Review of the Wash Fishery Order 1992 cockle and mussel survey methodologies

Eastern IFCA Report

September 2018

Ron Jessop

Contents

Figures

Tables

Executive summary

The Authority is seeking 50% cost recovery from the fishers for regulating the Wash Fishery Order 1992 cockle and mussel fisheries. As approximately £111,000 of the cost of regulating these fisheries is associated with conducting their annual stock surveys, a review of the current survey regimes has been conducted to determine their cost-effectiveness and to identify potential savings that could be made. This review details the current survey regimes and their benefits, then explores various options that could reduce costs. In most cases, the reduction in cost carries an associated risk, usually in the form of a decline in accuracy of the data provided. In some cases, the loss of accuracy is too large to still confidently support some of our current management measures, so alternative management would be required. These alternatives would carry their own financial burdens. For each option explored, financial savings and associated risks have been described. A summary of these findings can be found on page 90.

The review does not seek to recommend which options should be taken, but to inform stakeholders and Authority members of the various alternatives and their risks.

1.0 Introduction

Regulating the Wash Fishery Order cockle and mussel fisheries is currently estimated to cost £171,412 per annum. Of this, approximately £51,000 is used to conduct the cockle surveys and £60,000 to conduct the intertidal mussel surveys. Appendix 1 shows the breakdown of these survey costs, which also include data analysis and reporting in addition to the fieldwork.

At the Full Authority meeting held on 15th February 2017, members agreed to achieving 50% cost recovery from the 62 industry entitlement holders for regulating these two fisheries. As there will now be a significant cost to the industry participating in these fisheries, a review of the cockle and mussel survey methods was proposed to determine if and where costs can be reduced and to identify associated benefits and risks of doing so. A similar review, covering just the cockle fishery, was conducted and presented to the Authority in 2015. That particular review focused primarily on identifying savings in time that could condense the survey period, allowing the surveys to be conducted closer to the fishery opening date. This new review will look at the mussel surveys in addition to the cockle surveys, and provide a more detailed examination of potential changes that could be made to reduce survey costs, and their associated risks.

2.0 Background

With a combined annual first-sale value of approximately £2-4 million, the intertidal cockle and mussel fisheries in The Wash have traditionally provided a valuable resource for the local fishing industry, particularly to the ports of Boston and King's Lynn. In addition to supporting the fishery, these shellfish beds 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. It is important, therefore, for both the sustainability of the fisheries and for the wildlife communities relying on them, to ensure the cockle and mussel fisheries are both managed and targeted in a responsible manner that does not result in a crash to the stocks.

During the 1980s and 1990s the gradual replacement of small wooden vessels with larger all-purpose steel vessels, the introduction of hydraulic suction dredges for the cockle fishery and wash tanks and mechanised riddles for the mussel fishery all helped to increase the efficiency of the two fisheries. With management measures and legislation failing to keep pace with the advancement of new technologies and new markets abroad, both stocks became over-exploited, resulting in their populations crashing in the 1990s. In 1993 the Fishery Order 1992 was introduced to strengthen the management of the shellfisheries in The Wash. By focusing mainly on controlling daily quotas and temporal and spatial closures as methods of stock control, however, the efficiency of suction dredge equipment meant cockle stocks remained low through most of the 1990s. This was only rectified in 1998, when an improved management mechanism in the form of an annual Total Allowable Catch (TAC) quota was introduced to artificially limit exploitation of the cockle stocks to sustainable levels. This, together with the subsequent evolution of other management measures, helped to stabilise the cockle fishery and facilitate a stock recovery through the 2000s. Similarly, despite draconian fishery management measures being applied to the mussel fishery through most of the 1990s, frequently in the form of total closures, poor recruitment meant the mussel stocks were slow to recover until an exceptional spatfall in 2001 rejuvenated several of the beds and helped new ones to develop.

Since 2000, there has been an increasing awareness of the environmental importance the shellfish beds in The Wash have. Because of the ecological importance of the site, The Wash has been designated as several overlapping Marine Protected Areas (MPAs). These include a Special Site of Scientific Interest (SSSI), a Special Area of Conservation (SAC), a Special Protected Area (SPA), a RAMSAR site and a National Nature Reserve (NNR). These designations require the management of the fisheries to not only take into account the sustainability of the stocks, but also protect designated environmental features and communities from associated impacts. This has resulted in the requirement to submit detailed Habitats Regulations Assessments (HRAs) to Natural England before fisheries can be opened, ensuring management measures are sufficient to prevent the respective fisheries having an adverse impact on the site’s Conservation Objective targets.

When conducting fisheries within MPAs, managers must take a precautionary approach. That means the onus is on the managers to prove the activity will not cause an adverse impact. Failure to adequately prove this will prevent the fishery from proceeding. To help managers achieve the conservation targets in The Wash, a suite of shellfish management policies was agreed between the Authority’s predecessor, Eastern Sea Fisheries Joint Committee (ESFJC), Natural England and fishermen in 2008 (ESFJC, 2008). If followed, these measures should prevent the cockle and mussel fisheries having an adverse impact on the site.

While some of the measures in the policies are technical (e.g. restricting such things as vessel size and the types of equipment that can be used for each fishery), others are focused on the stocks themselves. These include the setting of annual quotas to prevent over-exploitation and protecting juvenile stocks to maintain sustainability. To prove there will not be an adverse impact, and to determine what quotas and protection should be given to the fisheries, sufficient evidence is required to confidently understand the size and distribution of the stocks, as well as the likely impacts of the respective fisheries on the conservation features. Because both the cockle and mussel stocks naturally fluctuate in size and distribution, the required evidence is currently provided from annual surveys that are conducted prior to each fishery opening.

3.0 Management Measures and Survey Requirements

Alternative approaches and methods can be used for managing fisheries. For instance, stock sustainability could be managed by restricting fishing effort in a number of ways - through the use of daily or annual quotas, temporal and/or spatial closures, limiting permits etc. Similarly, protection of juvenile stocks could be achieved by implementing spatial closures, introducing Minimum Landing Sizes (MLS) or through technical measures such as requiring riddling of catch. Depending on circumstances, some of these measures may be more effective than others. An example of this was the use of daily vessel quotas to protect cockle stocks. While this was an effective method used prior to 1986 to manage the hand-worked fishery, it proved to be an ineffective method for managing the greater efficiency achieved from hydraulic suction dredges. Their improved capability to still achieve daily quotas when fishing very low stock densities, meant that the cockle stocks in The Wash remained low following their introduction until an annual quota, in the form of a Total Allowable Catch, was introduced in 1998.

The current regimes for managing The Wash cockle and mussel fisheries, and the associated legislation, have been developed over time to respond to the changing nature of the fisheries, the equipment used and the natural pressures affecting the stocks. Because the surveys and management of the fishery have developed together over the years, the current management measures at our disposal are informed by specific information which the current survey regime provides. It is likely, therefore, that any changes in survey regime that resulted in the loss of information would possibly also require a change in the management and regulation (for example, if the surveys could no longer chart the distribution of juvenile cockles with sufficient accuracy to satisfy conservation measures, it might be necessary to introduce a minimal landing size on cockles to offer them alternative protection). Additionally, as the fishery takes place entirely within a heavily designated MPA, it is possible that having less information upon which to base management decisions may not be acceptable because there will be insufficient evidence to underpin them. An illustration of this has been seen in recent years, where it has been possible to increase the cockle fishery TAC after trends seen in survey data had highlighted the stocks as being vulnerable to high natural mortalities. Such options may not have been possible without good supporting evidence provided by the surveys. Such options are of particular relevance in the present climate, where cockle stocks are highly vulnerable to “atypical” mortality.

Tables 1 and 2, below, describe the current management measures for the cockle and mussel fisheries that depend on evidence derived from surveys, and the information they require.

Table 1 – Relevant management measures and evidence required for regulating the WFO cockle fishery

Measure	Required Evidence
Total Allowable Catch - The TAC for the fishery is calculated as being one third of the adult stock biomass	Adult cockle stock biomass
Minimum adult stock biomass - Adult cockle stock biomass must be maintained above 3,000 tonnes	Adult cockle stock biomass
Minimum total stock biomass - Total cockle stock biomass must be maintained above 11,000 tonnes	Total cockle stock biomass
Protection of juvenile cockles – Areas supporting densities of Year-0 cockles exceeding 1,000/m^2 will be protected from hand-worked fishery.	Distribution of Year-0 cockles
Protection of juvenile cockles – Beds will only be opened to dredge fishery if they support ≥70% biomass of adult cockles	Distribution and biomass of adult and juvenile cockles Sufficient sampling resolution to determine respective proportions at individual bed level.
Protection of mussel beds – Hand-worked cockle fisheries must not occur within mussel beds. Dredge fisheries must not occur within 100m of mussel beds	Distribution of mussel beds
Minimum Shellfish Biomass Threshold – The combined cockle and mussel stocks must remain above a minimum Ash Free Dry Mass (AFDM) threshold sufficient to support the Conservation Objective target number of oystercatchers (and equivalent waders)	Cockle stock ≥15mm length biomass Mussel stock ≥25mm length biomass

Table 2 – Relevant management measures and evidence required for regulating the WFO mussel fishery

Measure	Required Evidence
Total Allowable Catch – Harvestable fishery - The TAC for the harvestable fishery is calculated as being 20% of the adult stock biomass	Adult mussel stock biomass
Total Allowable Catch – Seed relaying fishery - The TAC for the seed relaying fishery	Juvenile mussel stock biomass

is calculated as being 20% of the juvenile stock biomass	
Minimum total stock biomass - Total mussel stock biomass must be maintained above conservation objective target of 12,000 tonnes (although allowed to be fished to 10,000 tonnes if evidence shows stocks will recover to 12,000 tonnes by following survey)	Total mussel stock biomass
Minimum adult stock biomass - Adult mussel stock biomass must be maintained above conservation objective target of 7,000 tonnes (although allowed to be fished to 5,000 tonnes if evidence shows stocks will recover to 7,000 tonnes by following survey)	Adult mussel stock biomass
Minimum juvenile stock biomass - Juvenile mussel stock biomass must be maintained above 5,000 tonnes	Juvenile mussel stock biomass
Protection of juvenile mussels – Mussel beds will only be opened to harvestable fishery if they support ≥70 adult mussel biomass	Adult and juvenile mussel stock biomass at sufficient resolution to determine respective proportions at a bed level.
Protection of adult mussels – Mussel beds will only be opened to relaying seed fishery if they support <70 adult mussel biomass	Adult and juvenile mussel stock biomass at sufficient resolution to determine respective proportions at a bed level.
Maximum exploitation level per bed – Fisheries should not reduce individual mussel beds below mean densities of 25 tonnes/hectare	Area of individual mussel beds Total mussel stock biomass within individual mussel beds
Use of vulnerable beds – Beds considered to be vulnerable can be opened to the relaying fishery	Evidence of mussel bed locations and thorough understanding of whether such areas are vulnerable
Minimum Shellfish Biomass Threshold – The combined cockle and mussel stocks must remain above a minimum Ash Free Dry Mass (AFDM) threshold sufficient to support the Conservation Objective target number of oystercatchers (and equivalent waders)	Cockle stock ≥15mm length biomass Mussel stock ≥25mm length biomass

4.0 Current WFO 1992 cockle survey regime

4.1 Timing of surveys

The annual spring cockle surveys are usually conducted over a 6-week period covering the spring tide periods between the third week of March and the end of April. Occasionally delays to the survey regime cause the surveys to continue into the first week of May. This allows time for other necessary tasks associated with opening the fishery to be conducted ready for a mid-June fishery opening date. These tasks include:

- Analysis of survey data and creation of cockle distribution charts
- Development of appropriate management measures
- Development of a Habitats Regulation Assessment for the proposed fishery, and opportunity for Natural England to review and provide advice.
- Production of reports and papers to inform fishers and Authority members prior to industry and Authority meetings
- Informing the fishers of the details of the coming fishery, with a minimum 7-day notice of the fishery opening.

From a scientific perspective, conducting the surveys at the same time each year is beneficial, as it eliminates a seasonal variable. This means the results from annual surveys can be compared without needing to factor in seasonal differences between them.

The timing of the surveys is contentious with the fishers, however, as they generally occur while the sea temperatures are still relatively cool following winter. As cockles tend to grow rapidly in early summer once the sea temperatures have warmed up, there are large discrepancies between the cockle stock biomass at the time of the surveys and at the start of, and during the fishery. As the annual TAC for the fishery is calculated from the biomass of ≥14mm width cockles identified during the surveys, many fishers feel the TAC is lower than it should be, and that the TAC should reflect the state of the stocks at the time of the fishery. Because the survey and management processes require too much time to be conducted at the time of the fishery, a growth study was conducted in 2012 to determine if cockle growth could reliably be factored in to the survey results. This process itself, however, significantly increased the time taken to conduct the surveys and the error margins associated with the results proved too large to be reliably used. As an alternative, some fishers have suggested conducting the surveys later in the season, once the cockles have had an opportunity to grow. Others, however, wish to have an earlier start date to the season, which would require the surveys to be conducted even earlier.

Although it is understandable that fishers would desire to artificially inflate the TAC by manipulating the survey times to more favourable conditions, or by factoring in growth, caution is required. Since its introduction as a management tool in 1998, the TAC has been consistently calculated from surveys conducted at this time of the year. It may not accurately reflect the cockle biomass in summer, but it has been applied to a consistent baseline. The stock biomass may be higher as the season progresses, but additional stock has not actually been created. In effect, inflating the TAC using these methods would be nothing more than changing the goal posts.

An attempt is made to reduce the impact of growth that occurs during the 6-week survey period. This is achieved by sampling the lower density and slower growing beds at the start of the survey period and leaving the faster growing beds, and those with more cockles on, until later.

Ideally, the surveys are conducted on spring tides (>6.5m). These allow best access to the beds either using a boat at high water or when walking the beds at low water. During neap tides some of the higher sites are inaccessible to the research boat at high water, while the lower sites may not drain adequately at low water to be accessible on foot. The timing of the high water periods during spring tides is also more conducive for working than during neap tides. On spring tides, where high water tends to be between 04:00-10:00 and 16:00-22:00, the tides are suitable for conducting grab surveys during both high water tides each day. This allows the samples to be measured over the day-time low water period when dried out, while the night time low water period is suitable for sleeping. During periods of neap tides, however, when the high water periods tend to fall between 10:00-16:00 and 22:00-04:00, the night time high water period is not as good for working. Taking these difficulties associated with intertidal surveying on neap tides into account, usually the surveys are only conducted during spring tide periods. This enables the vessel and crew time to perform other necessary duties during the neap tide periods.

Because the moorings are located in a tidal river, in which access is only available 2.5 hours each side of high water on spring tides, it is not productive to conduct intertidal grab surveys during day trips, as the vessel would need to spend a high proportion of the available survey time steaming to or from port. The cockle surveys, therefore, tend to be conducted in blocks of 3-4 days at a time, with the vessel staying out at sea overnight. This allows grabbing to occur during two full tides each day, with only the first and last day of each trip being impacted by steaming to or from port. To gain back some of the lost time taken by steaming, foot surveys are usually conducted during the first low water period of the first day.

The rate of grab sampling depends on how muddy the sediment is and how much shell and small cockles need sorting. Adverse weather conditions will also slow the process if the vessel is required to turn head to sea for each grab. When conducting grab surveys from *Three Counties*, though, rates of 15-22 stations/hour are usually achieved. This equates to about 45-80 stations per tide if the vessel does not have to steam far to the area being surveyed. By contrast, on day trips, it is usually only possible to grab about 40 stations per day.

Foot surveys are usually conducted by three people, each sampling separate transects. The number of stations each person can sample depends on the sediment conditions and ease of walking. Usually, each person can sample between 10 stations (in muddy conditions) and 18 stations (on firm sand) per low water period. This equates to 30-54 stations per tide. Because of the distance between transect lines, employing three single-person teams to collect the samples is optimal. If additional teams are added, the outer transects tend to be a long distance to access before surveying commences. For Health and Safety reasons, an additional person acts as a safety support officer during foot surveys, maintaining contact with those conducting the surveys. The safety officer remains either on the boat during vessel-based foot surveys, or in a vehicle on the bank if the beds have been accessed on foot from shore. Unlike grab surveys, which can be conducted after dark, foot surveys can only be conducted during daylight hours.

4.2 Sampling strategy

The cockle surveys are conducted by taking samples from stations arranged in a predetermined regular grid pattern. Regular grid patterns are ideal for these types of stock assessment because they provide a uniform coverage of the survey area, thus reducing the risk of unintentional bias. Regular grid patterns also enable surveyors to locate stations easier and faster than when using random sample stations and they also provide a better framework for mapping interpolated data than random sampling patterns.

The same sample station positions are used each year. While this means the areas between the survey stations never get sampled, it does provide a strong historic dataset from which annual comparisons of individual stations can be made. Using the same stations also saves significant time determining the positions of new stations and entering them into the vessel's navigation system each year.

Prior to 1995 the Wash cockle stocks were surveyed by Cefas. When ESFJC took over the responsibility for conducting the surveys, they adopted the sampling strategy and survey positions that had been used by Cefas. At that time the number of survey stations was limited to about 600 and not all sands were surveyed. Since 1995, further stations have been added to include more sands, to extend the extent of survey areas across sands where cockles have been found, and to fill in gaps that previously existed between neighbouring survey areas. Major additions occurred in 2004, when large areas of the upper shoreline that lay between the green marsh and the existing survey areas were included in the survey regime. These included the extended areas of Butterwick, Wrangle and Friskney, plus the upper shoreline of Herring Hill, Mare Tail and Holbeach. In 2010 the Dills sand was incorporated into the Black Buoy survey area and the Whiting Shoal and Peter Black sands were included for the first time.

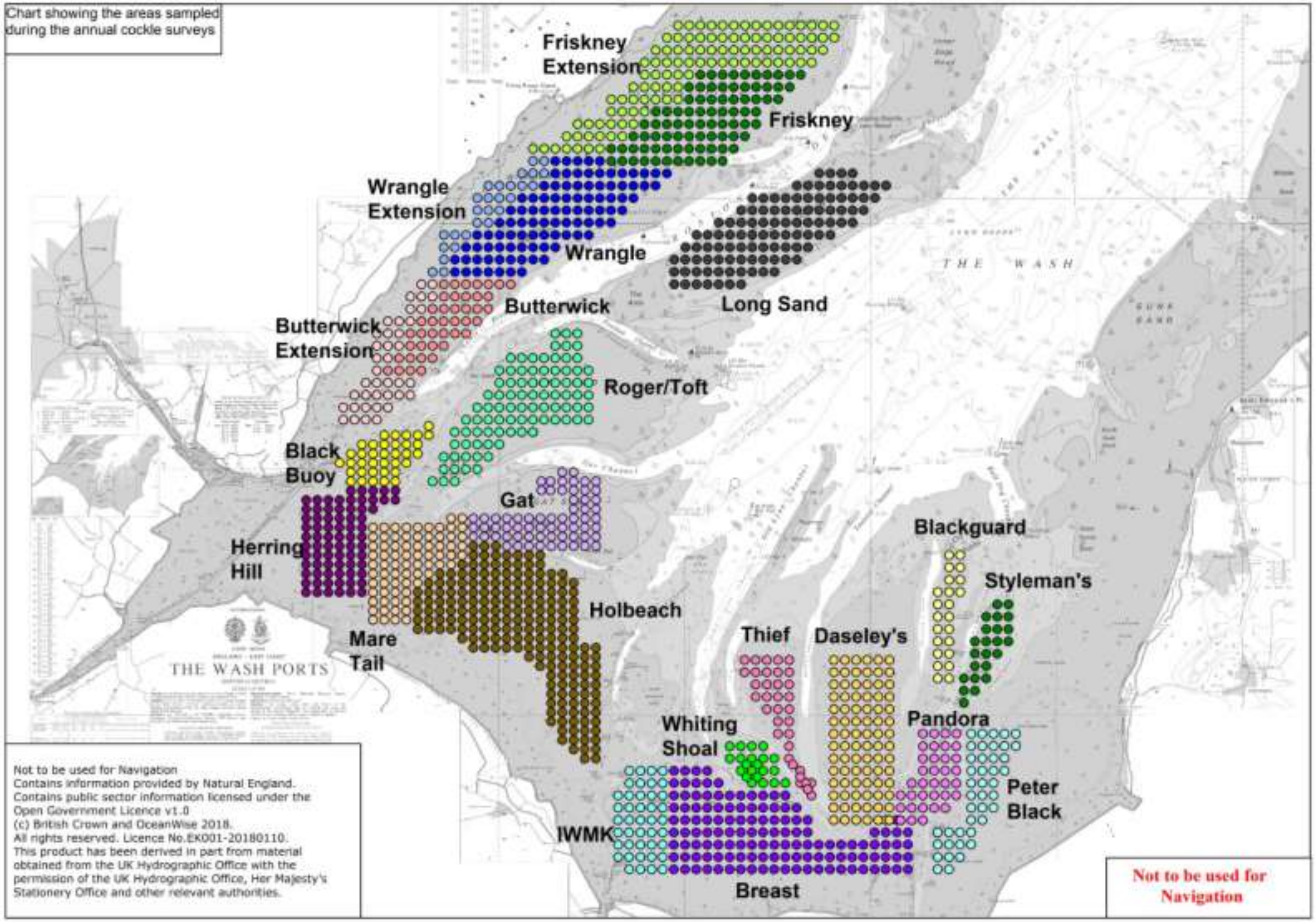

Figure 1 – Chart showing the cockle survey areas and sample station positions used during the annual WFO spring surveys

Under the current survey regime, there are a total of 1,464 stations that are split between 22 survey areas. 102 of these stations are situated on the Long Sand. As the only fishery on this bed occurred between 1978-79, and cockles are very rarely found there, these stations are only sampled sporadically. Figure 1 shows the distribution of the survey stations and the survey areas they are divided into.

In the majority of the survey areas the sample stations are spaced 0.2 degrees North-South and 0.3 degrees East-West apart. This equates to grids of a size 370m x 340m. Within the Black Buoy, Herring Hill, Mare Tail, Gat and Holbeach survey areas, the spacing of the sample stations has a higher resolution. In these areas the stations are 0.15 degrees North-South and 0.3 degrees East-West apart, which equates to 280m x 340m apart. While providing finer scale data, these higher resolution sites create a survey bias that prevents all of the data being analysed as a single group when determining stock biomass. Instead, the stock in each survey area is calculated individually and then summed together to determine a total biomass.

4.3 Sampling method

During the cockle surveys, $0.1m^2$ samples are collected using either a Day grab deployed from a vessel during high water periods or using a quadrat during low water foot surveys. Deploying the Day grab from *Three Counties*, using a winch mounted on a hydraulic A-frame, ideally requires five crew for safe operations (1 skipper, 1 winch operator, 2 grab operators/sample washers, 1 sample recorder). When the weather conditions are calm and the samples are relatively clean (sandy conditions that do not require much cleaning or sorting), four experienced officers can conduct the survey. Foot surveys are optimally conducted using three single-person teams, plus a safety support officer.

In the case of both Day grabs and quadrats, the seabed is sampled to a depth of at least 50mm, which is sufficient to capture any cockles within the grab or quadrat. Should the grab misfire, the sample is retaken.

In the case of grab surveys, the vessel's navigation system, on which the station locations are plotted, is used to position the vessel over the station. As each sample is collected, the colour of the station is changed on the screen to identify which stations have been sampled. Depending on weather conditions affecting how well the vessel can be held on station while the grab is deployed, samples will usually be collected within a 30m radius of the station. This margin of error does not affect calculations determining stock biomass, but can have minor impacts on the accuracy of the interpolated charts. During foot surveys, Garmin hand-held GPS units are used in conjunction with gridded charts of the survey stations to locate the stations. The accuracy of these GPS units is approximately 2m.

Samples taken with a Day grab are emptied into a large tub and transferred into a washing table, where the sample is washed over a 2mm grid with a deck hose to separate any cockle present in the sample from the surrounding sediment. Samples collected during foot surveys are washed over 0.5mm sieves. During the sieving process, the type of sediment is assessed and recorded. The presence of lugworm casts (only on foot surveys), sand mason worms and Macoma are also recorded.

Once sieved any cockles present in the sample are retained in labelled bags for later analysis (one bag/station) and stored in a cool place out of the sun. At low water the retained cockles from each sample are individually measured using Vernier callipers to the nearest millimetre by length and width (see figure 2 for dimensions).

Figure 2 – the width and length measurements recorded during cockle surveys

As they are measured, the cockles are separated into three size groups:

1. Those of width equal or greater than 16mm
2. Those of width 14 to 15mm
3. Those smaller than 14mm width.

The cockles within each size group are then further separated into age classes using their annual growth rings to age them (taking care to identify whether outer ring is a current or previous year's growth). All of the cockles in each of these size-age groups are then weighed to the nearest 0.01g using electronic scales with a range 0.01-200g. Due to the sensitivity of the scales used, the weighing of these samples can only take place ashore or once the vessel is aground.

Prior to 2014 all the biometric data were recorded on paper forms prior to digitisation. Since 2014, however, all data have been recorded directly into a bespoke Access database. This latter method takes slightly more time to conduct during the surveys but saves approximately a week of data entry after the surveys have been finished.

4.4 <u>Data analysis – Modelling cockle bed distribution</u>

The data collected during the surveys are analysed to provide the following information:

- An estimation of the cockle stock biomass for each survey area

- Charts showing the distribution of the cockle stocks
- Histograms showing the size and age frequencies of the cockle populations on each bed.

The charts showing the distribution of cockle stocks are created using MapInfo 15.2, a Geographical Information System (GIS). To prepare the data into a format that can be used for mapping, it is first sorted in Access so that the data from each survey area/bed can be transferred into separate Excel workbooks. These individual workbooks are then used to create MapInfo GIS tables for each area that contain information on the numbers, weights and ages of cockles found at each station, plus numbers and weights of cockles ≥14mm width and <14mm width.

Once the survey data have been transferred to MapInfo, they are used to model the distribution of the cockle stocks. These are hand-drawn within MapInfo, using a method of Nearest Neighbour interpolation. When creating and viewing the resulting charts, it should be noted that these are models that estimate the distribution of the cockles on the ground and are not a true map of the actual distribution. This is because the actual distribution is not known, only what is present at the survey stations. When drawing these cockle distribution models, the assumption is made that the edge of any patch of cockles lies at some unknown distance between a survey station supporting cockles and a survey station supporting no cockles. As it cannot be determined from the recorded data where precisely that edge actually is, a principle is used whereby the edge of the bed is drawn midway between stations supporting cockles and those without cockles. The exception to this is on stations close to sand edges. In those cases, the border is drawn so the bed does not extend into channels. Figure 3 shows how the extent of a cockle bed has been modelled using the above method.

Although this method will not accurately reflect the boundaries of the bed as they truly exist on the ground, given sufficient sample stations, the overall area of the bed should be relatively accurate. This is important, because an accurate estimation of the bed area is required to determine the cockle biomass. The accuracy of the distribution model is determined by the spatial resolution of the survey stations. The further apart they are, the less accurate the distribution model will be.

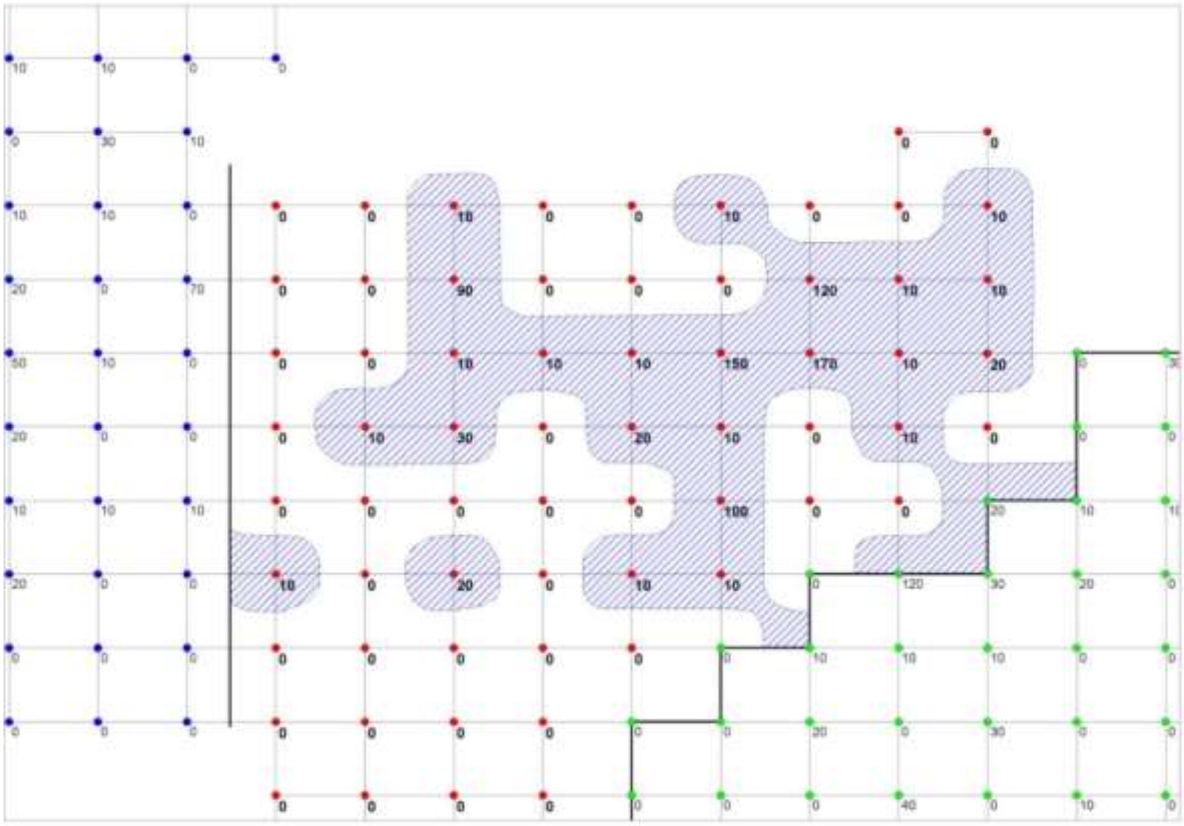

Figure 3 - Chart showing three survey areas, the borders between them and the modelled distribution of cockles within one area.

For The Wash cockle surveys, the cockle distribution charts are drawn to highlight the following densities of cockles:

Dark Blue	10-99 cockles/m^2 (1-9 cockles/0.1m^2)
Green	100-499 cockles/m^2 (10-49 cockles/0.1m^2)
Red	500-999 cockles/m^2 (50-99 cockles/0.1m^2)
Yellow	1000+ cockles/m^2 (100+ cockles/0.1m^2)

Whereas the initial (10-99 cockles/m^2) layer, which covers the total extent of the cockle bed, is drawn with borders that lay halfway between sites supporting cockles and those that don't, the subsequent densities have borders that are influenced by those stations around them. As such the border of the 100-499 cockles/m^2 chart will be pulled closer to a point supporting 90 cockles than one supporting only 10 cockles. This can be seen in figure 3, where some of the higher density borders have been "tugged" towards stations that have only just failed to achieve that particular density.

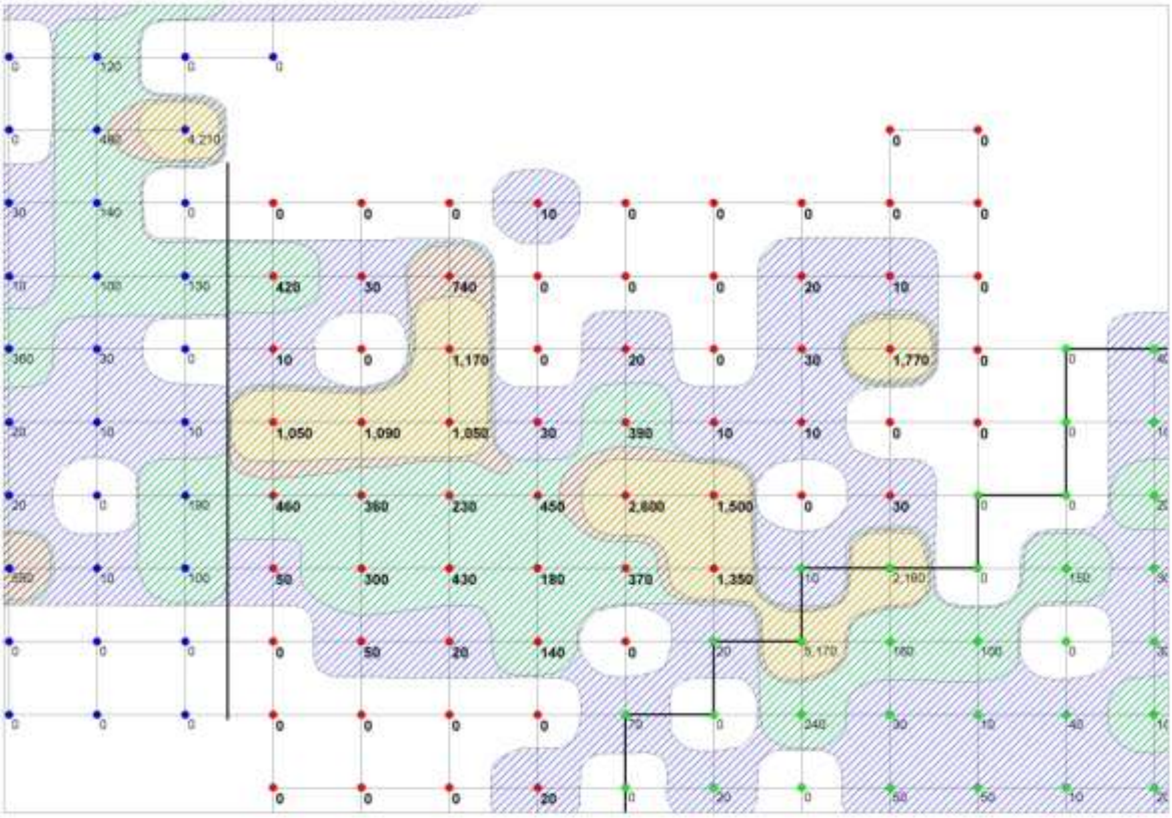

Figure 4 – Chart showing three survey areas and the distribution of four cockle densities within them.

Although there is no Minimum Landing Size for cockles in The Wash, several of the management measures and shellfish policies inaccurately refer to “adult” and “juvenile” cockles, which more accurately should read ≥14mm width cockles and <14mm width cockles. Because the policies distinguish between these two stocks, their distributions are modelled separately during the mapping process. A third set of charts are also created to model the distribution of Year-0 year-class cockles.

4.5 Data analysis - Calculating stock biomass

In this type of survey, the stock biomass is calculated by multiplying the mean biomass of cockles at the stations by the area. Two commonly used approaches that can be taken when doing this are:

1. The area used in the calculation is the area of the whole survey and includes data from all of the sampled stations (including nil-results). In figure 5 below, the survey area would be the large light blue area, and the mean cockle biomass would be derived from all 16 stations (14 of which contain no cockles).
2. The area used in the calculation is the area of the modelled cockle extent, and only those stations containing cockles are used to derive the mean biomass. In figure 5, the area would be the small dark blue patch, while the mean cockle biomass would be calculated from the 2 stations within that area containing cockles.

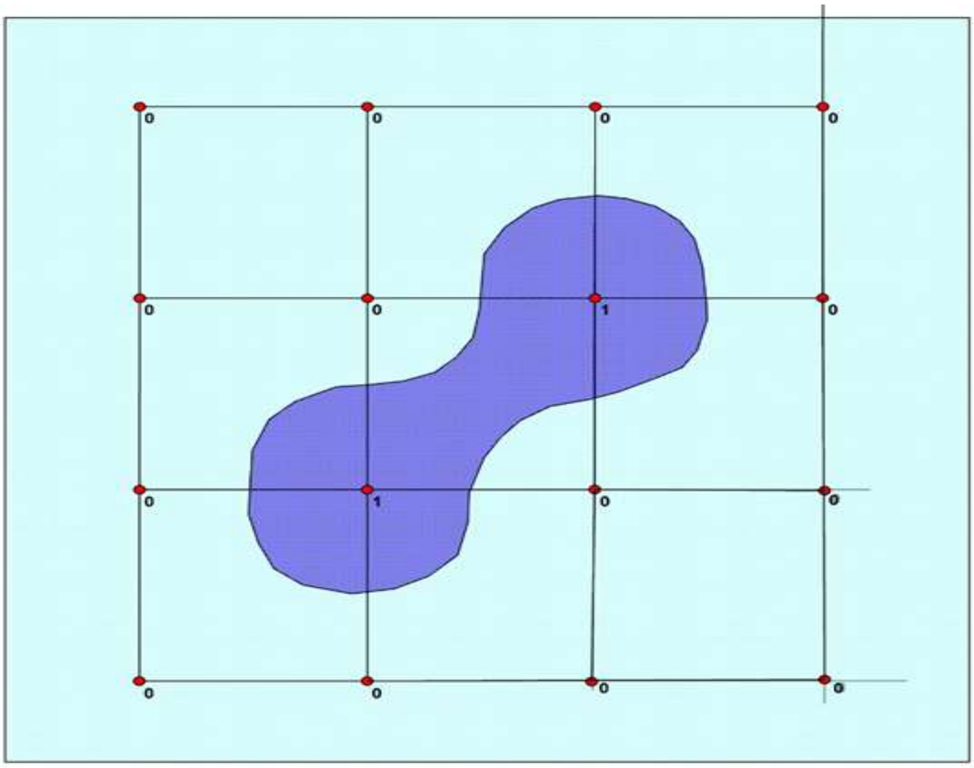

Figure 5 – Diagram showing the whole survey area (light blue) of 16 survey stations (including 14 nil-results), and the modelled area of cockle distribution (dark blue) around the two stations supporting cockles.

In theory both methods should yield the same result. The first method usually results in a lower mean cockle density than the second approach, but this is multiplied by a larger area to produce a similar stock. Because the first approach includes a lot of nil-results, however, while the second approach only uses data from stations where cockles were found, the standard deviation and error margins tend to be larger in the first approach. EIFCA uses the second approach when determining stock biomass because the 95% confidence intervals derived from the standard error margins tend to be narrower, thus providing a more confident result. Because this method relies on having an accurate estimation of bed area, however, should the sampling strategy ever be changed to one less conducive towards mapping the modelled cockle distribution data (e.g. by using a random sampling strategy instead of a regular grid distribution), the first, less accurate, method of assessment would need to be used instead.

When calculating the cockle stock biomass, the stock on each bed is determined individually and then summed to produce a total stock. Although the individual error margins for each bed will be larger, because fewer samples are taken into account for each bed than if The Wash were sampled as a single group, when summed together, these error margins should start to cancel each other out rather than consistently working to under- or over-estimate the biomass. The benefit of using this approach is that stocks can be determined for discrete beds (albeit with larger error margins), allowing management to be conducted at a higher resolution than a Wash-wide approach. This is important when specific measures are required that apply to some beds and not others. Further, this approach negates the bias that would otherwise occur as a result of the higher survey resolution used on the Black Buoy, Herring Hill, Mare Tail, Gat and Holbeach survey areas.

4.6 Data analysis - Cockle size and age frequency

The data to determine cockle size and age frequencies are taken directly from the Access cockle survey database, either as individual beds or for the whole survey area. These data are exported to Excel and histograms are created to display the size and age distributions of the cockles. These provide useful information for determining where the larger-sized cockles are, which areas might need protecting and where ridging out may occur. As a time-series, they also help to establish which areas support good or poor growth. Importantly, as "atypical" mortality appears to affect cockles once they reach a certain size, these data provide information on which beds may be most vulnerable to high levels of mortality.

4.7 Data analysis – Additional environmental data

In addition to collecting cockle biometric data, additional environmental data are also collected at each station. These include an assessment of the type of sediment at the site, plus the presence/absence of Sand Mason worms, *Lanice concheliga*, number of lugworm, *Arenicola marina*, casts (only collected during foot surveys) and the numbers of Baltic Tellins, *Macoma balthica*. These data are recorded in the Access cockle database and exported into MapInfo GIS software for analysis. Interpolated models of their spatial distribution are mapped using Vertical Mapper software.

5.0 Current WFO 1992 mussel survey regime

5.1 Timing of surveys

The annual intertidal mussel surveys are usually conducted over a 6-week period covering the spring tide periods between the second half of September and the end of October. This timing allows sufficient time to analyse the data and produce the necessary documentation to open a harvestable fishery in December. Similar to the cockles, this includes:

- Analysis of survey data and creation of charts showing the locations of mussel beds and an indication of mussel size frequencies within each bed. This period of analysis does not extend quite so long after the surveys as that required for the cockle surveys because the analysis is less involved and is possible to partially conduct while still at sea following the individual surveys.
- Development of appropriate management measures
- Development of a Habitats Regulation Assessment for the proposed fishery, and opportunity for Natural England to review and provide advice.
- Production of reports and papers to inform fishers and Authority members prior to industry and Authority meetings
- Informing the fishers of the details of the coming fishery, with a minimum 7-day notice of the fishery opening.

Since 2009, when there was a rapid decline in mussel stocks, there have not been sufficient adult mussels on the Regulated beds to open a harvestable fishery. The surveys are still conducted with the view to informing a December opening date, however, because until the surveys are conducted, it is not known whether there are sufficient stocks for a winter harvestable fishery or not. From an operational perspective, this timing fits in well around other EIFCA duties, usually occurring towards the end of the cockle fishery and before the shortening winter daylight periods restrict the time that can spent on the sands. It also avoids the more sensitive periods of cold weather during which the over-wintering waders feeding on the beds are most vulnerable to disturbance. Relaying fisheries usually occur between April-September. Surveying immediately prior to these, however, would create an operational clash with the cockle surveys.

As is the case with the cockle surveys, conducting the surveys at the same time each year is beneficial from a scientific perspective because it eliminates a seasonal variable. This means the results from previous annual surveys can be compared without needing to factor in seasonal differences between them.

All of the intertidal mussel surveys are conducted on foot during daylight low-water periods, albeit accessed using a vessel. Spring tides (>6.5m) are best for these, both for accessing the beds, but also due to the timing of the low-water periods. Because low water on neap tides tends to fall between 04:00-10:00 and 16:00-22:00, survey time would be restricted at a time of year when daylight periods are roughly between 07:00 and 18:00.

Although it usually only takes 3 or 4 hours to conduct the actual survey, because the beds require access by a vessel from a tidal port, a typical survey day lasts 12 hours. For beds that have lower elevations and/or are located closer to port, this may be a little shorter, while those that are higher and/or further away, the time might be a little longer. Because only the daytime low water period is used for surveying, most of the surveys are conducted as day-trips.

There are usually between 18 and 20 areas of intertidal mussel bed that are currently surveyed each year. Because the vessel providing access to the bed dries out close to the bed, and most beds are too far away from each other to allow access between them on foot, in most cases only one bed can be surveyed each day. Some survey areas are close enough to each other to allow two beds to be surveyed the same day, though. These include the Gat beds, the Roger and Toft beds, the Shellridge and East Mare Tail beds and the West and East Breast beds. These beds tend to be surveyed in pairs. While this does save the associated vessel costs, an additional team of surveyors is required to be on board to conduct the surveys.

Because four of the beds are situated within the Holbeach bombing range, which restricts weekday access, four weekend days are required to conduct these surveys.

5.2 Sampling strategy

Unlike cockles, which mostly live infaunally beneath the surface, mussels grow in epifaunal clumps that are easily visible. This, and the fact their extent is much smaller than that covered by cockle beds, allows them to be surveyed differently. Rather than taking representative grab or quadrat sub-samples, the mussel beds can be measured more directly. This provides a much more accurate estimation of their extent and biomass than sub-sampling with grabs would be able to achieve.

When determining the stock on these beds, the biomass of mussels within a bed is calculated by multiplying the area of the bed by the mean biomass of the mussels within the bed. Because the mussels within the beds in The Wash have patchy distributions, the mean biomass is estimated by multiplying the mean mussel density within the mussel patches with the mean percentage coverage of the patches.

5.3 Survey method

5.3.1 Determining Area of mussel bed

To calculate the area of a mussel bed, one member of the survey team walks around the perimeter of the mussel bed, close to the edge of the mussels. At each change of direction, a waypoint is entered in a handheld GPS, creating a geographic record of the perimeter of the bed. This data can be analysed using MapInfo 15.2 GIS software to calculate the area of the bed.

Determining the edge of the bed can be subjective at times as not all beds have clearly defined edges. Sometimes mussel beds gradually thin out, have long fingers that follow gullies or have isolated patches beyond the main bed. Experience is required to determine how much of these should be included in the perimeter. Scattered mussels are often ignored if their density is greatly below that of the main bed. If a mental assessment judges them to contain significant numbers of mussels, however, and the main bed has a low density, they are included. Similarly, with isolated patches. If they are a long way from the bed and contain few mussels, they can be ignored. If they are close and contain high numbers of mussels, they should be included. If they are distant but contain significant numbers of mussels, they can have their perimeter measured separately.

5.3.2 Assessing Coverage and Patch Density

Surveys to assess coverage and patch density are conducted by walking zig-zag transects through the bed, recording coverage data and collecting samples on route. For a survey to be accurate, it is important that the whole area within the mapped perimeter has an equal opportunity to be sampled. Failure to do so will create a survey bias. Therefore, if large areas of scattered mussels or bare patches along the edge of the bed have been included within the perimeter, they must be included in the survey. To maintain equal bias to all parts of the bed, the survey transects have equal spacing and run all the way to the perimeter. Because the beds in The Wash do not generally change their overall shape significantly, it is possible to determine the positions of the transect lines prior to the survey. These are drawn onto a gridded chart of the bed, and their bearings calculated with a Portland plotter (see figure 6). Surveyors use this information in conjunction with a hand-held GPS and a hand bearing compass to navigate along the transect lines. If it is the first time a bed has been surveyed, it would be necessary to map the perimeter prior to conducting the survey in order to produce such a chart.

When drawing the transect lines, consideration should be given to their spacing. If they are spaced too widely apart, large areas of the bed between them will not be represented. If, on the other hand, they are too close together, there may be insufficient time to complete them during the low water period. This would lead to bias.

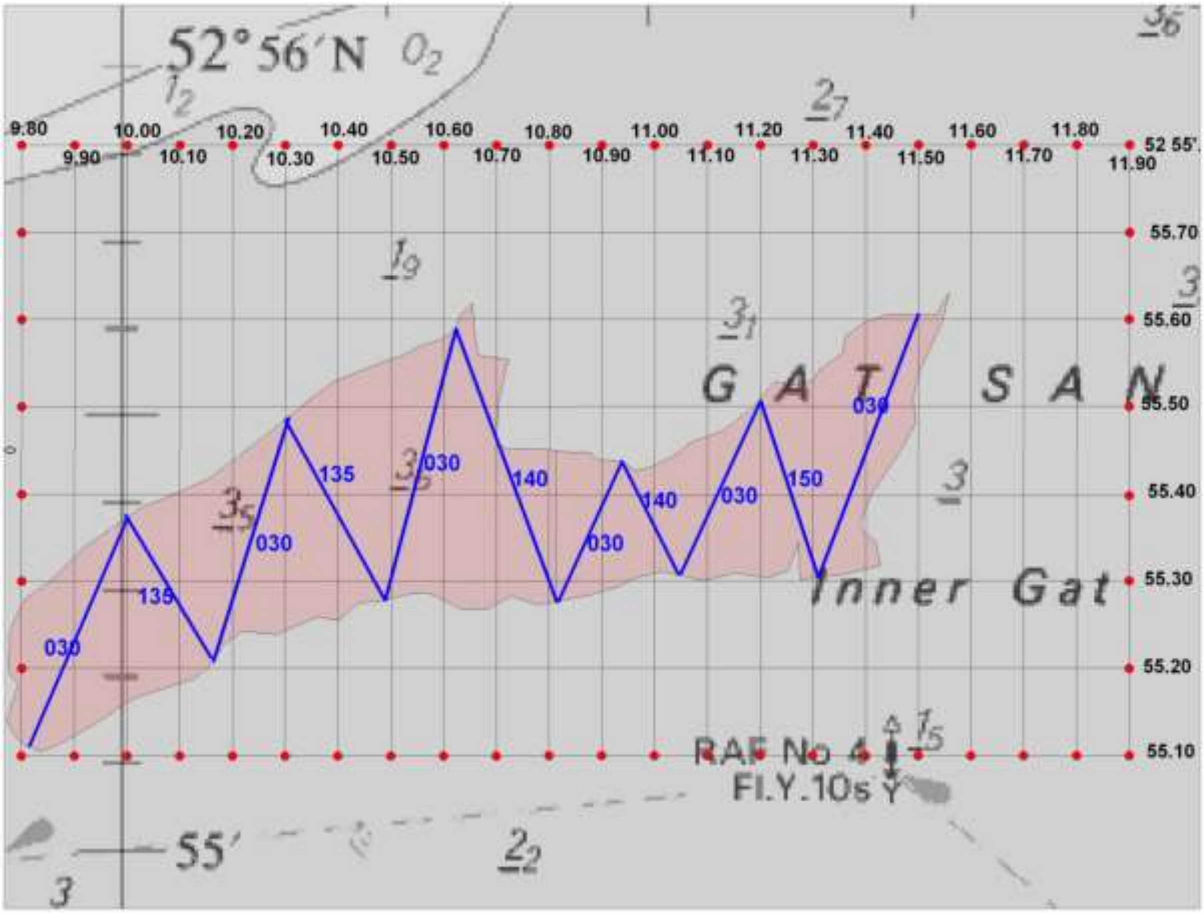

Figure 6 – Example of a chart used when conducting surveys within mussel beds to enable good coverage of transects

The survey within the bed is conducted by a pair of surveyors using a “Dutch wand” to assess mussel coverage and patch density. The “Dutch wand” is a plastic ring (roughly 11cm diameter) attached to a bamboo cane that is used to assess the coverage of mussels within the bed. A plastic corer (of the same diameter as the wand) is used for collecting mussel samples from within the mussel patches. The lead surveyor is responsible for assessing the mussel coverage with the wand and collecting the mussel samples with a corer. The second surveyor is responsible for recording the data and carrying the mussel samples.

Walking in a straight line along the transect, the wand is used to determine mussel coverage by swinging it randomly onto the ground every three paces and recording the presence (hit) or absence (miss) of mussels within the ring. The mussel coverage is calculated from the proportion of assessments that contain mussels. For most of the beds in The Wash, samples are collected from either 1 in 4 or 1 in 5 of those containing mussels. 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. Whatever sampling frequency is chosen at the start, however, should be maintained throughout the survey.

When a sample is collected it is taken directly from within the ring that produced the "hit" determination, using a corer with the same diameter as the wand ring. All the mussels within the corer are stored in a container with the other samples from that transect. At the end of each transect (or pre-determined numbers of hit/miss determinations, the samples in the container are washed using a 0.5mm sieve and stored in a labelled bag.

Once back at the boat, the mussel samples are separated from any debris prior to measuring. The lengths of the mussels are then recorded to the nearest mm. For WFO 1992 surveys, these mussels are divided into groups of those above Minimum Landing Size (≥45mm length) and those below MLS. Since 2010, this latter group has been sub-dived to include a category that are <25mm length, as these are not usually preyed upon by oystercatchers, so should not be included in the Ash Free Dry Mass (AFDM) model for determining food availability. The total weight of mussels in each group are weighed to the nearest 1 gram and the weight of debris from the sample also recorded.

5.4 Data analysis

The waypoints taken from around the perimeter of the bed are entered into MapInfo GIS, from which the area of the bed can be calculated. The transect positions taken during the survey are also entered to ensure the adequate coverage by the transects had been achieved.

The hit/miss data and weights of mussels in each group from each transect are entered into a bespoke Excel spreadsheet, along with the total area of the bed and the diameter of the corer that was used to collect the samples. The spreadsheet automatically calculates the biomass of mussels present in the bed, the mean coverage and the mean patch density.

The size frequencies of the mussels in the population are obtained from the recorded measurements and displayed as histograms using Excel. These data can subsequently be displayed using MapInfo to create size frequency pie charts for each transect area.

Because mussels do not form clear annual rings like cockles, no attempt is made to age them. Strong age cohorts can be seen within the size frequency charts, however, providing some indication of mussel ages.

6.0 Strengths and weaknesses of current survey regimes

Both of the cockle and mussel survey regimes have strengths and weaknesses that are described in the following tables (3-6).

6.1 Cockle surveys

Table 3 – Benefits provided by the current cockle survey regime

Information	Description	Management benefit
Total stock biomass	The data are currently recorded and analysed to calculate the total biomass of: • Adult (≥14mm width) cockles, • Juvenile (<14mm width) cockles • Year-0 juvenile cockles. Because the data is derived from sampling approximately 1,250+ stations, the confidence intervals are good (+/- 11-13%)	• The adult (≥14mm width) cockle stock biomass is used to calculate the fishery TAC • The total cockle stock biomass is required to ensure the total stock is maintained above 11,000 tonnes • The adult (≥14mm width) cockle stock is required to ensure the adult stocks are maintained above 3,000 tonnes • Cockle stock biomass of cockles older than Year-0 required to calculate AFDM for food availability model
Stock biomass on individual beds	The data are currently recorded and analysed to calculate the total biomass of Adult (≥14mm width) cockles, Juvenile (<14mm width) cockles and Year-0 juvenile cockles within each of the 22 individual survey areas. On the larger beds, which support 80+ sample stations, confidence is moderate. On the smaller beds which have <50 stations, confidence is poor.	The proportion of adult cockles on individual beds is required for dredge fisheries, where beds can only be opened if they support ≥70% biomass of adult (≥14mm width) cockles. In cases where some beds are closed, this information helps to determine whether the TAC can be achieved from the beds that remain open.

Cockle stock distribution	The data are interpolated to map the modelled spatial extent of the cockle distribution. Models are mapped to show the extent of: • Adult (≥14mm width) cockles, • Juvenile (<14mm width) cockles • Year-0 juvenile cockles. Regular grid survey patterns, as used in the current surveys, are ideal for mapping stock distribution models. The resolution of these models is determined by the size of the survey grids, which in the case of our surveys are either 370m x 340m or 280m x 340m. In addition to determining the accuracy of the charts, the resolution of the sampling also determines the finest resolution that can be utilised for management measures. Using our current resolution, protecting an area of Year-0 juvenile cockles that were found at a single sample location would require a closure of approximately 10 hectares. Reducing the resolution would result in larger closures, and/or the risk of missing patches of juvenile stock.	• The distribution of Year-0 stocks is required to protect areas supporting densities of Year-0 cockles exceeding 1,000/m^2 from the hand-worked fishery • Mapping the extent of the beds enables a more accurate method to be used for calculating stock biomass • The distribution charts highlight where the better fishing opportunities are likely to occur, where ‘ridging out’ is likely to be problematic and help to predict where the following year’s fishery will be.
Cockle size and age frequencies	The data are analysed to provide cockle size and age frequencies for each survey area.	• When coupled with the distribution information, this data can provide evidence of where the best fishing opportunities are, and also where high mortality is likely to occur through ridging-out or atypical mortality. This information can help

		support contingency measures to reduce mortality.
Historic data set	Analysis of a long-term dataset enables trends to be seen that can help inform predictions about future fisheries and mortality events.	• Long term size and age data provides evidence of which areas support better or slower growth rates. This information can be used to predict when newly settled stocks will be of a fishable size and if ridging out might be problematic. • Trends in past data can help to inform management decisions by predicting what the likely outcomes of certain measures might be. • Trends predicting high mortality events can be used to highlight where management measures may be required to reduce mortality
Additional environmental data	Additional environmental data is collected at each survey station. These include: • Assessment of sediment type • Presence/absence of Sand Mason worms, *Lanice concheliga* • Numbers of Baltic Tellins, *Macoma balthica* • Numbers of lugworm, *Arenicola marina*, casts (foot surveys only)	• The sediment data is primarily used to inform which areas could be opened to dredge fisheries, but is also useful for informing the conditions likely to be encountered during future foot surveys and enforcement operations. • The data for the additional species are used to inform the fisheries' HRAs. These data have also been used in studies looking at potential fishery disturbance.
Evidence for HRA	Much of the data collected during the surveys is used as evidence to inform HRAs. These include stock biomass, cockle distributions (particularly Year-0 stocks), cockle age and size frequencies,	• The data from the cockle surveys are used to inform the Habitats Regulations Assessments for the fisheries. This information helps to confidently answer a wide range of questions about the impacts of potential disturbance and

	plus evidence of trends gained from the historic dataset.	inform mitigation. Care would need to be taken when considering potential changes to the survey regime, to ensure sufficient evidence was still collected to inform the HRA process.
Other uses	The historic dataset is a powerful resource holding a large quantity of spatial cockle and environmental data dating back to 2001. These data are regularly used, both by EIFCA and other users, in numerous studies and while developing management.	• Historic cockle and environmental spatial extents are used to inform decisions about several fishery lay applications, to demonstrate whether applications are in areas that have historically supported cockles or other important species. • Historic cockle spatial extents and densities are used to inform EIFCA projects looking into food availability and primary production. • Historic cockle data extents and stock biomass have been used by the Authority and Natural England to develop appropriate Conservation Objective targets for the site. • Cockle spatial extents and stock biomass are used by several other agencies and organisations (including Environment Agency, Cefas, various universities and consultancies) to inform their own studies.

Table 4 – Disadvantages of the current cockle survey regime

Disadvantage	Description
Resource costs	• The costs of the current survey regime are described in Appendix 1. These are a significant drain on Authority resources, including 15 vessel days and 132 officer days (based on 8-hour days). Including subsistence, these cost the Authority approximately £51,000/year. • The current survey regime requires staying out overnight to optimise sampling. This requires the Authority to have and maintain a vessel capable of accommodating a minimum of five crew overnight
Survey resolution	• Although the current survey regime has 1,464 stations, the highly variable distribution of the cockle stocks across the site mean the confidence margins for the stock biomass are +/- 11-13%. Improving on this, however, would have diminishing returns from the amount of additional effort required. • Because the survey stations are divided between 22 areas, the confidence margins are much wider when estimating cockle biomass on individual beds. • The distance between the survey stations determines the maximum resolution and accuracy of the charts depicting the modelled cockle distributions. With survey grids of 370m x 340m over the majority of the survey area, the modelled edges of beds could be up to 370m off from their actual position. This also applies to the resolution of any management measures that are based on these models. • By using a survey grid of 370m x 340m, a single $0.1m^2$ sample represents approximately 12.6 hectares of ground (or 9.5 hectares for the beds in the SW of The Wash where the resolution is 280m x 340m). This is either a 1.26 million-fold mark-up (or 0.95 million for the SW beds) when used to calculate cockle stocks. This means every 1 gram of cockles in a sample equates to 1.26 (or 0.95) tonnes on the ground. • Because the survey stations are up to 370m apart, it is possible for small dense patches of cockles to be totally missed. This has less significance on the results when cockle stocks are high, but can be quite significant when stocks are low (particularly when they are fragmented into small scattered patches).
Temporal accuracy	The surveys only form a snapshot of the stocks, as they are at the time of the survey. Subsequent growth and mortality have significant impacts on the stock biomass over time.

6.2 Mussel surveys

Table 5 – Benefits provided by the current mussel survey regime

Information	Description	Management benefit
Total stock biomass	The data are currently recorded and analysed to calculate the total biomass of three size ranges of mussels: • Adult (≥45mm length) mussels • Juvenile (25mm – 44mm length) mussels • Juvenile (<25mm length) mussels From these figures the total mussel biomass can be calculated.	• The total mussel biomass if required to ensure the total mussel biomass is maintained above the 12,000 tonnes Conservation Objective target threshold. • The adult (≥45mm length) mussel stock biomass is used to calculate the TAC for the harvestable fishery • The adult (≥45mm length) mussel stock biomass is required to ensure the adult stocks are maintained above the 7,000 tonnes Conservation Objective target threshold. • The juvenile (<45mm length) mussel stock biomass is used to calculate the TAC for the relaying seed fishery • The juvenile (<45mm length) mussel stock biomass is required to ensure the adult stocks are maintained above the 5,000 tonnes Shellfish Management Policy target threshold. • Mussel stock (≥25mm length) biomass required to calculate AFDM for food availability model
Total area and stock biomass on individual beds	The data are currently recorded and analysed to calculate the total biomass of Adult (≥45mm length) mussels, Juvenile (25mm – 44mm length)	• Mussel beds will only be opened to the harvestable fishery if they support ≥70 adult mussel biomass, and only opened to the relaying

	mussels and Juvenile (<25mm length) mussels on each of the beds. There are usually between 18-22 beds within the regulated fishery.	seed fishery if they support <70 adult mussel biomass. The adult and juvenile stock biomasses • Because fisheries should not reduce the mean densities of mussels on individual beds below 25 tonnes/hectare, the mussel stock biomass and area for each bed are required. These figures are used to calculate the maximum TAC that can be harvested from each bed. • In cases where only some beds are opened, this information helps to determine whether the TAC can be achieved from the open beds.
Mussel bed distribution	Mussel beds are relatively stable in The Wash, maintaining their general overall shape and extent for many years. The surveys provide annual updates on their shape and distribution.	• It is a SSSI conservation objective target to maintain a spatial spread of mussel beds across The Wash • Maintaining up-to-date shapefiles of the mussel beds aids sampling strategies of future surveys
Mussel size frequencies	The data are analysed to provide mussel size frequencies for each bed.	• Size frequencies of mussels are used to determine the respective stock biomasses required to open harvestable and relaying fisheries. • Size frequency data provides information about which beds have received successful settlements of seed, which can then be used to predict how well certain beds will respond to fishery disturbance.

		• Because mussels cannot be easily aged by annual growth rings, the age of strong cohorts can be tracked using size frequency data.
Historic data set	Analysis of a long-term dataset enables trends to be seen that can help inform predictions about future fisheries and mortality events.	• Long term data trends can be used to determine if newly established beds are vulnerable to being washed away • Historic survey data coupled with fishery data can be used to identify which beds recover well or poorly from fishing pressure • Long term survey data coupled with mussel size frequency data can be used to predict when and where high mortalities are likely to occur.
Evidence for HRA	Much of the data collected during the surveys is used as evidence to inform HRAs. These include stock biomass, bed distributions and area, plus evidence of trends gained from the historic dataset.	• The data from the mussel surveys are used to inform the Habitats Regulations Assessments for the harvestable and relaying mussel fisheries. This information helps to confidently answer a wide range of questions about the impacts of potential disturbance and inform mitigation. Care would need to be taken when considering potential changes to the survey regime, to ensure sufficient evidence was still collected to inform the HRA process.
Other uses	As with the cockle survey data, the historic dataset is a powerful resource holding a large quantity of spatial mussel data dating back to 2001. These data are regularly used, both by EIFCA and other users, in numerous studies and while developing management.	• Historic spatial extents of mussel beds are used to inform decisions about several fishery lay applications, to demonstrate whether applications are in areas that have historically supported wild mussel beds.

		• Historic spatial extents of mussel beds and densities are used to inform EIFCA projects looking into food availability and primary production. • Historic mussel bed distributions and stock biomass have been used by the Authority and Natural England to develop appropriate Conservation Objective targets for the site. • Spatial extents of mussel beds and stock biomass are used by several other agencies and organisations (including Environment Agency, Cefas, various universities and consultancies) to inform their own studies.

Table 6 – Disadvantages of the current mussel survey regime

Disadvantage	Description
Resource costs	• The costs of the current survey regime are described in Appendix 1. These are a significant drain on Authority resources, including approximately 20 vessel days and 154 officer days (based on 8-hour days). Including subsistence, these cost the Authority approximately £60,000/year. • Because most of the beds are only accessible using a vessel, the Authority needs to have and maintain an appropriate vessel. As most of the beds are difficult to access from shore, the vessel needs to be capable of drying out on sandbanks.
Bed access	• Because of the distances between beds, it is generally only possible to survey one (or occasionally two) beds each day. Although some of the beds are small, requiring only a short survey, the logistics of accessing them mean a full day is required to survey them.
Level of detail	• The coverage and densities of mussels can vary greatly across individual mussel beds. The surveys only record their mean densities and coverage, however. This can result in fishing opportunities on some beds appearing better or worse than they actually are. This lack of detail also limits how fishery disturbance can be recorded.
Subjective approach to mapping bed perimeters	• In many cases a bed will be composed of core patches of mussels (frequently interspaced with bare or low-density patches) that are surrounded with wide areas of low density mussels or areas containing small scattered clumps of mussels. This can make mapping the perimeter (and thus, the area) of a mussel bed quite difficult. As it can be quite subjective determining what density of mussel should be included within the bed, results can vary between surveyors.

7.0 Review of cockle survey regime to identify savings and associated risks

The cockle surveys and the management of the cockle fishery have both evolved over time alongside each other. In many cases, the management measures and fishery and environmental targets have been developed using metrics that the surveys were known to provide. As such, there is a strong connection between them. This review will look at various ways in which savings could potentially be made. As most of these will carry varying degrees of risk, either in diminished accuracy or by no longer being able to provide certain required information, the associated risks will also be described.

This review will look at ways in which costs can be reduced in two ways:

1. By streamlining the current survey regime
2. By exploring alternative methods and approaches

7.1 Streamlining the current survey regime

The most significant component of the current cockle survey costs are the 15 days that the research vessel *Three Counties* and its crew of 5 are at sea conducting the surveys. This is a good starting point, therefore, to identify possible savings. These could include ideas such as reducing the number the crew (described in 7.1.1), using an alternative vessel (described in 7.1.2) and identifying ways of reducing the number of days at sea by reducing the survey effort (described in 7.1.3).

7.1.1 Reducing crew numbers

When conducting cockle surveys with a Day grab deployed from *Three Counties*, 5 crew are used. These are:

- 1 skipper – responsible for safe navigation of the vessel between stations and holding the vessel on station while the grab is deployed.
- 1 winch/A-frame operator – responsible for operating the A-frame and winch that deploys and recovers the grab. This crew member is usually the vessel's engineer, who is also responsible for conducting regular inspections of the engine rooms (every half hour) and making minor repairs if needed.
- 2 grab operators/sample washers – responsible for safely deploying and recovering the grab, then washing and sorting the samples between successive grabs.
- 1 sample recorder – responsible for bagging and labelling each sample, recording associated data and updating the vessel plotter showing which samples have been collected. When the engineer is conducting engine room inspections, the sample recorder operates the winch/A-frame. If the samples contain more shell or cockle spat than the sample washers can sort between grabs, the sample recorder also processes the back-log of samples.

When the weather conditions are calm, and the samples are relatively clean (sandy conditions that do not require much cleaning or sorting), four experienced officers can conduct the survey. In these circumstances, a single crew person acts as sample washer and is assisted by the sample recorder when recovering the grab. Alternatively, the sample recorder can act as the winch/A-frame operator, allowing 2 crew to remain operating the grab and washing samples. However, this number of crew can only operate like this when conditions are calm and the samples do not require much sorting. Once sea conditions worsen or the samples are muddy or require a lot of sorting, the loss the additional crew person becomes apparent and the rate of sampling decreases. Additionally, because this arrangement does not allow the spare capacity for the engineer to conduct the necessary engine room inspections, operations need to stop for five minutes every half hour to allow them to be conducted. Although the vessel is fitted with engine sensors and fire, smoke and flood alarms, failure to conduct these inspections and regular maintenance could lead to engines being damaged, requiring cancellation of surveys and expensive repairs.

The rate that samples are collected depends a great deal on weather conditions and how much sorting and cleaning the samples require. In calm conditions, the vessel can steam in straight lines between samples, and deploy the grab once on station. Under these conditions, if the samples do not require much sorting, a rate of about 22 samples/hour can be achieved. In poorer sea conditions, however, which from experience seem to occur about half the time, the vessel needs to turn head-to-sea once on station in order to provide a stable enough platform for the grab to be deployed safely. This additional manoeuvring, first turning head-to-sea, then turning back towards the next station, costs about 1 minute per sample, reducing sampling rates to about 15 samples/hour. Washing and sorting of samples is conducted between grabs. When the substrate is sandy this is easily achievable. When the samples are muddy or contain a lot of shell or small cockle spat, however, which is the situation in approximately half of the samples, it takes longer to sort them. Usually, if the sample recorder is able to assist, the crew are able to keep pace and a sample rate of about 18-20 samples/hour can be maintained. If only 4 crew are present, however, this support would not be available and the sampling rate would decline significantly.

Operating the vessel with 4 crew rather than 5 over a 15-day survey period would result in savings of £3,832.20 in wages and £573.15 in subsistence (total £4,405.35). Based on 50% cost recovery spread over 62 entitlement holders, this would be a saving of £35.53 per entitlement. However, due to the associated inefficiencies described above for operating with a sub-optimal crew, the average sample rate would decline from approximately 17.5 grabs/hour to 14 grabs/hour. At these rates, the surveys would require the vessel to be at sea for 19 days instead of 15 days. This would incur additional costs which rather than resulting in net savings being made, would result in the cost of the surveys actually increasing by £6,764.09 (equivalent to £54.55 per entitlement).

7.1.2 Using an alternative vessel for surveys

The surveys are currently conducted using the Authority's own research vessel, *Three Counties*. This vessel has been designed with a large A-frame for efficient deployment of a Day grab, and the accommodation and facilities for the crew to remain at sea overnight during the surveys. It also has the space and equipment required for efficient washing and sorting of the samples.

The main disadvantage of *Three Counties* is its 10 knots maximum speed, which means it takes a relatively long time to steam from port to the areas being sampled compared to a faster vessel. When operating out of a tidal port with an access window of about 4 hours per tide, this can pose severe restrictions on surveying activities, particularly as both accessing the port and the survey areas requires the same high-water states of the tide. If the surveys were to be conducted purely as day-trips, much of the potential survey time would be lost due to steaming back and forth. This can be seen from the figures in table 7, which highlight how long a 10kn vessel would take to reach the various survey areas when pushing into the prevailing 3 knot tides. For most areas, the vessel would take between 1 and 2 hours to reach the survey sites. This would limit surveying operations in those areas to a maximum of between 4-6 hours per day. Under the current survey regime, this problem is minimised by keeping the vessel at sea overnight for 3 or 4 days at a time. Because the vessel then only needs to access port on the first and last tide of each trip, the actual survey opportunities are maximised. In terms of cost, operating day-trips with a slow vessel would save a small amount on crew subsistence, but significantly increase the number of days taken to conduct the survey.

Table 7 – The distances from Sutton Bridge moorings to various survey areas and the time taken to steam to them at 7 knots and 15 knots

Survey area	Distance from Sutton Bridge Port (nm)	Time taken to access at 7kn (minutes)	Time taken to access at 15kn (minutes)
IWMK	5	43	20
Breast	8	69	32
Thief	8	69	32
Holbeach	8	69	32
Daseley's	9	77	36
Mare Tail	10	86	40
Gat	10	86	40
Herring Hill	12	103	48
Roger/Toft	12	103	48
Butterwick	13	112	52
Wrangle	14	120	56
Friskney	16	137	64

7.1.2.1 Chartering a faster research vessel for surveys, eliminating requirement for overnight surveys

If a faster vessel was used instead of *Three Counties*, less time would be required to steam between port and the survey areas. Table 7 shows the time that would be required to reach the various sands by a 18kn vessel when pushing prevailing 3kn tides. At this speed most areas can be accessed in under an hour, which would leave a maximum of 6 hours per day for surveying. It should be noted, however, that once at the survey site, no added benefit would be gained from the vessel's faster speed because sampling rates would still be limited by how long it takes to deploy/recover the grab and wash/sort the samples. Although, in theory, *Three Counties* can access the survey areas for 8 hours each day by staying at sea overnight, her slower access times at the start and end of each trip reduces the average available time to a level similar to what an 18kn vessel would achieve during day-trips.

On the surface, using a faster vessel to conduct the surveys appears a feasible option. In reality, however, it poses problems with the MCA regulations concerning maximum working hours at sea. These regulations restrict crew from working more than 14 hours per day and require at least one 6-hour uninterrupted break. When calculating the maximum time available for surveying, the assumption was made the vessel would leave port 2 hours before high water and return 2 hours after high water on the following tide. Due to the rate which tides advance, that would usually mean the vessel would be away from port 16.5 hours each day. Once time is added for driving each way between the office and the moorings, conducting pre-voyage engine checks and measuring the samples collected on the second tide (the first set of samples being measured during the first low water period at sea), the crew would potentially be working 19-20 hours/day. These hours could be reduced if the crew were taken off duty during the 8-hour low-water period they were at sea and did not measure the samples they collected during the second high-water sampling period. This, however, would require a second team to be available to measure the samples ashore the following day. This would not only require additional staff, but water loss from the cockles during that period would result in the cockles losing weight. This weight loss would result in the fishery having a reduced TAC and the potential for some of the target thresholds not being achieved. This is not a problem when conducting surveys on *Three Counties*, as all samples are measured during the low water periods while at sea, or on returning to port at the end of the last day.

In terms of savings, a fast research vessel working day-trips would take the same number of days to conduct the surveys as *Three Counties*. However, when chartering vessels, down time, lost sea days and transit to and from their home port is usually charged. Because it is only practical to conduct the surveys during spring tides, unless the vessel was based locally, the additional charges incurred for down time or transiting to and from the vessel's home port would be a significant surcharge. The only recent experience the Authority has of hiring a fast research vessel is K&EIFCA's

research vessel, *Tamesis*, which was used to conduct cockle surveys in the Suffolk rivers in 2012. At that time the Authority had a MOU with K&EIFCA regarding the use of *Tamesis* and its charter costs. In 2012 the charter rate for *Tamesis* was £1,500 per 7.5 hour day or £1,800 per 12 hour day (and £300 per 3 hour period thereafter). These costs were discussed in an Authority paper for a meeting held on 25th April 2012 (see Appendix 2). Even without taking into account transit times to and from its home port, the cost of *Tamesis* is higher than that of *Three Counties*. Some savings would be made on crew, however, as the Authority would only need to supply two crew. Based on the 2012 figures, the approximate cost of conducting the surveys using *Tamesis* instead of *Three Counties* would be £65,138 (based on 15 x 16.5 hour survey days, 6 x 12hour transit days, 2 x crew/day, plus 2 additional crew measuring samples after each trip). Using this vessel to conduct the surveys would, therefore, cost an additional £15,000 to that currently used, equivalent to £242 per entitlement. Unless a local vessel could be chartered, whose daily costs were equal to or lower than that of *Three Counties*, this option would not be cost effective. Should the Authority at some stage replace *Three Counties* with a fast day-boat, the figures indicate the costs and time taken to conduct the surveys would be similar to those currently incurred.

<u>7.1.2.2 Chartering fishing vessels for surveys</u>

Another alternative is to look at the potential to use a local fishing boat to conduct the survey fieldwork. These have similar or slightly slower speeds to *Three Counties,* but would most likely be accessing the beds from either King's Lynn or Boston. As mentioned above, with a slower vessel, the most efficient way of conducting the surveys is to remain at sea for several days, negating the daily transits to and from port. If the fishing boat had the capability and accommodation to remain at sea for several days at a time, the survey should in theory take a similar number of days to complete as when conducted from *Three Counties*. In reality, this would potentially not be the case. Although the modern fishing vessels operating in The Wash have Hiab deck cranes, and various derricks and lifting arms that could be used for deploying the grab, these have been designed primarily for lifting and deploying heavy gear a few times each day rather than the rapid deployment and recovery of a grab. Grab deployment on *Three Counties* is conducted using a small winch mounted on a hydraulic retractable A-frame, which has proven to be highly efficient for rapid grab deployment and recovery. Prior to buying *Three Counties*, the Authority used another research vessel, *Surveyor*, for conducting the surveys. This used a Hiab deck crane for deploying the grab, but even in ideal conditions could only achieve a sampling rate of about 14 grabs/hour compared to the average 17.5 grabs/hour achieved by *Three Counties*. Based on these figures, this reduction in sampling rate would extend the survey time and associated costs from 15 days to approximately 19 days.

If the fishing vessel did not have the capability of remaining at sea for three or four days at a time, the number of required sea days to conduct a grab survey would be considerably longer as daily transit to and from port would be required. These transit times could be reduced if vessels from King's Lynn were used to conduct surveys on the east side of The Wash and from Boston for the west side. If such vessels remained at sea for 16.5 hours per day, potentially 4-5 hours could be spent grabbing. Using the grab rates of 14/hour described above for deployment using a Hiab crane, this would achieve approximately 56-70 grabs per day. At this rate the current survey regime would take about 18-23 vessel-sea days to complete, but would encounter the same issues as described in section 7.2.1.1 regarding excessive working hours of crew. This would require additional staff to be available to measure samples ashore.

The Authority has chartered fishing vessels to conduct specific research projects on a number of occasions in the past ten years. Tenders for such work have varied in vessel costs ranging from £962/day (for a joint project with the industry, where the vessels were going to be chartered at cost) to over £2,000/day. In all these cases, however, the planned work was for trips not exceeding 12 hours/day, so costs for 16.5 hour trips or for working 3 or 4 days at a time would potentially be higher.

Table 8 below shows the costs of the surveys at various charter prices for vessels. These figures assume the vessel will have its own crew of 3 who will be able support 2 IFCA officers conduct the survey. In addition to the 2 IFCA staff aboard the vessel, 2 additional staff would be required to measure samples ashore. Staff costs also include subsistence for meals but do not include travel. Costs are shown for scenarios in which the vessel was hired for 15, 18 and 23 days.

Table 8 – The costs of hiring a fishing vessel to conduct the cockle surveys

Days	Vessel cost	Vessel cost	Vessel cost	IFCA staff cost
Daily cost	1,000	1,500	2,000	800
15	15,000	22,500	30,000	12,000
18	18,000	27,000	36,000	14,400
23	23,000	34,500	46,000	18,400

It can be calculated from table 8 that the fieldwork for the surveys would range from a minimum of £27,000 (15 days @ £1,000/day vessel charter) to £64,400 (23 days @ £2,000/day vessel charter). For reasons described above, however, unless the chartered vessel was equipped with a winch mounted on a retractable A-frame, it is unlikely to be able to complete the current survey regime in under 18 days. For that duration, the minimum cost of survey fieldwork would be £32,400. In addition to the costs of conducting the fieldwork are the costs associated with data analysis and reporting. These are currently £4,574.40.

These figures provide a wide range of costs that are dependant on how much vessel charter would be and how many days the vessel would take to conduct the surveys. Invitations for vessel owners to provide charter costs could be undertaken to better inform these figures, but until a survey is conducted on one of these vessels, the sampling rate and time taken to conduct the survey would be unknown.

When considering the savings that can be made by utilising alternative vessels, it must be remembered that the Authority is currently seeking 50% cost recovery, with the remaining 50% coming from public funding (e.g. the IFCA levy). This is achievable because the use of existing IFCA resources, in this case *Three Counties*, is not an additional cost to the Authority. Chartering alternative vessels to conduct the surveys would be an additional burden, so might require a higher level of cost recovery.

When considering chartering other vessels for conducting the surveys, Health and Safety considerations must not be neglected. Because the grab is deployed and recovered over 1,250 times during the course of a survey, it is important that the lifting equipment is suitable for ease of deployment and allows the grab to be safely lifted from and lowered onto its stand without a lot of swinging or banging. When the grab was previously deployed from a modern fishing vessel during a sub-littoral mussel survey, a derrick was used for deployment. Because there wasn't much lateral movement on the derrick, the grab could not be swung easily inboard. This meant that the grab needed to be man-handled inboard as it was lowered and tended to swing violently outboard when lifted. During that particular survey, the grab was damaged after about 25 grabs, after it hit the rail while being deployed. This resulted in the survey being cancelled prematurely. The operators also had to take great care to avoid injury. When considering the use of alternative vessels, the Authority must be assured of safe working conditions for its officers and minimise the risk of damaging equipment that would lead to the delay in sampling.

7.1.3 Reducing the number of survey stations

Under the current survey regime, there are a total of 1,464 stations that are divided between 22 survey areas. Most years, however, only 1,150-1,250 of these stations get sampled. 79 of the stations that are regularly missed are located on the Long Sand. This bed only attracts cockle settlement on rare occasions and in recent decades, has only supported a significant cockle fishery in 1979. As such, this bed is only surveyed if there is time remaining at the end of the end of the survey programme, which relies on no time being lost through poor weather or breakdowns. The remaining stations that are frequently missed are those located at elevations above 4.0m chart datum. These mostly form a band along the upper shoreline, close to the green marsh areas of the coast. These were not originally part of the survey regime but were added in 2004, when due to technical issues with *Three Counties*, a high proportion of the surveys were conducted on foot by walking off from shore. As these sites were being walked over in order to access the existing stations, stations were added and sampled. However, once the surveys reverted back to using *Three Counties*, they proved difficult to access with a vessel due to their height. Omission of these sites is thought to have little impact on the size of the TAC because on the occasions they have been sampled, they have been found to support only low densities of cockles, few of which reach 14mm width (the size at which cockles contribute towards the TAC). Figure 7 shows the frequency that each survey station has been sampled during the past ten years. When options are considered in the following sections of ways in which the number of survey stations can be reduced, it should be remembered that not all stations are currently sampled every year.

When various options are considered for reducing the number of survey stations, care should be taken to ensure bias is not inadvertently introduced into the sampling regime. This was mentioned briefly in section 4.5, when describing the current method of data analysis. Basically, if the survey strategy uses a random sampling strategy, every piece of ground within the survey area should stand an equal opportunity of being sampled. Similarly, when using a standard grid strategy, as we currently do, each part of the survey area should be given equal representation. Failure to achieve this would produce overestimations of stock if sampling was higher in high cockle density areas than low density areas, and an underestimation of stock if the other way around. The same resolution of sampling should, therefore, be applied across the whole survey area. This is a particularly important factor to take into account when considering strategic and semi-strategic sampling patterns, that deliberately increase sampling resolution in areas known to support higher concentrations of stock.

It should be noted, that if the stock for the whole Wash was calculated as a single sum using all of our current stations, sampling bias <u>would</u> exist. This is because the survey stations in the Black Buoy, Herring Hill, Mare Tail, Gat and Holbeach survey areas are closer together than those used elsewhere in The Wash. While this produces higher resolution, more accurate data for these areas, it could lead to stock calculations being biased towards whatever stocks are in these regions. When calculating stocks, however, this bias is currently removed by calculating the stock for each individual survey area, then summing these results together rather than pooling all of the data into a single group and making a single calculation. Consideration should be given to this potential source of bias when alternative methods are discussed.

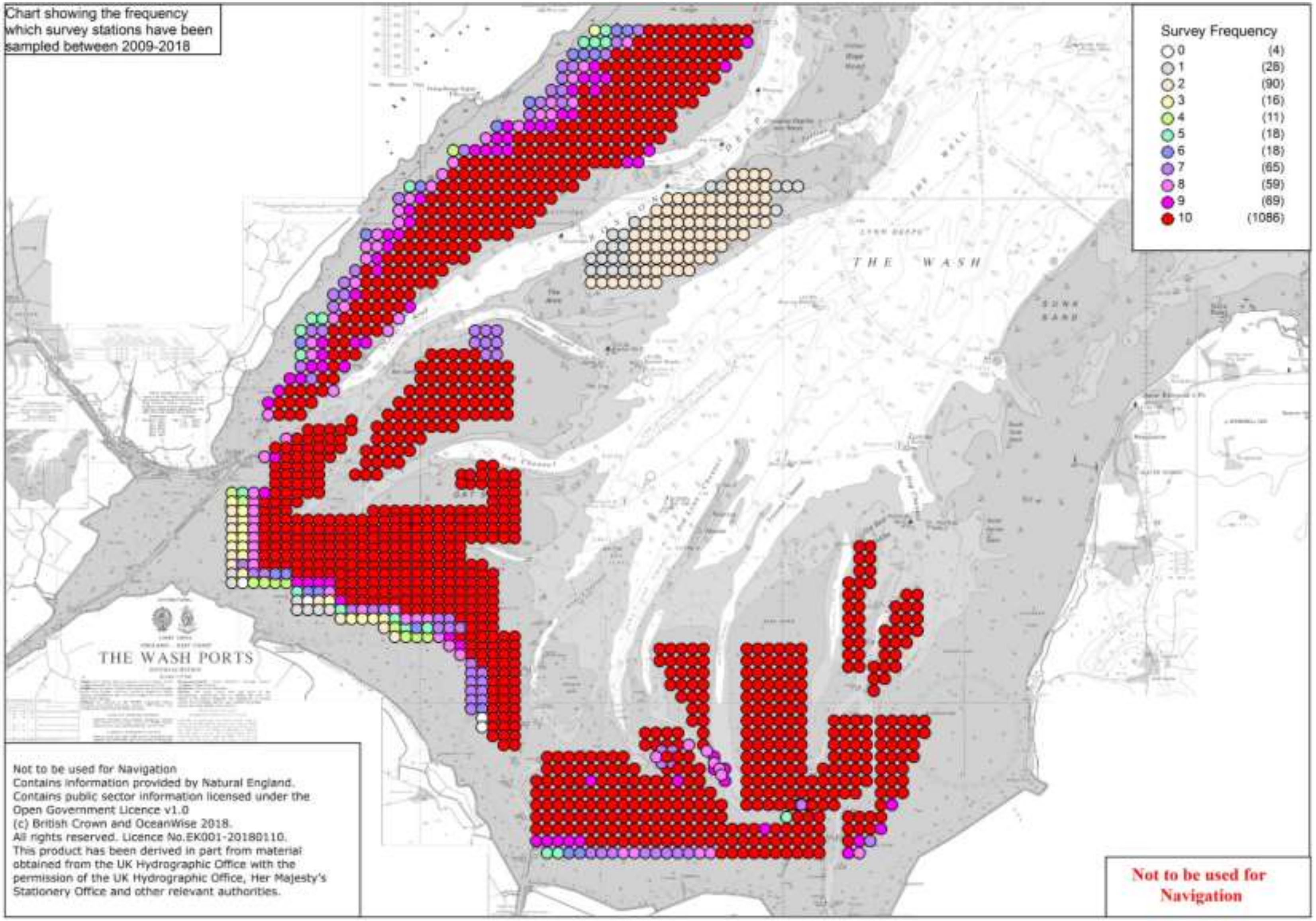

Figure 7 – Chart showing the cockle survey stations and the frequency they have been surveyed between 2009-2018

7.1.3.1 Removal of whole beds from survey area

When looking to reduce the number of sample stations from the survey regime, the simplest approach would be to remove entire survey areas from the regime. Table 9 shows how many stations would be saved by omitting each area and the biomass of “adult” (≥14mm width) cockles that have been identified in those areas during each survey.

Table 9 – The number of stations sampled in each area and the biomass of adult cockles found at those sites since 2008

Area	Stations	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Mean
Butterwick	42	678	419	37	67	470	555	260	137	417	437	195	**334**
Wrangle	96	2326	288	182	150	1833	709	243	166	5616	2155	1329	**1363**
Friskney	84	2001	276	119	63	460	209	79	50	4254	1684	1316	**956**
Butterwick Ext	36	751	103	122	248	146	246	182	191	222	500	312	**275**
Wrangle Ext	29	197	76	33	15	54	35	40	75	140	63	78	**73**
Friskney Ext	103	1060	325	100	53	277	313	76	116	895	432	289	**358**
Roger/Toft	81	384	397	79	118	84	538	621	477	3464	4578	1549	**1117**
Gat	65	636	37	9	6	18	13	130	39	1178	171	546	**253**
Longsand	79	0	n/a	n/a	0	0	n/a	n/a	n/a	n/a	n/a	n/a	**0**
Herring Hill	54	419	168	559	493	154	607	392	463	313	224	226	**365**
Black Buoy	36		2280	291	137	55	536	546	531	282	824	548	**548**
Mare Tail	66	181	417	1108	753	456	946	1418	826	1502	1427	1447	**953**
Holbeach	197	1330	986	947	480	378	1395	2341	590	1186	2079	951	**1151**
IWMK	41	894	762	439	396	455	1315	1210	574	292	615	576	**684**
Breast	129	785	1362	1548	1039	1508	2045	2114	1172	1535	1790	1677	**1507**
Thief	32	164	104	209	308	37	53	22	6	3311	1969	1008	**654**
Whiting Shoal	17	n/a	287	572	143	110	111	0	0	13	0	258	**136**
Daseley's	84	417	32	367	477	200	1253	967	388	1089	1524	494	**655**
Styleman's	23	74	22	7	5	320	0	0	0	36	331	262	**96**
Pandora	35	144	7	34	0	45	158	355	139	43	136	50	**101**
Blackguard	23	50	47	25	0	16	0	0	0	0	23	0	**15**
Peter Black	42	96	419	16	0	0	122	13	78	38	86	275	**104**

The disadvantage of omitting whole survey areas from the survey regime is the loss of information from those omitted areas. At present, the biomass of cockles in each area is summed to produce a stock for the regulated beds. The biomass of those cockles that have reached 14mm width is used to calculate the TAC. If some of the survey areas were omitted from the survey programme, the risk to the fishers could be a significant loss of TAC that could far outweigh any potential savings that would be made in reducing the time spent conducting the surveys. The right-hand column of table 9 shows the mean biomass of ≥14mm width cockles that have been estimated to be present in each survey area between 2008-2018. These figures are between 0 tonnes for the Long Sand, which was only surveyed twice during this 11-year period, and 1,507 tonnes for the Breast sand. During this period only the Wrangle Extension, Long Sand, Styleman's and Blackguard sites have averaged less than 100 tonnes. The removal of these four areas from the survey regime would reduce the number of stations by 154. However, as the Long Sand has only been surveyed twice in 11 years (only being surveyed when time has allowed at the end of the usual survey programme), the time spent surveying the 79 stations present on this bed would not actually be saved if this bed was removed from the survey programme. As such, the saving from removing these four beds would be 75 stations.

Based on the current survey regime using *Three Counties* to conduct surveys, in which an average sample rate of 17.5 grabs/hour is achieved while grabbing, this would save approximately 4 ¼ hours of grabbing and up to 3 hours of steaming (as these sites are currently sampled when the vessel is conducting surveys on nearby beds). The figures in appendix 1, show the costs for *Three Counties* and crew (including subsistence) is £3,086.05 per 12 hour/day. The 7 ¼ hour saving for not sampling these beds would, therefore, be £1,864.49. Divided between the 62 entitlements, at 50% cost recovery, this would result in a saving of £15.03 per entitlement.

It is difficult determining what the cost to the fishery would be if these beds were omitted from the survey, as the stocks on them have fluctuated over time and the value of cockles also changes regularly. These beds have supported an average of 184 tonnes of cockles ≥14mm width between them during this period. These would have contributed 61 tonnes towards the annual TAC. Based on a figure of £350/tonne, this would equate to an average loss of TAC worth £21,350 to the fishery (equivalent to £344.35 per entitlement). In actuality, these losses could be greater, as in some years these beds have supported between 300 and 417 tonnes of adult cockles - contributing between 100 and 139 tonnes to the TAC. The £350/tonne value used in these calculations is also a conservative estimate, sometimes reaching £600 to £800/tonne. Potential loss to the industry by taking this approach, therefore, is likely to be far greater than any benefits that would be achieved.

This approach could also lead to additional problems when managing the fishery. Areas that have been identified as supporting high levels of juvenile stock are currently protected from the fishery using spatial closures. Without the evidence to show significant juvenile stocks were not present, a precautionary approach would need to be applied. Without evidence, therefore, it would be difficult for managers to open these beds to the fishery. In addition to restricting access to the industry, this could also result in additional costs as the Authority would need to monitor and enforce these closures.

This approach poses a further risk when considering the minimum stock thresholds that need to be met before a fishery can be opened. Although the stocks are usually safely above these thresholds, during years where stock levels are poor, the cockles present on these beds could be critical in achieving the required targets to open a fishery.

So far when considering this option, the assumption has been taken that if a bed is omitted from the survey programme, there will be no evidence submitted for those areas for that particular year. As such, there would be a loss of TAC and potential closures. Management decisions, however, require “best available” evidence. This does not necessarily mean the evidence has to be recent. In the absence of recent data, older data would become the best available. If this approach were to be used, there could be potential for using average stock values, or most recent values in lieu of conducting surveys in every area each year. This could have the potential to reduce sampling efforts significantly, as in theory a regime could be used whereby individual beds were only surveyed in rotation once every four or five years. This could enable a sampling regime of just 250-300 stations to be used each year.

The main risk associated with this approach would be loss of accuracy. When surveying stable populations, the loss of one or more years’ data would not create large inaccuracies. Table 9, however, highlights how variable the cockle stocks on individual beds can be from one year to the next. Figures 8-13 show graphically these variations on six of the beds. The first three of these show definite peaks in stock in either 2016 or 2017, while the other three show a more generalised level of stock over the decade, albeit still fluctuating annually. From the perspective of adopting a survey regime in which beds would only be surveyed on a rotational basis, with one or more years passing between surveys, these annual fluctuations could lead to large errors. If, for instance, Wrangle or the Thief beds had not been surveyed in 2016, their mean values of 1,363 tonnes and 654 tonnes may have been used in the stock assessment summary rather their actual estimations of 5,616 tonnes and 3,311 tonnes. This would have been a significant loss of fishing opportunity to the industry in terms of lost TAC. On the other hand, if those beds were surveyed on that particular year, and then not surveyed again for several years, those peaks in stock would artificially inflate the TAC for several years, possibly impacting the sustainability of the fishery. Even if the sustainability were not impacted, the charts showing stock distributions would be very inaccurate and of no use to fishermen using them to guide where they fished.

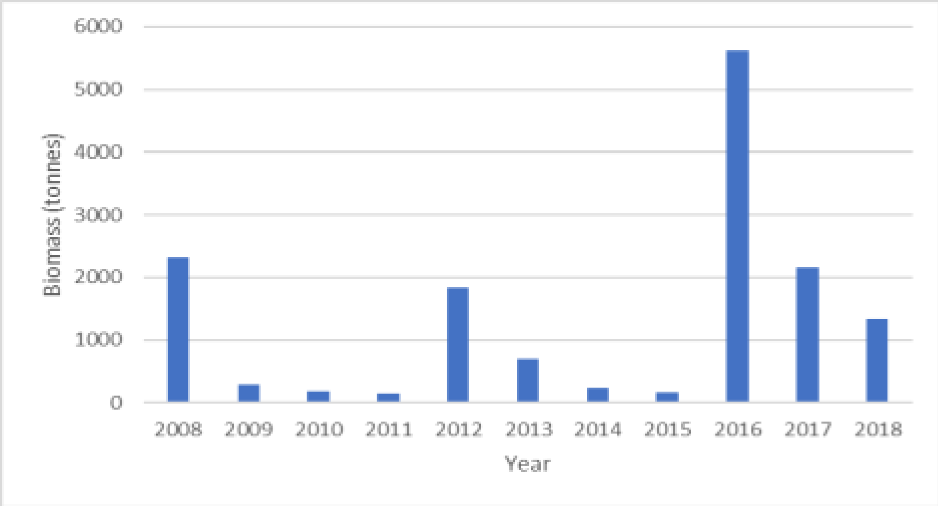

Figure 8 – Chart showing biomass of adult cockles on Wrangle between 2008-2018

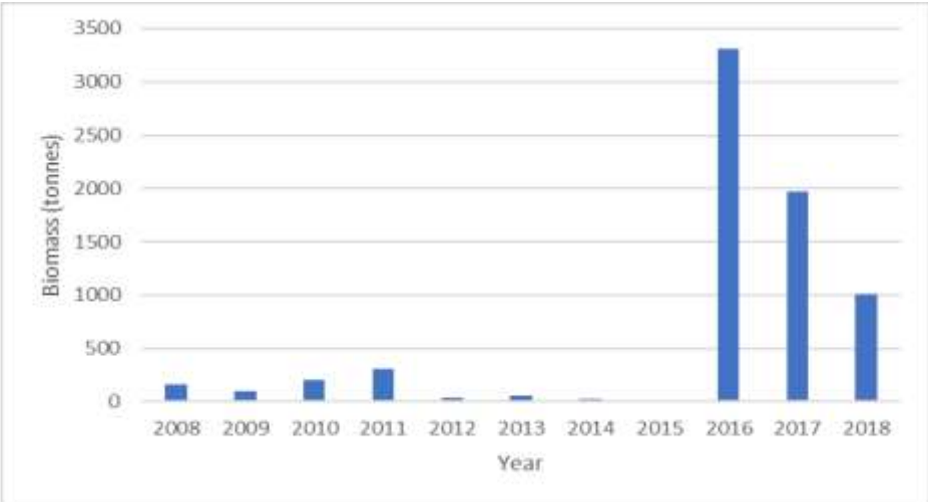

Figure 9 – Chart showing biomass of adult cockles on the Thief between 2008-2018

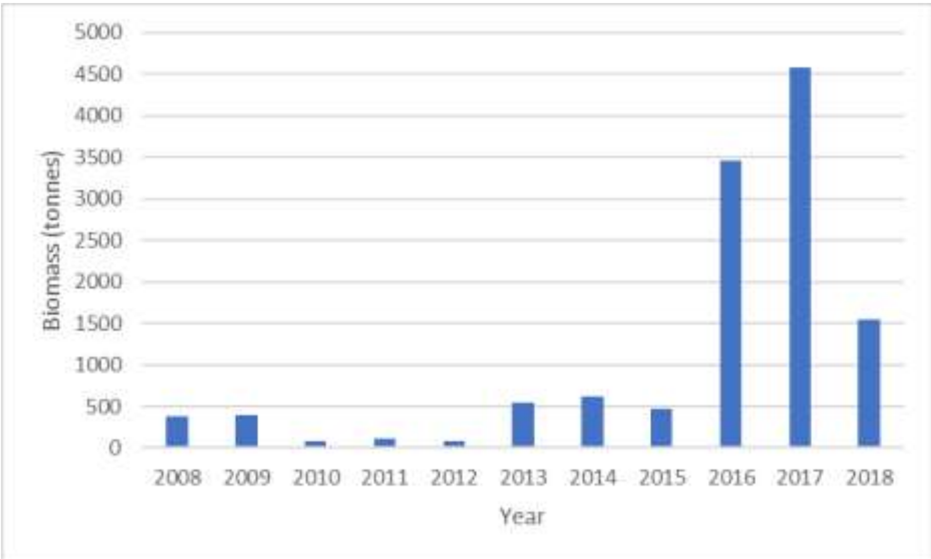

Figure 10 – Chart showing biomass of adult cockles on Roger/Toft between 2008-2018

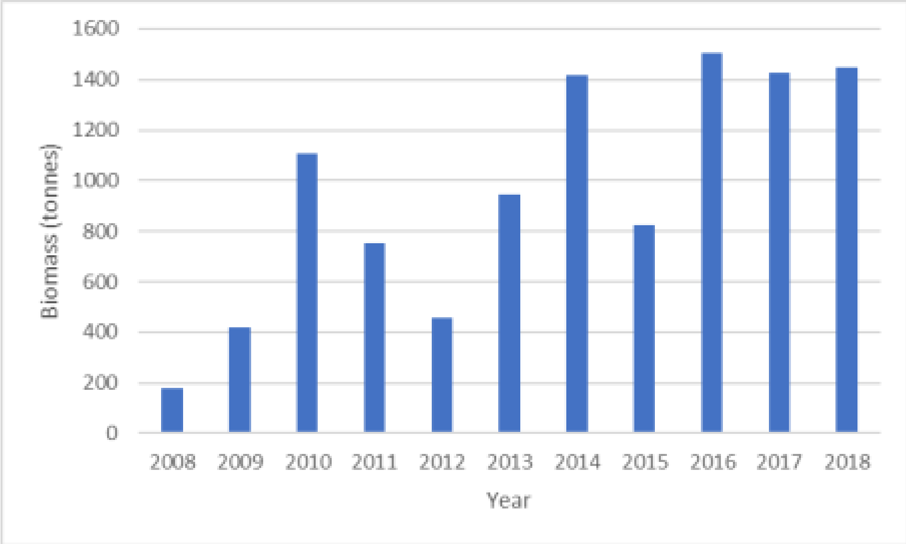

Figure 11 – Chart showing biomass of adult cockles on Mare Tail between 2008-2018

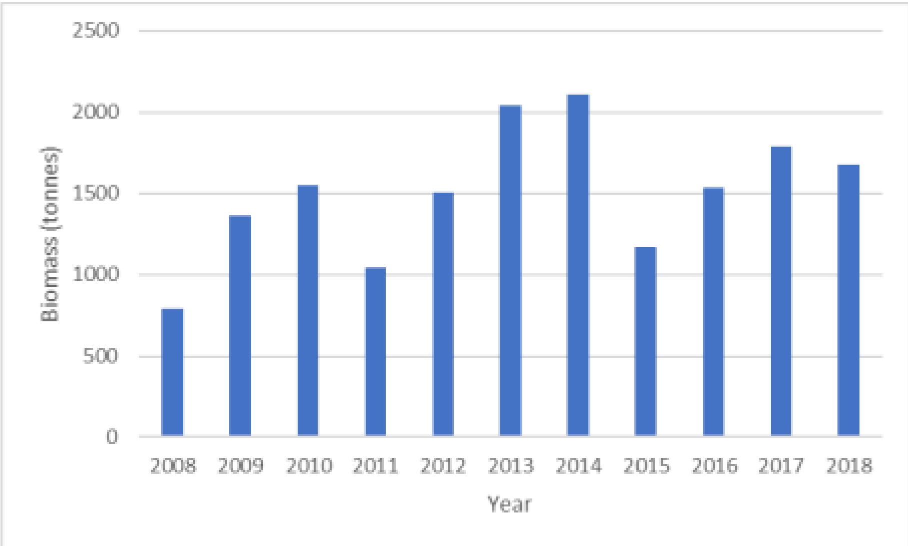

Figure 12 – Chart showing biomass of adult cockles on the Breast between 2008-2018

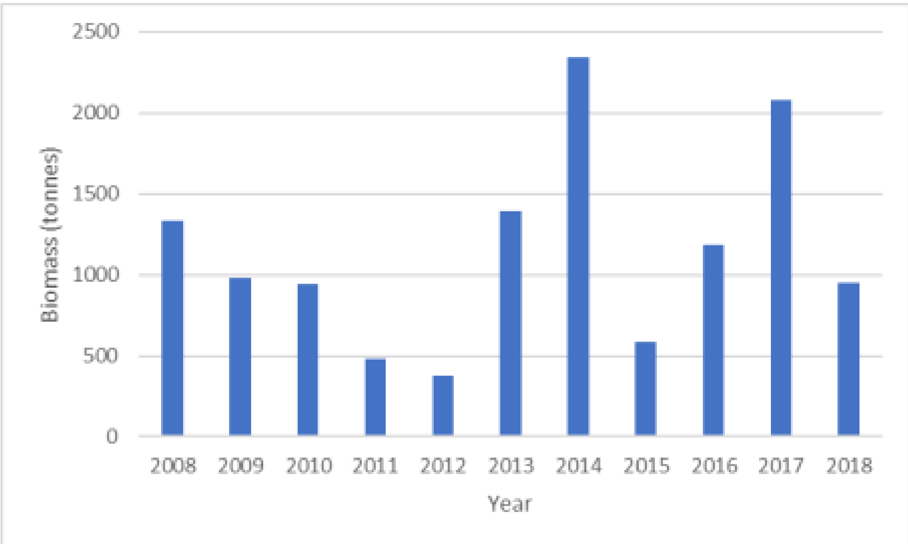

Figure 13 – Chart showing biomass of adult cockles on Holbeach between 2008-2018

The variability of the annual stock levels seen in each survey area over the 11-year period can be expressed in terms of their 95% confidence intervals. These are shown in table 10.

Table 10 – The mean biomass of adult cockles found on each bed between 2008-2018 and their 95% confidence intervals

Area	Stations	Mean	95% CI
Butterwick	42	334	140
Wrangle	96	1363	1104
Friskney	84	956	875
Butterwick Ext	36	275	129
Wrangle Ext	29	73	35
Friskney Ext	103	358	223
Roger/Toft	81	1117	1016
Gat	65	253	255
Longsand	79	0	0
Herring Hill	54	365	106
Black Buoy	36	548	425
Mare Tail	66	953	315
Holbeach	197	1151	416
IWMK	41	684	223
Breast	129	1507	272
Thief	32	654	715
Whiting Shoal	17	136	122
Daseley's	84	655	320
Styleman's	23	96	92
Pandora	35	101	69
Blackguard	23	15	13
Peter Black	42	104	88

While these confidence intervals do <u>not</u> mean that in any given year the stocks have a 95% chance of falling within the given range, the width of the range does provide an indication of how variable the figures are, and therefore how reliable future estimations based on them would be. Using these figures, for example, on the Wrangle stocks, the mean stock over the 11-year period is 1,363 tonnes. However, with a confidence interval of 1,104 tonnes, this produces a 95% confidence interval range of 1,363 +/- 1,104 tonnes, or a range of 259 tonnes to 2,467 tonnes. This is quite a wide range, so any approach to estimate stocks based on average values in lieu of up-to-date data would have a high probability of being inaccurate. These high stock variations are evident on most of the beds, making them unsuitable for this approach. The most stable, with the least variability compared to mean stock level, appears to be the Breast sand. This has a mean adult cockle biomass of 1,507 tonnes with 95% confidence intervals of +/- 272 tonnes; so a range of 1,235 tonnes to 1,779 tonnes. If this bed was only surveyed once every four years, with a rolling average being used in those years surveys did not occur, for those years the bed was not surveyed, there would be a saving of 129 stations. Taking into account the muddy conditions encountered over much of this bed, which slows the sampling rate, this would equate to a saving of one full day from the survey programme, which from appendix 1 would be £3,086.05 each year the survey was not conducted. Divided between the 62 entitlements, at 50% cost recovery, this would result in a saving of £24.89 per entitlement. However, the risk associated with doing this would include lack of up-to-date knowledge of whether the bed supported high densities of Year-0 cockles that needed protecting. If a precautionary approach was taken, this could lead to this bed having to remain closed if other means could not be found to determine if and where juvenile cockles were located. Additionally, using a mean value would underestimate stocks in good years and overestimate them in poor years. Looking at figure 12, which shows the adult cockle biomass present on this sand between 2008-2018, if a mean value of 1,507 tonnes had been used in 2008, the stocks would have been overestimated by 722 tonnes. This would have resulted in the fishery gaining an additional 241 tonnes of TAC, which at £350/tonne would have been worth £84.350, an equivalent of £1,360 per entitlement. However, in 2014 the stock would have been underestimated by 607 tonnes, resulting in the fishery losing 202 tonnes of TAC. At £350/tonne this would have resulted in a loss of revenue to each entitlement of £1,140.

7.1.3.2 Removal of sample stations from areas not supporting cockles

Another alternative to consider when attempting to reduce the number of survey stations that are sampled each year, would be to strategically remove those stations in which no cockles have previously been found. In order to determine what costs could be achieved by using this approach, the historic dataset was analysed to identify sites in which no cockles had been found during any of the surveys between 2008 and 2018. Our GIS survey data extends back to 2001, but the review has only included data from 2008 onwards because the full complement of survey stations that are currently sampled only extends back that far. Although there is a slight risk that by only looking at data from 2008 onwards, some historic cockle grounds may be missed, the 2014 year-class of cockles was particularly extensive and has resulted in extensive distributions of cockles being present since then. The 2008-2018 dataset, therefore, provides a good foundation for determining where cockle beds are likely to occur on the beds and which stations do not support cockles.

Once the analysis identified which stations had not supported any cockles during the survey period, these were compared with the chart showing the frequency at which stations had been surveyed, seen in figure 7. From this analysis a chart was produced identifying which of the current survey stations had not supported cockles and showing the frequency that they have been surveyed since 2009. Figure 14 shows these stations, while Table 11 shows the number of stations that have been sampled at each frequency.

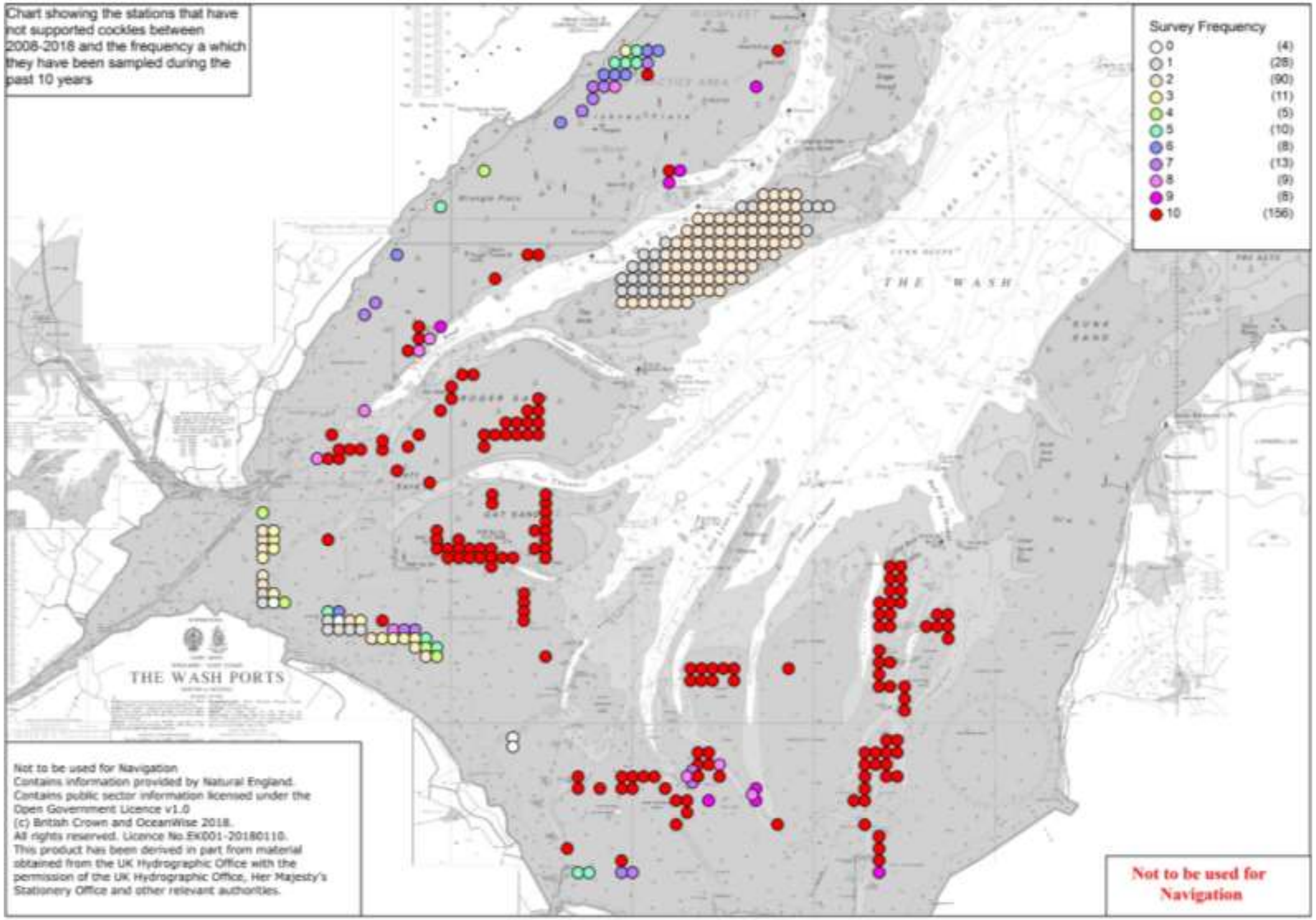

Figure 14 – Chart showing the cockle survey stations in which no cockles have ever been found during the period 2008-2018. Colours denote the frequency at which they have each been surveyed in the last 10 years

Table 11 – The frequency that stations not supporting cockles have been sampled in the past 10 years and an indication of survey effort directed towards them.

Frequency sampled	Number of stations	Annual effort (Fr x No)/10
0	4	0
1	28	2.8
2	90	18
3	11	3.3
4	5	2
5	10	5
6	8	4.8
7	13	9.1
8	9	7.2
9	8	7.2
10	156	156
Total	**342**	**215.4**

Table 11, shows that 342 of the 1,464 currently used survey stations have not supported cockles in the past ten years. The distribution of these stations can be seen in figure 14. Although it would seem that removing all of these stations from the survey regime would reduce the annual survey effort by 342 samples per year, the actual saving would not be quite so high because not all of these stations have been sampled every year. The third column of table 11, which takes into account the frequency at which these stations have each been sampled in the last ten years, provides an indication of survey effort that would actually be saved if these stations were permanently removed from the regime. This equates to an annual average saving of 215 stations.

Because all of these stations are within areas that would still continue to be surveyed, there would be no saving in vessel steaming times by removing them from the survey regime. Time taken to sample them would be saved, though. Based on an average sampling rate of 17.5 grabs/hour, this would equate to an estimated saving in time of 12.3 hours. Using the figures in Appendix 1, this would equate to a saving of £3,150, which at 50% cost recovery would be equivalent to £25.41 per entitlement.

Because this approach would only remove stations in which cockles have not been identified previously, the risks are relatively low. The main danger is that should a settlement occur in these areas once the stations have been removed, they would remain undetected and not contribute to the survey data. At £350/tonne, it would only take 27 tonnes of adult cockles to be present in these areas for the fishers to lose whatever savings had been made by removing these stations.

7.1.3.3 Reduction of sampling resolution by increasing distances between sample stations

In the current survey regime, the sample stations in the majority of the sample areas are spaced 0.2 degrees North-South and 0.3 degrees East-West apart. This equates to grids of a size 370m x 340m. Within the Black Buoy, Herring Hill, Mare Tail, Gat and Holbeach survey areas, the spacing of the sample stations has a higher resolution. In these areas the stations are 0.15 degrees North-South and 0.3 degrees East-West apart, which equates to 280m x 340m apart. There are 418 stations within these higher resolution areas and 1,046 stations in the lower resolution sites.

When looking at reducing the number of sample stations by reducing the survey resolution, the most obvious option to initially consider would be to reduce the resolution of the 418 higher resolution sites to match those of the lower resolution sites. By doing this, approximately 316 stations would be required, a saving of 102 stations. As the surveys would still be conducted in these areas, there would be no saving in vessel steaming times, but approximately 6 hours of sampling would be saved. From the figures in appendix 1, this would equate to a saving of £1,543.03. Divided between the 62 entitlements, at 50% cost recovery, this would result in a saving of £12.45 per entitlement.

The risk of doing this would be a reduction in accuracy in the high-resolution areas, but only down to levels provided by the surveys in the rest of the site. Additionally, because the survey stations would all be moved to new locations, site specific data from the historic dataset could no longer be applied to them. Time would also be required assigning the new stations, changing the database and entering the new sites into the vessel plotters. This would take several days to complete but would be a one-off task.

Further savings could be made by reducing the resolution further across the site. Table 12 shows the estimated number of stations that would be required at various resolutions. This table assumes the 418 high resolution sites would have already been adapted to match the resolution of the other sites, resulting in a survey regime of 1.362 stations.

Table 12 – The number of survey stations estimated to be required at various sampling resolutions

Grid dimensions (m)	Area per grid (ha)	Number of stations
370 x 340	12.6	1,362
518 x 476	24.7	695
740 x 680	50.3	341
1036 x 952	98.6	174

The figures above look at the scenarios in which all the stations are spaced at the current lower resolution of 370m x 340m, then at resolutions requiring roughly half, a quarter and an eighth that number of stations. While these options would significantly reduce survey costs there would be associated risks of reduced accuracy in determining stock biomass, lower resolution distribution charts and increased probability of entirely missing smaller beds of cockles and patches of high density juvenile stocks. Additionally, the distances between the stations at the two lower resolutions are so large, it would be difficult to fit a grid sampling pattern on any but the larger beds. At these two resolutions, a random sampling strategy would be required to provide adequate coverage to the smaller beds. Even then, too few samples stations would be present to provide accurate stock biomass figures for individual beds.

To test what impact reducing the survey resolution would have on the accuracy of the surveys, past survey data were analysed. In this study, the full dataset from 2011, 2016, 2017 and 2018 were initially analysed to determine their standard deviations (SD) and 95% confidence intervals, from which their percentage error margins could be calculated. For each year, this analysis was conducted in two ways:

1. Using all survey station data, including those that were nil results (e.g. did not support cockles)
2. Using only data from stations containing cockles (e.g. excluding data from stations not supporting cockles)

Section 4.5 describes the difference between these two approaches. The second approach, which excludes nil results, is the method currently used for our surveys. However, if resolution was reduced to a level where a random strategy was required, the first approach would be required to analyse the data.

It should be noted that because this exercise was to explore the impact on accuracy that the number of survey stations have rather than being an accurate assessment of stock biomass, no attempt has been made to eliminate the bias in the data caused by the higher resolution sites in the Black Buoy, Herring Hill, Mare Tail, Gat and Holbeach survey areas that have been discussed previously. As such, the estimated stock biomasses shown in the tables below are slightly different to those that were published following the actual annual stock assessments. Table 13 shows the number of stations used in the analysis, the estimated stock biomass and the percentage error margin when all stations (including nil results) were included. Table 14 shows these values when nil results were excluded.

Table 13 – Estimated biomass and error margins for all stations (including nil results)

Year	Stations	Estimated biomass (t)	Error margin (% +/-)
2011	1363	10,505	21.2
2016	1363	54,181	14.3
2017	1363	35,839	12.2
2018	1363	28,805	13.1

Table 14 – Estimated biomass and error margins for all stations supporting cockles (excluding nil results)

Year	Stations	Estimated biomass (t)	Error margin (% +/-)
2011	505	10,152	20.0
2016	744	55,544	13.5
2017	814	36,852	11.4
2018	675	30,084	12.0

From tables 13 and 14, it can be seen the second method of analysis, whereby stations not supporting cockles are excluded from the analysis, provides slightly improved error margins. For years when there was a high stock abundance (2016-2018), and therefore more stations supporting cockles, the error margins are lower than during years of poor stock abundance (2001). This is because during periods of high abundance, the distribution of the cockle stocks is more consistent and less patchy than during periods of low stock, thus reducing the overall variability.

To study the impact that reducing sampling resolution would have on accuracy, the 2017 and 2018 datasets have been analysed further. Although this study is looking at the impacts of reducing survey resolution by increasing the distance between sample stations, because we can only use data already available to us, the analysis can only use data from existing stations. As the different sampling resolutions would require entirely new stations to what have currently been used, it has not been possible to study the impacts of these various resolutions in a regular grid pattern. Instead, the analysis has been conducted using a quasi-random strategy. To create these quasi-random stations, the full datasets from 2017 and 2018 have each been divided to create two pairs of datasets, each containing half of the stations of the originals. These were then divided again to create quarter-sized groups, and for the 2017 data, divided further into eighths. All of these groups were then analysed to determine their accuracy in terms of error margins. Figures 15 to 22 show the distribution of sample stations created from the 2017 dataset during this process (only a single chart shown for the 1/8th dataset). The colours represent the abundance of cockles found at each station.

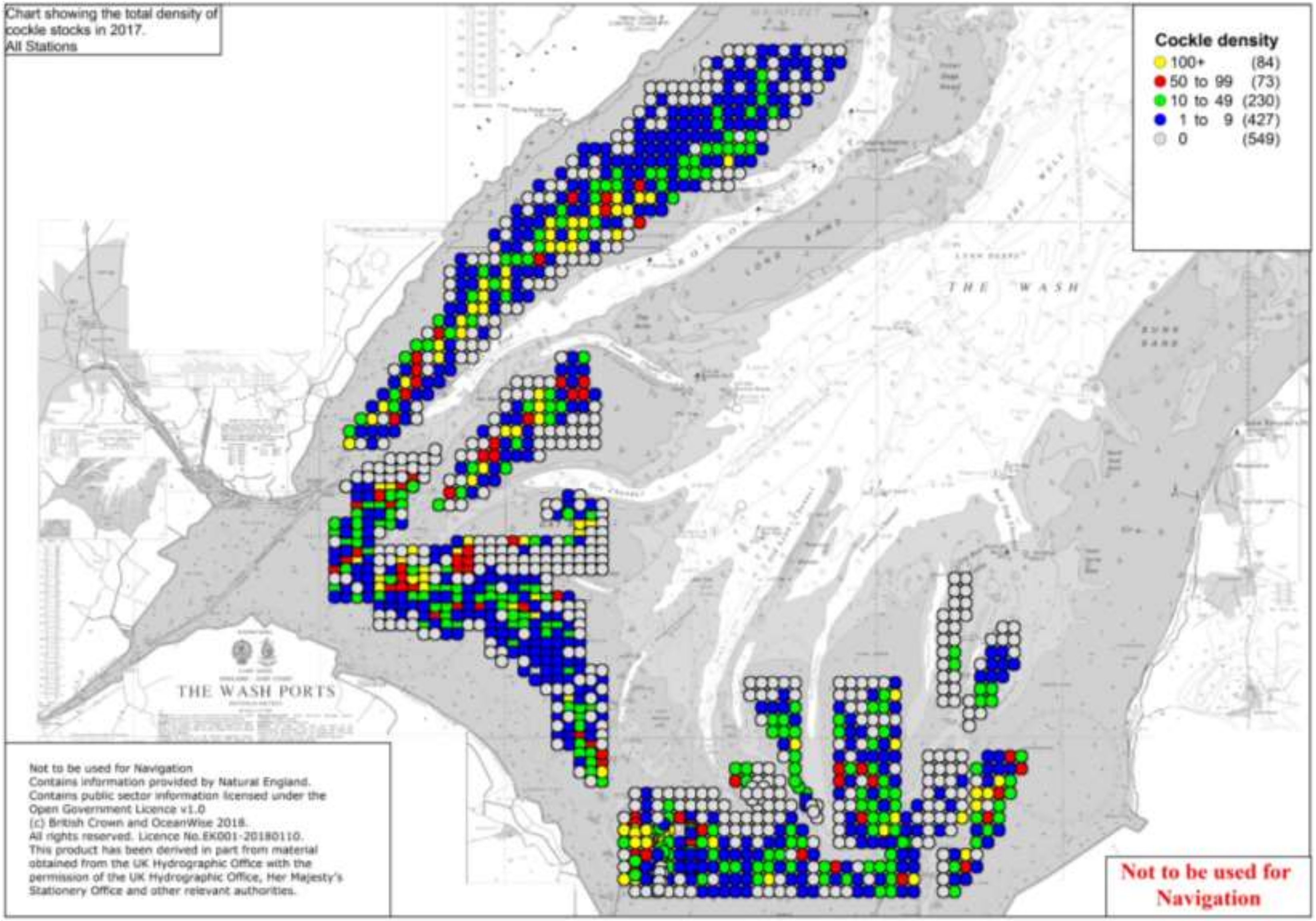

Figure 15 – Chart showing the cockle densities in 2017, using full dataset of 1,363 stations

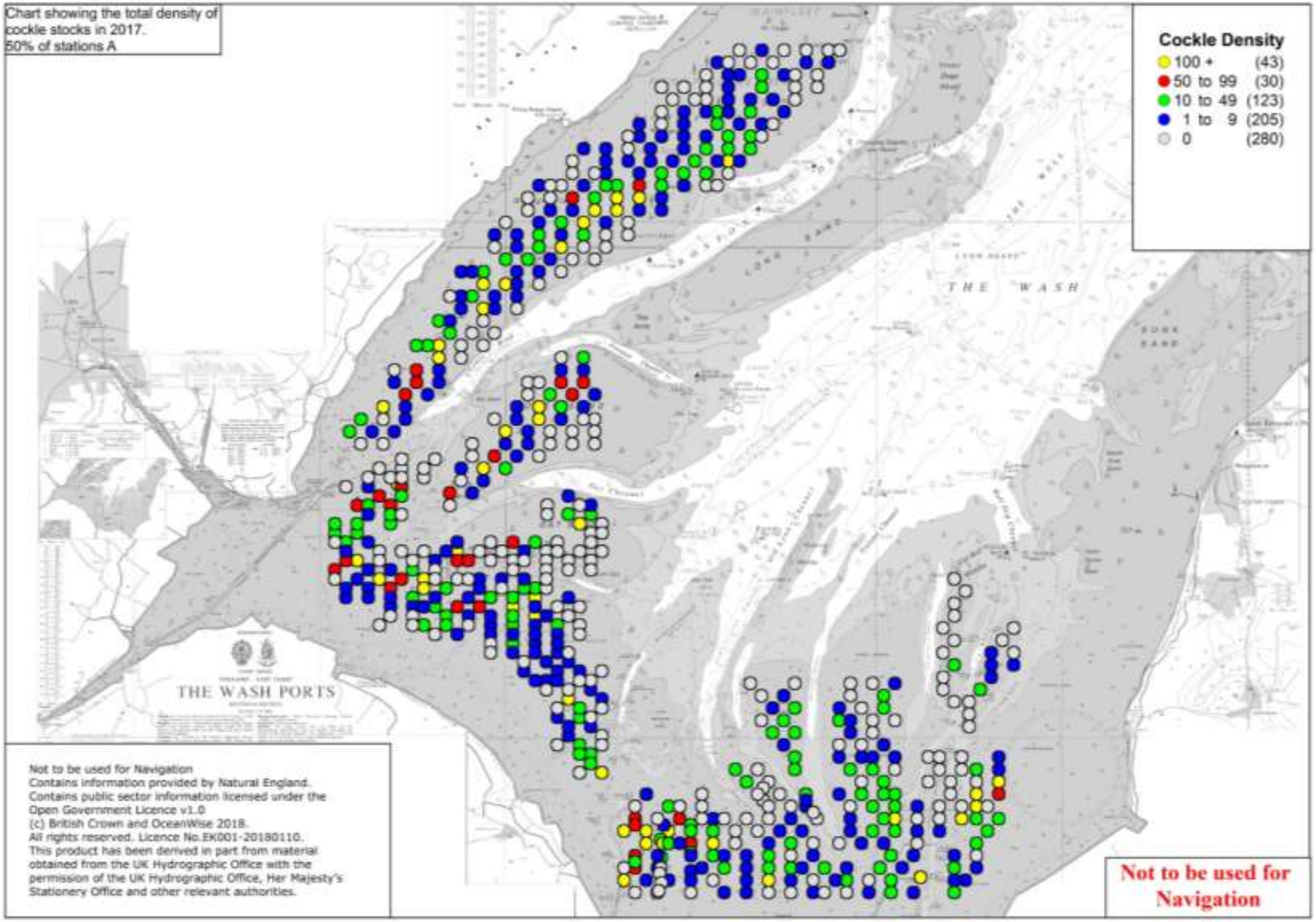

Figure 16 – Chart showing the cockle densities in 2017, using half dataset A of 682 stations

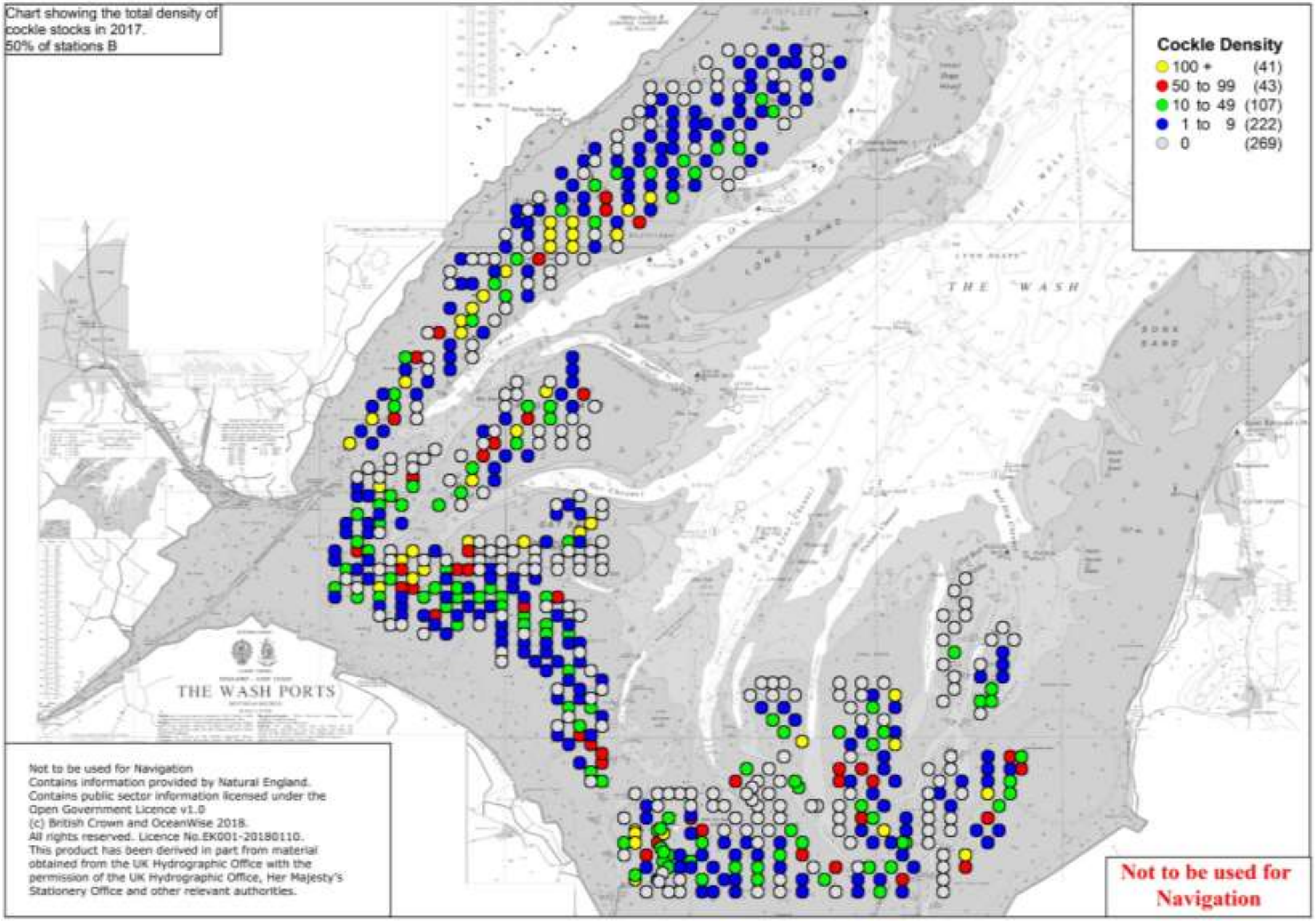

Figure 17 – Chart showing the cockle densities in 2017, using half dataset B of 682 stations

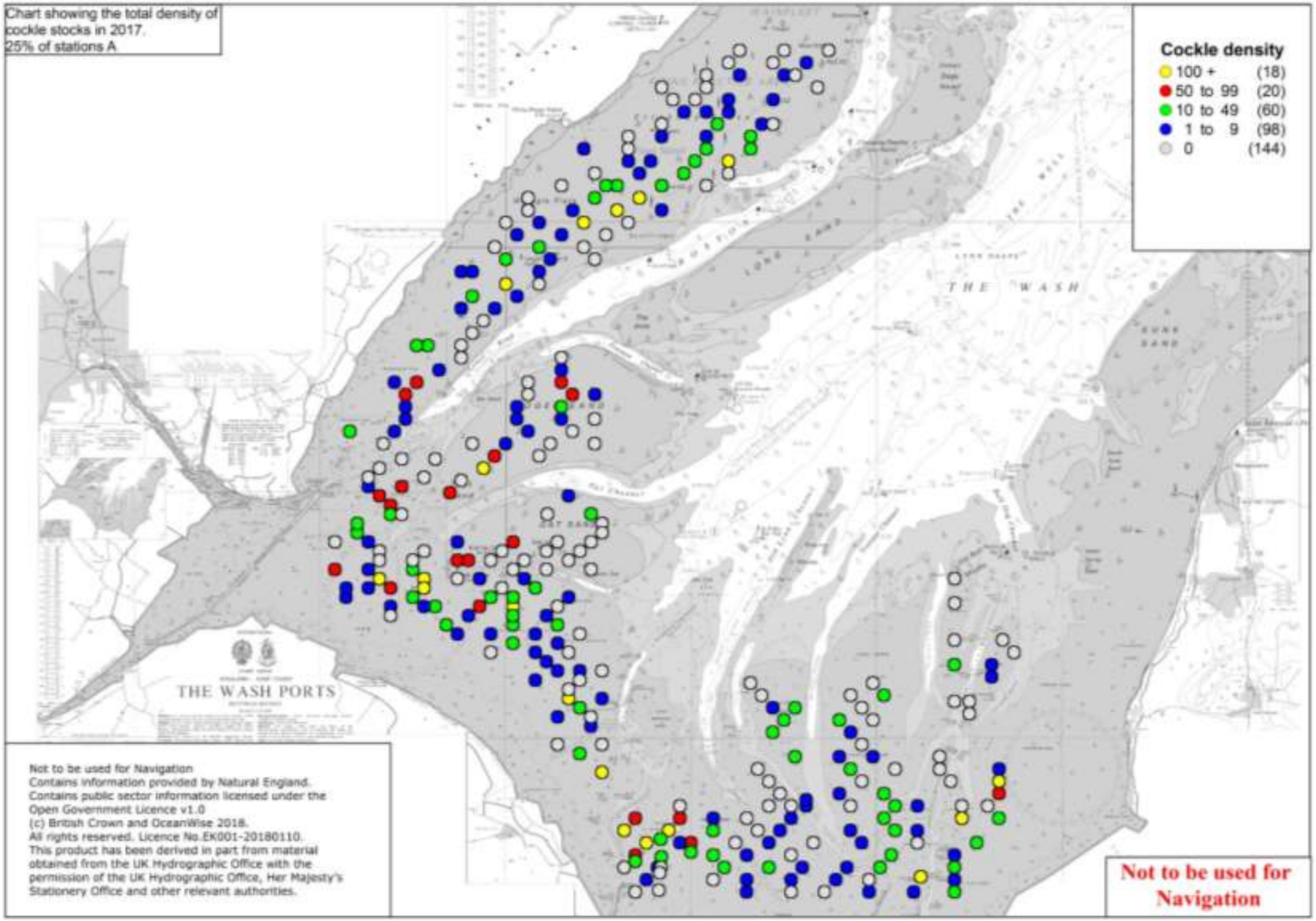

Figure 18 – Chart showing the cockle densities in 2017, using quarter dataset A of 341 stations

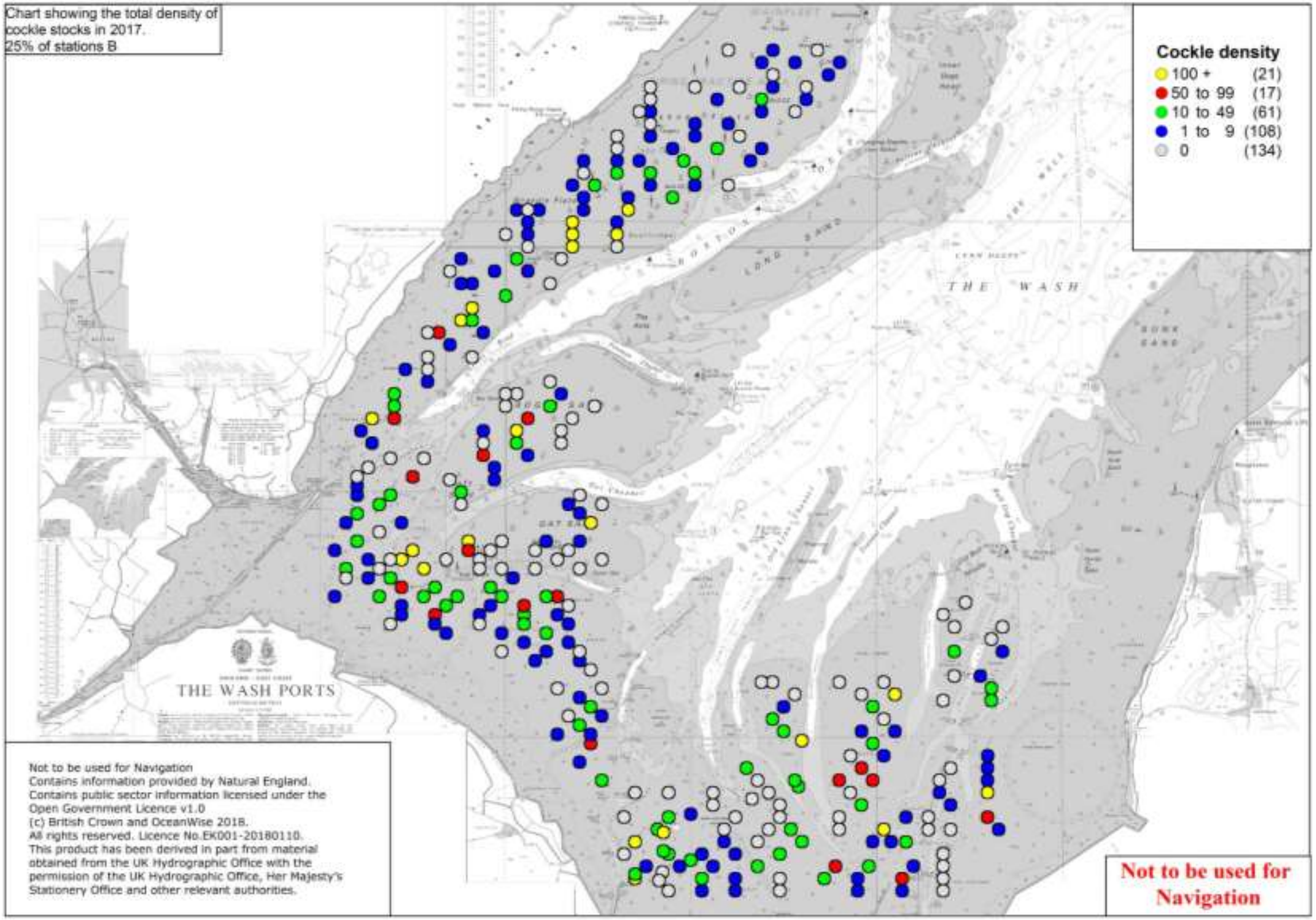

Figure 19 – Chart showing the cockle densities in 2017, using quarter dataset B of 341 stations

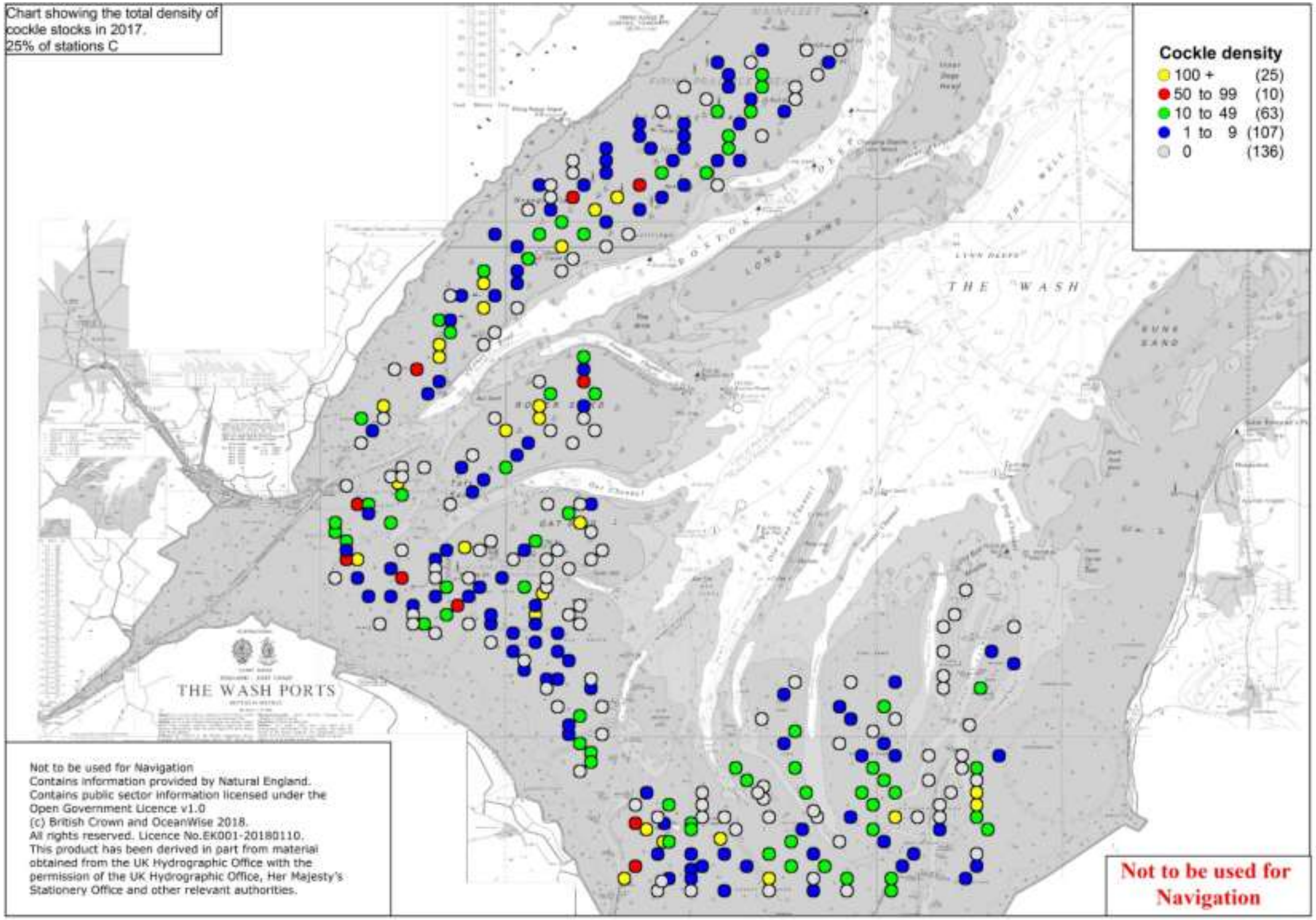

Figure 20 – Chart showing the cockle densities in 2017, using quarter dataset C of 341 stations

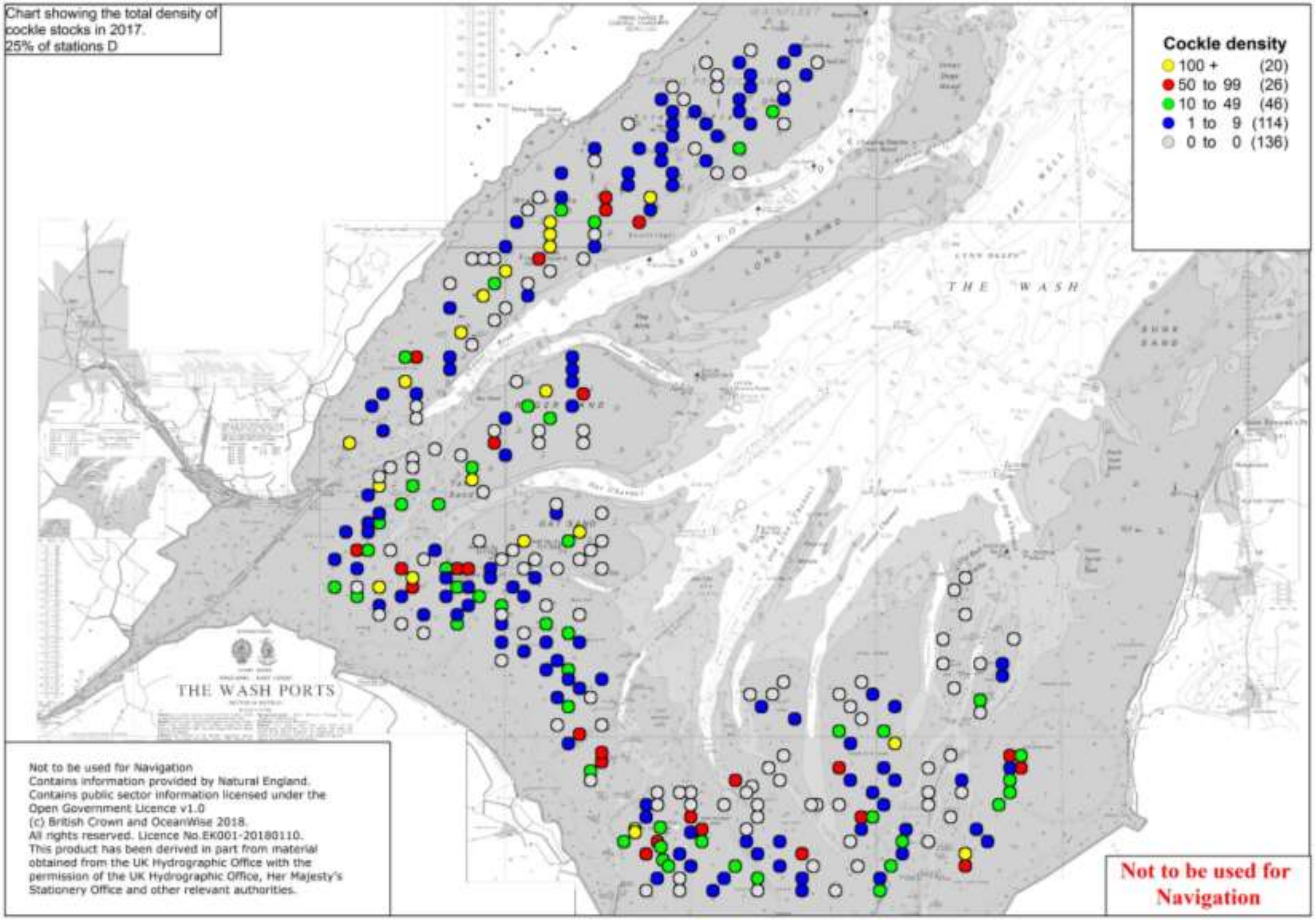

Figure 21 – Chart showing the cockle densities in 2017, using quarter dataset D of 341 stations

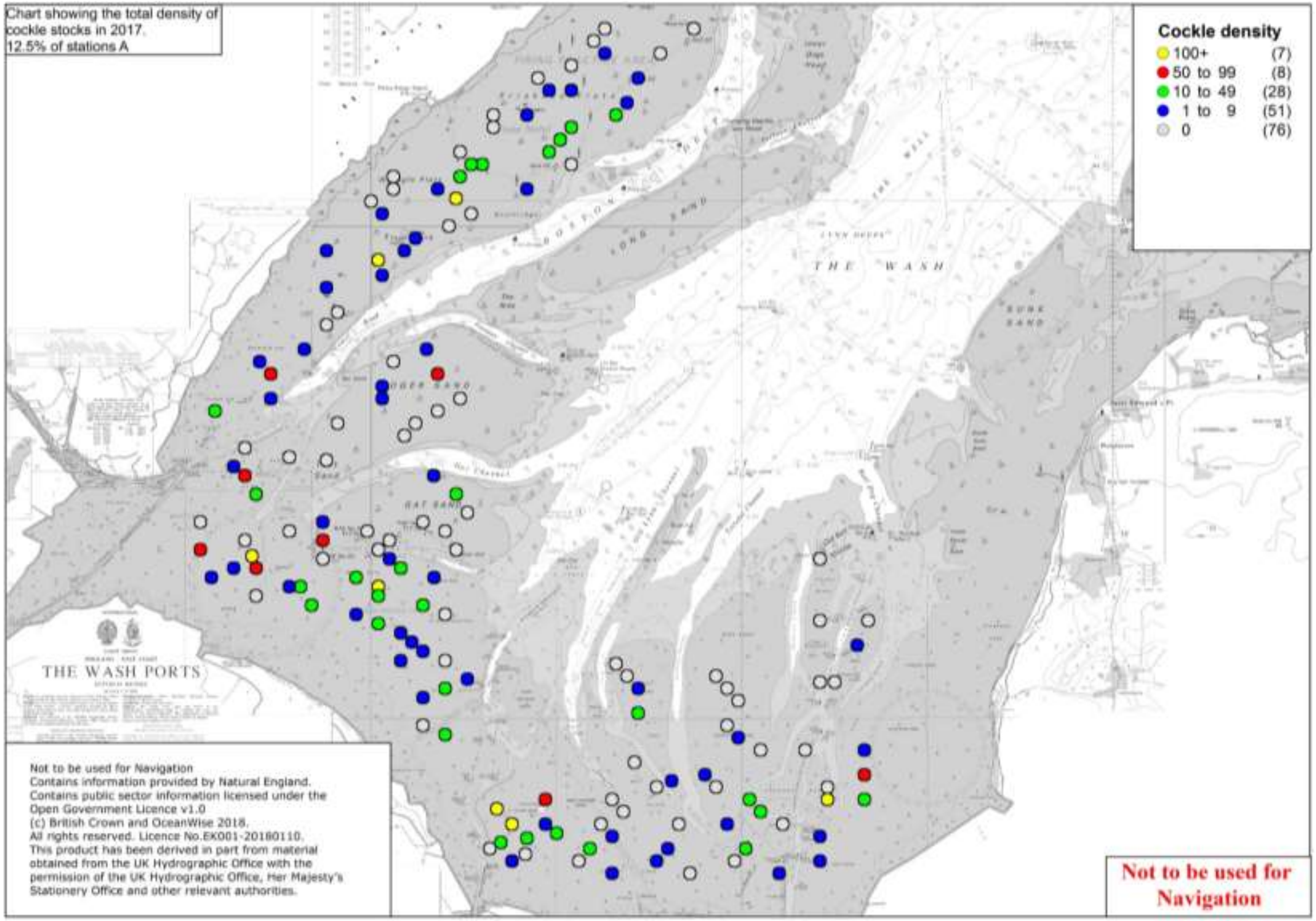

Figure 22 – Chart showing the cockle densities in 2017, using an eighth of the dataset A of 170 stations

Tables 15 and 16 show the impact that reducing survey sampling resolution has on the error margins associated with stock analysis.

Table 15 – Estimated biomass and error margins for various resolutions of 2017 and 2018 data (including nil results)

Dataset	Stations	Estimated biomass (t)	Error margin (% +/-)
2018 All data	1,363	28,805	13.1
2018 ½ data A	682	30,892	17.6
2018 ½ data B	682	26,844	19.7
2018 ¼ data A	341	27,119	24.0
2018 ¼ data B	341	25,922	25.9
2018 ¼ data C	341	34,665	25.3
2018 ¼ data D	341	27,767	29.5
2017 All data	1,363	35,839	12.2
2017 ½ data A	682	35,470	17.3
2017 ½ data B	682	36,260	17.1
2017 ¼ data A	341	35,397	26.1
2017 ¼ data B	341	36,131	25.1
2017 ¼ data C	341	35,649	23.0
2017 ¼ data D	341	36,496	23.4
2017 1/8 data A	170	27,528	33.6
2017 1/8 data B	170	35,853	26.8
2017 1/8 data C	170	31,346	25.7
2017 1/8 data D	170	39,170	35.0
2017 1/8 data E	170	43,265	37.0
2017 1/8 data F	170	36,409	42.6
2017 1/8 data G	170	39,953	35.9
2017 1/8 data H	170	33,821	30.5

Table 16 – Estimated biomass and error margins for various resolutions of 2017 and 2018 data (excluding nil results)

Dataset	Stations	Estimated biomass (t)	Error margin (% +/-)
2018 All data	1,363	30,084	12.0
2018 ½ data A	682	32,433	15.9
2018 ½ data B	682	27,769	18.3
2018 ¼ data A	341	29,080	21.4
2018 ¼ data B	341	26,503	23.8
2018 ¼ data C	341	35,649	23.0
2018 ¼ data D	341	29,065	27.5
2017 All data	1,363	36,852	11.4
2017 ½ data A	682	36,992	16.2

2017 ½ data B	682	36,717	16.1
2017 ¼ data A	341	37,707	24.5
2017 ¼ data B	341	36,444	23.7
2017 ¼ data C	341	44,168	21.6
2017 ¼ data D	341	36,990	21.9
2017 1/8 data A	170	30,573	31.0
2017 1/8 data B	170	35,647	24.2
2017 1/8 data C	170	31,168	22.9
2017 1/8 data D	170	38,945	33.2
2017 1/8 data E	170	44,282	34.9
2017 1/8 data F	170	37,265	40.8
2017 1/8 data G	170	41,710	33.8
2017 1/8 data H	170	37,522	27.6

At all levels of resolution, the error margins are larger when all data including nil results are used (table 15) than when those stations not containing cockles are excluded (table 16).

The breadth of the error margins can also be seen to increase as the survey sampling resolution decreases. For the method of analysis currently used, which excludes nil results (table 16), these values increase from +/- 11.4 - 12.0% for the full dataset to +/- 22.0 - 40.8% for the 1/8th datasets.

In addition to the error margins being wider at the lower resolutions, the stock biomass estimations also vary considerably at these lower resolutions, ranging between 30,573 tonnes and 44,282 tonnes. Although there was a wide range of values generated by the eight 1/8th resolution groups of 2017 data, statistical analysis using ANOVA found they were all behaving as similar populations at a $p<0.05$ level of confidence. However, while statistically these eight groups are similar to each other, and their 95% confidence margins overlap with those generated from the full dataset, in three cases (replicates A, C and E), the mean estimated values for biomass fall outside of the 95% confidence margins predicted from the full dataset. In these three cases, should those values be used to estimate the stock biomass, it is likely that the stock would be greatly over or under estimated.

In figure 23, the relationship between the sampling frequency and the percentage error margins have been plotted. The trendline for this chart shows that any further reduction in sampling resolution would cause the error margins to rapidly increase. When extrapolated beyond the current level of sampling, however, it shows adding additional survey stations would result in rapidly diminishing returns in increased accuracy. This chart could be used to provide an estimation of how many stations would be required to provide a desired level of accuracy. When doing so, however, it should be remembered that the stocks were high in 2017, which has been shown above to reduce variability and increase accuracy. During years of poorer stocks, more samples would be required to produce the same level of accuracy.

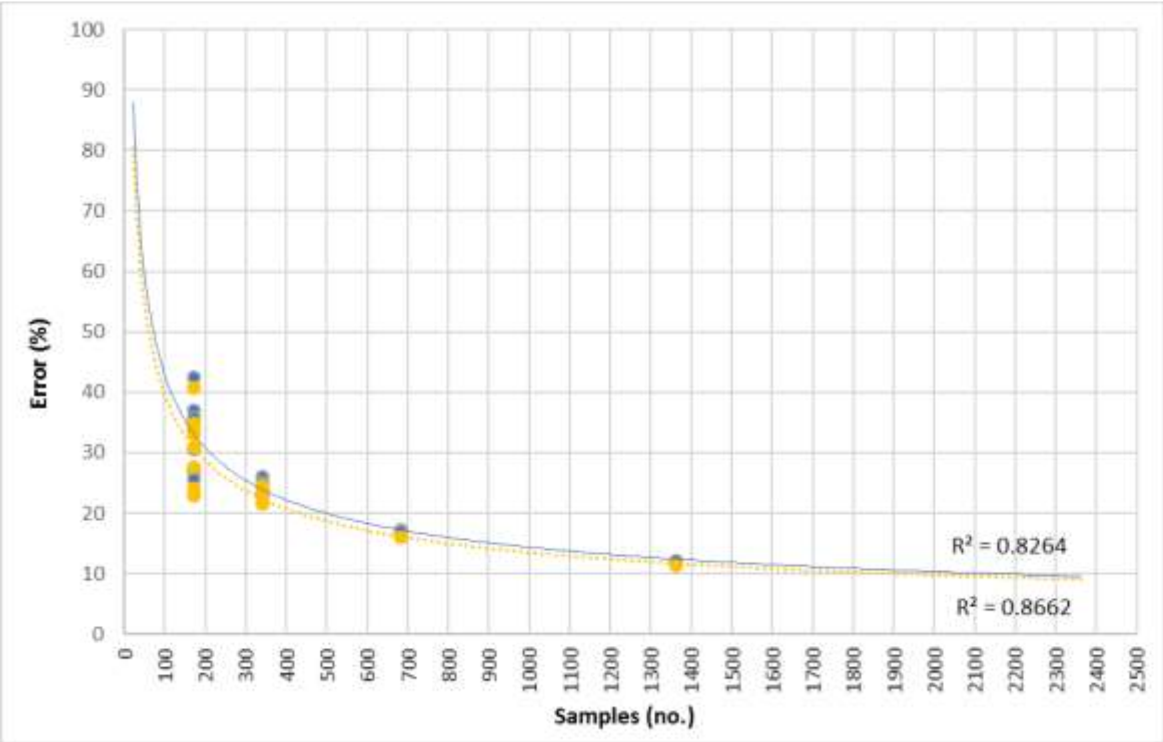

Figure 23 – The relationship between sampling resolution and percentage error margins.

Reducing the sampling resolution would not only reduce the accuracy of stock biomass estimations, from which the TAC is calculated, but would also reduce the resolution of the charts used to model the cockle distribution. This loss of resolution would not only make them a less effective resource for fishers using them to identify the better fishing grounds, but would also make them less effective at identifying areas of Year-0 juvenile cockles that require protecting. Examples of this can be seen in figures 24 – 30, which show the modelled distributions of Year-0 cockles in 2017, using the full dataset (figure 24), half datasets (figures 25 and 26) and quarter datasets (figures 27 – 30). Figures 31 – 36 show a similar set of charts using the same datasets for the Gat, Mare Tail and north Holbeach beds.

In both areas, the higher resolution charts using the full dataset (figures 24 and 31) should be more accurate models than the lower resolution charts generated from fewer survey stations. In the case of the Roger/Toft, the full dataset identified three discrete patches of high density Year-0 cockles. In contrast, the charts modelled using a half or a quarter of the stations produced quite different distributions, either failing to chart some or all of the Year-0 patches, or producing larger patches. The charts for the Gat, Mare Tail and Holbeach showed similar discrepancies.

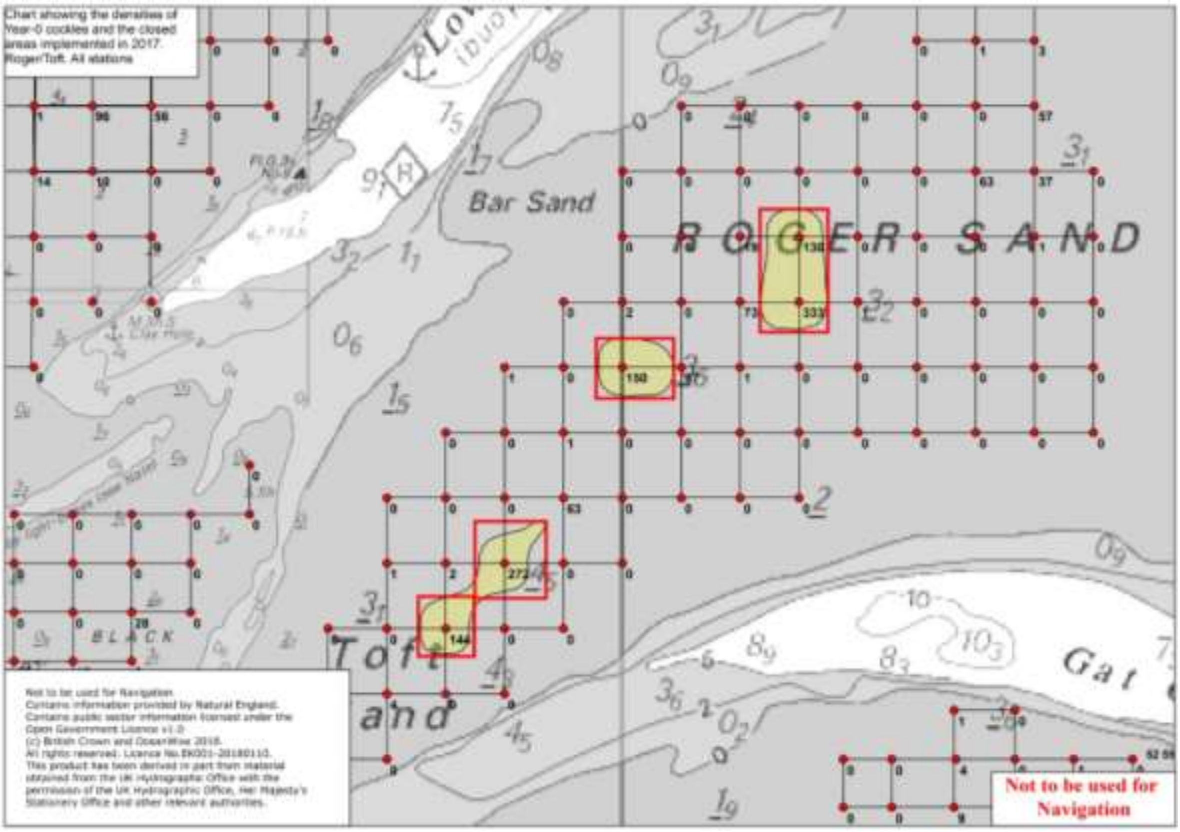

Figure 24 – Extent of Year-0 cockles in densities ≥1,000/m^2 on Roger/Toft. Modelled using 2017 full data set

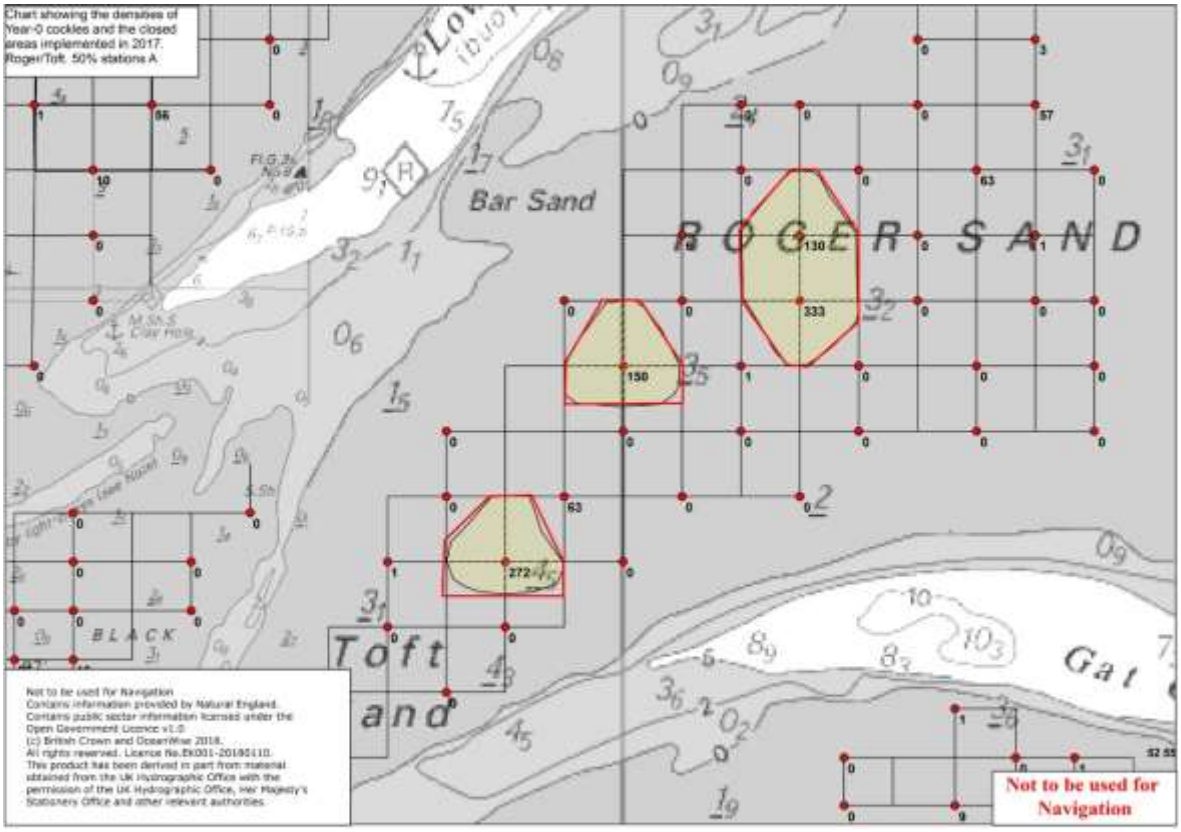

Figure 25 – Extent of Year-0 cockles in densities ≥1,000/m^2 on Roger/Toft. Modelled using 2017 ½ data set A

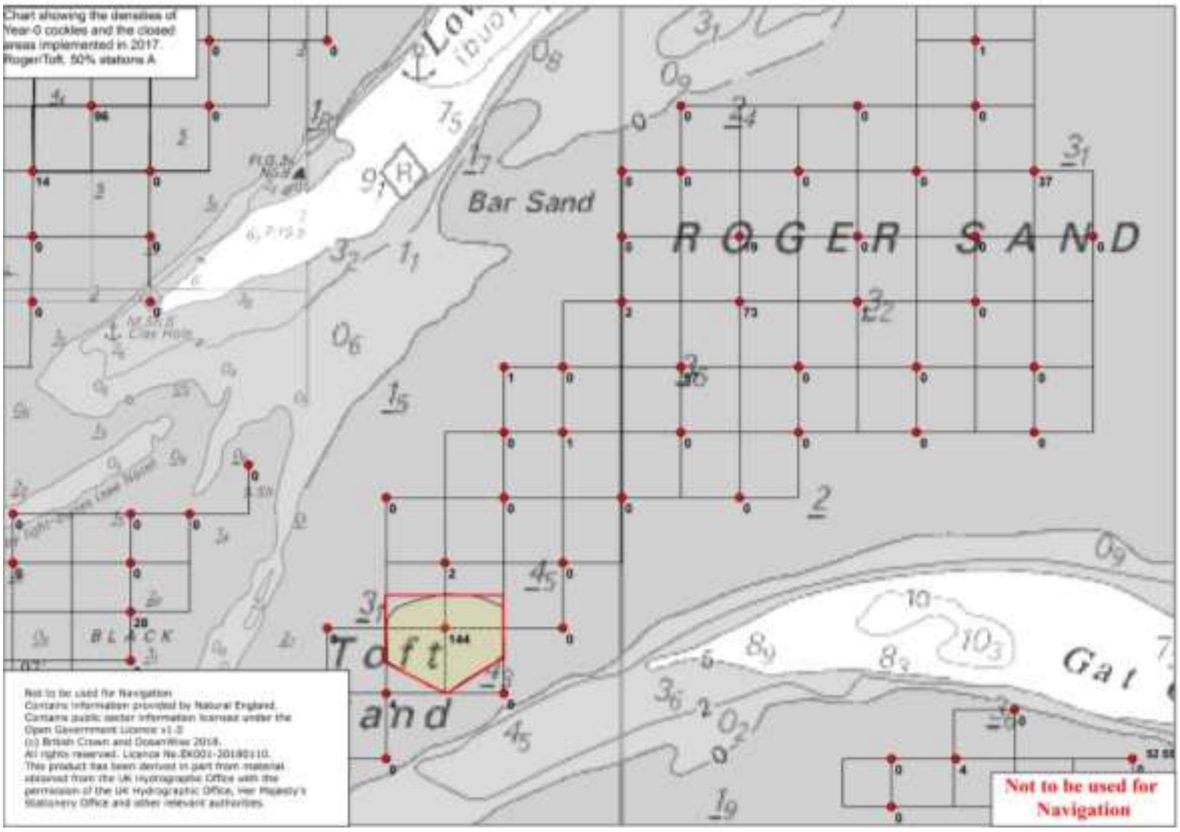

Figure 26 – Extent of Year-0 cockles in densities ≥1,000/m² on Roger/Toft. Modelled using 2017 ½ data set B

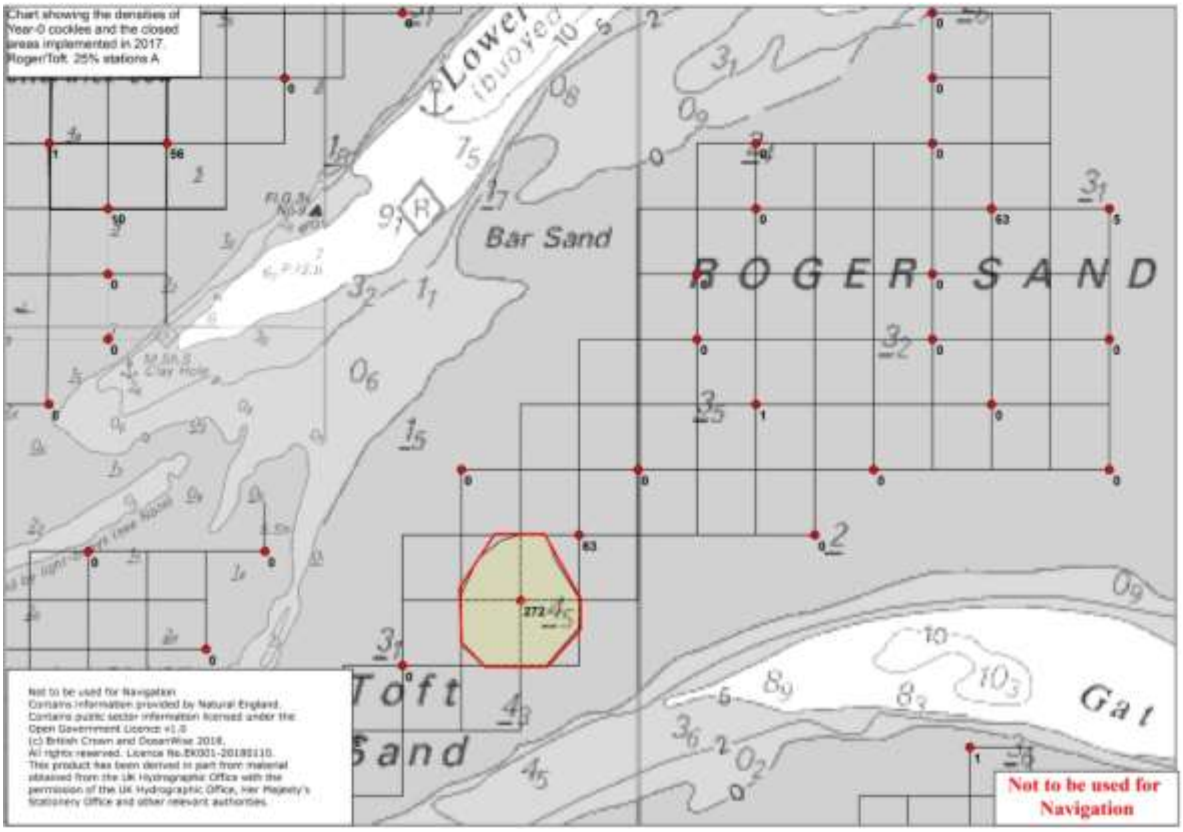

Figure 27 – Extent of Year-0 cockles in densities ≥1,000/m² on Roger/Toft. Modelled using 2017 ¼ data set A

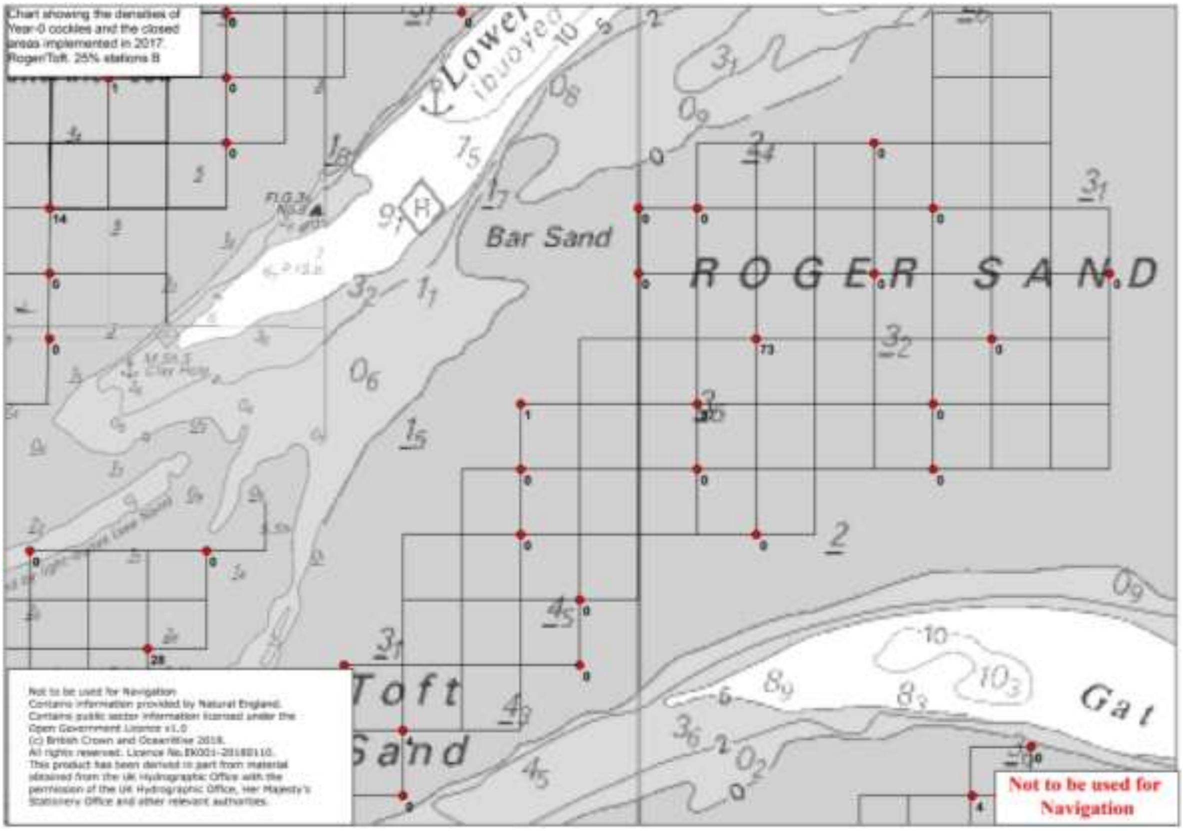

Figure 28 – Extent of Year-0 cockles in densities ≥1,000/m^2 on Roger/Toft. Modelled using 2017 ¼ data set B

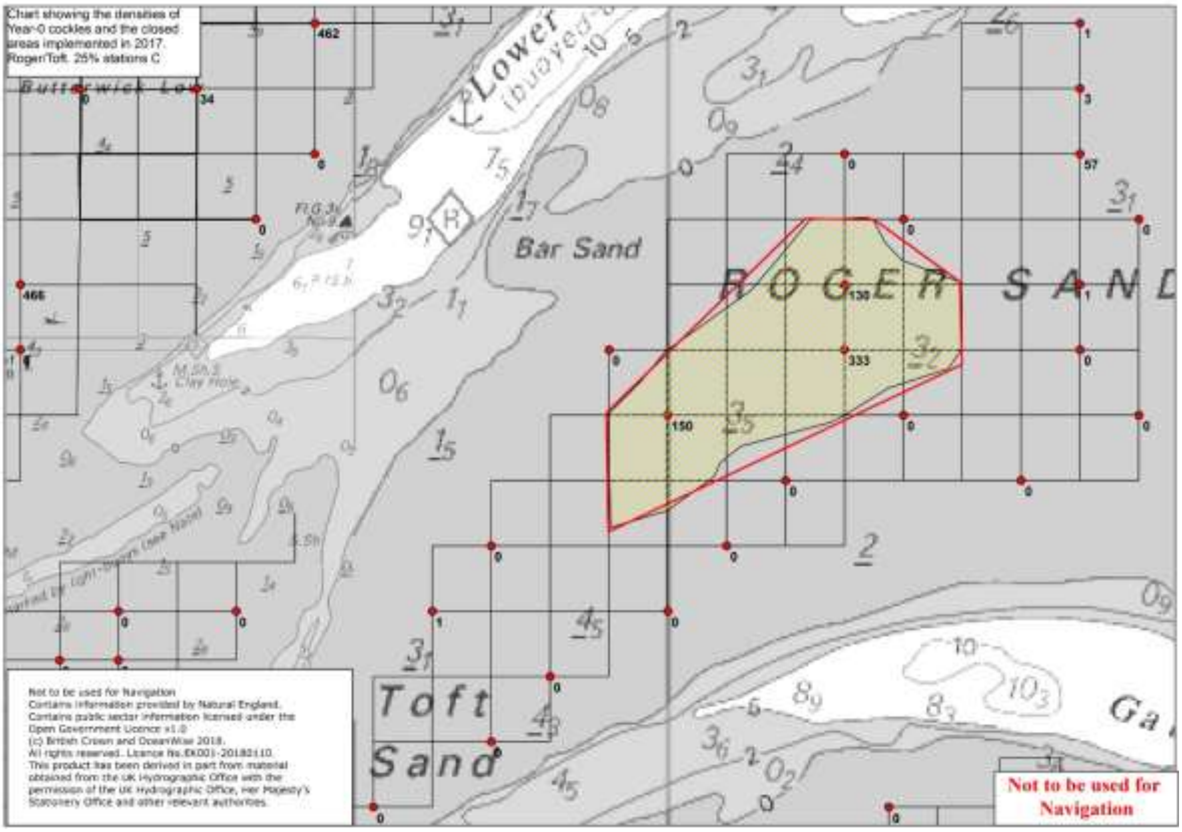

Figure 29 – Extent of Year-0 cockles in densities ≥1,000/m^2 on Roger/Toft. Modelled using 2017 ¼ data set C

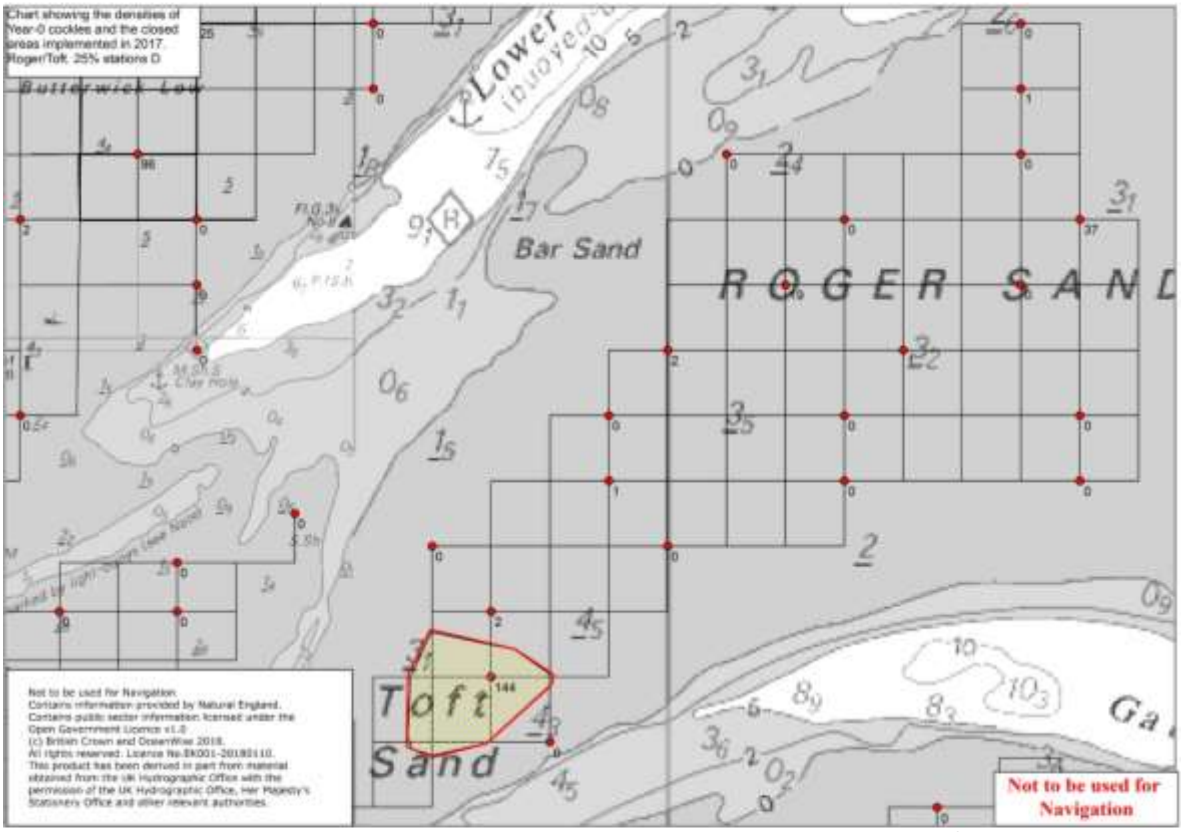

Figure 30 – Extent of Year-0 cockles in densities ≥1,000/m^2 on Roger/Toft. Modelled using 2017 ¼ data set D

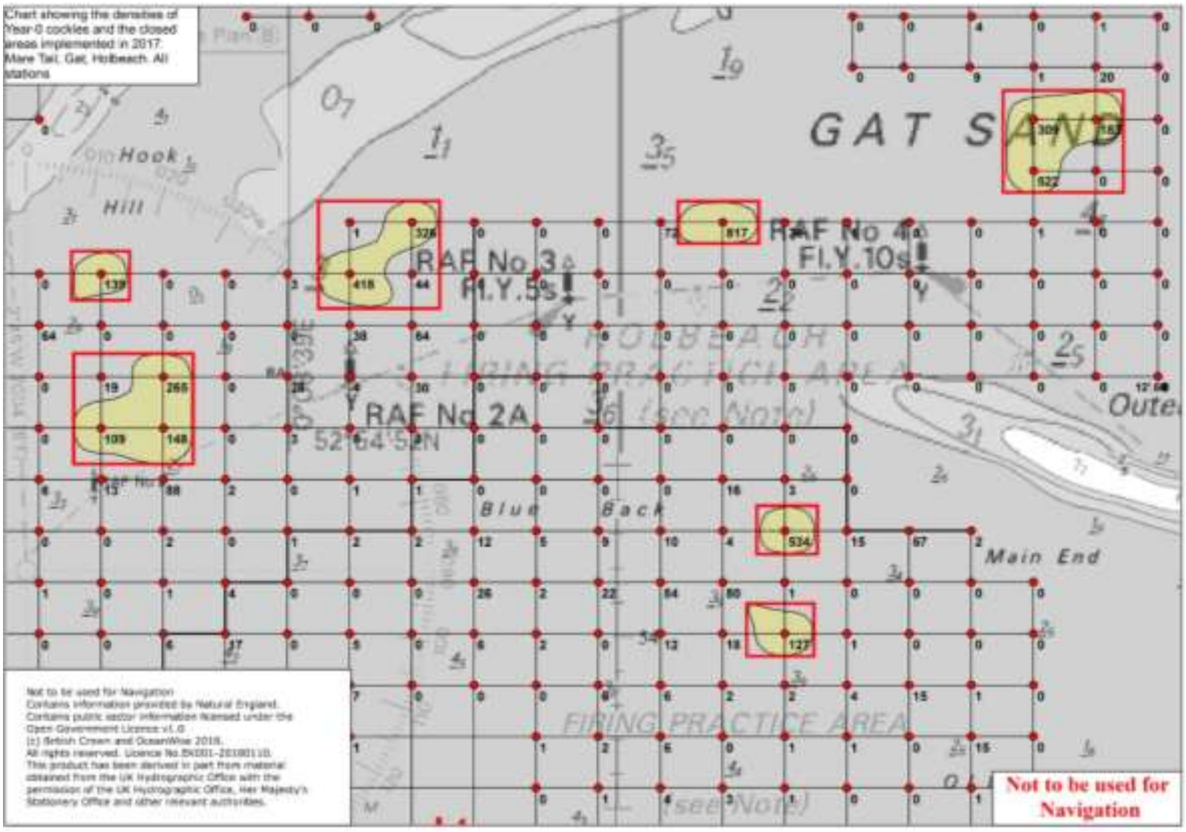

Figure 31 – Extent of Year-0 cockles in densities ≥1,000/m^2 on Mare Tail, Gat and north Holbeach. Modelled using 2017 full data set

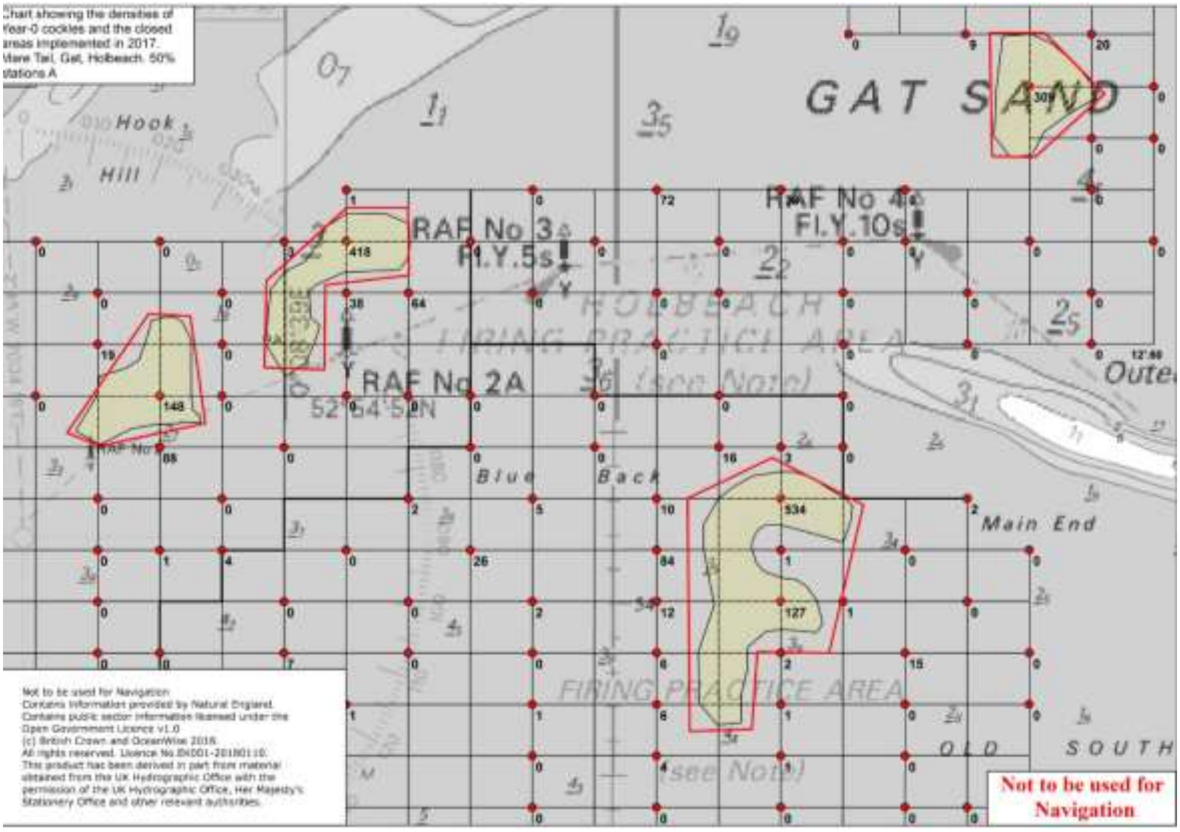

Figure 32 – Extent of Year-0 cockles in densities ≥1,000/m^2 on Mare Tail, Gat and north Holbeach. Modelled using 2017 ½ data set A

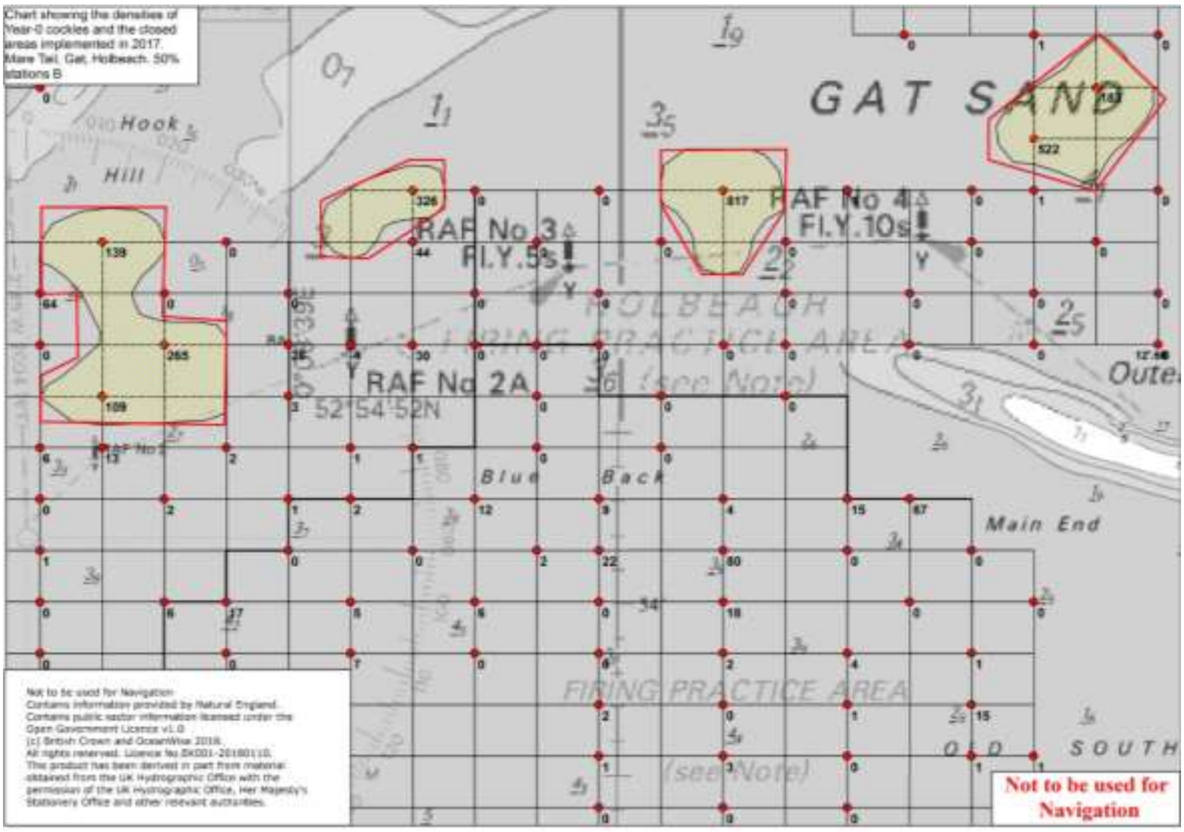

Figure 33 – Extent of Year-0 cockles in densities ≥1,000/m^2 on Mare Tail, Gat and north Holbeach. Modelled using 2017 ½ data set B

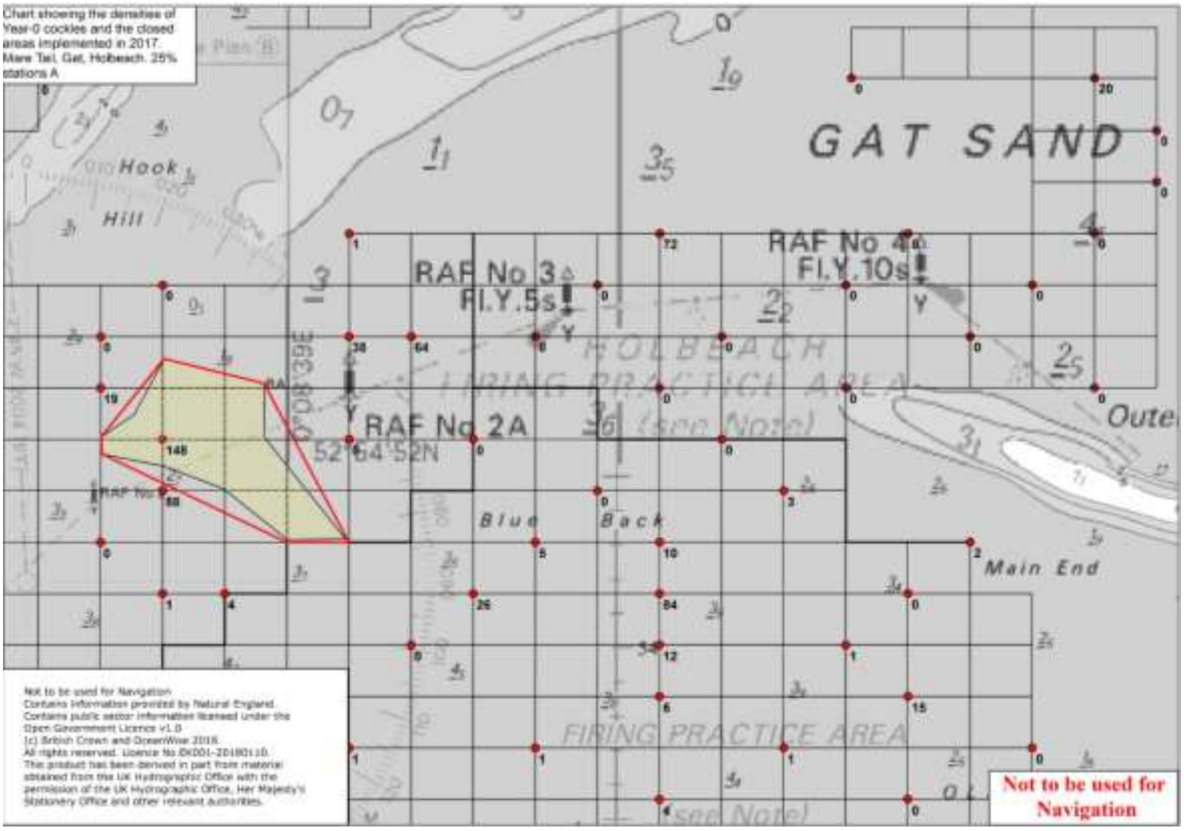

Figure 34 – Extent of Year-0 cockles in densities ≥1,000/m^2 on Mare Tail, Gat and north Holbeach. Modelled using 2017 ¼ data set A

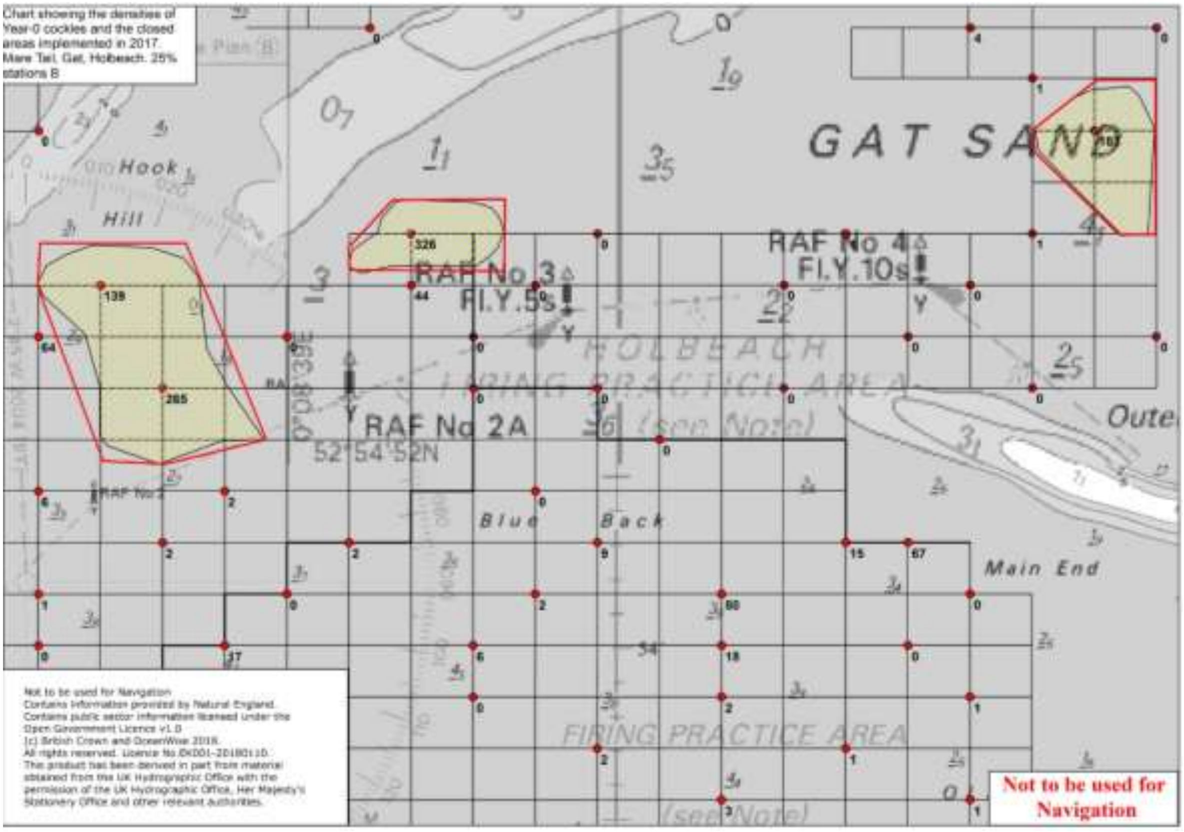

Figure 35 – Extent of Year-0 cockles in densities ≥1,000/m^2 on Mare Tail, Gat and north Holbeach. Modelled using 2017 ¼ data set B

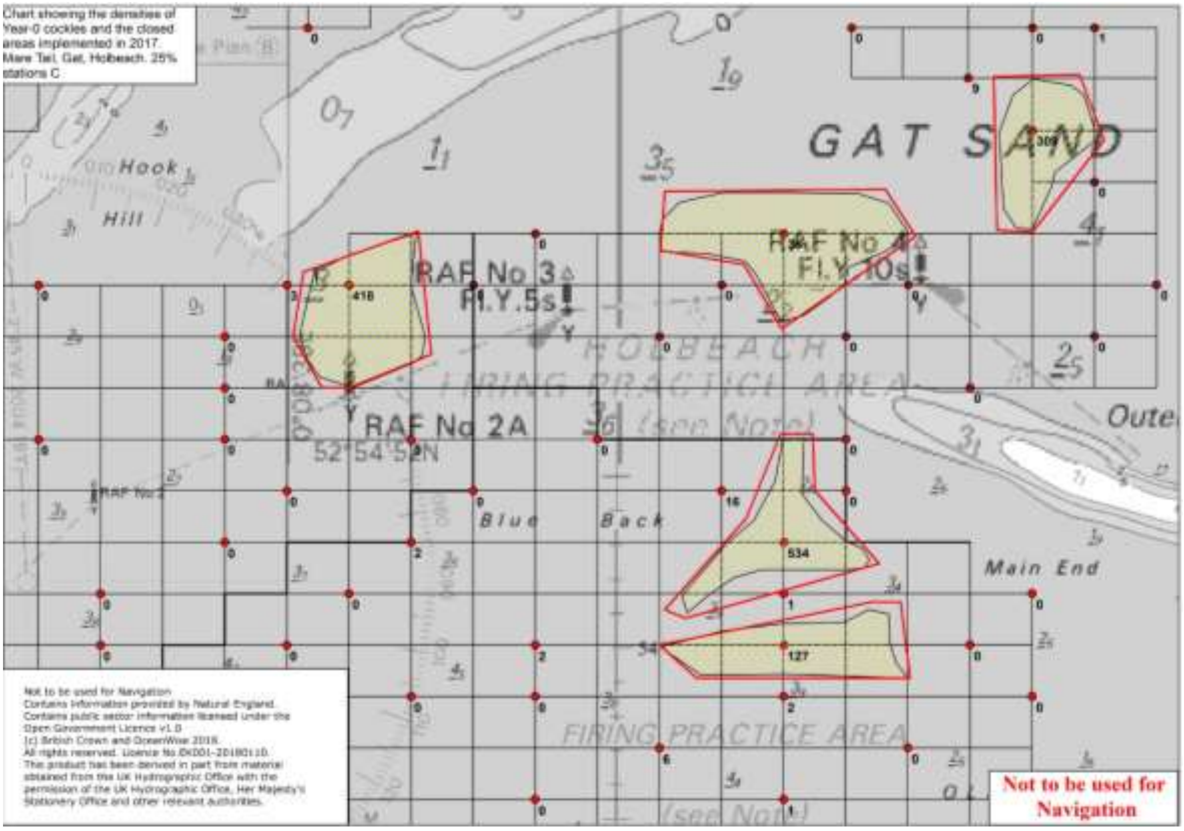

Figure 36 – Extent of Year-0 cockles in densities ≥1,000/m^2 on Mare Tail, Gat and north Holbeach. Modelled using 2017 ¼ data set C

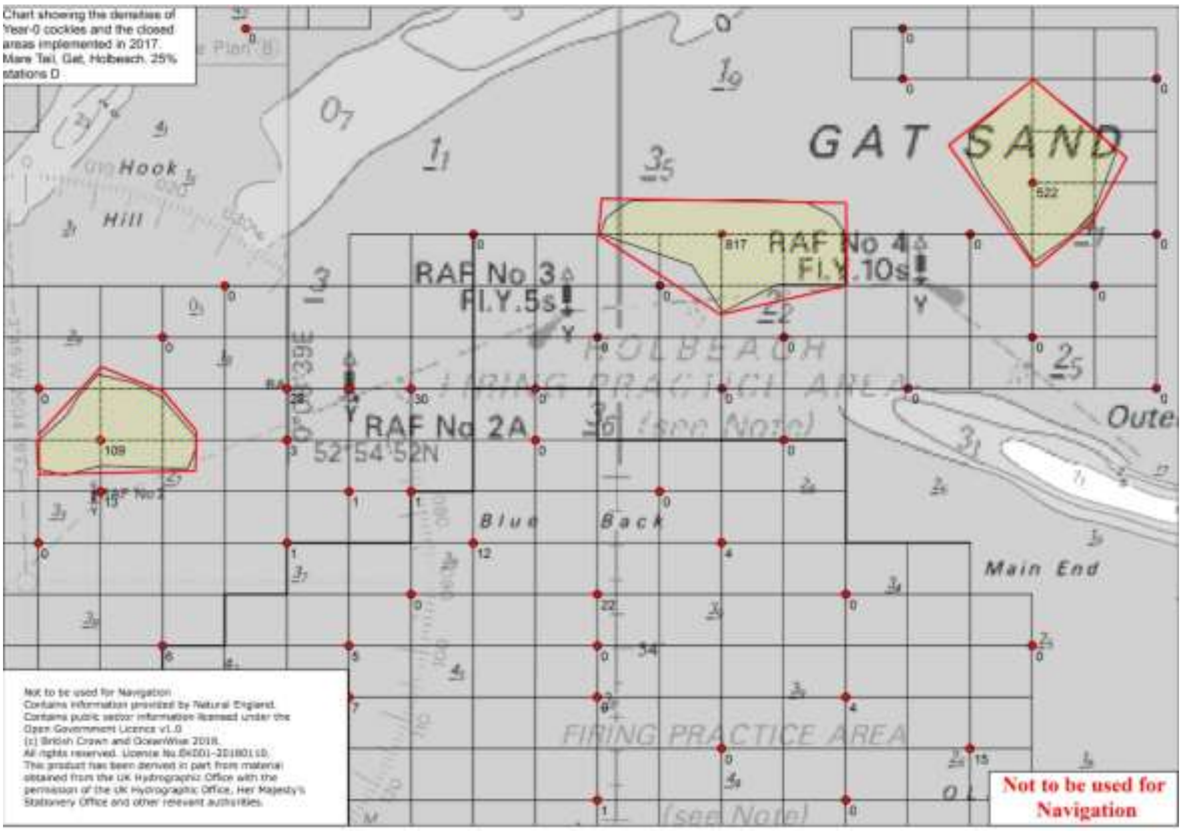

Figure 37 – Extent of Year-0 cockles in densities ≥1,000/m^2 on Mare Tail, Gat and north Holbeach. Modelled using 2017 ¼ data set D

Table 17 – The area of closures required to protect Year-0 cockles using the models generated in figures 24 - 37

Model	Roger/Toft	Mare Tail	Holbeach	Gat	Total
All stations	70	85	19	46	220
Half stations A	121	69	96	29	315
Half stations B	31	113	0	84	228
Quarter stations A	42	72	0	0	114
Quarter stations B	0	132	0	40	172
Quarter stations C	192	46	86	99	423
Quarter stations D	41	36	0	115	192

The figures in table 17 show the area (in hectares) that would require closing on each bed if the data in figures 24 – 37 were used. These figures vary greatly, highlighting the inaccuracies that would occur if lower resolution sampling were to be adopted. In addition to the risk the fishers would face from the potential to overestimate the extent of Year-0 patches, causing areas to be unnecessarily closed, these charts also show there is a high risk that high density patches of juveniles could be totally missed, preventing them from having the protection they should be given. If the sampling resolution was to be reduced, therefore, it is likely that another approach other than spatial closures would be required to protect the juvenile stocks. This would possibly require the mandatory use of riddles to remove the juveniles that had been harvested, although this measure would only be effective if the riddled juveniles were subsequently scattered. Enforcing the mandatory use of riddles during a hand-worked fishery would be difficult, requiring a greater enforcement presence on the sands or inspections on the quayside. This additional enforcement requirement would negate some of the savings that would made by reducing sampling effort.

Reducing the survey sampling resolution as described above would enable significant savings to be made to the cost of the surveys. The scenarios above have looked at reducing the current resolution by two, four and eight-fold. These do not equate to direct savings in cost, however. Because steaming times to the survey areas would still be required, the savings would not be directly proportionate to the level of sampling reduction. Also, because the stations would be further apart, the additional time required to steam or walk between them would reduce the hourly sampling rate, further reducing efficiencies. Taking into account the distances between survey stations shown in table 12, the figures in table 18 estimate how much time would be required to collect and process the samples under each of the sampling resolutions. Although there would be less data generated at the lower sampling resolutions, the analysis, mapping and reporting would still require the same process as for the current resolution. No saving would be made at that stage, therefore.

Table 18 – Breakdown of the time taken to conduct various elements of the cockle surveys at various sampling resolutions (all times in hours)

Resolution	Steam to survey area	Steam between stations	Grab samples	Process samples	Total
Current	66	45	24	45	180
Half	66	31.5	12	22.5	132
Quarter	66	22.5	6	11	105.5
Eighth	66	16	3	5.5	90.5

At present the cockle survey costs in appendix 1 can be broken down into £46,290.75 (or £3,086.05/day) for expenses associated with sample collection and £4,574.40 for post survey analysis and reporting. Using these figures, table 19 shows the costs for conducting the surveys at each of the tested sampling resolutions.

Table 19 – Cost of conducting cockle surveys at various sampling resolutions

Resolution	Days sampling	Sampling cost	Analysis and reporting	Total cost
Current	15	£46,290.75	£4,574.40	£50,865.15
Half	11	£33,946.55	£4,574.40	£38,520.95
Quarter	8.8	£27,157.24	£4,574.40	£31,731.64
Eighth	7.5	£23,145.38	£4,574.40	£27,719.78

Using the estimated costs shown in table 19, at 50% cost recovery, each of the 62 entitlements would save the following amounts if the sampling resolution was changed:
Half – £99.55
Quarter – £154.30
Eighth - £186.66

Of the various methods that have so far been discussed for reducing cockle survey costs, this approach would achieve the greatest savings. Also, as all of the beds would still be surveyed, there would be no associated loss of TAC or fishing grounds. As has been detailed above, however, the loss of sampling resolution would reduce the accuracy of the surveys, both for estimating the stock biomass and modelling the cockle distribution. These inaccuracies would carry risks that the TAC could be significantly under- or over-estimated, resulting in potential loss of fishing opportunity or over-fishing, and reduce the resolution of sampling to levels whereby spatial closures would be ineffective for protecting Year-0 juvenile stocks. These changes would be particularly noticeable on the smaller beds, where the number of samples would be reduced to levels too low to conduct individual assessments with reasonable confidence.

7.2 Using alternative methods and approaches

The current survey method (and variations of, described in section 7.1) all focus on assessing the stocks by collecting physical samples using either a Day grab or a quadrat. In this section, other techniques will be discussed.

7.2.1 Using dredges to collect samples

Where stocks are sparse and cover large areas, dredges are frequently the preferred tool for sampling. These allow low-density stocks to be sampled from large areas, providing a sample of sufficient size to be measured. In this capacity, they are sometimes used by the industry for “prospecting” for sub-littoral mussel seed, in areas where the presence of beds is suspected but not known. There are problems associated that the use of dredges for surveying, however. These include:

- Dredge efficiency – Dredges are seldom 100% efficient at collecting samples, so any assessment made from them tends to be underestimated. Because there are numerous factors that can affect their efficiency, including seabed conditions, sea state, water depth, towing speed, blade depth and how full they are, it is difficult factoring in these inefficiencies to obtain a reliable sample.
- Towing distances – Although GPS readings can be taken to determine the positions that dredges enter and leave the water, it is difficult to determine the positions they hit and leave the seabed at the start and end of their tows. Without being able to accurately record these positions, it is not possible to accurately calculate towing distances and area of dredge coverage.
- Full bags – If the type of dredge being used utilises a bag for collecting the catch, once the bag is full, no further samples will be collected from a tow. As it is difficult to determine precisely at what stage in a tow the bag became full, it is difficult to account for this factor in the calculations. If shorter tows are made to prevent the bag from filling, the inaccuracies associated with determining the towing distances are increased.
- Seabed disturbance – The current survey regime of approximately 1,250 sample stations has a Day grab footprint of 125m^2. This level of footprint would be achieved in 125m using a 1m Baird dredge or 164m using a standard suction dredge. To provide adequate coverage of the beds, a survey using dredges would require several km of tracks to be conducted, not only providing samples that were too large to measure, but also creating an inappropriate level of disturbance.

In the Netherlands, the scientists assessing their cockle stocks do use dredges. These are specially modified suction dredges, however, that are not towed, but are deployed from anchored vessels in order to collect precise spot samples. In this way, they are being used akin to a grab rather than a towed dredge. These are potentially more efficient at collecting a sample than a Day grab, particularly in conditions where the ground is too hard or stony for the grab to penetrate fully, but take much longer to deploy. The cost of making or hiring one of these specialist dredges, chartering a vessel to deploy it and the increased survey times would significantly increase the cost of conducting the surveys.

7.2.2 Using remote sensing techniques

The Authority has RoxAnn AGDS and an Edgetch 4200 side scan that are used for conducting habitat mapping surveys. Neither of these would be able to accurately assess cockle stocks, however. Both systems require deeper water to operate than we usually have on the cockle beds, and cockles are individually too small for either system to individually resolve. Dense cockle beds that have bio-engineered the seabed to some extent may be detectable with these systems, but because cockles do not leave much of a presence on the seabed surface, their presence would almost certainly be masked by features like sand ripples and waves, or changes between sand and muddy conditions. At very best, this method would be highly inaccurate at mapping bed extent and physical samples would still need to be collected to estimate stock biomass.

Satellite technology is improving and becoming more accessible. Combinations of filters can be used to effectively detect spectrums of light associated with chlorophyll from plant growth, but they do not currently appear effective at detecting cockle beds. As with other remote sensing techniques, they would only be useful for mapping bed extent. Physical samples would still be required to estimate stock biomass.

7.2.3 Using drones

Drones are relatively cheap to buy and can be mounted with high definition cameras, GPS and a variety of sensors and grabs that could be used to facilitate surveying. Several organisations do currently use drones to conduct habitat mapping surveys in inter-tidal zones, mainly by filming features from altitude. This can be particularly useful in areas that are sensitive to trampling or are difficult to reach on foot.

The use of drones for surveying would be classified as a commercial operation. As such, they fall under a lot of regulation. Civil Air Authority (CAA) permissions are required for all commercial flights, and these must be conducted by a qualified pilot. There are further regulations restricting maximum flight distances and maintaining a line of sight between the pilot and the drone that must be adhered to. Their maximum flight durations of approximately 25 minutes also restricts their application. The greatest problem with using a drone to conduct cockle surveys, however, would be their inability to accurate detect cockles buried beneath the surface. As cockles are predominantly infaunal, drones would not be able to detect them.

8.0 Review of mussel survey regime to identify savings and associated risks

As is the case with the cockles, the mussel surveys and the management of the mussel fishery have both evolved over time alongside each other, with the management measures and the fishery and environmental targets using metrics that the surveys were known to provide. This review will look at various ways in which savings could potentially be made, highlighting what the associated risks are likely to occur as a consequence in terms of diminished accuracy or inability to provide required information. The review will look at ways in which the current survey regime could be streamlined, and also explore alternative methods and technologies.

8.1 Streamlining the current survey regime

Section 5 describes how the mussel surveys are currently conducted annually on foot during low water periods. Because most of the beds are difficult to access from shore while carrying survey equipment, access to the beds is usually achieved by beaching the research vessel on the sand close to each bed. This not only facilitates easier access than from shore, or from a vessel anchored in the nearest channel, but also provides a stable platform from which the samples can be measured and weighed. Of the £59,681.38 these surveys are estimated to cost (see Appendix 1), all but £914.88 is associated with the fieldwork. This is because, unlike the cockle surveys, most of the data analysis and mapping can be conducted on board the vessel while steaming back to port, rather than requiring additional office time following the surveys. As the fieldwork accounts for such a large proportion of the survey costs, the following sections will explore ways in which these costs could be reduced.

8.1.1 Utilising a faster vessel to conduct the surveys

The costs in appendix 1 are based on each survey taking a total of 12 hours to conduct. This time can be broken down into the vessel steaming to and from the survey site, waiting for the tide to ebb and flow, time spent dried out and additional time spent travelling between the office and moorings. Utilising a faster vessel would only have an impact on the time spent steaming to and from the survey site. Depending on which beds were being surveyed, and the speed of the faster vessel, this would save approximately 1.5 to 2 hours per day from the current regime. If the Authority were to change *Three Counties* for a faster vessel, this could result in savings of between £7,345.81 and £9,794.42. This would equate to savings of between £59.24 and £78.99 per entitlement at 50% cost recovery. As has been described in section 7.1.2.1, however, where the option of chartering a fast research vessel for the cockle surveys was explored, this saving is only made if the Authority actually owns the vessel. If there is a requirement to charter such a vessel, the additional costs exceed any savings that can be made.

8.1.2 Reducing the number of crew used to conduct the surveys

The current method used to conduct a mussel survey requires 1 person to map the perimeter of the mussel bed and 2 people to conduct the sampling within the bed. On small beds, it is possible for the two people conducting the sampling to also map the perimeter, negating the requirement for the third person. On the medium and larger sized beds, however, this is not possible in the time available during the low water period.

More staff than those described above are required to conduct the surveys, however. The Authority must work within MCA regulations regarding safe crewing levels and qualifications of vessel crew. This requires the survey vessel has a qualified skipper and engineer on board and must be adequately staffed with experienced crew. More experienced members of the marine science team may contribute towards the vessel compliment of experienced crew, but none are qualified as skippers or engineers. This requires a skipper and engineer are on board in addition to the survey team. In addition to these minimum legal requirements, the Authority's Health and Safety risk assessments also require a safety officer to remain in contact with survey teams when they are conducting foot surveys in the intertidal zone. This could be the skipper or the engineer.

Options were explored whereby the either the skipper or engineer were incorporated into the survey team, thus negating the requirement for one of the three research officers. However, this is not possible because the MCA coding of the vessel preventing lone working practices applies when the vessel is beached as well as when afloat. It would still be possible to reduce crew for surveys on the small beds, where only two surveyors are required. This has its risks, however. Currently, if the survey on a particular bed is postponed due to poor weather, there is sufficient flexibility within the crew to survey a more sheltered bed instead. If in that instance, however, the vessel was carrying a lower compliment of crew, that flexibility might be lost causing a complete loss of a day's survey.

8.1.3 Reducing the number of survey days by surveying multiple beds per day

Because the vessel providing access to the bed being surveyed dries out close to the bed, and most beds are too far away from each other to allow access between them on foot, in most cases only one bed can be surveyed each day. The costs in appendix 1 are based on the assumption that 20 beds will be surveyed at a rate of 1 bed per day. However, the number of beds that are present to be surveyed does change as some beds decline and disappear, while new beds occasionally appear. Figures 38 and 39 show the mussel beds that have been surveyed in the last two years (in red) and further beds that have been surveyed in the last 20 years but are no longer present (in blue). At the time the costs were estimated, there were 20 survey areas present (including the Welland Bank, which is not shown on the charts).

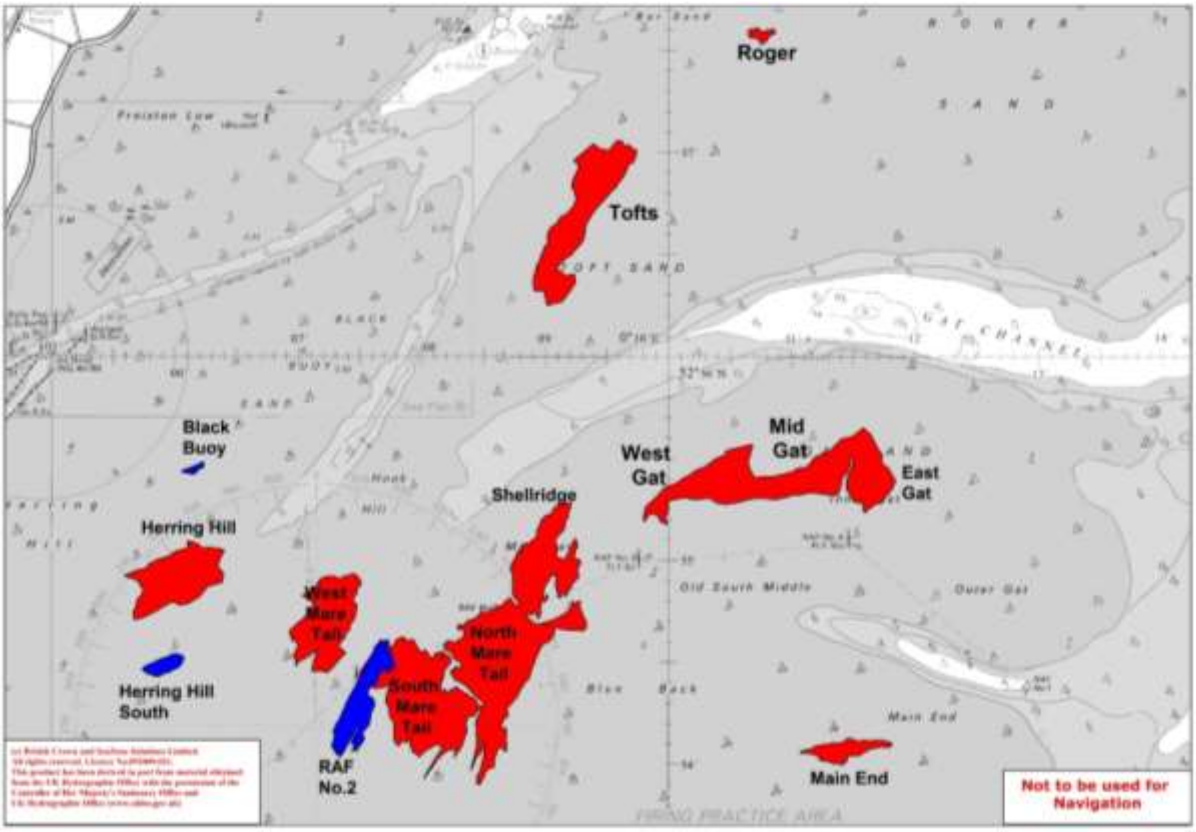

Figure 38 – Chart showing the distribution of current and historic mussel beds on the west side of The Wash.

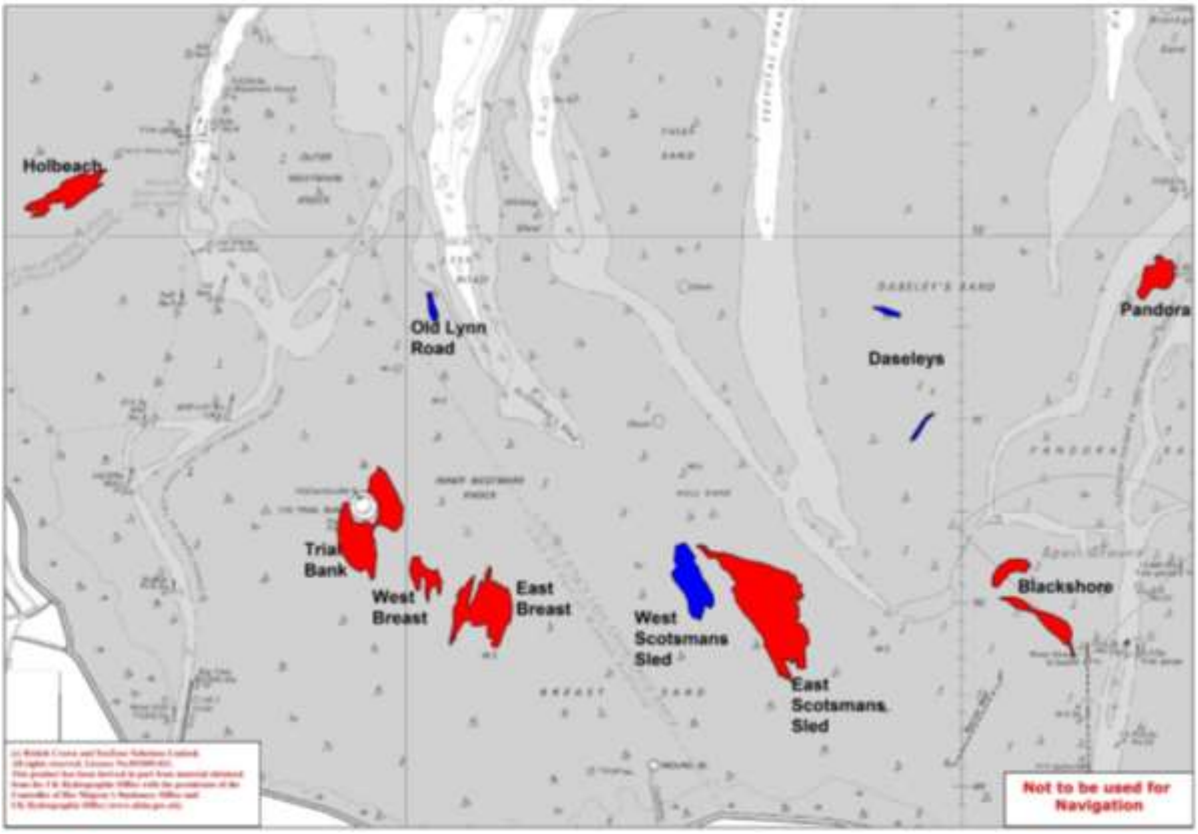

Figure 39 – Chart showing the distribution of current and historic mussel beds on the east side of The Wash.

Although the assumption has been made that only one bed can be surveyed per day, some of the survey areas are close enough to each other to allow two beds to be surveyed the same day. Where doing this is an option, this approach has already been taken in recent years. This has included conducting the following pairs of surveys on the same day as each other:

- West and Mid Gat
- Shellridge and East Mare Tail
- West and East Breast

While this approach saves the cost of three days of vessel time, an additional team of surveyors is required to be on board to conduct the surveys. Based on the current number of beds present and the ability to survey those listed above in pairs, it is possible to conduct the surveys in 17 days (three of which require additional crew). This approach results in a cost saving of £7,281.99 compared to the figures listed in appendix 1. This equates to a saving of £58.73 per entitlement at 50% cost recovery. The only risk associated with this approach is it does not provide any contingency to survey additional beds that might be identified. Should additional beds be identified and require surveying, additional costs would be incurred.

8.1.4 Reducing the number of survey days by reducing the sampling frequency of beds

It is a Success Criteria of the IFCA to use best available evidence when making management decisions. The evidence the Authority currently uses for the management of the WFO 1992 mussel fishery includes the annual mussel survey stock assessment. These surveys don't necessarily need to be conducted every year, however, to be considered best "available" evidence. Should a bed not be surveyed, the results from the previous survey would be considered to be the best available evidence. When considering options that include reducing survey frequency, it is important to understand what impact there would be on the accuracy of the evidence. If stocks are relatively stable from one year to the next, reducing sampling frequency would have a lower impact on the accuracy than if there was a large variation between annual results. Table 20 shows the biomass of mussels on each of the beds between 2002-2017. These figures have been used to determine the standard deviations and 95% confidence intervals shown in table 21. The 95% error margins have also been displayed in this table as a percentage of the mean stock on each bed.

Although the mussel beds appear to be relatively stable, in that individual beds have persisted throughout the survey period, the figures in tables 20 and 21 show there are large variations occurring annually to the actual biomass of mussels contained within them. This ranges from +/- 29.6 tonnes for the small bed on the Roger, which represents a range of +/- 52% of the mean biomass on the bed, to +/- 497.2 tonnes on the Tofts, which represents +/- 32.2% of the mean biomass for that bed. Failure to survey beds annually could, therefore, produce large errors through annual variations not being detected.

Table 20 – Mussel biomass (tonnes) on individual beds between 2002-2017

Bed	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean
North Mare Tail	901	1156	1977	1073	1012	1032	1205	1509	1685	1701	2644	2398	2437	1969	2190	3176	1754.1
South Mare Tail	526	760	1337	813	614	440	584	863	503	716	615	890	782	632	718	1328	757.6
Mare Tail, East			134	312	206	257	121	174	126	44	102	54	51	79	79	124	116.4
Mare Tail, West													342	239	435	803	454.8
Shellridge		229	311	436	505	183	158	208	166	13	8	6	26	0	0	548	174.8
Gat, West	1319	1546	2123	2722	3469	2249	2844	2943	1164	1088	539	1110	699	828	1095	1255	1687.1
Gat, Mid	1180	719	812	1557	1668	1522	1598	1575	634	737	566	388	186	225	496	443	894.1
Gat, East	886	827	837	1086	1260	989	1093	1086	387	152	308	337	361	373	549	356	680.4
Tofts			102	501	1137	1611	2736	2774	2357	2106	2234	2005	1638	1428	2148	1878	1540.9
Roger					174	127	128	140	55	32	41	64	28	31	31	51	56.4
Herring Hill	475	588	490	833	396	293	330	436	235	293	693	881	710	748	1014	1157	598.3
Main End	1529	192	160	225	94	169	86	214	47	36	88	95	141	45	179	142	215.1
Holbeach	1504	216	256	219	215	285	433	411	325	584	741	502	303	280	254	452	436.3
Trial Bank	202	184	285	363	480	681	504	805	709	1352	585	1014	686	695	635	1701	680.1
Breast, West	0	173	214	344	172	540	248	703	268	282	585	316	162	259	308	95	291.8
Breast, East	180	163	214	231	300	160	203	461	237	825	1066	1154	893	804	853	764	531.8
Scotsman'sSled	1057	1312	1422	1417	635	534	420	637	299	294	369	365	291	518	584	1253	712.9
Blackshore									197	759	852	386	171	50	202	427	380.5
Pandora	0	226	281	478	158	147	32	84	130	158	279	135	149	122	189	189	172.3
Total	11384	9746	11858	12971	12697	12117	12760	15188	9626	11214	12338	12100	10127	9366	12002	15953	11965.4

Table 21 – Annual variation in mussel stocks in terms of standard deviation, 95% confidence limits and the confidence limits as a percentage of the mean biomass

Bed	Mean	SD	SE	95% CI	% variation
North Mare Tail	1754.1	681.7	170.4	361.3	20.6
South Mare Tail	757.6	258.6	64.6	137.0	18.1
Mare Tail, East	116.4	86.9	21.7	46.1	39.6
Mare Tail, West	454.8	245.6	122.8	341.4	75.1
Shellridge	174.8	189.0	47.3	100.2	57.3
Gat, West	1687.1	907.7	226.9	481.1	28.5
Gat, Mid	894.1	534.0	133.5	283.0	31.7
Gat, East	680.4	361.4	90.4	191.6	28.2
Tofts	1540.9	938.2	234.5	497.2	32.3
Roger	56.4	55.8	13.9	29.6	52.4
Herring Hill	598.3	276.7	69.2	146.7	24.5
Main End	215.1	355.5	88.9	188.4	87.6
Holbeach	436.3	321.2	80.3	170.3	39.0
Trial Bank	680.1	402.9	100.7	213.6	31.4
Breast, West	291.8	182.4	45.6	96.7	33.1
Breast, East	531.8	361.8	90.4	191.7	36.1
Scotsman's Sled	712.9	425.5	106.4	225.5	31.6
Blackshore	380.5	289.4	69.6	160.8	42.3
Pandora	172.3	110.9	27.7	58.8	34.1
Total	11965.4	1827.5	456.9	968.6	8.1

The annual variation in mussel biomass within the beds is sufficiently high that it would be unwise not to conduct annual surveys. Some of the beds are relatively small, however, individually supporting <2% of the total mussel biomass. These include the East Mare Tail (1.0%), Shellridge (1.4%), The Roger (0.5%), Main End (1.8%), and Pandora (1.4%). If these beds were only surveyed on alternate years in a rotation, the maximum inaccuracies caused by failing to detect annual variation would only amount to approximately +/- 3% of the total mussel biomass, or approximately +/- 360 tonnes.

Because the East Mare Tail and the Shellridge beds are usually surveyed on the same day, reducing the survey frequency of these five beds to alternate years would save two days per year from the survey programme.

If combined with the option of surveying multiple beds on the same day, as described in section 8.1.3 above, the total number of vessel days required to conduct the surveys would be 15 days. Taking into account some of the surveys would require additional crew to enable two beds to be surveyed on the same day, the cost of conducting the fieldwork would be £45,352.28. This would be a saving of £13,414.23, or £108.18 per entitlement at 50% cost recovery.

8.2 Using alternative methods and approaches

The current survey method and the various options described in section 8.1 all focus on laying a vessel close to the mussel beds and conducting the surveys on foot during the low water period. In section 7.2 innovative approaches, such as using dredges, remote sensing techniques and drones were explored for conducting the cockle surveys. Although these techniques were considered unsuitable for assessing cockle stocks, some of them could have applications for surveying mussel beds.

Dredges could be used, and have been in the past for assessing sub-littoral mussel beds that cannot be surveyed on foot, but they would have the same limitations in accuracy as described in section 7.2.1. Conducting the surveys using dredges would be much less accurate than the current method, more invasive, and not likely to save any time or cost.

Whereas the use of satellites and drones were dismissed in sections 7.2.2 and 7.2.3 for surveying cockles, because mussels are epifaunal rather than infaunal, these technologies might be able to detect them. Although drones should be able to detect mussel beds, and might be able to assist in mapping their extent, the same operational limitations would apply to operating drones for surveying mussel beds as for cockle beds. Because physical samples would still need to be collected, requiring surveyors to access the beds, drones are unlikely to be able to save any time spent surveying. Similarly, although some of the mussel beds can be seen on Sentinel 2 satellite images of The Wash, physical samples would still be required to assess the stock and determine its biomass. While neither of these technologies would currently be able to provide accurate stock data, there is potential for both to assist in the detection of beds that have not currently been identified.

9.0 Summary of the options

The review has identified a number of alternative approaches in which the current WFO 1992 cockle and mussel survey regimes could be changed to reduce costs. In most cases, however, the changes carry associated risks, usually in the form of reduced accuracy of the data. Table 22 summarises the various options described above for reducing survey costs. In each case the estimated savings and associated risks have been described.

Table 22 – Summary of the options for adjusting surveys and their associated savings and risks

Change to current regime	Implications on cost	Associated risks
Cockle surveys		
Reducing crew numbers from 5 to 4.	Because the vessel would need to be at sea an additional 4 days to compensate for slower sampling rates, the cost of surveys would <u>increase</u> by £6,764.09 (equivalent to £54.55 per entitlement).	Reducing crew from 5 to 4 would result in sampling rates declining from approximately 17.5 grabs/hour to 14 grabs/hour. This would require the vessel to be at sea for 19 days instead of 15 days to complete the surveys.
Chartering a faster research vessel to conduct surveys as day trips rather than current method of staying at sea overnight	Using *Tamesis* to conduct the surveys would increase the cost of the surveys by £15,000 (equivalent to £242 per entitlement). Unless a local vessel could be chartered, whose daily costs were equal to or lower than that of *Three Counties*, this option would not be cost effective. Should the Authority at some stage replace *Three Counties* with a fast day-boat, the figures indicate the costs and time taken to conduct the surveys would be similar to those currently incurred.	Although faster steaming times are achieved, these barely compensate for the time lost by no longer staying at sea overnight. Working two tides per day on day trips would also create problems with MCA regulations concerning safe working hours. This would require a second team to measure samples ashore. Unless Three Counties is replaced with a faster vessel, the Authority would need to charter a vessel for the surveys.
Chartering fishing vessels for surveys	Precise costs are dependent on how many days would be required to complete the surveys and the daily charter cost for the vessel. Costs are estimated to range between a minimum of £27,000 (15 days @ £1,000/day vessel charter) to £64,400 (23 days @	Unless equipped with a winch on a hydraulic retractable A-frame, sampling rates would be reduced, requiring more time to conduct the surveys. Unless the vessel could remain at sea for several days, surveys would take longer

	£2,000/day vessel charter). The fieldwork currently costs £46,290.75 to conduct, so costs could amount to a saving of up to £19,290.75 or an additional burden of up to £18,109.25. Chartering alternative vessels to conduct the surveys would be an additional burden to the Authority, so would possibly require a higher level of cost recovery.	to complete. Maximising working during day trips could incur MCA regulations concerning safe working hours. Unless vessel is equipped properly for deployment of Day grab, there could be H&S concerns.
Removal of whole beds from survey area	Removal of the Wrangle Extension, Long Sand, Styleman's and Blackguard sites would save 75 stations. This would save approximately £1,864.49 (equivalent to £15.03 per entitlement). This would result in an average loss of 61 tonnes of TAC (equivalent to £21,350 @ £350/tonne)	Removal of whole beds from survey area would result in loss of information from those areas. This could result in reductions to the TAC that potentially outweigh any savings made. Absence of Year-0 juvenile cockle data could result in unsurveyed beds having to remain closed.
Reducing frequency at which beds are surveyed and using rolling average for years when not surveyed	The bed with the least annual variation is the Breast Sand. Not surveying this bed in any particular year would reduce sampling by 129 stations, or 1 day at sea. This would result in a saving of £3,086.05 (equivalent to £24.89 per entitlement).	There are large annual variations in cockle biomass on the beds. Attempts to estimate stocks in lieu of survey data will be subject to large inaccuracies that would affect the TAC. Using this approach on the Breast Sand in recent years would have resulted in an overestimation of stock in 2008 of 722 tonnes and an underestimation in 2014 of 607 tonnes.

		An absence of Year-0 juvenile cockle data would mean an alternative method of protecting juvenile stocks would be required to be implemented.
Removal of sample stations from areas not supporting cockles	Removal of survey stations that have not historically supported cockles would reduce the survey regime by an average of 215 stations. This would save an estimated 12.3 hours sea time, resulting in a cost saving of £3,150, (equivalent to £25.41 per entitlement).	Because this approach would only remove stations in which cockles have not been identified previously, the risks are relatively low. However, should a settlement occur at these stations after they have been removed, they would remain undetected. At £350/tonne, it would only take 27 tonnes of adult cockles to be present in these areas for the fishers to lose whatever savings had been made by removing these stations.
Reduction of sampling resolution in Herring Hill, Mare Tail, Gat and Holbeach sites to match that used elsewhere in The Wash	This would reduce sampling by 102 stations, saving approximately 6 hours sea time. This would result in a saving of £1,543.03 (equivalent to £12.45 per entitlement).	There would be a reduction in accuracy in these areas, but only down to levels provided by the surveys in the rest of the site. Because the survey stations would all be moved to new locations, site specific data from the historic dataset could no longer be applied to them. Time would also be required assigning the new stations, changing the database and entering the new sites into the vessel plotters. This would take several days to complete but would be a one-off task.

<table>
<tr>
<td>Reduction of sampling resolution by increasing distances between sample stations. Scenarios were tested looking at sampling regimes of 1,362, 695, 341 and 174 stations</td>
<td>Reducing survey resolution would have the following costs in terms of sea time and survey costs:

<table>
<tr><th>Stations</th><th>Sea days</th><th>Cost</th></tr>
<tr><td>1,362</td><td>15</td><td>£50,865.15</td></tr>
<tr><td>695</td><td>11</td><td>£38,520.95</td></tr>
<tr><td>341</td><td>8.8</td><td>£31,731.64</td></tr>
<tr><td>174</td><td>7.5</td><td>£27,719.78</td></tr>
</table>

Although survey costs could be significantly reduced using this approach, the loss of accuracy and spatial resolution would require the introduction of new management measures to adequately protect juvenile stocks. Enforcement of these measures could exceed potential savings.

If the spatial resolution of the data was no longer sufficient to inform the micro-management of the stocks, significant fishing opportunities might be lost that can currently be supported (e.g. managing adaptive fisheries where high stock die-offs have been predicted. Such an opportunity in 2015 enabled additional stocks on the Roger Sand worth over £2million to be opened to the fishery).</td>
<td>Reduction of survey resolution would impact on the accuracy of the data used to estimate stock biomass and TAC. The current regime of 1,362 stations provides accuracy of +/- 11.7%. This would decline to approximately +/- 16.6% for 695 stations, +/- 23.4% for 341 stations and +/- 31.1% for 174 stations. This could result in stocks being significantly over or under estimated.

Spatial resolution of stock distribution charts would decline significantly. At lower resolutions, these would be inadequate for informing spatial closures to protect Year-0 juvenile stocks. Additional measures would need to be introduced to protect juvenile stocks. Similarly, spatial resolution would not be sufficient to inform micro-management of the stocks to the level currently conducted.

These changes would be particularly noticeable on the smaller beds, where the number of samples would be reduced to levels too low to conduct individual assessments with reasonable confidence.

The distances between the sample stations for the two lowest resolutions are</td>
</tr>
</table>

		too great to still use a regular grid survey strategy on all but the largest beds. For these resolutions, a random grid strategy would be required. This would make modelling stock distributions difficult. Changing survey stations would disrupt the current dataset that can be used for comparing annual stock data and determining trends. These data in the past have helped improve our understanding of settlement patterns, growth rates, the dynamics of “atypical” mortality and to help predict where and when die-offs are likely to occur. Time would be required assigning the new stations, changing the database and entering the new sites into the vessel plotters. This would take several days to complete but would be a one-off task.
Using dredges to collect samples	To provide similar coverage and accuracy to that of the current grab survey, a dredge survey is likely to take more time both in terms of deploying equipment and measuring samples. Costs would most likely increase.	Dredges are not considered the most appropriate method for surveying cockles, either not providing sufficient spatial coverage, or producing too large samples to measure. Additional problems of determining their efficiency at fishing also reduces their accuracy. A survey using dredges would have a much larger environmental impact than current use of a Day grab.

Using remote sensing techniques	Methods not appropriate	Neither the RoxAnn AGDS, the EdgeTech side scan sonar, or satellite imagery are capable of accurately charting cockle beds so are not appropriate methods. In all cases, physical samples would still be required to estimate stock biomass.
Using drones	Method not appropriate	Drones will not detect infaunal cockles. As such would not be able to assess stocks.
Mussel surveys		
Utilising a faster vessel to conduct the surveys	Using a faster vessel could save 1.5 to 2 hours steaming per day from the current regime. If the Authority were to change *Three Counties* for a faster vessel, this could result in savings of between £7,345.81 and £9,794.42 (equivalent to £59.24 and £78.99 per entitlement). If the Authority chartered a faster vessel, charter costs would greatly exceed any saving that could be made.	Provided the vessel could still safely beach near the mussel beds, there would be no associated risks
Reducing the number of crew used to conduct the surveys from 5 to 4	The option of reducing the crew by incorporating the engineer into the survey team was explored but found not to be possible due to MCA policies regulating lone working aboard vessels. Reducing the survey team on 4 of the smaller beds would result in a saving of £1,056.56 (equivalent to £8.52 per entitlement)	Reducing the survey team on the smaller beds would risk losing flexibility to survey other more sheltered areas if the planned survey was postponed due to poor weather. This would result in additional costs being incurred.

Reducing the number of survey days by surveying multiple beds per day	Due to distances between beds, this is only possible for some beds. By taking this approach, the number of survey days could be reduced from 20 to 17 (but three of these surveys would require a larger crew in order to survey two beds). This approach would achieve a cost saving of £7,281.99 (equivalent to £58.73 per entitlement).	The only risk associated with this approach is it does not provide any contingency to survey additional beds that might be identified. Additional surveys required would incur additional costs.
Reducing the number of survey days by reducing the sampling frequency of beds and using rolling average for years when not surveyed	If combined with the option of surveying multiple beds on the same day, the total number of vessel days required to conduct the surveys could be reduced to 15 days. This would produce a total saving of £13,414.23 (equivalent to £108.18 per entitlement).	The data shows there are large annual variations in stock biomass on all of the beds. Reducing survey frequency and using a rolling average would, therefore, risk introducing large inaccuracies to the stock estimates. This could be minimised by only using this approach on some of the smaller beds that individually support <2% of the total mussel biomass. If the East Mare Tail (1.0%), Shellridge (1.4%), The Roger (0.5%), Main End (1.8%), and Pandora (1.4%) beds were only surveyed on alternate years in a rotation, the maximum inaccuracies caused by failing to detect annual variation would amount to approximately +/- 3% of the total mussel biomass, or approximately +/- 360 tonnes.
Using dredges to collect samples	To provide similar coverage and accuracy to a grab survey, a dredge survey is likely to take more time both in	Using dredges would be much less accurate than the current method.

	terms of deploying equipment and measuring samples. Costs would most likely increase.	A survey using dredges would have a much larger environmental impact than the current foot surveys.
Using remote sensing techniques	Vessel access to the beds would still be required to collect physical samples, so no savings would be made.	Although some of the mussel beds can be seen on satellite images of The Wash, not all of the beds are visible. Their accuracy and resolution is low confidence, therefore. Physical samples would still be required to assess the stock and to determine its biomass.
Using drones	Vessel access to the beds would still be required to collect physical samples, so no savings would be made.	Because physical samples would still need to be collected, requiring surveyor to access the beds, drones are unlikely to be able to save any time spent surveying.

10.0 References

ESFJC, 2008. Eastern Sea Fisheries Joint Committee Shellfish Management Policies. Available online at http://www.eastern-ifca.gov.uk/wp-content/uploads/2016/03/WFO_Shellfish_management_policies_2008.pdf

Appendix 1 – Revised WFO costs

WFO cockle fishery costs

Estimated annual costs associated with conducting the annual Wash Fishery Order 1992 cockle surveys					
Cockle survey costs	**£ 50,865.15**				
Officer costs	**Days**	**Officers**	**Officer grades**	**Duration (hrs)**	**Totals**
IFCO crew	15	3	1 senior skipper, 2 grade 5 IFCOs	12	£12,810.60
MSO crew	15	2	2 MSOs	12	£ 7,664.40
Analysis and reports	20	1	1 senior MSO (Research)	8	£ 4,574.40
Vessel costs	**Trips**	**cost/trip**			
RV Three Counties	15	1,530			£22,950.00
Subsistence	**Allowance**	**trips**	**Officers**		
Breakfast	6.41	15	5		£ 480.75
Lunch	8.81	9	5		£ 396.45
Evening meal	10.92	9	5		£ 491.40
Nights away	33.27	9	5		£ 1,497.15

Summary of WFO cockle survey costs

Costs are primarily associated with operating costs of Research Vessel *Three Counties* and with required crewing levels during the surveys. Costs are likely to vary in accordance with days (i.e. part of trips) being lost to poor weather of vessel breakdowns and requiring additional trips to sea.

Costs are also associated with analysing the data post survey and reporting the conclusions

Subsistence costs include meal and captive overnight allowances made for staff being captive at sea during the surveys.

WFO Mussel fishery costs

Estimated annual costs associated with conducting the annual Wash Fishery Order 1992 mussel surveys					
Mussel survey costs	**£ 59,681.38**				
Officer costs	**Days**	**Officers**	**Officer grades**	**Duration (hrs)**	
IFCO crew	20	3	1 senior skipper, 2 grade 5 IFCOs	12	£ 17,080.80
MSO crew	20	2	2 MSOs	12	£ 10,219.20
Analysis and reports	4	1	1 senior MSO (Research)	8	£ . 914.88
Vessel costs	**Trips**	**cost/trip**			
RV Three Counties	20	1,530			£ 30,600.00
Subsistence (surveys)	**Allowance**	**trips**	**No Officers**		
Breakfast	6.41	10	5		£ 320.50
Evening meal	10.92	10	5		£ 546.00

Summary of WFO mussel survey costs

Costs are primarily associated with operating costs of Research Vessel *Three Counties* and with required crewing levels during the surveys. Costs are likely to vary in accordance with days (i.e. part of trips) being lost to poor weather of vessel breakdowns and requiring additional trips to sea.

Analysis and reporting costs are artificially low as a result of analysis being undertaken whilst at sea.

Subsistence costs are meal allowances made for staff being captive at sea during the surveys.

Appendix 2 – Authority paper detailing use and cost of hiring FPV *Tamesis*

5th EIFCA Meeting

Agenda Item:28

25th April 2012

<u>Use of *FPV Tamesis* (Kent & Essex IFCA)</u>

The Authorities vessels are moored at Sutton Bridge at the base of the Wash, with a long passage required for the vessels to access the river harbours and coastline of Suffolk. Over the last two years the Authority has explored ways to allow it to access the southern part of its district without increased cost by using the Kent & Essex IFCA Fisheries Patrol Vessel *Tamesis*. This use has focused mostly on surveys for shellfish in the Stour and Orwell estuaries at the time when the Authorities own research vessel *Three Counties* is undergoing its annual refit (usually in July each year). The Authority has also used this vessel in smaller projects of one to three days (which does not justify the two day passage each way of *Three Counties*).

The arrangement with Kent & Essex IFCA has been *ad hoc*, often managed by verbal agreement. Kent & Essex IFCA recently sought greater clarity in the programme of use so they can manage their vessel time appropriately. With the completion of the Authorities research/environment plan we have this surety required.

Officers recently met with Kent & Essex IFCA to discuss the shared management and the deployment of vessels in the Stour and Orwell estuaries currently agreed in an MOU. The use of vessels was discussed at this meeting. Projects identified for the southern Suffolk coast were:

- Continuation of the Stour and Orwell shellfish survey
- Surveying of proposed/possible MCZ's in southern Suffolk
- Small/juvenile fish surveying in southern Suffolk estuaries

As part of the MOU the use of this vessel was discussed between the two IFCA's. It was agreed that the appropriate day rate for *Tamesis* in 2012 would £1500 for a seven and a half hour shift and £1800 for a twelve hour shift. Shift times would be agreed between the skipper and the research project leader with an approximate total of 14 days usage.

Kent & Essex IFCA suggested that longer term agreements could see better utilisation of their vessel elsewhere and the possibility of a lower charter cost. Eastern Authority officers did not want to fetter the incoming CEO with a long term agreement, particularly since the vessel working group is yet to report with its findings. Other longer term options include slowly moving the refit of *Three Counties* until later in the year, exploring other charters or RIB usage and changes in other working patterns. Authority officers will review the usage of *Tamesis* at the end of the Calendar year once a new CEO is in post and the outcome of the vessel working group is known. Maintaining an option on *Tamesis* would also provide enforcement cover should *ESF Protector III* go in an early sale.

Authority members are asked to note the usage of the *FPV Tamesis* for managing waters in the southern Suffolk estuaries this year

Authority member are asked to note the cost of this use and the plan to review cost/usage at the end of the year.

Duncan Vaughan
Chief Executive Officer
April 2012

LOCAL GOVERNMENT (ACCESS TO INFORMATION) ACT 1985