Eastern IFCA
Inshore Fisheries and Conservation Authority

RESEARCH REPORT 2015

WFO MUSSEL STOCK ASSESSMENT

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WFO MUSSEL SURVEY

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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. Because of their importance as both a fishery and conservation resource, these beds are protected by strict management measures and policies. In order to inform the Authority's management decisions, these beds are monitored annually each autumn.

The historic data record is fragmented but shows the abundance of mussels on the regulated beds has been variable during last century, with at least five major fluctuations having occurred. Following a peak biomass of 30,000 tonnes in the 1920s, however, the magnitude of each peak since then appears to have successively declined to more recent levels of 18,000 tonnes in the 1980s and 15,000 tonnes in 2009. Between peaks there have been periods of low stock abundance when the biomass of mussels has declined to approximately 7,000 tonnes. Although there is evidence from historic bailiff reports to suggest over-fishing has been responsible for stock declines in the past, it is difficult to determine whether fishing mortality has been the driver for all of the recorded declines or whether other natural factors have influenced them. Certainly, heavy fishing pressure, coupled with poor recruitment, appear to have caused the declines seen in the 1980s. The more recent decline that has been observed since 2009, however, does not appear to be fishery related. Strict management measures have been in place since the previous decline in the 1990s that have restricted the possible impacts that fisheries have on the stocks. These have resulted in only relatively small fisheries being opened on the inter-tidal beds since 2009, and none at all during 2015, yet the stocks have continued declining at an alarming rate.

Samples analysed by Cefas in 2010, following a decline that caused the mussel biomass to fall from 15,188 tonnes to 9,600 tonnes, attributed the die-off to high infestation rates of the copepod parasite, *Mytilicola intestinalis*, which had been found in high numbers in the mussels. Since then, recent die-offs have affected

high proportions of 2 and 3 year-old mussels, while older mussels appear to have been less affected. Although the cause of these mortalities is not currently known, it has had a devastating impact on several of the beds that had recently settled and been composed primarily of younger mussels. Because older mussels seem less affected, the impacts to the older, more established beds are slightly less apparent than on the younger beds, but over time these are beginning to support increasingly ageing populations that will eventually die.

Recruitment in recent years has also been relatively poor. A widespread settlement in 2001 helped to rejuvenate many of the beds and established several new ones. Such widespread settlements are uncommon in the Wash, though, with the majority of recruitment tending to occur within existing beds. This is likely to be 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 existing beds have been declining, however, their densities have dropped below levels at which these raised matrices tend to form. In 2014 the Authority began a research project to study the feasibility of laying a culch of cockle shells to encourage the settlement of mussel seed. The initial results from this experiment, while indicating the shells did have a positive effect on recruitment, showed only limited success. More recent results have been more positive, however.

This report documents the results of the 2015 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.

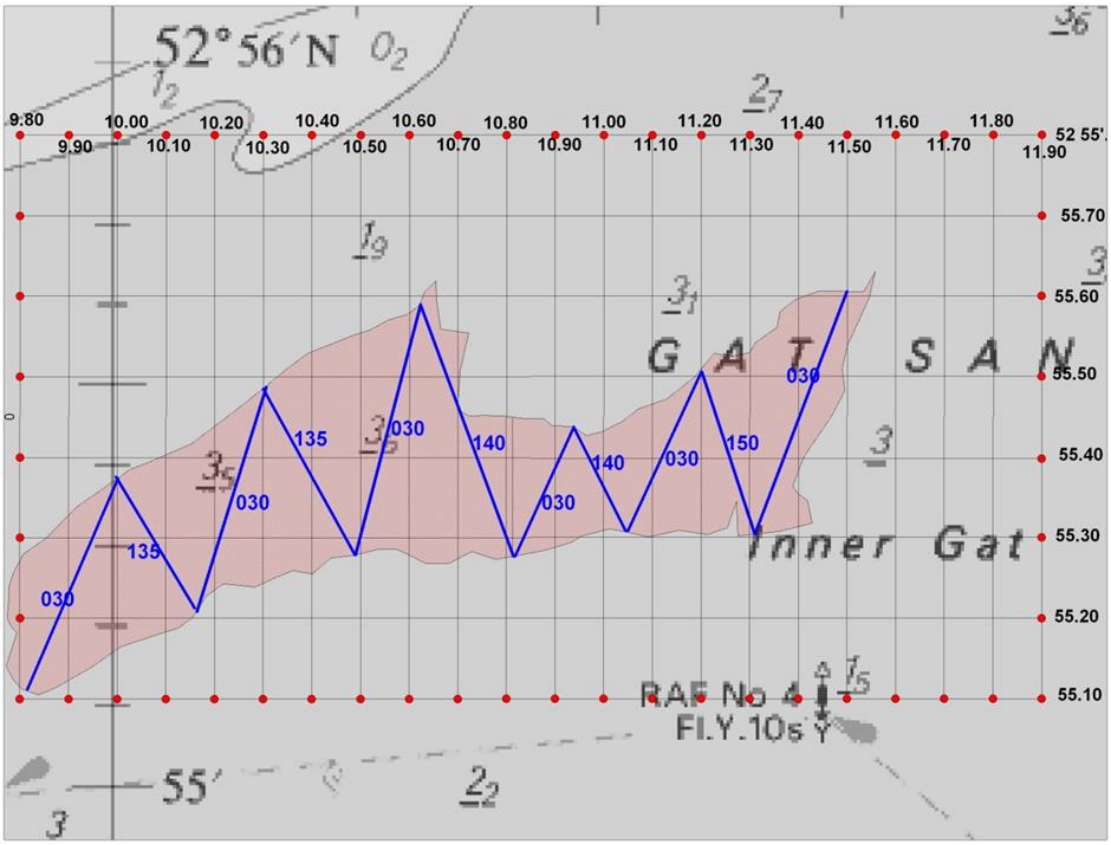

Figure 1 – Chart showing the area of a mussel bed, the transect lines to be surveyed, their bearings and an overlaid grid showing the lat/long positions

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. The weights of these samples are then recorded (during the 2012 surveys, the number and weight of mussels ≥25mm length were 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 2015 surveys commenced on September 28th and were completed on October 31st. During this period 20 areas of mussel bed were surveyed, including two small beds between Mare Tail and Herring Hill that were first identified in 2014. Figure 2 shows the distribution of these beds. In addition to these inter-tidal beds, the mussels on the Welland Bank were also surveyed.

Although there had been no fishery on the inter-tidal mussel beds during 2015, the survey results found that the general decline observed in recent years had continued. Table 1 summarises the stocks found on the beds at the time of the survey and compares them to the previous year's level. From this table it can be seen that the total mussel biomass had declined from 10,127 tonnes in 2014 to 9,376 tonnes. This is the lowest stock level for 14 years. Eleven of the beds were found to have declined in biomass during the year. These changes can be seen figure 3. Of these, the Shellridge bed, which supported over 500 tonnes in 2006, had declined to level where it was considered to no longer support enough mussels to warrant surveying. The Blackshore bed was also found to have suffered heavy losses. This bed was first identified in 2010 when it was noticed that mussel seed had settled among ridged-out cockles. Following further settlements in 2011 and 2012, this bed reached a peak of 852 tonnes in 2012. Unfortunately, each of these cohorts had suffered high mortality rates on reaching three years old, resulting in the rapid decline of what appeared to be a healthy bed. The losses this year have caused area of this bed to decline from 21.6 to 3.0 hectares. Mortality of young mussels on three of the Mare Tail beds resulted in the loss of 748 tonnes from these areas. Although the surveys found the Gat beds had increased slightly in biomass, the light settlement seen on there was only partially responsible. Most of this increase was due to growth of the remaining older mussels that had survived recent die-offs. Following high mortality levels among 3-year old mussels over the past five years, the Gat, and most of the older beds, are now composed mainly of dwindling populations of ageing mussels. While these older populations are gradually declining, on the younger beds like the Blackshore, which do not have a reserve of older mussels, the declines are more dramatic.

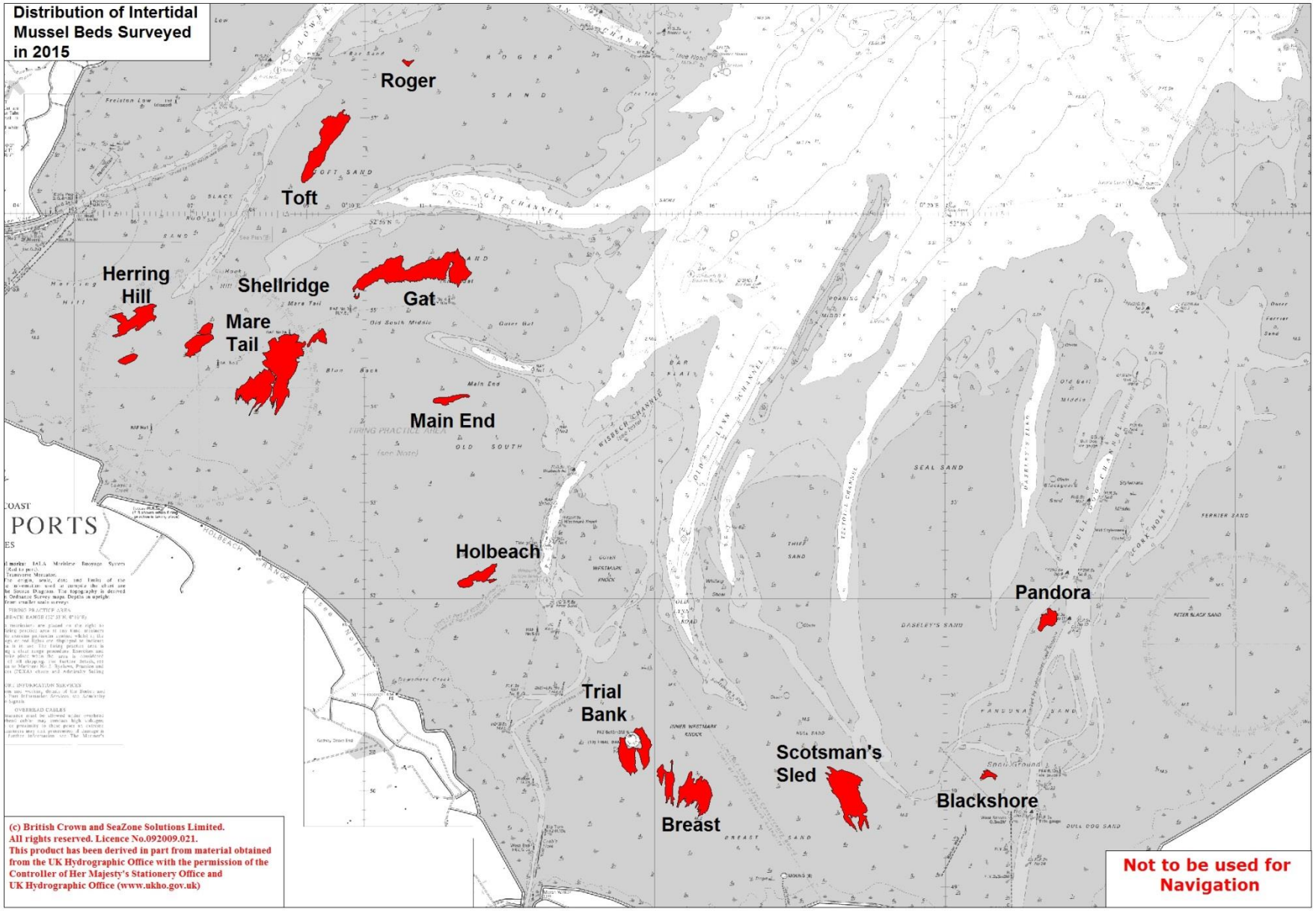

Figure 2 - Distribution of intertidal mussel beds surveyed during 2015

Table 1 – Summary of the mussel stocks on individual beds at the time of the 2015 surveys

	2015							2014	
BED	AREA (ha)	COVERAGE (%)	PATCH DENSITY (kg/0.1m)	TOTAL STOCK (tonnes)	STOCK >45MM (tonnes)	% ≥45MM (%)	BED DENSITY (Tonnes/ha)	TOTAL STOCK	% CHANGE
Mare Tail North	62	36	0.87	1969	1030	52.3	31.8	2437	-19.2
Mare Tail South	31.4	32	0.63	632	197	31.2	20.1	782	-19.2
Mare Tail East	5.7	38	0.37	79	26	32.9	13.9	51	54.9
Mare Tail West	13	32	0.51	212	64	30.2	16.3	342	-38.0
Mare Tail West (ext)	4.2	47	0.13	27	0	0.0	6.4	0	-
Shellridge	-	-	-	-	-	-	-	26	-100.0
Toft	40	31	1.14	1428	1305	91.4	35.7	1638	-12.8
Roger	1.35	33	0.69	31	27	87.1	23.0	28	10.7
Gat, West	35.1	35	0.68	828	513	62.0	23.6	699	18.5
Gat, Mid	26.6	22	0.39	225	190	84.4	8.5	186	21.0
Gat, East	16.9	40	0.55	373	307	82.3	22.1	361	3.3
Main End	6.6	19	0.45	55	45	81.8	8.3	141	-61.0
Holbeach	13.72	47	0.43	280	141	50.4	20.4	303	-7.6
Herring Hill	24.7	37	0.82	748	171	22.9	30.3	710	5.4
East Herring Hill	4.3	23	0.43	41	7	17.1	9.5	71	-42.3
Trial Bank	28.2	33	0.73	695	271	39.0	24.6	686	1.3
Breast, West	12.6	17	1.24	259	118	45.6	20.6	162	59.9
Breast, East	30.4	25	1.07	804	352	43.8	26.4	893	-10.0
Scotsman's Sled, East	49.5	19	0.56	518	256	49.4	10.5	291	78.0
Blackshore	3	22	0.76	50	27	54.0	16.7	171	-70.8
Pandora	7.7	27	0.58	122	102	83.6	15.8	149	-18.1
TOTAL	**417**			**9376**	**5149**	**54.9**	**22.5**	**10127**	-7.4
Welland Bank	2.16	74	2.78	442	300	67.9	264.2	210	110.5

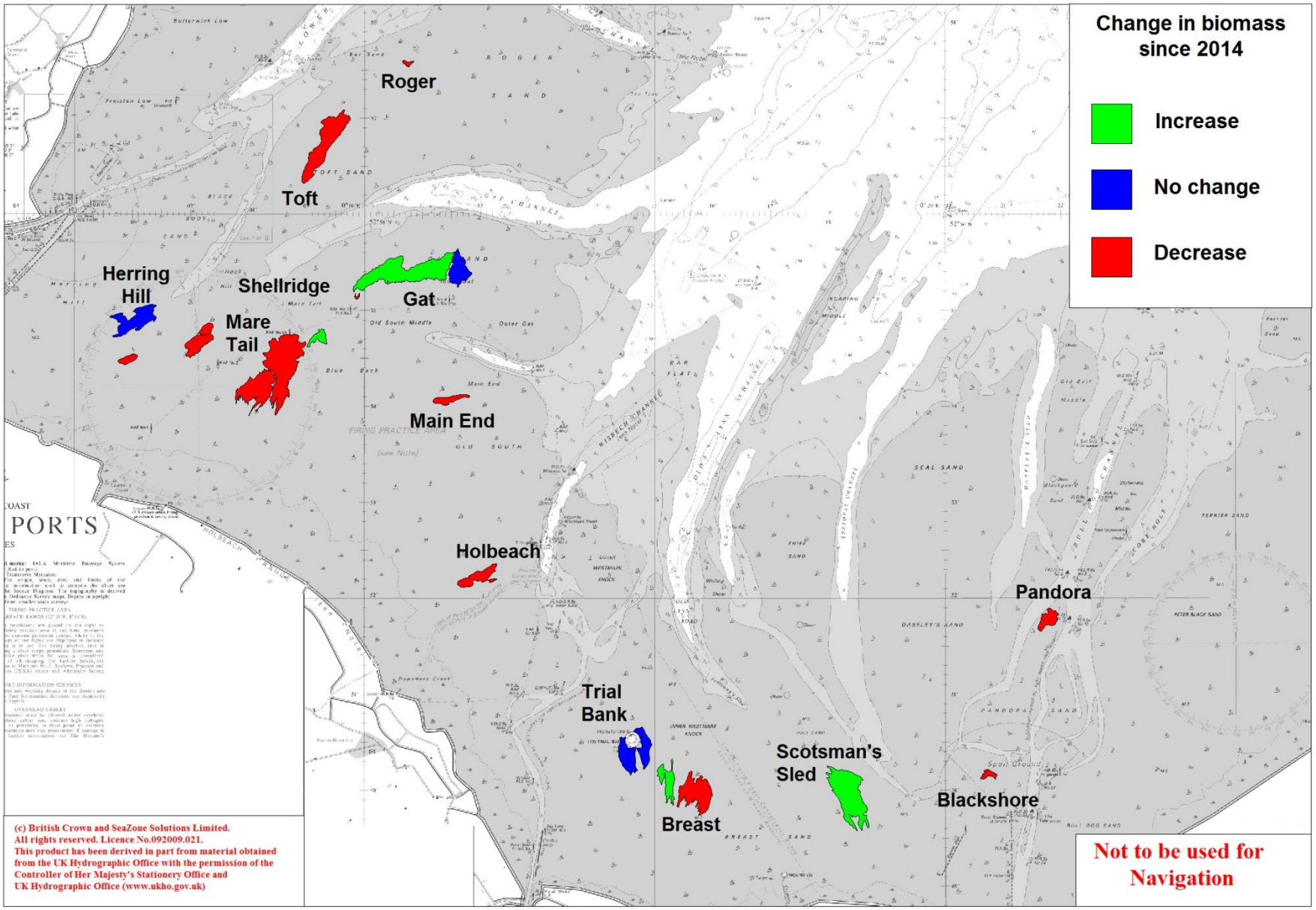

Figure 3 – Chart highlighting the changes in mussel biomass to individual beds between the 2014 and 2015 surveys

The following section describes the individual beds at the time of the 2014 survey.

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. Figure 4 shows the distribution of these beds. Until this year the Shellridge bed was also situated to the north of this area, but following several years of declining stocks had deteriorated to a level no longer warranting surveying. The area was found to support high densities of ridged out cockles and cockle shell, though, so it is hoped these will attract future settlements of mussel seed.

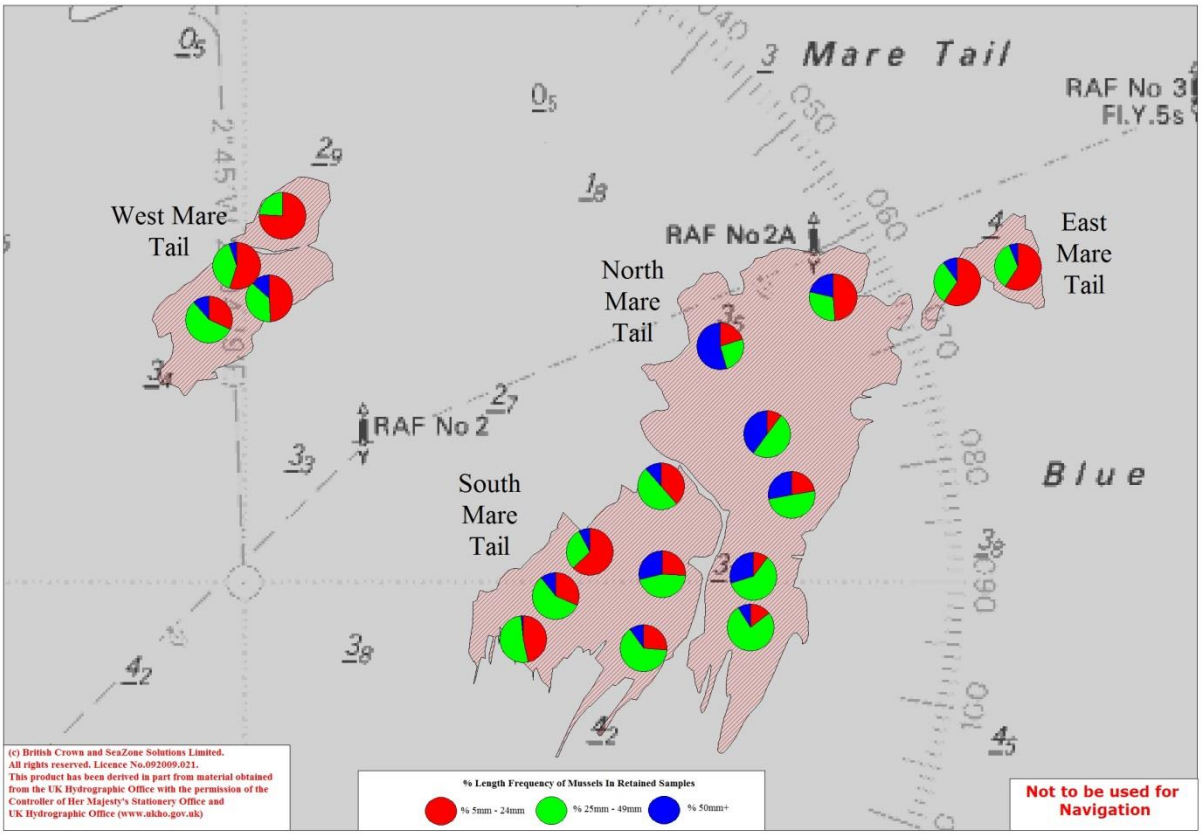

Figure 4 - Mussel size distributions on the Mare Tail mussel beds – October 2014

The individual beds on the Mare Tail are described as follows.

North Mare Tail

- Area: 62.0 hectares
- Coverage: 36%
- Mean Density: 0.87 kg/0.1m^2
- Total Stock: 1,969 tonnes
- Stock ≥ 45mm: 1,030 tonnes

The North Mare Tail bed was surveyed on October 10th, during which samples were collected from every fifth "hit", producing 65 samples from six transects. Figure 5 shows the mussel size frequency within the population taken from these samples.

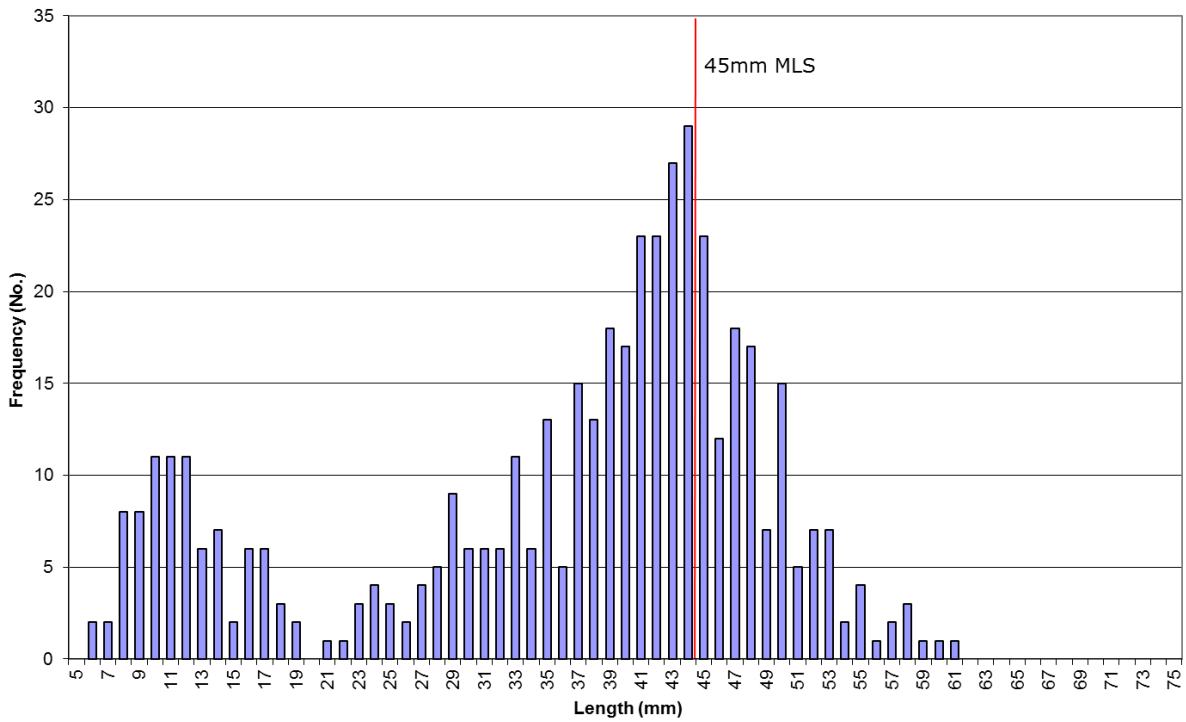

Figure 5 - Mussel size frequency on North Mare Tail - October 2015

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 recent deterioration of the bed. The 2015 survey found this had resulted in several bare patches developing. Where these had occurred around the edge of the bed they had resulted in the area declining from 66.7 hectares to

60.0 hectares. Within this area the coverage had also declined from 41% to 36% and the mean density of the mussel patches from 0.90 kg/0.1m^2 to 0.7 kg/0.1m^2. From these figures the mussel biomass on the bed was calculated to have declined from 2,437 tonnes in 2014 to 1,969 tonnes. Although the total mussel biomass had declined, growth enabled the biomass of mussels that had attained 45mm to increase slightly from 991 tonnes to 1,030 tonnes.

The size frequency chart in figure 5 shows there has been a light settlement during the year.

South Mare Tail

- Area: 31.4 hectares
- Coverage: 32%
- Mean Density: 0.63 kg/0.1m^2
- Total Stock: 632 tonnes
- Stock ≥ 45mm: 197 tonnes

The South Mare Tail bed was surveyed on October 11th. Samples were taken from every fourth "hit", producing 63 samples from six transects. Figure 6 shows the mussel size frequency within the population taken from these samples.

The recent survey found that the area of this bed had declined from 35.5 hectares to 31.4 hectares. A light settlement of mussel seed was observed to have settled among washed-out cockles in gullies to the north of the bed, though, that could potentially see the bed expand during the coming year. Within the bed the coverage of mussels had increased from 28% to 32% but their mean density had declined from 0.78 kg/0.1m^2 to 0.63 kg/0.1m^2. From these figures the total biomass of mussels in the bed was calculated to be 632 tonnes compared to 782 tonnes the previous year. During the same period, the biomass of ≥45mm mussels had declined from 214 tonnes to 197 tonnes.

The mussel size frequency in figure 6 shows there had been a moderate settlement of seed on this bed during the year.

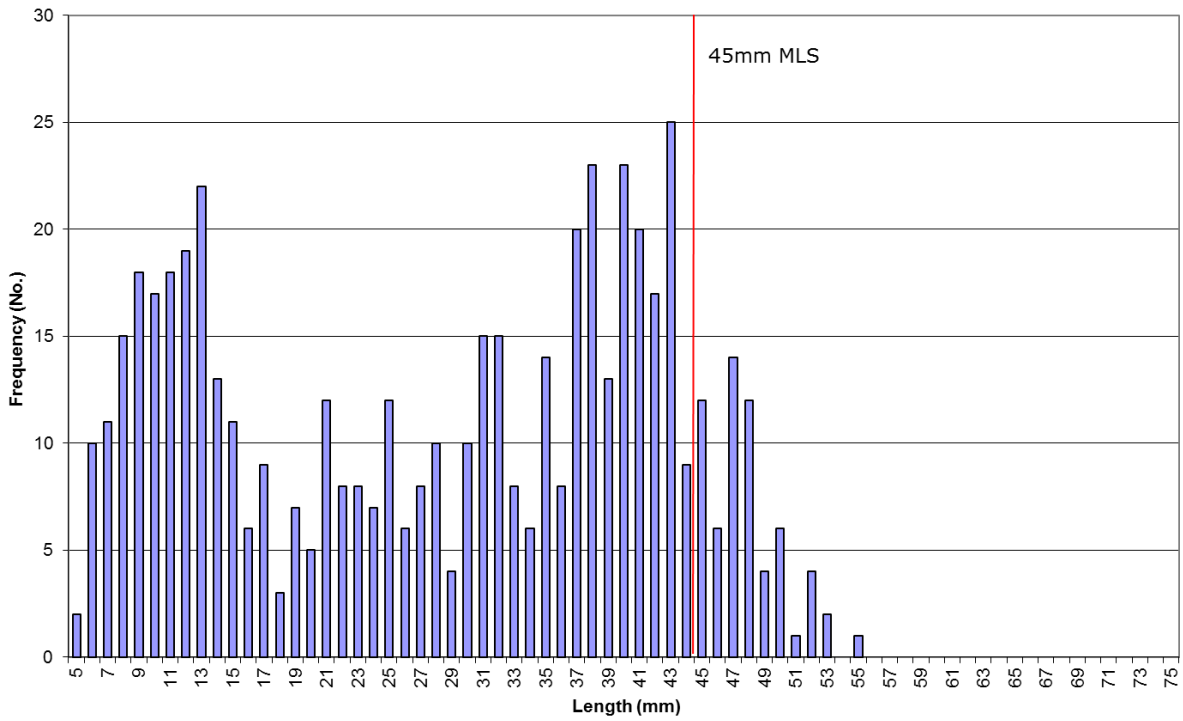

Figure 6 - Mussel size frequency on South Mare Tail - October 2015

East Mare Tail

- Area: 5.7 hectares
- Coverage: 38%
- Mean Density: 0.37 kg/0.1m^2
- Total Stock: 79 tonnes
- Stock ≥ 45mm: 26 tonnes

The East Mare Tail bed was surveyed on October 31st. Samples were collected from every third "hit", resulting in 35 samples being taken from two transects. Figure 7 shows the size distribution of the mussels collected from the samples.

During the last decade this bed has attracted little settlement, resulting in a declining, ageing population. The recent survey found the population of older mussels had declined further, but the bed had benefitted from a light recruitment of mussel seed that had settled among patches of ridged-out cockles and shells. These changes helped the area of the bed increase from 4.7 hectares to 5.7 hectares. Within this area the settlement of seed had helped the mussel coverage increase from 26% to 38%, but the loss of larger mussels caused the patch density to decline from 0.41 kg/0.1m^2 to 0.37 kg/0.1m^2. From

these figures the total biomass of mussels in the bed was calculated to have increased from 4.7 hectares to 5.7 hectares.

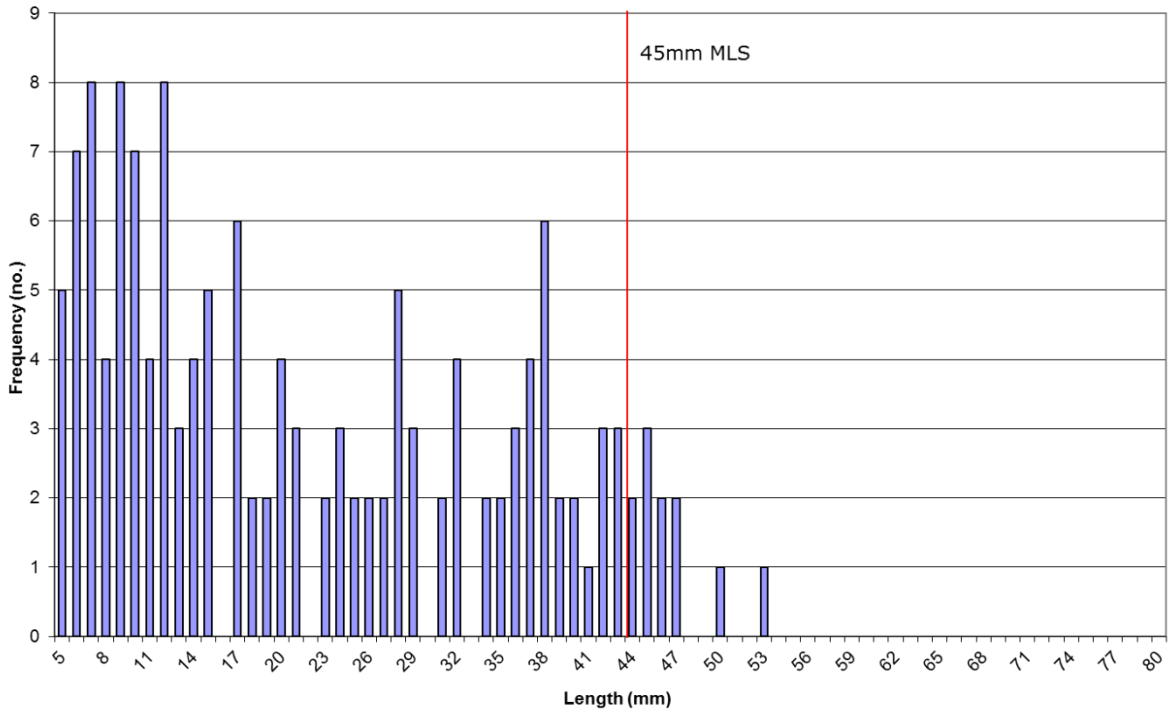

Figure 7 - Mussel size frequency on East Mare Tail – October 2015

West Mare Tail

Main bed

- Area: 13.0 hectares
- Coverage: 32%
- Mean Density: 0.51kg/0.1m^2
- Total Stock: 212 tonnes
- Stock ≥ 45mm: 64 tonnes

Extended area

- Area: 4.2 hectares
- Coverage: 47%
- Mean Density: 0.13kg/0.1m^2
- Total Stock: 27 tonnes
- Stock ≥ 45mm: 0 tonnes

The West Mare Tail bed was surveyed on October 29th. During this survey the bed was found to have extended northwards during the year as a result of mussel seed settling amongst ridged out cockles and shells. Because this area was different in character to the main bed, it was surveyed separately. During these surveys, samples were collected from every fourth "hit", producing 34 samples from three transects within the main bed and 17 samples from a single transect in the new area. The size frequency of the mussels found in these two areas can be seen in figure 8.

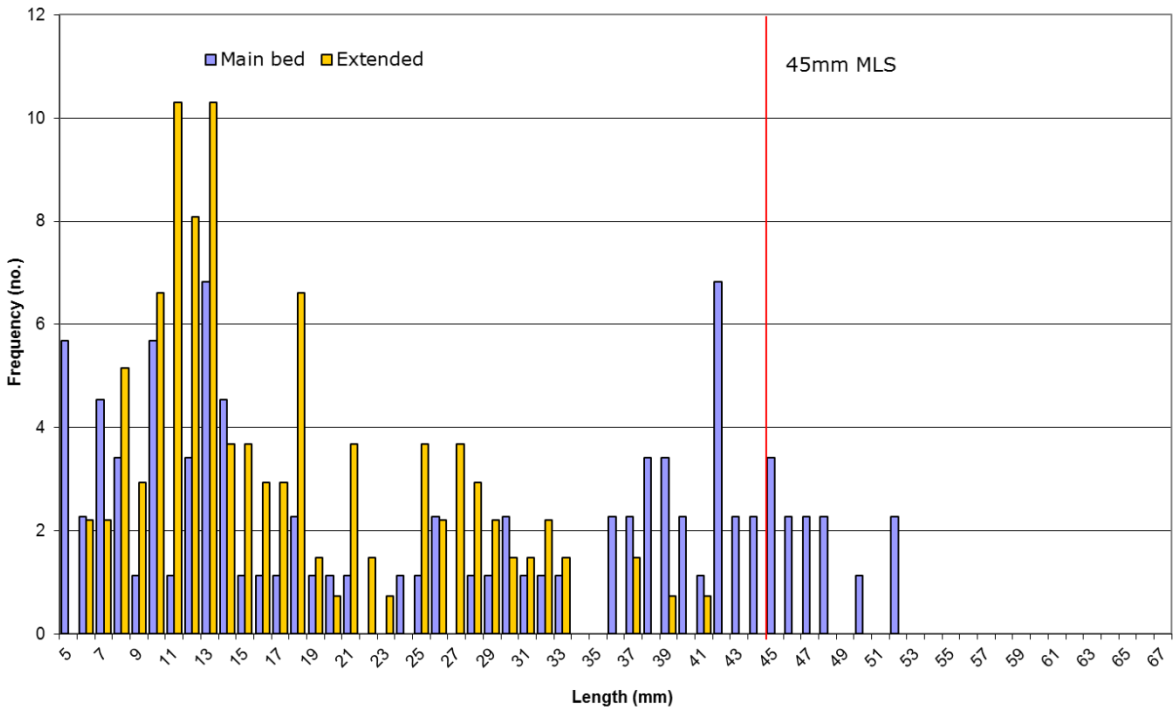

Figure 8 - Mussel size frequency on West Mare Tail – October 2015

Although this bed was first identified and surveyed in 2014, the size of the mussels during that survey suggested the bed had settled prior to 2013. The recent survey found the main part of the bed had increased in area from 11.4 hectares to 13.0 hectares, but within this area there was evidence that some of the mussels had died. This resulted in the coverage declining from 37% to 32% and the mean density from 0.80kg/0.1m^2 to 0.51kg/0.1m^2. From these figures the total mussel biomass within this part of the bed was calculated to have declined from 342 tonnes to 212 tonnes. Growth helped the biomass of harvestable sized mussels increase from 48 tonnes to 64 tonnes.

The area of recently settled seed was found to cover 4.2 hectares. Within this area the mussels had a good coverage of 47%, but due to their small size their mean density was only 0.13kg/0.1m^2. From these figures their biomass was calculated to be 27 tonnes, none of which had reached 45mm.

The Gat Beds

The Gat sand supports an extensive area of mussels that for survey purposes is divided into three beds (see figure 9). 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 suggest this decline is due to poor recruitment during this period, 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. The recent survey found there had a been a light settlement of seed on these beds during the previous year, but this was not thought to be sufficient to offset recent mortalities.

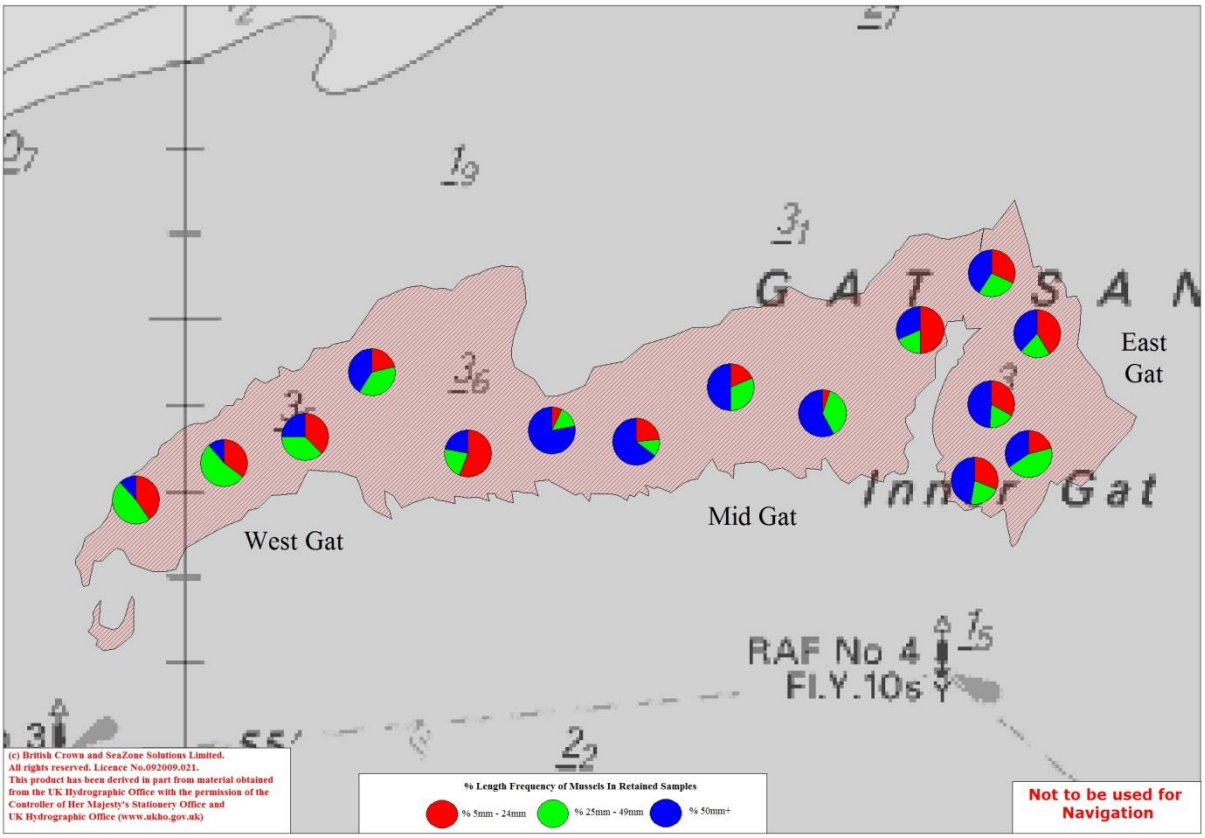

Figure 9 - Mussel size distributions on the Gat mussel beds – October 2015

West Gat

- Area: 35.1 hectares
- Coverage: 35%
- Mean Density: 0.68kg/0.1m^2
- Total Stock: 828 tonnes
- Stock ≥ 45mm: 513 tonnes

The West Gat bed was surveyed on October 28th. Samples were taken from every fifth "hit", producing 58 samples from six transects. Figure 10 shows the size frequency of mussels found in the samples taken during this survey.

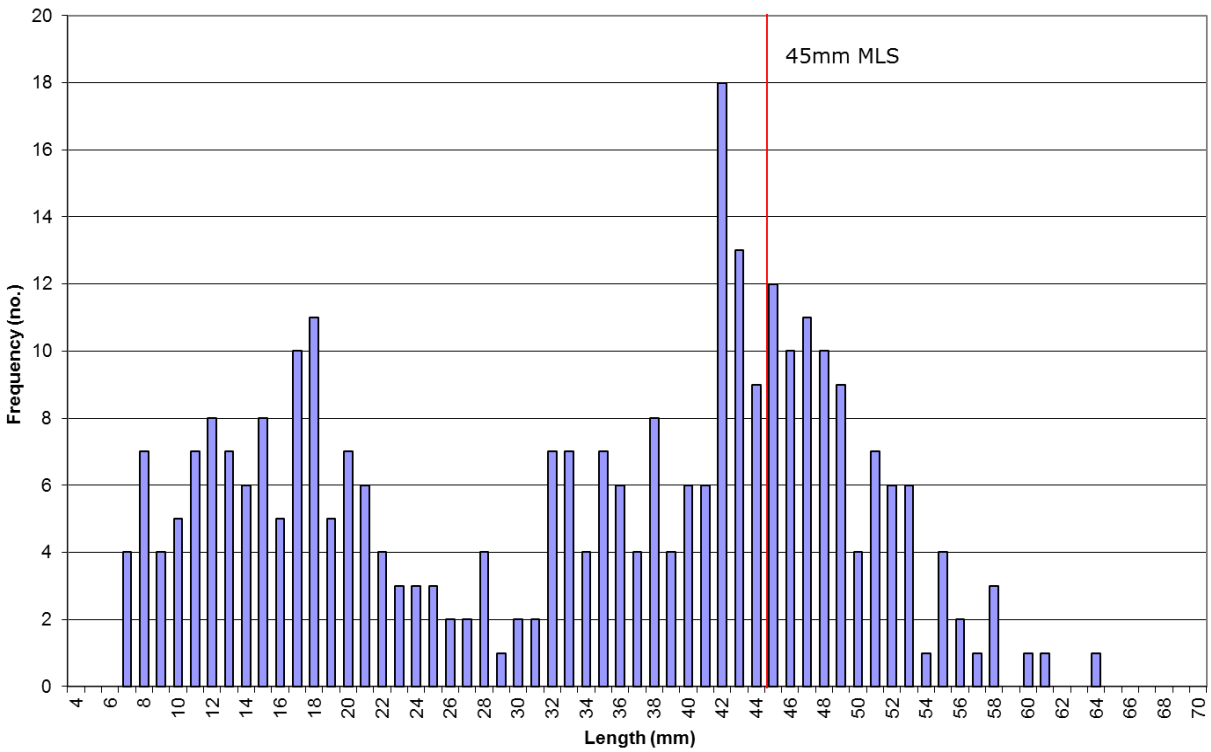

Figure 10 - Mussel size frequency on West Gat – October 2015

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. The 2015 survey found this was particularly noticeable along the far western tip of this bed. Whereas previous surveys had found this area still supported low densities of mussels, by 2015 these had disappeared causing the tip of the bed to fragment. The loss of this area, and further patches along the southern edge of the bed, resulted in the overall area of the

bed declining from 43 hectares in 2014 to 35.1 hectares. There had been a light settlement of seed within the beds that helped the mussel coverage increase from 30% to 35% and the mean density from 0.54kg/0.1m^2 to 0.68kg/0.1m^2. From these figures the total mussel biomass on this bed was calculated to have increased from 699 tonnes to 828 tonnes. Growth enabled the biomass of harvestable sized mussels to increase from 401 tonnes to 513 tonnes.

Mid Gat

- Area: 26.6 hectares
- Coverage: 22%
- Mean Density: 0.39kg/0.1m^2
- Total Stock: 225 tonnes
- Stock ≥ 45mm: 190 tonnes

The Mid Gat was surveyed on October 28th. Samples were collected from every third "hit", producing 41 samples from four transects. Figure 11 shows the size frequency of the mussels collected in these samples.

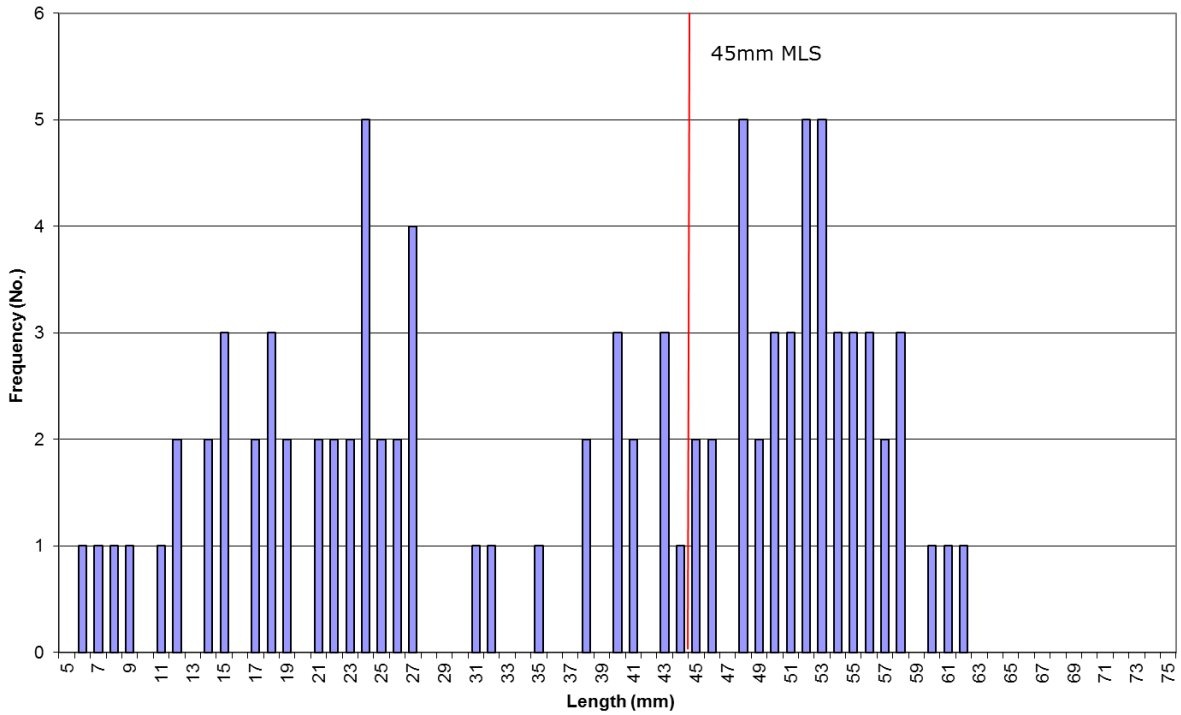

Figure 11 - Mussel size frequency on Mid Gat – October 2015

The survey found the area of the bed had increased from 24.1 hectares in 2014 to 26.6 hectares. There had been a light settlement within this area that helped the coverage increase from 13% to 22%. Because these mussels were still small, coupled with further loss of larger mussels, the mean density was found to have declined from 0.58kg/0.1m^2 to 0.39kg/0.1m^2. From these figures the total biomass of mussels on the bed was calculated to have increased from 186 tonnes to 225 tonnes. Of these, 190 tonnes were found to have attained harvestable size compared to 142 tonnes the previous year.

East Gat

- Area: 16.9 hectares
- Coverage: 40%
- Mean Density: 0.55kg/0.1m^2
- Total Stock: 373 tonnes
- Stock ≥ 45mm: 307 tonnes

The East Gat was surveyed on October 30th. Samples were taken from every fourth "hit", producing 75 samples from five transects. Figure 12 shows the size frequency of the mussels collected in these samples.

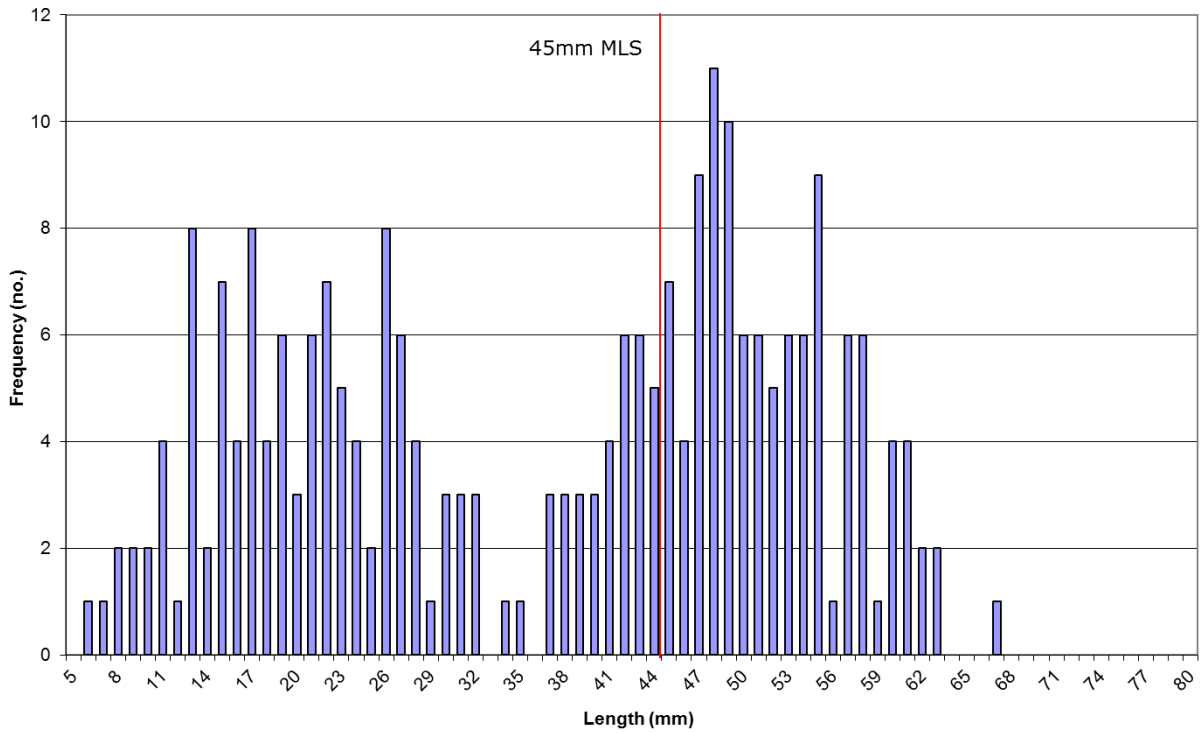

Figure 12 - Mussel size frequency on East Gat – October 2015

The area of this bed was found to have increased slightly from 16.5 hectares to 16.9 hectares. Although a light settlement of seed helped the coverage in the bed to increase from 31% to 40%, the mean density was found to have declined from 0.71kg/0.1m2 to 0.55kg/0.1m^2. From these figures the total mussel biomass on the bed was calculated to have increased slightly from 361 tonnes in 2014 to 373 tonnes. During the same period the biomass of mussels that had attained 45mm had declined slightly from 309 tonnes to 307 tonnes.

Tofts

- Area: 40.0 hectares
- Coverage: 31%
- Mean Density: 1.14 kg/0.1m^2
- Total Stock: 1,428 tonnes
- Stock ≥ 45mm: 1,305 tonnes

Because of the size of this bed, the perimeter was surveyed on October 1st and transects conducted using two teams on the following day. Samples were taken from every sixth "hit", producing 55 samples from eight transects. Figure 13 shows the mussel size distribution over the bed, while figure 14 shows the size frequency of the mussels in the samples. Both of these show an ageing population of mussels on this bed.

Since the previous survey, the area of this bed was found to have decreased from 43.1 hectares to 40.0 hectares. Although the mussel coverage within the bed had remained the same at 31%, the mean coverage had declined from 1.24 kg/0.1m^2 to 1.14 kg/0.1m^2. From these figures the total biomass of mussels on the bed was estimated to have declined from 1,638 tonnes to 1,428 tonnes. 1,305 tonnes of these had reached a size of 45mm compared with 1,346 tonnes the previous year.

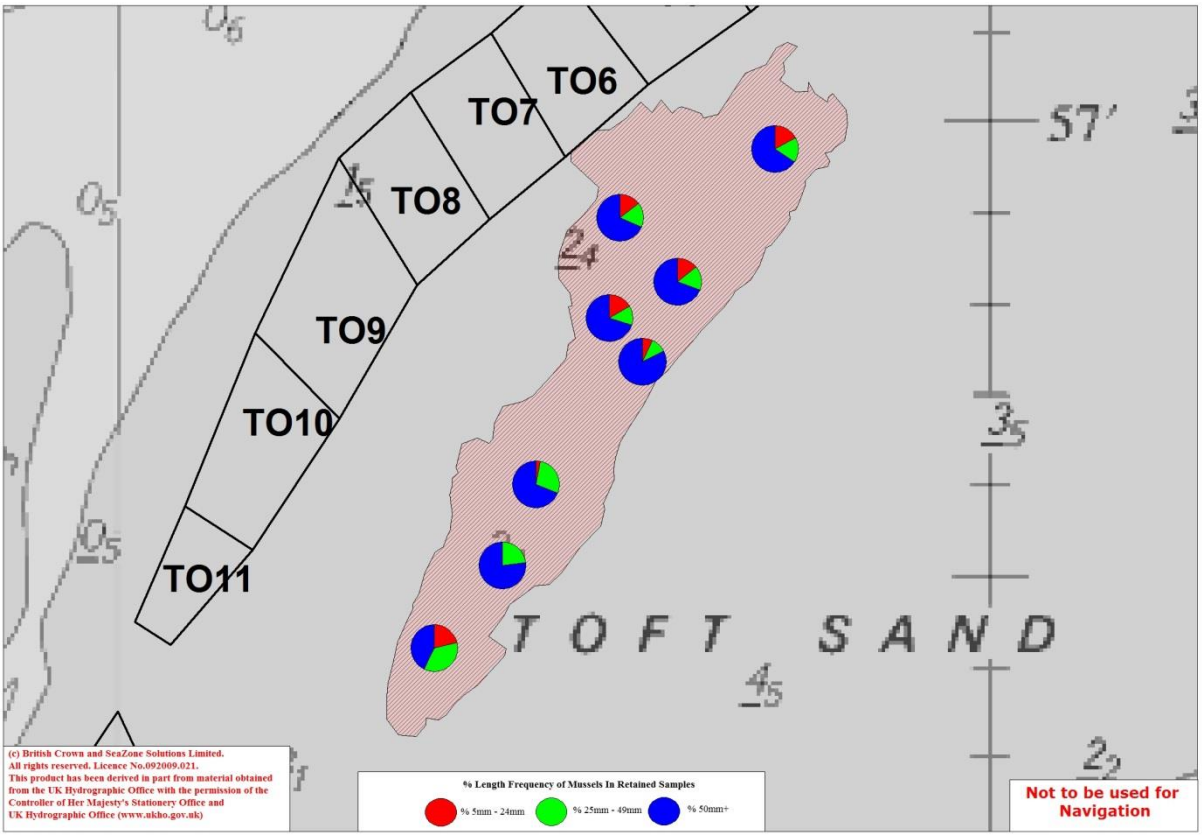

Figure 13 - Mussel size distributions on the Toft mussel bed – October 2015

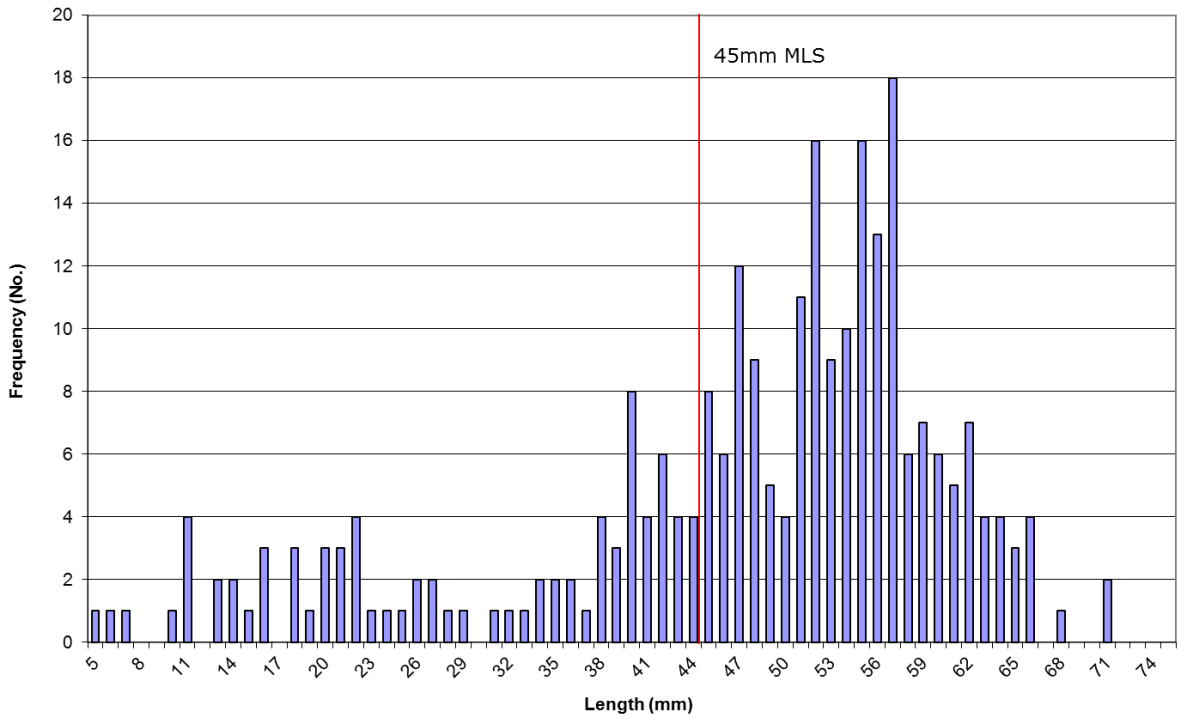

Figure 14 - Mussel size frequency on the Tofts – October 2015

Roger

- Area: 1.4 hectares
- Coverage: 33%
- Mean Density: 0.69 kg/0.1m^2
- Total Stock: 31 tonnes
- Stock ≥ 45mm: 27 tonnes

This small bed was surveyed on October 1st. Samples were collected from every fourth "hit", producing 7 samples from three shortened transects. Figure 15 shows the mussel size distribution on this bed while figure 16 shows the size frequency within the population.

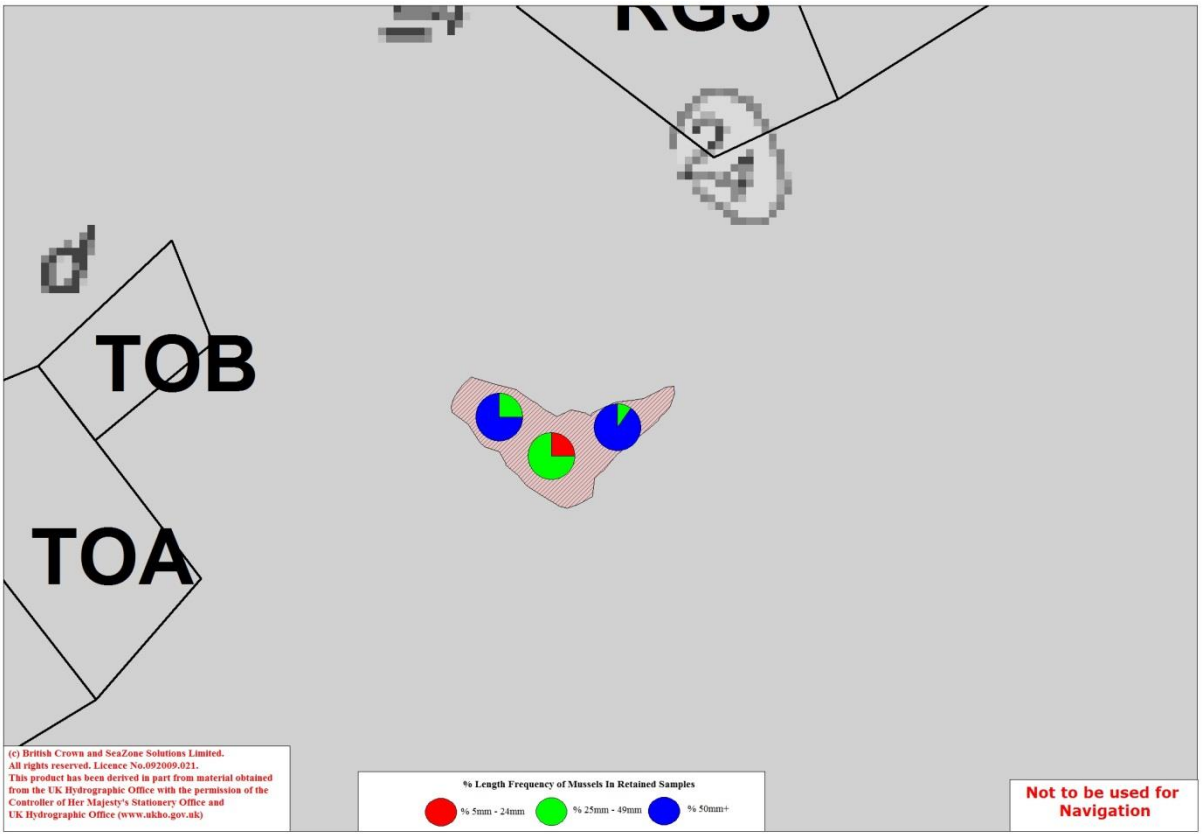

Figure 15 - Mussel size distribution on the Roger mussel bed – October 2015

Since the previous survey, the area of the bed was found to have declined from 1.6 hectares to 1.4 hectares. Within this area the coverage of mussels was found to have increased from 25% to 33% while the mean density had remained the same at 0.69 kg/0.1m^2. From these figures the total biomass on the bed was calculated to have

increased slightly from 28 tonnes to 31 tonnes. Of these, 27 tonnes were found to have reached a size of 45mm compared to 18 tonnes the previous year.

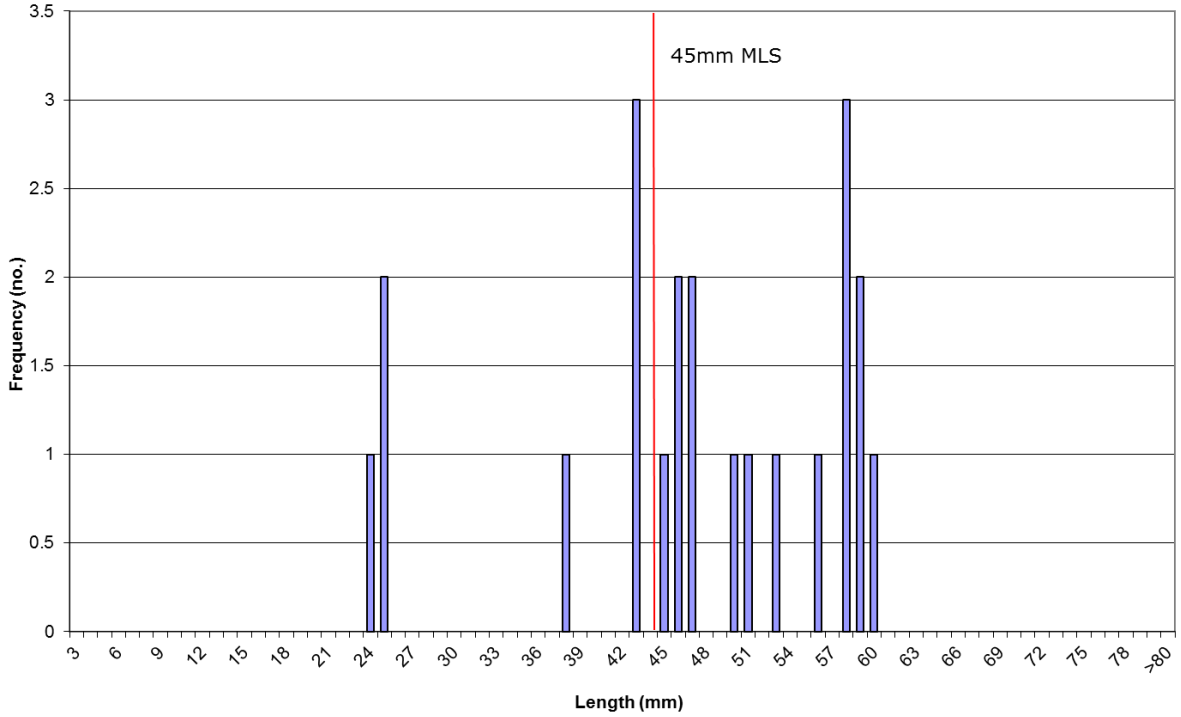

Figure 16 - Mussel size frequency on the Roger – October 2015

Herring Hill

- Area: 24.7 hectares
- Coverage: 37%
- Mean Density: 0.82 kg/0.1m^2
- Total Stock: 748 tonnes
- Stock ≥ 45mm: 171 tonnes

The Herring Hill bed was surveyed on September 30th. Samples were taken from every fourth "hit", producing 62 samples from five transects. Figure 17 shows the mussel size distribution across the bed, while figure 18 shows the size frequency of the mussels collected in the samples. The area of the bed was found to have declined slightly from 25.1 hectares to 24.7 hectares. Within this area the coverage was found to have declined slightly from 38% to 37%, while the mean density had increased slightly from 0.79 kg/0.1m^2 to 0.82 kg/0.1m^2. From these figures the mussel biomass on this bed was

calculated to have increased from 710 tonnes to 748 tonnes. Of these, growth had enabled the biomass of harvestable mussels to increase from 96 tonnes to 171 tonnes.

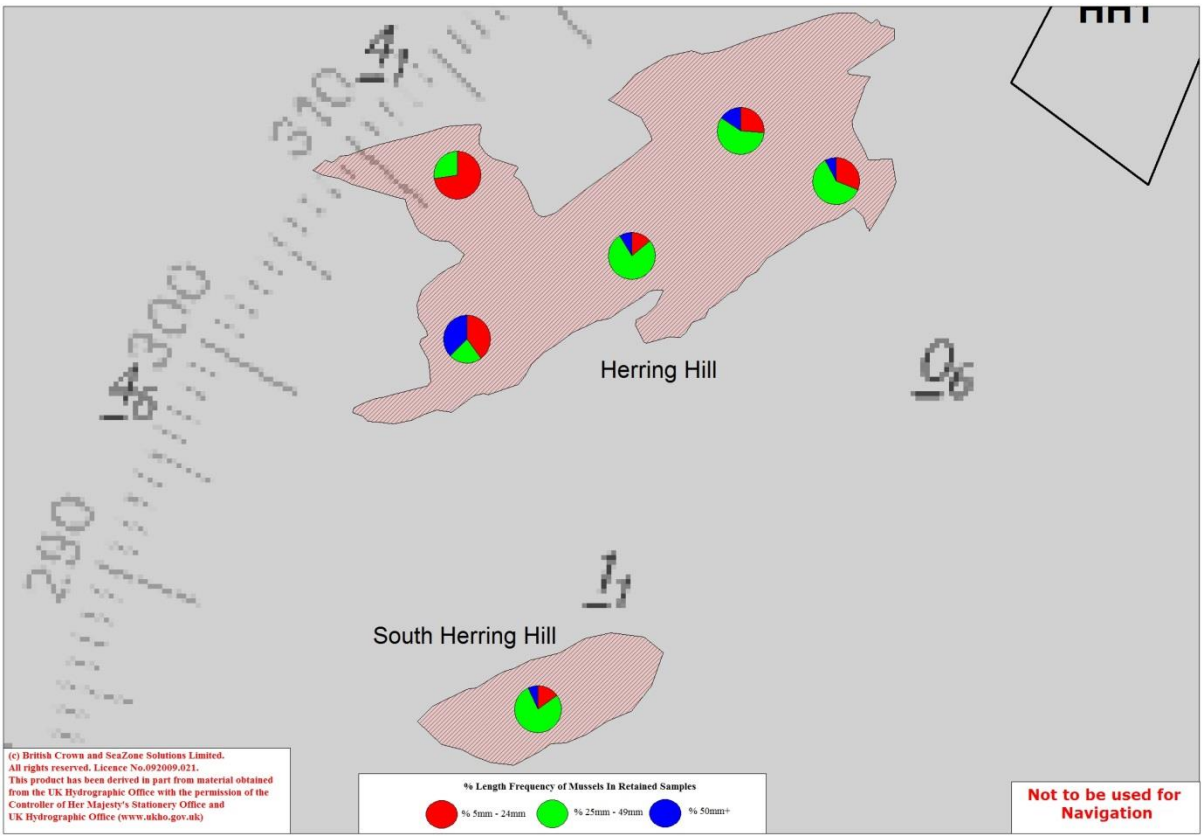

Figure 17 - Mussel size distribution on the Herring Hill mussel beds – October 2015

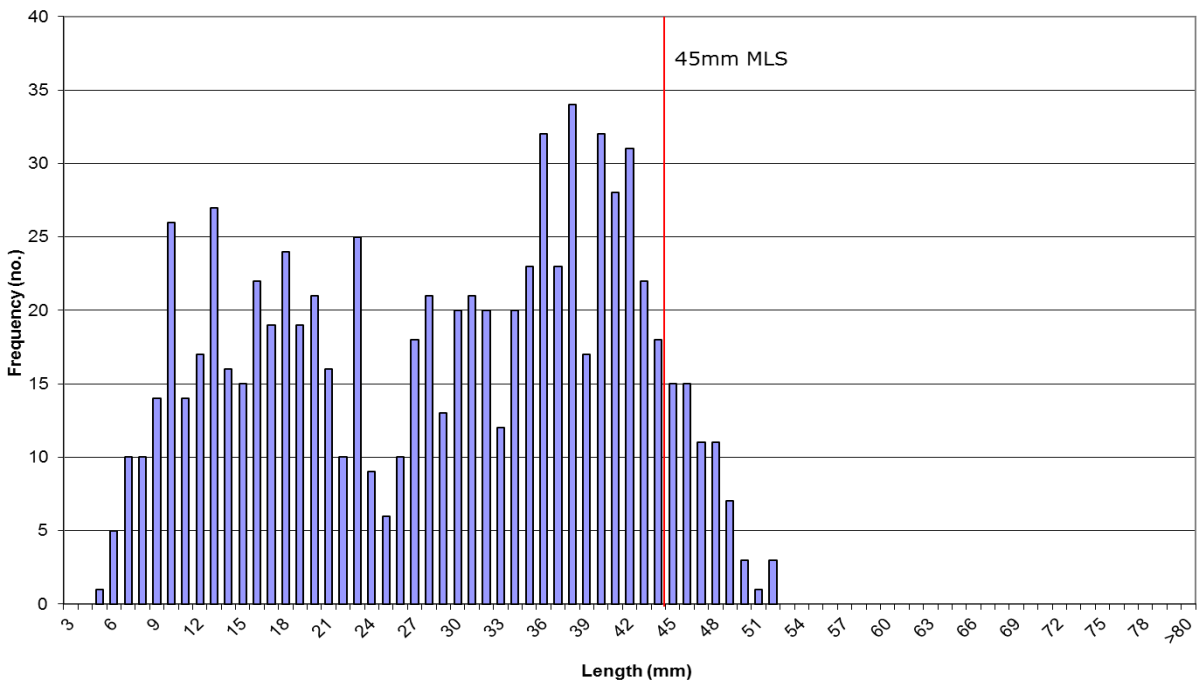

Figure 18 - Mussel size frequency on Herring Hill - October 2015

South Herring Hill

- Area: 4.3 hectares
- Coverage: 23%
- Mean Density: 0.43 kg/0.1m^2
- Total Stock: 41 tonnes
- Stock ≥ 45mm: 7 tonnes

The South Herring Hill bed was surveyed on October 29th, during which samples were taken from every third "hit", producing 12 samples from a single transect. The location of the bed is shown in figure 17. Although this bed is close to the main Herring Hill bed, a deep channel runs between the two making access between them too dangerous to attempt on foot. Although there had been previous suspicions that a small bed was present at this location, no attempt was made to survey it prior to 2014 due to these difficulties. For these surveys, access was made from the West Mare Tail bed rather than from Herring Hill.

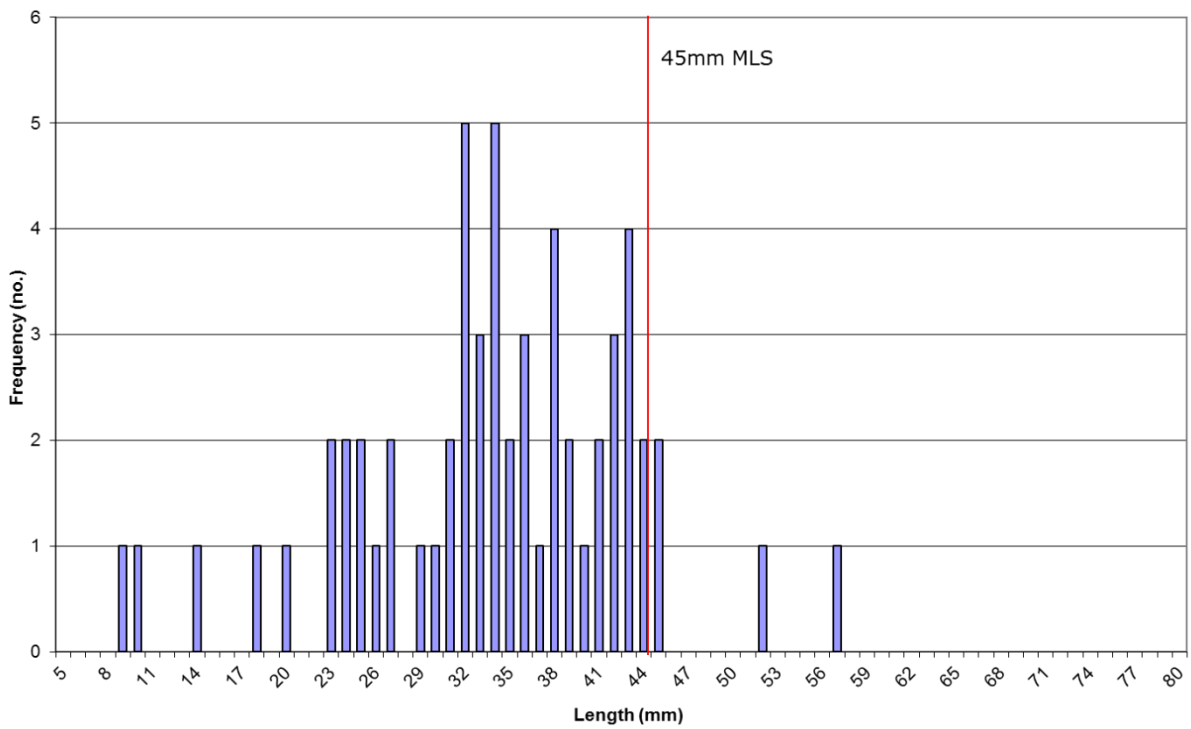

Figure 19 - Mussel size frequency on South Herring Hill - October 2015

Between the two surveys the area of the bed was found to have increased from 3.9 to 4.3 hectares, but the coverage had declined from 38% to 23% and the mean density

from 0.49 kg/0.1m^2 to 0.43 kg/0.1m^2. From these figures the total biomass of mussels on this bed was calculated to have declined from 71 tonnes to 41 tonnes. The biomass of mussels that had attained a size of 45mm had declined from 15 tonnes to 7 tonnes.

Main End

- Area: 6.6 hectares
- Coverage: 19%
- Mean Density: 0.45 kg/0.1m^2
- Total Stock: 55 tonnes
- Stock ≥ 45mm: 45 tonnes

The Main End bed was surveyed on October 17th, during which samples were collected from every second "hit", producing 28 samples from two transects. Figures 20 and 21 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 survey found that the area of the bed had not changed from the 6.6 hectares recorded the previous year, but the coverage had declined from 29% to 19% and the mean density from 0.74 kg/0.1m^2 to the 0.45 kg/0.1m^2. From these figures the total mussel biomass in the bed was calculated to have declined from 141 tonnes to 45 tonnes. Of these, 45 tonnes were estimated to have attained 45mm compared to 111 tonnes the previous year.

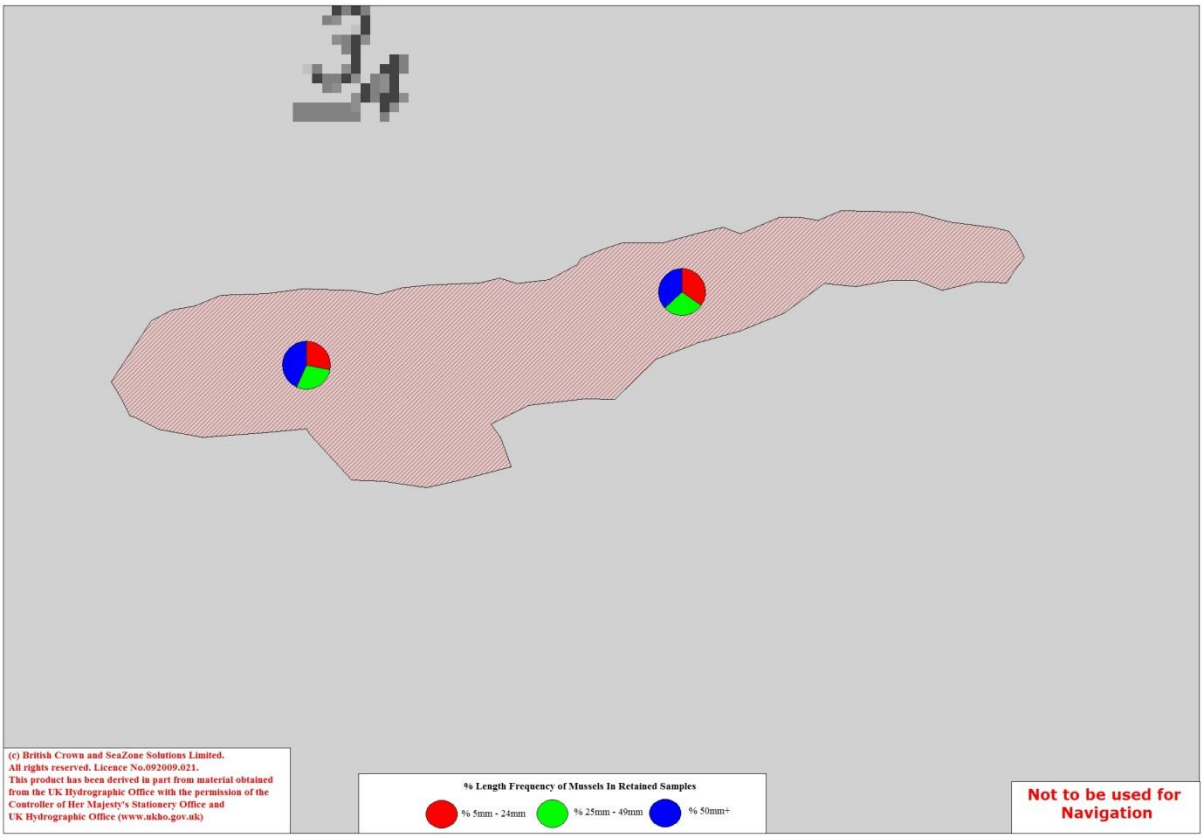

Figure 20 - Mussel size distribution on the Main End mussel bed – October 2015

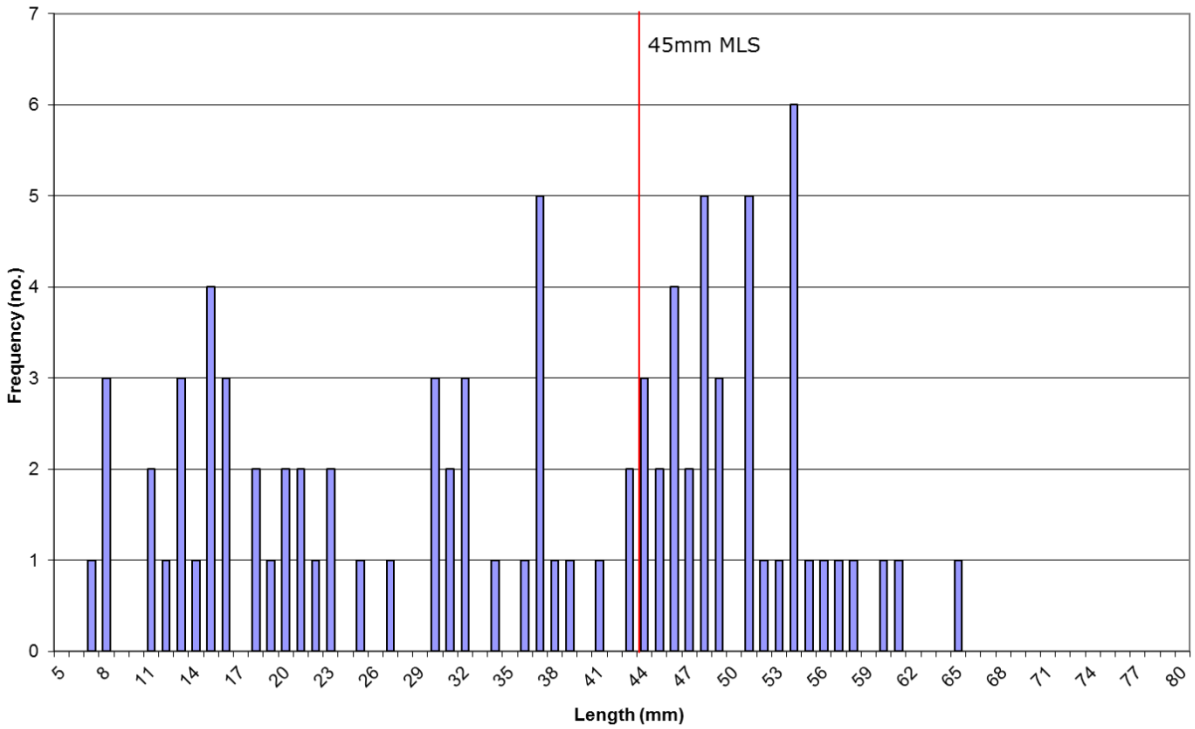

Figure 21 - Mussel size frequency on Main End - October 2015

Holbeach

- Area: 13.7 hectares
- Coverage: 47%
- Mean Density: 0.43 kg/0.1m^2
- Total Stock: 280 tonnes
- Stock ≥ 45mm: 141 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 spat. Like most of the other inter-tidal beds, it has suffered from high mortalities in recent years.

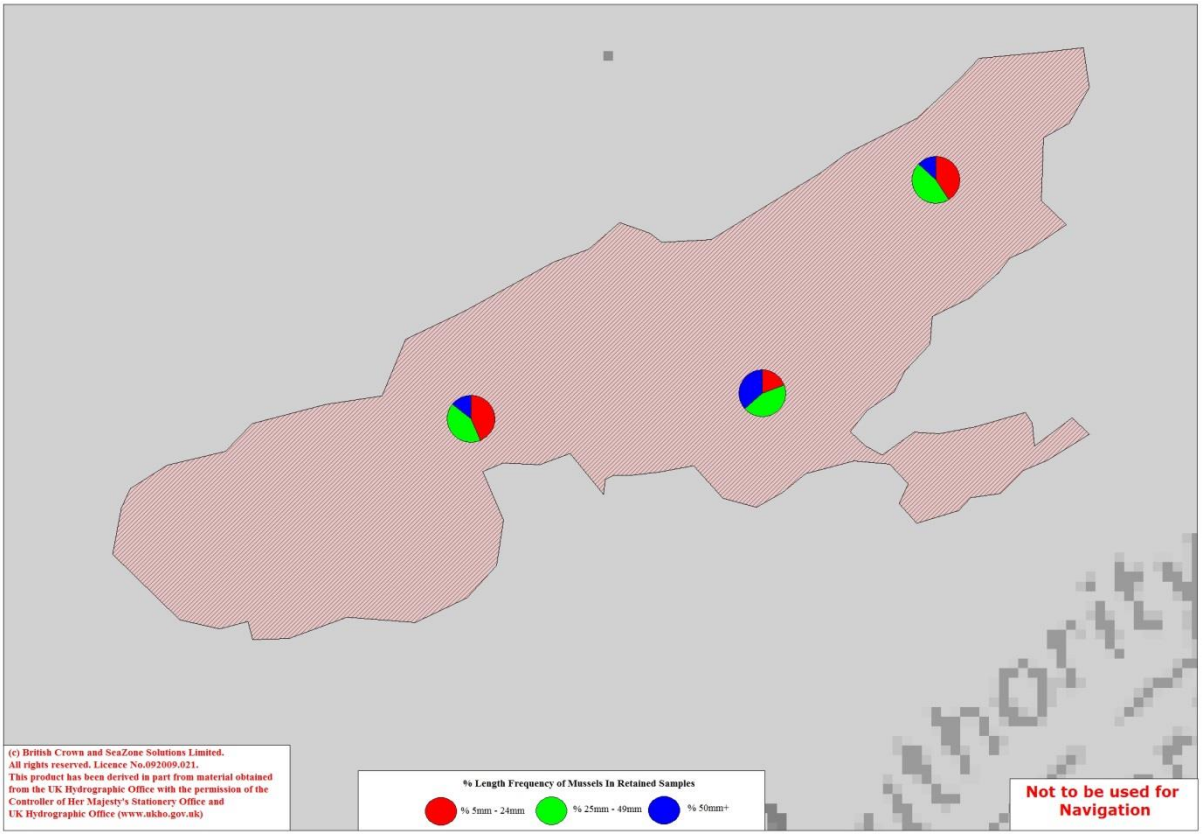

Figure 22 - Mussel size distribution on the Holbeach mussel bed – October 2015

It was surveyed on October 3rd, during which samples were collected every fourth "hit", generating 53 samples from three transects. Figures 22 and 23 show the size

distribution of mussels across the bed and the mussel size frequency within the population.

The survey found the area of the bed had increased from 12.4 hectares in 2014 to 13.7 hectares. Although the mussel coverage had increased from 37% to 47%, high mortality had caused most of the mussel clumps to thin-out. This caused the mean density within the patches to decline from 0.66 kg/0.1m^2 to 0.43 kg/0.1m^2. From these changes the total mussel biomass on the bed was calculated to have declined from 303 tonnes to 280 tonnes. Mussel growth helped the biomass of harvestable mussels increase from 102 tonnes to 141 tonnes.

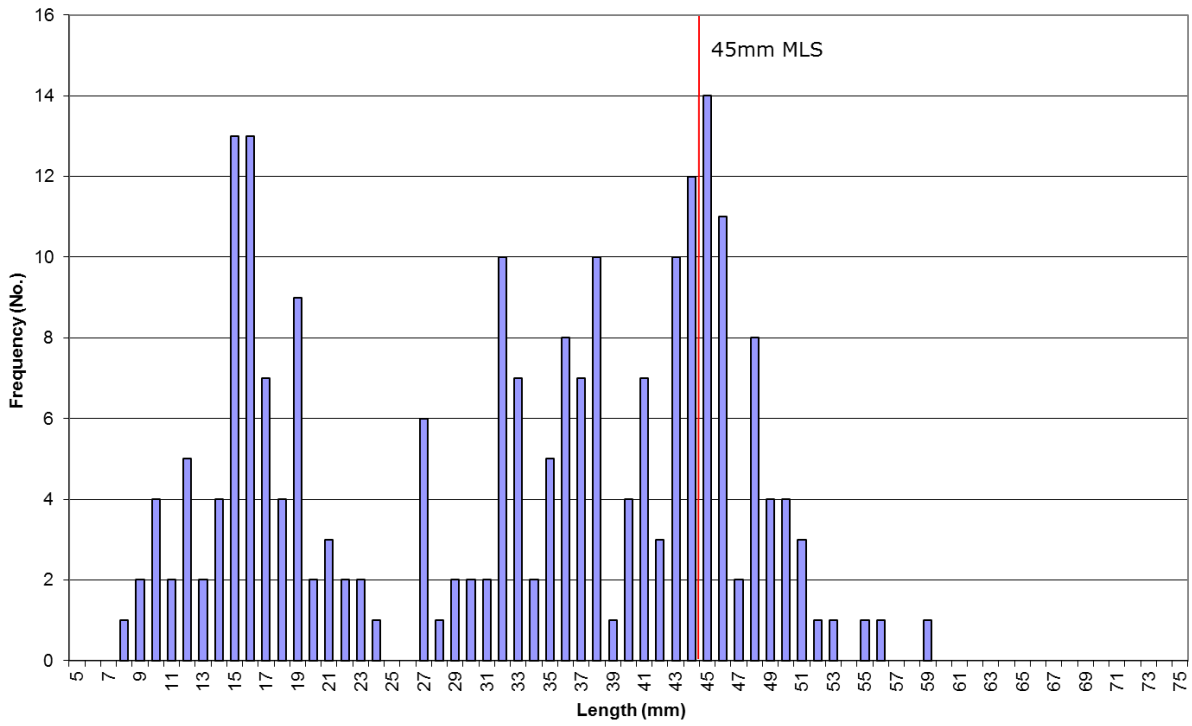

Figure 23 - Mussel size frequency on Holbeach – October 2015

Trial Bank

- Area: 28.2 hectares
- Coverage: 33%
- Mean Density: 0.73 kg/0.1m^2
- Total Stock: 695 tonnes
- Stock ≥ 45mm: 271 tonnes

The Trial Bank mussel bed was originally established in 2001 after mussel spat settled on cockle shells. The bed 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 has continued to decline and now supports only low densities of mussels. In 2015 the bed was surveyed on September 29th, during which samples were collected from every fourth "hit", producing 52 samples from five transects. Figures 24 and 25 show the size distribution of mussels across the bed and the mussel size frequency within the population.

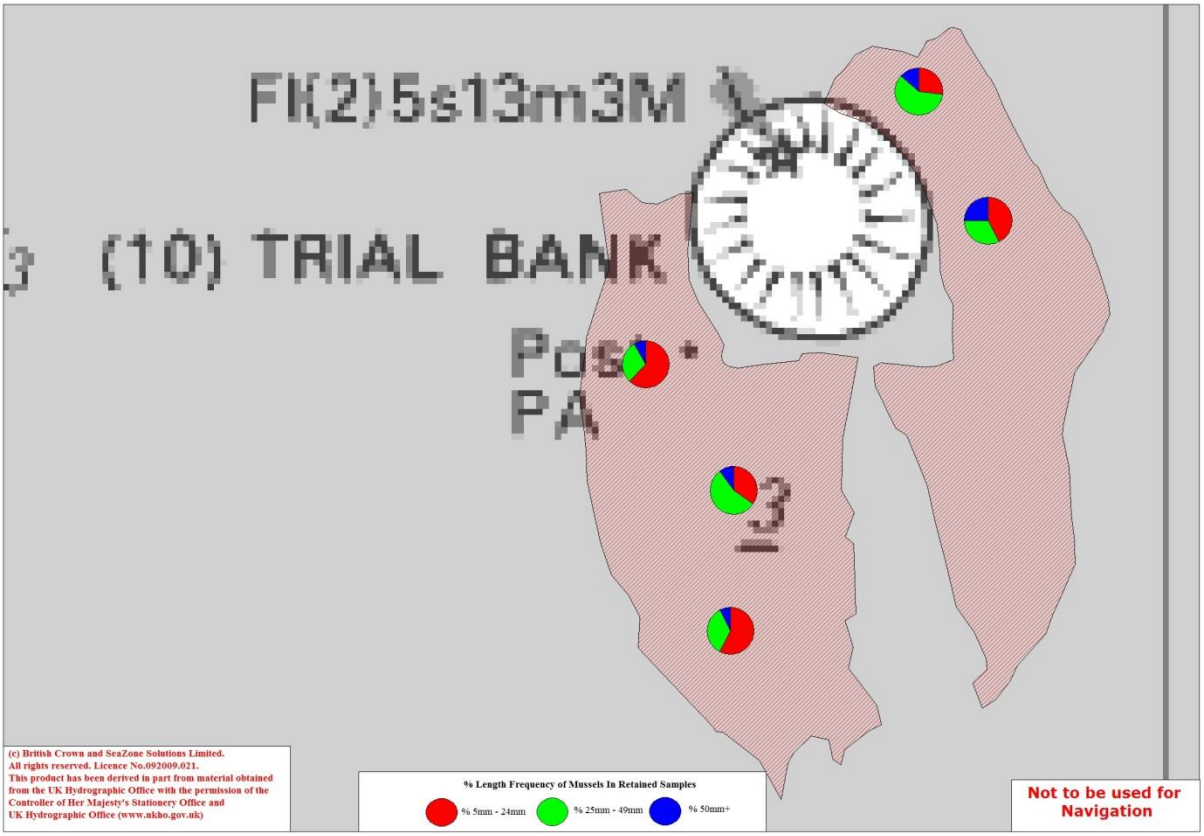

Figure 24 - Mussel size distribution on the Trial Bank mussel bed – September 2015.

The inclusion within the survey area of part of the south-eastern edge of the bed that had not been included the previous year helped the bed increase in area from 24.9 hectares to 28.2 hectares. Within this area the mussel coverage was found to have remained unchanged at 33% but the mean density had declined from 0.85 kg/0.1m^2 to 0.73 kg/0.1m^2. From these figures the total biomass of mussels in the bed was

calculated to have increased slightly from 686 tonnes to 695 tonnes. Individual mussel growth helped the biomass of harvestable sized mussels increase from 137 tonnes to 271 tonnes.

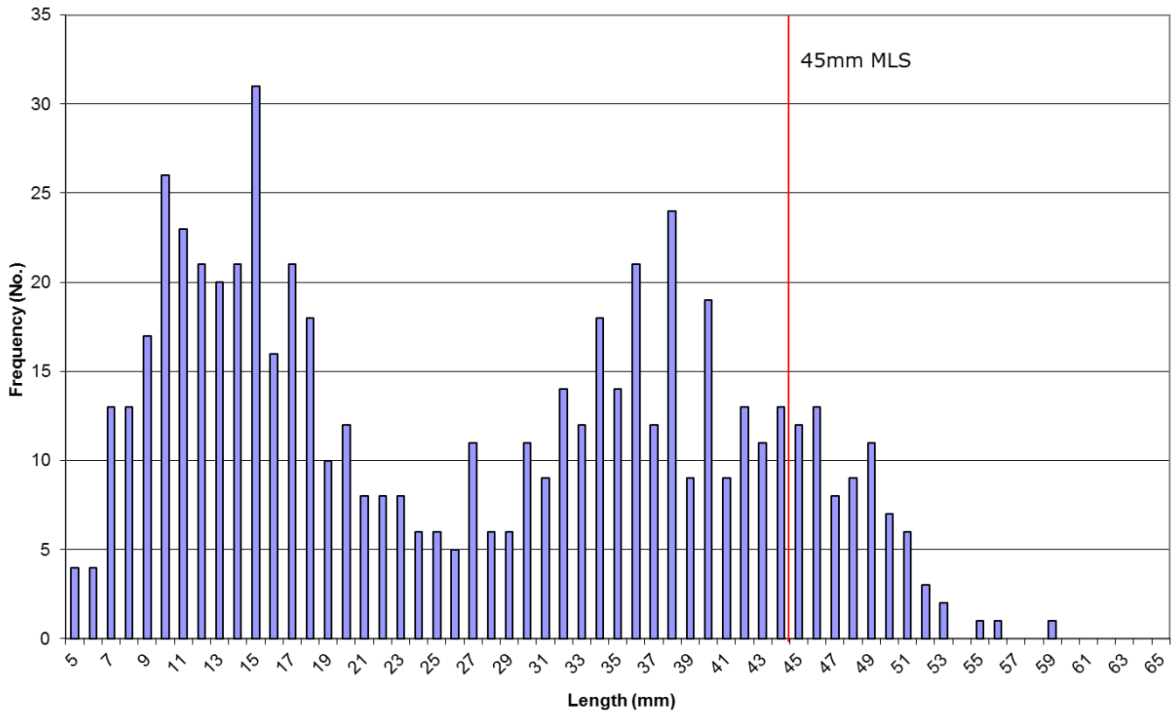

Figure 25 - Mussel size frequency on Trial Bank - September 2015

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 26 shows the mussel size distribution over these beds following the 2013 surveys.

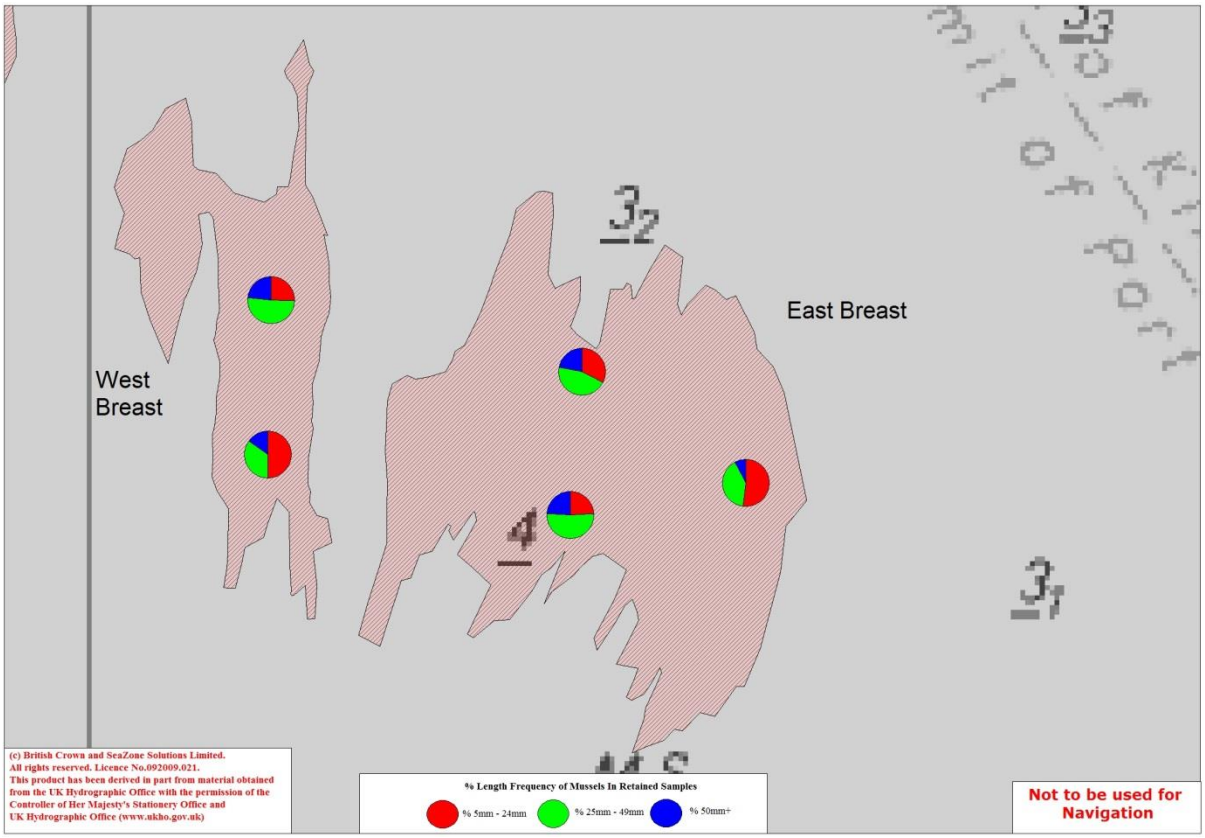

Figure 26 - Mussel size distribution on the Breast mussel beds – October 2015

West Breast

- Area: 12.6 hectares
- Coverage: 17%
- Mean Density: 1.24kg/0.1m^2
- Total Stock: 259 tonnes
- Stock ≥ 45mm: 118 tonnes

The West Breast bed was surveyed on October 27th, during which samples were collected from every third "hit", producing 14 samples from two transects. Figure 27 shows the mussel size frequency within the population taken from these samples.

The survey found that the area of the bed had declined from 15.4 hectares in 2014 to 12.6 hectares. Within this area, though, the mussel coverage had increased from 12% to 17% and the mean density from 0.91 kg/0.1m^2 to 1.24 kg/0.1m^2. From these figures the total biomass of mussels on this bed was calculated to have increased from 162 tonnes to 259 tonnes. The biomass of mussels that had reached harvestable size had increased from 55 tonnes to 118 tonnes.

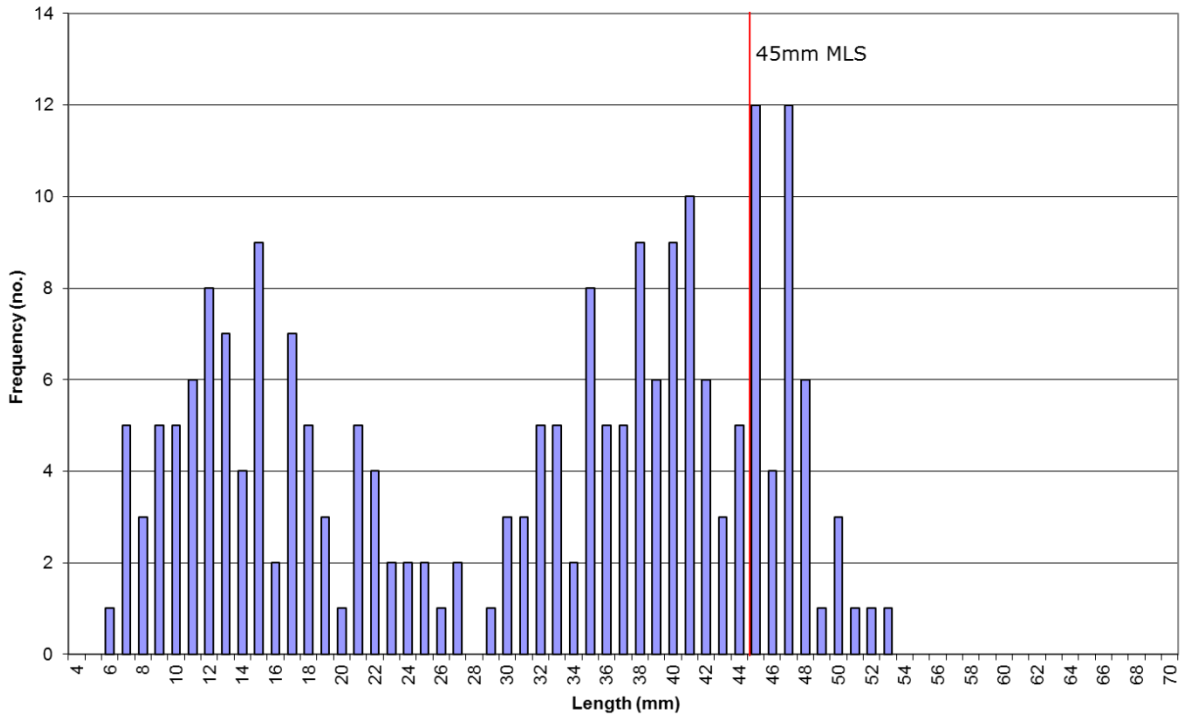

Figure 27 - Mussel size frequency on West Breast – October 2015

East Breast

- Area: 30.4 hectares
- Coverage: 25%
- Mean Density: 1.07 kg/0.1m^2
- Total Stock: 804 tonnes
- Stock ≥ 45mm: 352 tonnes

The East Breast bed was surveyed on October 27th, during which samples were collected from every fourth "hit", producing 27 samples from three transects. Figure 28, shows the size frequency of mussel in the population on this bed.

The area of the bed was found to have declined from 31.7 hectares in 2014 to 30.4 hectares. Within the bed there had been a slight decline to the mussel stocks resulting in minor changes to the coverage and mean density. The coverage was found to have declined from 26% to 25% and the mean density from 1.08 kg/0.1m^2 to 1.07 kg/0.1m^2. From these figures the total biomass of mussels on this bed was calculated to have declined from 893 tonnes to 804 tonnes. Growth had enabled the biomass of harvestable sized mussels to increase from 247 tonnes to 352 tonnes.

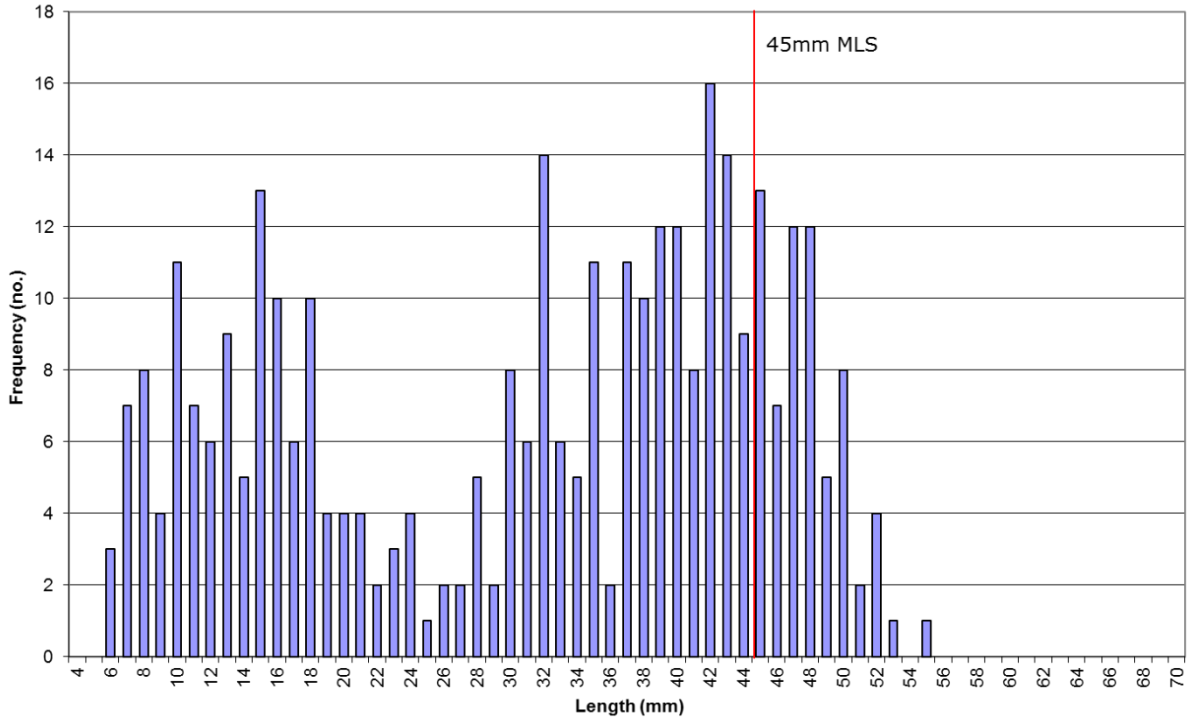

Figure 28 - Mussel size frequency on East Breast – October 2015

East Scotsman's Sled

- Area: 49.5 hectares
- Coverage: 19%
- Mean Density: 0.56 kg/0.1m^2
- Total Stock: 518 tonnes
- Stock ≥ 45mm: 256 tonnes

The Scotsman's Sled bed was surveyed on October 16th, during which samples were collected from every fourth "hit", producing 42 samples from six transects. Figures 29 and 30 show the mussel size distribution over the bed and the mussel size frequency within the population taken from these samples.

Scotsman's Sled is one of the few beds found to have improved significantly this year. The northern part of this bed had disappeared following heavy fishing activity in 2006, which in addition to harvesting the mussels had also flattened out the gullies that the mussels had been situated in. Recovery following this fishery was slow, with no signs of recolonization until 2013, when a light settlement of seed was found to have settled among ridged-out cockles. The recent survey found there had been further light

settlements of seed in this area and shallow gullies were beginning to reform. Although mussel coverage in this recolonised area is still sparse, it was judged sufficient to include within the perimeter of the bed. This has helped the bed to increase in size from 25 hectares in 2012 to 36.9 hectares in 2014 and 49.5 hectares in 2015. Because of the inclusion of this sparsely covered area, the average coverage was found to have declined from 24% to 19%. The mean density was, nevertheless, found to have increased from 0.33 kg/0.1m^2 to 0.56 kg/0.1m^2. From these figures the total biomass of mussels on the bed was calculated to have increased from 291 tonnes to 518 tonnes. Growth had enabled the biomass of marketable sized mussels to increase from 78 tonnes to 256 tonnes.

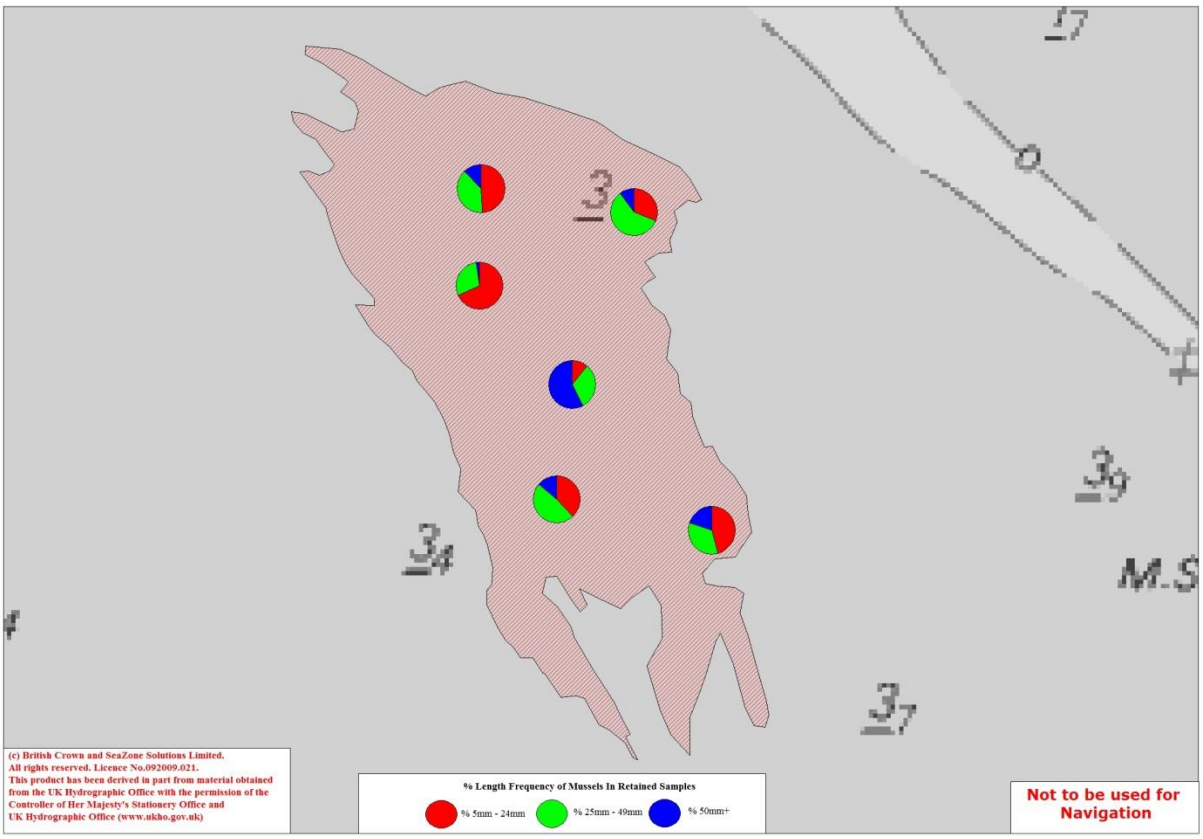

Figure 29 - Mussel size distribution on the East Scotsman's Sled mussel bed – October 2015

The lengthy period that it has taken 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.

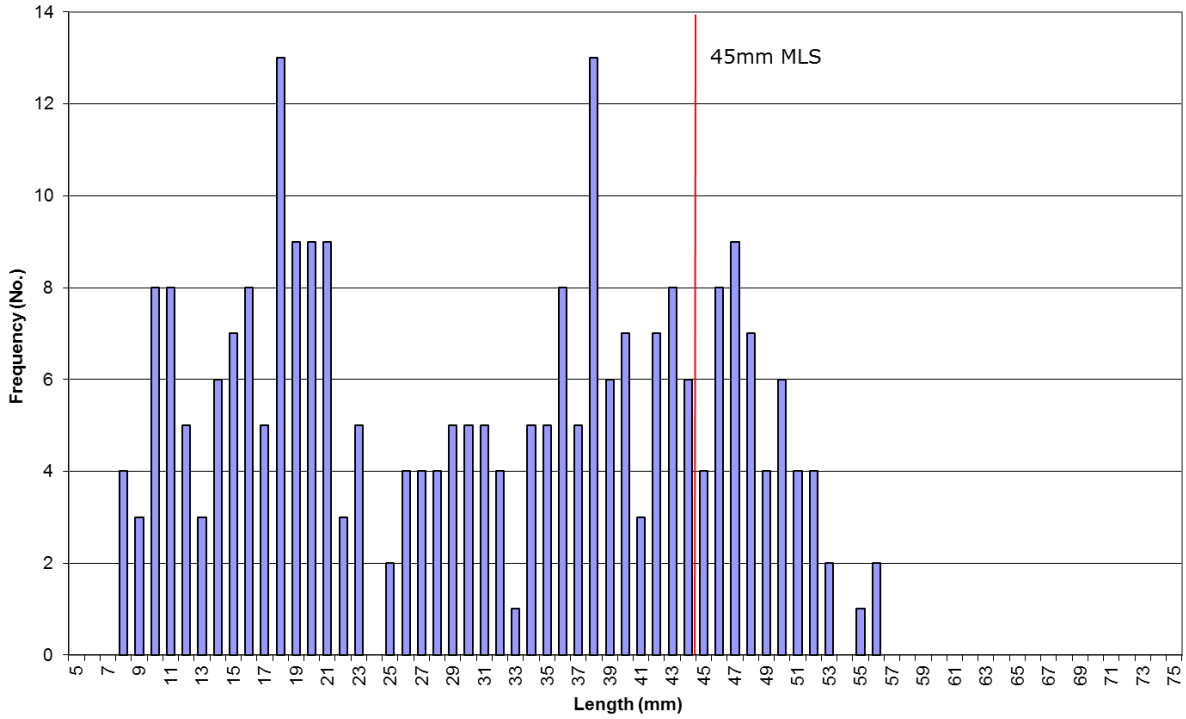

Figure 30 - Mussel size frequency on East Scotsman's Sled – October 2015

Pandora

- Area: 7.7 hectares
- Coverage: 27%
- Mean Density: 0.58 kg/0.1m^2
- Total Stock: 122 tonnes
- Stock ≥ 45mm: 102 tonnes

The Pandora bed was surveyed on October 26th, during which samples were collected from every second "hit", producing 36 samples from two transects. Figure 31 shows the mussel size distribution within the bed while figure 32 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.

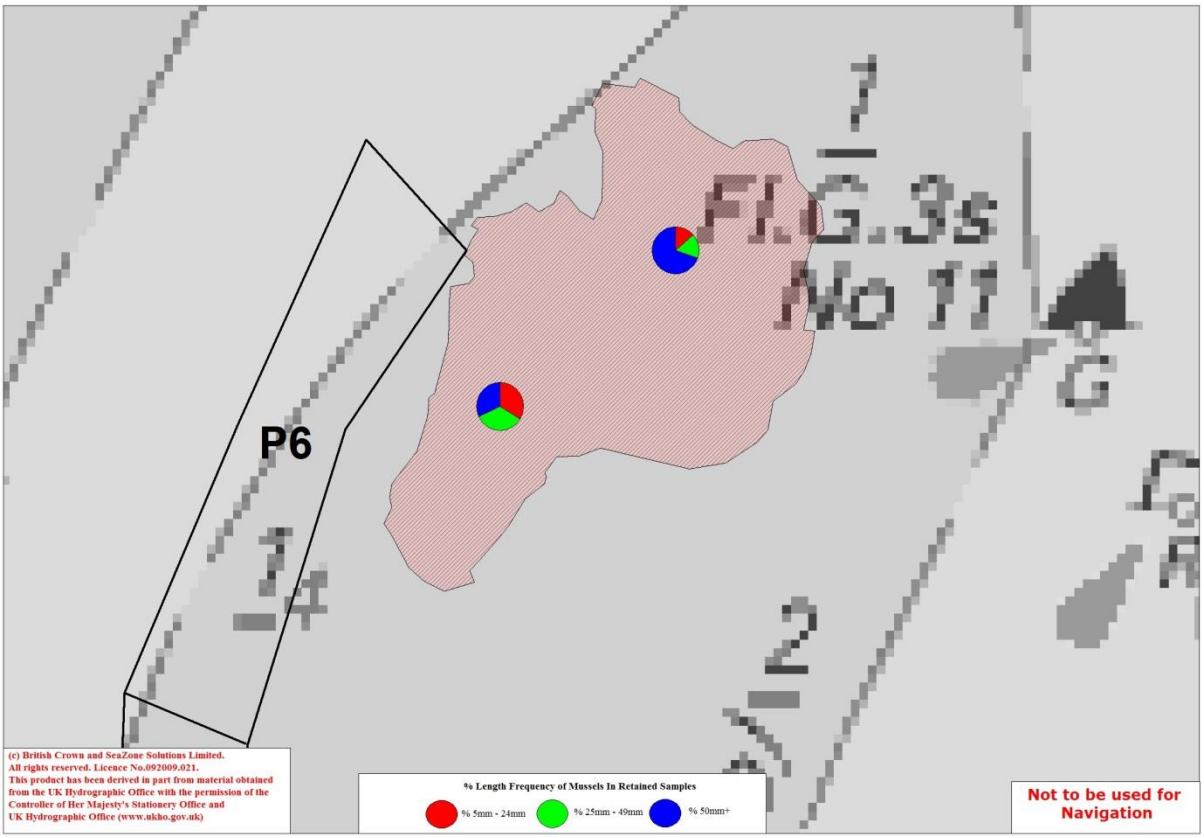

Figure 31 - Mussel size distribution on the Pandora mussel bed – October 2015

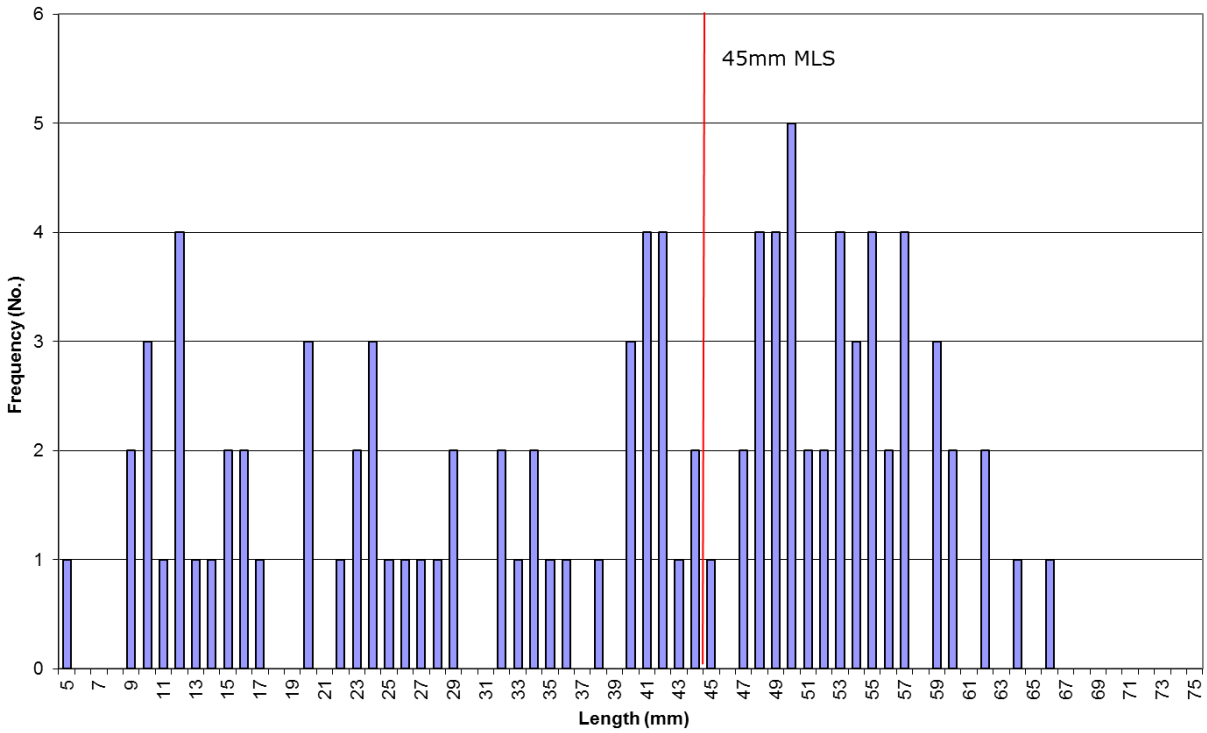

Figure 32 - Mussel size frequency on Pandora – October 2015

During the recent survey the area of the bed was estimated to be 7.7 hectares compared to 9.5 hectares recorded the previous year. Within the bed the mussel coverage was found to have increased from 21% to 27% but the mean density had declined from 0.74 kg/0.1m^2 to 0.58 kg/0.1m^2. From these figures the total biomass of mussels on the bed was calculated to be 122 tonnes compared to 149 tonnes in 2014. During the same period the biomass of marketable sized mussels was calculated to have declined from 139 tonnes to 102 tonnes.

Blackshore

- Area: 3.0 hectares
- Coverage: 22%
- Mean Density: 0.76 kg/0.1m^2
- Total Stock: 50 tonnes
- Stock ≥ 45mm: 27 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.

The bed was surveyed again on October 15th 2015, during which samples were collected from every third "hit", producing 13 samples from a single transect. This survey found further declines had resulted in the extent of the bed shrinking significantly from 21.6 hectares to 3.0 hectares. This loss of area can be seen in figure 33 that compares the extent of the bed between 2014 and 2015. Because the remaining patch of mussels was of a higher mean density than the previous year, the coverage was found to have increased from 17% to 22%, while the patch density had increased from 0.46 kg/0.1m^2 to 0.76 kg/0.1m^2. Following these changes the total biomass of mussels on this bed was found to have declined from 171 tonnes to 50 tonnes. Of these, 27 tonnes were found to have attained a size of 45mm compared to 104 tonnes the previous year.

Figure 34 shows the size frequency of the mussels collected in the samples from the survey.

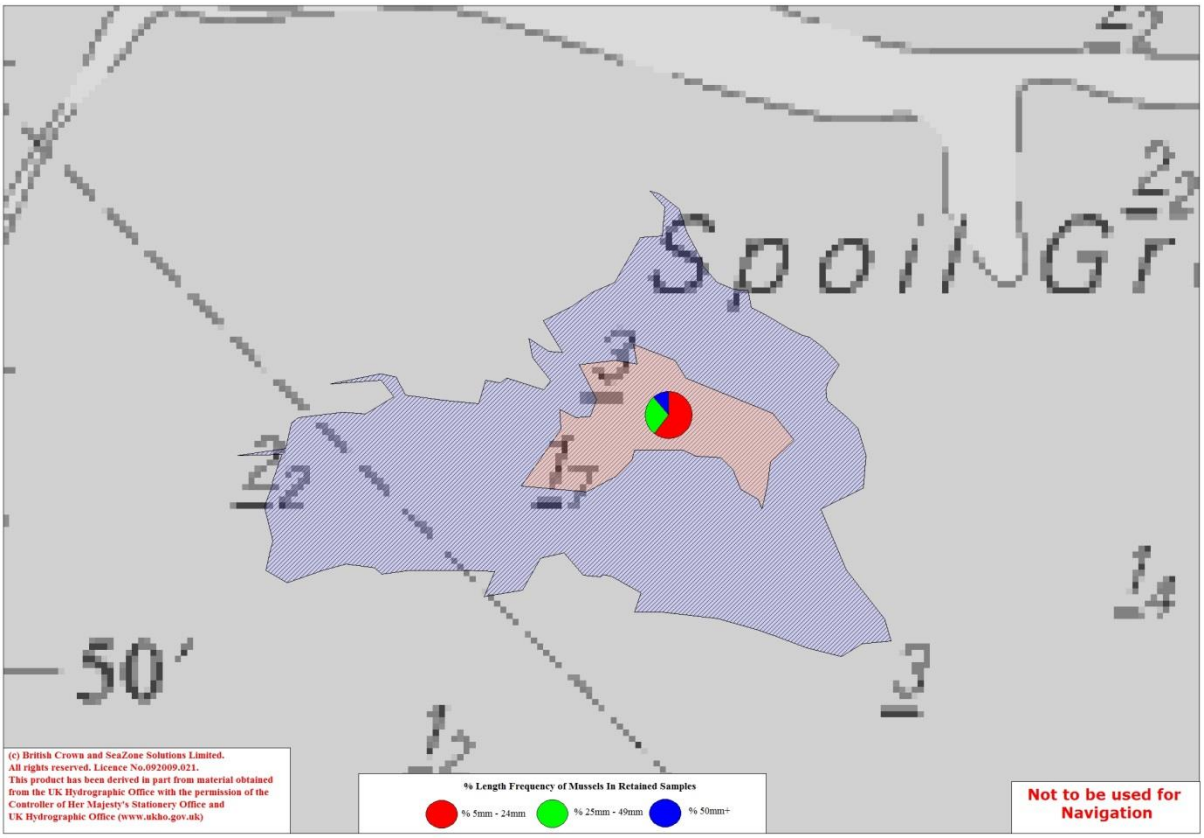

Figure 33 – Chart showing the extent of the Blackshore mussel bed in October 2015 (red) compared to September 2014 (blue)

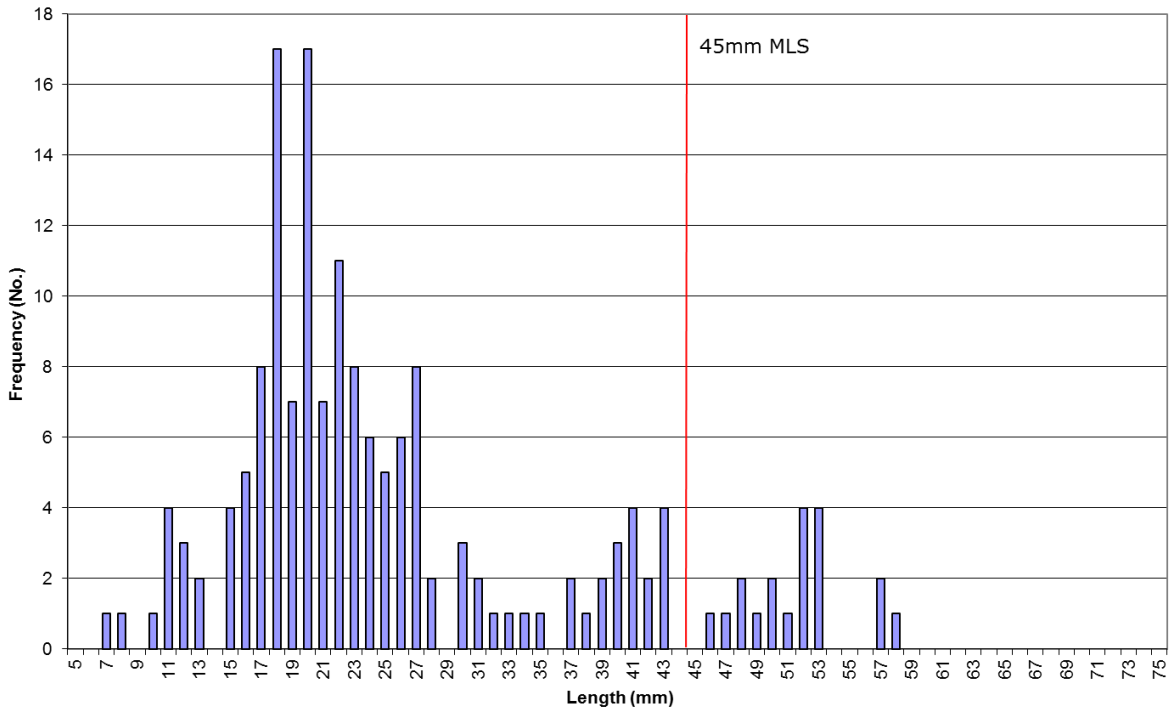

Figure 34 - Mussel size frequency on Blackshore – October 2015

Welland Bank

- Area: 2.2 hectares
- Coverage: 74%
- Mean Density: 2.78 kg/0.1m^2
- Total Stock: 442 tonnes
- Stock ≥ 45mm: 300 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 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 fishery while all of the other inter-tidal beds remained closed.

Figure 35 - Photograph of the River Welland at mid-water, showing the exposed banks

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 36). 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.

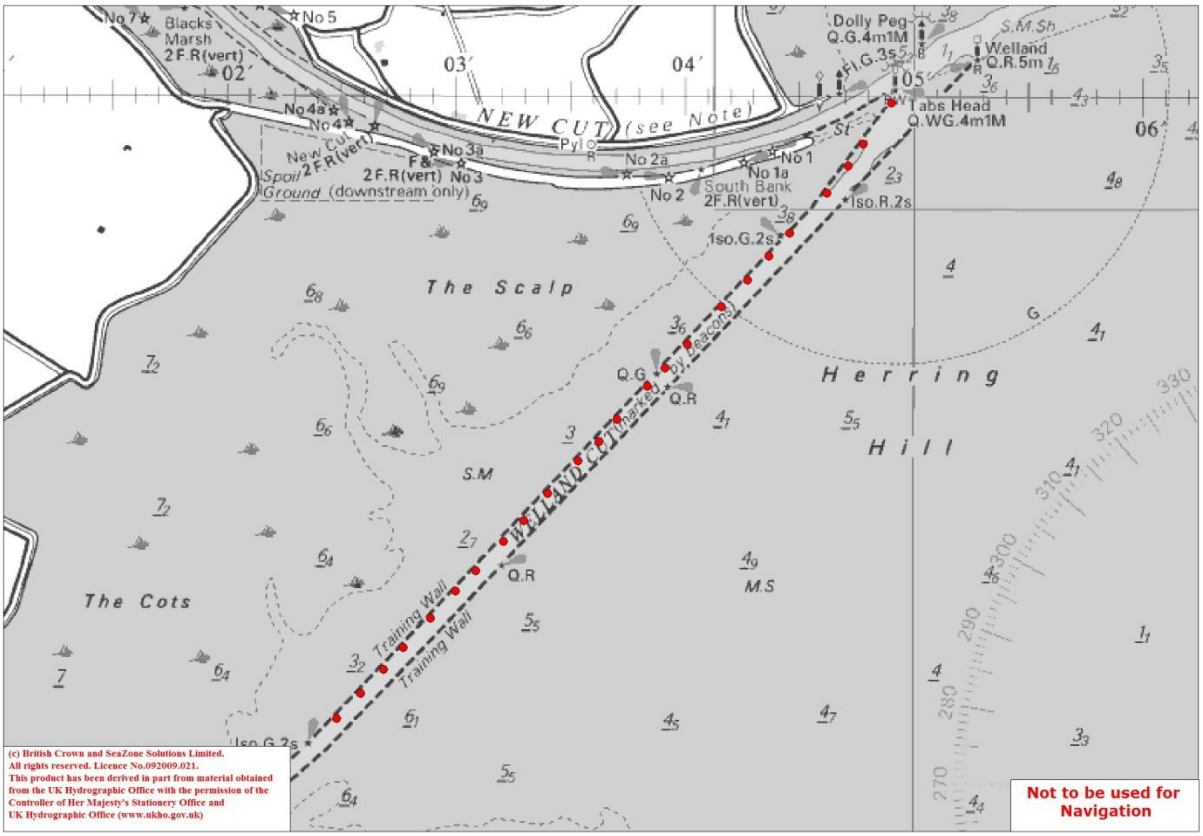

Figure 36 Chart showing the positions of sample sites on the Welland Bank – October 2014

This year's Welland Bank survey was conducted on September 28th, over the low water period of an 8.4m tide. Samples were collected from every second "hit", producing 54 samples from 24 sample stations. Figure 37 shows the mussel size frequency of the population taken from these samples.

Irrespective of being opened to the fishery, the area occupied by mussels was found to have increased from 1.6 to 2.2 hectares. Within this band the coverage of mussels was

found to have increased slightly from 72% to 74%, while the mean density had increased to a greater extent from 1.87 kg/0.1m^2 to 2.78 kg/0.1m^2. From these figures the total biomass of mussels on the bank was calculated to be 210 tonnes, a reduction from the 328 tonnes recorded there the previous year. Of these, 127 tonnes were of harvestable size compared to 214 tonnes the previous year.

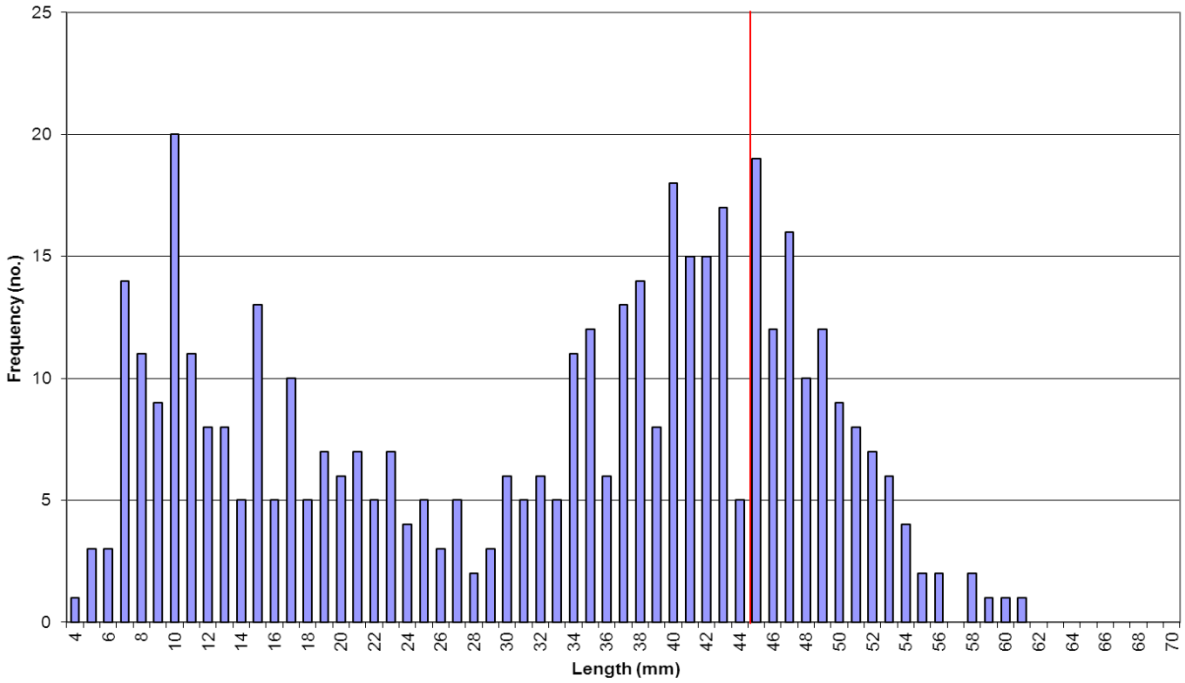

Figure 37 - Mussel size frequency on Welland Bank – September 2015

Discussion

Figure 38 shows the biomass of mussels that have been present on the inter-tidal beds of the Wash since 2002, and how these compare to the Conservation Objective targets for the site. Although from the chart it can be seen that management measures had successfully stabilized the stocks around their respective Conservation Objective targets between 2004 and 2009, since then the stocks have fallen below target thresholds. Although the biomass of juvenile mussels has fluctuated since 2010, the adult stock (mussels ≥45mm) biomass has remained consistently low, albeit slowly improving. As the high mortalities observed among the populations of 2 and 3 year old mussels will be having a serious impact on the number of juvenile mussels that are able to recruit to the adult stock, this improvement to the adult biomass is likely to be a result of adult mussels growing in size rather than younger mussels recruiting into this population. While the longevity of mussels offers some stability to the stocks, without recruitment to the adult population, this group is steadily ageing and will eventually die. Once that occurs, many of the beds are likely to disappear.

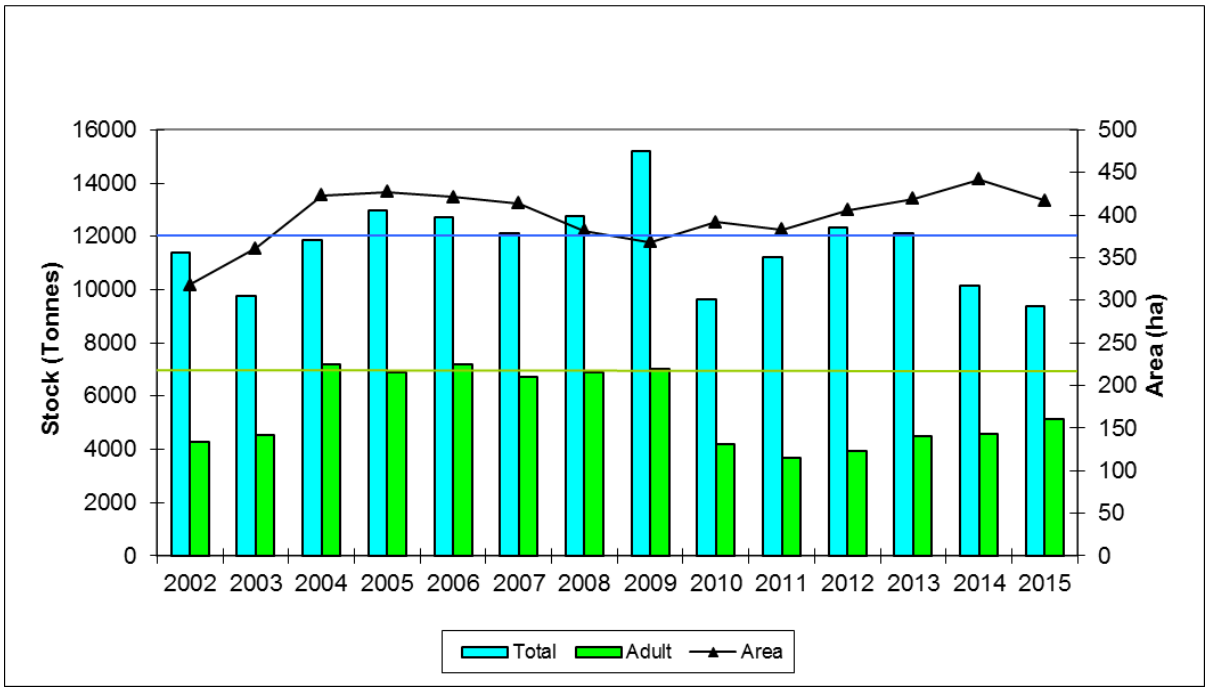

Figure 38 – Intertidal mussel stock levels in the Wash since 2002 and the Conservation Objective targets

Recruitment

The recent high levels of mortality among the successive populations of 2 and 3 year old mussels is beginning to have serious implications on the size of the spawning stock.

Although there is still a dwindling population of older mussels on the beds, the recent mortalities mean the average life-expectancy of the population has been reduced, placing a greater reliance on annual recruitments to replenish losses. Unfortunately, since the last good settlement in 2011, recruitment has been poor. Figure 39 shows the overall size frequency of the mussels sampled from all of the beds during the 2015 surveys. While individual survey bias means this is not an exact reflection of the overall size frequency on the actual beds, it does provide a good proxy for estimating the success of annual spatfalls. The bimodal distribution of this chart shows there has been a measurable settlement this year. Usually this proportion of smaller mussels in the population would indicate a moderate spatfall. As this chart shows proportions of mussels in each size range rather than actual numbers, though, it doesn't show the actual size of the settlement. As the number of mussels collected in the samples has fallen in response to the mussel decline on the beds, figure 39 has been derived from a sample of 5,213 mussels compared to a more usual sample size of 10,000-15,000 mussels used to develop similar charts in previous years.

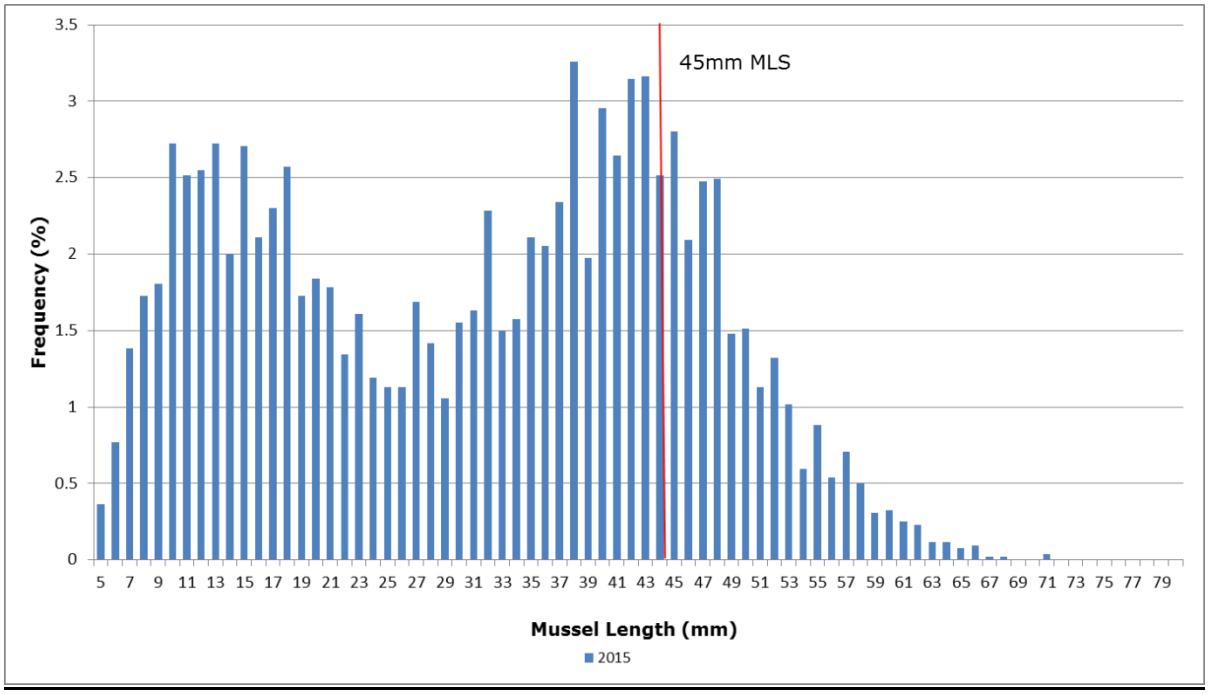

Figure 39 – Chart showing the size frequency of all the mussels collected in samples during the 2015 Wash inter-tidal mussel surveys.

Figure 40 shows the numbers of <25mm and ≥25mm mussels measured during the samples between 2003 and 2015. Although this again carries a slight bias associated with the survey method, it does provide a useful indication of the relative numbers of

mussels that are present on the beds from one year to the next, and the relative success of their annual spatfalls.

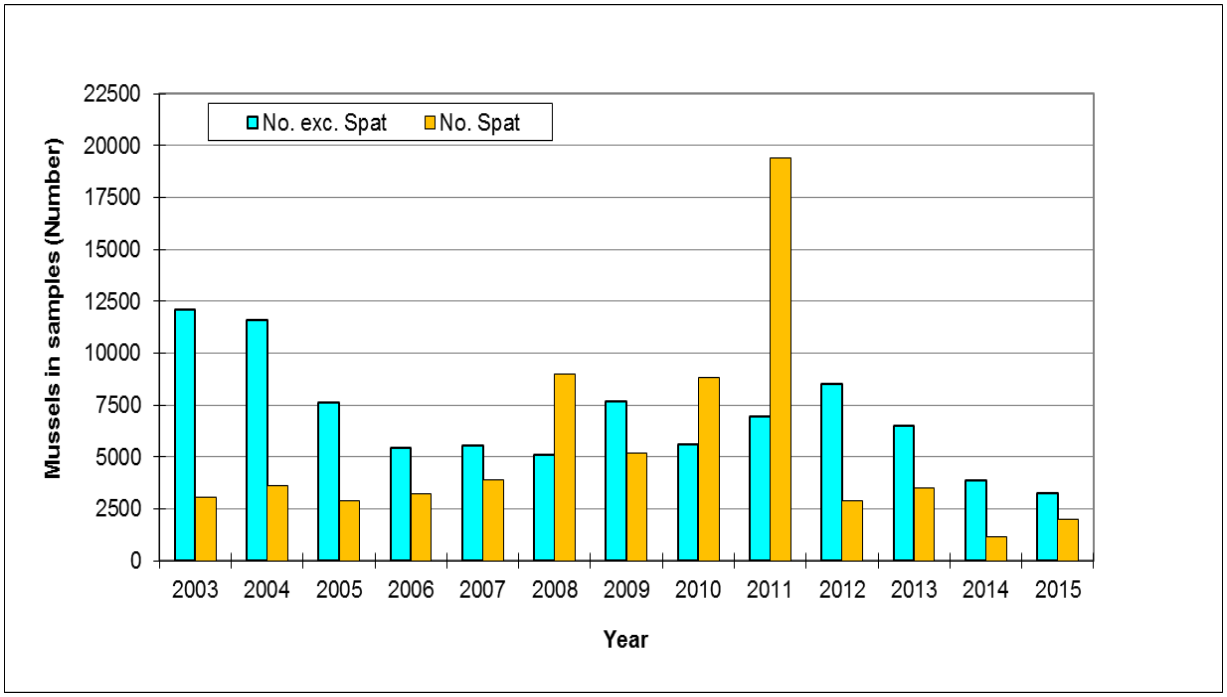

Figure 40 – The numbers of <25mm (spat) and ≥25mm mussels collected during the annual surveys between 2003 and 2015

From this chart it can be seen that as the beds have recently declined, so too have the number of mussels collected in the samples. Although the bimodal distribution seen in figure 39 would usually indicate a moderate settlement, the actual numbers of spat seen in figure 40 highlights the 2015 settlement has actually been comparatively poor. While the good settlements seen in 2008, 2010 and 2011 would have been expected to significantly improve stock levels in the years following settlement, the ones seen since 2012 will barely compensate for natural mortality. Following these recent poor spatfalls, it is likely that the mussel stocks will continue to decline further during 2016.

MUSSEL REGENERATION PROJECT

Results from past mussel surveys indicate the majority of the mussel settlement that occurs on the inter-tidal beds in the Wash, happens within existing mussel beds. Occasionally new areas are colonised, generally as a result of mussel seed settling among ridged out cockles or patches of cockle shells. 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 initial results of this study were inconclusive. Although the shells did have a positive impact, attracting fifteen times as many mussels to the shelly areas compared to the bare controls, the numbers were not large and would not have been cost effective as a long term solution. Mussel settlement throughout the Wash in 2014 was poor, however, so the Authority gave approval to repeat the experiment on a larger scale during 2015. The majority of the Fishermen's Associations working in the Wash gave permission for £15,000 to be used from the Wash Fishery Order Fund in order to buy 200 tonnes of cockle shells and to charter fishing vessels to relay them. Concerns were raised by the associations, however, that the shells were planned to be laid too late in the season (May/June) to attract seed. Further, reconnaissance of several potential sites for the experiment were found to contain high densities of cockle spat. This new trial was postponed until March 2016, allowing time for other suitable sites to be found and enabling the shells to be relayed earlier in the season.

During October 2015 the opportunity was taken to resurvey the original regeneration sites. This survey found that during the year since the previous survey, there had been a settlement of seed within the shelly areas. 13 of the 15 quadrats taken from the shelly areas were found to contain mussels compared to just 1 out of 15 taken from the bare control sites. These samples contained 236 mussels from the shelly areas compared to 3 from the control areas. Figure 41 shows the size frequency of these mussels. 81% of these were found to be <25mm length, indicating they had settled into the area during 2015. These shelly areas were calculated to support 428kg of mussels. Although this is not high compared to the 72 tonnes of shells that were originally relayed, because of their small size, these juvenile mussels are not currently contributing much to the overall biomass of mussels in the area. If they survive, their growth over the coming years should increase the biomass significantly.

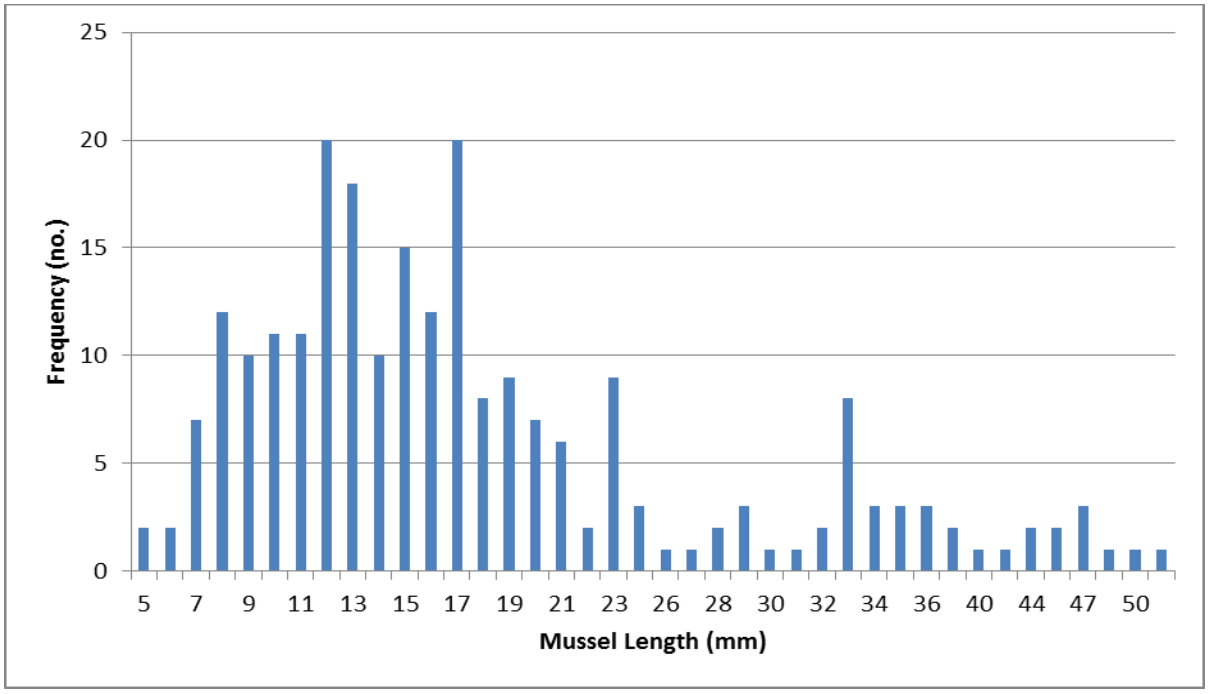

Figure 41 – Size frequency of the mussels sampled from the regeneration sites – October 2015

Figure 42 – Photograph showing one of the regeneration sites. October 2015.

Figure 42 shows one of the regeneration plots when surveyed in October. Although some darker patches can be seen among the shells where mussels are beginning to aggregate, the area by no means resembles a mussel bed. However, the majority of the mussels within this patch are currently too small to be noticeable in a photograph and are only really apparent when clumps of cockle shells are prised apart during analysis. The area was actually found to support an average of 157 mussels/m^2 (127 of which were <25mm length). Table 2 shows the mean number of mussels/m^2 of various size ranges found on each of the inter-tidal beds during the 2015 surveys. From this table it can be seen that the regeneration site actually supports a higher mean density of mussels than eight of the actual beds, although this reflects the deterioration of these beds as much as the success of the regeneration site. In terms of new settlement, only six of the beds supported higher densities of seed (mussels <25mm) than the regeneration sites.

These recent results show that the areas containing cockle shell have benefited from significantly higher levels of settlement than the control sites. Although the shells are facilitating settlement to a level comparable with many of the mussel beds, it is still questionable whether the amount of mussels gathered will justify the cost associated with relaying the shells. At present the site has only attracted 428kg of mussels. As it is not possible to determine how many of these will survive the coming year, it is difficult to estimate what the mussel biomass within the experimental areas could potentially become. To offset the £5,000 cost of buying and relaying the shell, however, approximately 15 tonnes of mussels will need to be attracted. As this would equate to a density of approximately 125 tonnes/hectare, it is probably an unrealistic goal, making it an unfeasible option for mussel aqua-culturists, particularly if seeking a fast return. The inter-tidal beds in the Wash hold great conservation value in addition to their commercial value, however. With all of the beds suffering worrying declines, it is important to explore methods of attracting seed back into them. This study has found that a culch of cockle shells does attract mussel seed, but to be commercially viable would need to use lower levels of shell than was deposited in 2014. During this study the shells were laid to a depth of 15-20cm on fairly soft ground. Although they initially sank fairly rapidly into the mud, figure 42 shows they stabilised and still remained visible on the surface 17 months after being deposited. Future studies should, therefore, explore the effects of using varying depths of shells, conducting the trials on firmer ground and potentially depositing the shells in ridges rather than spreading them flat.

Table 2 –Mean number of mussels/m^2 within each of the mussel beds surveyed during 2015

	Number of mussels/m^2 found on each bed during 2015			
Bed	**<25mm**	**25-44mm**	**>45mm**	**Total**
Herring Hill	223	294	46	563
Trial Bank	220	178	54	452
West Mare Tail (Ext)	323	103	0	426
East Breast	130	170	71	371
Blackshore	204	96	38	338
South Mare Tail	131	158	37	325
West Breast	119	128	58	305
North Mare Tail	60	155	81	296
Holbeach	79	103	53	236
West Gat	77	81	62	220
East Mare Tail	108	63	11	182
Toft	21	33	123	177
Regeneration Site	127	25	5	157
East Gat	48	41	66	155
Scotsman's Sled	55	56	27	139
East Herring Hill	21	106	9	136
Roger	6	33	83	121
West Mare Tail	47	36	13	97
Pandora	24	24	40	88
Main End	22	20	29	70
Mid Gat	19	14	28	60