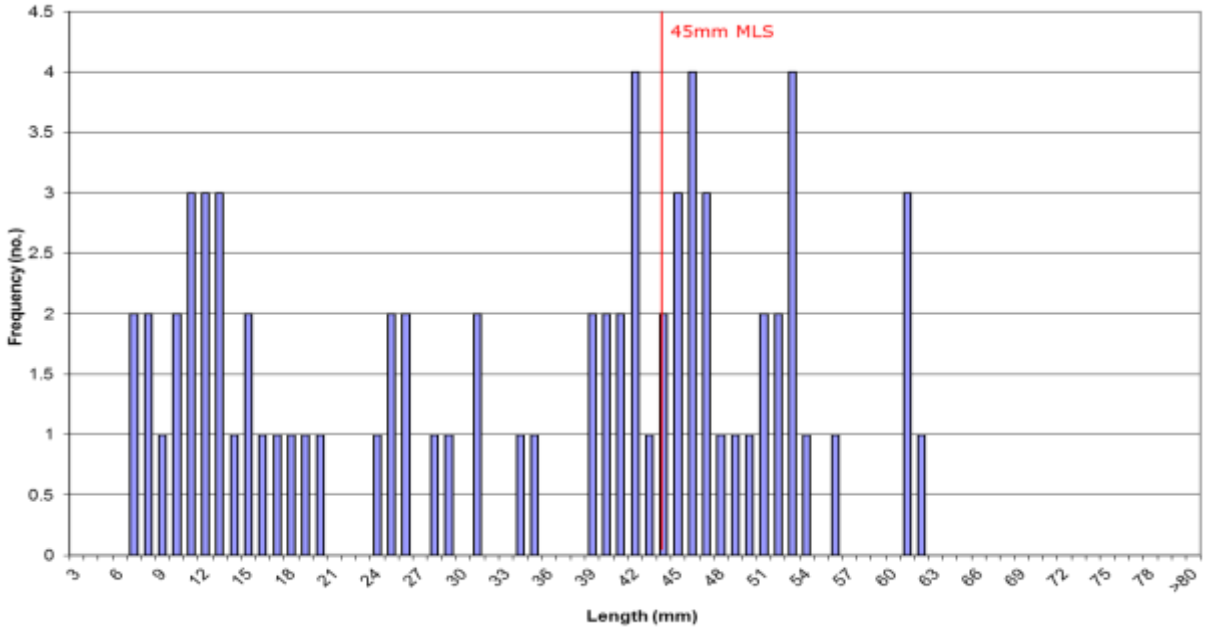

Figure 15 - Mussel size frequency on the Roger – October 2016

Herring Hill

- Area: 34.6 hectares
- Coverage: 35%
- Mean Density: 0.85 kg/0.1m^2
- Total Stock: 1,014 tonnes
- Stock ≥ 45mm: 338 tonnes

The Herring Hill bed was surveyed on October 17th. Samples were taken from every fifth "hit", producing 42 samples from four transects. Figure 16 shows the mussel size distribution across the bed, while figure 17 shows the size frequency of the mussels collected in the samples.

The survey found there had been a settlement of mussel seed both in the bed and among areas of cockle shells outside of the bed. The addition of these latter areas enabled the bed to increase in area from 24.7 hectares in 2015 to 34.6 hectares. Because the areas of newer settlement were lower density than within the bed, the mean coverage was found to have declined from 37% to 35%. Growth of the older mussels within the bed compensated for this, however, enabling the mean density to increase slightly from 0.82 kg/0.1m^2 to 0.85 kg/0.1m^2. From these figures, the total biomass of mussels within the bed was calculated to be 1,014 tonnes compared to 748 tonnes the previous year. Of

these, 338 tonnes had reached a size of 45mm, compared to 171 tonnes the previous year.

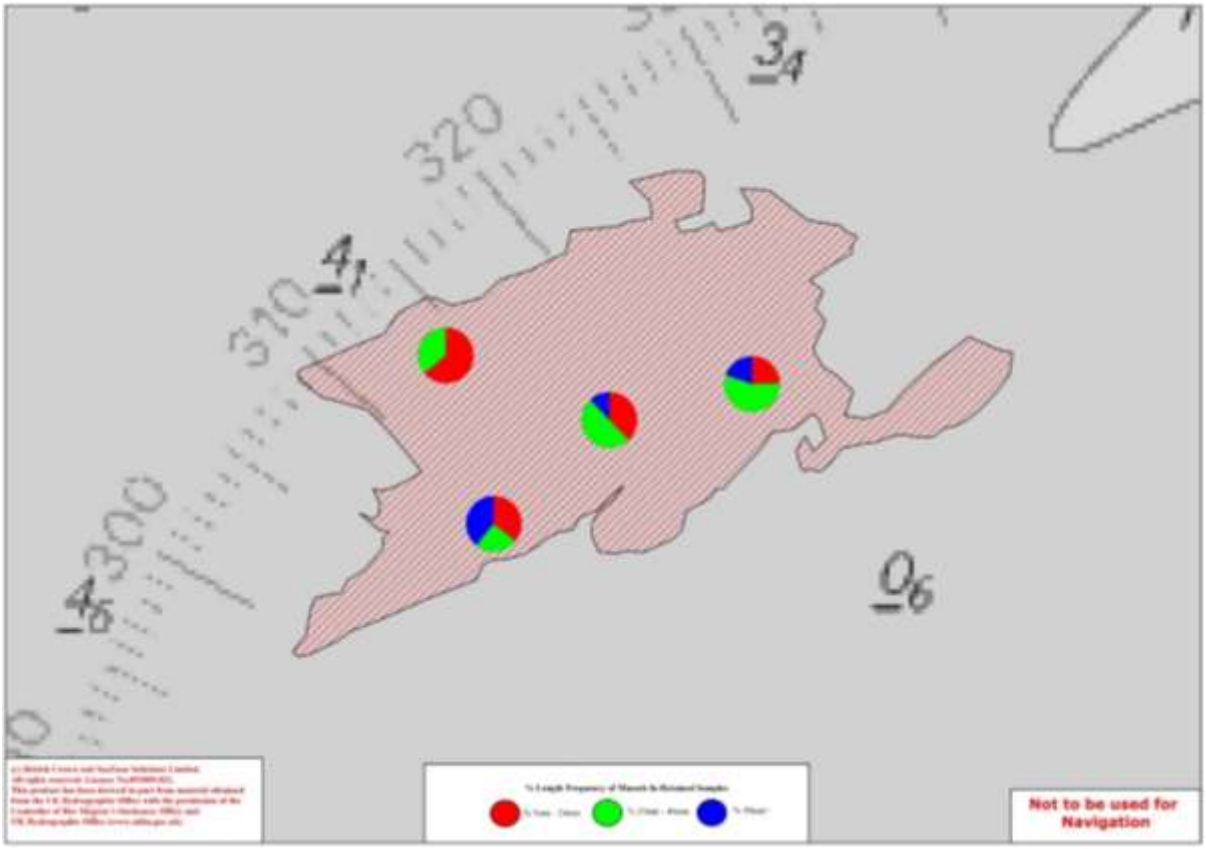

Figure 16 - Mussel size distribution on the Herring Hill mussel bed – October 2016

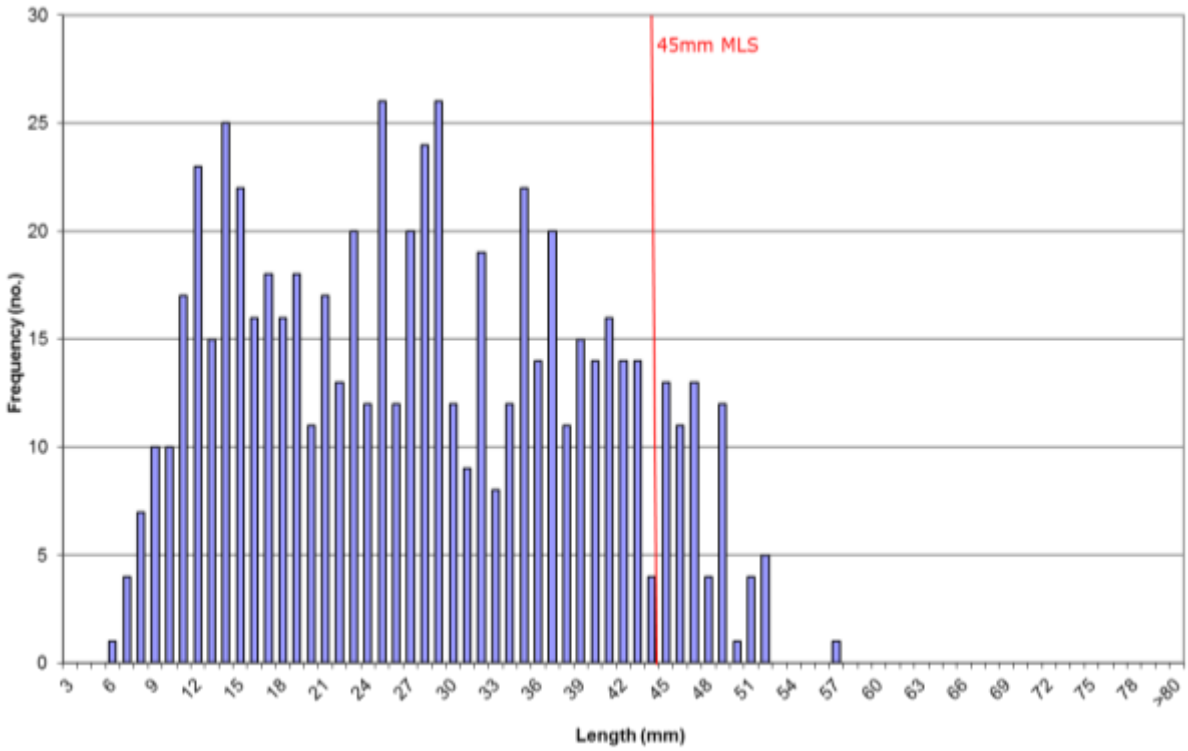

Figure 17 - Mussel size frequency on Herring Hill - October 2016

Main End

- Area: 9.0 hectares
- Coverage: 31%
- Mean Density: 0.64 kg/0.1m^2
- Total Stock: 179 tonnes
- Stock ≥ 45mm: 121 tonnes

The Main End bed was surveyed on October 15th, during which samples were collected from every third "hit", producing 36 samples from three transects. Figures 18 and 19 show the mussel size distribution across the bed and the mussel size distribution within the samples.

In 2001 this area benefitted from a large settlement of seed. At the time this seed was considered to be vulnerable to storm damage so was opened to the relaying fishery in 2002 before it was lost to natural causes. Following this fishery a small bed remained along the edge of a large run that has remained fairly stable since. The bed has received little settlement since 2001, however, so in recent years mortality among the ageing population has caused the bed to decline. Most of the remaining mussels in this bed are now situated in submerged ridges in the bottom of the run. This creates difficulties when surveying the bed and explains some of the fluctuations that have been seen between recent annual surveys.

The 2016 survey found there had been a light settlement of seed along the southern edges of this bed that had helped it increase in area from 6.6 hectares to 9.0 hectares. Within the bed, the mean coverage had increased from 19% to 31% and the mean density from 0.45 kg/0.1m^2 to 0.64 kg/0.1m^2. From these figures, the total mussel biomass was calculated to have increased from 45 tonnes to 179 tonnes. Of these, 121 tonnes were estimated to have attained 45mm compared to 45 tonnes the previous year. These increases are high considering the settlement was only light, so may be an artefact of the submerged nature of the bed affecting survey accuracy.

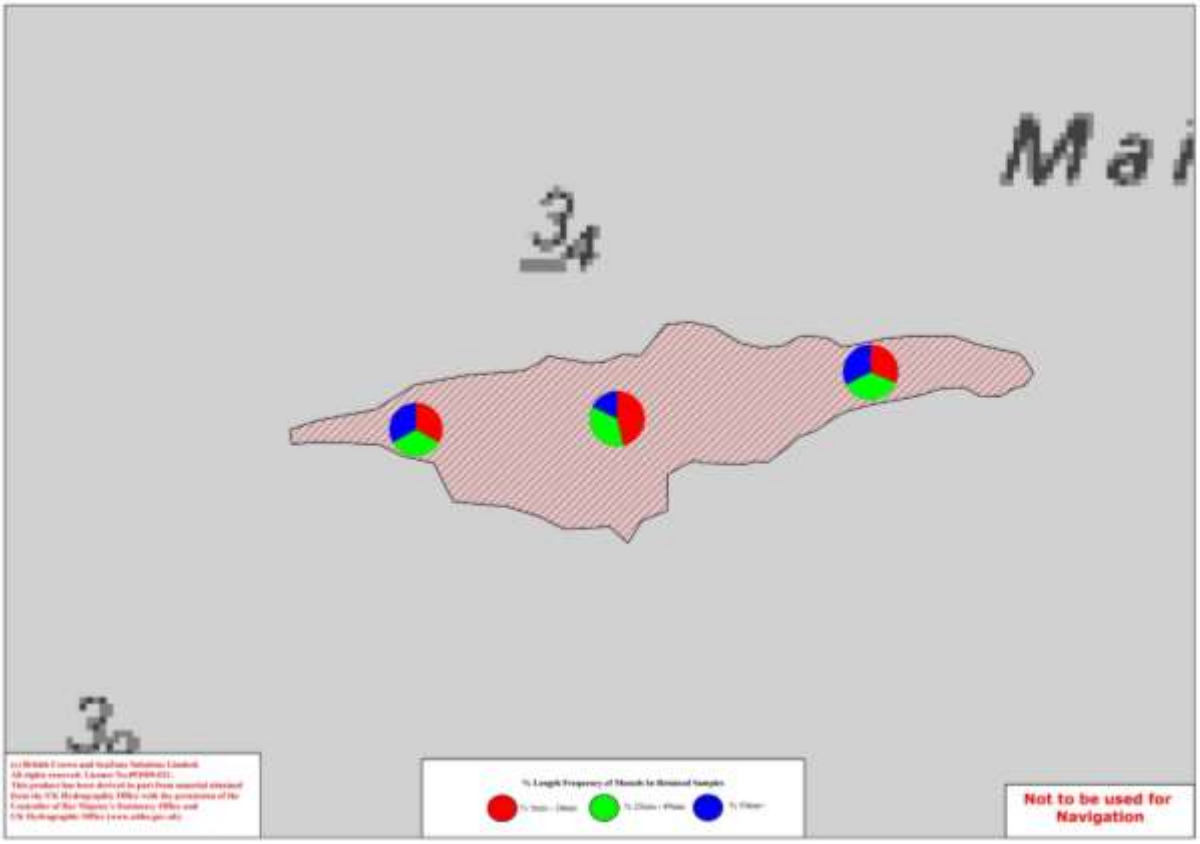

Figure 18 - Mussel size distribution on the Main End mussel bed – October 2016

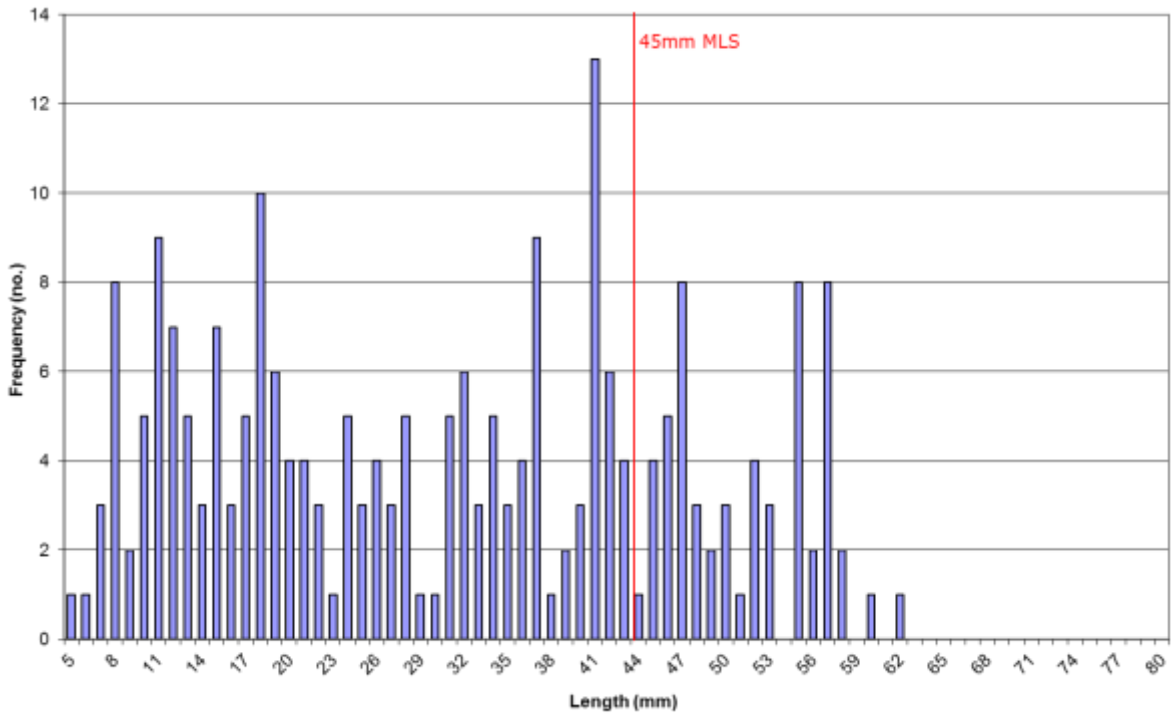

Figure 19 - Mussel size frequency on Main End - October 2016

Holbeach

- Area: 14.6 hectares
- Coverage: 52%
- Mean Density: 0.34 kg/0.1m^2
- Total Stock: 254 tonnes
- Stock ≥ 45mm: 57 tonnes

The Holbeach bed was one of the new beds to be established following the exceptional spatfall that occurred during 2001. At the time, this area was considered to be vulnerable to natural losses so the bed was opened to the seed fishery in 2002. Part of the bed remained after this fishery, and in subsequent years has attracted some good settlements of seed. Like most of the other inter-tidal beds, it has suffered from high mortalities in recent years.

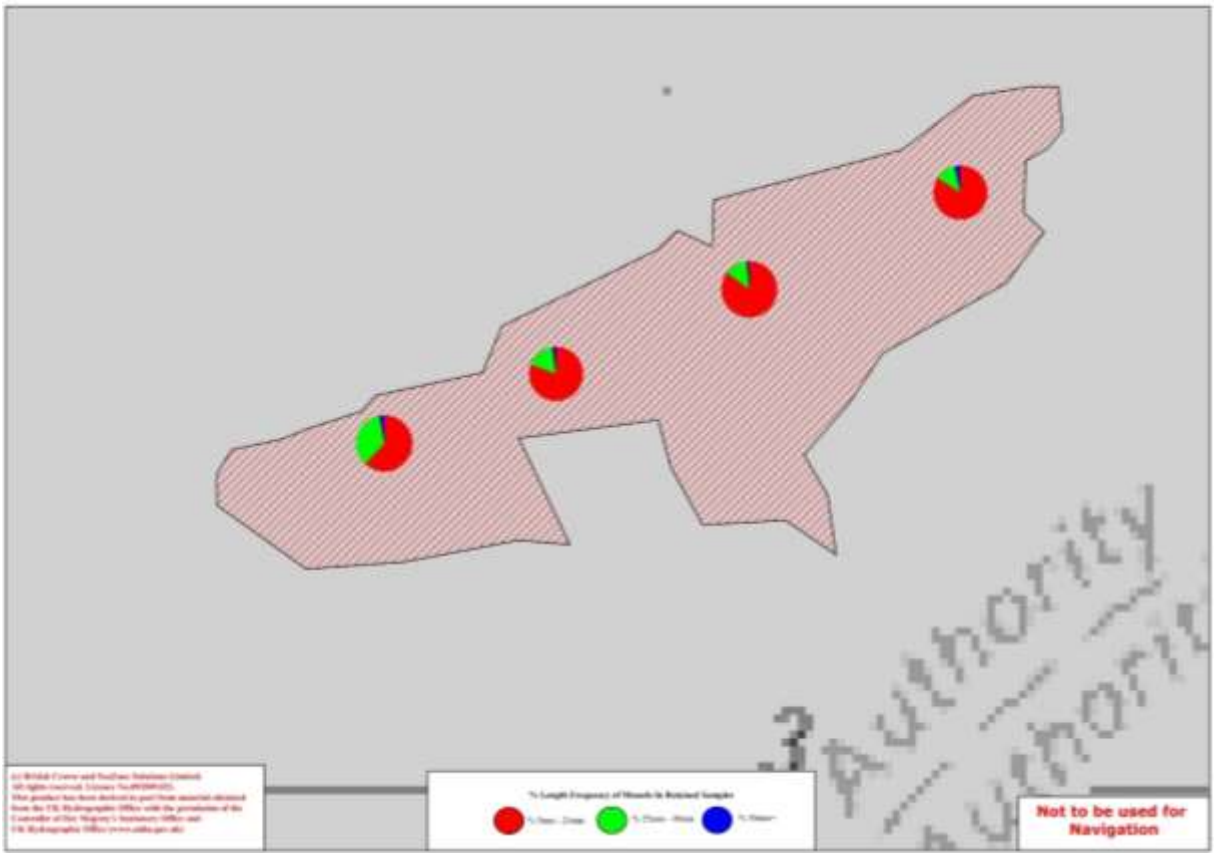

Figure 20 - Mussel size distribution on the Holbeach mussel bed – October 2016

The recent survey took place on October 15th, during which samples were collected every fourth "hit", generating 76 samples from four transects. Figures 20 and 21 show the size distribution of mussels across the bed and the mussel size frequency within the population.

The survey found that there had been a good settlement of seed since the previous survey, but there had been high levels of mortality among the older mussels. The area of the bed was found to have increased from 13.7 hectares to 14.6 hectares, and the mean coverage of mussels from 47% to 52%, but the mean density had declined from 0.43 kg/0.1m^2 to 0.34 kg/0.1m^2. From these figures, the total mussel biomass on the bed was calculated to have declined from 280 tonnes to 254 tonnes. Of these, 57 tonnes were found to have reached 45mm, compared to 141 tonnes the previous year.

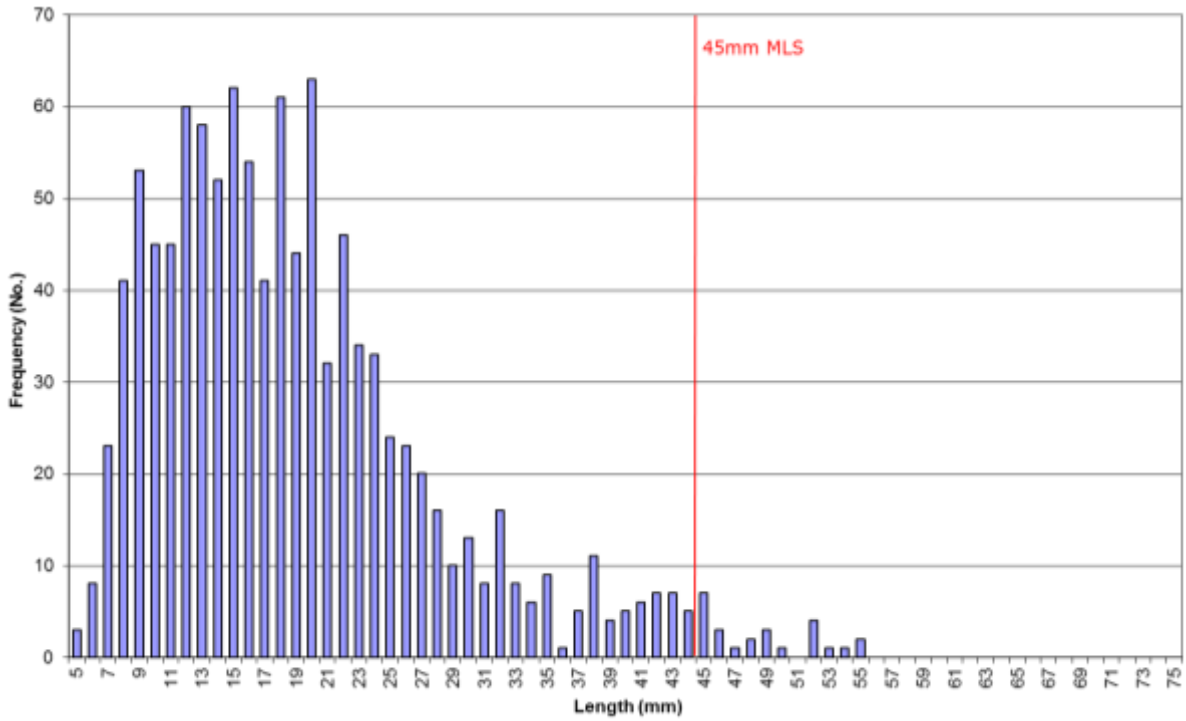

Figure 21 - Mussel size frequency on Holbeach – October 2016

Trial Bank

- Area: 19.6 hectares
- Coverage: 32%
- Mean Density: 1.01 kg/0.1m^2
- Total Stock: 635 tonnes
- Stock ≥ 45mm: 193 tonnes

The Trial Bank mussel bed was surveyed September 18th, during which samples were collected from every fifth "hit", producing 38 samples from four transects. Figures 22 and 23 show the size distribution of mussels across the bed and the mussel size frequency within the population.

The bed was originally established in 2001 after mussel spat settled on cockle shells. It subsequently attracted several other settlements of seed and grew in area and biomass over the next decade. In 2012, however, the bed suffered heavy disturbance during a fishery that caused it to decline in biomass from 1,352 tonnes to 585 tonnes. Although the bed has received further settlements since then that have facilitated some recovery, the south-eastern area of the bed that had received the heaviest disturbance continued to decline. The recent survey found that decline had continued during 2016, to such an extent that the south-eastern part of the bed has been lost. This loss has caused the area of the bed to decline from 28.2 hectares to 19.6 hectares.

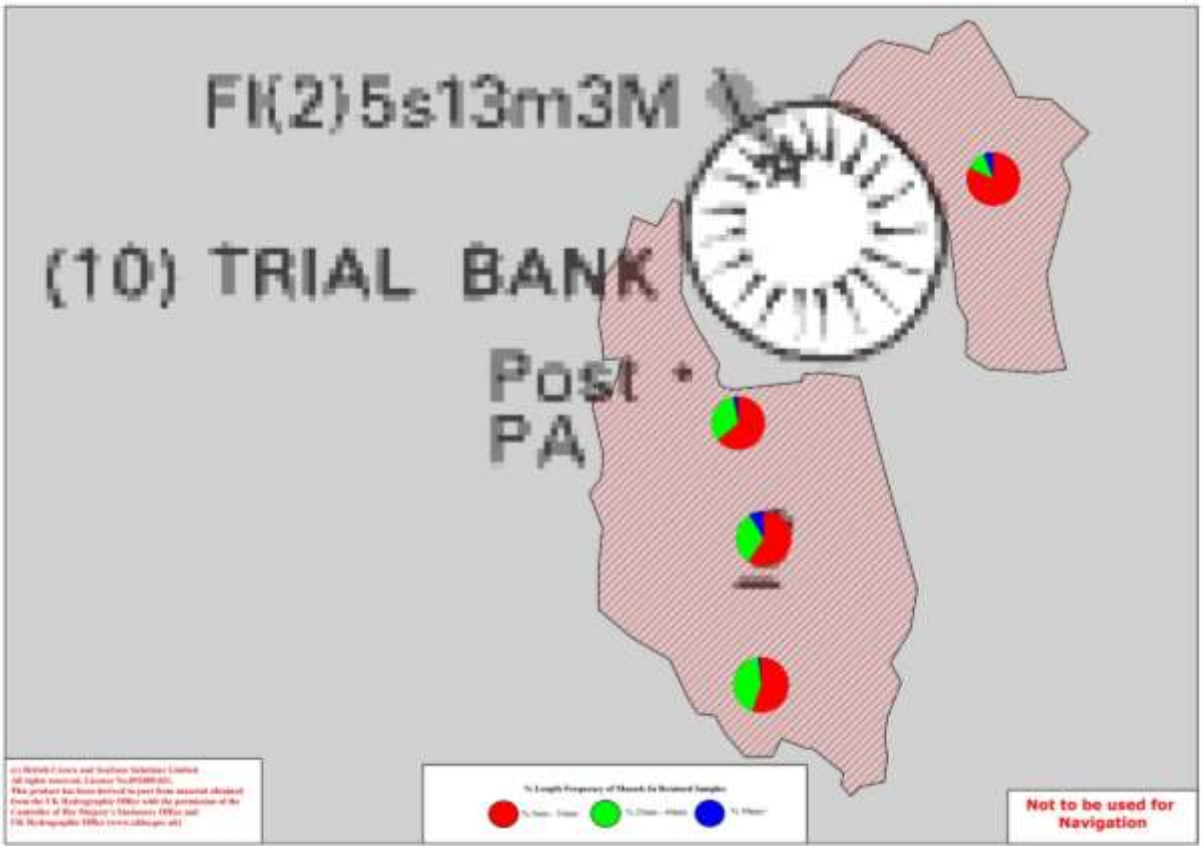

Figure 22 - Mussel size distribution on the Trial Bank mussel bed – September 2016.

At 32%, the mussel coverage within the bed has remained similar to the 33% recorded the previous year, but growth of older mussels and a moderate settlement during 2016 have helped the mean density increase from 0.73 kg/0.1m^2 to 1.01 kg/0.1m^2. From these figures, the total biomass of mussels in the bed was calculated to have declined from 695 tonnes to 635 tonnes. Loss of larger mussels have caused the biomass of mussels that have attained a size of 45mm to decline from 271 tonnes to 193 tonnes.

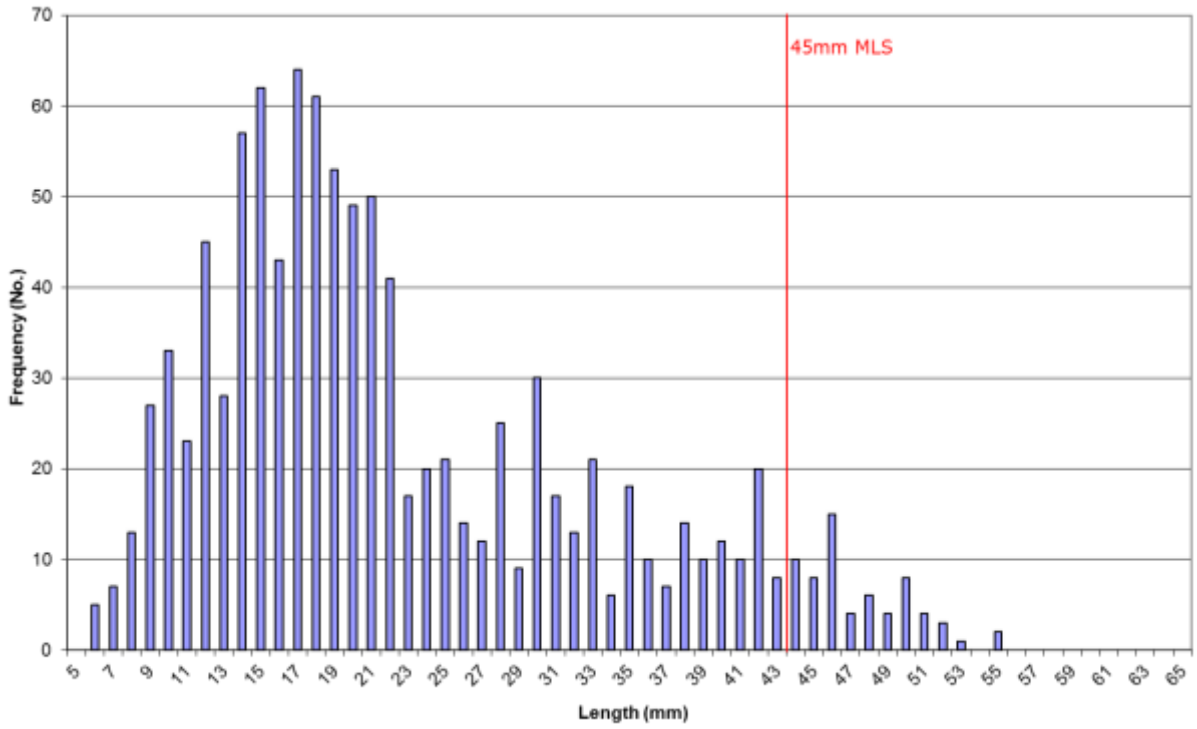

Figure 23 - Mussel size frequency on Trial Bank - September 2016

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. Following disparate fishing effort on these beds in 2010, however, the middle bed disappeared. In 2011 another good settlement of spat in this area enabled both the West and East beds to increase in size. Although this growth enabled them to encroach over ground that had formally been part of the Middle bed, they still formed two beds rather than three. As such, the surveys conducted since 2011 have reported the stocks from this area as being from two rather than three beds. For a time the mussel coverage was sufficient for the two beds to join, but recent surveys have found the mussel patches have thinned along the eastern edge of the West bed, creating a gap between the two beds once more. Figure 24 shows the mussel size distribution over these beds following the 2016 surveys.

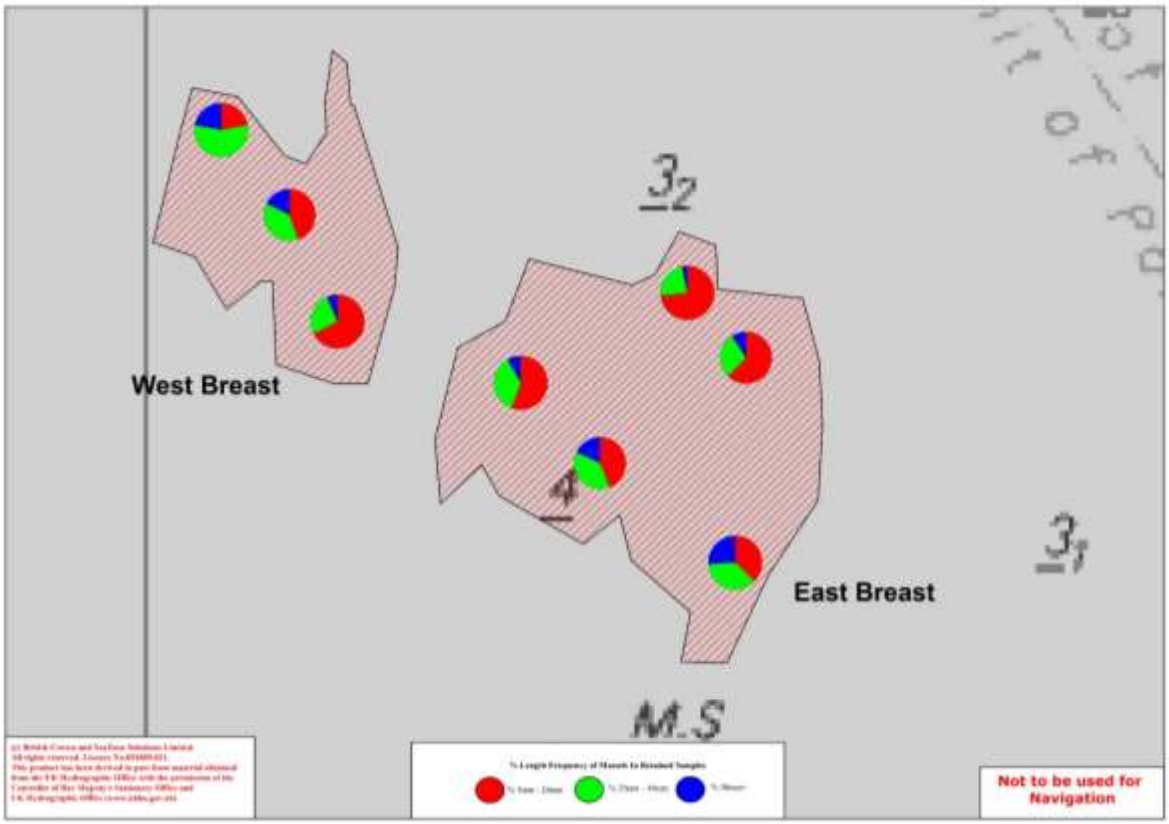

Figure 24 - Mussel size distribution on the Breast mussel beds – October 2016

West Breast

- Area: 11.6 hectares
- Coverage: 24%
- Mean Density: 1.12kg/0.1m^2
- Total Stock: 308 tonnes
- Stock ≥ 45mm: 145 tonnes

The West Breast bed was surveyed on October 6th, during which samples were collected from every fourth "hit", producing 19 samples from three transects. Figure 25 shows the mussel size frequency within the population taken from these samples.

The survey found there had been a light settlement of seed within the bed, but there had been some erosion around the southern edge of the bed that had caused the area to decline from 12.6 hectares to 11.6 hectares. Within this area, the mussel coverage was found to have increased from 17% to 24% but the mean density had declined from 1.24 kg/0.1m^2 to 1.12 kg/0.1m^2. From these figures, the total biomass of mussels on this bed was calculated to have increased from 259 tonnes to 308 tonnes. Of these, 145 tonnes had reached a size of 45mm compared to 118 tonnes the previous year.

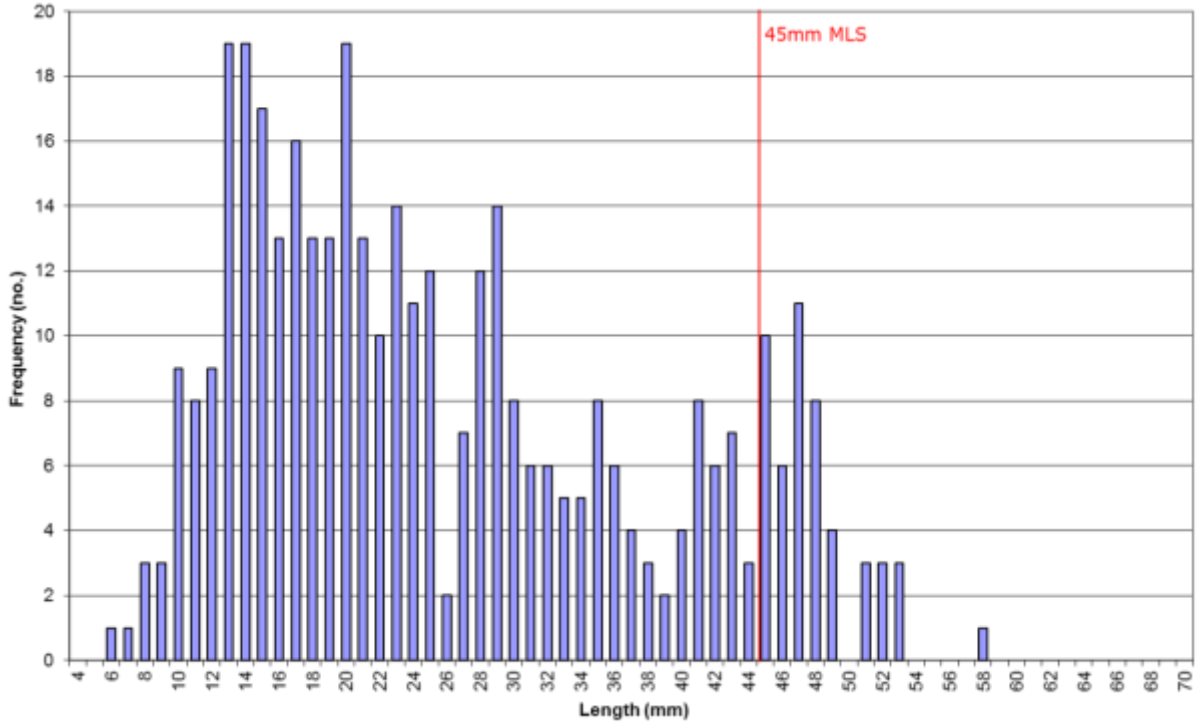

Figure 25 - Mussel size frequency on West Breast – October 2016

East Breast

- Area: 25.4 hectares
- Coverage: 30%
- Mean Density: 1.13 kg/0.1m^2
- Total Stock: 853 tonnes
- Stock ≥ 45mm: 390 tonnes

The East Breast bed was surveyed on October 6th, during which samples were collected from every fifth "hit", producing 42 samples from five transects. Figure 26, shows the size frequency of mussel in the population on this bed.

Although the area of the bed was found to have declined from 30.4 hectares in 2015 to 25.4 hectares, the mussel coverage within the bed had increased from 25% to 30% and the mean density from 1.07 kg/0.1m^2 to 1.13 kg/0.1m^2. From these figures, the total biomass of mussels on this bed was calculated to have increased from 804 tonnes to 853 tonnes. Growth had enabled the biomass of harvestable sized mussels to increase from 352 tonnes to 390 tonnes.

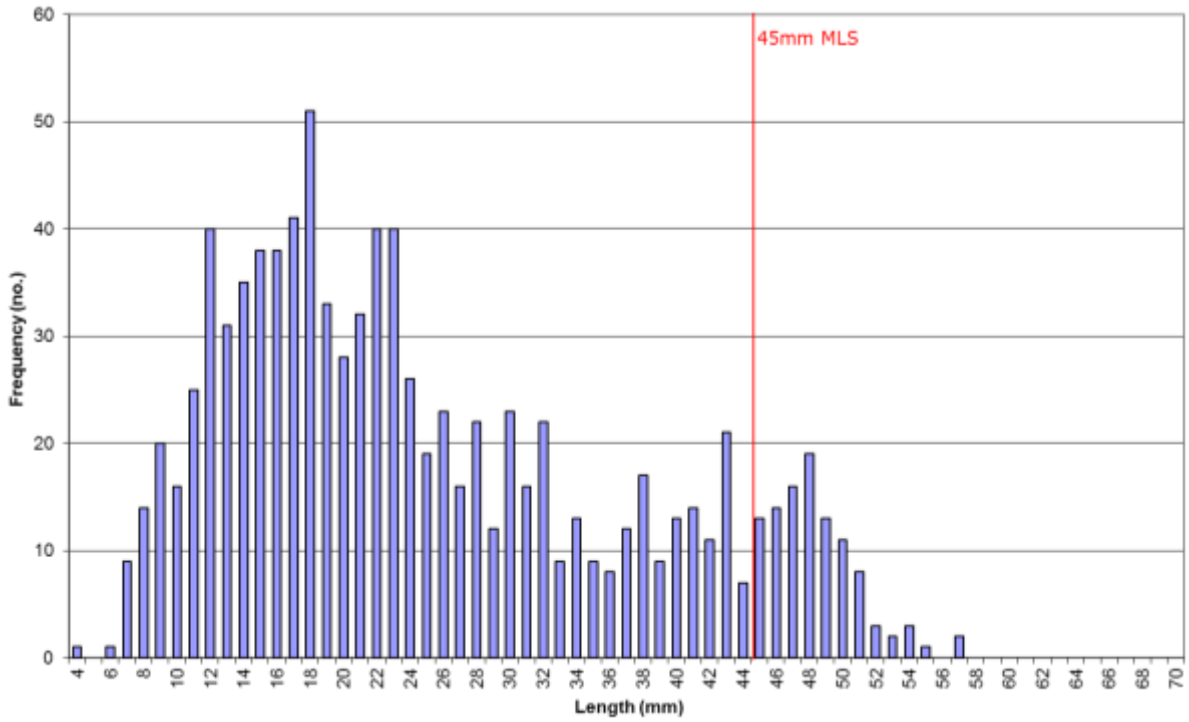

Figure 26 - Mussel size frequency on East Breast – October 2016

East Scotsman's Sled

- Area: 53.1 hectares
- Coverage: 19%
- Mean Density: 0.59 kg/0.1m^2
- Total Stock: 584 tonnes
- Stock ≥ 45mm: 180 tonnes

The Scotsman's Sled bed was surveyed on September 20th, during which samples were collected from every fourth "hit", producing 33 samples from five transects. Figures 27 and 28 show the mussel size distribution over the bed and the mussel size frequency within the population taken from these samples.

The mussels on Scotsman's Sled mostly lay within long narrow gullies that cover most of the bed. Following heavy fishing activity in 2006, the northern part of the bed disappeared and the gullies were flattened out. Recovery in this area was slow, possibly due to the loss of the gullies, and there was no sign of recovery until 2013, when a light settlement of seed was found to have settled among ridged-out cockles. Recent surveys have found there have been further light settlements of seed in this area and shallow gullies have begun to reform. The 2016 survey found there had been a further light settlement along the northern edge of the bed, helping it to increase in area from 49.5 hectares to 53.1

hectares. Within the bed, the coverage of mussels remained the same at 19%, while the mean density had increase slightly from 0.56 kg/0.1m^2 to 0.59 kg/0.1m^2. Although the total mussel biomass had increased from 518 tonnes to 584 tonnes, the loss of some of the older mussels had caused the biomass of harvestable-sized mussels to decline from 256 tonnes to 180 tonnes.

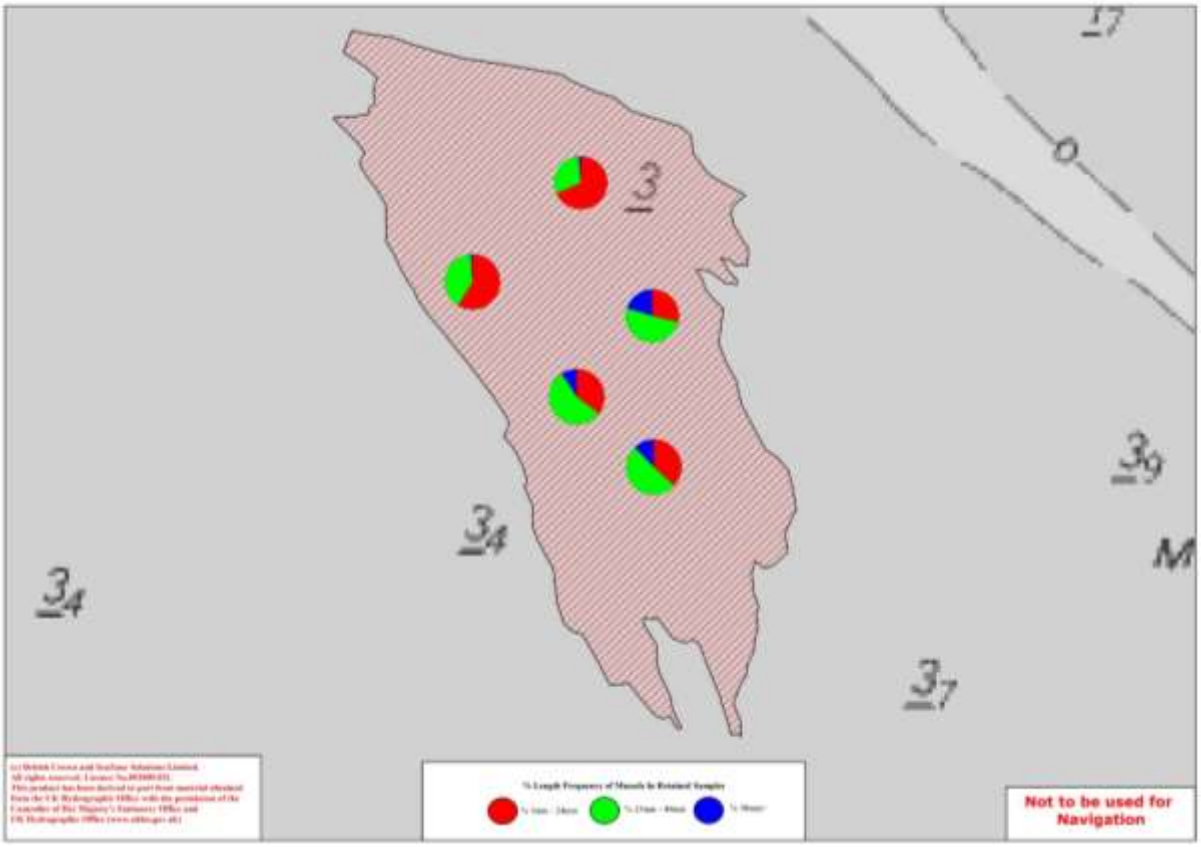

Figure 27 - Mussel size distribution on the East Scotsman's Sled mussel bed – September 2016

The lengthy period that it has taken the northern part of this bed to begin recovering following the fishing activity that occurred in 2006, highlights the importance of maintaining a minimum threshold of mussels on the beds, and also the impact that the surrounding habitat (eg. the gullies) may be having on attracting successful settlements.

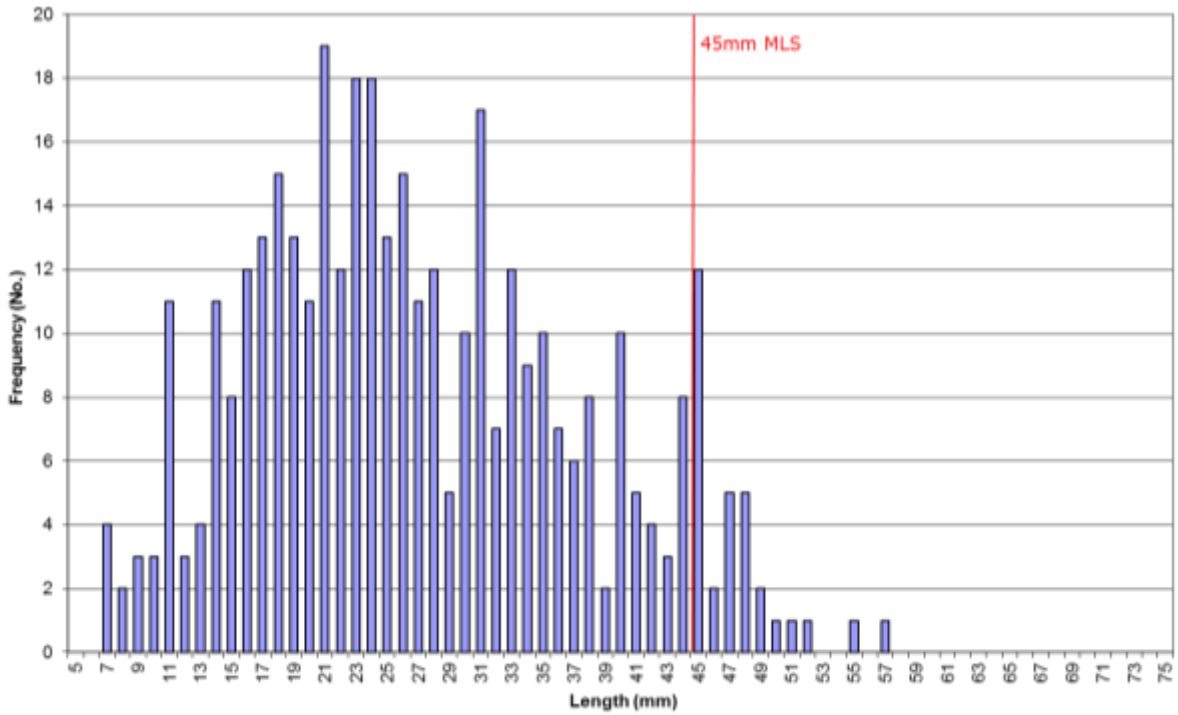

Figure 28 - Mussel size frequency on East Scotsman's Sled – September 2016

Pandora

- Area: 6.6 hectares
- Coverage: 28%
- Mean Density: 1.01 kg/0.1m^2
- Total Stock: 189 tonnes
- Stock ≥ 45mm: 144 tonnes

The Pandora bed was surveyed on September 30th, during which samples were collected from every third "hit", producing 28 samples from two transects. Figure 29 shows the mussel size distribution within the bed while figure 30 shows the mussel size frequency within the population taken from the samples.

The Pandora bed was established during the exceptional settlement that occurred in 2001. Since that initial settlement the bed has attracted little further natural recruitment, resulting in an ageing population. Over most of this bed the mussels are now present in low densities in small scattered clumps situated in ridges of mussel and clam shells. This makes surveying the bed difficult, particularly when trying to determine the extent of the bed amid the shells. As a result, successive annual surveys often show more variation in the statistics for this bed than actually occurs.

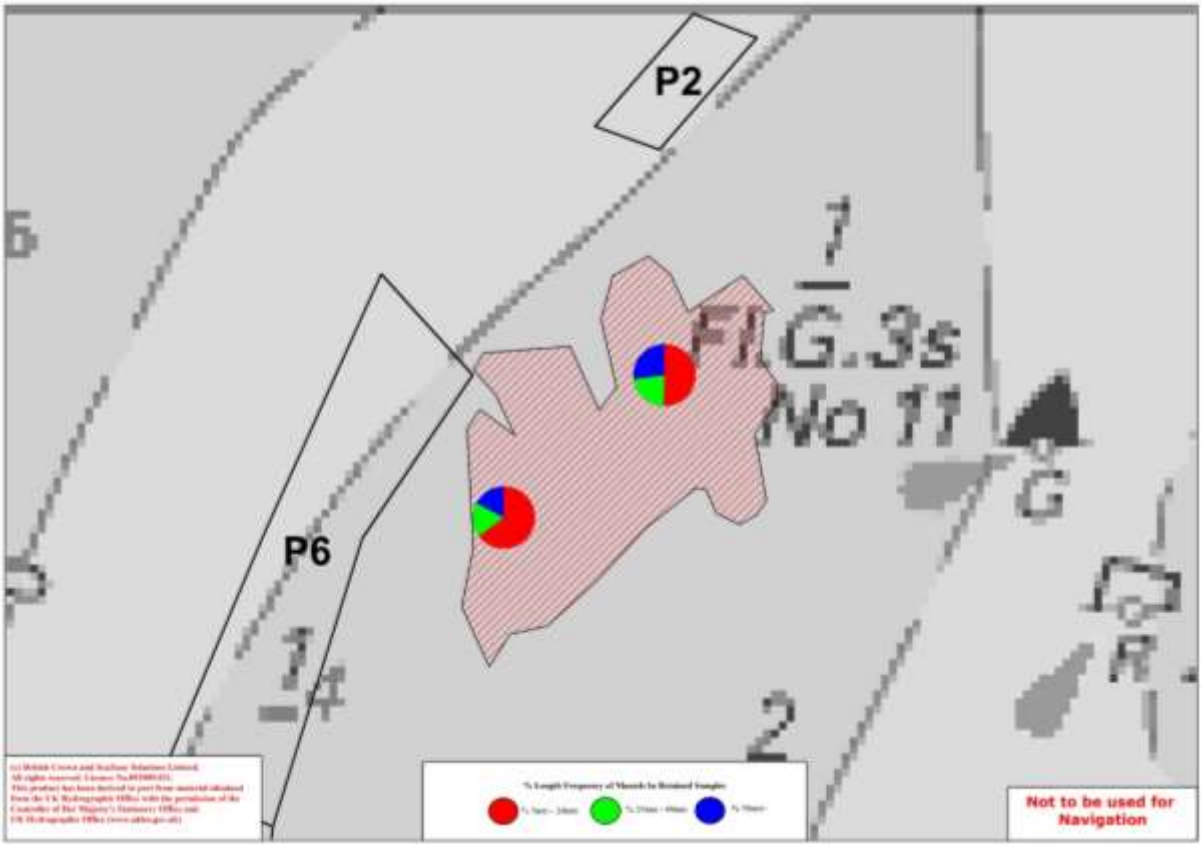

Figure 29 - Mussel size distribution on the Pandora mussel bed – September 2016

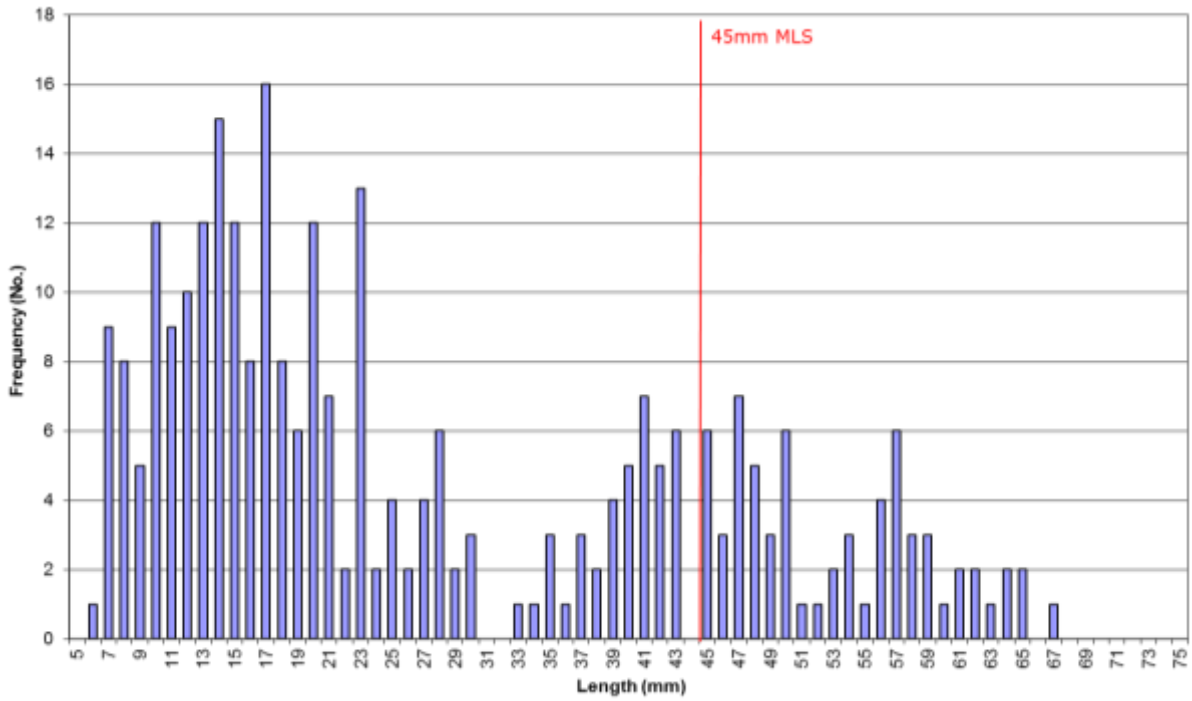

Figure 30 - Mussel size frequency on Pandora – September 2016

During the recent survey, the edge of the sand on which the bed is situated was found to have been scoured away taking part of the bed with it. This had caused the area of the bed to decline from 7.7 hectares to 6.6 hectares. Within the bed there had been a light

settlement that had attached to existing mussel clumps. These had helped the mussel coverage to increase slightly from 27% to 28% and the mean density more significantly from 0.58 kg/0.1m^2 to 1.01 kg/0.1m^2. From these figures, the total biomass of mussels on the bed was calculated to have increased from 122 tonnes to 189 tonnes. Of these, 144 tonnes were of marketable size compared to 102 tonnes the previous year.

Blackshore

- Area: 15.0 hectares
- Coverage: 23%
- Mean Density: 0.57 kg/0.1m^2
- Total Stock: 202 tonnes
- Stock ≥ 45mm: 13 tonnes

The Blackshore bed was first established in 2010 and, following a second settlement in 2011, grew quickly in size to a peak biomass of 852 tonnes in 2012. It was opened during both the 2012 and 2013 fisheries but did not attract much fishing effort. The 2013 survey found there had been high mortalities among the 3 year-old mussels on this bed, however, that had resulted in half of the mussel biomass being lost. The 2014 survey found this decline had continued, with many of the 2011 year-class cohort having died. By 2015 the area of the bed had shrunk to less than 20% of its former size and only 50 tonnes of mussels remained.

The bed was surveyed again on September 22nd 2016, during which samples were collected from every fourth "hit", producing 38 samples from five transects. This survey found there had been a good settlement in the area that had re-established much of the area that had been lost the previous year. Figure 31 shows the mussel size distribution within the bed at the time of this survey, while figure 32 shows the mussel size frequency within the population taken from the samples.

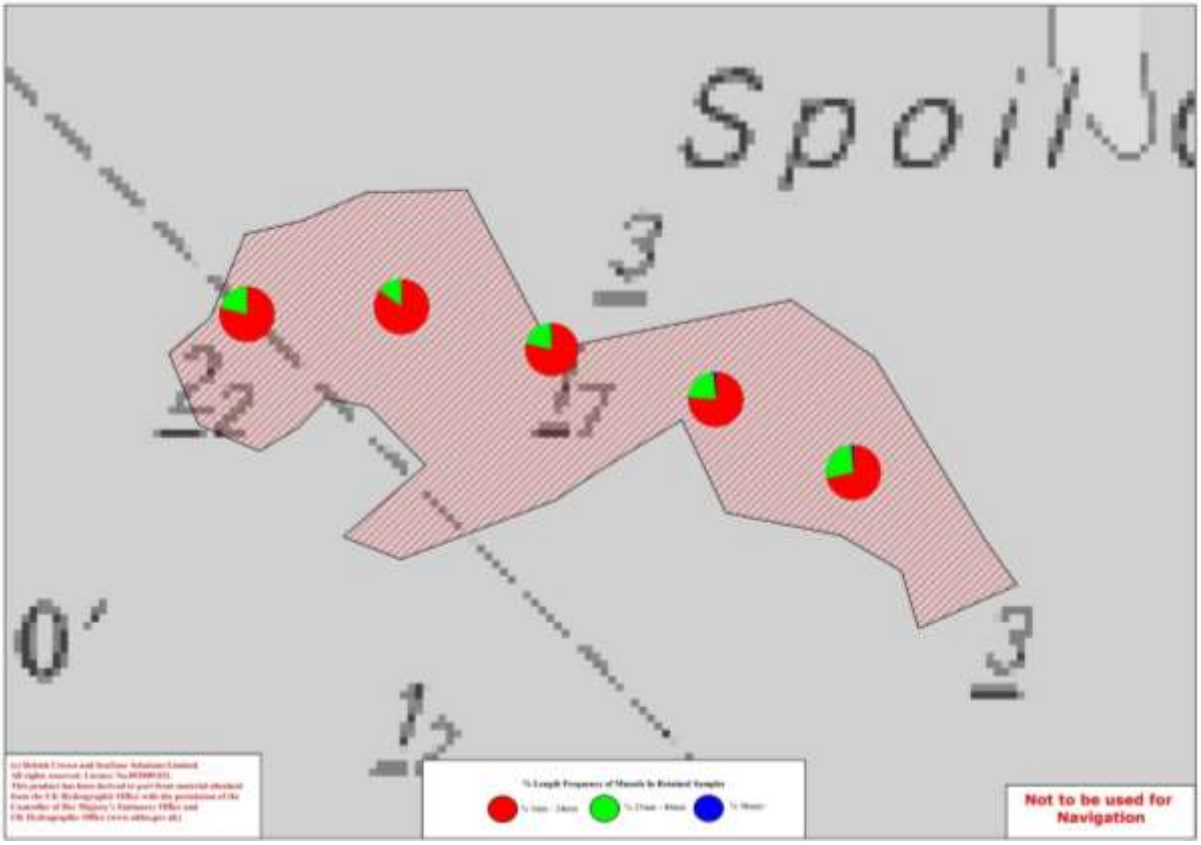

Figure 31 – Chart showing the extent of the Blackshore mussel bed - September 2016

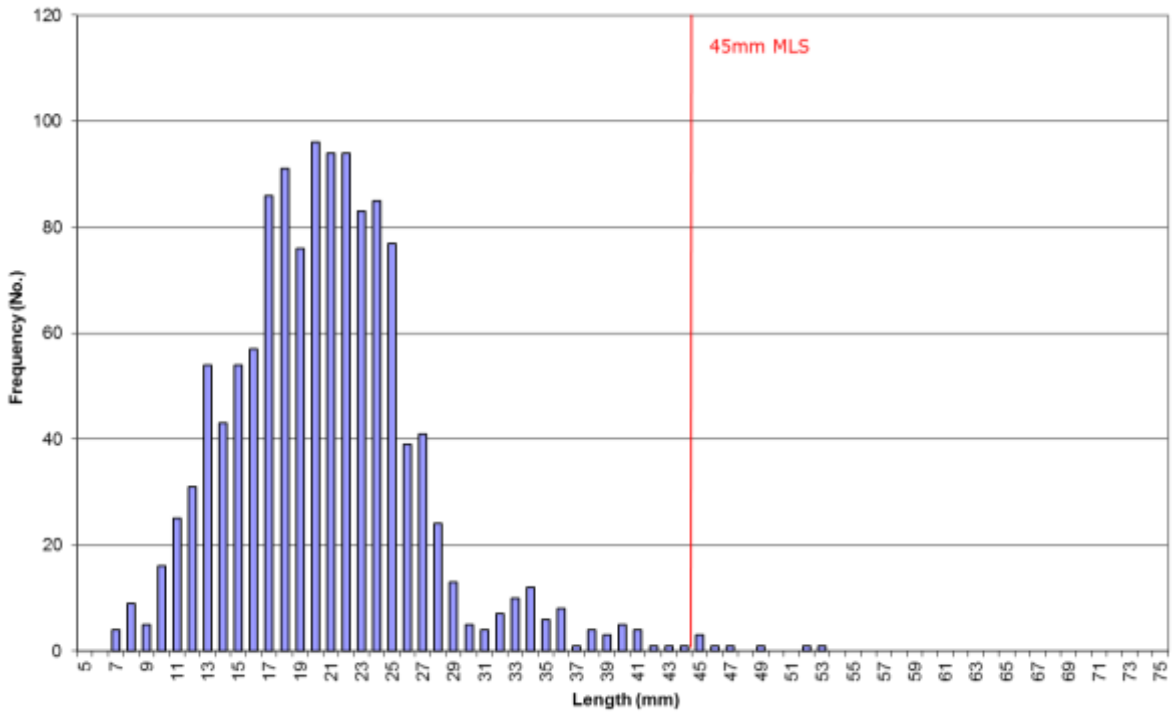

Figure 32 - Mussel size frequency on Blackshore – September 2016

The area of the bed had increased from 3.0 hectares to 15.0 hectares. The mussel coverage within the bed was found to have increased slightly from 22% to 23%, but

because there was only light settlement across a lot of the bed, the mean density was lower at 0.57 kg/0.1m2 than the 0.76 kg/0.1m^2 recorded the previous year. Due to the settlement, the total mussel biomass in the bed was found to have increased from 50 tonnes to 202 tonnes. There had been further losses to the older mussels on this bed, though, reducing the biomass of harvestable sized mussels from 27 tonnes to 13 tonnes.

Welland Bank

- Area: 2.5 hectares
- Coverage: 75%
- Mean Density: 2.38 kg/0.1m^2
- Total Stock: 438 tonnes
- Stock ≥ 45mm: 345 tonnes

Figure 33 - Photograph of the River Welland at mid-water, showing the exposed banks

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 the mussel seed that settles on the wall

tends to be sheltered in the crevices between the rocks, this bed tends to recover well from fisheries. As such, it was possible to open these stocks to the 2015 and 2016 fisheries while all of the other inter-tidal beds remained closed.

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 inter-tidal beds, but as it would be dangerous to attempt walking transects along the wall, a series of samples are tested at distances along the wall (see figure 34). As the best coverage of mussels on this wall is found at the lower extremities, the survey is generally conducted at low water on the largest possible spring tides.

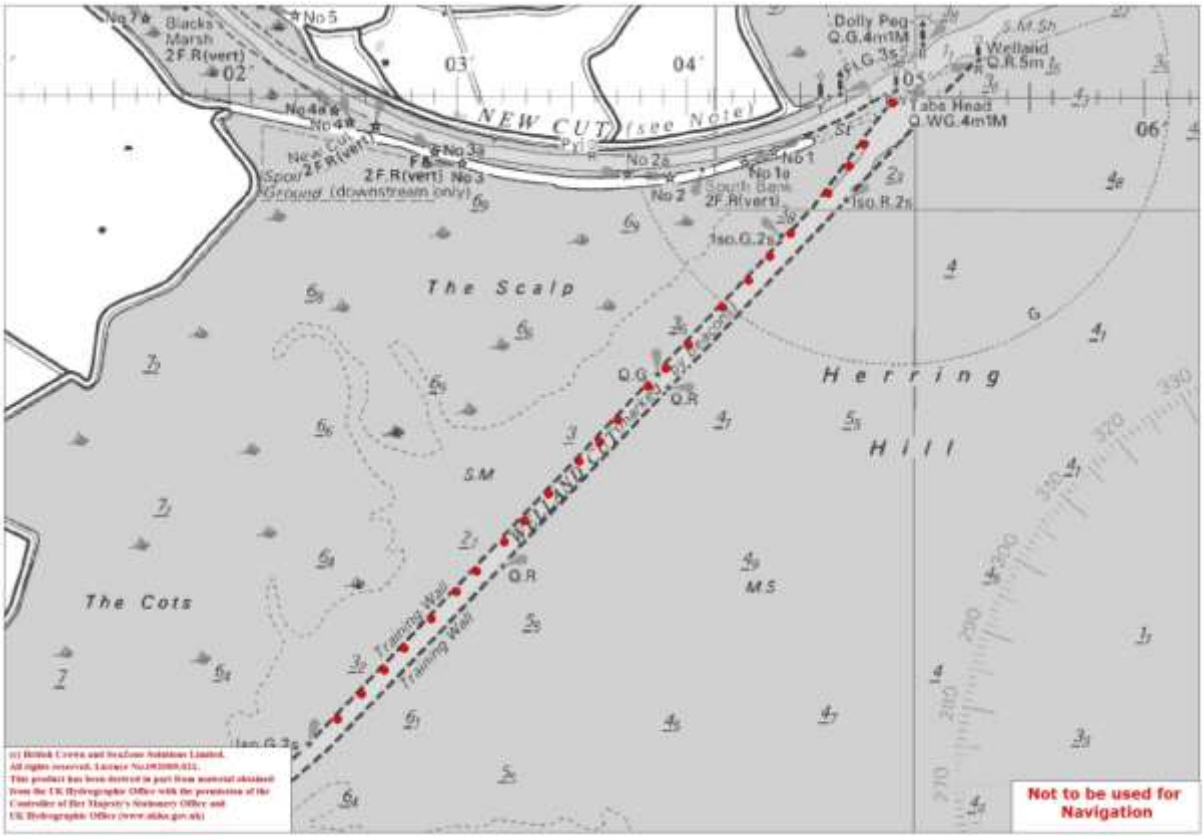

Figure 34 Chart showing the positions of sample sites on the Welland Bank – September 2016

The 2016 survey was conducted on September 19th, over the low water period of an 8.4m tide. Samples were collected from every second "hit", producing 41 samples from 24 sample stations. Figure 37 shows the mussel size frequency of the population taken from these samples.

Although this area had been opened to the fishery during the course of the year, the mussels appeared to have been only lightly thinned out. The area of coverage had increased slightly from 2.2 hectares to 2.5 hectares and the coverage from 74% to 75%. The mean density had declined, though, from 2.78 kg/0.1m^2 to 2.38 kg/0.1m^2. From these figures, the total biomass of mussels on the bank was calculated to be 438 tonnes, a very small reduction from the 442 tonnes recorded there the previous year. Of these, 345 tonnes were of harvestable size compared to 300 tonnes the previous year.

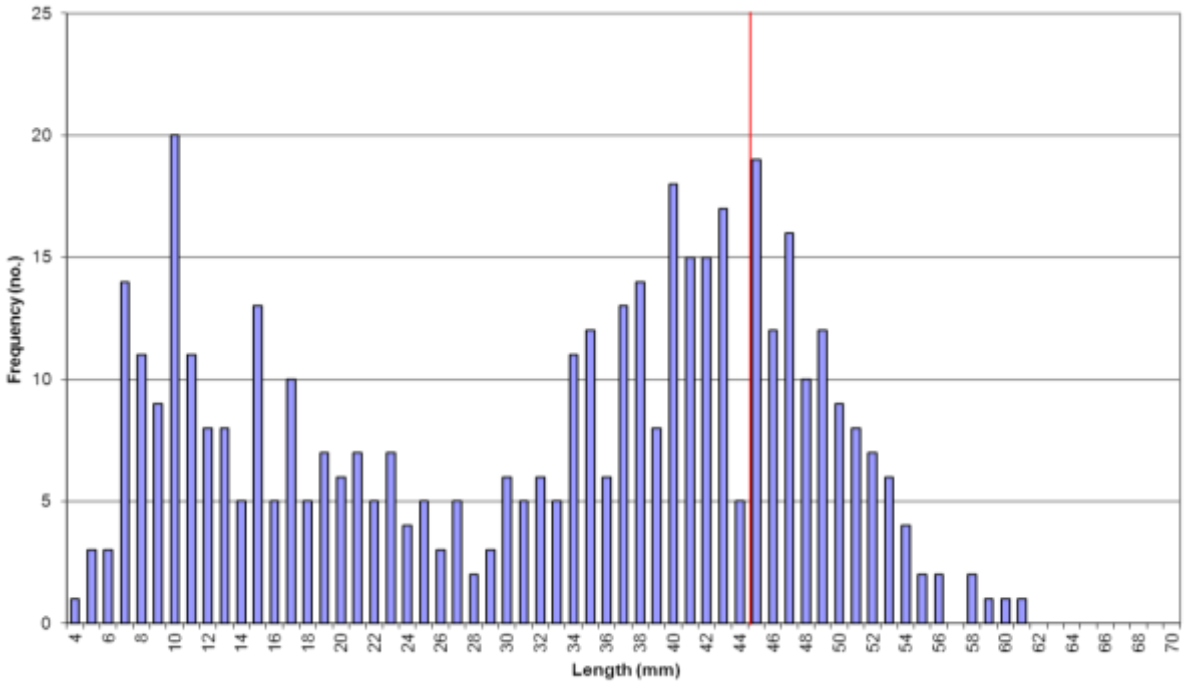

Figure 35 - Mussel size frequency on Welland Bank – September 2016

Discussion

The results of the 2016 survey show most of the beds have benefited this year from light to moderate settlements of seed. On some beds, this has also occurred outside of the beds, where mussel spat has attached to ridged-out cockle shells. While this recruitment has been a welcome change from the recent poor settlements experienced on the inter-tidal beds, and has prevented most of the beds continuing their recent declines this year, it has not been sufficient to rejuvenate the beds to a healthy condition. Most are still in a poor condition and vulnerable to being lost.

Figure 36 shows total biomass and the level of adult mussel stocks present on the inter-tidal beds since 2002, compared with their respective Conservation Objective targets of 12,000 tonnes and 7,000 tonnes. Although the adult stocks had remained close to the Conservation targets between 2004 and 2009, heavy mortalities during 2010 caused these stocks to decline sharply. Impaired by high proportions of young mussels dying as they reach maturity, the subsequent recovery has been slow. At 6,375 tonnes, the adult stocks are currently still below their Conservation Objective target. Boosted by the recent spatfall and mussel growth, the target for total mussel biomass has just been achieved.

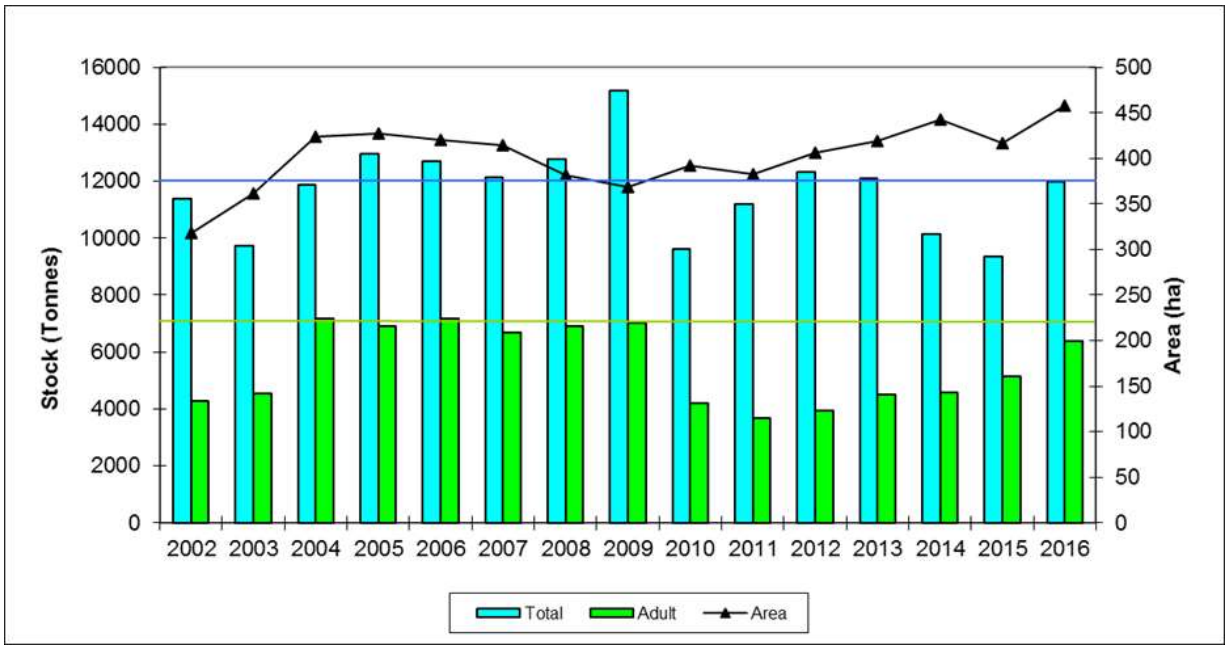

Figure 36 – Intertidal mussel stock levels in the Wash since 2002 and the Conservation Objective targets

MUSSEL REGENERATION PROJECT

The results from past mussel surveys indicate the majority of the mussel settlement that occurs in the Wash happens within existing mussel beds. Healthy mussel beds with a good coverage and high mussel density create a raised structure of live mussels and dead shell bound together with byssus threads. This is an important habitat for attracting fresh settlements of seed, which then find shelter from weather and protection from predators among the crevices. When fishery pressure or natural mortalities cause a bed to decline, however, the mussel densities can fall below the critical thresholds required to create raised structures. Once in this state, having reduced their potential to attract new seed, these beds struggle to attract sufficient recruitment to reverse their decline. Even if these beds are closed to further fishing, the decline can be terminal or very slow to recover from.

Following several years of high natural mortality, many of the inter-tidal mussel beds in the Wash have reached the stage where they are struggling to recover. With their decline continuing irrespective of fishery closures, in 2014 the Authority explored ways of facilitating a recovery. Relaying partially grown mussel seed from elsewhere is an effective way of accelerating the recovery of a bed. The cost of mussel seed is prohibitive for large-scale rejuvenation projects, however, and could not be sustained long-term as a viable management option. Instead the Authority trialled the use of culch to attract seed.

A culch of shell has long been recognised as an important substrate for growing bivalve molluscs, particularly in the oyster aquaculture industry. Observations made during the annual inter-tidal mussel surveys have highlighted that mussel shells alone appear to be a poor medium for recruitment, however. Dense patches of mussel shell often remain in the ground following fisheries or natural mortality, but these areas frequently take many years to recover. Mussel seed has frequently been observed to have settled in gullies containing either ridged out cockles or cockle shells, though. The reason for this difference in ability to attract mussel seed may be in the disposition for mussel shells to lay flat on the ground and become buried, while cockle shells being more rounded, tend to remain raised, providing a suitable habitat for attachment. As there is an abundance of relatively cheap cockle shells that are a by-product of the cockle fishery, in 2014 the Authority conducted a trial to determine whether it would be possible to attract mussel settlement by laying a culch of cockle shells close to a mussel bed. The purchase of the cockle shells and charter of the fishing vessels used to lay the shells during the course of these experiments were funded from the Wash Fishery Order 1992 Propagation Fund.

During the initial trial, in which 72 tonnes of cockle shell were laid in three 20m x 20m plots near the Trial Bank mussel bed on Inner Westmark Knock (see figure 37), the results were inconclusive.

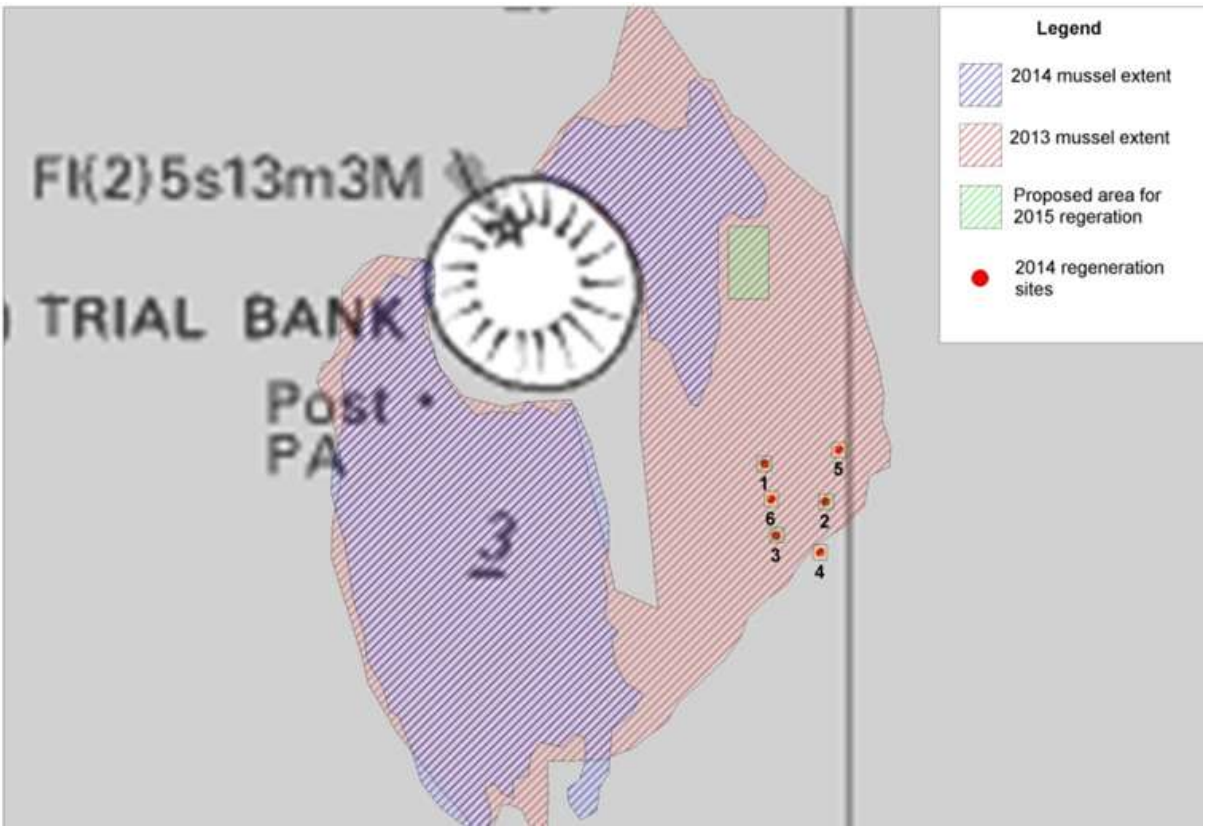

Figure 37 – Location of the six trial mussel regeneration plots on the Trial Bank mussel bed.

Although the shells did have a positive impact, attracting fifteen times as many mussels to the shelly areas compared to the nearby bare control sites, the numbers were not large and would not have been cost effective as a long-term solution. Mussel settlement throughout the Wash during 2014 was poor, however, so approval was given to continue the study. The plan to lay 200 tonnes of cockle shell in 2015 was cancelled because the experimental site received a dense settlement of cockle spat, but in 2016 200 tonnes of shell were deposited on two alternative sites near the Gat and Mare Tail mussel beds (see figures 38 and 39).

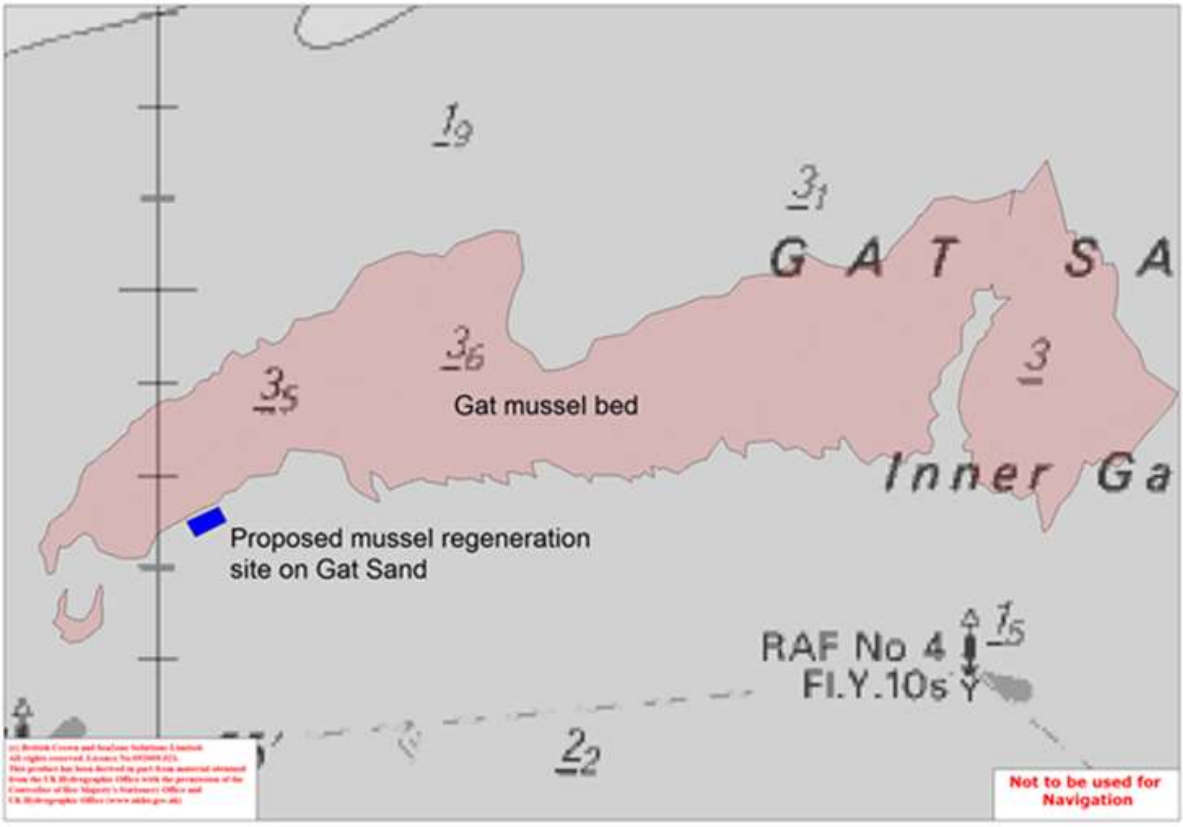

Figure 38 – Location of the mussel regeneration plot near the West Gat mussel bed.

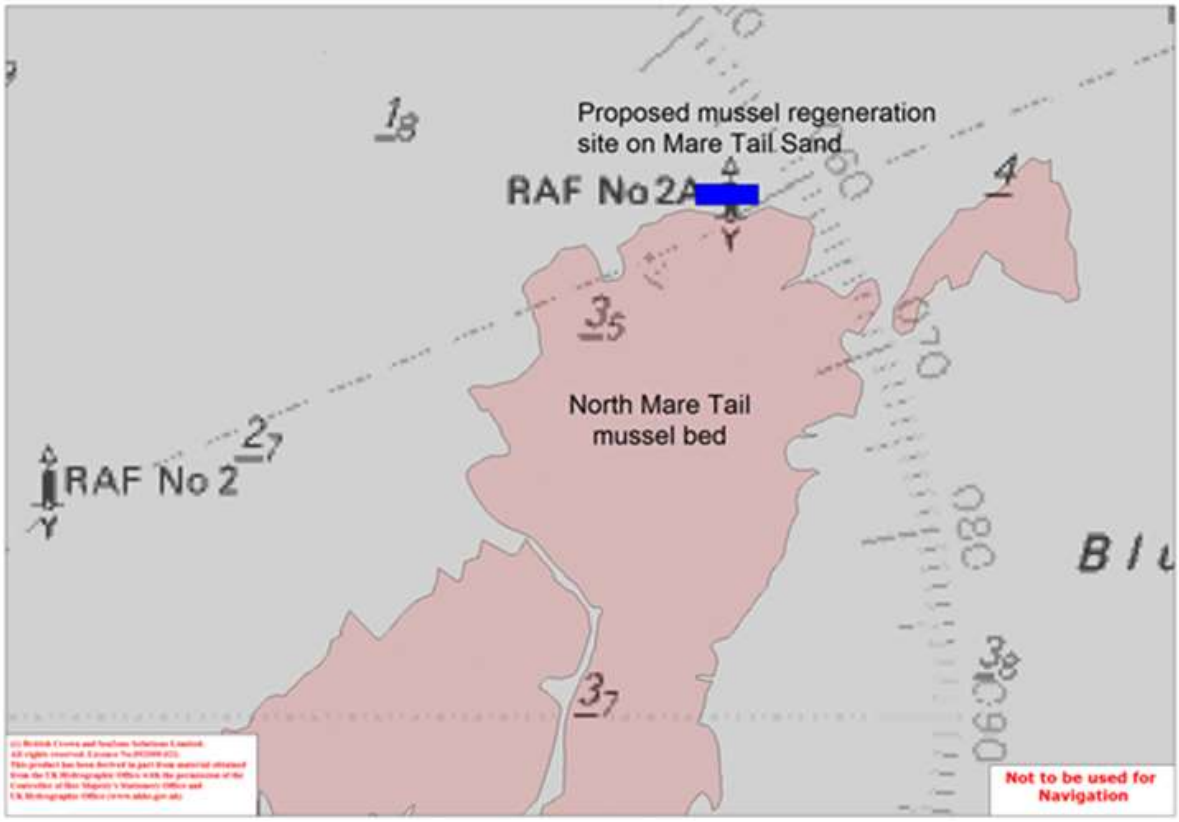

Figure 39 – Location of the mussel regeneration plot near the North Mare Tail mussel bed.

Monitoring at all the experimental sites was continued. In 2015 the initial trial sites on Inner Westmark Knock were found to have attracted a much better settlement of seed than the previous year. Although most of the mussels that had attached to the cockle shells were too small to be readily visible without close observation, they were present in densities of 157 mussels/m^2. This was comparable with many of the inter-tidal mussel beds. When monitored again in September 2016, the three plots were found to support several natural-looking ridges of mussels that had grown from the previous year's seed. In addition, there had also been another settlement that had boosted the average mussel density over the plots to 921 mussels/m^2. This density is higher than the average densities found on any of the inter-tidal beds barring the nearby Trial Bank bed. Due to their small size, however, these mussels only had a biomass of 890kg, which equated to 7 tonnes/hectare.

Both the Gat and Mare Tail sites were also found to have attracted seed since being laid six months earlier. These were present in densities of 466 mussels/m^2 on the Mare Tail site and 148 mussels/m^2 on the Gat site. In terms of mussel biomass, these equated to 4.5 tonnes/hectare on Mare Tail and 5.4 tonnes/hectare on the Gat. While the biomass estimated for the Mare Tail is predominantly composed of new seed, the figure for the Gat has been inflated by the ingress of some larger mussels that had washed out of the nearby wild bed. Figures 40-43 are images taken from the Mare Tail regeneration site.

Figure 40 – Mare Tail regeneration site immediately after laying cockle shell culch – March 2016

Figure 41 – Mare Tail regeneration site 6 months after laying cockle shell culch – September 2016

Figure 42 – Clumps of juvenile mussels and cockle shells bound together with byssus threads. Taken from Mare Tail regeneration site – September 2016

Figure 43 – Sample of mussels collected from Mare Tail regeneration site – September 2016

Table 2 shows the average density of mussels on the regeneration sites compared with the inter-tidal beds at the time of the 2016 surveys. Numerically, within two years of being laid, the shells on the Trial Bank sites had attracted a higher density of mussels than was found on any of the inter-tidal beds other than the adjacent Trial Bank bed. After just six months, the Mare Tail site was also found to have higher mussel densities than eight of the inter-tidal beds, and in terms of new seed, only four of the existing beds had attracted higher densities of seed during the year. That Gat site had also successfully attracted mussel seed in the six months since the shells had been deposited, but the settlement on this site was lower than the others. It should be noted that the figures provided in table 2 compare the average numbers of mussels/m^2 on each bed and not their biomass. As most of the mussels on the regeneration sites are still small seed, their biomass compared to those on the inter-tidal beds is currently much lower.

Table 2 – Average density of mussels on the regeneration sites compared with the inter-tidal beds at the time of the 2016 surveys

	Number of mussels/m^2 found on each bed during 2016			
Bed	**<25mm**	**25-44mm**	**>45mm**	**Total**
Trial Bank	677	278	53	1008
TB Regeneration Site	874	47	0	921
Blackshore	699	185	6	890
Holbeach	686	163	20	870
East Breast	465	247	88	799
East Gat	409	171	68	647
West Gat	412	163	69	644
Herring Hill	237	303	62	633
South Mare Tail	242	315	35	592
West Mare Tail	391	180	17	587
West Breast	317	192	74	582
MT Regeneration Site	417	50	0	466
Mid Gat	274	134	52	460
North Mare Tail	182	170	88	440
Toft Ext	273	77	18	368
Pandora	195	69	76	340
Toft	77	78	161	317
Scotsman's Sled	122	118	21	261
Main End	92	82	55	229
Roger	73	67	79	218
Gat Regeneration Site	119	16	13	148

Feasibility of laying cockle shell culch commercially

The mussel regeneration project was conducted to determine if laying a culch of cockle shells could be used as a feasible method of rejuvenating mussel beds. The initial results from the experiment have shown the shells do successfully attract seed mussels at levels comparable to those seen on the wild mussel beds. The question of whether this is a feasible proposition in terms of cost however, is still to be answered. After 2½ years 890kg of mussels have accumulated on the three Trial Bank plots, while after six months the larger sites on the Mare Tail and Gat have collected 2.4 tonnes and 1.3 tonnes respectively. As it cost £5,000 to lay 72 tonnes of shell on the Trial Bank sites and £15,000 to lay 200 tonnes of shell on the Gat and Mare Tail sites, the outlay greatly exceeds the value of the mussels that have currently been attracted to the sites. At present, though, the individual mussels that have settled on the shells are still small and of relatively low weight. Although

it is planned to continue monitoring these sites during the annual Autumn mussel surveys, at the moment the experiment has not been running long enough to determine what biomass of harvestable-sized mussels this seed will develop into. In order to recover the costs of laying the shell, however, the Trial Bank site would need to produce mussel densities equivalent to 120 tonnes/hectare. Even with good settlement and growth this density is unlikely to be achieved. Unless the culch remained after harvesting, facilitating further settlements, the depth of shell deployed on this site is not likely to be cost effective. On the Gat and Mare Tail sites, where the cockle shells were not laid as deep as on the Trial Bank plots, mussel densities of 58 tonnes/hectare would be required to recover the cost of laying the shell. That density is equivalent to that seen on an established, healthy mussel bed, so is potentially achievable.

Even though the culch has been demonstrated to successfully attract settlement of seed, the amount of shell required to conduct large-scale recovery programmes might prove prohibitive. It could be suitable for smaller-scale programmes to facilitate recovery of bare patches within exiting beds, or encouraging settlement in environmentally important areas, however. There are also applications for the industry, where the method could be used to encourage the settlement of seed onto their lays. The two main costs associated with laying the shells during the experiment were purchasing the shells and the charter of fishing boats to lay the shells on the designated sites. If fishermen were able to access the shells cheaper and willing to invest their own time, possibly while conducting other fishing activities, this could be a viable solution of attracting seed on their Several Fishery lays. It would, however, be wise for them to conduct a small-scale feasibility study at such sites before investing heavily. On soft ground, as was trialled on the Inner Westmark Knock sites, the shells quickly sank into the sediment before creating a firm foundation and stabilising. Also, depending on local environmental conditions, not all locations might be as successful at attracting seed. All three of the experimental plots used in this study were situated close to natural mussel beds where there might be a predisposition for mussel larvae to settle. Elsewhere, the chance of success might be reduced.