The Wash Fishery Order Regulated Cockle Fishery

Hydraulic Suction Dredging Impact Assessment

Eastern IFCA Report

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Executive summary

Traditionally an entirely hand-worked fishery, hydraulic suction dredges were first introduced into The Wash for harvesting cockles in 1986. The efficiency of such gears at harvesting cockles meant that it became economically viable to target lower density beds than had previously been possible. However, due to this increased efficiency, within two years of their introduction stocks had declined to densities that were too low for a hand-worked fishery to operate commercially alongside the dredge fishery. The following decade saw the fishery follow a "boom and bust" pattern, with a peak of 8,910 tonnes being landed in 1991 and the total closure of the fishery during 1997. Following the introduction of an annual quota in the form of a Total Allowable Catch (TAC) in 1998, stocks appeared to stabilise, but the average length of the fishing season was only about six weeks compared to four or five months for hand-worked fisheries prior to the introduction of dredges. Many of the fishers were dissatisfied with this situation and following a particularly short season of three weeks in 2004, became more vocal about banning the use of dredges. In 2005 support for the hand-work fishery increased when stocks were too low to open a dredge fishery but there was a small, but profitable hand-worked fishery. Support for the hand-work fishery, and opposition towards dredging grew further over the following years, to the extent that there has not been a dredge fishery since 2008 on the regulated beds.

At the 27th April 2016 Eastern Inshore Fisheries and Conservation Authority (EIFCA) meeting it was agreed by the Authority members that by default the fishery would be hand-worked, with an option for dredging only as a contingency in exceptional circumstances. Such circumstances were not defined but could potentially include situations in which significant cockle stocks were present in Holbeach bombing range or when large amounts of cockle stock are anticipated to be lost due to "atypical" mortality and need to be harvested quickly. However, whilst both circumstances have occurred in recent years, the majority of the fishermen have still strongly opposed the use of dredges.

Before the Authority could consent a dredge fishery, it would need to demonstrate that the proposed fishery would not have an adverse impact on the site's designated conservation features. This would require the proposed fishery to pass a Habitats Regulations Assessment (HRA). While previous dredge fisheries have satisfied this HRA process, advice has become much stricter since the last dredge fishery was opened, so there is uncertainty as to whether such fisheries would pass now and what mitigation would be needed. In addition, a dredge fishery also brings socio-economic concerns and management implications that would require careful consideration.

For a fishery to be opened within The Wash, a HRA must conclude that the fishing activity will not have an adverse effect on site integrity by ensuring associated fishing pressures will not have a significant impact on designated site features and that site conservation objectives are met. The processes involved in hydraulic suction dredging for cockles have the potential to result in a variety of environmental impacts that extend beyond the target species. These include impacts on the habitats and communities in which cockles occur and impacts on species that have dependencies on cockles and are affected by their removal. A review of the available literature surrounding the potential impacts of cockle dredging in The Wash has been carried out and the outcomes of this review used to inform an assessment of whether such a fishery would pass a HRA.

Following consideration of the available data and literature, we have been unable to identify any significant changes to the benthic biota and sediments in The Wash following previous dredge fisheries. However, due to the lack of available evidence, we cannot conclude that dredging, at or beyond previous levels, would not result in significant impacts on the benthos, particularly if the activity is repeated over multiple years. Uncertainties remain around the potential impacts of dredging on mud sediments, the long-term effects of repeated dredging and the level of effort that can be sustained in The Wash without having adverse effects on the environment and site features. Because of these uncertainties, it is concluded that to meet the requirements of a HRA, effort would need to be limited to ensure no long-term changes to sediment composition were to occur; vulnerable, muddy beds should be closed to dredging activity; and sediment monitoring in dredged and non-dredged areas would be required to monitor effects.

When assessing the potential impacts on cockle predators, Oystercatcher were the only SPA species identified as vulnerable to the removal of cockles by the fishery, as adult cockles form their main prey resource. Application of the same management measures currently used in WFO hand-work fishery, to manage bird feeding requirements, would mitigate this risk and with the above described mitigation in place, for impacts on sediments and biota, it is predicted that a hydraulic suction dredge cockle fishery in The Wash could pass a HRA and receive consent.

In terms of stock sustainability, there are concerns that the 10% smash rate limit in the Eastern IFCA district does not account for all discard mortality and that the TAC does not represent all the fishing mortality incurred. This would need to be addressed in any future dredge fishery. Assessment of Eastern IFCA WFO cockle survey data between 2004 and 2013, showed no clear effect of dredging on adult stocks or spatfalls. However, as there have been no dredge fisheries since 2008, the study was only able to draw potential impacts from five years of data. Should dredge fisheries be permitted to occur on certain beds, it is unclear at what level dredging could become unsustainable if multiple gear passes were regularly repeated on the same beds, particularly over multiple years. If a hydraulic suction dredge fishery were to take place in The Wash, management would follow the same annual TAC approach, but would likely require further effort limitation, strict monitoring of effort in line with the assessment of stocks and would benefit from having both open and closed areas of dredged beds for monitoring and comparison.

The socio-economic impacts, management implications and enforcement challenges associated with the above also require careful consideration. Opening a dredge fishery is likely to favour those with larger commercial fishing operations over those with small business models and could have large financial implications on some fishers. In terms of management, to ensure effective management of a dredge fishery alongside a hand-work fishery a significant increase in workload would be required to monitor and enforce two TAC’s, ensure poaching does not occur and ensure compliance with the 10% smash rate.

After consideration of the above, it is clear that the risk associated with a hydraulic suction dredge fishery is much higher than that associated with a hand-work fishery. To mitigate this risk, it is evident that a significant increase in resources would be required by the Authority. When combined with the levels of uncertainty around the environmental and socio-economic impacts of a dredge fishery, which would require a heavy commitment of resources for the authority to answer, pursuing this fishery would be a costly (and possibly unfeasible) option for the Authority.

1 Introduction

1.1 The Wash

The Wash is a large embayment located on the east coast of England designated as a Special Area of Conservation (The Wash and North Norfolk Coast SAC), a Special Protection Area (The Wash SPA)[1], a Ramsar site and a Site of Special Scientific Interest (SSSI). The Wash hosts the second largest expanse of intertidal mud and sand flats in the UK and provides a dynamic environment composed of tidal rivers, estuaries, lagoons, mud and sand flats and deeper central channels. The designations applied to The Wash embayment highlight the importance of its extensive intertidal and subtidal habitats and the large populations of overwintering water birds which it supports.

The intertidal mud and sandflats in The Wash have traditionally supported a valuable cockle (*Cerastoderma edule*) fishery (Figure 1), provided an important resource to the local fishing industry. Traditionally this fishery was entirely hand-worked (facilitated with the practice of "blowing-out"), until hydraulic suction dredges were introduced in 1986 as a more efficient method of harvesting cockles. Since 2008, however, it has reverted back to a predominantly hand-worked fishery. Over time the management of the fishery has evolved and whilst it originally primarily focused on the sustainability of

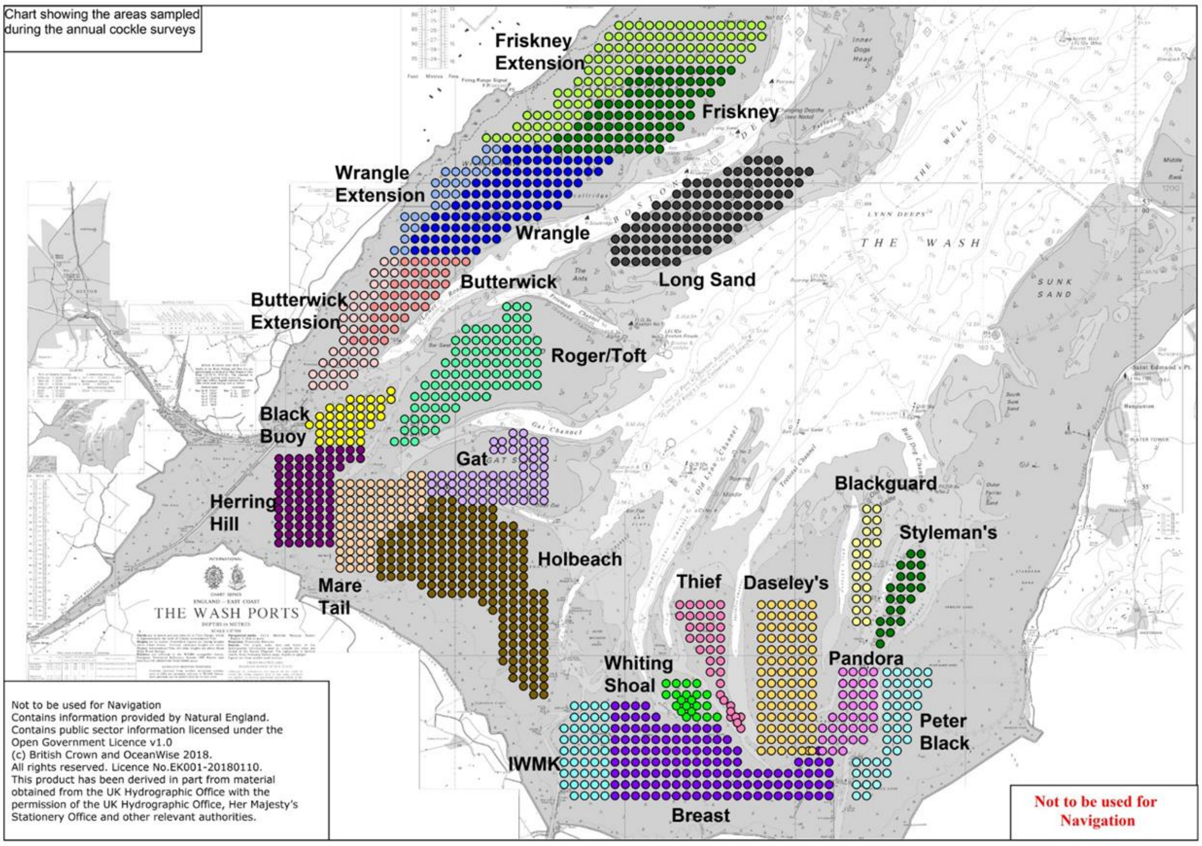


Figure 1: The Wash cockle beds. EIFCA conduct annual springs cockle surveys across all cockle beds. Each point indicates a survey station.

[1] Where Special Areas of Conservation and Special Protection Areas occur in the marine environment, they are referred to as European Marine Sites.

cockle stocks, the conservation designations have introduced a requirement to ensure the cockle fishery does not prevent the designated environmental features within the site being maintained in, or allowed to recover to, favourable condition. Environmental features include The Wash cockle stocks, which provide an essential food resource for the internationally important communities of birds that reside or over-winter, and the sandbanks and mudflats on which they are situated, which provide an important habitat for invertebrate communities. As a result of this increased environmental awareness, there is a requirement to undertake a detailed assessment of the impacts of the fishery on designated features – a Habitats Regulations Assessment (HRA) – and consider Natural England (NE)'s advice, prior to a fishery being consented within the site.

1.2 Hand-worked vs. dredge cockle fishery

Hydraulic suction dredges were introduced in The Wash in 1986 as a method of harvesting cockles. However, the legislation in place at the time was not sufficient to manage the efficiency of the new gear, resulting in over-fishing and a rapid decline in cockle stocks. Dredges are very efficient at harvesting cockles, allowing lower densities of cockles to be fished than is economically viable for the hand-work fishery. Whilst this ability to target such stocks has some benefits, such as fishing large stocks of cockles that would otherwise be lost or exploiting low densities that would be unviable for the hand-worked fishery, there are concerns over this level of efficiency. From a sustainability perspective, their ability to effectively fish low densities of cockles can easily result in over-fishing and there is also increased environmental concern regarding physical impacts of this type of gear, particularly on more stable, muddy habitats.

When suction dredging was initially introduced, the management of the fishery used daily vessel quotas rather than an annual Total Allowable Catch (TAC) to restrict the fishery. Although daily quotas had previously been an effective mechanism to maintain sustainability of the hand-work fishery, it proved to be ineffective with the dredge fishery. Within two years of their introduction, cockle stocks had declined to densities that were too low for a hand-worked fishery to operate commercially alongside, and after an initial three years in which landings exceeded 7,000 tonnes per year, landings fell to 1,202 tonnes in 1989 (Figure 2[2]). The following decade saw the fishery follow a

[2] It is important to note that whilst annual cockle stock assessments have been conducted in The Wash since 1994, the number of stations surveyed significantly increased to 1300 stations across all beds within The Wash. Prior to this, surveys initially focused on only the most important cockle beds and fishable stocks. Beds with low densities, relatively small cockles or on high ground were not systematically surveyed and so did not contribute to the total stock. Over the years these beds were gradually incorporated and included in future surveys. Since 2004, 1300 stations across all beds have been surveyed every year. The values for total stock (tonnage) presented in Figure 1 between 1994 and 2004 are therefore likely to be artificially low because of this. A review conducted in 2007 by ESFJC of the cockle and mussel policies estimated the biomass on areas that were not included in these assessments based on the assumption that the relative contribution of specific beds or areas to the total stock had not changed over time (van Stralen, 2007). Findings are presented in Appendix 6.

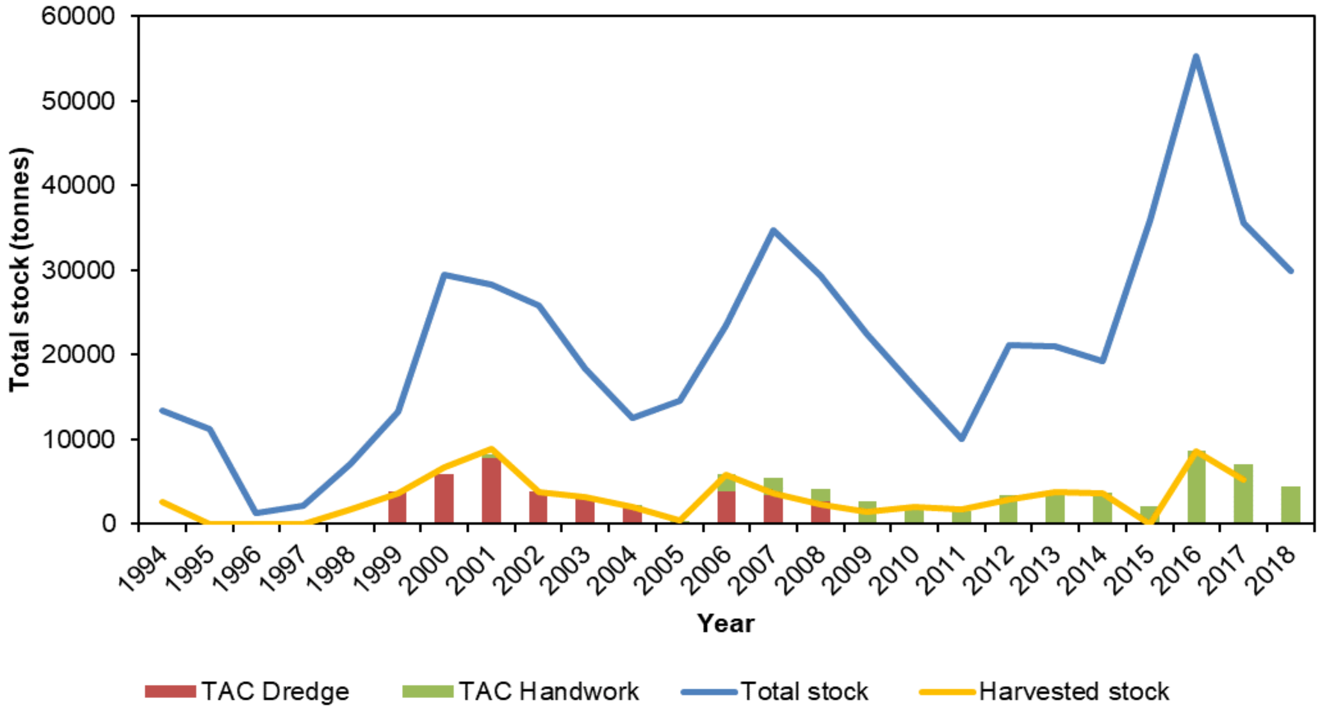


Figure 2: Summary of cockle stocks, the annual TAC and the total stock landed (dredged or hand-worked) over the last 18 years in the Wash Fishery Order (WFO) area of The Wash. The last dredge fishery took place in 2008. (It is important to note that prior to 2004 stock assessments did not reflect all beds within The Wash, only those that were important to the fishery and therefore are likely to be artificially low.

"boom and bust" pattern, with a peak of 8,910 tonnes being landed in 1991 and total closure of the fishery because of insufficient stocks during 1997. Whilst the management of the fishery strengthened in 1993 with the introduction of the Wash Fishery Order (1992) (WFO 1992), it wasn't until the introduction of a TAC as a control mechanism in 1998 that stocks appeared to stabilise.

The introduction of an annual quota in the form of a TAC, whereby the fishers can take one third of the adult stocks, bought more stability and helped facilitate a stock recovery through the 2000's (Figure 2). Under the TAC system, however, the average length of the fishing season was only about six weeks compared to four or five months for hand-worked fisheries prior to the introduction of dredges. Many fishers were dissatisfied with this situation and following a particularly short season of three weeks in 2004, became more vocal about banning the use of dredges. In 2005 support for the hand-work fishery increased when stocks were too low to open a dredge fishery but the subsequent hand-work fishery of just 468 tonnes lasted most of the summer and provided a good income for the participating fishers.

Following the success of the 2005 hand-worked fishery, efforts were made to enable this fishery to operate more successfully. Whereas previously only 10% of the TAC had been set aside for the hand-worked fishery, a third was set aside between 2006 and 2008 (Figure 2). In addition, whilst previously the hand-work fishery had been expected to operate on the same beds as the dredge fishery, between 2006 and 2008 the dredge fisheries were restricted to operating within just two areas, the Friskney and Holbeach bombing ranges, from a total of 18 cockle beds. Industry support for the hand-work fishery, and opposition towards dredging grew further during this period, to the extent that there has not been a dredge fishery since 2008 on the regulated beds.

Although only hand-worked fisheries have operated since 2009, officers continued to present management options to the Authority members that included dredge and mixed fisheries. Because the production of these options was time-consuming, the future use of hydraulic suction dredges was raised and discussed at a Full Authority meeting on 27th April 2016. The outcome of that discussion was a decision from the members that, while future fisheries would by default be hand-worked, the option of using hydraulic suction dredges should be retained in case exceptional circumstances require their use. A dredge fishery has not been considered as an option for 2017 and 2018, since this decision was made.

Under the Habitats Regulations, to be certain a fishing activity meets environmental requirements the activity can only commence following completion of an annual Habitats Regulations Assessment (HRA). Although hand-working activities are generally considered less environmentally damaging than dredging, particularly in terms of seabed disturbance, such a fishery still poses environmental risks (EIFCA, 2016), and these must be appropriately mitigated before approval is granted. For example, the main risk associated with the hand-work fishery is the routine use of ‘prop-washing’ which if poorly conducted can have significant impacts on the seabed, however, management measures and monitoring introduced by the Authority are sufficient enough to mitigate this risk. In The Wash, the hand-work cockle fishery has occurred annually since 2004 and is seen as an environmentally sound activity, evidenced by the successful completion of a HRA each year. Such an assessment has not been completed for a hydraulic dredge cockle fishery in The Wash since 2008. There is uncertainty as to whether the risks associated with such a fishery (EIFCA, 2016) could be mitigated by the Authority to prevent it from having an adverse effect on site integrity.

1.3 Requirement for an Impact Assessment

The decision for a default hand-worked fishery with an option for dredging as a contingency in exceptional circumstances has subsequently been included in the draft Management Plan for The Wash fisheries which has been agreed in principle by the Authority subject to consultation with the industry. The conditions of “exceptional circumstances” are not defined but could potentially include situations in which significant cockle stocks were present in Holbeach bombing range[3] or when large amounts of cockle stock are anticipated to be lost due to “atypical” mortality. The difficulty with such definitions, however, is that both have occurred in recent years, but the majority of the fishermen have still strongly opposed the use of dredges. However, these occasions have also been highlighted by fishermen supporting the use of

[3] The former Friskney/Wainfleet bombing range is now no longer being operated by the MoD so is, therefore, accessible to the fishery.

dredges, who have vigorously raised their own concerns over the amount of cockle stock that has been lost to natural mortality.

Most of the fishermen opposed to dredging are fearful of a return to fisheries that are dominated by dredges, in which seasons are short and the hand-work fishery is unable to successfully compete with the efficiency of dredges. To manage a successful mixed fishery, management would need to strictly restrict which areas could be opened to dredges and to determine which would need to remain hand-worked only. If dredging was limited to specific beds, cockle densities elsewhere should remain viable for hand-working. However, barring possibly Holbeach, which is mostly inaccessible to the hand-work fishery, few fishermen currently opposed to dredge fisheries would willingly surrender beds they currently fish. Additionally, there are fears from many that prices would fall if dredge fisheries were operating.

Setting to one side the various viewpoints of the fishermen regarding the use of dredges, there are also environmental and sustainability concerns. In accordance with the Habitats Regulations, Eastern IFCA must undertake a formal assessment, known as a HRA, to ensure consented fishing activities do not adversely affect the integrity of European Marine Sites. The Wash is a heavily designated Marine Protected Area, and although dredge fisheries have passed Habitats Regulations Assessments in the past, the environmental impacts of fisheries have come under far greater scrutiny since the last dredge fishery was consented in 2008.

1.3.1 Habitats Regulations Assessment (HRA)

Before authorising a hand work or dredge fishery, the Authority is required to demonstrate that the proposed fishery would not have a significant damaging impact on the site's environmental features (referred to as an "adverse effect on site integrity" for European Marine Sites). This requires detailed information of the impacts hydraulic suction dredges have on all the conservation features and ecological functioning of the site. This assessment can be a lengthy process – it includes a formal consultation with the statutory nature conservation advisor, Natural England – and should there be a need to open a dredge fishery, the time taken to conduct this assessment could delay the opening too long and lose the opportunity. Therefore, a desk-based literature review of the environmental impact of hydraulic suction dredging is required, so that should a dredge fishery be presented as a realistic option, much of the ground work and background research will already have been completed.

The aim of this desk study is to understand the environmental impacts of a suction dredge cockle fishery in The Wash sufficient to determine whether it would pass a HRA, and if so, what level of dredging effort the features could sustain. The study will also consider the effects a dredge fishery would have on the sustainability of cockle stocks, the management of the fishery and the socio-economic impacts involved, as well as the opportunities such a fishery could introduce.

1.4 Fishing gears and methods used in The Wash

1.4.1 Hydraulic suction dredges

Hydraulic suction dredges direct high-pressured jets of water (through mechanical pumping of water) into the sediment to fluidise and dislodge any cockles (Figure 3). As the dredge blade moves through the fluidised sediment, cockles are collected and delivered to the vessel from the dredge head via suction created from a pump. Size selection is achieved at the dredge head and at the onboard riddle (Figure 3).

Under the terms of the WFO 1992, previous dredge fisheries in The Wash permitted only one dredge per vessel with a maximum dredge head blade and aperture width of 0.76m. Dredge heads were equipped with straight moveable blades which could penetrate the seabed to a depth of around 5cms. Flexible or solid pipework lifted the cockles from the dredge head to an onboard rotary riddle. Whilst flexible pipes could be used in slightly deeper water, solid pipes were considered easier and safer to use as blockages were less common. Solids handling pumps (up to 10ins in pipe diameter) were used to create suction and transport cockles onboard. The draft WFO Cockle Fishery Management Plan details management measures specific to dredge fisheries (Appendix 1).

Figure 3 Images of suction dredge fishing gears used previously in The Wash by fishermen (top) and by ESFJC (EIFCA'S predecessor) for research and monitoring purposes (bottom).

1.4.2 Hand-working

Hand-working is the process whereby fishers use hand rakes to skim the surface of the sediment and collect cockles into hand nets at low water (Figure 4). This fishing method was previously facilitated by the practice of 'blowing out' using an anchored vessel as the tide ebbs. 'Blowing out' involves hand workers preparing the area to be fished by manoeuvring the fishing vessel in concentric rings whilst anchored in shallow water. This helped to displace the upper layer of sediment from the substratum, effectively bringing cockles to the surface of the seabed and pushing them into large heaps. "Blowing out" was alternately prohibited and allowed throughout the 1970s before finally being banned in 1986. 'Prop-washing', whereby the vessel is manoeuvred in circles without being anchored to the seabed (and as such cannot create the concentric rings created when "blowing out") is still allowed and continues to be used by the fishery. Management measures applied to the fishery are detailed in the draft WFO Cockle Fishery Management Plan (Appendix 1).

Figure 4 Hand-working of cockles in The Wash (August 2013)

2 Environmental impacts

The processes involved in hydraulic suction dredging for cockles have the potential to result in a variety of environmental impacts that extend beyond the target species. These include impacts on the habitats and communities in which cockles occur and impacts on species that have dependencies on cockles and are affected by their removal.

For a fishery to go ahead within The Wash, a HRA must conclude that the fishing activity will not have an adverse effect on site integrity by ensuring associated fishing pressures will not have a significant impact on designated site features and that site conservation objectives are met. The Wash is designated to protect numerous subtidal, intertidal and terrestrial features across the site (Appendix 2). Features within The Wash that have the potential to interact with a suction dredge fishery and their associated pressures are listed below (Table 1).

Table 1 List of designated sub-features within The Wash which have the potential to interact with a hydraulic suction dredge cockle fishery and the significant pressures that would require consideration under the HRA process. Taken from Natural England's online Conservation advice package[4]

Sub-features	Significant pressures
Intertidal sand and muddy sand **Intertidal mud**	Abrasion/disturbance of the substrate on the surface of the seabed
	Changes in suspended solids (water clarity)
	Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion
	Removal of non-target species
	Removal of target species
	Smothering and siltation rate changes (Light)
Harbour seal	Removal of non-target species
	Removal of target species
	Visual disturbance
SPA assemblage	Visual disturbance
	Changes in suspended solids (water clarity)
	Removal of target species*
	Removal of non-target species*
Water column (Supporting habitat for Harbour seal and SPA assemblage)	Changes in suspended solids (water clarity)
	Removal of non-target species
	Visual disturbance

*Not identified as a significant pressure in conservation advice package, but considered a significant pressure by Eastern IFCA requiring consideration in a HRA.

[4] Natural England's online Conservation advice package (Accessed 14/09/2018) https://designatedsites.naturalengland.org.uk/Marine/FAPMatrix.aspx?SiteCode=UK9008021&SiteName=wash+&SiteNameDisplay=The+Wash+SPA&countyCode=&responsiblePerson=&SeaArea=&IFCAArea= https://designatedsites.naturalengland.org.uk/Marine/FAPMatrix.aspx?SiteCode=UK0017075&SiteName=wash+&SiteNameDisplay=The+Wash+and+North+Norfolk+Coast+SAC&countyCode=&responsiblePerson=&SeaArea=&IFCAArea=

The potential environmental impacts resulting from a hydraulic suction dredge cockle fishery in The Wash are considered in more detail below and have been assessed against the requirements of a HRA, to ascertain whether, if such a fishery were proposed in The Wash, it would pass this process and if so, what scale of fishery would be viable to ensure conservation objectives continue to be met and site integrity not compromised. For a fishery to proceed, Eastern IFCA must be able to prove that its activity will not cause an adverse impact on site integrity. However, if there is an element of uncertainty or effects are unknown, then a precautionary approach must be applied to ensure features are not at risk. This section attempts to review and discuss the existing literature and make conclusions about the potential impacts of conducting a cockle suction dredge fishery in The Wash.

2.1 Cockle habitat and associated benthic communities in The Wash

Cockles occur on intertidal sand and mud-flats and are found in clean sand, muddy sand, mud or muddy gravel sediments (Tyler-Walters, 2003). They contribute to the accumulation of fine sediments by filtering fine particles from the water column and depositing them as faeces and pseudofaeces (Elliott *et al.,* 1993). Within The Wash, cockles are known to be present in several different intertidal benthic communities and to form particularly important components of two intertidal biotopes: A2.241 and A2.242 (EUNIS codes) (Yates *et al*., 2002). It is important to note at this stage that across most of The Wash cockle beds, cockles successfully out-compete other species, thus such communities are typically low in biodiversity but abundant in cockles.

The biotope 'A2.241: *Limecola balthica* and *Arenicola marina* in littoral muddy sand' occurs as extensive intertidal flats of muddy sand or fine sand which generally remain saturated at low water (Ashley, 2016). This community is characterised by the lugworm *Arenicola marina* and the Baltic tellin *Limecola balthica (*formally *Macoma balthica)*. Polychaetes *Scoloplos armiger* and *Pygospio elegans* are typically superabundant and common, respectively, Oligochaetes, mainly *Tubificoides benedii* and *Tubificoides pseudogaster*, may be common, and the cockle *Cerastoderma edule* may be abundant.

The biotope 'A2.242: *Cerastoderma edule* and polychaetes in littoral muddy sand' refers to extensive clean fine sand or muddy sand shores with an abundance of cockles and is mainly found on the mid to lower shore where the sediment is water saturated most of the time (Tillin and Tyler-Walters, 2016). The community consists of the polychaetes *Eteone longa*, *Scoloplos armiger*, *Pygospio elegans*, *Spio filicornis* and *Capitella capitata*, the crustaceans *Bathyporeia sarsi*, *Bodotria arenosa arenosa* and *Crangon crangon*, the spire shell *Hydrobia ulvae*, as well as the cockle *Cerastoderma edule* and the baltic tellin *Limecola balthica (*formally *Macoma balthica)*.

Another important biotope for cockles found in The Wash is *Lanice conchilega* in littoral sand (EUNIS code: A2.245) which occurs in medium fine sand and muddy sand on the lower shore and often in tide-swept conditions (McQuillan and Tillin, 2016). This biotope supports dense populations of the sand mason worm *Lanice conchilega,* polychaetes *Anaitides mucosa*, *Eumida sanguinea*, *Nephtys hombergii*, *Scoloplos armiger*, *Aricidea minuta*, *Tharyx* spp. and *Pygospio elegans,* the baltic tellin *Limecola balthica* and can be abundant with the mud shrimp *Corophium arenarium* and the cockle *Cerastoderma edule.*

2.1.1 Effects of suction dredging on sediments

The dredge blade is designed to penetrate the seabed up to 5cm, and the high-pressured water jets, to fluidise the sediment and dislodge the cockles. Therefore, there is no doubt that this method of fishing results in direct disturbance to the sediments and biota that the dredge head encounters and could cause significant changes to the structure of sediments and benthic communities. Compared to other towed beam trawls and dredges the footprint of impact from the dredge head is relatively small, however, over time this high level of penetration has been known to cause losses of fine particles and consequent destabilisation of sediment (Piersma *et al*., 2001; Zwarts *et al*., 2004). However, whilst such effects have been reported, the type, level and scale of these effects appear to vary from long term ecologically significant changes observed in the Wadden Sea (Piersma *et al*., 2001; Zwarts *et al*., 2004) to no detectable short-term effects identified in Oosterschelde (Wijnhoven *et al*., 2011) and the Thames Estuary (Franklin and Pickett, 1978).

In the Wadden Sea, Zwarts *et al.,* 2004 observed substantial long-term effects following dredging activity with tidal flats in nearly all offshore areas along the western half becoming sandier[5]. Post dredging, Piersma *et al*., 2001 reported an increase in median grain size and a decrease in silt content of sediments in areas fished for cockles and found that sediment characteristics did not return to pre-dredged levels until 8 years after fishing had stopped. However, in Oosterschelde, Wijnhoven *et al*. (2011) found no short-term impacts of mechanical cockle fisheries on median grain size. There are concerns however as to how useful median grain size can be as a descriptor as there could be large changes to mean grain size without necessarily having an impact on the median size. Effects and recovery times are thought to be very dependent on silt content, benthic fauna (Dernie *et al*., 2003; Kaiser *et al*., 2006) and the local hydrodynamic regime, such as exposure to winds and tide conditions (Dare *et al*., 2004; Sciberras *et al*., 2013; Wijnhoven *et al*., 2011), and it appears that sediment modification caused by dredging can be temporally as well as spatially specific, as seen in Traeth Lafan (Cook, 1991). Dernie *et al*., (2003), found that in disturbed plots the rate of sediment infilling was strongly correlated with the recovery rate of the number of individuals.

[5] Whilst efforts have been made, we have been unable to quantify the level of fishing activity (number of vessels, size of fished area and intensity of fishing) in the Wadden Sea that led to such effects in order to compare them to those previously observed in The Wash

Specific to The Wash

Most sediments in commercially fished areas of The Wash are classified as sands or muddy sands, however, commercial stocks do occur on some of the muddier beds as well. Figure 5 shows the distribution of sediment types across cockle beds in The Wash, as assessed in March and April 2018 during EIFCA's annual cockle stock assessment[6]. There is currently minimal data available to assess changes in the sedimentary environment resulting from suction dredging in The Wash. However, the continued settlement of spat (Figure 13, Appendix 7) in previously dredged areas and the absence of any obvious dramatic changes to sediment suggest suction dredging has not caused adverse changes in the structure and composition of intertidal sediments (Appendix 4a). The sediments where major concentrations of cockles occur in The Wash and the beds where most of the dredging effort has been targeted are considered naturally very dynamic (Figure 9). Large levels of natural disturbance could contribute to the lack of impact observed on sediment composition in an area that has been repeatedly dredged.

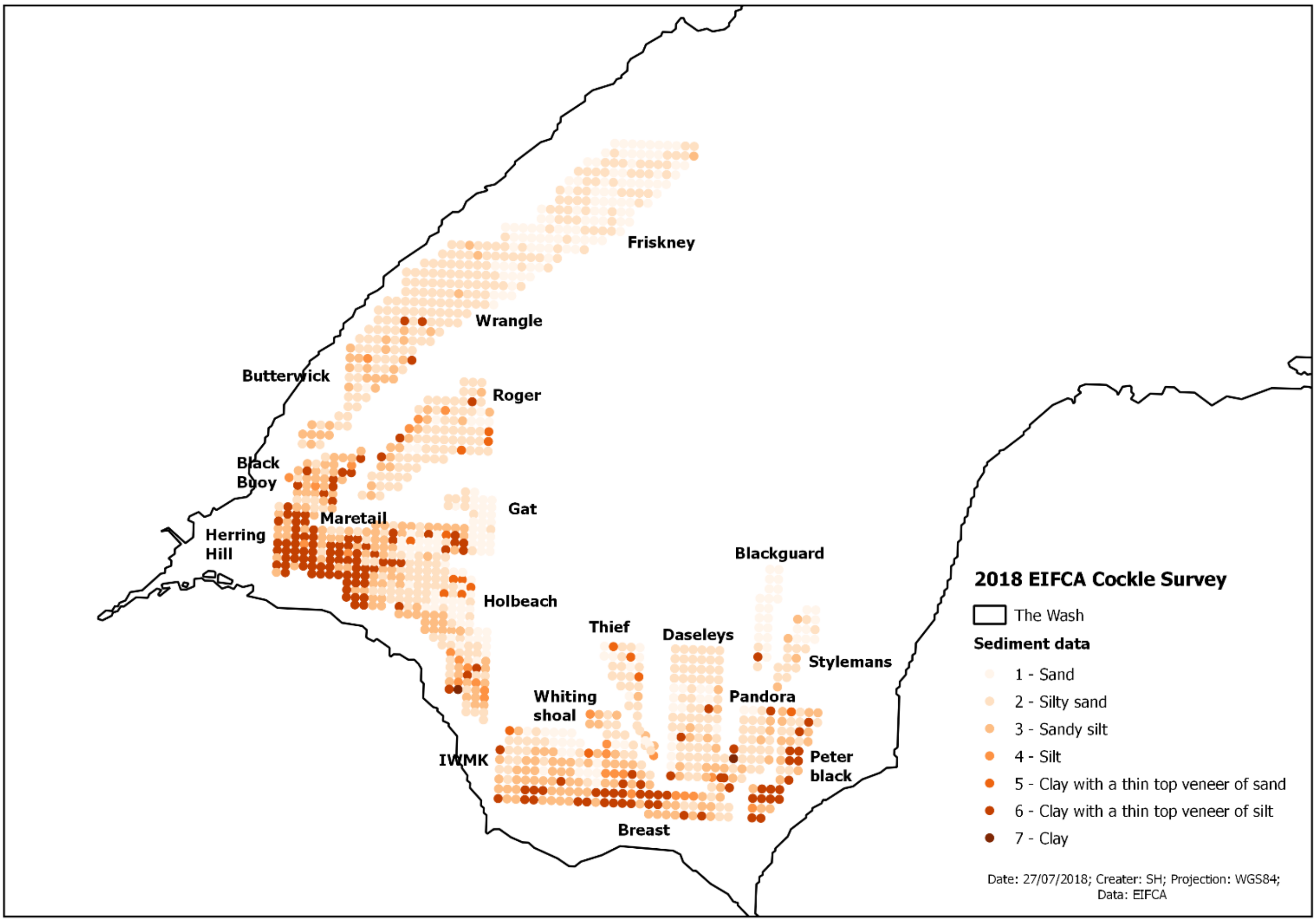


Figure 5: Sediment characterisation across the Wash intertidal cockle beds following EIFCA's 2018 cockle surveys.

[6] Sediment type assessed by eye using a seven-point scale. It is important to note that this is not a continuous scale, each point is a description of a different sediment type.

Our understanding of the spatial distribution and level of effort across The Wash from previous dredge fisheries is limited. Figure 6 shows the distribution of cockle landings by the hydraulic suction dredge fishery in The Wash between 1988 and 1996. Almost 50% of cockles landed were dredged from the Wrangle, and Friskney beds along Boston Main, and almost a further 20% from the Roger/Toft sands. These beds are made up of sandier sediments with lower percentages of fines when compared to some of the other muddier beds in the Wash (Figure 5). During this period the remaining effort was spread across Holbeach range, the Gat, Daseley's, the Breast and IWMK, with minimal effort (around 8%) across the remaining high shore beds that are known to have higher fines content. Since 1996, there have been major dredge fisheries on Wrangle, Friskney, Holbeach and Daseley's, plus some lower levels of effort on the Roger, Mare Tail, IWMK.

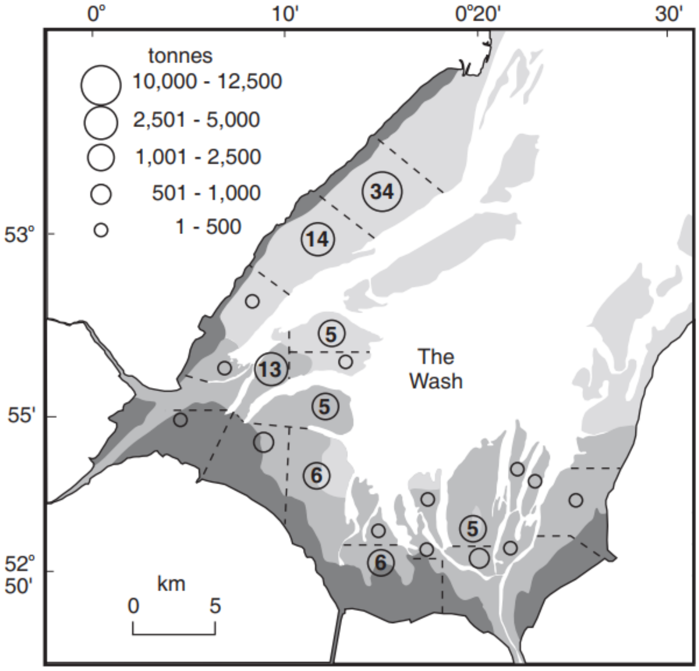


Figure 6: Distribution of hydraulic dredge cockle landings between 1988 and 1996 (ESFJC data) across the Wash cockle beds (taken from Dare et al., 2004). Numbers show the percentage of sub-area landings from the total.

Comparison of sediment data between 1986 (before suction dredging started in The Wash) and 1998-1999 showed that following the introduction of suction dredging there has been no tendency for Wash sediments to become coarser over this period, (Yates *et al*., 1993; 2002; Bell and Walker, 2005). Further analysis of these datasets by Bell and Walker (2007) incorporated sediment data collected by ESFJC in 2005 and allowed comparison over an 18-year period. Bell and Walker (2007) found the similarity of sediment characterisation in the area to be high across all survey periods. Analysis of Eastern IFCA's sediment data collected during the annual cockle surveys between 2008 and 2018, using the same approach as Bell and Walker (2007), showed similar results (Appendix 4a). Whilst there was some variation in sediment characterisation across beds during this eleven-year period, no clear trends were observed that suggest an effect on sediment particle on previously dredged beds and no clear differences in sediment type were seen across beds when making comparisons with the other available datasets (1986, 1998, 1999 and 2005)[7].

[7] It is important to note that the data collected by Eastern IFCA can be highly subjective, as sediment type is based on a by-eye assessment by different individuals over time. It is therefore not appropriate to apply statistical tests of significance but instead make qualitative observations and potential identify trends and patterns. Eastern IFCA assess sediment using a 7 point scale (1=Sand, 2=Silty sand, 3= Sandy silt, 4=Silt, 5=Clay with a thin top veneer of sand, 6= Clay with a thin top veneer of silt, 7=Clay), however in this assessment sediment classification was subsequently grouped into 3 different classifications: Sand (1,2), Sand/Mud (3,4,5) and Mud (6,7) to align with the

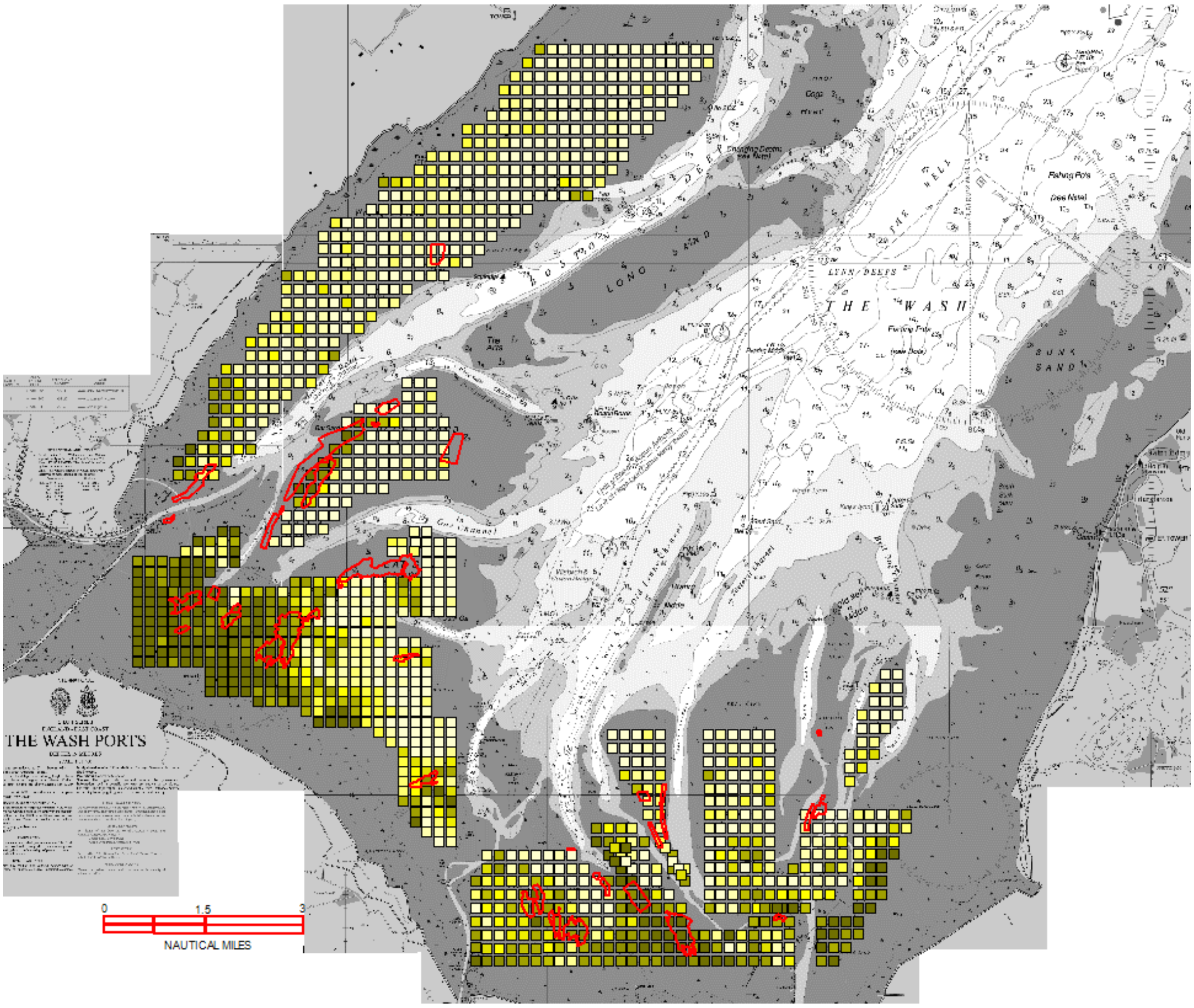


Figure 9: Average sediment type in The Wash 2005-2016 assessed during Eastern IFCA cockle surveys. Consistent sand-based sediments in white. Consistent silt/clay-based sediments in darkest tone. Mussel beds are outlined in red.

An analysis conducted by Eastern IFCA in 2016, plotted the average sediment type in The Wash across cockle survey sites between 2005 and 2016 (Figure 7), further supporting the general distribution of sediment types observed. This analysis also assessed change in sediments over time and found the most noticeable areas of change in transition were areas around river mouths, independent of fishing activity (Figure 8). Large numbers of runs and creeks are found along the shoreline and were considered the probable cause for the changes seen along the edges of the Wrangle and Butterwick sands as these areas further up shore are generally not associated with dredging activity. Such variation could also potentially be a result of large weather events. Mussel beds and lays also appeared to have a strong effect on the sediments (Figure 8). Mussels produce pseudo-faeces that cause the surrounding sediment to have a higher proportion of silt/clay, thus changes to mussel beds could result in increased variation in sediments over time. As discussed previously, subjectivity in sediment classification also likely contributes to some of the changes observed. Some

previous assessments conducted by Bell and Walker (2007) but to also minimise the effect of subjective sampler error.

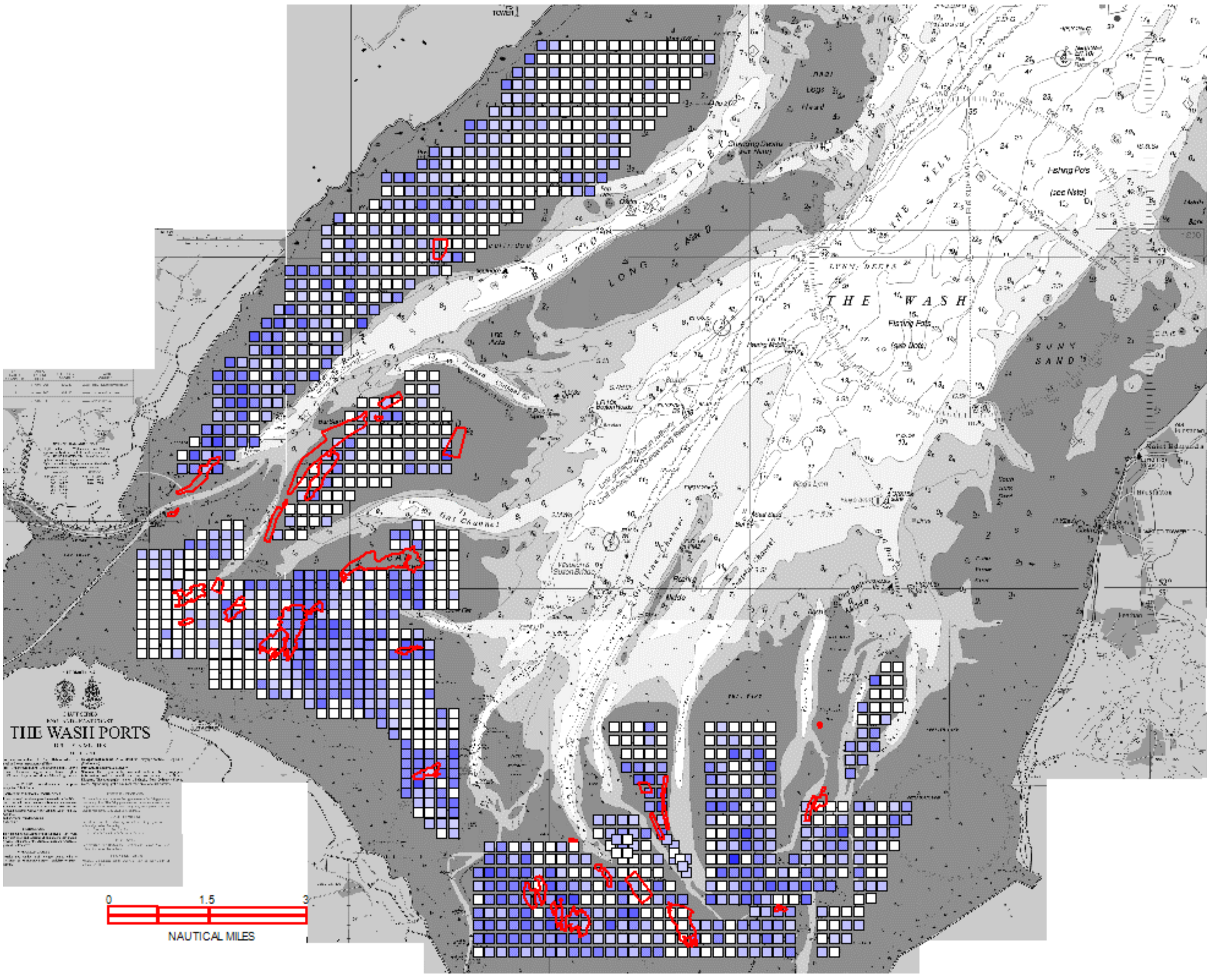


Figure 10: Map showing the change in sediments in The Wash between 2005-2016, as assessed during Eastern IFCA's annual cockle surveys. White shows the most consistent sediments, whilst the darkest shades of blue denote sediments with the greatest number of changes.

of the large areas of change observed on Holbeach, Daseley's and the Breast are likely attributed to inconsistency of classification as these are known to be areas that are particularly hard to classify due to the sediments at each site sitting between 2 (silty sands) and 3 (sandy silts) on the 7-point classification scale (*Pers. Coms.* Senior Marine Science Officer, Eastern IFCA). With regards to fishing activity, between 2005 and 2008 dredge fisheries occurred predominantly on Friskney (2006 and 2008), Holbeach (2007) and Daseley's (2007). Post-2008 there have been no dredge fisheries in The Wash. Whilst Friskney showed consistent sediments between 2005 and 2016, Holbeach and Daseley's showed a higher level of variation during this period. However, as discussed, this could be a result of inconsistencies during classification on these beds. The Breast and IWMK beds also showed high variation during this period but were not targeted heavily by the dredge fishery. Findings do not provide any clear evidence but indicate that sediments have remained consistent on beds where dredging activity has been high and highlight how changes in sediment type can be influenced by a variety of factors.

Bell and Walker (2007) identified sediment data from Rooks Middle (Daseley's) and Pandora sand across the period 1997 to 2004 which overlapped with dredging activity on Rooks Middle in 1998 and 2003 and low levels of activity on Pandora in 2000.

Examination of this data indicated substantial natural variation over time in the sediment composition of samples taken from these adjacent beds. Both sites exhibited a rise in fines in 1999 and 2000, but before and after these years there was no common pattern between sites, similarly the changes in fines content along transects show no common features. This analysis provided no evidence to suggest that dredging activity causes lasting effects to the sediments of this area. Daseley's and Pandora sands both have relatively low levels of fines and sediments do not appear to be affected by dredging pressure, however, the response at other muddier areas may differ.

The analyses conducted by Bell and Walker (2007) had the goal of defining and identifying sediments within The Wash most likely to be vulnerable to dredging. Whilst they were not able to come up with a definition for 'vulnerable sediments', using the literature they found a common feature of vulnerable sediments to be those that have high fines content and identified the muddier areas of the south east (Breast sand) and south west (Herring Hill) as those most likely to be impacted by dredging. However, whilst they identified these beds as vulnerable it appears that dredging effort in these areas is low. Bell and Walker (2007) concluded that dredgers are unlikely to access and operate in these areas efficiently, because of their inshore location both beds are generally only accessible using a dredge for an hour or two over high-water spring tides and it appears that operation over such soft sediments increases the risk of clogging gear, reducing the efficiency of the process. Such sediments are, therefore, generally avoided.

A study conducted by Eastern IFCA in 2011 with Natural England and Thomson Unicomarine investigated changes to the benthos following experimental suction dredging at Wrangle sand in The Wash (Sebastian *et al*., 2012). They examined the impacts of dredging on particle size and biota and recovery over time and found no significant differences in sediment composition between control and experimentally dredged sites across 4 different time periods post dredging (1 day, 2 weeks, 1 month and 3 months).

The Wash is a highly dynamic environment, exposed to high winds and strong tidal conditions. Figure 9 shows the level of seabed kinetic energy in The Wash resulting from wave action. Areas of high seabed energy occur in the intertidal areas of The Wash where cockles are found. These areas are, therefore, likely to already experience elevated levels of natural disturbance and are unlikely to be as vulnerable to disturbance caused by dredging (Bell and Walker, 2007; Sciberras *et al*., 2013). After consideration of the available data and literature, dredging at the levels previously observed in The Wash does not appear to have resulted in changes to the sedimentary environment. However, the extent to which dredging activity could occur in The Wash without resulting in adverse impacts on sediments is unknown. In addition, the sediment scale used by Eastern IFCA for the annual cockle surveys does not provide a quantitative measure that can be used be to assign sediment type in line with a recognised standard. Therefore, to better assess and understand the sediment types in The Wash and their vulnerability to dredging it would be useful to conduct particle size analysis of representative samples so that the Eastern IFCA sediment scale can be translated and provide a more comparable measure to other studies. If

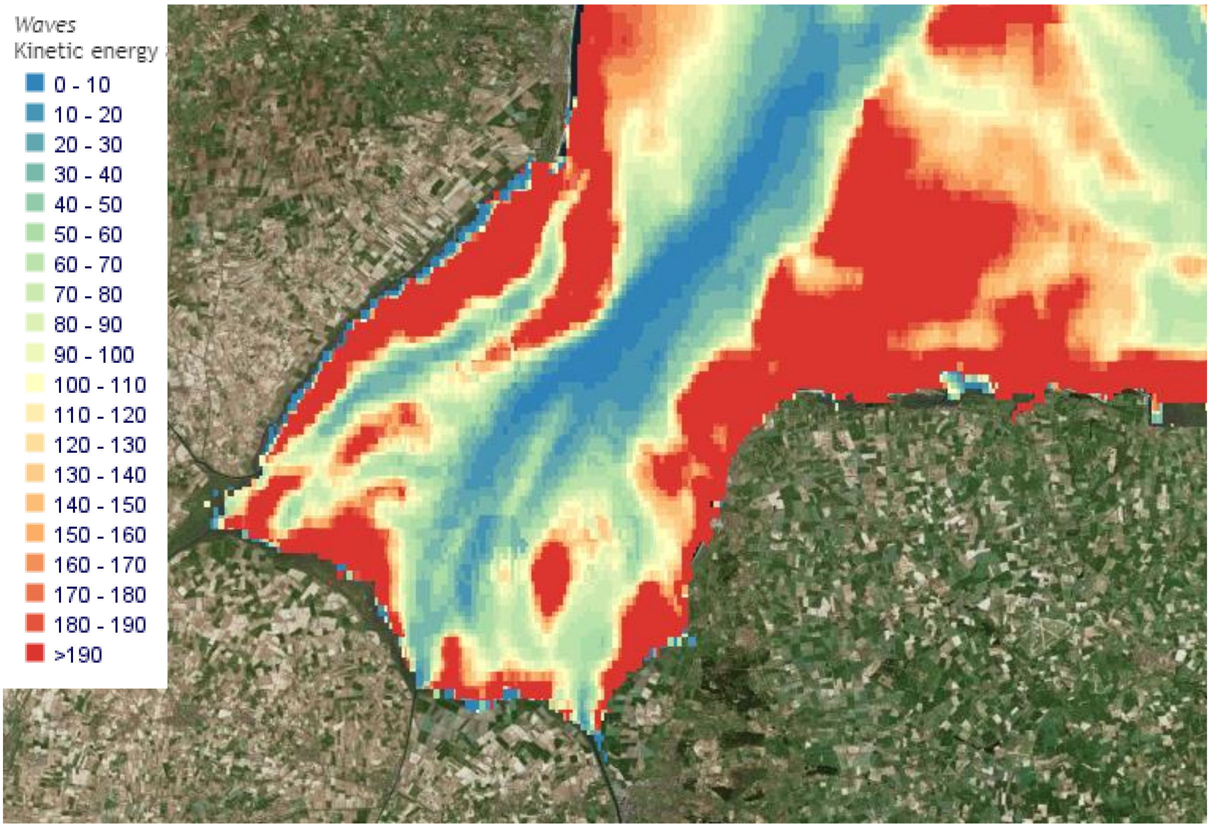


Figure 11: Kinetic energy at the seabed due to waves in The Wash (taken from EMODnet Seabed Habitats Map viewer: http://www.emodnet-seabedhabitats.eu/access-data/launch-map-viewer/)

a dredge study was to be consented this would also provide a quantitative measure that could be used to monitor changes to sedimentary characteristics.

2.1.2 Impacts on biota

As discussed previously, the dredge head will penetrate the seabed to 5cm and thus will undoubtedly disturb any fauna it encounters. It is well understood that dredging activities can have long-term effects on benthic communities (Jennings and Kaiser, 1998), however, the scale of these effects is largely dependent on the life-history characteristics of the affected species (Claudet *et al*., 2010, Kaiser *et al*., 2018) the physical environment (Dernie *et al*., 2003; Kaiser *et al*., 2006) and natural disturbance regime (Sciberras *et al*., 2013; Stewart *et al*., 2009). The literature indicates that communities in naturally dynamic environments, with more mobile, fast-growing and highly fecund species, are less vulnerable to dredging activities than those in more stable environments which provide habitat to more long-lived, fragile species. Viable cockle beds are typically dominated by cockles with few other species (as they are successfully out-competed by the cockles) reducing the potential for large impacts on other biota. This is supported by observations seen on fishing vessels which indicate typically very low levels of bycatch from cockle dredges (*Pers. Coms.* Senior Marine Science Officer, Eastern IFCA). However, it must be noted that not all species that encounter the dredge are subsequently observed on the vessel, some are discarded at the dredge head and remain unknown.

Non-target benthic fauna in the sediments disturbed by the dredge head are either collected as bycatch or washed out into sediments adjacent to the dredge track. Dredges typically penetrate the sediment and wash out sediment to a depth up to 5cm, thus the mortality of benthic fauna is restricted to species that dwell in the upper layer or to those that have body parts present that cannot regenerate. Post cockle dredging, it is clear that biomass of non-target organisms is immediately reduced (de Vlas, 1987; Perkins, 1988; Cook, 1991; Moore 1991; Hall and Harding 1997; Hiddink, 2003; Ens *et al*., 2004), however effects, particularly in dynamic environments (such as Traeth Lafan, Blackshaw flats and the Thames Estuary), appear to generally be short-lived (Franklin and Pickett, 1978; Moore 1991; Hall and Harding, 1997; Wijnhoven *et al*., 2011). In Oosterschelde, Wijnhoven *et al*. (2011) found no short-term impacts of mechanical cockle fisheries on total macrofaunal densities or species diversity, richness and evenness, two months and one year after dredging activity and found an increase in biomass of non-target species almost compensated for the loss of total biomass due to the extraction of cockles. In some areas however, effects appear to extend beyond immediate mortality, for example those observed in the Wadden Sea, (de Vlas, 1987; Piersma *et al*., 2001; Hiddink *et al*., 2003; Ens *et al*., 2004). It is thought that the long-lasting effects of cockle suction dredging on benthic communities observed in the Wadden Sea resulted from losses of fine silts caused by sediment reworking (Piersma *et al*., 2001) and was caused by a negative feedback process whereby such changes in sediment prevented the accumulation of fines vital to bivalve settlement, thus effecting the recruitment of bivalves and other invertebrates.

Much of the benthos in the dredge tracks is washed out of the sediment following dredging, and whilst some individuals do survive, survival rates are very much dependent on species and their burrowing depths. Several studies indicate that *Macoma balthica* suffer the highest levels of mortality post-dredging (Perkins 1988; Cook, 1991; Hiddink 2003), which is likely due to direct damage from the dredges or from being dislodged and transported into surrounding sediments. On the other hand, evidence suggests minimal dredging impacts on *Hydrobia ulvae* (Perkins 1988, Hiddink 2003) and for *Lanice conchilega,* a positive relationship has been observed with dredging effort. This is likely due to the life-history characteristics of this typically rapid coloniser (Ens *et al*., 2004).

It appears that like the effects on sediments, the effects of dredging on benthic communities are highly dependent on the scale and duration of activities, composition of the sediments and communities affected and exposure to the local hydrodynamic conditions.

Specific to The Wash

There are few studies that have assessed the effects of suction dredging on infaunal communities specifically in The Wash. However, some more recent approaches to assessing the environmental effects of fishing activities have used global meta-analyses to create tools to estimate the response of benthic fauna to different bottom fishing gears. In this assessment we have been able to apply such tools to suction dredging in The Wash (Hiddink *et al*., 2017; Sciberras *et al*., 2018; Szostek *et al.,* 2017). Hiddink *et al*., (2017) identified hydraulic suction dredges as having the largest effects on benthic communities with an average penetration depth of 16.1cm and average removal of organisms of 41% following a single gear pass. This average penetration depth is much higher than that observed for gears typically used in The Wash (typically up to 5cm). However, penetration depth was found to be highly correlated with depletion (Hiddink *et al*., 2017) and Szostek *et al.,* (2017) provide us with a tool to estimate depletion rates using a known penetration depth (Szostek *et al.,* 2017) (see below). Using a penetration depth of 5cm and a maximum gear width of 0.76m, this tool was applied to the hydraulic dredges typically used in The Wash and calculated a proportional benthic community depletion from a single dredge pass as 0.16 (16% of fauna depleted). Sciberras *et al*., (2018) conducted a global meta-analysis of benthic response to fishing activities and used reported recovery rates to predict the time required for abundance and species richness in the fished area to return to control conditions. For hydraulic dredging this was estimated as being over three years, for both abundance and species richness. However, it is important to note that the results from this analysis were largely based on the same studies that were used in the Hiddink *et al*., (2017) study and thus are likely to be more applicable to gears with much higher penetration depths than those observed in The Wash. Community species richness and abundance were predicted to recover within three months when impacted by gears with penetration depths of 3 and 6cm in soft sediments (more applicable to gears used in The Wash). This is similar to the previously reported recovery rates for cockle suction dredging at Traeth Lafan (Cook, 1991) and Blackshaw flats (Moore 1991; Hall and Harding, 1997).

The areas of The Wash generally exploited by the cockle fishery are exposed, dynamic and low in silt content and thus it is expected that recovery times following dredge activity to be short-term and perhaps similar to that observed in Traeth Lafan (less than 3 months) (Cook, 1991). However, there are some areas where the sediments present have much higher silt content, generally associated with increased adverse effects and recovery rates (Sciberras *et al*., 2018). Sciberras *et al*., (2018) investigated trends in benthic community recovery at different gear penetration depths in sediments with three different levels of silt content (10, 50 and 90% mud). For gears with a penetration depth of 6 cm (slightly larger than that observed from the suction dredges used in The Wash) they predicted a recovery response of approximately 5 and 9 months for species richness in sediments with 50% and 90% mud content, respectively. However, for species abundance, a recovery response of over 3 years was predicted for sediments with both 50% and 90% silt content[8]. This recovery of species richness indicates the variety (or number of) different species has recovered within a year, but their abundance takes longer to recover to former numbers. It seems following dredging, there is a rapid recovery of richness as various species settle into the dredged area but it takes much longer for their numbers to fully recover. In terms of recovery assessments, weight should be given to the time it takes the habitat to fully recover (eg. both richness and abundance). Care should also be taken with these metrics, as richness and abundance do not necessarily mean that the former species

[8] Recovery response extrapolated from recovery plots (Sciberras *et al*., 2018)

that were present have returned. Whilst this could provide an indicator of the type of sediments that can recover following dredging activity, there has been no particle size analysis carried out on sediments from the Wash cockle beds that allow us to determine the percentage silt content across different beds and assess recoverability[9].

The available literature reporting on impacts of hydraulic dredging on invertebrate communities specific to The Wash is minimal. However, a study conducted by Eastern IFCA in 2011 with Natural England and Thomson Unicomarine investigated changes to the benthos following experimental suction dredging at Wrangle sand in The Wash (Sebastian *et al*., 2012) and examined the impacts of dredging on particle size, biota and recovery over time. The study simulated what was considered very heavy fishing activity expected from a fleet of fishing vessels operating on a small cockle bed using a control and impact design. They found no significant differences in sediment composition between control and experimentally dredged sites across 4 different time periods post dredging (1 day, 2 weeks, 1 month and 3 months). Analysis of biota suggested that whilst cockle dredging had some immediate impacts on benthic infauna, recovery occurred within 1-3 months. Wrangle is comprised of relatively sandy sediments and in this study, all stations were assigned the biotope: A2.242 (*Cerastoderma edule* and polychaetes in littoral muddy sand) following sampling. As discussed above findings were similar to that observed in other studies (Moore 1991; Hall and Harding, 1997; Wijnhoven *et al*., 2011) providing some evidence to suggest that suction dredging is unlikely to have long-term impacts on benthic sediments and communities in relatively sandy areas of The Wash.

In another study, Cefas were able to map the coarse scale distribution of *Macoma balthica* in 1997 along Boston Main in relation to cockle abundance in 1998 (Bell and Walker, 2007). They found the highest densities of *Macoma* on the upper shore, in areas less likely to be targeted by suction dredgers (constrained by their draught), as opposed to cockles where the highest distributions occurred in the mid and lower shores. Prior to the introduction of dredging, the distribution of *Macoma* was mapped in 1973 and was congruent with that observed in 1998, with the highest distributions in the upper part of the shore suggesting the difference in distribution between species across the upper and lower shores is not an effect of dredging activity. However, Yates *et al*., (2002) compared changes in invertebrate density in The Wash between 1986 (before suction dredging), 1998 and 1999 and found some major changes in invertebrate community composition, even over the course of a single year which could reflect an effect of dredging. Bell and Walker (2005) highlighted that highly mobile and/or short-lived species and communities are known to exhibit dynamic populations, but sustained decreases in long-lived bivalves, in this case observed decreases in *Macoma balthica* and *Mya arenaria*, could indicate a direct response of

[9] Although EIFCA have not conducted particle size analysis on Wash cockle bed sediments, we do have a system in place recording sediment type in cockle beds that has been sufficient to differentiate between predominantly fine (silt) or coarse (sand) sediments. Noting the limitations of this qualitative assessment of sediment type (set out in section 2.1.1), EIFCA has used this system – in agreement with conservation advisors Natural England – to restrict cockle dredging to coarse sediment areas to avoid the more sensitive fine sediment areas.

dredging (e.g. from being harvested or damaged) as opposed to dredging having an impact on sediment which in turn has had a deleterious impact on future settlement. However, it is important to note that these comparisons take no account of effects in relation to dredging activities and that such populations are thought to exhibit high natural variation. In addition to this, fewer sites were sampled in the 1998 and 1999 surveys, distributions of *Macoma* are known to be higher in the upper shore and so the positions of sites in the later surveys could reflect the observed lower abundances of this species.

Prior to 2006, cockle surveys conducted in the area did not provide much spatial overlap between years, however since 2006 Eastern IFCA, surveys have covered most intertidal cockle beds within The Wash and now record the number of *Macoma* and the presence or absence of *Lanice conchilega* at each station, and the density of *Arenicola marina* casts at foot survey stations. This data has the potential to provide an important insight into fishery effects on these species, however, the last dredge fishery occurred in 2008 and thus only provides a small-time frame to identify any dredge effects. Assessment of the available Eastern IFCA survey data identified only one occasion where data was collected on the distribution of *Macoma* prior to, and post, a dredge fishery occurring on the same bed, adjacent to a bed where data was also collected but no dredging activity occurred, thus providing a control for comparison. In 2008 a dredge fishery occurred on Friskney, adjacent to Wrangle where no dredging occurred. Both beds were surveyed in spring 2008 (April through to May) prior to the fishery opening and again in November 2008 following the main fishery season[10].

These beds were also surveyed in 2009, providing an indication of immediate and longer-term effects. The average number of *Macoma* per m^2 has been plotted for each bed (including the extension areas) across this time-period (Figure 10; Appendix 4b). Extension areas for both beds are generally not targeted by the dredge fishery, as they are located further up shore, and are known to contain higher numbers of *Macoma* (Bell and Walker, 2007), and are therefore considered separately to the main beds.

Results indicated higher distributions across extension areas as expected (Figure 10). Immediately following the main fishery period, the distribution of *Macoma* appeared to decrease during the November survey across all beds (dredged and non-dredged) except for Friskney extension area where an increase in abundance was observed which continued into spring 2009. As the fishery focused on the main Friskney bed, this increase on Friskney extension is likely to be an effect unrelated to dredging but indicates that the decreases in abundance observed on Friskney bed could have been a result of dredging activity. However, the decreases observed on Wrangle, where no dredging occurred, suggest that such effects could be the result of other natural

[10] According to records, since 2001 Wrangle was not a bed that was targeted heavily by the dredge fishery, however, in 2006 and 2008 the main dredge fishery took place on Friskney. It is also important to note that although the last dredge fishery took place in 2008, hand worked fisheries have taken place across all beds since the early 2000's and have continued since 2008. According to recent historical records, in 2008 Wrangle was heavily targeted by the hand-work fishery, as it was in 2011 and 2012, whereas Friskney has not been heavily targeted during the same period.

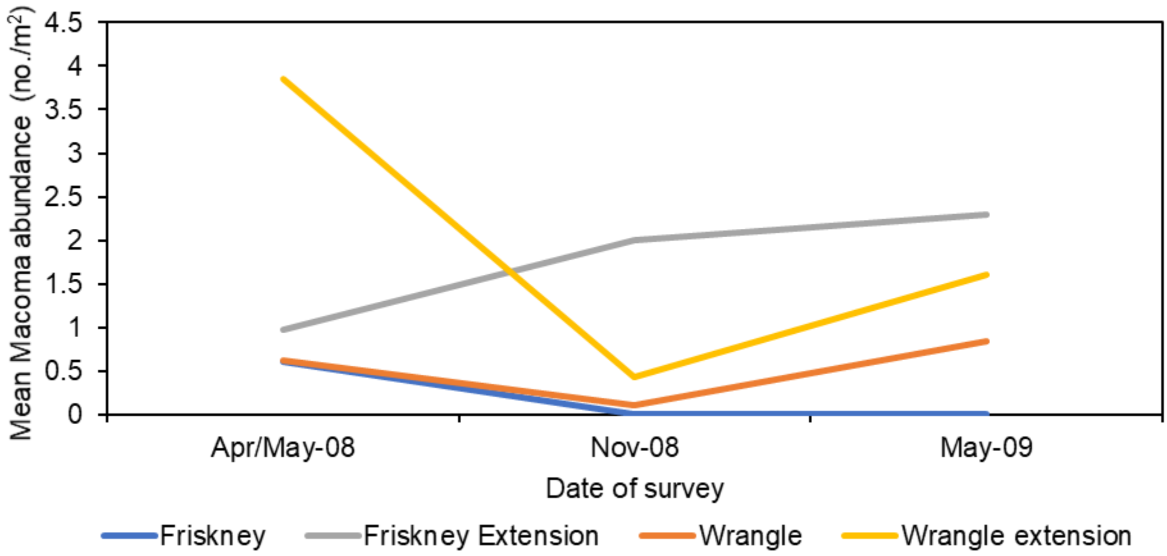


Figure 12 Average abundance of Macoma balthica (number/m^2) across Wrangle and Friskney beds pre, and post, the dredge fishery that occurred on Friskney bed in summer 2008.

pressures. The largest decrease in abundance was observed on Wrangle extension, with a subsequent increase the following spring, with a similar pattern observed on the main Wangle bed. These sites were considered controls and thus suggest any decreases observed at Friskney may not be a direct result from dredging activity. Friskney however, did not appear to show any recovery response the following year unlike the other beds, with no *Macoma* recorded in November 2008 (post-fishery) and continuing into spring 2009.

The limitations of this analysis should be noted: the range of abundances observed across the two years, particularly for the main beds, are extremely small (0-20 individuals/m^2 across main beds) and whilst plotting standard error bars (Appendix 4b) suggest some significant differences, the differences in mean values on the main beds range between 0 and 1 and thus more likely be an indication of variation. Using this data, comparisons of *Macoma* abundance with studies conducted in 1973 (prior to suction dredges being used in The Wash) and in 1997 and 1998 (eleven and twelve years after dredging first occurred) (Bell and Walker, 2007) show similar low distributions across these beds suggesting no major effects of dredging activity on *Macoma* abundance. Analysis of this data does not provide any evidence to suggest that dredging activity, at the level that it has occurred in The Wash, has had negative impacts on the distribution of *Macoma balthica*. However, the beds analysed are generally known to accommodate low distributions of *Macoma,* therefore findings cannot be applied to beds higher up shore where distributions are known to be much higher, such as on the Breast sand.

It appears that in other environments dredging can result in sedimentary changes which lead to reduced bivalve settlement, however, in dynamic environments such as the Thames Estuary (Appendix 5) such effects are not observed. After review of the literature and available data, which went back to 1973, no apparent major changes in sediment composition or benthic communities in The Wash that can be attributed to suction dredging were found. The continued settlement of spat across the period when dredging activities were allowed also supports the case that dredging in The Wash does not cause sedimentary changes that could prevent spat or other bivalve settlement. Previous dredge fisheries in The Wash have generally targeted the sandier beds with lower fines content so the effects on beds with muddy sediments and their associated communities are less clear.

2.2 Ecosystem effects

Any changes in the benthic environment and its associated communities resulting from suction dredging are considered ecosystem effects that have the potential to result in much wider environmental impacts. It is well understood that the benthic communities that occur on soft sediments are closely linked to the physical structure and stability of the environment. For example, bivalves appear to play a key role in bio-deposition (deposit of organic matter onto the seabed), increasing the potential for effect from the removal of cockles or other non-target bivalves on sediments (Piersma *et al*., 2001). Dredging disturbs and mobilises sediment into the water column, potentially reducing water clarity and affecting fish populations through changes in primary production by phytoplankton (Essink, 1999) and thus food availability for seabird species. Mobilisation of sediment can also result in smothering (where sediments resettle) and siltation rate changes which can lead to the accumulation of sediments on the seabed, and potentially long-term changes to the substratum and local environment. As discussed, such effects have not been observed within The Wash following previous cockle dredge fisheries. Higher up the trophic level however, bivalves are an important prey source for many species and thus their removal could lead to wider ecosystem effects within The Wash, particularly for the large populations of many wading bird species for whom this site provides a critical feeding ground.

2.2.1 Sediment mobilisation

Dredging is designed to release cockles from the sediment by mobilising sediments into water column. Sediment suspension can result in smothering and burial, siltation rate changes and reduced water clarity and any redistribution of sediments and fauna could result in reduced density of non-target fauna (Hiddink *et al*., 2003). Any alteration of the physical structure of the seabed can lead to the degradation of overall communities within an ecosystem. The lack of change observed in sediment type across The Wash during the period when dredging activity occurred, suggests that dredging has not resulted in smothering and siltation rate changes that have led to the accumulation of sediments on the seabed and significant changes to sediment composition or benthic community assemblage. However, it is important to note that whilst no long-term effects have been observed, there may have been short-term impacts that have not been observed.

Reduced water clarity can affect fish populations through changes in primary production by phytoplankton (Essink, 1999) and increased suspended material has been found to be unfavourable to young herring and smelt (Essink, 1999). Changes in water clarity, therefore, have the potential to affect not only the availability of prey species but also the success of water bird species capturing prey in the water or identifying them from the air. The Wash is known to provide important nursery grounds to several fish and ray species, including thornback rays, herring, cod, whiting, plaice and sole (Ellis *et al*., 2012), which can form important prey species for seals and many bird species that utilise The Wash. There is currently no evidence available that would allow us to assess the impacts of dredging on water column species in The Wash resulting from sediment mobilisation. However, because of the relatively low footprint of a dredge fishery, localised effects and the already highly dynamic environment, it is not predicted that activities would have significant impacts or result in long term effects on the ecosystem through sediment mobilisation.

2.2.2 Cockle predators

As in many other estuaries, cockles form an important part of the food web in The Wash. Potentially important predators include crustaceans, particularly the brown shrimp *Crangon crangon* and shore crab *Carcinus maenus*, both of which predate on newly settled spat (Dare *et al* 2004). Common starfish *Asterias rubens* and flatfish are also known to feed on cockles and cockle spat, however, it is unlikely that cockle availability is a significant factor in the population dynamics of these species, due to the range of prey items they generally feed on. The most important predators of cockles are undoubtedly birds, particularly Oystercatcher, *Haematropus ostralegus,* and Knot, *Calidris canutus*, both of which form part of the internationally important waterbird assemblage and are present in The Wash during the winter in internationally important numbers (Atkinson *et al*., 2000, 2003).

Knot are particularly important predators of cockle spat, taking individuals in the size range of 5-15mm shell length (roughly up to 10mm width) (Goss-Custard *et al.,* 1977). Dare (1999) concluded that dredging is unlikely to adversely affect knot populations as the fishery does not take the spat on which the knot feed. However, although they are not deliberately harvested, if dredge disturbance reduces spat densities, it could have an impact on knot. Section 3.2 discusses population level impacts of dredging on cockle stocks and concludes that dredging at the levels previously observed in The Wash does not appear to have had adverse effects on spat settlement or survival that has led to reduced densities, and thus is unlikely to be significant to knot populations. In addition to this, *Macoma (Limecola balthica),* provide a more stable and dependable food resource for the species (Dare, 1999) and in The Wash the preferred distribution of *Macoma* on the upper shore, is unlikely to overlap with a dredge fishery.

Oystercatchers, on the other hand, are known to predate on cockles greater than 15mm in shell length (roughly greater than 10mm width), particularly those between 20-30mm (Goss-Custard *et al.,* 1996). This size range overlaps with that targeted by the commercial fishery and if not managed appropriately could result in impacts on the oystercatcher population. Whilst oystercatcher will predate on a variety of other invertebrates, their only other significant prey item within The Wash, aside from cockles, are mussels, a species that are also targeted by fishers and have experienced a population decline.

Atkinson *et al*., (2000, 2003) conducted a 30-year study (1968 - 1998) to assess the effects of changes in shellfish stocks and winter weather on shorebird populations in The Wash. For knot they concluded no effects of weather or spat abundance could be found on adult knot survival, but for oystercatcher, survival was more closely linked to shellfish stock and winter weather. Survival trends indicated that knot showed more year to year variation in survival, compared to oystercatcher populations which generally remained stable with occasional periods of mass mortality, attributed to cold-weather and periods when both cockles and mussels were at low stock levels. Within The Wash SPA the conservation objective for knot is to maintain the non-breeding population within the SPA at a level above 75,000 individuals, and for oystercatchers, to restore the population to a level above 24,000 individuals. The latest mean peak count (2008/09 – 2012/13) for both species is 134,338 and 20,635 individuals, respectively. Oystercatcher are, therefore, considered at risk from the over-exploitation of cockles by the fishery. Management measures are currently in place for the WFO hand-work fishery to ensure that stock levels are not fished below threshold levels required to support protected bird populations and would be included in any proposed suction dredge fishery accounting for any associated fishing mortality and mitigating this risk.

2.2.3 Predators of non-target fauna

Most of the literature focuses on the effects of hydraulic suction dredging on cockle-predating bird species. However, the short-term effects of dredging on non-target benthos also has the potential to result in wider effects on bird or other species that predate on other benthic invertebrates. For example, in the Wadden Sea, both positive and negative effects were observed on nine species of shorebird following the disappearance of mussel beds (Ens *et al*., 2004). Given the dynamic nature of The Wash sediments, the low level of non-target fauna typically present in cockle beds and the concluded short-term effects of hydraulic suction dredging on non-target fauna in The Wash, it is unlikely the effects on benthivorous birds, that do not rely on cockles for prey items, will be significant.

2.2.4 Fishery disturbance effects

Of more recent concern, is the effect of activities, including fishing activities, in intertidal areas of The Wash that are utilised by internationally important water-bird assemblages and their potential to cause disturbance to birds that feed and over-winter at a level that could result in declines in populations. This is of particular concern for hand-work fisheries that occur at low-tide, where activities overlap with wading bird feeding areas. However, such birds are most at risk between November and February when they over-winter in The Wash and have increased food requirements to survive the winter conditions. During this period cockle fishing effort is generally much lower, with the main season running through the summer months, reducing the potential for adverse impacts. Similarly, for seals, hand-work fisheries have the potential to cause disturbance when hauled out during the low tide period. This is of high concern during the pupping and moulting season which generally occurs between June and September, coinciding with the main cockle fishery season. However, to ensure the fishery does not have adverse impacts on seal populations, management measures are in place which allow Eastern IFCA to close important haul-out areas to the fishery, if it is predicted they will be heavily targeted.

Dredge fisheries on the other hand, occur over the high tide period, and as such are unlikely to cause disturbance to birds and seals that utilise the intertidal areas of The Wash at low tide. Activities do, however, have the potential to cause disturbance effects on diving birds, water column species and Harbour seals, but are not predicted to cause significant effects on populations due to the relatively low level of activity and limited footprint of fishing activities compared with the range of these species.

2.3 Application to the HRA process

Table 1 identifies significant pressure-feature interactions from hydraulic suction dredging in The Wash that are considered high risk, as per Natural England's online conservation advice. This section assesses these interactions to determine whether a future dredge fishery would pass a HRA and to identify if further management measures would be required for it to do so.

Pressures: Abrasion/disturbance of the substrate on the surface of the seabed; Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion; Smothering and siltation rate changes (light)

- *Intertidal sand and muddy sand*
- *Intertidal mud*

There is no substantial evidence to suggest that hydraulic suction dredging for cockles in The Wash, at the levels observed historically, would lead to significant impacts on intertidal sand and muddy sand sediments or the water column and their associated communities through abrasion, penetration or disturbance of the substratum or through suspension and smothering of sediments. Dredging appears to have occurred on The Wash cockle beds without previously having negative impacts on sediments and biota. However, the limit at which dredging can occur on such sediments without having significant effects on the environment is unknown. Because of this uncertainty, any future dredge fishery would have to be very carefully managed and monitored and would likely require much stricter controls than previously seen in the Wash.

Additionally, the response of intertidal mud sediments to these pressures is less clear. The vulnerability and response of such sediments to dredging is known to increase with silt content. Cefas identified the Breast and Herring Hill sands as potentially the most vulnerable beds to dredging activities because of their high silt content. It appears that dredgers are unlikely to access these areas due to their high shore locations and the inefficiency of gears in such sediment types; however, the majority of the beds are accessible on big tides to dredgers. Given suitable alternatives, dredgers would avoid these areas, but if they presented the best fishing opportunities, they would fish these beds when able. To ensure activities do not have adverse effects on site integrity, if a dredge fishery were to be consented in The Wash, muddier beds should remain closed as a precautionary approach. As well as the Breast and Herring Hill sands, this should also include other predominantly muddy beds, such as, Butterwick and Mare Tail, even though these have been dredged in the past.

Pressure: Changes in suspended solids (water clarity)

- *Intertidal sand and muddy sand*
- *Intertidal mud*
- *SPA assemblage*
- *Water column*

Changes in suspended solids (water clarity) caused by dredging activities in The Wash are not predicted to have significant impacts on the above features because of the relatively low footprint of a dredge fishery, localised effects and the already highly dynamic environment experienced by The Wash cockle beds.

Pressure: Removal of non-target species; Removal of target species

- *Intertidal sand and muddy sand*
- *Intertidal mud*
- *Harbour seal*
- *SPA assemblage*
- *Water column*

Although there is no evidence to suggest that previous cockle dredge fisheries in the Wash have resulted in long-term changes to sediment composition through the removal of target species, such changes have been observed elsewhere. The effort levels that can be sustained in The Wash before such effects are observed are unclear and because of this, the potential for such effects cannot be ruled out. If a dredge fishery were to be consented, effort would need to be limited so that it did not exceed previous levels to ensure no long-term changes to sediment composition were to occur. It is considered that should a dredge fishery be consented, sediment monitoring in dredged and non-dredged areas should be required to monitor effects. Furthermore, there should also be a minimum density threshold for dredged beds to prevent higher risk, low density beds from being targeted.

The removal of non-target fauna is not predicted to cause significant impacts on intertidal sand and muddy sand and intertidal mud features. This is because of the already dynamic environment of The Wash, low by-catch rate and recovery response of affected species. In addition, there is no evidence to suggest that dredging has previously resulted in significant changes to non-target fauna in The Wash.

Similarly, the removal of non-target bird prey items is not predicted to have significant impacts on the SPA assemblage. However, the removal of target species has been identified as likely to have significant impacts on the oystercatcher populations within The Wash if not carefully controlled. The current management applied to the hand-worked cockle fishery is based on a yearly quota (Total Allowable Catch or TAC), calculated as a third of the total adult stock. Within this, the remaining stock must also meet the minimum shellfish biomass requirement threshold required to support overwintering oystercatcher populations. This threshold is calculated using a model that determines the food requirements for the number of birds supported by the site in terms of Ash Free Dry Mass (AFDM), and since the overwintering species prey on both cockles and mussels, calculations take both species into account[11]. If a dredge cockle fishery were proposed the same management measures would be applied and a fishery would not go ahead if these requirements were not met. Under this management it is, therefore, predicted unlikely the pressure *Removal of target species* would have significant impacts on oystercatcher populations and thus the SPA assemblage.

Harbour seal are not known to feed on cockles or non-target benthic fauna but do prey on fish species higher up the trophic level. Indirect effects have the potential to result in reduced prey items, but this is considered extremely unlikely due to the limited effects thought to occur on water column species (discussed in section 2.2.1). The same is applied to bird species designated under The Wash SPA that prey on water column species. The removal of target and non-target species through dredging activity is not predicted to have significant impacts on the Harbour seal population or water column species in The Wash.

Pressure: Visual disturbance

- *Harbour seal*
- *SPA assemblage*
- *Water column*

Whilst dredging activities in The Wash do have the potential to cause visual disturbance effects on the SPA assemblage, water column species and Harbour seals, they are not predicted to cause significant effects on populations due to the relatively low level of activity, the timing of activity (over high water rather than low water when birds utilise the intertidal flats) and small footprint of fishing activities.

2.3.1 Summary of predictions and recommendations

Following consideration of the above environmental impacts and cited literature (Section 2.1 and 2.2), assessment of the pressures associated with hydraulic suction dredging for cockles in the WFO area of The Wash which have the potential to result

[11] Number of oystercatchers relates to latest mean peak count, shown in The Wash SPA conservation advice at: https://designatedsites.naturalengland.org.uk/Marine/SupAdvice.aspx?SiteCode=UK9008021&SiteName=wash+&SiteNameDisplay=The+Wash+SPA&countyCode=&responsiblePerson=&SeaArea=&IFCAArea= [accessed 12/07/18].

in significant effects on designated site features has been summarised in table 2. For pressure/sub-feature interactions where significant impacts could not be ruled out, recommended mitigation has also been included in this summary (Table 2).

Having reviewed the available literature, evidence and data, it appears that hydraulic suction dredge fisheries for cockles in The Wash have occurred in the past without having significant impacts on designated sites. However, the available information is very limited and does not allow us to assess the maximum level of activity that could occur on beds without having adverse effects on site integrity. There is also limited understanding of the effects of multiple vessels and dredge passes over the same area over time. If a dredge fishery were to be consented, effort would need to be restricted to ensure it does not go beyond levels that could compromise site integrity or stock sustainability. This would require increased management measures and future monitoring of fishing activity and environmental features.

There is also a lack of information on the effect of dredging on muddier sediments. In The Wash, such sediments are found in the southeast and southwest corners. It is known that during previous dredge fisheries these areas have generally been avoided by fishers because of their high shore locations and the inefficiency of gears in such sediment types. As a precautionary approach, it is therefore recommended that such beds remain closed to any future fishery.

Table 2: Summary of assessment and mitigation for pressure/sub-feature interactions resulting from hydraulic suction dredging for cockles in The Wash.

Sub-features	Significant pressures	Assessment	Recommended Mitigation
Intertidal sand and muddy sand **Intertidal mud**	Abrasion/disturbance of the substrate on the surface of the seabed	Cannot conclude no significant impacts on sediments with high mud content or at levels greater than previously observed in The Wash	No dredging on beds where sediments have high fines content Effort restriction and spatial management Monitoring of sediments and biota
	Changes in suspended solids (water clarity)		
	Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion		
	Smothering and siltation rate changes (Light)		
	Removal of target species		
	Removal of non-target species	No significant impacts predicted	No mitigation required
Harbour seal	Removal of non-target species	No significant impacts predicted	No mitigation required
	Removal of target species		
	Visual disturbance		
SPA assemblage	Visual disturbance	No significant impacts predicted	No mitigation required
	Changes in suspended solids (water clarity)		
	Removal of non-target species		
	Removal of target species	Cannot conclude no significant impacts on Oystercatcher population	Application of the same management measures used in the hand-work fishery to control exploitation rate and ensure minimum shellfish biomass requirement threshold is met
Water column	Changes in suspended solids (water clarity)	No significant impacts predicted	No mitigation required
	Removal of non-target species		
	Visual disturbance (SPA assemblage)		

3 Cockle stocks

3.1 Dredge impacts

Suction dredging principally impacts cockle stocks in terms of increased mortality. Whilst part of this increased mortality comes from direct fishing mortality of the commercial stock (retained catch), indirect mortality caused by the activity also contributes to the overall mortality. Indirect fishing mortality can result from damage to, or mortality of, cockles that encounter the dredge but do not form part of the retained catch and can occur at various stages of the dredging process (Figure 11).

Indirect fishing mortality appears to vary depending on the size of cockles, with those ≤14mm width showing better survival rates than those over 14mm (Jessop, 2003). The dredge head and onboard riddle are designed to remove small cockles from the catch and thus most of the discards will be juvenile cockles smaller than the size of the bar-spacing on the dredge or the riddle. Discard mortality is, therefore, more likely to have a larger effect on the small juvenile cockles, whereas fishing mortality is more likely to affect the spawning stock (adult cockles). However, it is important to note that if the gear (particularly the blade) is not set up correctly, higher proportions of larger cockles can be broken and can contribute significantly to the discard component of the catch.

Throughout the dredging process, impacts on cockles caused by the blade and the dredge track are thought to be a relatively small component of the overall mortality and damage to cockles. The dredge blade provides the first opportunity for impact, but in more modern dredge gears the blade is designed to guide cockles into the dredge head rather than penetrate the substrate, with the latter function being provided by the high-pressure digging jets directed forward of the dredge blade, providing further opportunity for impact. Damage caused at the dredge track includes that to cockles which encounter the dredge head but are not retained or damage resulting from disturbance following the passage of the dredge.

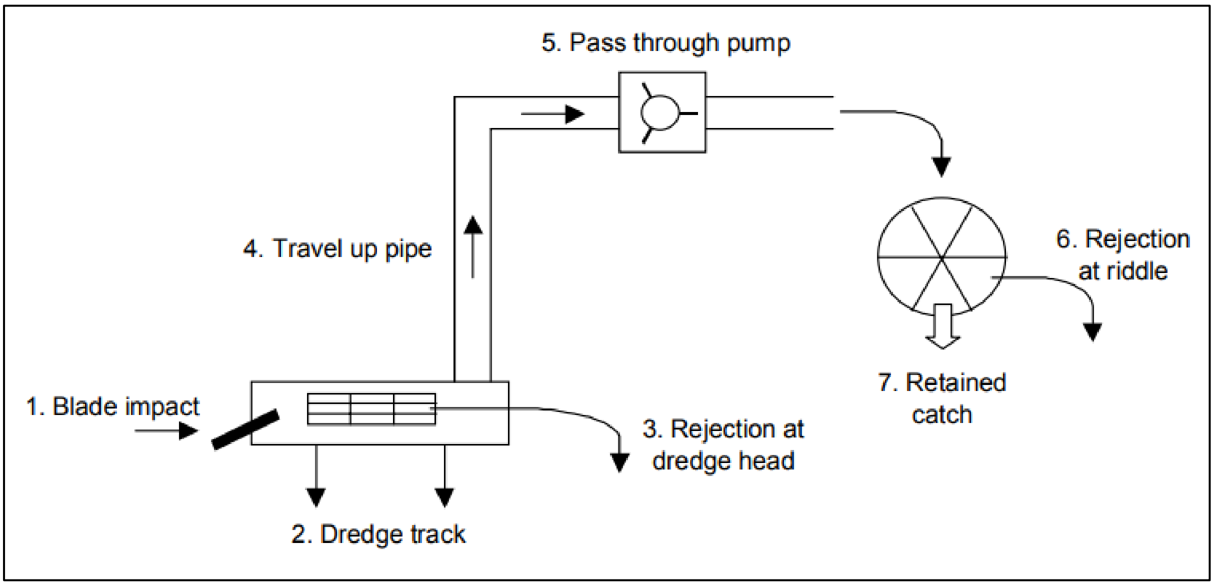


Figure 15 Stages of the dredging process where cockle mortality can occur (taken from Bell and Walker, 2005)

Rejection at the dredge head and rejection at the riddle are considered the most important factors contributing to indirect fishing mortality and damage caused by the dredging process (Jessop, 2008). Impacts from travel up the pipe and passage through the pump resulting from abrasion are extremely difficult to separate from each other and from damage caused at the riddle. However, it is generally considered that cockle damage rates are lower in dredges fitted with solid pipework than in dredges with flexible pipes (Stoutt, 2008). Pump design can also affect the extent to which passage through the pump can cause damage. This has previously led to fishermen experimenting with different pump specifications.

The sorting and rejection of undersized cockles at the riddle is the most studied part of the dredging process and is known to cause damage to cockles, reducing the chance of survival if discarded and potentially having large impacts on stocks (Franklin and Pickett, 1978; Cook, 1991; Wiggins, 1991; Mander and Trundle, 2001). It is important to note that damage at the riddle can result from all stages of the dredging process. To restrict damage, Eastern Sea Fisheries Joint Committee (ESFJC) (Eastern IFCA's predecessor) introduced a byelaw in 1997 (ESFJC Byelaw 3 - Molluscan Shellfish methods of fishing) which prohibited a vessel from dredging for cockles if their gear resulted in damage to more than 10% (by weight) of the cockles fished. This encouraged most of the fishing industry to invest in more modern, less-damaging equipment, and often resulted in damage rates considerably lower than 10%. However, the method used to monitor breakage rates from the riddle does not account for the component of the catch rejected at the dredge head as it is not practical to be routinely sampled.

Jessop (2008) conducted a study to answer questions concerning the mortality of discards from the dredge head. When using a dredge head with bar-spacing of 12mm it was found that between 10.2% and 21.4% of the catch was being discarded through the dredge head compared with 26.2% to 28.6% from the riddle. The dredge head was particularly effective at removing small cockles from the catch, with on average 62% of cockles smaller than 12mm width discarded at this stage. With regards to discard mortality, it was concluded that discards of visually undamaged cockles from the riddle suffered a mortality rate of 24.6%, 11.3% above the background level (13.3%). Visually undamaged discards from the dredge head averaged mortalities of 17.3%, only 4% above that of control samples. At a confidence level of $p \geq 0.05$, survival rates differed significantly between cockles discarded at the riddle and those hand-picked from the sand, supporting earlier discard mortality studies conducted by ESFJC between 2001 and 2006 (Mander & Trundle, 2001; Jessop et al.,2003; Jessop et al.,2004). For cockles discarded at the dredge head, mortality rates were not significantly different to those hand-picked[12].

Another objective of this study was to determine whether cockles discarded from the dredge head settle back into the dredge track. It appeared that only 15-30% of cockles discarded from the dredge head fell back into the dredge track from which they were

[12] It is important to note that this was mainly due to wide variance observed between the mortality rates of the three samples collected from the dredge head, in which two of the samples suffered higher mortality rates than those of the controls, while the third was lower. This made statistical analysis inconclusive.

taken, and that the remaining discards were likely to fall adjacent to the track on already densely populated ground, further reducing the chance of survival. However, this meant the dredge head discards were more likely to resettle back into the track from which they were taken compared to those discarded from the riddle. In the track, cockle densities are low increasing the chance of survival. Fishing generally occurs on dense cockle beds and so many of the riddle discards will settle on ground that is already densely packed and may struggle to re-burrow without displacing other individuals. In such conditions, chances of survival are further reduced as energy will be expended in the struggle to rebury, and those on the surface are likely to suffer increased predation, particularly from birds, and stress from temperature extremes (Boyden, 1972; Hummel, *et al*., 1988).

Throughout the study the dredge head was responsible for discard of between 9-17% of the total number of cockles fished and the riddle responsible for an additional 22-24%. This demonstrated that for every tonne of cockle retained, a further 250-375kg of cockle were lost as discards, and of these discards, the mortality study indicated that 15% (40-200kg) [13] would not survive more than 25 tides following the surveys. It is important to note that discard rates will vary with size frequency of the cockles. Had the stocks been smaller, discard rates would have been higher. For instance, when measuring breakage rates on Daseley's sand in 2003 (Jessop *et al.,* 2003), discard rates were 5-fold higher than those being retained, so for every 1 tonne retained, 5 tonnes were being rejected.

The 10% smash rate limit in the Eastern IFCA district means that gear will not be approved if more than 10% by weight of the target species fished is smashed. In theory this 10% should include those cockles within the retained catch, those discarded at the riddle and those discarded at the dredge head. However, previous assessments were not able to consider those cockles discarded at the dredge head due to practical constraints. In addition, the 10% only applies to smashed cockles and it is proved that mortality is not limited to smashed individuals but also affects unsmashed cockles (Jessop, 2008). This means that the TAC does not represent all the fishing mortality incurred. Furthermore, subsequent mortality rates of smashed and unsmashed cockles are likely to be higher if the same cockles are exposed to gear multiple times during the same season (Jessop, 2003; Bell and Walker 2005). One way of addressing this, would be for the Authority to consider adjusting TAC to account for this additional mortality. Quantifying such mortality, however, would be extremely difficult and likely require a significant amount of additional work.

3.2 Population level consequences

The effects of suction dredging on cockle stocks are not consistent across studies and appear to differ largely depending on other environmental factors. For example,

[13] Figures calculated have been adjusted to compensate for a natural background mortality of 13.3%. It should be noted that the background mortality of 13.3% itself is high. Experiments conducted in previous years had much lower background mortality rates (approx. 3-4%). The cause of this high level was subsequently attributed to Atypical mortality, which was first noticed in The Wash in 2008 after this experiment had been conducted.

dredging for cockles in the Thames Estuary has been sustained for over 40 years, whereas in the Dutch Wadden Sea, studies concluded dredging to have had long-term negative impacts on cockle spatfall and other bivalves due to changes in sediment characteristics (Piersma *et al*., 2001). In The Wash there have been no specific studies to assess the long-term effects of repeated dredging activities on stocks. However, annual stock surveys conducted by EIFCA (previously ESFJC) (section 3.2.2) have provided a long time-series of cockle stock data for The Wash and individual cockle beds within the area.

Dredging has the potential to indirectly impact on the future recruitment of cockles through reduction of the spawning stock or damage caused to year-0 juveniles. Settlement of larvae is likely to commence in late May/June, with the main fishery generally occurring from June to September/October likely to coincide with the period where cockle spat are becoming established, increasing the potential for impact at this stage. There are concerns that changes to sediment characterisation resulting from dredging activity could lead to a reduction in spat settlement. Dare *et al*., (2004), however, found the highest mortalities of spat in The Wash generally occur during the winter outside of the main fishery period indicating they are likely to be linked to other environmental factors, rather than fishing pressure. For example, high predation by birds (particularly knot) as the site is an important overwintering site. However, whilst first winter mortalities of cockles have been observed to be high, and possibly far greater than the impacts of dredging, there is still potential for in-combination effects. In contrast, one issue that has been observed with high-density beds of spat in The Wash is subsequent ridging out as the cockles grow (natural thinning of cockle beds as a result of intra-specific competition between cockles competing for space). Thus, it has been suggested that thinning out from dredges might be beneficial in preventing future ridging out.

The survival and growth of pre-recruits (juveniles) appears more heavily impacted by dredging. This results mainly from the rejection of cockles at the dredge head and riddle (as well as dredge head or blade impacts) and has the potential to significantly reduce the number of cockles recruiting to adult stocks as well as resulting in reduced growth. The efficiency of the dredge gear at reducing the number of discards (damaged and undamaged) and the level of damage to discards is a key factor that effects mortality and growth at this stage and is taken account of in more modern gears.

Usually the largest suction dredging impacts on cockle stocks are those on the adult population, resulting from direct fishing mortality (removal of the retained catch) or from indirect dredge effects on growth and mortality. Spawning usually occurs from May to June/July but can on occasions be as late as August. In The Wash the main fishery occurs from June - September/October and thus disturbance from dredging activities to spawning cockles is likely to be low.

Review of the literature provides no conclusive evidence as to the long-term effects of dredging on cockle stocks. It appears that if changes in sediment characteristics are caused by dredging there will likely be negative impacts on stocks (Piersma et al., 2001). However, such sediment changes are very much dependent on the local tidal conditions and wave action. Where sand flats are exposed to tidal forces and wave action, dredge tracks have been found to persist for only a few days/weeks depending on conditions (Rees, 1996). The Thames Estuary and The Wash are examples of such environments. Between 1969 and 1971 Franklin and Pickett (1978) assessed the effect of dredging in the Thames Estuary on subsequent spatfalls and their survival. They found experimentally dredged areas were similar to those in adjacent unfished areas, indicating rapid recovery of dredged grounds following fishing activity and predicted long-term recruitment would not be affected. The regularity of cockle spatfall seen on the Thames Estuary further supports this, but it is important to note that this applies to settlement and not spat survival. In another set of experiments, they found that compared with unfished areas, the number of spat surviving to the October in dredged areas was significantly lower, resulting in significant additional cockle spat mortality (Franklin and Pickett, 1978). Similar mortality levels were seen in second year cockles, reducing recruitment into the fishery. This increased mortality was thought to result from accumulated stress of repeated fishing over resettled cockles and the dredge rejection process (discussed in section 3.1).

In the Dutch Wadden Sea, suction dredging led to a loss of fine sediments and took 8 years to return to pre-dredged levels (Piersma *et al*., 2001). This loss of fines coincided with a decrease in abundance of cockles and other bivalves, and Piersma *et al*. (2001) drew conclusions that suction dredging had long-lasting effects on bivalve recruitment resulting from changes to sediment characteristics. Although, The Wadden Sea stocks have since produced several large spatfalls and recruitments that have allowed stocks to recover whilst still supporting dredge fisheries, dredging has since been prohibited in this area (2005). There is uncertainty of the dredging intensity levels previously experienced in The Wash and whether these were similar or approaching those that led to negative impacts in the Dutch Wadden Sea.

3.2.1 The Wash cockle stocks

Whilst there have been no specific studies to assess the effects of dredging in The Wash, in 2004 Dare *et al*., (2004) reported on the current and historical status of both cockle and mussel stocks in The Wash between the 1970s and 2004. They concluded that whilst depleted stock levels in the 1990s were a result of high exploitation rates, there had since been a failure to replenish depleted stocks to previous levels despite stabilisation following the introduction of a Total Allowable Catch (TAC) in 1998. Dare *et al*., 2004 concluded that since this decline in stocks, cockle spatfalls and their variability between years have remained similar to historical records, however, high post-settlement mortality of young cockles, particularly over the first winter, appears to have resulted in low recruitment to the fishable stock. Dare *et al.,* 2004 were unable to draw conclusions about the causative factors behind these observations and as to whether they are a result of natural or anthropogenic effects. Observations in The Wash show that cockle spatfalls have occurred on sands that have been regularly dredged for ten years or more and that substantial settlements have been recorded on previously dredged sands (Dare *et al*., 2004). Since 2004, similar patterns have been observed, even in the absence of dredging activity (post 2008). However more recent years have seen stocks return to historical levels. This is thought to have been a result of extremely large spatfalls in 2014 and 2016 (section 3.2.2).

Analysis of sediments in The Wash suggest there have been no changes to sedimentary characteristics[14], including in areas previously heavily dredged (section 2.2.1; Figure 7). The evidence suggests this is likely due to The Wash being a dynamic environment, already affected by strong tidal currents and wind energy (Figure 9, 12). It is unclear if there is a preferred sediment type for spat settlement in The Wash, but previous management closed beds predominantly comprised of more muddy vulnerable sediments to dredging. Similarly, as a precautionary management measure, areas of significant cockle spatfall in The Wash were also closed to fishing activity. However, there remains the possibility that some settlements could be affected by the fishery before they have grown to a detectable size, if they are not detected in the spring surveys. Our ability to monitor future dredge fisheries in The Wash would benefit from fished beds having open and closed areas, so that control sites can be used to fully assess the success of settlement following dredging and the potential long-term effects.

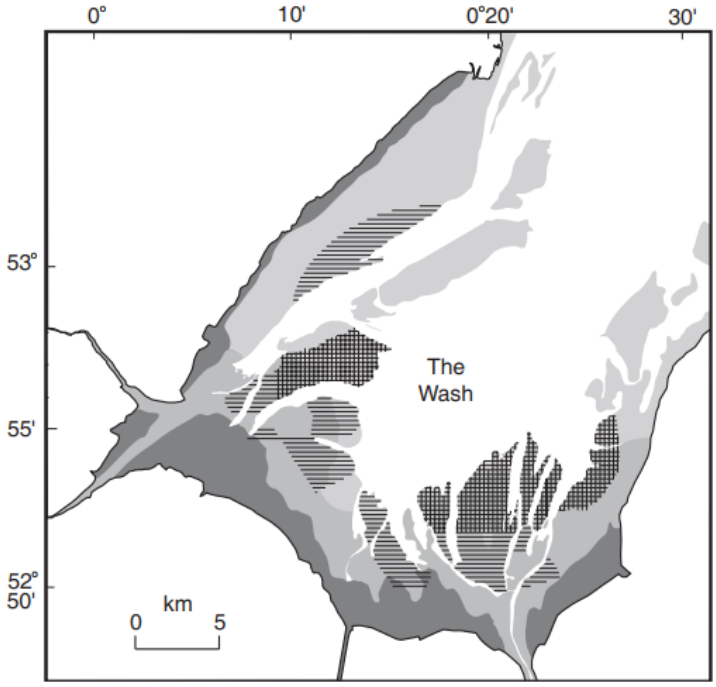


Figure 16 Vulnerability of Wash cockle beds to destruction by winter storms (based on ESFJC records). Cross-hatching denotes the most vulnerable beds, horizontal lines for those less at risk and the remaining areas are rarely (if ever) affected. Image taken from Dare et al., 2004.

Cockle mortality

It is understood that a certain level of fishing mortality can often replace other sources of mortality (Bell *et al*., 2001), and this applies in The Wash. Normal mortality events, generally referred to as 'ridging out' are linked to high densities of cockles and competition for space. However, 'atypical' mortality has also been observed in The Wash since 2008 and refers to large unexplained die offs of cockles of a certain size over a protracted period of time (Jessop, 2012). In addition to this, The Wash cockle beds often experience periodic and widespread destruction following very cold winters or severe North Sea storms which can result in entire beds being swept into channels or ridges and lost (Dare *et al.,* 2004). The vulnerability of beds to extreme tides and weather conditions varies across The Wash, with the most vulnerable being the more

[14] It is important to note that that the methods of sediment analysis used to make this assessment are based on by-eye assessments and can be highly subjective. Any conclusions drawn must therefore be taken with caution a merely provide us with an indication of potential effects.

central, exposed beds, such as Roger, Thief and Daseley's (Dare *et al.,* 2004) (Figure 12).

The potential for 'atypical' mortality or severe weather events to cause losses to stocks provide opportunities for the cockle fishery. Our understanding of the dynamics of atypical mortality is such that we can make reasonable predictions where the highest die-offs will occur. Unfortunately, in most cases mortalities do not occur in discrete patches that could easily be targeted by dredges but tend to be widespread and scattered among healthy stocks. Using dredges to prevent losses would, therefore, require increasing harvest rates of healthy cockles, and more than likely an increase in TAC, to achieve this. This approach would not be sustainable and unlikely to get consent.

3.2.2 Analysis of Eastern IFCA survey data

The Wash cockle fishery is currently managed using a yearly TAC (Total Allowable Catch) to ensure adult stocks are not fished below sustainable levels. Since this management approach was introduced in 1998 stocks appear to have stabilised from the "boom and bust" patterns seen previously to a more natural annual variation. Stocks were heavily exploited in the 1990s following the introduction of hydraulic suction dredges in 1986, eventually leading to a collapse in the fishery in 1996. Dredge fisheries continued until 2008 when the fishery returned to more traditional hand-working methods. Recent years have seen recovery of stocks to historical levels (Figure 2), but they now appear to be very heavily influenced by atypical mortality with single year classes observed across beds rather than the healthier multi-year classes observed historically. Extremely high spatfalls in 2014 and 2016 appear to have compensated for the effects of atypical mortality, resulting in high stock levels in 2016, 2017 and 2018.

Eastern IFCA (previously ESFJC) conduct annual stock assessments of The Wash cockle beds and hold records of assessments going back to 1994. Many of the earlier assessments only focused on the most important cockle beds with fishable stocks and it was not until 2004 that all beds were surveyed. As such, the total number of stations surveyed has increased significantly to previous years. Since 2004, approximately 1300 stations have been surveyed each year, covering all areas of beds in the regulated parts of The Wash. These later records provide opportunity for further analysis of effects alongside changes in fishing activity. Detailed records of dredging intensity and spatial effort are not available for this period, but details of the beds that received the most effort each year have been recorded (Table 3). These highlight four years of data where dredge fisheries overlap with these later survey records. Analysis of this data has provided an insight into the potential effects of dredging on stocks. Detailed results of this assessment can be found in Appendix 7 and are summarised below.

Table 3 The Wash cockle beds where the majority of effort was targeted between 2001 and 2018 by the dredge and hand-work fishery. A dash denotes no fishery that year and a blank no records for that year.

Year	Main effort	
	Dredged	**Hand-worked**
2001	Boston Main, Tofts	
2002	Boston Main	
2003	Daseley's, Butterwick, Mare Tail	
2004	Holbeach, IWMK	All
2005	-	All (Wrangle and Roger)
2006	Friskney	All
2007	Holbeach, Daseley's	All except Roger and Mare Tail
2008	Friskney	All (IWMK, Wrangle, Butterwick)
2009	-	All (Black Buoy)
2010	-	All (Thief, Whiting Shoal, Breast, Herring Hill)
2011	-	All except Whiting Shoal (mainly Breast and Wrangle)
2012	-	All (Wrangle and Roger)
2013	-	All (Black Buoy and Daseley's)
2014	-	All (Gat, Daseley's, Breast, IWMK)
2015	-	All (Roger)
2016	-	Thief, Roger, Wrangle, Friskney
2107	-	All except Wrangle
2018	-	All

Effects on spat settlement

Annual spring stock assessments allow us to calculate the average density of year-0 cockles across each cockle bed and give us an indication of the previous year's spatfall. Figure 13 shows the mean density and mean biomass of year-0 cockles (number per m^2) across all beds between 2004 and 2018. More detailed figures for individual beds can be seen in Appendix 7. During this period a biennial pattern in spat settlement has been observed across most beds with high spatfalls generally having occurred on even years. However, between 2008 and 2013, whilst some beds still showed this pattern, several beds saw large decreases in spatfall across both odd and even years and more irregular spatfalls. This variation across beds during this period explains the plateau effect observed in Figure 13, which has resulted from averaging out across beds where spatfalls have and have not occurred. Interestingly, these observed declines occurred post-2008 when dredging had ceased within The Wash, but also coincided with the period where 'atypical' mortality started to impact cockle stocks. Whilst this decline in year-0 cockles could indicate a long-term effect of dredging on spat settlement, dredging had been happening in The Wash for over twenty years prior to this without having any obvious impacts on spat settlement (Dare *et al*., 2004). The observed declines are more likely to be an effect of 'atypical' mortality and have since seen a return to the biennial pattern previously observed. An increase in spat settlements have been seen across many of the beds, with extremely high settlements seen in 2014 and 2016. Furthermore, between 2004 and 2008, cockle suction dredging occurred predominantly on four different beds in The Wash: Holbeach, IWMK, Daseley's and Friskney (Table 3). More detailed examination of spat settlement on these beds during these years indicate no correlation with dredging

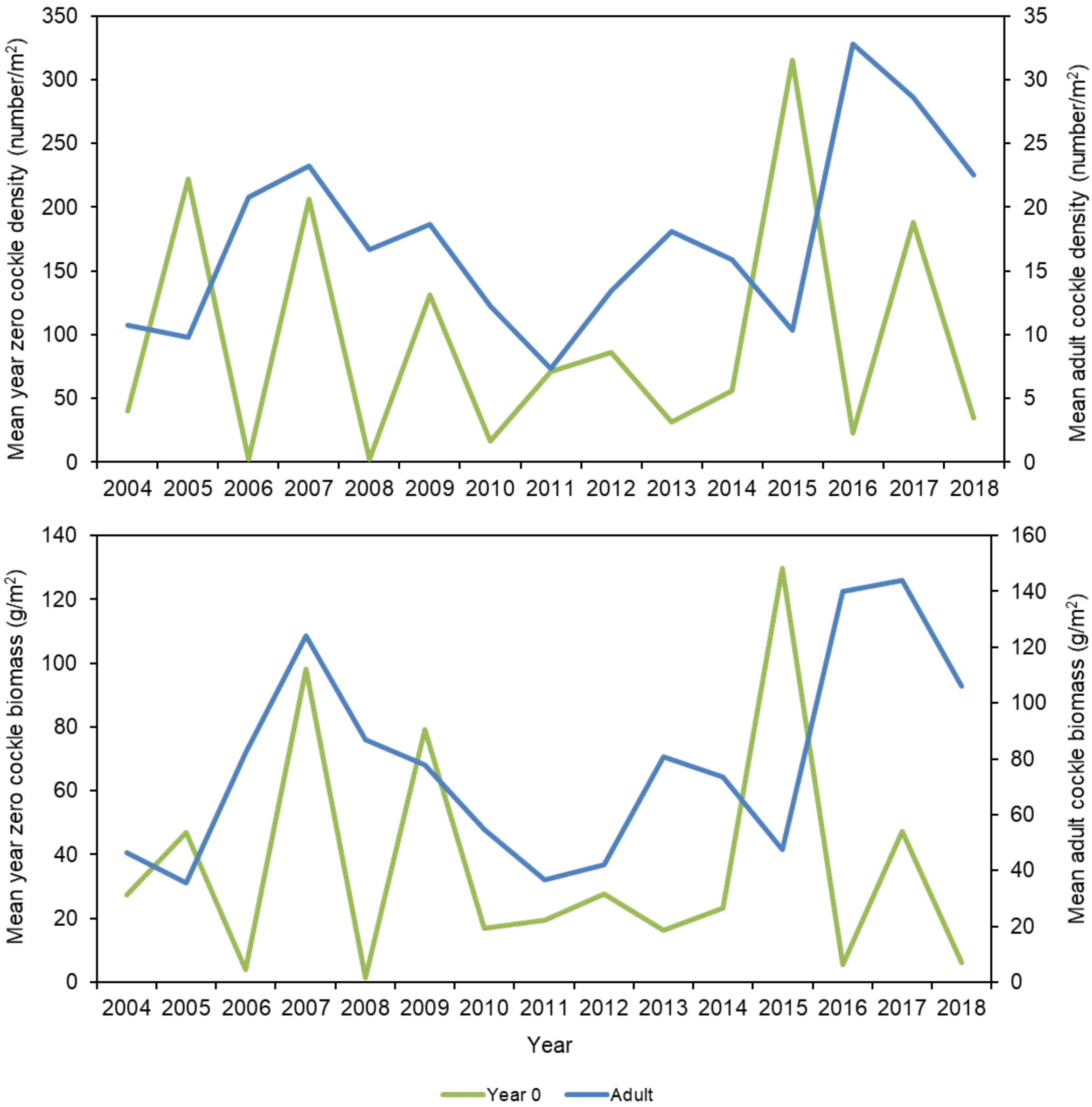


Figure 13 Mean density (number/m²) (top) and mean biomass (g/m²)(bottom) of year-0 and adult cockles between 2004 and 2018, assessed during Eastern IFCA's annual cockle surveys.

activity, with beds generally following the biennial pattern of spat settlement, with high settlements on even years, irrespective of dredging activity (Appendix 7).

Effects on adult stocks

The density of adult cockles each year forms part of the annual stock assessment and is used to calculate the yearly TAC for the fishery. Adult cockles are considered as those ≥ 14mm in width which are targeted by the fishery and are usually in the year-2 age class (or older), or on faster growing beds can be year-1 cockles. Similar to year-0 cockles, the period between 2008 and 2013 showed a decrease in abundance of adult cockles across most beds (Appendix 7). Whilst there was variation in recruitment to the adult stock prior to 2008 when dredging regularly occurred, these years saw much higher recruitment than those post-2008. It is well understood that dredging activity can have short term impacts on adult growth rates and mortality, subsequently reducing adult stocks, however the observed declines are likely to be a direct result of low densities of year-0 recruitment combined with the atypical mortality events observed after 2008.

2007 Holbeach dredge fishery

The 2007 Holbeach dredge fishery was managed in such a way that half of the bed was closed to fishing activity and the other half open. This provided an opportunity to investigate the effects of the fishery on cockle stocks by providing control and impact areas for comparison. Cockle stocks on the adjacent bed, IWMK, were also used in this analysis to provide a further control as the bed exhibited similar stock composition and growth rates to those on Holbeach and was also closed to dredging in 2007. Appendix 8 details the results of this analysis. Results showed no clear indication of negative effects of dredging on juvenile or adult cockles or on the settlement of spat and whilst some stock declines were observed, natural mortalities were identified as the most likely cause, as these were observed on both open and closed areas of the bed. However, it is important to note that the analysis of this data only provides us with a snapshot of information for Holbeach across one year, and responses on other beds may be different. The 2009 spring cockle surveys indicated a spatfall in 2008 on Holbeach and IWMK, but on both beds these were not as high as previous years (Appendix 7). Atypical mortality events that have been observed in The Wash since 2008 are thought to have resulted in these observed declines and there is no evidence to suggest that it is an effect of dredging. Further supporting this, Holbeach and IWMK were both heavily targeted in 2004 by the dredge fishery. Both beds had high densities of year-0 cockles in 2005 indicating a good spatfall during the summer of 2004 despite dredging activity (Appendix 7).

3.2.3 Management implications

Direct fishing mortality results from the retained (landed) catch. In 1998 a TAC was introduced into The Wash cockle fishery and is calculated as one third (33%) of the total adult (≥14mm width) stock (based on data from the annual cockle surveys conducted by Eastern IFCA). Once this TAC has been exhausted, the fishery is then closed until the next year. The maximum direct fishing mortality each year is, therefore, likely to be around the TAC set for the year. It is important to note that in addition to the TAC, there are also three minimum thresholds which must be met to ensure the fishery does not deplete stocks below threshold limits. These are a:

- Minimum total cockle stock biomass of 11,000 tonnes
- Minimum spawning stock (≥14mm) biomass of 3,000 tonnes

- Minimum shellfish biomass above the threshold required to support overwintering bird populations[15]

It appears that following the introduction of a TAC, dredging in The Wash did not have significant impacts on cockle stocks that led to the activity becoming unsustainable. However, it is unclear at what level dredging could become unsustainable if multiple gear passes were regularly repeated on the same beds, particularly over multiple years. If a hydraulic suction dredge fishery were to take place in The Wash, management would follow the same annual TAC approach, would require strict monitoring of effort in line with the assessment of stocks and would benefit from having both open and closed areas of dredged beds for comparison.

In addition, the findings from Jessop (2008) which indicated higher mortality from riddle discards compared to dredge discards should be considered. Whilst previous ESFJC policy required bar-spacing of riddles and dredge heads to be a maximum of 12mm, as cockles discarded from the dredge head appear to have a better survival than those discarded from the riddle, it is thought that allowing a 14mm bar-spacing on the dredge head, while retaining the 12mm spacing on the riddle, would increase the effectiveness of the dredge head at discarding shell whilst allowing more juvenile cockles to escape before they come into contact with the damaging pumps and riddles. This in turn should reduce the discard mortality and increase the survivability of juveniles. Re-deposition closer to the track will also increase survivability compared to the riddle. However, such management would require gear adaptions by the industry and may not be appropriate under conditions of atypical mortality currently experienced in The Wash, which have resulted in cockles being harvested at smaller sizes than previously. As discussed in section 3.1, there could be merit in lowering the TAC to account for additional mortality at the dredge head that is not already accounted for when assessing gears, however, quantifying this would be extremely difficult.

Riddle rejects suffer higher mortality, especially if they are picked up in multiple passes (Jessop, 2003). Therefore, there could be benefit in retaining and landing the whole catch, particularly in combination with an increase in dredge head bar spacing. Riddling the catch, however, also allows the associated sediment, water and other debris in the catch to be discarded. Landing the whole catch, therefore, would be largely inefficient and likely to be hard to enforce. Minimising instances of dredging the same area multiple times by different vessels could increase the survivability of rejects but would be very hard to manage and enforce.

Like the hand-work fishery, to protect small cockles from dredge impacts, areas supporting high densities (>1,000m^2) of year-0 cockles should remain closed to a dredge fishery and only those beds with >70% adult cockles opened. Hand-work fisheries are deemed much more spatially precise than dredge fisheries and easier to enforce, thus current management only closes areas of high densities. Enforcement carried out by Eastern IFCA would not be efficient enough to manage a dredge fishery with small discrete closures that are often seen in hand-work fisheries, and instead would require whole beds to be closed to protect beds of high-density year-0 cockles.

[15] This is calculated using a model that determines the food requirements for the birds in terms of Ash Free Dry Mass (AFDM), and since the overwintering birds prey on both cockles and mussels, takes both these species into account in calculations.

4 Other dredge cockle fisheries

4.1 Le Strange private fishery

Within The Wash, outside of the WFO area, the Le Strange private fishery also exists on intertidal sand and muddy sand sediments. A hydraulic suction dredge cockle fishery exists within this private fishery and has done for many years after receiving long-term consent from Natural England. This fishery however, is not managed or regulated by Eastern IFCA and we are unable to access any information on cockle stocks or fishing effort that would allow us to assess impacts on site features or the sustainability of stocks within The Wash. The main difference between this fishery and WFO cockle fishery is that only two vessels operate within the fishery and that the rights are held solely by one individual, thus meaning there is no competition.

4.2 The Thames Estuary Cockle fishery

Within the Essex coast two highly regulated and intensively managed cockle fisheries exist, one within the Thames Estuary Cockle Fishery Order (TECFO) area and one permitted fishery outside of this. Both fisheries are managed by Kent and Essex IFCA (KEIFCA) and the Thames Estuary cockle fishery provides an example of a hydraulic suction dredge cockle fishery that has operated sustainably. The Thames Estuary is similar to The Wash in that it is a highly dynamic environment which likely experiences high levels of natural disturbance (Appendix 5) and is made up of predominantly intertidal sand and mud sediments. However, there are several significant differences between this fishery and The Wash cockle fishery. The primary differences are the number of vessels that are licensed to operate in each and that the Thames Estuary fishery does not operate a commercial hand-worked fishery alongside their dredge fishery. Under the Thames Estuary Cockle Fishery Order (TECFO), KEIFCA restrict the number of licences issued to exploit the fishery to 14 (KEIFCA, 2018), much lower than the ~55 licences that are issued annually within The Wash fishery. KEIFCA apply strict controls to the fishery to reduce the potential impacts on cockle stocks and on benthic features in the area. These include spatial, temporal and effort restrictions on harvesting, along with gear restrictions and vessel size limitations to reduce impacts on EMS features (KEIFCA, 2018). Vessel fishing activity is also carefully monitored through the use of VMS and targeted seas patrols.

4.3 Dundalk Bay Cockle fishery

A hydraulic dredge cockle fishery previously existed in Dundalk Bay, Ireland. Cockle beds covering an area of 44.5km^2 sand and mud flats were traditionally hand-worked in this bay with little activity documented prior to 2001 when three vessels were recorded dredging a total of 9 tonnes of cockle for that year (Fahy *et al*., undated). By 2004 the number of vessels recorded as taking part in the dredge fishery had increased to 21, with a total of 201 tonnes of cockle landed. As seen in other inshore fisheries this resulted in gear conflict and led to concerns that the fishery should be managed in a more sustainable way. Following this, fishermen agreed to stop cockle fishing and many dredge boats re-directed their efforts to other cockle fisheries further south. In 2007 the cockle fishery was closed by local agreement after it was given

Natura 2000 status. However, in 2009 the fishery re-opened to both dredgers and hand gatherers following the conduction of an ‘appropriate assessment’ and the introduction of a permit scheme and 5-year management plan which required all vessels to have GPS tracking devices. The 2009 fishery saw a total of 32 vessels landing 108 tonnes of cockle. A five-year management plan is now in place for 2016-2020 which limits the number of dredging permits to 33 and hand gathering permits to 20, among a variety of other restrictions.

5 Socio-economic impacts

In addition to assessing the environmental impacts associated with a hydraulic suction dredge fishery, the socio-economic impacts also require consideration. The WFO regulated cockle fishery is extremely important to the local economy and community, thus any changes to the fishery could result in large social or economic effects. These include impacts on the value of the fishery and local employment, changes in the associated costs to the industry or displacement effects affecting other fisheries. The potential socio-economic impacts likely to result from changes to the fishery have been scoped in Table 4 and discussed further below.

There are a total of 62 entitlement holders who could take part in either a dredge or a hand-work fishery. However, it is important to note that some of the current boats in the fishery would be too small to carry and operate the gear used in a dredge fishery. If a dredge fishery were to open, these smaller vessels would need to continue targeting the hand-worked fishery. Should the hand-worked fishery fail to compete with a large-scale dredge fishery, as was the case following the introduction of dredges in 1986, these smaller vessels could either go out of business or be displaced to other fisheries. Either way, it is likely their entitlement would be transferred to a larger vessel.

Should a dredge fishery be opened, it is unlikely that the Authority would gain consent for a dredge fishery that involved 62 vessels. If this were the case, a decision would have to be made as to which entitlement holders would receive a dredge licence if such a fishery were consented.

Table 4 Aspects of the WFO cockle fishery where changes could result in socio- economic impacts:

Fishery aspects	**Socio economic impacts**
Duration of the fishery	Fishery value Displacement effects Employment Fishery costs
Number of fishers/vessels involved	Displacement effects Employment
Daily quota	Fishery value
Fishery effort	Fishery costs Displacement effects
Price of cockles	Fishery value
Gear required	Fishery costs
Operations and processing	Fishery cost
Global demand	Fishery value

5.1 Fishery value

The value of the Wash Fishery Order regulated cockle fishery is estimated at around £1 - 2 million per year, and is very much dependant on a number of variable factors. First and foremost is the annual TAC, set as a third of the total adult stock calculated during the annual spring cockle stock assessments. The TAC directly affects the total amount of cockle landed each year and remains the same regardless of whether there is a hand-work or a dredge fishery, or a combination of the two.

The price of cockles also has a large influence on the value of the fishery. Whilst the price is largely set by the processors, this can be affected by a number of factors, such as market demand, the quality of cockles and the daily quota. Previous experience in The Wash shows that dredge fisheries have often resulted in decreases in the first-sale price of cockles. This is mainly due to the size of the daily dredge quota being double that of the hand-worked fishery. Because they are able to harvest double the quantity of cockles each day, fishers are more accepting of a reduction in the price per tonne they receive for the cockles. The ease at which dredge cockles are harvested compared to hand-worked cockles may also influence the value fishers are willing to accept for them. Although the daily quota does not affect the size of the TAC, this reduction in price per tonne does affect the overall first-sale value of the fishery.

Because the size of the daily quota does not affect the size of the annual TAC, larger daily quotas result in the TAC being achieved faster. Assuming the same number of vessels are employed, a dredge fishery operating on 4 tonnes per day would exhaust the TAC twice as fast as a hand-worked fishery operating on two tonnes per day. This has been seen in some previous dredge fisheries, in which the available TAC has been fished within 2-6 weeks compared to hand-worked fisheries that tend to last 4 or 5 months. While some fishers would prefer a shorter fishery, allowing them to diversify to other fisheries sooner, others prefer the stability of a longer cockle fishery.

Proponents of the dredge fishery frequently quote the benefits that larger quotas have on reduced fuel costs. With half as many days at sea, it would seem fuel costs would be halved. However, this is not the case. Hand-worked fishers tend to go to sea on the ebbing tide and return on the flooding tide. As such, they are going with the prevailing tide both ways. Dredge fishers tend to push into the flood tide at the start of each trip and sometimes push into the ebbing tide on the way home. This means they use more fuel while at sea. Additionally, dredging also requires fuel while dredging is being conducted, both for the vessel’s main engine while towing the dredge and also for a second engine that powers the hydraulic pump.

The socio-economics of the fishery are further complicated by the different business models that are employed by the entitlement holders. In addition to independent vessel owners who operate their own vessels out of both Boston and King’s Lynn, approximately a third of the entitlements are owned by processors. Shorter seasons benefit the processors because they do not need to operate their factories for as long for the same amount of cockles to be processed. A reduction in first-sale value of cockles would also be of benefit to them, as the cockles they purchase would be cheaper. The vessels owned by the processors tend to be among the larger boats operating in The Wash. For these, the preferred option is for a short cockle fishery that enables them to target the brown shrimp fishery for longer. Previously, displacement to the shrimp fishery wasn't problematic, but having recently completed a HRA on this fishery, future effort will need to be capped in order to reduce the environmental footprint. Change to a short cockle season coupled with a capped shrimp fishery could result in vessels being unemployed for long periods – as was frequently the case during previous dredge fisheries.

5.2 Costs to the industry

Calculating the costs of a dredge fishery and making comparisons to a hand-work fishery are extremely difficult as many of the costs are unknown and highly variable. For example, fuel and operational costs vary largely between vessels, and the cost of fuel varies greatly over time. If a dredge fishery were introduced, one of the biggest costs to the fleet would be the cost of fitting their boats with modern gears that meet Authority standards. These are estimated to cost up to £60,000 per vessel[16]. Again, this would vary between boats depending on what gear they already have. Whilst this would be an initial one-off cost, it has the potential to prevent many entitlement holders from taking part in the fishery if they are not able to fit their boat with modern dredge gear that meets the Authority standard.

In addition to equipping the vessel, fishers have fixed costs to pay, such as licence fees, insurance and rent. These are required, irrespective of how many trips a vessel makes or catches it lands. There are also variable costs that fluctuate depending on usage and include fuel, maintenance of vessels and gear and transport costs. Many of the variables involved are unknown or are too complex to project accurate estimates of the potential costs and benefits to individuals, however, an attempt to summarise the potential effects on the industry can be found in table 5.

Table 5 Costs and benefits of a dredge fishery to both independent fishers and processors

	Costs	**Benefits**
Independent fishers	• Initial cost of gears • Increased fuel and maintenance costs • Potential decrease in price of cockles • Smaller boats can't dredge and may have to sell entitlements • Not all boats can take part in the shrimp fishery	• Fishery requires less effort
Processors	• Initial cost of gears • Increased fuel and maintenance costs	• Shorter cockle fishing season • Reduced factory and operation costs • Longer shrimping season • Less demand – decreased price • Fishery requires less effort

[16] Estimation is based on hydraulic suction dredge gears that meet conservation and sustainability requirements. It is thought that such gears could cost as little as £5,000 if consideration for the environment is not made.

5.3 Displacement effects

A decrease in the number of vessels or fishers involved in the fishery, the duration of the fishery and the effort involved could lead to fishers moving to other areas or different fishing activities to earn an income. This has the potential for large displacement effects on other fisheries. Many of the WFO cockle fishers take part in the shrimp fishery outside of the main cockling season. Therefore, any reduction in effort for the cockle fishery is most likely to be displaced to the fishery shrimp fishery. However, following the recent completion of a HRA for the shrimp fishery, proposed management measures are being consulted on and could include a cap on effort at current levels. Since cockle dredging ceased in 2008, fishers have put more effort into the cockle fishery and less effort into the shrimp fishery. Therefore, the level of effort that has been targeted towards the shrimp fishery over the past ten years is lower than that seen during the previous period of dredge cockle fisheries. Restrictions on effort to this fishery will reduce the effort that can be displaced onto this fishery. Some fishers with small boats could turn to other hand-work fisheries along the coast, increasing fishing pressure elsewhere or may turn to other gears. For example, potting for whelk or crab and lobster could increase in the central part of The Wash, while some boats with the appropriate licences could use other trawling gears or start using netting or long-line gears.

5.4 Employment

Impacts on employment and income to fishers could be seen if there is a reduced number of days fishing, less vessels are involved, or the daily quota is increased. Furthermore, less crew are generally required when dredging compared to hand-working. A shorter fishery will also reduce the overall number of days required to process the catch and thus the need for factory staff, reducing employment in this area.

6 Fishing opportunities

The option for a dredge fishery in The Wash has the potential to provide a number of opportunities for the WFO cockle fishery alongside the hand-work fishery. A dredge fishery could provide increased access to the large Holbeach cockle bed which is currently restricted to the hand-work fishery as it exists within the Holbeach bombing range. The RAF Holbeach bombing range is closed during weekdays between set hours[17] and so the hand work fishery can only target this bed during low tide periods outside of these hours. Unlike hand-working, in which the vessel would be captive within the area while dried out, dredging is conducted over the high-water period, meaning vessels have greater opportunities to fish there outside of closed periods because they can exit the site when required rather than being captive for long periods. Thus, consenting a dredge fishery on this bed would increase the opportunity for fishers to target the bed during weekdays outside of these hours (e.g. during early morning or evening high tides).

While some proponents of the dredge fishery have suggested dredging would allow fishers to rapidly harvest cockles identified as vulnerable to atypical mortality, in actual fact this is not a feasible option in most instances. We can make reasonable predictions about where die-offs may occur, but atypical mortalities do not occur in discrete patches that could be targeted by dredges. Instead, they tend to be widespread and scattered amongst healthy stocks. Unless these areas were specifically targeted instead of other parts of the fishery, using dredges to prevent losses would also result in healthy cockles also being harvested and could potentially require an increase in TAC to achieve this. Following this approach long-term would not be sustainable and unlikely to get consent. Another suggestion is that the increased efficiency of dredging compared to hand-working would make targeting low density cockle beds more viable to the fishing industry. However, targeting low density beds raises further questions regarding both sustainability and excessive disturbance to the substrate. KEIFCA have a minimum harvest rate of 1 tonne per hour. If the harvesting rate falls below this, the cockle management area will be closed due to low densities. The densities at which cockles can be sustainable dredged in The Wash are unknown but following heavy exploitation in the 1980s and early 1990s, the cockle stocks declined to very low levels by 1995 and took several years to begin to recover.

[17] RAF Holbeach range: standard operating times: Monday & Wednesday 0900hrs to 1715hrs possible extension to 1800hrs); Tuesday & Thursday 0900hrs to 2200hrs; Friday 0900hrs to 1230hrs. The range may open at different times at short notice, communicated via VHF broadcasts. Fishers must not be within the area of RAF Holbeach Range during these times or at any time the range is in operation.

7 Management implications

Dredging will result in shorter, more intense periods of activity and because the vessels are mobile rather than dried out on the seabed, such fisheries are more difficult to effectively monitor and enforce. Enforcement and management would only be effective at a bed level rather than the higher resolution seen in the current hand-work fishery. Additionally, because hand-worked fisheries cannot compete on the same sands as dredgers, hand-working and dredging would not be able to operate alongside each other. Instead, each would need to occur on individual beds and each fishery would require a separate TAC. From a management perspective, additional resources would be required to regulate the fishery, not only for monitoring two TAC's but also inspecting landings of dredge fishery vessels that are less predictable with their landing times than hand-workers.

Currently the maximum number of vessels that could prosecute the dredge fishery would be limited by the 62 Entitlements. In reality, previous dredge fisheries have tended to see between 45 and 55 vessels operate during any particular year. Sections 2 and 3 of this report discuss the potential impacts of dredging in terms of the environment and the sustainability of cockle stocks. Whilst it does not appear that historical dredging events in The Wash have had adverse long-term impacts on the environment or the features of the SAC, there is a lack of substantial evidence to suggest the limit at which effort can be sustainable in The Wash and the effects from multiple dredge passes. Other dredge fisheries, such as the Le Strange private cockle fishery and the Thames Estuary cockle fishery, are limited to 2 and 14 vessels, respectively. Because of our limited understanding of the effects in The Wash a precautionary approach would be to limit effort, one way of doing this would be to reduce the number of vessels involved in a dredge fishery. However, limiting the number of dredgers by any other means than by Entitlements would mean that a decision would have to be made regarding the number of licences distributed and as to which licence holders these would be given to. Those who are issued with licences would also require gear and vessels to be checked to ensure they meet requirements under the management measures (Appenidx 1) every year. This is timely and a further drain on resources, particularly aspects such as monitoring and enforcing minimum breakage rates. In addition, Eastern IFCA are currently working towards achieving 50% cost recovery of the fishery from licences fees, so an increase in any cost of management of the fishery resulting from consenting a dredge fishery will likely increase the licence holder fee for those who hold a dredge licence. This will likely be considerably higher if the increased costs are only shared between those vessels taking part in the fishery.

Monitoring and enforcing compliance with mitigation measures and the additional management requirements of a dredge fishery would likely require a significant increase in resource from the Authority. As such, if a dredge fishery were to be consented it is likely further management measures would be required to minimise the drain on resources. These could include: only opening the fishery on certain days, defining periods when fishers can land, or introducing a requirement for fishermen to give a specified notice period prior to landing after every cockle trip; limiting the number of vessels involved in the fishery; or increasing the daily quota to allow a shorter fishery period.

7.1 Mitigation and enforcement of dredged cockle fisheries

If a dredge cockle fishery was opened on the regulated beds of The Wash the following mitigation measures would be required:

- Protection of juvenile cockle stocks,
- Protection of mussel beds
- Protection of sensitive sediments and habitats
- Protection of areas assigned for hand-worked-only fisheries
- Use of approved gears (including compliance with <10% smash rate)
- Allocation of TAC for dredge fishery
- Daily vessel quota
- Effort limitation
- Transhipping prohibition

The protection of juvenile cockle stocks, mussel beds and sensitive features, as well as the allocation of different areas that would be opened to the dredge and hand-worked fisheries, would all require a mosaic of spatial closures. Effective enforcement of these areas from a highly-mobile fishery would be difficult to achieve without having a vessel at sea during all periods the fishery was open (and also available on stand-by when the fishery was closed). During previous dredge fisheries, the Authority maintained a vessel at sea throughout the opening periods of the dredge fisheries, which was a considerable drain on Authority resources. Even then, it was difficult to maintain compliance throughout an area the size of The Wash, with vessels working from two ports (and occasionally landing into a third). This was made more difficult due to some vessels fishing night tides, when it was more difficult to ascertain whether they were steaming or fishing without launching a RHIB. This proved a heavy drain on resources as a Sea Fishery Committee, and a similar presence would be difficult to maintain as an IFCA with its additional commitments.

There are concerns that if the dredge fishery was not closely monitored, poaching would occur on beds other than those opened to the fishery. The forthcoming introduction of iVMS would make it much easier to track a vessel's position with respect to open and closed areas, particularly if supported with rigorous management measures, but the intermittent nature of the iVMS data pings will only allow a series of snapshots to be taken. This will make iVMS less effective at determining whether a vessel working close to the border of a closed area is complying with regulations or is fishing in and out of the closed area. Therefore, a responsive presence would still be required while the fishery was open in order to investigate suspicious iVMS data. Further, iVMS will not be able to determine whether a vessel is actually fishing or not. This will be problematic when dredgers may legally transit closed areas on their way to and from the open beds. Due to the efficiency of hydraulic suction dredges, several tonnes of cockles could be illegally harvested in relatively short time periods by a vessel poaching while transiting a closed area. If cockles are significantly more abundant within the closed areas, as may be the case after a dredge fishery has been open for several weeks and the open areas are becoming depleted, there will be a high temptation to poach from them.

In addition to regulating the various closed areas, the Authority would be required to monitor and enforce the cockle breakage rates associated with the equipment. With respect to breakage rates, Byelaw 3 – Molluscan Shellfish Methods of Fishing states: “A certificate of approval will not be granted if the instrument or fishing gear results in being smashed.” Unfortunately, by referring to, “more than 10% by weight of the target species”, this byelaw does not distinguish between retained or discarded elements of the catch. That means the 10% refers to all cockles fished by a vessel, irrespective of whether they are retained or discarded. This makes determining a vessel’s breakage rate complex as it is not simply a case of taking measurements from one or the other. To determine the breakage rate of fished cockles, the amount of breakages must be determined for both the retained and discarded elements of the catch and then the relative proportion of each element ascertained. This requires several measurements and timings having to be taken from the retained and discarded components of the catch to calculate their respective rates. Even then, the element of fished cockles that are discarded at the dredge head cannot be accounted for. In addition to the monitoring of breakage rates being a complex task, because they can only be determined while fishing is occurring, the required certificate of approvals can only be granted once the fishery has commenced. Because only about ten vessels can be checked each day for their breakage rates, in a fishery of 40+ vessels, some may be fishing a week or longer before their rates are checked. That means considerable damage could be caused by a vessel with poorly-set equipment before it was detected and stopped. Further, the breakage rate monitoring only provides a snapshot of what is occurring. Some fishers in the past have been observed turning down the running speeds of their suction pumps when officers have boarded their vessels, with the aim of improving their results during the test.

Regulators would also need to inspect landings to monitor the uptake of TAC and ensure compliance with daily quotas. With a hand-worked fishery, most fishers will work the same tides, therefore, arriving back in port at similar times and landing together. This makes it relatively easy for officers inspecting the catches because they only need to be on the quaysides at one high-water period each day. Previous dredge fisheries saw different behaviour patterns, however, with some fishers working night tides rather than the daytime tides. This meant some vessels were landing on the morning tides while others were arriving on the evening tides. Inspections, therefore, required officers being on the quay more often.

Although the Authority managed to regulate large-scale dredge fisheries between 1986 and 2008, the responsibilities as an IFCA are broader than those of the old Sea Fisheries Committee. Far greater commitment is now needed assessing the impacts of each fishery than was formally required, creating a shift in how available resources are utilised. Whereas the SFC could afford resources to regulate a dredge fishery, the IFCA would struggle. To effectively enforce a dredge fishery now, additional restrictions would need to be imposed that would limit fishing opening times each day to manageable levels. This, however, would then place additional pressure on the fishers to harvest their daily quotas quickly in order to return to port. This itself would potentially encourage poaching activity, particularly if there were high-density cockle beds on the transit route to the open beds.

8 Conclusion

The Wash is a highly dynamic environment, exposed to high winds and strong tidal conditions. Areas of high seabed energy are known to occur in the intertidal areas where cockles are found, thus stocks are likely to experience high levels of natural disturbance. After consideration of the available data and literature, dredging at the levels previously observed in The Wash does not appear to have resulted in any significant changes to benthic biota and sediments. However, whilst the short-term effects of dredging in The Wash appear to be minimal, this assessment has highlighted the lack of understanding around the long-term effects of repeated dredging and the level of effort that can be sustained in The Wash without having adverse effects on the environment and site features. Repeated dredging over multiple years in the Dutch Wadden Sea led to long-term changes in sediment composition and it is unclear if there is potential for such effects to occur in The Wash. In addition, there are still uncertainties around the effects of dredging on mud sediments. Because of these uncertainties, the precautionary principle would need to be applied when proposing any future dredge fishery. Effort would need to be limited so that it did not exceed previous levels to ensure no long-term changes to sediment composition were to occur; vulnerable, muddy beds should be closed to dredging activity; and sediment monitoring in dredged and non-dredged areas would be required to monitor effects.

In terms of stock sustainability, since 1998, when the TAC system was introduced, there hasn't been any evidence to suggest dredging has had a significant impact on stocks. Prior to this, high exploitation and discard mortality rates led to depleted stock levels throughout the 1990's. Whilst the 10% smash rate limit in the Eastern IFCA district means that gear will not be approved if more than 10% by weight of the target species fished is smashed, there are concerns that this does not account for all discard mortality and that the TAC does not represent all the fishing mortality incurred. Repeated dredging in the same area is thought to further reduce the survivability of discards and has the potential to impact adult and juvenile stocks. However, assessment of Eastern IFCA WFO cockle survey data between 2004 and 2013, showed no clear effect of dredging on adult stocks or spatfalls, with spatfalls following a biennial pattern regardless of dredging activity. Furthermore, the declines in stocks observed across most of The Wash cockle beds between 2008 and 2013 appear to be a result of atypical mortality and not an effect of dredging (or hand-working for that matter). It is unclear at what level dredging could become unsustainable if multiple gear passes were regularly repeated on the same beds, particularly over multiple years. If a hydraulic suction dredge fishery were to take place in The Wash, management would follow the same annual TAC approach, but would likely require further effort limitation and strict monitoring of effort in line with the assessment of stocks and would benefit from having both open and closed areas of dredged beds for monitoring and comparison.

It appears the most likely opportunity for a dredge fishery, alongside the hand-work fishery, would be to provide increased access to fishers to the large Holbeach bed, currently restricted to the hand-work fishery. However, opening only this bed to a dredge fishery would mean many vessels exploiting only one relatively small area of The Wash cockle beds. The socio-economic impacts, management implications and enforcement challenges would need to be very carefully considered. There are concerns that opening a dredge fishery would result in a decrease in the first-sale price of cockles, reduce local employment (in terms of crew and processing staff), have displacement effects on other fisheries and incur high costs to licence holders, potentially excluding some of them from taking part in the fishery and favouring those with larger commercial fishing operations over those with small business models. Furthermore, to ensure effective management of a dredge fishery alongside a hand-work fishery a significant increase in workload would be required to monitor and enforce two TAC's, ensure poaching does not occur and ensure compliance with the 10% smash rate. The introduction of iVMS would make enforcement and monitoring easier, particularly if supported with rigorous management measures, but would still require a responsive presence to be maintained. Further management measures also would be needed to try and minimise the drain on resources but also to restrict effort to align with conservation objectives being achieved and to ensure that the fishery does not have adverse effects on the environment or future cockle stocks.

The risk associated with a dredge fishery is much higher than that associated with a hand-work fishery. To mitigate this risk, it is evident that a significant increase in resources would be required by the Authority. When combined with the levels of uncertainty around the environmental and socio-economic impacts of a dredge fishery, which would require a heavy commitment of resources for the authority to answer, pursuing this fishery would be a costly (and possibly unfeasible) option for the Authority to consider.

9 References

Ashley, M., 2016. [*Limecola balthica*] and [*Arenicola marina*] in littoral muddy sand. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: http://www.marlin.ac.uk/habitat/detail/1087 [Accessed 6th August 2018].

Atkinson, P.W., Clarke, N.A., Bell, M.C., Dare, P.J., Clarke, J.A. and Ireland. P.L., 2000. The effects of changes in shellfish stocks and winter weather on shorebird populations: results of a 30-year study on the Wash, England. BTO Research Report No. 238.

Atkinson, P.W., Clarke, N.A., Bell, M.C., Dare, P.J., Clarke, J.A. and Ireland. P.L., 2003. Changes in commercially fished shellfish stocks and shorebird populations in the wash, England. Biological Conservation, 114, 127-141.

Bell, M.C. and Walker, P., 2005. Desk study to assess the impact of cockle suction dredging on The Wash and North Norfolk Coast European Marine Site. Report to English Nature, CEFAS. Lowestoft.

Bell, M.C. and Walker, P., 2007. Cockle suction dredging in The Wash and North Norfolk Coast European Marine Site: Part 2 – analysis of existing data. Report to English Nature, CEFAS. Lowestoft.

Bell, M.C., Bannister, R.C.A., Walker, P., Atkinson, P.W. & Clark, N.A., 2001. Fisheries and bird predation as components of cockle (*Cerastoderma edule*) mortality in the Burry Inlet, South Wales.

Boyden, C.R., 1972. The behaviour, survival and respiration of the cockles Cerastoderma edule and Cerastoderma glaucum in air. Journal of the Marine Biological Association, 52: 661-680.

Claudet, J., Osenberg, C. W., Domenici, P., Badalamenti, F., Milazzo, M., Falcón, J. M., and Borg, J. A., 2010. Marine reserves: Fish life-history and ecological traits matter. Ecological Applications, 20, 830–839.

Cook, W., 1991. Studies on the effects of hydraulic dredging on cockle and other macroinvertebrate populations 1989-1990. North Western and North Wales Sea Fisheries Committee.

Dare, P.J., 1999. Health of the Wash ecosystem: Shorebird population trends, food, supplies and possible shellfisheries interactions in the Wash, 1972-1997. Report to English Nature.

Dare, P.J., Bell, M.C., Walker. P. and Bannister, R.C.A., 2004. Historical and current status of cockle and mussel stocks in The Wash. Lowestoft: CEFAS.

De Vlas, J., 1987. Effects of cockle fisheries on the macrobenthos in the Wadden Sea. Proceedings of the 5th International Wadden Sea Symposium, Esbjerg, 1986, 215-227.

Dernie, K. M., Kaiser, M. J. and Warwick, R. M., 2003. Recovery rates of benthic communities following physical disturbance. Journal of Animal Ecology, 72, 1043-1056.

EIFCA, 2016. Item 6 WFO cockle fishery 2016, Appendix 3: Risk Matrix. 24th Eastern Inshore Fisheries and Conservation Authority Meeting (1st June 2016)

Elliott, M., Nedwell, S., Jones, N.V., Read, S.J., Cutts, N.D. and Hemingway, K.L., 1998. Intertidal Sand and Mudflats & Subtidal Mobile Sandbanks (volume II). An overview of dynamics and sensitivity characteristics for 87 conservation management of marine SACs. Scottish Association for Marine Science (UK Marine SACs Project).

Ellis, J.R., Milligan, S.P., Readdy, L., Taylor, N. & Brown, M.J. 2012. Spawning and nursery grounds of selected fish species in UK waters. Sci. Ser. Tech. Rep., Cefas Lowestoft, 147: 56pp

Ens, B.J., Smaal, A.C. and de Vlas, J., 2004. The effects of shellfish fishery on the ecosystems of the Dutch Wadden Sea and Oosterschelde. Final report on the second phase of the scientific evaluation of the Dutch shellfish fishery policy (EVA II). Alterra, Wageningen.

Essink, K., Beukema, J.J., Madsen, P.B., Michaelis, H. & Vedel, G.R., 1998. Long-term development of biomass of intertidal macrozoobenthos in different parts of the Wadden Sea. Governed by nutrient loads? Proceedings of the 9th International Wadden Sea Symposium, November 1996, Norderney. Senckenbergiana marit 29:25–36

Fahy, E., Carroll, J., & Murran, S., Undated. The Dundalk cockle *Ceratomderma edule* fishery in 2003-2004. Irish Fisheries Investigations Number 14.

Franklin, A., and Pickett, G.D., 1978. Studies on the indirect effects of fishing on stocks of cockles, *Cardium edule*, in the Thames Estuary. Fisheries Research Technical Report, No. 42. Lowestoft: MAFF Directorate of Fisheries Research.

Goss-Custard, J.D., 1996. The oystercatcher: from individuals to populations. Oxford: Oxford University Press.

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

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

Hiddink, J.G., Jennings, S., Sciberras, M., Szostek, C., Hughes, K.M., Ellis, N., Rijnsdorp, A.D., McConnaughey, R.A., Mazor, T., Hilborn, R., Collies, J.S., Pitcher, R., Amoroso, R.O., Parma, A.M., Suuronen, P. and Kaiser, M.J., 2017. Global analysis of depletion and recovery on seabed biota after bottom trawling disturbance. Proceedings of the National Academy of Sciences, 114, 8301-8306.

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

Hummel, H., Fortuin, A.W., Meijboom, A., & de Wolf, L., 1988. Mortality of intertidal benthic animals after a period of prolonged emersion. Journal of Experimental Marine Biology and Ecology: 247-254

Jessop, R.W., 2008. A study to ascertain the effectiveness of the dredge head at discarding juvenile cockles, and the mortality rate of those discards. Eastern Sea Fisheries District Research Report 2008. Kings Lynn. Eastern Sea Fisheries Joint Committee

Jessop, R.W., 2012. Study of cockle mortality in The Wash – Eastern IFCA Research Report 2012. Eastern Inshore Fisheries and Conservation Authority, King's Lynn.

Jessop, R.W., Lowry, M. & Graves, K.M., 2003. Edible Cockle Discard Mortality Study. Eastern Sea Fisheries District Research Report 2003. Kings Lynn. Eastern Sea Fisheries Joint Committee: 61-69

Jessop, R.W., Lowry, M. & Graves, K.M., 2004. Edible Cockle Discard Mortality Study. Eastern Sea Fisheries District Research Report 2004. Kings Lynn. Eastern Sea Fisheries Joint Committee: 75-84

Jessop, R.W., Stringer, R., Thompson., S. and Welby. P., 2013. Assessing the impact of growth and mortality when determining the annual Total Allowable Catch (TAC) for the Wash cockle fishery. Eastern IFCA Research Report 2013. Eastern Inshore Fisheries and Conservation Authority, King's Lynn.

Kaiser, M.J., Clarke, K.R., Hinz, H., Austen, M.C.V., Somerfield., P.J. and Karakassis, I., 2006. Global analysis of response and recovery of benthic biota to fishing. Marine Ecology Progress Series, 311, 1-14.

Kaiser. M.J., Hormbrey, S., Booth, J.R., Hinz, H. and Hiddink, J.G., 2018. Recovery linked to life history of sessile epifauna following exclusion of towed mobile fishing gear. Journal of Applied Ecology, 55(3), 1060-1070.

KEIFCA, 2018. Fisheries in EMS Habitats Regulations Assessment for the 2018 Thames Estuary Cockle Fishery Order Area Fishery. Kent and Essex Inshore Fisheries Conservation Authority.

Mander, M.R. & Trundle, C.J., 2001. Cockle Discard Mortality study. Eastern Sea Fisheries Joint Committee Research Report (2001). Kings Lynn. Eastern Sea Fisheries Joint Committee: 43-56

McQuillan, R. M. and Tillin, H,M., 2016. [*Lanice conchilega*] in littoral sand. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: http://www.marlin.ac.uk/habitat/detail/195 [Accessed 6th August 2018].

Moore, J., 1991. Studies on the impact of hydraulic cockle dredging on intertidal sediment flat communities. Report to the Nature Conservancy Council, Field Studies Council Research Centre, Pembroke, Report FSA/RC/4/91.

Perkins, E.J., 1988. The impact of suction dredging upon the population of cockles in Auchencairn Bay, 1988. Report to the Nature Conservancy Council, South-west Region, Scotland, NC 232 I, Solmaris.

Piersma, T., Koolhaas, A., Dekinga, A., Beukema, J. J., Dekker, R. and Essink, K., 2001. Long-term indirect effects of mechanical cockle-dredging on intertidal bivalve stocks in the Wadden Sea. Journal of Applied Ecology, 38, 976-990.

Rees, E.I.S., 1996. Environmental effects of mechanised cockle fisheries: a review of research data. Report to MAFF Marine Environmental Protection Division, 41 pp.

Sciberras, M., Hiddink, J.G., Jennings, S., Szostek, C., Hughes, K.M., Kneafsey, B., Clarke, L.J., Ellis, N., Rijnsdorp, A.D., McConnaughey, R.A., Hilborn, R., Collies, J.S., Pitcher, R., Amoroso, R.O., Parma, A.M., Suuronen, P. and Kaiser, M.J., 2018. Response of benthic fauna to experimental bottom fishing: A global meta-analysis. Fish and fisheries, 19, 698-715.

Sciberras, M., Hinz, H., Bennell, J. D., Jenkins, S. R., Hawkins, S. J., and Kaiser, M. J., 2013. Benthic community response to a scallop dredging closure within a dynamic seabed habitat. Marine Ecology Progress Series, 480, 83–98.

Sebastian, S., Pears, S. & Worsfold, T.M., 2012. Changes to the benthos following experimental suction dredging at Wrangle Sand, The Wash in September 2011. Unicomarine Report ESFWASH11 to Natural England and the Eastern Inshore Fishery and Conservation Authority, March 2012.

Stewart, G. B., Kaiser, M. J., Côté, I. M., Halpern, B. S., Lester, S. E., Bayliss, H. R., and Pullin, A. S., 2009. Evaluating the effectiveness of temperate marine reserves exposes critical knowledge gaps. Conservation Letters, 2, 243–253.

Stoutt, J.C., 2008. A review of the commercial suction dredge fishery in The Wash and North Norfolk Coast European Marine Site and the relationship between shell damage, discard mortality and gear type. M.Sc. Thesis, University of Hull.

Szostek, C.L., Hiddink, J.G., Sciberras, M., Caveen, A., Lart, W., Rodmell, D. and Kaiser, M.J., 2017. Tools to estimate fishing gear penetration depth and benthic habitat impacts of fisheries at a regional scale. Fisheries & Conservation report no. 68, Bangor University, pp. 87.

Tillin, H.M. and Tyler-Walters, H., 2016. [*Cerastoderma edule*] and polychaetes in littoral muddy sand. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: http://www.marlin.ac.uk/habitat/detail/206 [Accessed 6th August 2018].

Tyler-Walters, H., 2007. *Cerastoderma edule* Common cockle. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United

Kingdom. Available from: https://www.marlin.ac.uk/species/detail/1384 [Accessed 6th August 2018].

vab Stralen, M.R., 2007. A review of the third draft of the Eastern Sea Fisheries Joint Committee cockle and mussel policy. MarinX report.

Wiggins, J., 1991. Survival of cockles rejected by cockle dredgers. Kent & Essex Sea Fisheries Committee, unpublished report.

Wijnhoven, S., Escaravage, V., Herman, P.M.J., Smaal, A.C. and Hummel, H., 2011. Short and mid-long term effects of cockle-dredging on non-target macrobenthic species: a before-after-control-impact experiment on a tidal mudflat in the Oosterschelde (The Netherlands). Marine Ecology, 32(1) 117-129.

Yates, M. G., Goss-Custard, J.D., McGrorty, S., Lakhani, K.H., Le V. Dit Durell, S.E.A., Clarke, R.T., Rispin, W.E., Moy, I., Yates, T., Plant, R.A., and Frost, A.J., 1993. Sediment Characteristics, Invertebrate Densities and Shorebird Densities on the Inner Banks of the Wash. Journal of Applied Ecology, 30(4), 599-614.

Yates, M.G., Garbutt, R.A., Barratt, D.R., Turk, A., Brown, N.J., Rispin, W.E., McGrorty, S., le Vdit Durell, S.E.A., Goss-Custard, J.D., Murray, E. and Russell, D., 2002. Littoral sediments of the Wash and North Norfolk Coast SAC: The 1998 and 1999 surveys of intertidal sediment and invertebrates. English Nature Research Reports, No. 470.

Zwarts, L., Dubbeldam, W., Essink, K., van de Heuvel, H., van de Laar, E., Menke, U., Hazelhoff, L., & Smit, C. J., 2004. Bodemgesteldheid en mechanische kokkelvisserij in de Waddenzee. RIZA rapport. RIZA, Lelystad.

Appendices

Appendix 1: WFO regulated fishery draft management measures (taken from the draft management plan)

The following tables describe the management measures for the Wash Fishery Order 1992 cockle fishery. These have been grouped topically into technical measures, cockle stock sustainability measures, environmental conservation measures, measures for assessing stocks and monitoring fishery and additional measures that are specific for managing dredge fisheries.

TECHNICAL MEASURES	
Maximum vessel length	No vessel over 14m in length can participate in the Regulated cockle fisheries, unless subject to a derogation.
Approved design of fishing gear	All equipment used in the fishery must be of a design approved by the Authority.
Limiting vessels to a single method of fishing	Only one fishery (either dredged or hand worked) may be targeted by a fishing vessel in one calendar day. No hydraulic suction dredging equipment shall be on board any vessel participating in the hand worked cockle fishery.
Limiting vessels to a single fishery	Vessels must not fish cockles from within the Regulated fishery on the same calendar day that they have fished other species from within the Regulated fishery or fished cockles from outside of the Regulated fishery.
Requirement for IVMS	Vessels participating in the Wash Regulated cockle fisheries must have an Inshore Vessel Monitoring System of an approved design on board and working.
Limited licence entitlement	The Authority may limit the maximum number of entitlements to a Wash Fishery Order licence, which is required to fish the Regulated cockle fishery. The Order stipulates the conditions under which entitlement holders may purchase a dredging or hand worked licence.

COCKLE STOCK SUSTAINABILITY MEASURES	
Minimum landing size for cockles	There is no legal minimum landing size stipulated for cockles fished from The Wash. However, the Authority's management measures are based on a differentiation between "juvenile" and "adult" cockles, the latter having achieved a minimum size of 14mm width (approx. 19-21mm length).
Selection of cockle beds to be opened to the fishery to protect Yr-0 juvenile cockles and/or to reduce in-combination impacts from predicted mortalities.	Areas supporting high densities (>1,000/m^2) of Year-0 juvenile cockles will remain closed to cockle fisheries unless EIFCA survey data shows it would be more beneficial to open them (eg. widespread ridging-out is predicted). On occasions, when cockle mortality is predicted to be high on specific beds, fishers may be directed to harvest these stocks in preference to other beds to reduce potential in-combination effects the mortalities would otherwise cause. Prior to the opening of the fishery, the Authority will provide Entitlement holders with charts showing areas that are open and closed to the fishery.
Protection of juvenile cockles	When Year-0 juvenile cockles are present in significant densities on a bed being fished, fishermen must use either a cockle net or a riddle to allow these juveniles to be discarded. Stocks containing Year-0 cockles must not be shovelled directly into bulk bags without being riddled.
Minimum total stock biomass	It is one of the site's Conservation Objectives targets to achieve a minimum total cockle stock of 11,000 tonnes in The Wash (including le Strange) at the time of the Authority's annual spring stock surveys and prior to the opening of the public fishery. A fishery can proceed below the Conservation Objective stated level, provided the Authority's annual cockle survey demonstrates that the proposed fishery will not prevent stocks returning to the minimum level as assessed by the following year's stock assessment. This can be demonstrated by providing information on recent trends in spatfall and recruitment to the cockle stock (analysis of size class distribution of stock), related to recent fishing activities (and other activities that may reduce stock levels – through the in-combination assessment). Overall, the site will be in favourable condition for this attribute if the 6-year mean achieves or exceeds 11,000t total stock.
Minimum spawning stock biomass	The fishery will not be opened unless a minimum of 3,000 tonnes "adult" cockle (≥14mm width) is identified in the Authority's surveys.

Minimum shellfish biomass threshold	The fishery will not be permitted to reduce the combined mussel and cockle stocks below a minimum threshold calculated to support the over-wintering oystercatcher population (as defined in the Conservation Objective targets). See Appendix 1 for details.
Total Allowable Catch (TAC) quota	Provided the stocks do not go below the various thresholds stated in the plan, the baseline annual quota (TAC) for the intertidal cockle fishery can be up to 33.3% of the total adult cockle stock (≥14mm width) identified in the Authority's surveys. See Appendix 2 for details. Where there is evidence from the Authority's spring surveys or on-going monitoring of the beds predicting large-scale mortalities are imminent or predicted to cause long-term problems, at the Authority's discretion the TAC may be increased or stocks on specific beds ring-fenced outside of the TAC in order to harvest cockles that are expected to die. See Appendix 3 for details.
Daily vessel quota for hand-worked fishery	Vessels participating in the hand-worked fishery may fish for, take or remove from the Regulated fishery a maximum of two tonnes of cockles in any one calendar day. The daily quotas may be increased at the Authority's discretion if the annual quota is too large to achieve during the course of a normal fishing season or scientific advice predicts widespread mortalities will occur before the TAC is achieved.

ENVIRONMENTAL CONSERVATION MEASURES	
Habitats Regulation Assessment of cockle fishery proposals	Proposed hand-worked cockle fisheries are subject to a detailed Long Term (25 years) Habitats Regulation Assessments by EIFCA, under advice from Natural England, to ascertain their likely impact on conservation features of The Wash and North Norfolk Coast European Marine Site (EMS).
Protection of seal haul-out sites during sensitive periods	Seals are particularly sensitive to human disturbance during periods in which they are pupping, moulting and breeding. Cockle fisheries will not be opened within 600m of seal haul-out sites during these periods, unless there is a ridge on the sand that prevents the fishing activity from being seen from the haul-out site. The Authority will provide charts showing closed areas around haul-out sites prior to the fishery starting. Best available and most up to date data – such as that provided by the provided by the Sea Mammal Research Unit - shall be used to identify the location of seal haul-out sites.
Buffer zone around mussel beds	Cockle fisheries will not occur within the boundaries of identified mussel beds. Prior to the start of the fishery, the Authority will provide entitlement holders with charts showing the positions of mussel beds and potential buffer zones around them.
Prohibition of "blowing out"	Fishermen participating in the hand-worked cockle fishery generally prepare the ground they are going to fish by disturbing the sediment with the wash from their propellers prior to drying out. The practice known as "blowing out", whereby vessels are anchored to the seabed while circling in concentric rings is prohibited.
"Prop-washing" limitations	"Prop-washing", whereby the vessel is manoeuvred in circles without being anchored, is allowed if conducted in a responsible manner. Fishermen conducting "prop-washing" activities must follow the guidance provided in the Code of Best Practice as agreed with Natural England. Only one ring may be created by a vessel each day and care should be taken to avoid unnecessary disturbance of the seabed. To facilitate circling, a single 1-tonne bag may be suspended in the water column while conducting "prop-washing".
Spreading unharvested cockles	Any unharvested cockles that remain piled within the "prop-wash" rings after the daily quota has been achieved must be spread out to prevent them from smothering.

Protection of seabed habitats from vessels	Cockle fishers must minimise the disturbance they cause to the seabed with their keels when steaming on/off the cockle beds, while "prop-washing" and when laying on the sands. After fishing, fishermen must ensure their vessels are properly afloat before attempting to steam off the sands.
Closure of fishery if fishing activity is found to be damaging	The Chief Executive Officer or their nominated deputy can close the cockle fishery if it is found that fishing activities are damaging the site.
Limiting duration of fishery by using specified opening date/stated days	The level of disturbance created by the hand-worked cockle fishery is not thought sufficient to require a short-term recovery. As such the hand-worked fishery could potentially operate seven days per week. Usually, however, due to industry preference this fishery operates 4 days/week. The preference is for the fishery to occur on week days, but also to include consideration for tidal heights and times. The fishery is only opened on days when the tide exceeds 6.2m height.

MEASURES FOR ASSESSING STOCKS AND MONITORING FISHERIES	
Extensive cockle stock assessment surveys	The Authority conducts extensive surveys in spring to evaluate the distribution, abundance and stock composition characteristics of the Wash cockle population prior to the fishing season. This enables the total fishable stock to be quantified, suitable fishing areas to be identified and spatfall and recruitment levels to be assessed. Survey data can also be analysed to determine mortality, although it may be difficult to separate fishery-associated mortality from natural mortality.
Monitoring of sediment characteristics within cockle beds	The Authority collects some additional environmental data during the cockle surveys. At each survey station an assessment of the sediment type is recorded, from which sediment charts can be produced. The presence of two indicator species *Macoma balthica* (Baltic tellin) and *Lanice conchigela* (Sand mason) are recorded.
On-going monitoring of cockle stocks	EIFCA officers monitor the cockle beds during the fishery to identify any environmental factors that might require a change to the management measures in place for the fishery.
Monitoring and enforcement of quota	EIFCOs conduct frequent quayside inspections to inspect and record cockle landings. Licence holders are also required to provide weekly catch returns detailing their activities and catch.
Monitoring and enforcement of fishing activities	IFCOs conduct monitoring at sea to ensure the fishing activities are being conducted in a compliant manner and are not causing excessive disturbance to the site features. IVMS data from vessels participating in the cockle fishery is monitored.

ADDITIONAL SPECIFIC MEASURES FOR MANAGING DREDGE FISHERIES	
Occurrence of dredge fisheries	By default, cockle fisheries will be hand-worked. Dredge fisheries will only occur in exceptional circumstances that indicate that it is necessary to optimise the socio-economic benefits of the fishery. The decision to authorise a dredge fishery will be at the discretion of the Authority.
Maximum dredge head width	Hydraulic suction dredge head inside opening (horizontal) must not exceed 76cm.
Maximum number of dredges	No vessel may deploy more than one dredge when engaged in cockle fishing.
Smash rate limit	Studies have found that very few discarded cockles survive if they have been visibly damaged. No more than 10% (by weight) of cockles may be visibly damaged during the dredge fishing operation. A Certificate of Approval, issued by the Authority, is required by each vessel wishing to participate in the dredge fishery, and can only be issued once that vessel has demonstrated a breakage rate of <10%.
Mandatory riddling of catch *in situ*	Cockles fished by dredge must be riddled where they are fished, to return juvenile and small adult cockles to the substratum. ESFJC research demonstrated that a high proportion of undersized cockles returned to the sea will survive and re-enter the cockle population.
Specified bar spacing	The bar spacing on the riddle and dredge head will be specified by the Authority. ESFJC discard studies found cockles <12mm survive significantly better than larger cockles but do still have associated mortality. Cockles discarded from the dredge head were found to have significantly improved survival rates to those discarded from the riddle. Bar spacing for riddles will usually be 12mm, but may be increased if local stock composition characteristics indicate this will be beneficial to the fishery. Bar spacing on dredge heads may be up to 14mm
Allocation of Total Allowable Catch (TAC) quota between fisheries	In the case that a dredge fishery is to occur, the annual quota (TAC) will be sub-divided into separate allocations for the dredged and hand worked fisheries prior to either fishery opening. Allocations will be determined at the Authority's discretion according to stock and socio-economic conditions following consultation with Entitlement holders.
Habitats Regulation Assessment of cockle fishery proposals	Proposed dredged cockle fisheries will be subject to detailed Habitats Regulation Assessments by EIFCA, under advice from Natural England, to ascertain their likely impact on conservation features of The Wash and North Norfolk Coast European Marine Site (EMS).
Buffer zone around mussel beds	Dredge cockle fisheries will not occur within 100m of the boundaries of identified mussel beds. Prior to the start of the fishery, the Authority will provide entitlement holders with charts showing the positions of mussel beds and the buffer zones around them.
Protection of seabed habitats from hydraulic suction dredges	Hydraulic suction dredge fisheries will only be allowed to take place on beds where the survey data has identified the sediment across the area of the bed is predominantly mobile sands.

Limiting duration of fishery by using specified opening date/stated days	To provide periods in which the cockle stocks and site features can gain short-term recovery from fishing disturbance, the dredged cockle fishery is limited to four days per week, from an agreed opening date.
Selection of cockle beds to be opened to the fishery to protect small (<14mm width) cockles	To protect small cockles, dredge fisheries may only operate on beds that contain at least 70% (by weight) "adult" (≥14mm width) stock. Areas supporting high densities (>1,000/m^2) of Yr-0 juvenile cockles will remain closed The Authority will provide Entitlement holders with charts showing areas that are open and closed to the fishery.
Daily vessel quota for dredge fishery	In any one calendar day, a vessel may fish for, take or remove from the Regulated fishery a maximum of four tonnes of cockles per vessel if participating in the dredged fishery. The daily quotas may be increased at the Authority's discretion if the annual quota is too large to achieve during the course of a normal fishing season or scientific advice predicts widespread mortalities will occur before the TAC is achieved.

Appendix 2: List of site features and sub-features for each designation within the Wash and North Norfolk Coast European Marine Site (EMS), as per Natural England Conservation Advice package[18]

Orange - intertidal and saltmarsh features
Blue - subtidal features
Green – terrestrial features

EMS Designation	Feature	Sub-feature(s)
Wash and North Norfolk Coast SAC	Sandbanks which are slightly covered by sea water all the time	Subtidal mixed sediments
		Subtidal coarse sediments
		Subtidal sand
		Subtidal mud
	Mudflats and sandflats not covered by seawater at low tide	Intertidal coarse sediments
		Intertidal mixed sediments*
		Intertidal mud
		Intertidal sand and muddy sand
		Intertidal seagrass beds
	Coastal lagoons	
	Large shallow inlets and bays	Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)
		Circalittoral rock
		Intertidal biogenic reef: mussel beds
		Intertidal biogenic reef: *Sabellaria* spp.[19]*
		Intertidal coarse sediment
		Intertidal mud
		Intertidal rock
		Intertidal sand and muddy sand
		Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*)

[18] https://designatedsites.naturalengland.org.uk/ (Accessed 12/07/2018)

[19] * Intertidal mixed sediments and intertidal biogenic reef: *Sabellaria* spp. were not included in the habitat extent data provided to EIFCA by Natural England (August 2017). However, NE clarified that the features are present in the site but their extent is not mapped.

		Subtidal biogenic reefs: mussel beds
		Subtidal biogenic reefs: *Sabellaria* spp.
		Subtidal coarse sediment
		Subtidal mixed sediments
		Subtidal mud
		Subtidal sand
		Subtidal stony reef
	Reefs	Circalittoral rock
		Intertidal biogenic reef: mussel beds
		Intertidal biogenic reef: *Sabellaria* spp.[2]*
		Intertidal rock
		Subtidal biogenic reef: mussel beds
		Subtidal biogenic reef: *Sabellaria* spp.
		Subtidal stony reef
	Salicornia and other annuals colonising mud and sand	
	Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)	
	Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*)	
	Otter (*Lutra lutra*)	
	Harbour (common) seal (*Phoca vitulina*)	
The Wash SPA	Bar-tailed godwit (Limosa lapponica), Non-breeding	
	Bewick's swan (Cygnus columbianus bewickii), Non-breeding	
	Black-tailed godwit (Limosa limosa islandica), Non-breeding	
	Common scoter (Melanitta nigra), Non-breeding	
	Common tern (Sterna hirundo), Breeding	
	Curlew (Numenius arquata), Non-breeding	
	Dark-bellied brent goose (Branta bernicla bernicla), Non-breeding	
	Dunlin (Calidris alpina alpina), Non-breeding	
	Gadwall (Anas strepera), Non-breeding	
	Goldeneye (Bucephala clangula), Non-breeding	

	Grey plover (Pluvialis squatarola), Non-breeding
	Knot (Calidris canutus), Non-breeding
	Little tern (Sternula albifrons), Breeding
	Oystercatcher (Haematopus ostralegus), Non-breeding
	Pink-footed goose (Anser brachyrhynchus), Non-breeding
	Pintail (Anas acuta), Non-breeding
	Redshank (Tringa totanus), Non-breeding
	Sanderling (Calidris alba), Non-breeding
	Shelduck (Tadorna tadorna), Non-breeding
	Turnstone (Arenaria interpres), Non-breeding
	Waterbird assemblage, Non-breeding
	Wigeon (Anas penelope), Non-breeding
The Wash SSSI	Coastal saltmarsh
	Saline lagoon
	Vegetated shingle
	Littoral sediment
	Sub-littoral sands and gravels
	Sabellaria reefs
	Supralittoral sediment
The Wash NNR	Breeding bird assemblage
	Coastal saltmarsh
	Common seal
	Demonstration
	Economic Use
	Estate Assets
	Invertebrate assemblage
	Landscape
	Plant assemblage
	Public Access

	Sand/mudflats
	Wintering passage birds
The Wash Ramsar	No features listed – covered under other designations

Appendix 3: Advice on Operations: Hydraulic dredges – The Wash and North Norfolk Coast SAC [20]

Viewing Advice on Operations for: Hydraulic dredges

	Annex I habitat																																				Annex II species							
					LSIB																Mud flats and sand flats					Reefs							Sand banks					Harbour seal						
																																							Sup hab					
Pressure Name	Coastal lagoons	Mediterranean and thermo-Atlantic halophilous scrubs	Salicornia and other annuals colonising mud and sand	Atlantic salt meadows	Mediterranean and thermo-Atlantic halophilous scrubs	Atlantic salt meadows	Intertidal rock	Intertidal biogenic reef: mussel beds	Intertidal biogenic reef: Sabellaria spp.	Intertidal coarse sediment	Intertidal mud	Intertidal sand and muddy sand	Subtidal biogenic reefs: Sabellaria spp.	Subtidal stony reef	Subtidal biogenic reefs: mussel beds	Subtidal coarse sediment	Subtidal mixed sediments	Subtidal mud	Subtidal sand	Circalittoral rock	Intertidal seagrass beds	Intertidal coarse sediment	Intertidal mixed sediments	Intertidal mud	Intertidal sand and muddy sand	Intertidal rock	Intertidal biogenic reef: mussel beds	Intertidal biogenic reef: Sabellaria spp.	Subtidal biogenic reefs: Sabellaria spp.	Subtidal stony reef	Subtidal biogenic reefs: mussel beds	Circalittoral rock	Subtidal coarse sediment	Subtidal mixed sediments	Subtidal mud	Subtidal sand	Otter	Harbour seal	Coastal lagoons	Intertidal coarse sediment	Intertidal mixed sediments	Intertidal mud	Intertidal sand and muddy sand	Water column
Abrasion/disturbance of the substrate on the surface of the seabed	S							S	S	S	S	S	S		S	S	S	S	S		S	S	S	S	S		S	S	S		S		S	S	S	S			S	S	S	S	S	
Changes in suspended solids (water clarity)	S						S*	NS	S	S	S	S	NS	S*	NS	S	NS	S	S	S*	S	S	NS	S	S	S*	NS	S	NS	S*	NS	S*	S	NS	S	S			S	S	NS	S	S	S
Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion	S							S	S	S	S	S	S		S	S	S	S	S		S	S	S	S	S		S	S	S		S		S	S	S	S			S	S	S	S	S	
Removal of non-target species	S		NS	S		S		S	S	S	S	S	S		S	S	S	S	S		S	S	S	S	S		S	S	S		S		S	S	S	S			S	S	S	S	S	S
Removal of target species								NA			NA	NA			S	NA	NA	NA	NA				NA	NA	NA		NA				S		NA	NA	NA	NA					NA	NA	NA	
Smothering and siltation rate changes (Light)	S						S*	S	NS	S	S	S	NS	S*	S	S	S	S	S	S*	S	S	S	S	S	S*	S	NS	NS	S*	S	S*	S	S	S	S			S	S	S	S	S	
Visual disturbance										NS		NS				NS		NS	NS			NS			NS								NS		NS	NS				NS			NS	S
Deoxygenation	S		NS	NS		NS		NS	S	NS	NS	S	IE		NS	S	S	S	S		NS	NS	NS	NS	S		NS	S	IE		NS		S	S	S	S			S	NS	NS	NS	S	S
Hydrocarbon & PAH contamination	NS		NS	NS		NS		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS		NS	NS	NS	NS	NS		NS	NS	NS		NS		NS	NS	NS	NS			NS	NS	NS	NS	NS	S
Introduction of light	S							IE	IE	IE	NS	S			IE	IE	IE	NS	S		S	IE		NS	S		IE	IE			IE		IE	IE	NS	S			S	IE		NS	S	S
Introduction of microbial pathogens	IE		S	S		S		S	IE	IE	S	S	IE		S	S	IE	S	S		S	IE	NS	S	S		S	IE	IE		S		S	IE	S	S			IE	IE	NS	S	S	NS
Introduction or spread of invasive non-indigenous species (INIS)	S							S	S	NS	S	S	NS		S	S	S	S	S		S	NS	S	S	S		S	S	NS		S		S	S	S	S			S	NS	S	S	S	S
Litter	NA		S	S		S		NA	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA		NA	NA	NA	NA	NA		NA	NA	NA		NA		NA	NA	NA	NA			NA	NA	NA	NA	NA	S
Nutrient enrichment	NS		NS	NS		NS		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS		S	NS	NS	NS	NS		NS	NS	NS		NS		NS	NS	NS	NS			NS	NS	NS	NS	NS	S
Organic enrichment	S		NS	NS		NS		NS	NS	NS	NS	NS	NS		NS	IE	IE	S	S		S	NS	NS	NS	NS		NS	NS	NS		NS		IE	IE	S	S			S	NS	NS	NS	NS	S
Physical change (to another sediment type)	S		S					NS		S	S	S	S		S	S	S	S	S		S	S	S	S	S		NS		S		S		S	S	S	S			S	S	S	S	S	
Synthetic compound contamination (incl. pesticides, antifoulants, pharmaceuticals)	NS		NS	NS		NS		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS		NS	NS	NS	NS	NS		NS	NS	NS		NS		NS	NS	NS	NS			NS	NS	NS	NS	NS	S
Transition elements & organo-metal (e.g. TBT) contamination	NS		NS	NS		NS		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS		NS	NS	NS	NS	NS		NS	NS	NS		NS		NS	NS	NS	NS			NS	NS	NS	NS	NS	S
Underwater noise changes																	NS		NS															NS		NS								S

[20]https://designatedsites.naturalengland.org.uk/Marine/FAPMatrix.aspx?SiteCode=UK0017075&SiteName=wash+&SiteNameDisplay=The+Wash+and+North+Norfolk+Coast+SAC&countyCode=&responsiblePerson=&SeaArea=&IFCAArea= (Accesses 12/07/2018)

Advice on Operations: Hydraulic dredges – The Wash SPA [21]

Viewing Advice on Operations for: Dredges

Bird

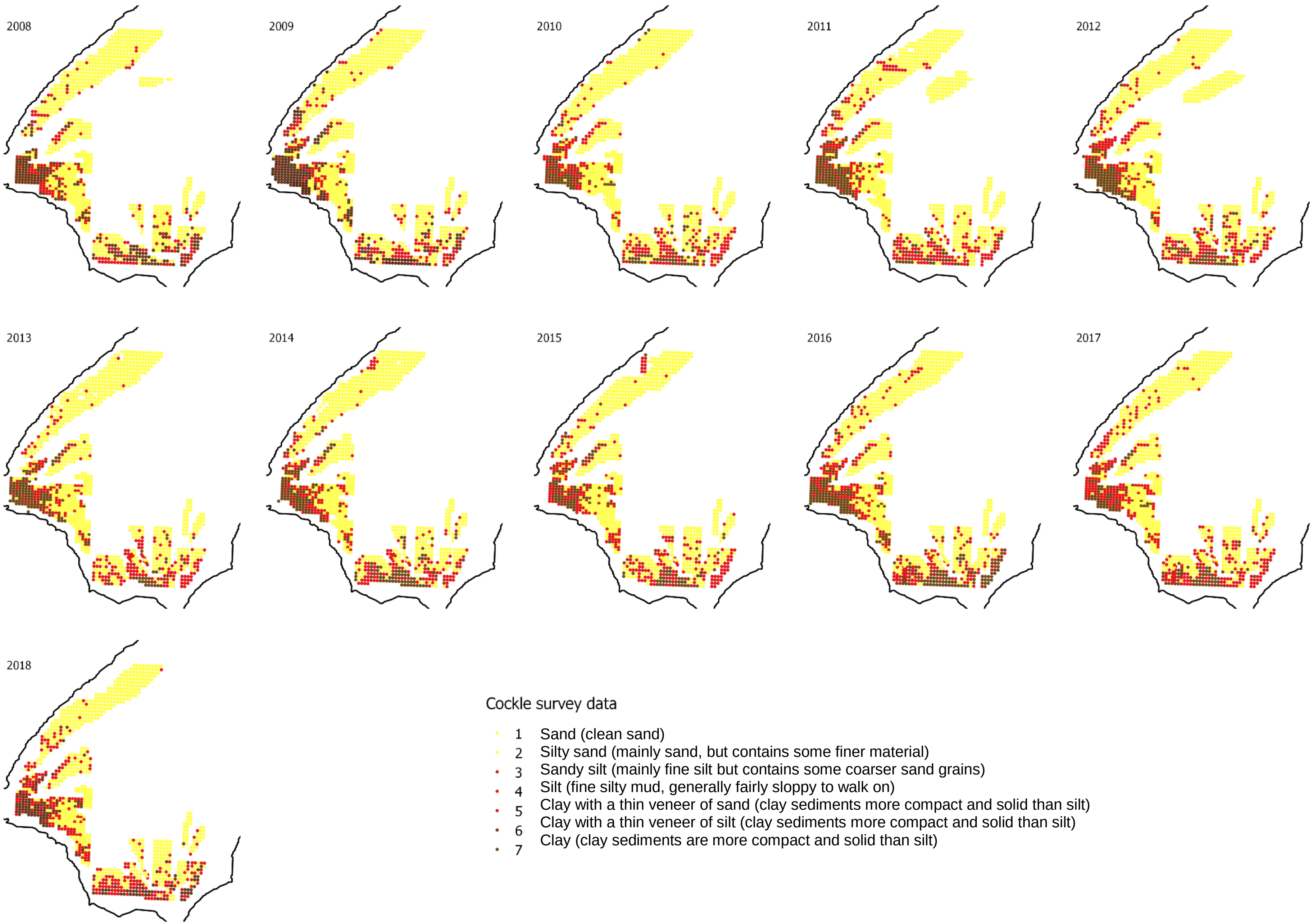
Pressure Name	Bar-tailed godwit, Non-breeding	Bewick's swan, Non-breeding	Black-tailed godwit, Non-breeding	Common scoter, Non-breeding	Common tern, Breeding	Curlew, Non-breeding	Dark-bellied brent goose, Non-breeding	Dunlin, Non-breeding	Gadwall, Non-breeding	Goldeneye, Non-breeding	Grey plover, Non-breeding	Knot, Non-breeding	Little tern, Breeding	Oystercatcher, Non-breeding	Pink-footed goose, Non-breeding	Pintail, Non-breeding	Redshank, Non-breeding	Sanderling, Non-breeding	Shelduck, Non-breeding	Turnstone, Non-breeding	Wigeon, Non-breeding
Abrasion/disturbance of the substrate on the surface of the seabed																					
Changes in suspended solids (water clarity)				IE	S				NS	IE			S								
Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion																					
Removal of non-target species																					
Removal of target species																					
Smothering and siltation rate changes (Light)																					
Visual disturbance	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Above water noise	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Collision ABOVE water with static or moving objects not naturally found in the marine environment (e.g., boats, machinery, and structures)	S	S	S	S	S	NS	S	S	S	S	S	S	S	S	S	NS	S	S	S	S	S
Collision BELOW water with static or moving objects not naturally found in the marine environment				S	S				NS	S			S								
Deoxygenation																					
Hydrocarbon & PAH contamination	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
Introduction of light	S	S	S	S	IE	S	S	S	IE	S	S	S	IE	S	S	S	S	S	S	S	S
Introduction of microbial pathogens	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Introduction or spread of invasive non-indigenous species (INIS)	NS	IE	S	NS	S	NS	IE	S	NS	NS	S	S	S	S	IE	S	S	NS	S	NS	IE
Litter	IE	IE	IE	S	S	IE	IE	IE	S	S	IE	IE	S	IE	IE	IE	IE	IE	IE	IE	IE
Nutrient enrichment																					
Organic enrichment																					
Physical change (to another seabed type)																					
Physical change (to another sediment type)																					
Synthetic compound contamination (incl. pesticides, antifoulants, pharmaceuticals)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
Transition elements & organo-metal (e.g. TBT) contamination	S	S	S	IE	IE	NS	S	S	IE	IE	S	S	IE	S	S	S	S	S	S	S	S
Underwater noise changes		IE		NS	IE		IE		IE	NS			IE		IE	IE			IE		IE

Supporting habitat

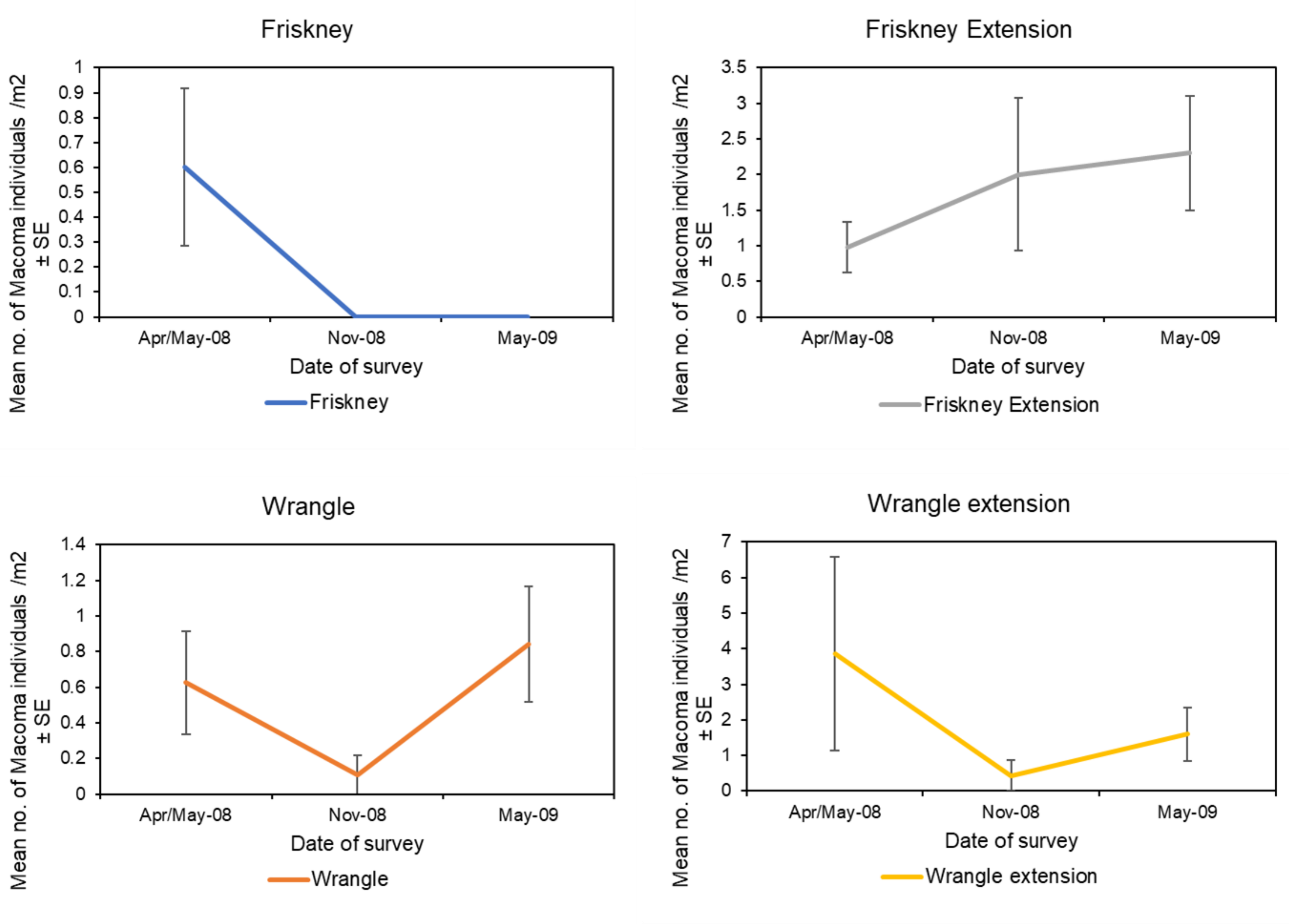
Pressure Name	Coastal lagoons	Coastal reedbeds	Freshwater and coastal grazing marsh	Mediterranean and thermo-Atlantic halophilous scrubs	Salicornia and other annuals colonising mud and sand	Atlantic salt meadows	Intertidal rock	Intertidal stony reef	Intertidal biogenic reef: mussel beds	Intertidal coarse sediment	Intertidal mixed sediments	Intertidal mud	Intertidal sand and muddy sand	Subtidal biogenic reefs: Sabellaria spp.	Subtidal stony reef	Subtidal biogenic reefs: mussel beds	Subtidal coarse sediment	Subtidal mixed sediments	Subtidal mud	Subtidal sand	Circalittoral rock	Water column
Abrasion/disturbance of the substrate on the surface of the seabed	S						S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	
Changes in suspended solids (water clarity)	S						S	S	NS	S	NS	S	S	NS	S	NS	S	NS	S	S	S	S
Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion	S						S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	
Removal of non-target species	S				NS	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Removal of target species									S		NA	NA	NA			S	NA	NA	NA	NA	NA	
Smothering and siltation rate changes (Light)	S						S	S	S	S	S	S	S	NS	S	S	S	S	S	S	S	
Visual disturbance							NS			NS			NS		NS		NS		NS	NS	NS	S
Above water noise																						
Collision ABOVE water with static or moving objects not naturally found in the marine environment (e.g., boats, machinery, and structures)																						
Collision BELOW water with static or moving objects not naturally found in the marine environment																						
Deoxygenation	S				NS	NS	S	S	NS	NS	NS	NS	S	IE	S	NS	S	S	S	S	S	S
Hydrocarbon & PAH contamination	NS				NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	S
Introduction of light	S						S	S	IE	IE		NS	S		S	IE	IE	IE	NS	S	IE	S
Introduction of microbial pathogens	IE				S	S	S	S	S	IE	NS	S	S	IE	S	S	S	IE	S	S	S	NS
Introduction or spread of invasive non-indigenous species (INIS)	S						S	S	S	NS	S	S	S	NS	S	S	S	S	S	S	S	S
Litter	NA				S	S	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	S
Nutrient enrichment	NS				NS	NS	IE	NS	NS	NS	NS	NS	NS	NS	S	NS	NS	NS	NS	NS	NS	S
Organic enrichment	S				NS	NS	S	S	NS	NS	NS	NS	NS	NS	S	NS	IE	IE	S	S	S	S
Physical change (to another seabed type)							S	S							S						S	
Physical change (to another sediment type)	S				S				NS	S	S	S	S	S		S	S	S	S	S		
Synthetic compound contamination (incl. pesticides, antifoulants, pharmaceuticals)	NS				NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	S
Transition elements & organo-metal (e.g. TBT) contamination	NS				NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	S
Underwater noise changes							IE	IE							NS			NS		NS	NS	S

[21] https://designatedsites.naturalengland.org.uk/Marine/FAPMatrix.aspx?SiteCode=UK9008021&SiteName=wash+&SiteNameDisplay=The+Wash+SPA&countyCode=&responsiblePerson=&SeaArea=&IFCAArea= (Accesses 12/07/2018)

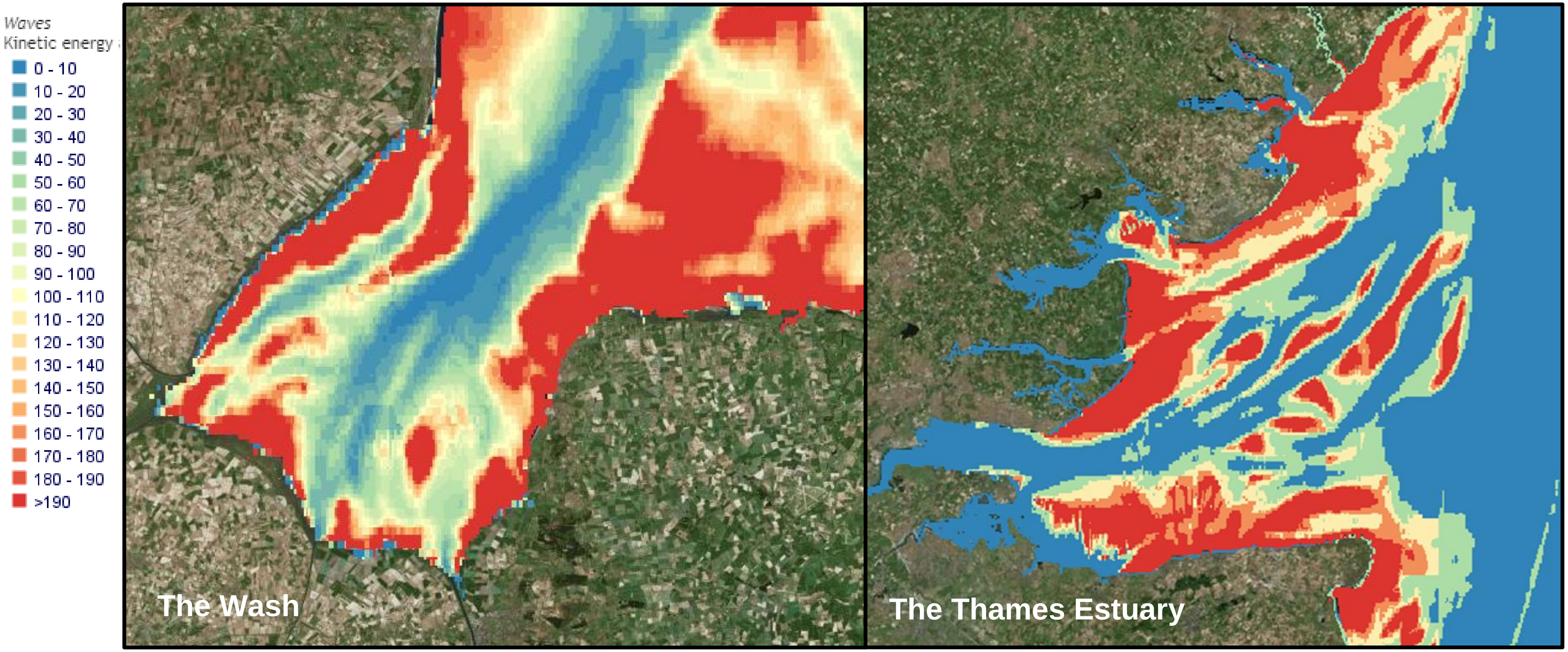
Appendix 4a: Variation in sediment data collected during the Eastern IFCA's annual cockle surveys between 2008 and 2018.



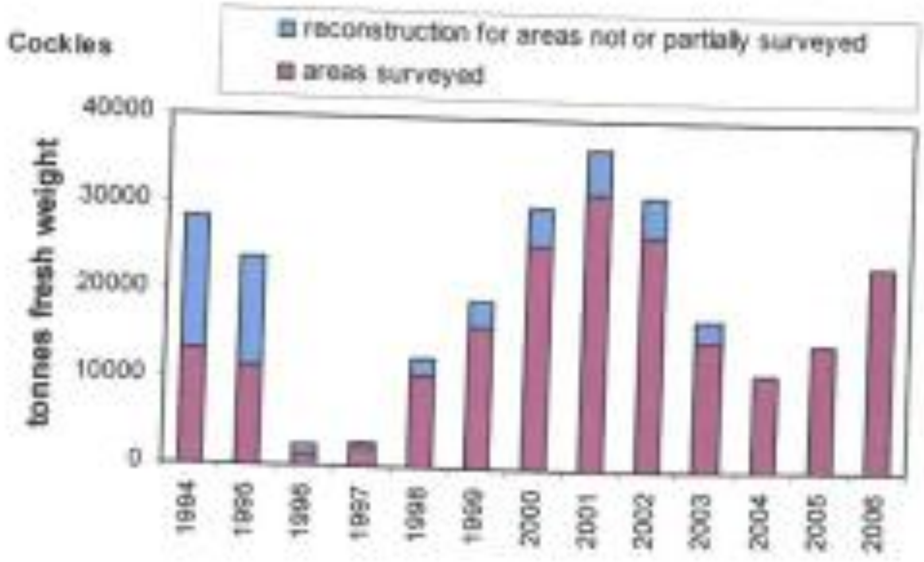
Appendix 4b: Average abundance of Macoma balthica/m^2 ± standard error (SE) across Wrangle and Friskney beds pre, and post, the dredge Fishery that occurred on Friskney bed in summer 2008. (NB. Samples sizes for beds are not the same across all years)



Appendix 5: Kinetic energy at the seabed due to waves in The Wash and Thames Estuary (taken from EMODnet Seabed Habitats Map viewer: http://www.emodnet-seabedhabitats.eu/access-data/launch-map-viewer/)



Appendix 6: Reconstruction of ESFJC cockle survey data for areas not surveyed in certain years prior to 2004 (taken from van Stralen, 2007). Annual cockle stock sizes in the Wash in tonnes fresh weight:



Appendix 7: The Wash annual spring cockle stock assessments (2004-2018)

Eastern IFCA (previously ESFJC) have conducted annual stock assessments of the Wash Fishery Order cockle beds since 1994 and hold detailed records of stock assessments on all beds going back to 2004. These records provide opportunity for further analysis of beds and effects alongside changes in fishing activity. Figure 1 shows the total cockle stock (tonnes) calculated following the annual surveys since 1994 and the allocated TAC for the dredge and hand-work fisheries after 1998 when the TAC was first introduced. Prior to this, stocks were heavily exploited in the 1990s following the introduction hydraulic suction dredges in 1986, eventually leading to a collapse in the fishery in 1996 (Figure 1). Although it appears there is annual variation in stocks with regular declines every 6-7 years, the general trend over the last 24-year period has shown a gradual increase since the 1990's, particularly over the last five years.

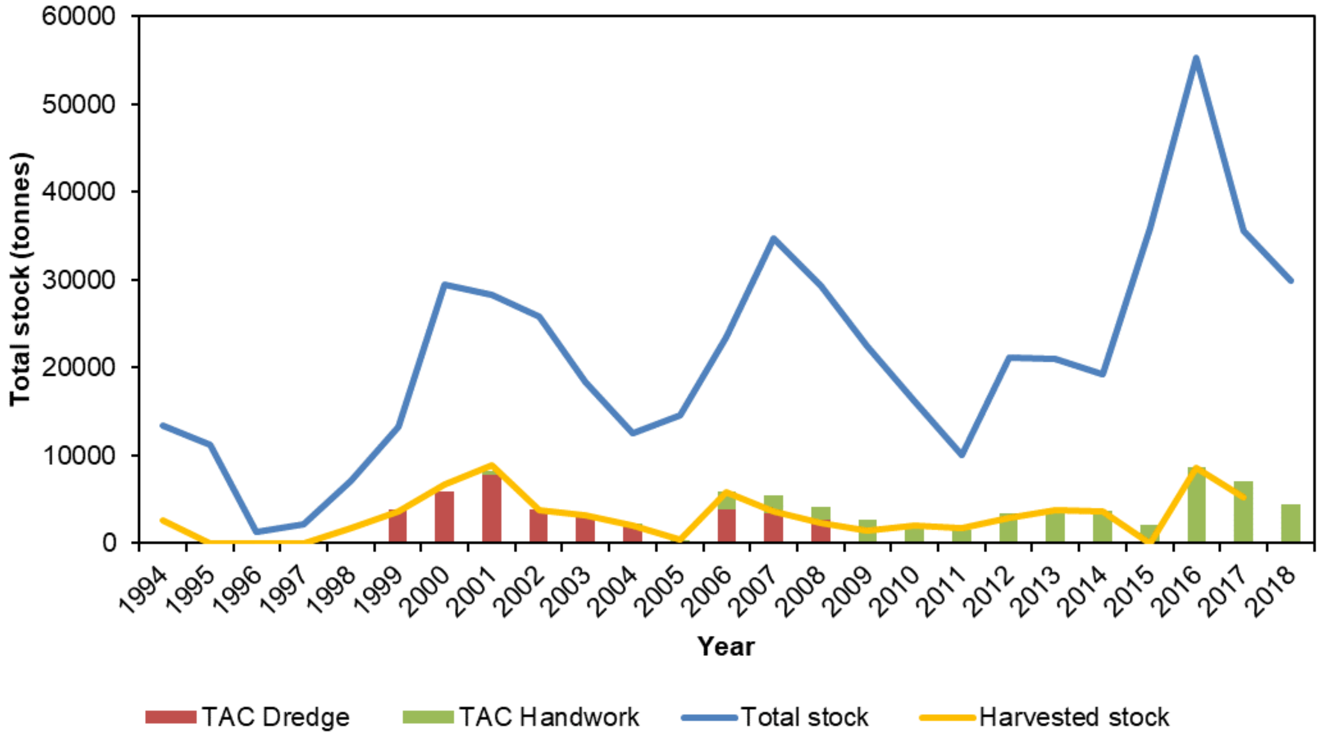


Figure 18 Annual total cockle stock (tonnes) across the Wash Fishery Order cockle beds (bed) and total harvested stock (tonnes) (yellow). Assessed during Eastern IFCA (previously ESFJC) annual cockle surveys. Bars indicate the yearly TAC allocated to the dredge (red) and hand-work (green) fisheries.

Since 2004, surveys have collected and reported on data for individual cockle beds (Figure 2) as well as the total stock. Detailed records of dredging intensity and spatial effort are not available for this period, however details of the beds that received the most fishery effort each year have been recorded and highlight four years of data where dredge fisheries have occurred across several of the beds (Table 1). Analysis of this data has provided an insight into the potential effects of dredging on stocks and the results have been presented in this appendix. For each bed the average density and average biomass of year-0 (green), juvenile (red) and adult (blue) cockles have been plotted. For those beds that have received dredging activity between 2004 and 2008 this has been indicated with an asterisk on plots.

Table 1 The Wash cockle beds where the majority of effort was targeted between 2001 and 2018 by the dredge and hand-work fishery. A dash denotes no fishery that year and a blank no records for that year.

Year	Main effort	
	Dredged	**Hand-worked**
2001	Boston Main, Tofts	
2002	Boston Main	
2003	Daseleys, Butterwick, Mare Tail	
2004	Holbeach, IWMK	All
2005	-	All (Wrangle and Roger)
2006	Friskney	All
2007	Holbeach, Daseley's	All except Roger and Mare Tail
2008	Friskney	All (IWMK, Wrangle, Butterwick)
2009	-	All (Black Buoy)
2010	-	All (Thief, Whiting Shoal, Breast, Herring Hill)
2011	-	All except Whiting Shoal (mainly Breast and Wrangle)
2012	-	All (Wrangle and Roger)
2013	-	All (Black Buoy and Daseley's)
2014	-	All (Gat, Daseley's, Breast, IWMK)
2015	-	All (Roger)
2016	-	Thief, Roger, Wrangle, Friskney
2107	-	All except Wrangle
2018	-	All

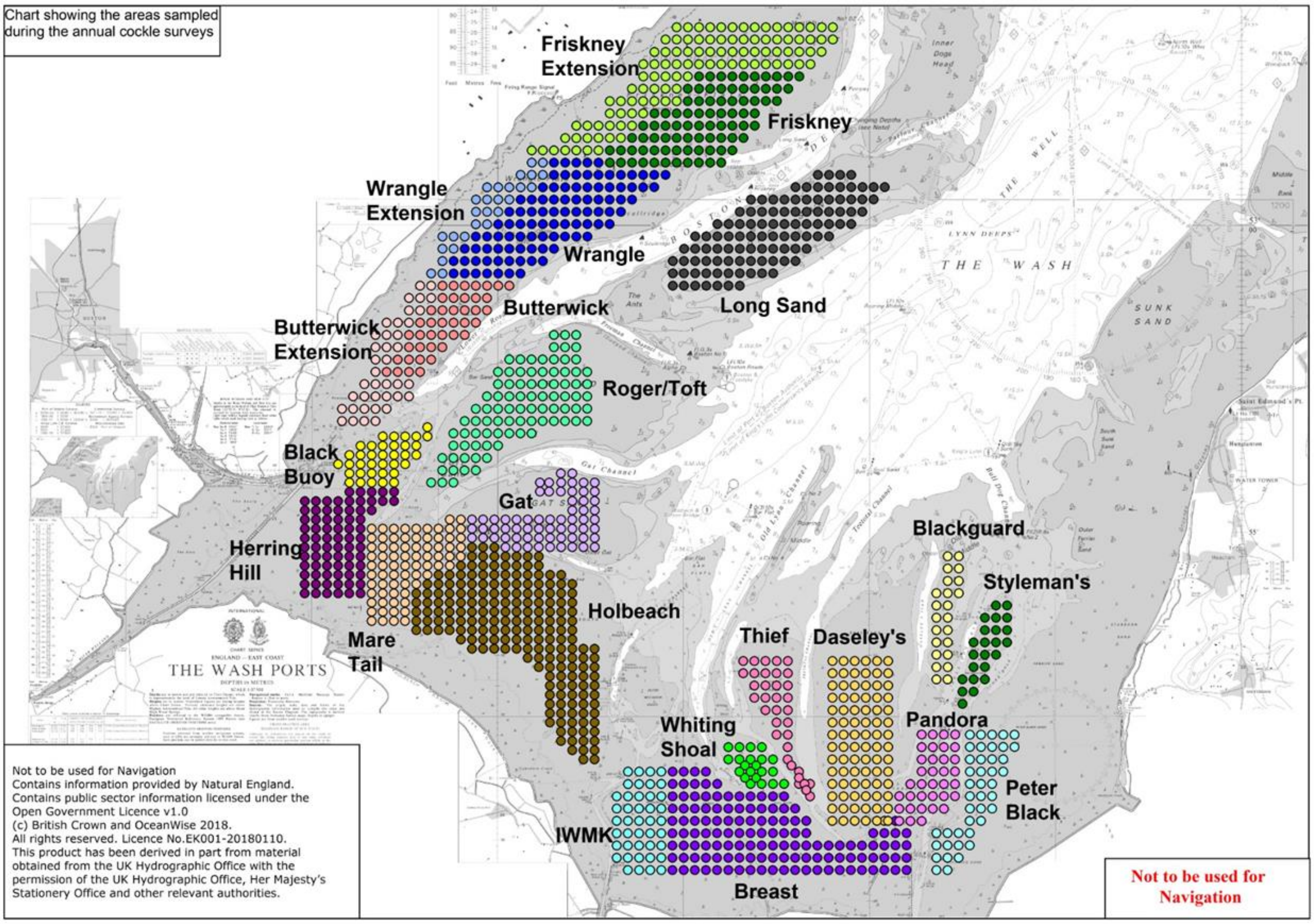


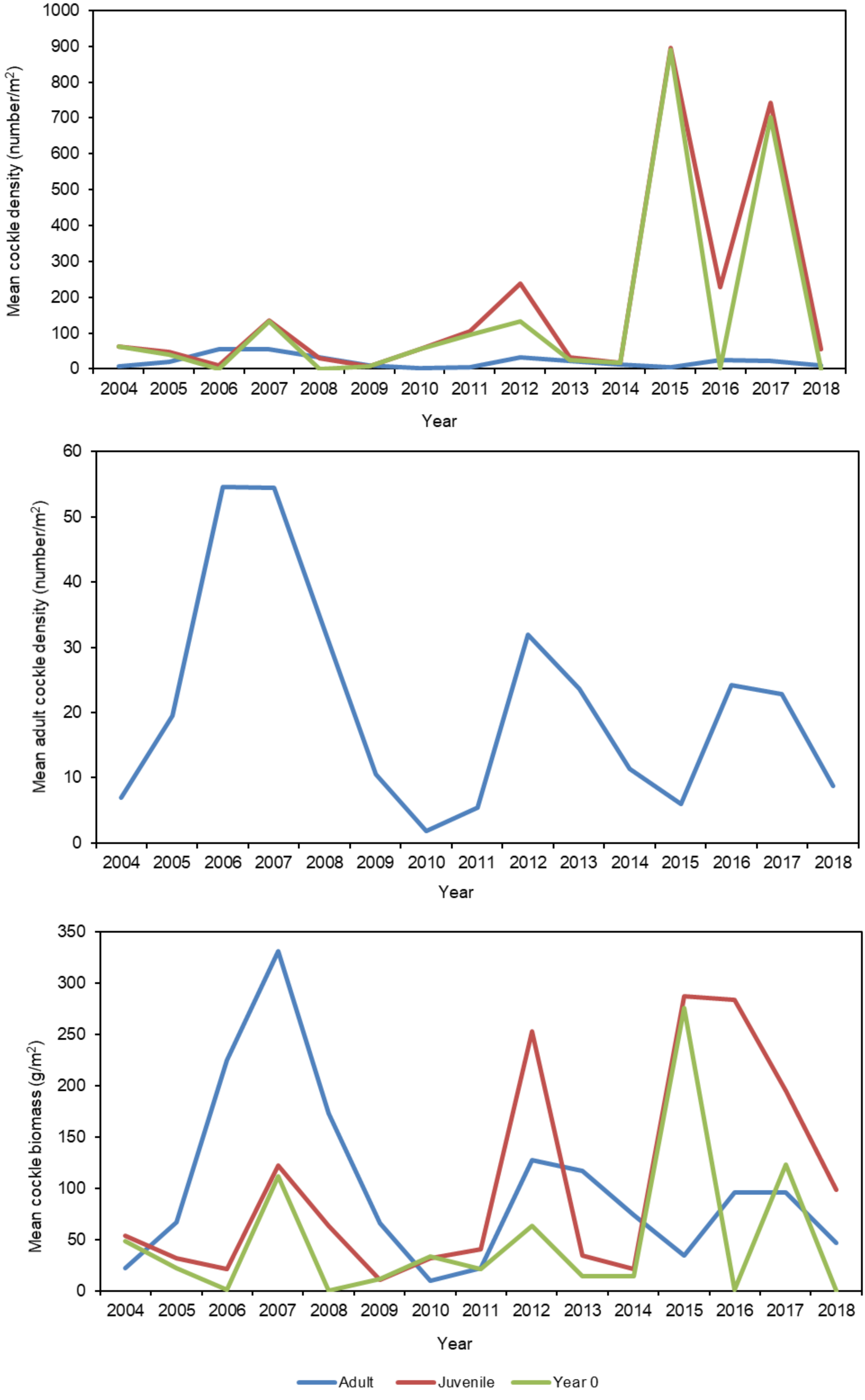
Figure 19 Distribution of annual spring WFO cockle survey sample stations across The Wash cockle beds within the WFO area of The Wash.

Boston Main

Butterwick

Butterwick lies south of Boston Main and is considered a relatively slow growing bed (Jessop *et al*., 2013). Spatfalls at Butterwick have been very low since 2004, up until recently where large densities of year-0 cockles and a higher biomass indicate large spatfalls in 2014 and 2016, similar to that observed across much of The Wash cockle beds. However, such large spatfalls do not appear to have resulted in an increase in the adult population on this bed.

Boston Main and Butterwick were targeted by the dredge fishery in 2001, 2002 and 2003, and have since been targeted by the hand-work fishery. However, as we do not have data for these years, it is not possible to identify any responses to this fishing pressure.

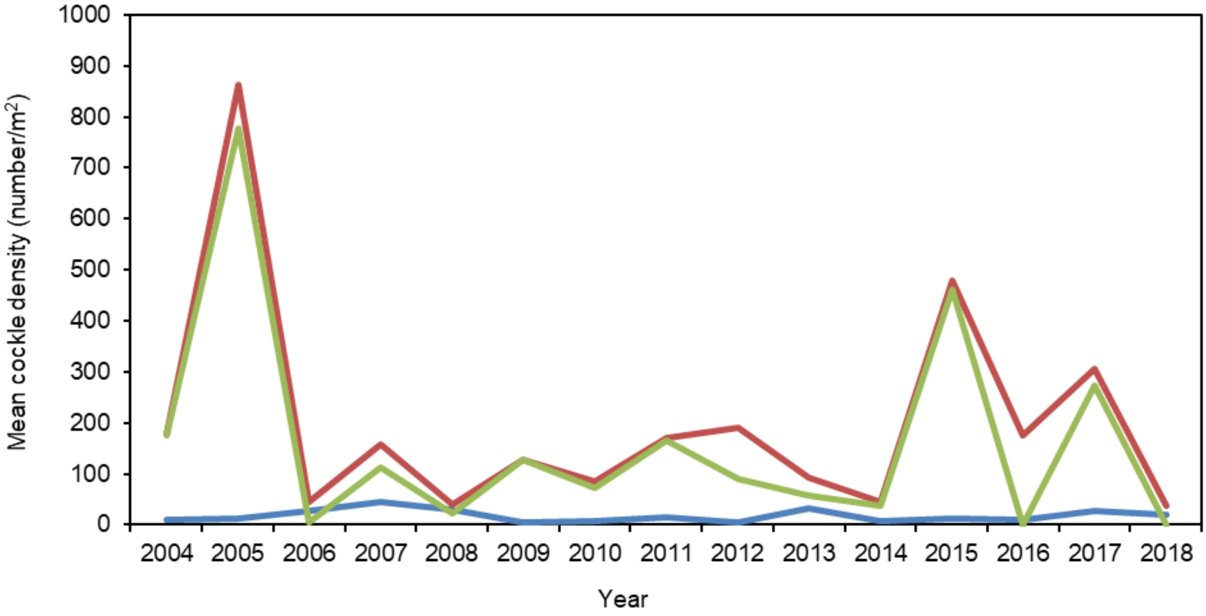

Mean cockle density (number/m2)
0
100
200
300
400
500
600
700
800
900
1000
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Mean adult cockle density (number/m2)
0
10
20
30
40
50
60
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Mean cockle biomass (g/m2)
0
50
100
150
200
250
300
350
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Adult
Juvenile
Year 0

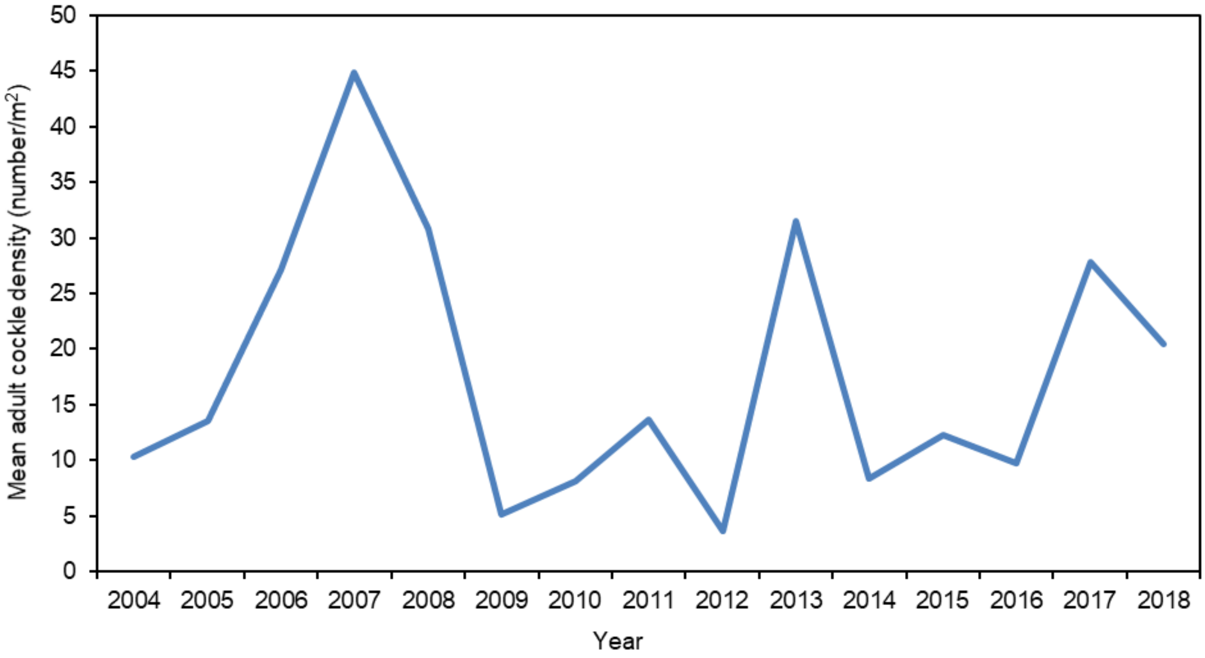
Butterwick

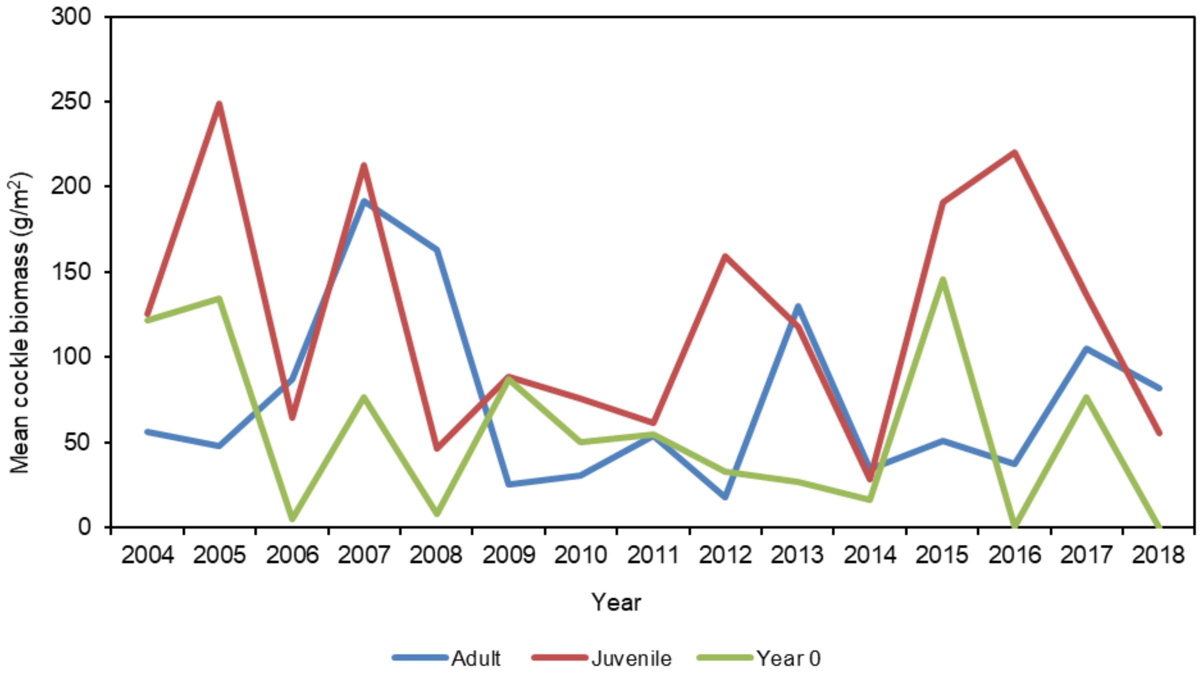
Butterwick extension

The Butterwick extension area lies along the upper shore and is targeted much less by the dredge fishery than the main part of the bed. Spatfalls in this part have shown a more regular biennial pattern than those on the main part of the bed, with high densities of year-0cockles in 2005, 2015 and 2016, congruent with the general observations across The Wash. Peaks in adult stocks have followed years of high spatfall as expected, and a decline in stocks recruiting to the adult population is seen between 2008 and 2011.

There are no known dredge fisheries that heavily targeted this area of the bed between 2004 and 2018.



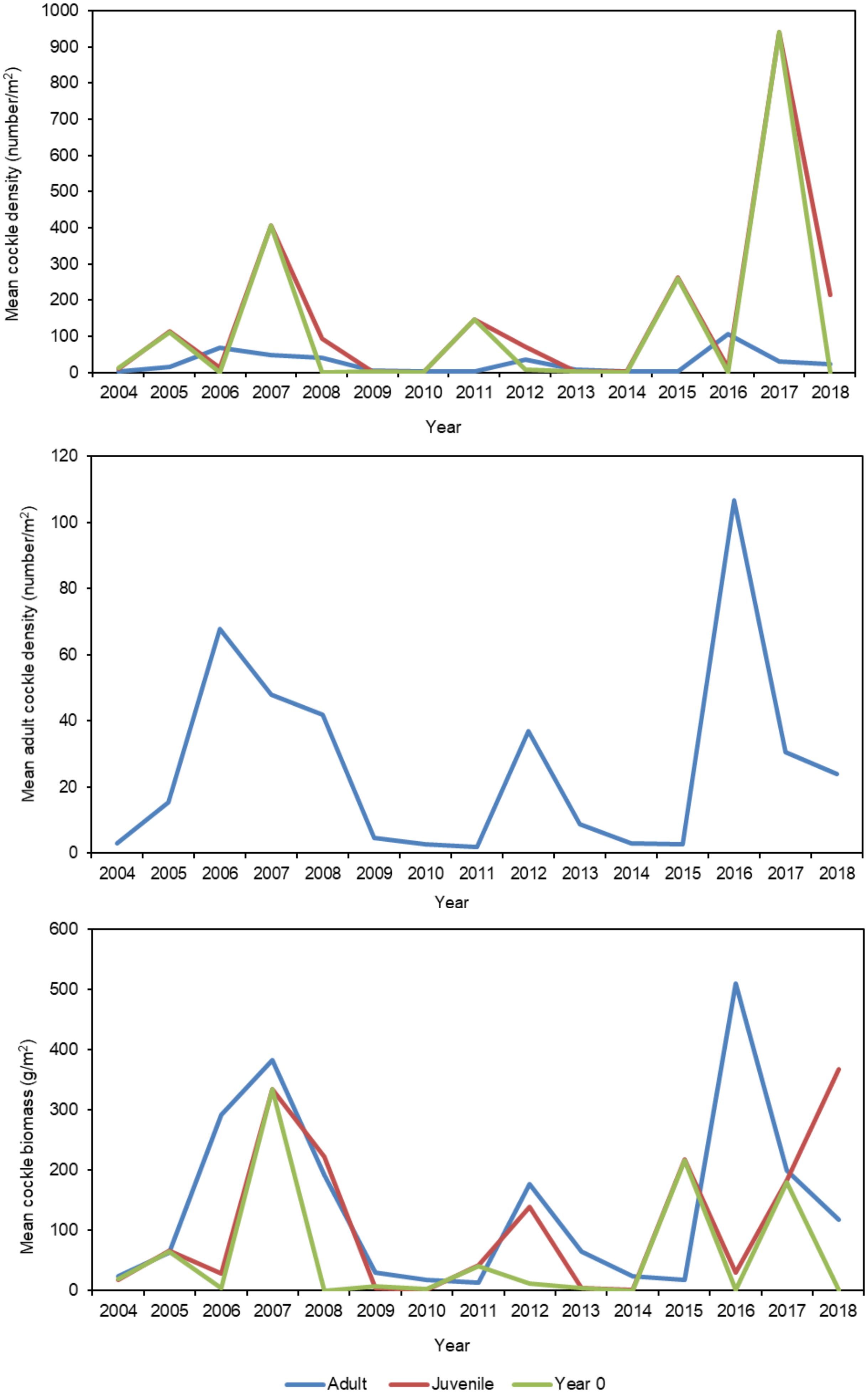




Butterwick extension

Wrangle

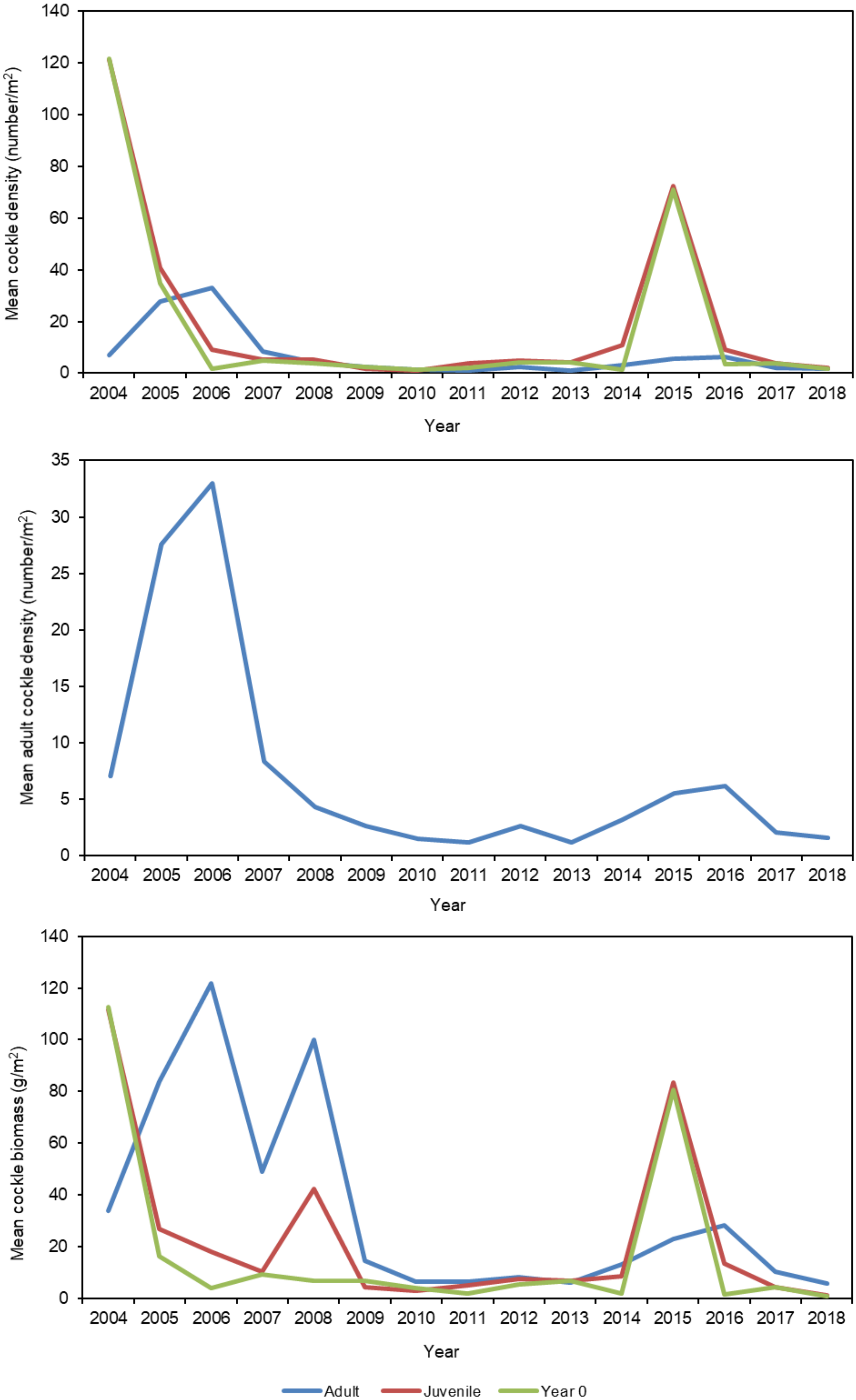
Wrangle is situated in the middle of Boston Main on the edge of the north easterly side of The Wash with the extension area along the upper shore. Boston Main was targeted by the dredge fishery in 2001 and 2002 but it is unknown how much of this effort was targeted on Wrangle and the bed was not heavily targeted between 2003 and 2008. Spatfall and stock patterns are generally consistent with those observed across The Wash, stock declines are observed between 2008 and 2014.


Mean cockle density (number/m^2)
Year
Mean adult cockle density (number/m^2)
Year
Mean cockle biomass (g/m^2)
Year
Adult
Juvenile
Year 0

Wrangle

Wrangle Extension

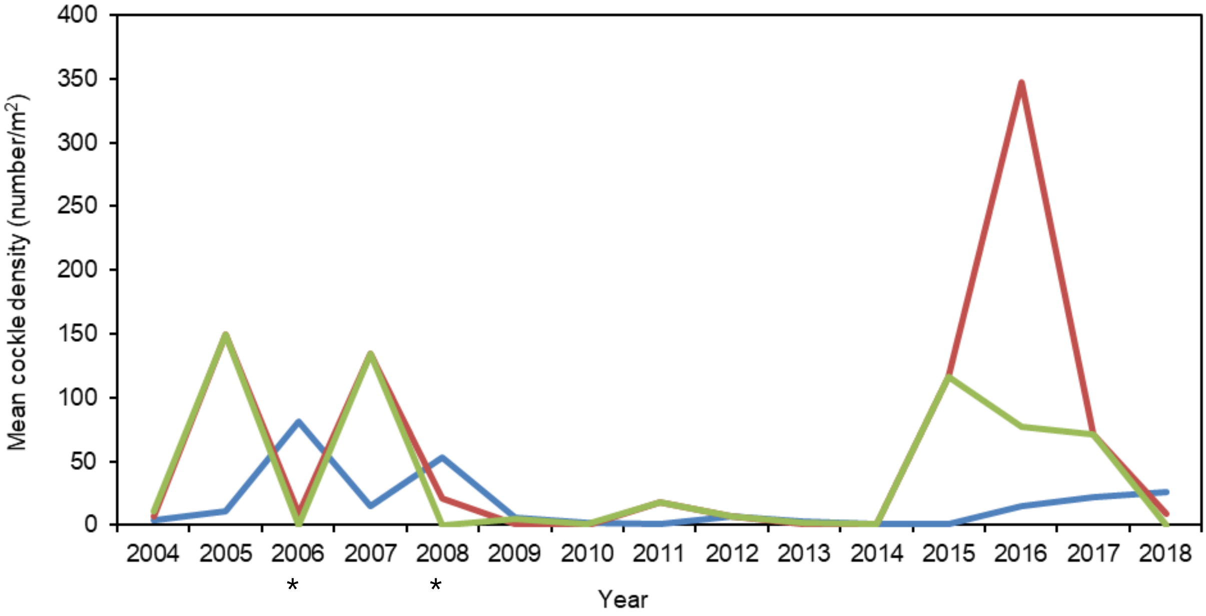
On the extension area of the bed patterns are similar to that observed on the main bed but generally with a much lower average density and biomass on the extension area than on the main bed. It is unlikely the fishery will have ever targeted the extension area of the bed.

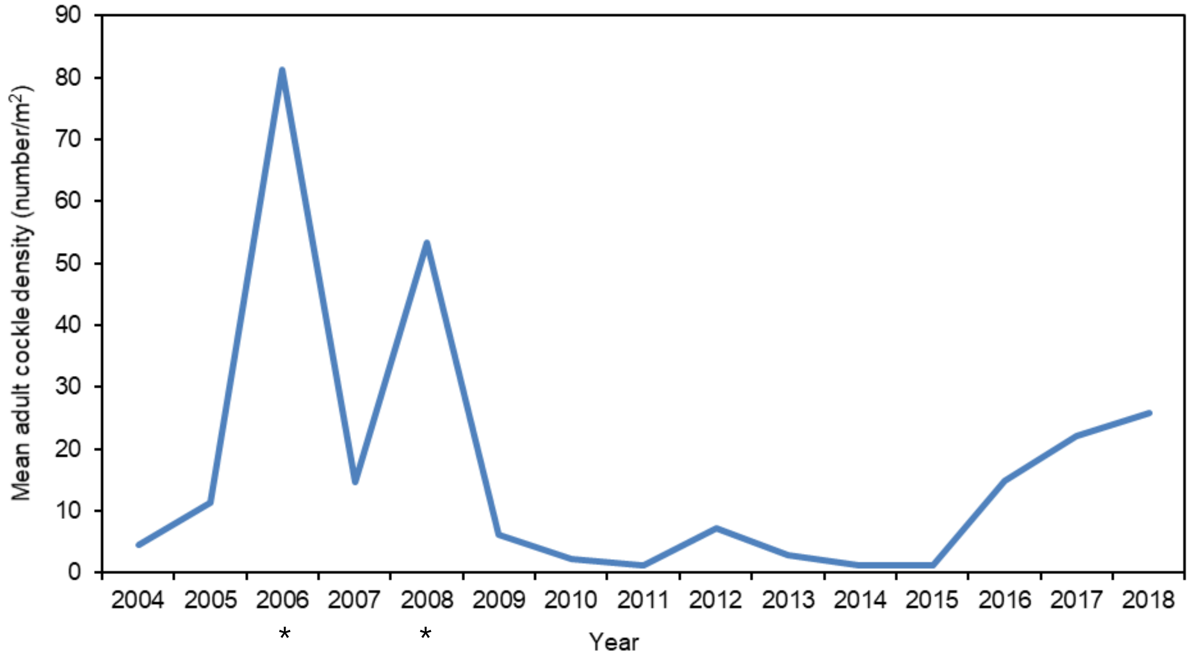


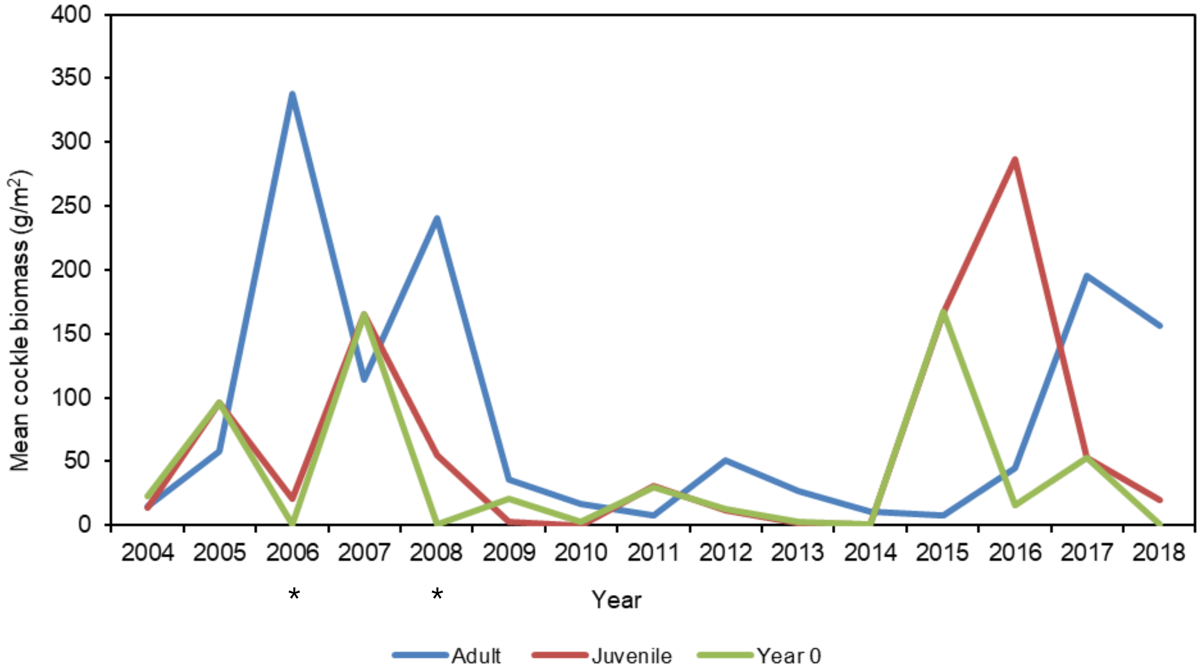
Wrangle Extension

Friskney

Friskney is situated in the northern part of Boston Main with the extension area along the upper shore and is generally considered a fast-growing bed. Spatfall and stock patterns are generally consistent with those observed across The Wash. A dredge fishery targeted Friskney in 2006 and 2008, and it has since been targeted by the hand-work fishery. Boston Main was also targeted by the dredge fishery in 2001 and 2002, but how much of this effort was targeted on Friskney is unknown. An increase in year-0 density in 2007 and 2009 suggest dredging has not had an effect on spatfall. Similar effects and patterns of spatfall observed across most of the cockle beds in The Wash further support this.


Mean cockle density (number/m²)
400
350
300
250
200
150
100
50
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
* *
Year

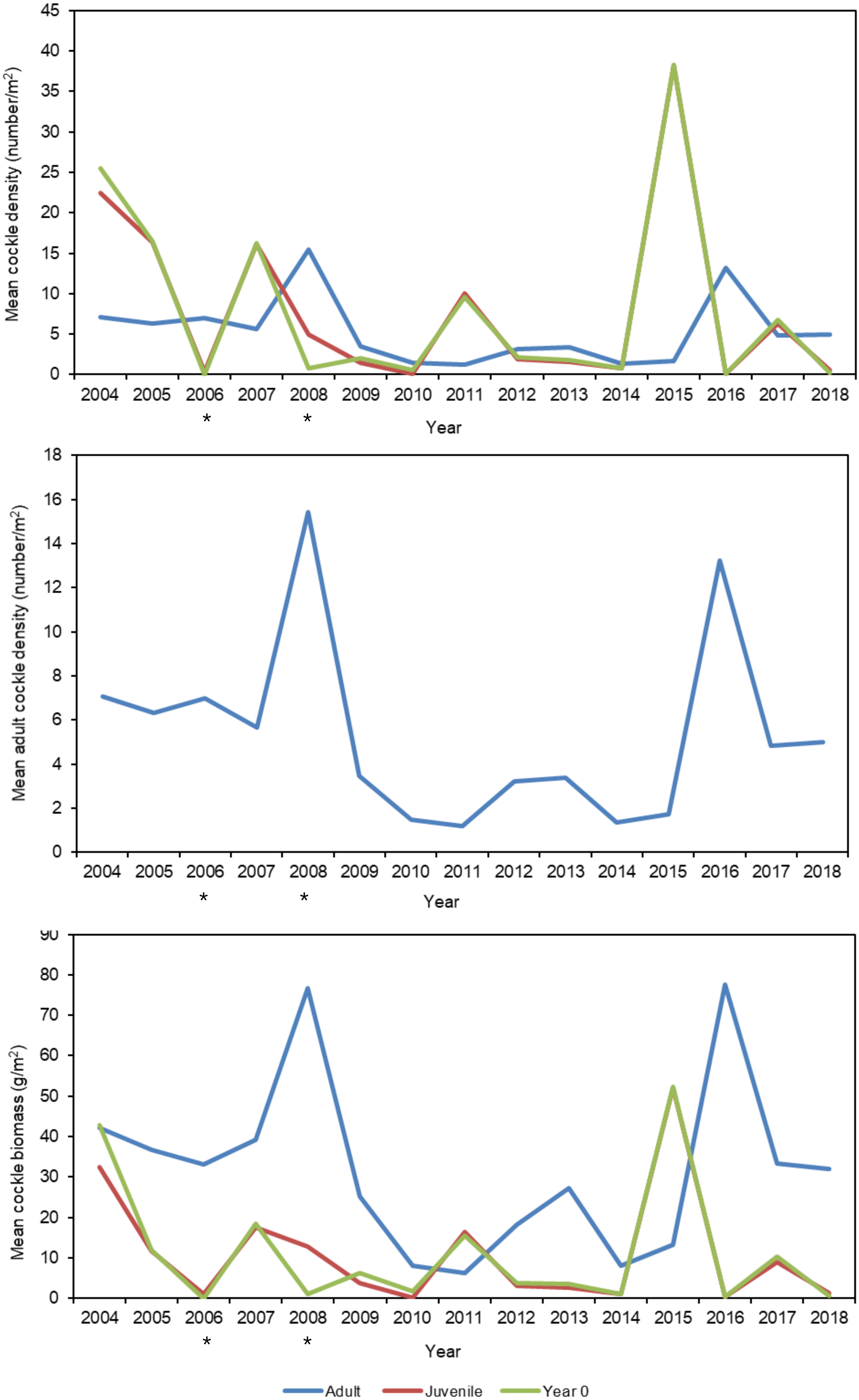

Mean adult cockle density (number/m²)
90
80
70
60
50
40
30
20
10
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
* *
Year


Mean cockle biomass (g/m²)
400
350
300
250
200
150
100
50
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
* *
Year
Adult
Juvenile
Year 0

Friskney

Friskney Extension

Patterns in spatfall and stocks are similar to that observed on the main bed, however, are generally much lower in density and biomass. The northern part of this bed can be targeted by dredges, so it is likely this area received fishing pressure in 2006 and 2008. Similarly, to the main Friskney bed, an increase in year-0 density in 2007 and 2009 suggest dredging has not had an effect on spatfall, with spatfall following the biennial pattern during these years.

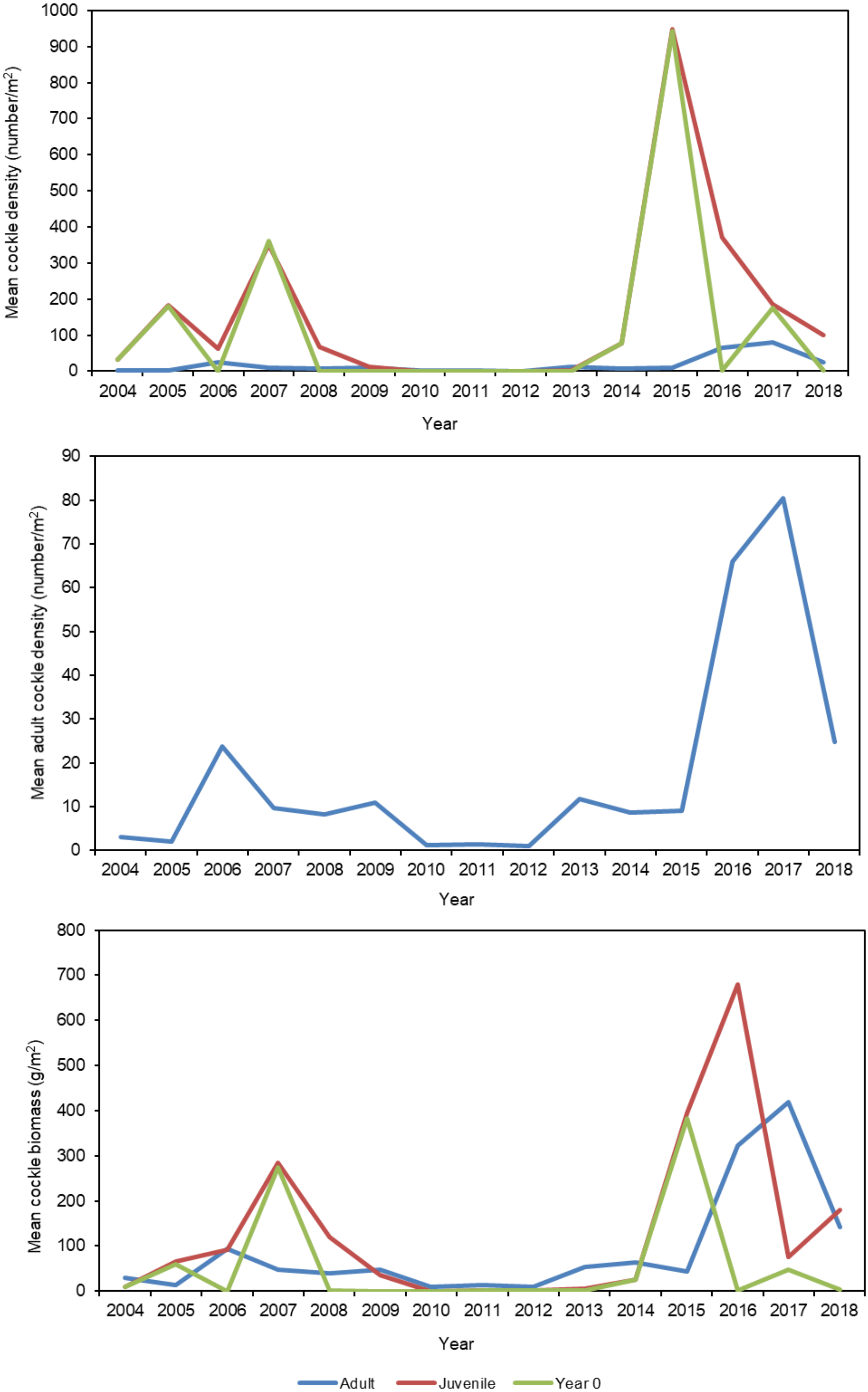


Friskney Extension

South West beds

Roger/Toft

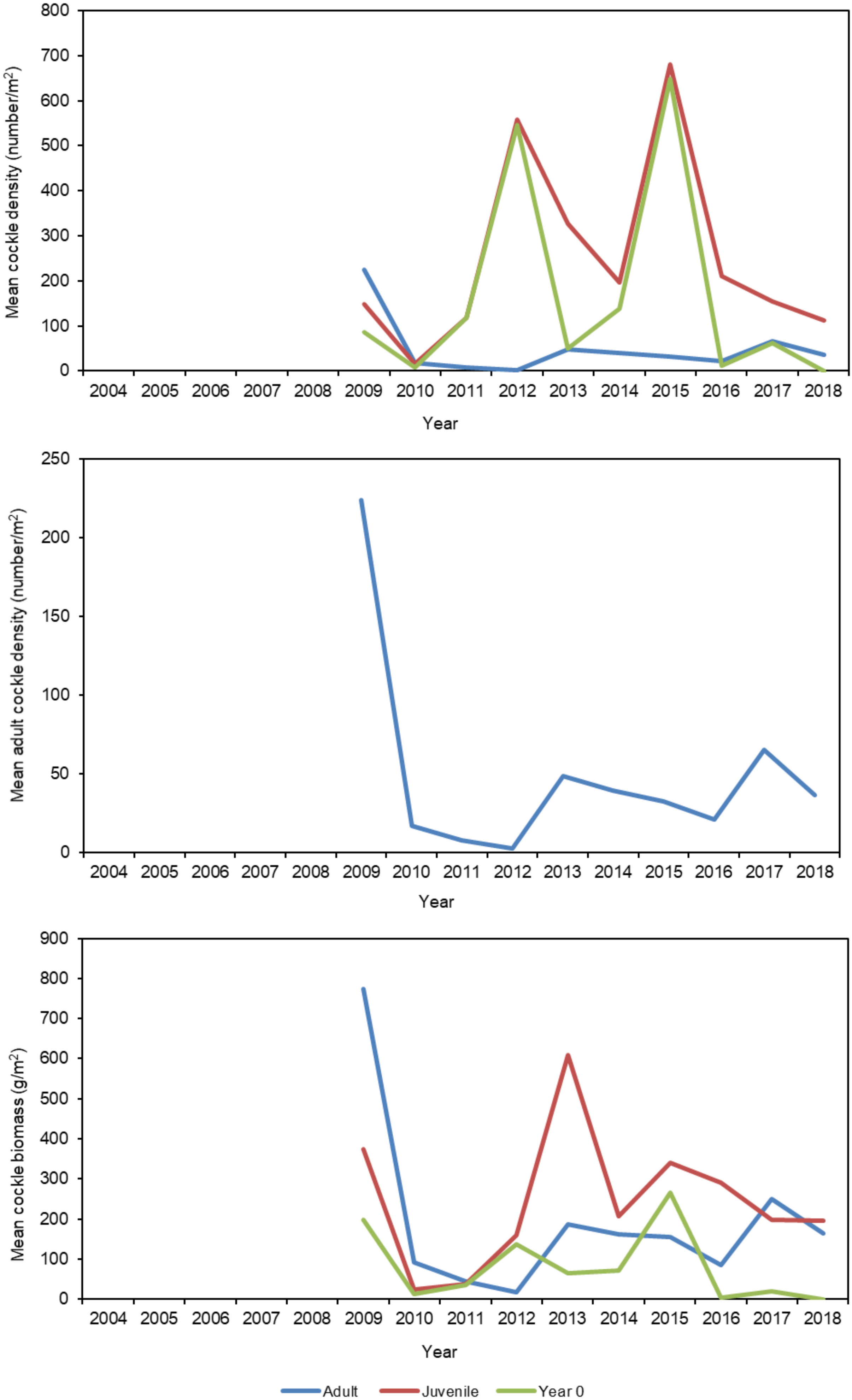
A relatively fast-growing bed (Jessop *et al.,* 2013) not heavily targeted by the dredge fishery between 2001 and 2008, but since has been regularly targeted by the hand-work fishery. Spatfall and stock patterns are generally consistent with those observed across The Wash beds, with very low densities and biomasses of year 0 cockles between 2008 and 2013.


Mean cockle density (number/m2)
1000
900
800
700
600
500
400
300
200
100
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Mean adult cockle density (number/m2)
90
80
70
60
50
40
30
20
10
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Mean cockle biomass (g/m2)
800
700
600
500
400
300
200
100
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Adult
Juvenile
Year 0

Roger/Toft

Black Buoy

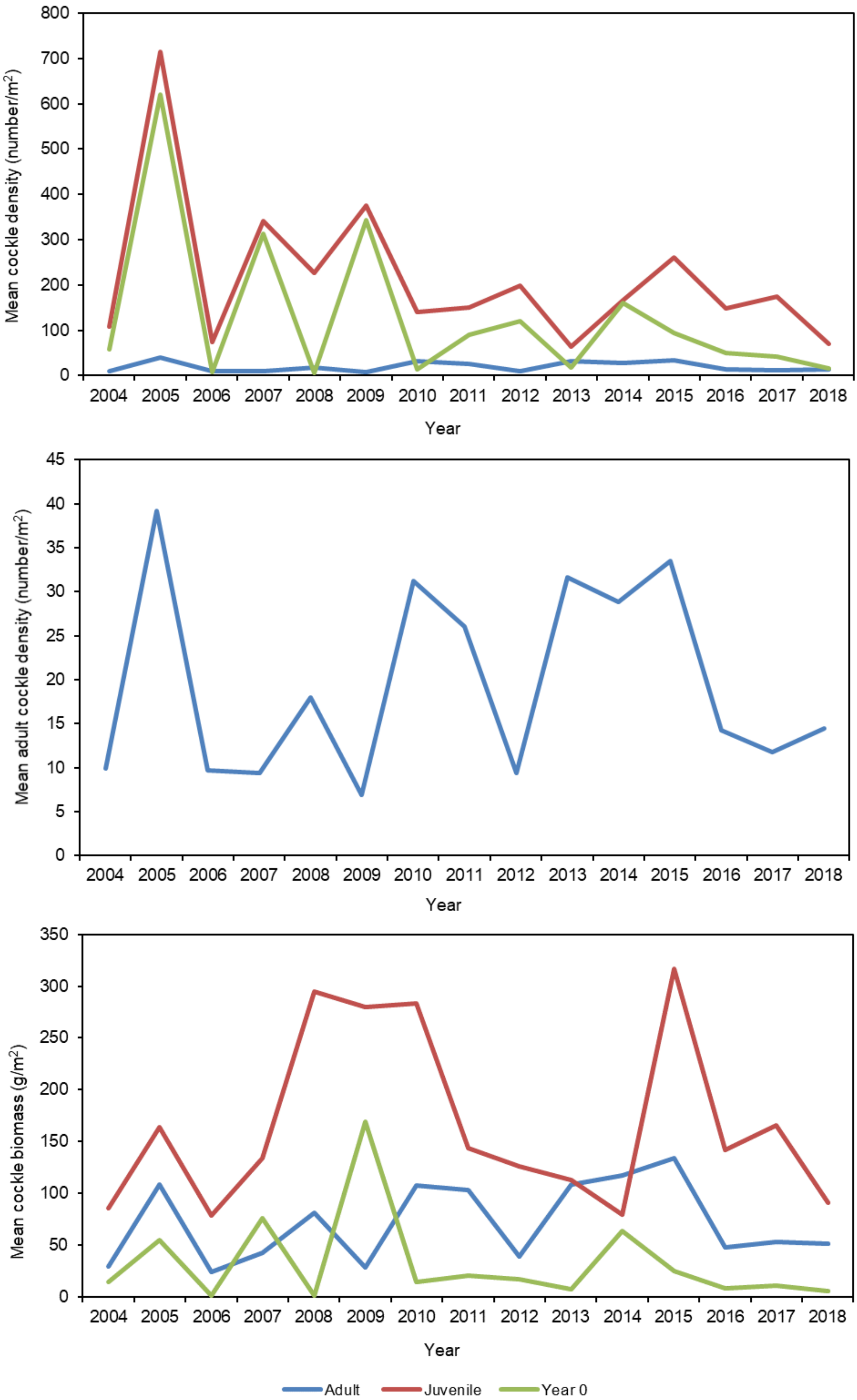
A relatively slow-growing bed (Jessop *et al.,* 2013) not heavily targeted by the dredge fishery between 2001 and 2008, but since regularly targeted by the hand-work fishery. Prior to 2009 the majority of this bed (on the Dills) was not annually assessed and as such analysis has only been made post 2009. Spatfall and stock patterns post 2008 are generally consistent with those observed across The Wash beds.


Mean cockle density (number/m²)
Year
Mean adult cockle density (number/m²)
Year
Mean cockle biomass (g/m²)
Year
Adult
Juvenile
Year 0

Black Buoy

Herring Hill

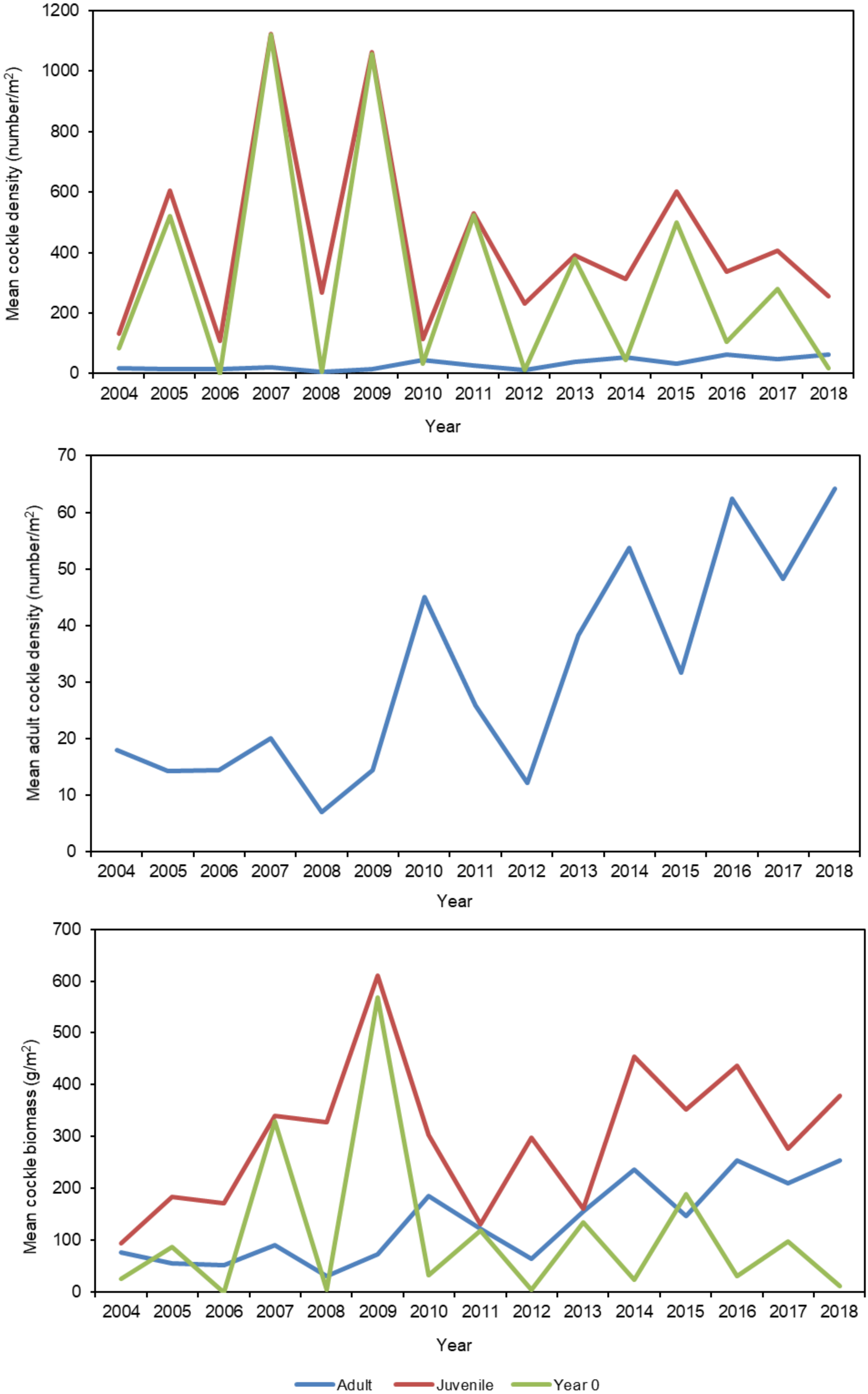
A relatively slow-growing bed (Jessop *et al.,* 2013) not heavily targeted by the dredge fishery between 2001 and 2008 and occasionally targeted by the hand-work fishery. Between 2004 and 2008 surveys on this bed included some stations within the Black Buoy bed, prior to it being sampled as a separate bed post-2009. Spatfall and stock patterns generally consistent with those observed across The Wash beds, although adult stocks appear more regular between 2008 and 2013 compared to the declines seen on other beds.



Herring Hill

Mare Tail

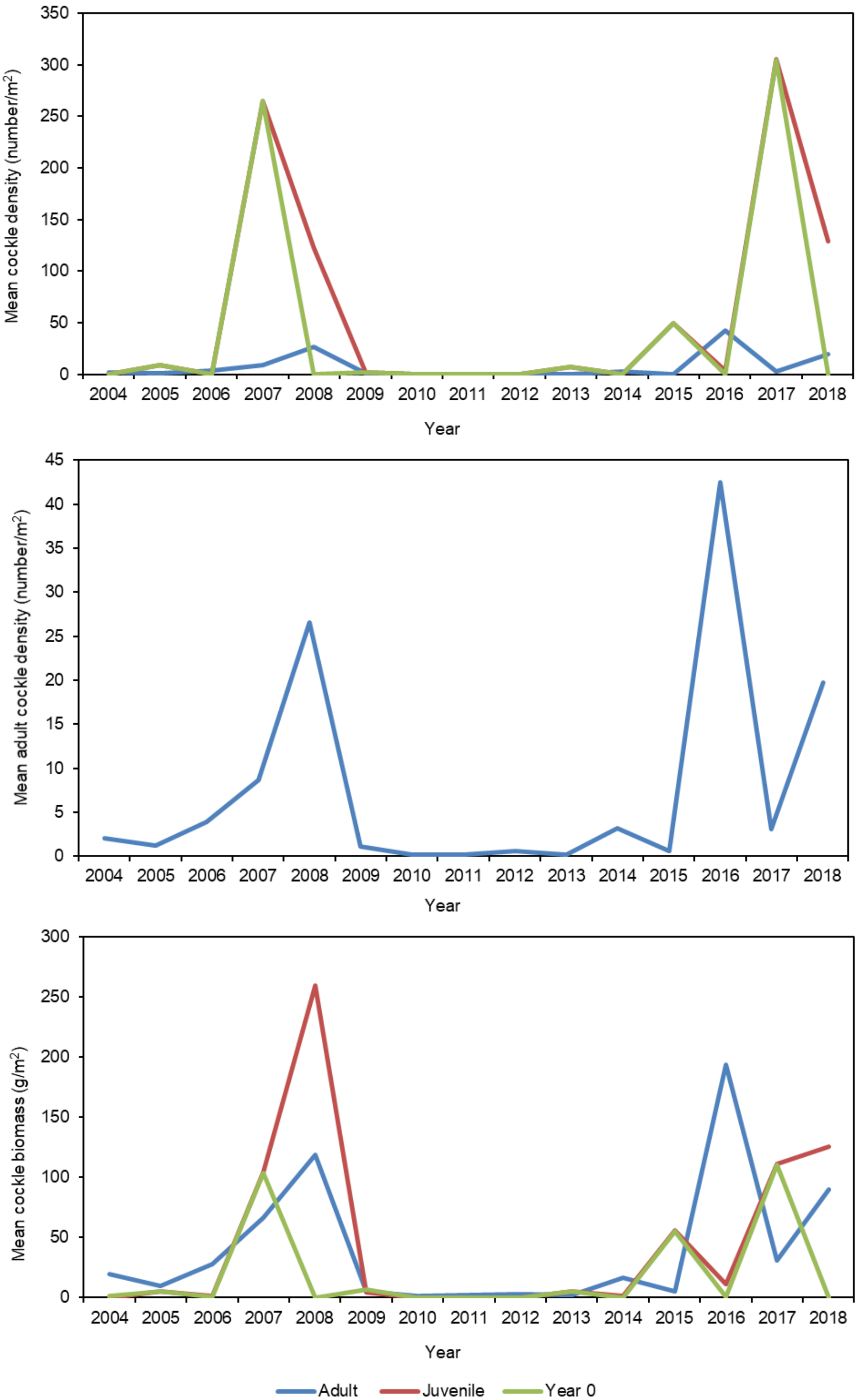
A relatively slow-growing bed (Jessop *et al.,* 2013) targeted by the dredge fishery in 2003 and since regularly targeted by the hand-work fishery (particularly north-eastern parts of the bed). Spatfall and stocks patterns are much more regular than those observed on many of the other beds with no obvious declines in spatfall or stocks between 2008 and 2013 and a general increase in adult stocks over time.


Mean cockle density (number/m^2)
1200
1000
800
600
400
200
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Mean adult cockle density (number/m^2)
70
60
50
40
30
20
10
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Mean cockle biomass (g/m^2)
700
600
500
400
300
200
100
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Adult
Juvenile
Year 0

Mare Tail

Gat

A largely fast-growing bed (Jessop *et al*., 2013) not heavily targeted by the dredge fishery between 2001 and 2008, but since regularly targeted by the hand-work fishery. Spatfall and stock patterns are generally consistent with those observed across The Wash beds, with very low densities of year-0 cockles between 2008 and 2013, however low densities and biomass were also observed between 2004 and 2006.

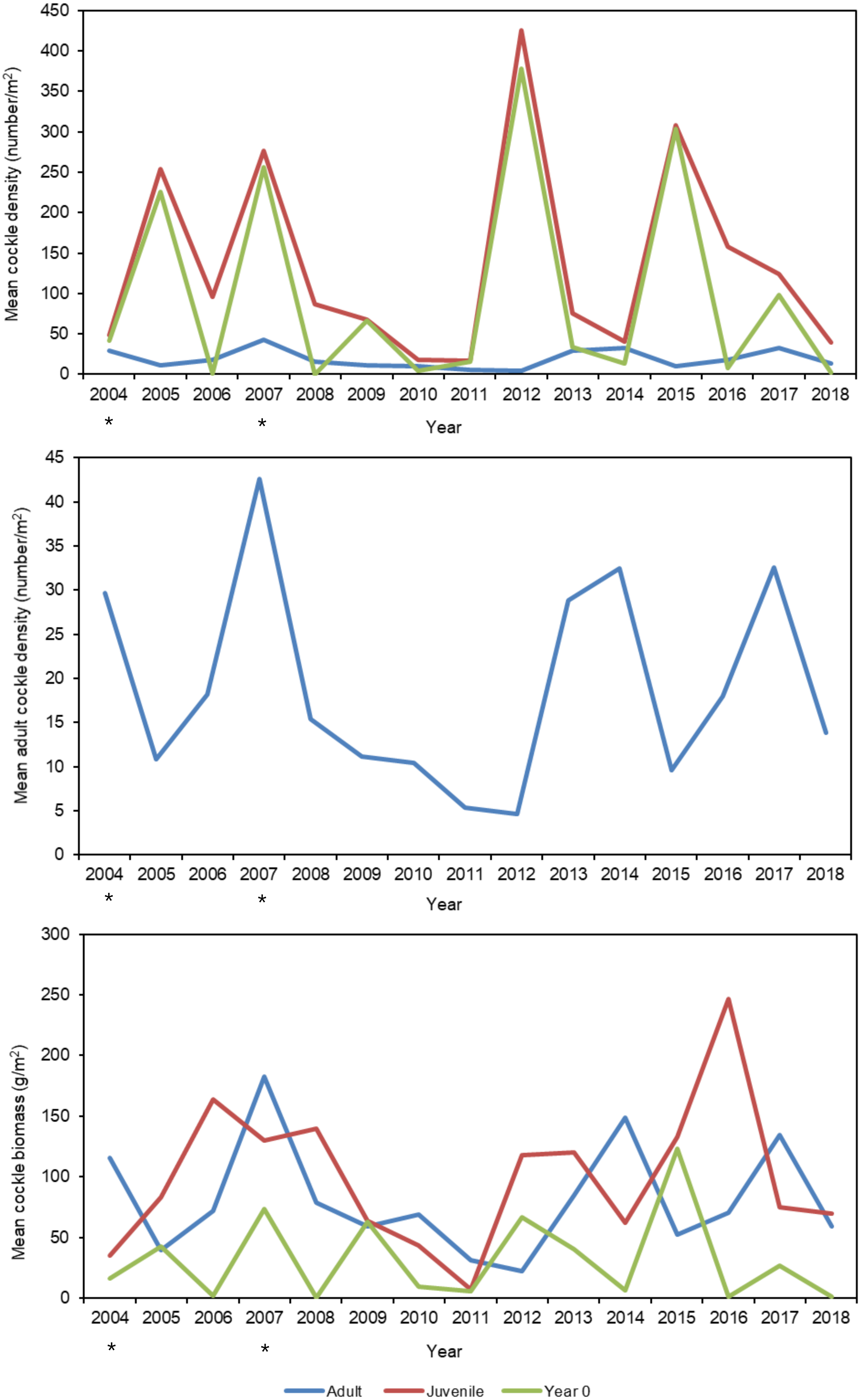


Mean cockle density (number/m2)
350
300
250
200
150
100
50
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Mean adult cockle density (number/m2)
45
40
35
30
25
20
15
10
5
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Mean cockle biomass (g/m2)
300
250
200
150
100
50
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Adult
Juvenile
Year 0

Gat

Holbeach

Dredge fisheries predominantly targeted Holbeach in 2004 and 2007. However, this bed has since not been regularly targeted by the hand-work fishery, likely due to the restricted access to this bed during low tide periods incurred by Holbeach Range. Spatfall and stock patterns are generally consistent with those observed across The Wash beds, with very low densities of year-0 cockles between 2008 and 2011. An increase in year-0 density in 2005 and a decrease in 2008 follow the biennial spatfall generally observed in The Wash and do not indicate effects specifically associated with dredging activity.



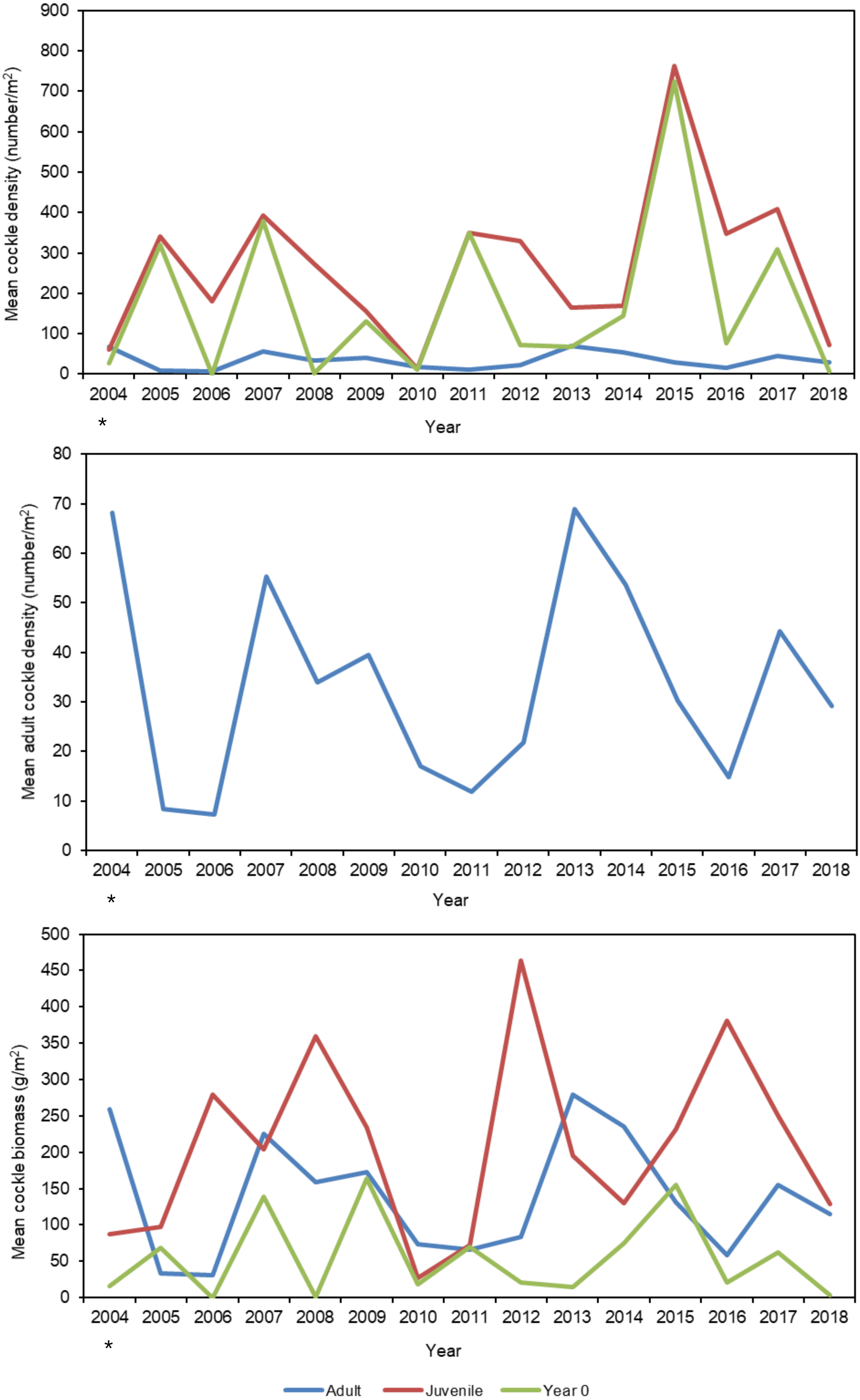
Mean cockle density (number/m2)
450
400
350
300
250
200
150
100
50
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
*
*
Year
Mean adult cockle density (number/m2)
45
40
35
30
25
20
15
10
5
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
*
*
Year
Mean cockle biomass (g/m2)
300
250
200
150
100
50
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
*
*
Year
Adult
Juvenile
Year 0

Holbeach

South East side

IWMK

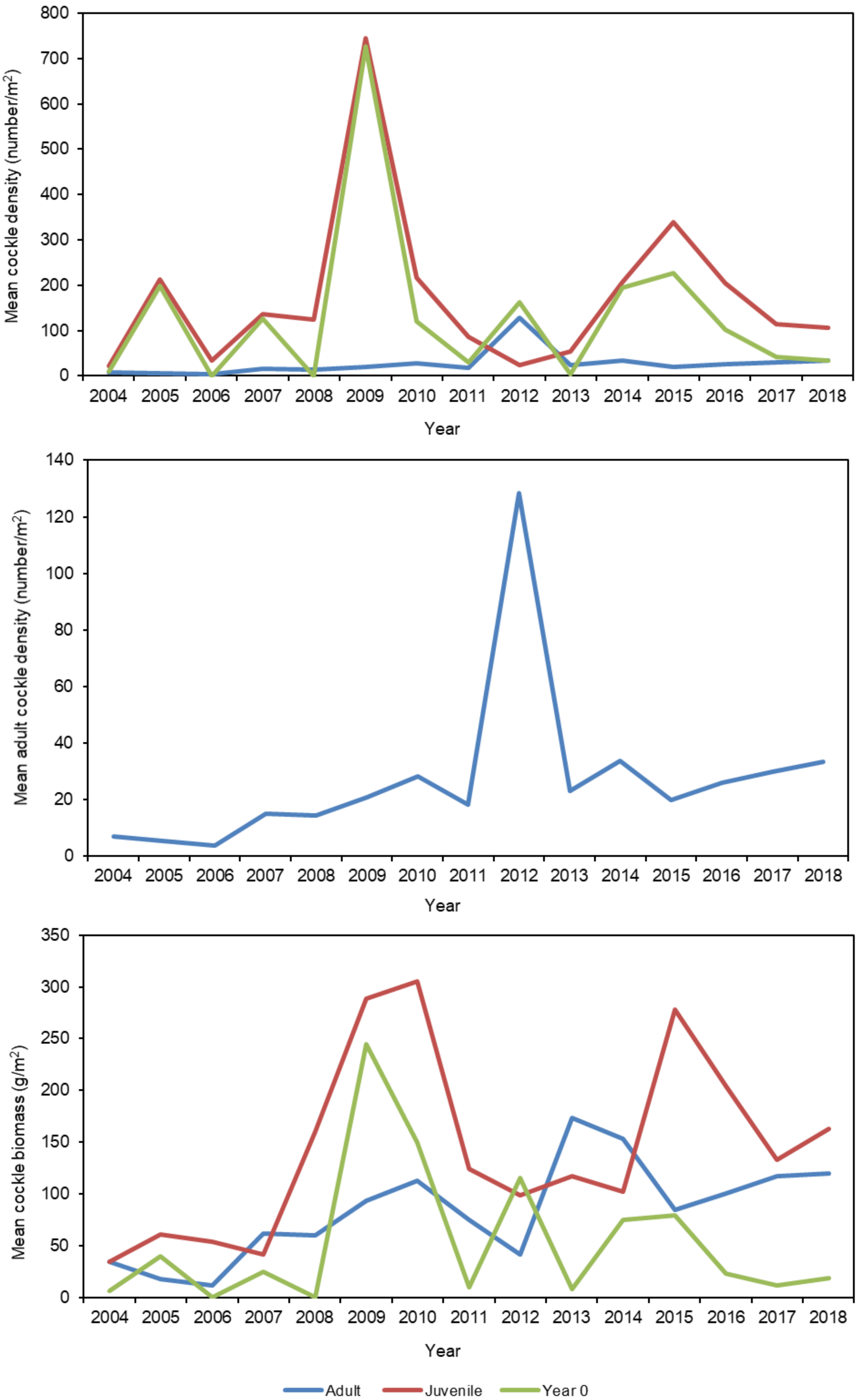
A relatively slow growing bed (Jessop *et al*., 2013) targeted by the dredge fishery in 2004, and since regularly targeted by the hand-work fishery. Spatfall and stock patterns are generally consistent with those observed across The Wash beds, but with lower densities of year-0 cockles between 2008 and 2013 than observed on other beds.


Mean cockle density (number/m2)
Year
Mean adult cockle density (number/m2)
Year
Mean cockle biomass (g/m2)
Year
*
Adult
Juvenile
Year 0

IWMK

Breast

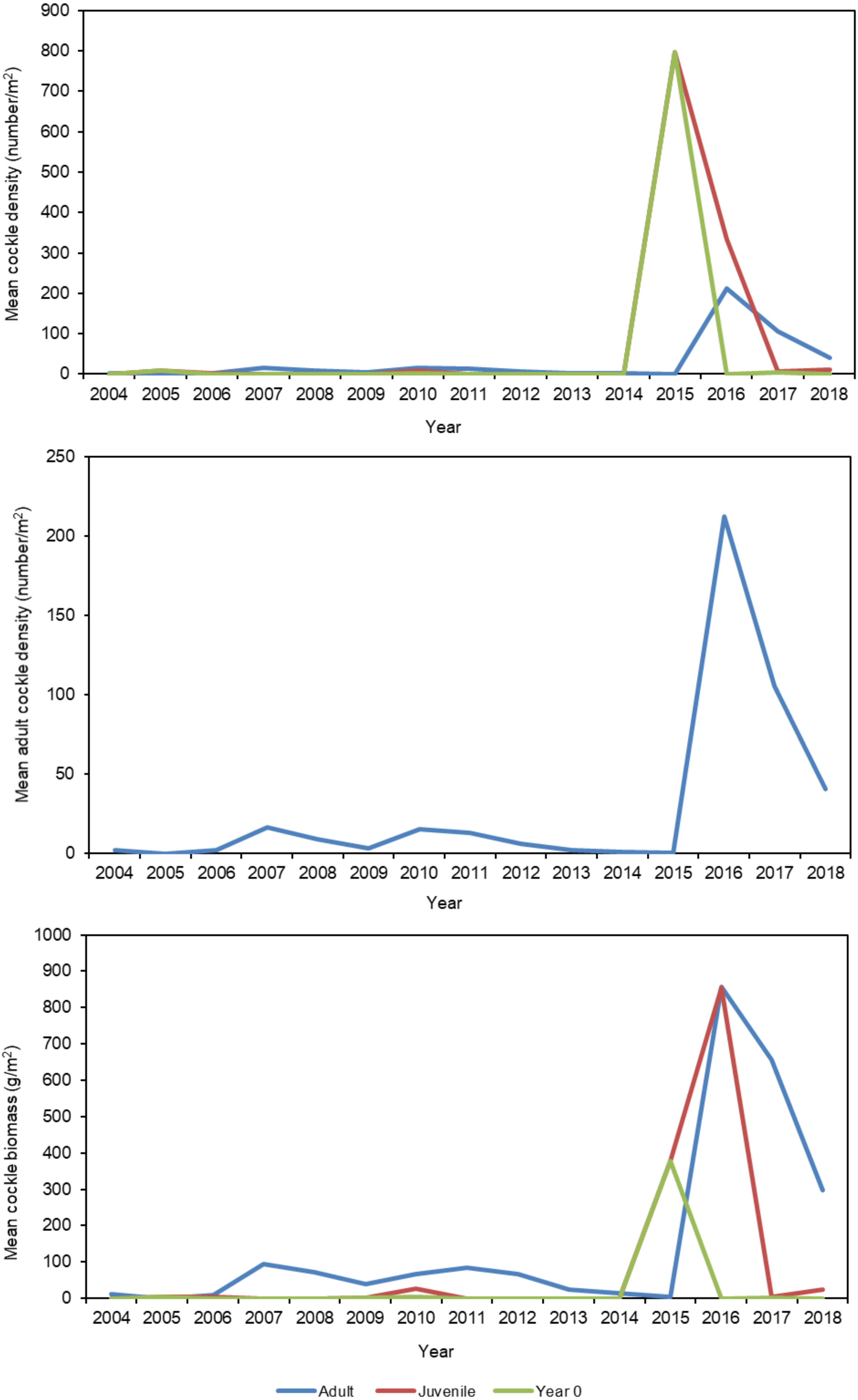
A largely slow growing bed (Jessop *et al*., 2013) not heavily targeted by the dredge fishery between 2001 and 2008, but parts of which have since been regularly targeted by the hand-work fishery. Spatfall patterns are not as similar as on other beds. Whilst generally following the biennial pattern, high and low densities of year-0 cockles indicate a high spatfall in 2008 and declining spatfalls in more recent years. Adults stocks, however, appear to have remained relatively stable, apart from a peak in 2012 which likely resulted from the large spatfall in 2008.


Mean cockle density (number/m^2)
0
100
200
300
400
500
600
700
800
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Mean adult cockle density (number/m^2)
0
20
40
60
80
100
120
140
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Mean cockle biomass (g/m^2)
0
50
100
150
200
250
300
350
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Adult
Juvenile
Year 0

Breast

Thief

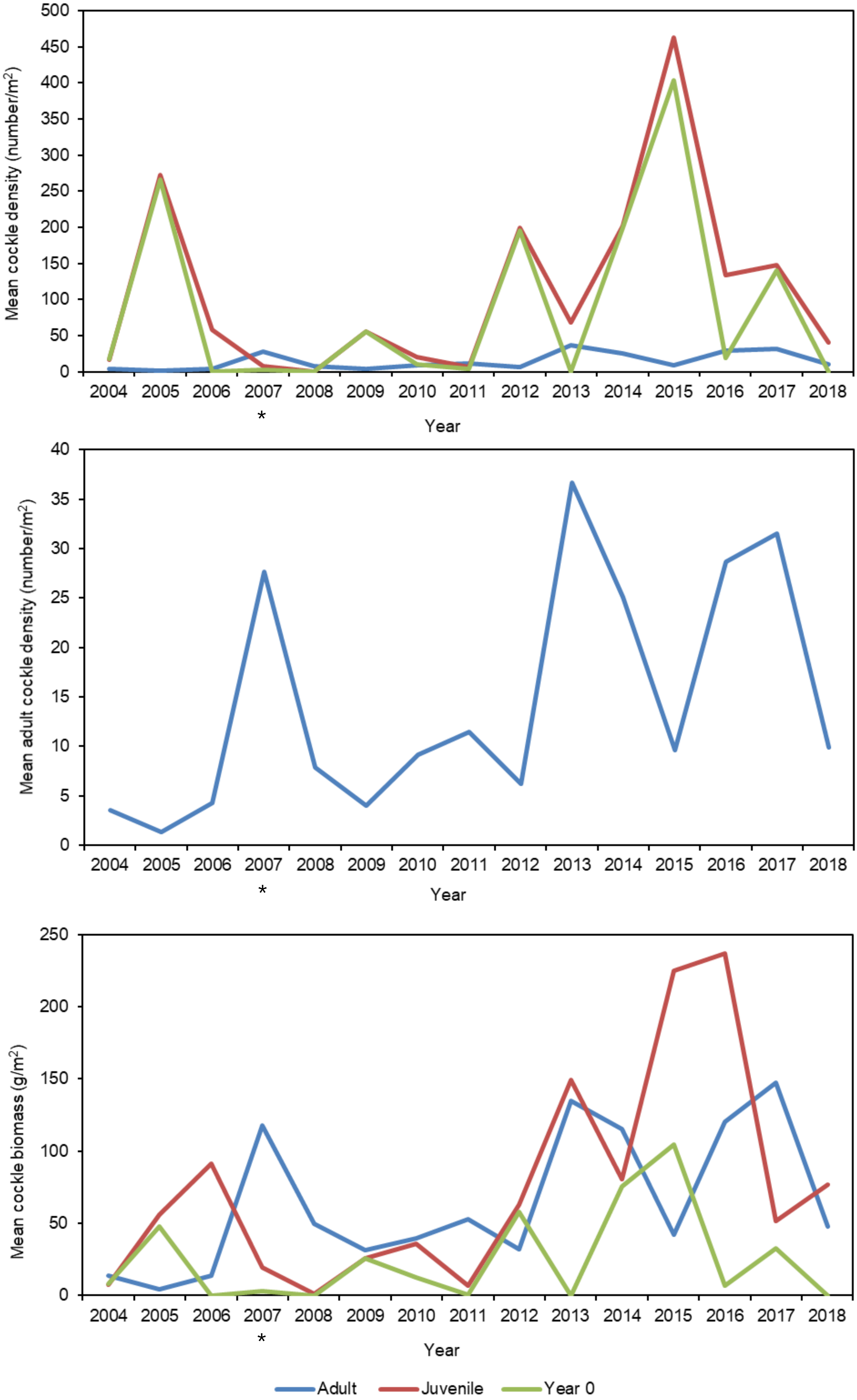
A largely fast-growing bed (Jessop *et al*., 2013) not heavily targeted by the dredge fishery between 2001 and 2008, but since regularly targeted by the hand-work fishery. Very low densities of year-0 cockles indicate poor spatfall between 2004 and 2014, but adult stocks remained relatively stable between this period. A high spatfall in 2014 was followed by an increase in the adult population in 2016.


Mean cockle density (number/m2)
Mean adult cockle density (number/m2)
Mean cockle biomass (g/m2)
Year
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Adult
Juvenile
Year 0

Thief

Daseley's

Daseley's is largely a relatively slow growing bed (Jessop *et al*., 2013) targeted by the dredge fishery in 2003 and 2007, and since 2008 has been regularly targeted by the hand-work fishery. Stock patterns are generally consistent with those observed across The Wash beds, but year-0 densities suggest spatfalls are less regular than those observed on other beds. The dredge fishery in 2007 saw a slight decrease in adult and juvenile stock in 2008, but this was likely the result of very low densities of year-0's in 2006, 2007 and 2008 indicating a run of several poor spatfalls prior to this dredging event.

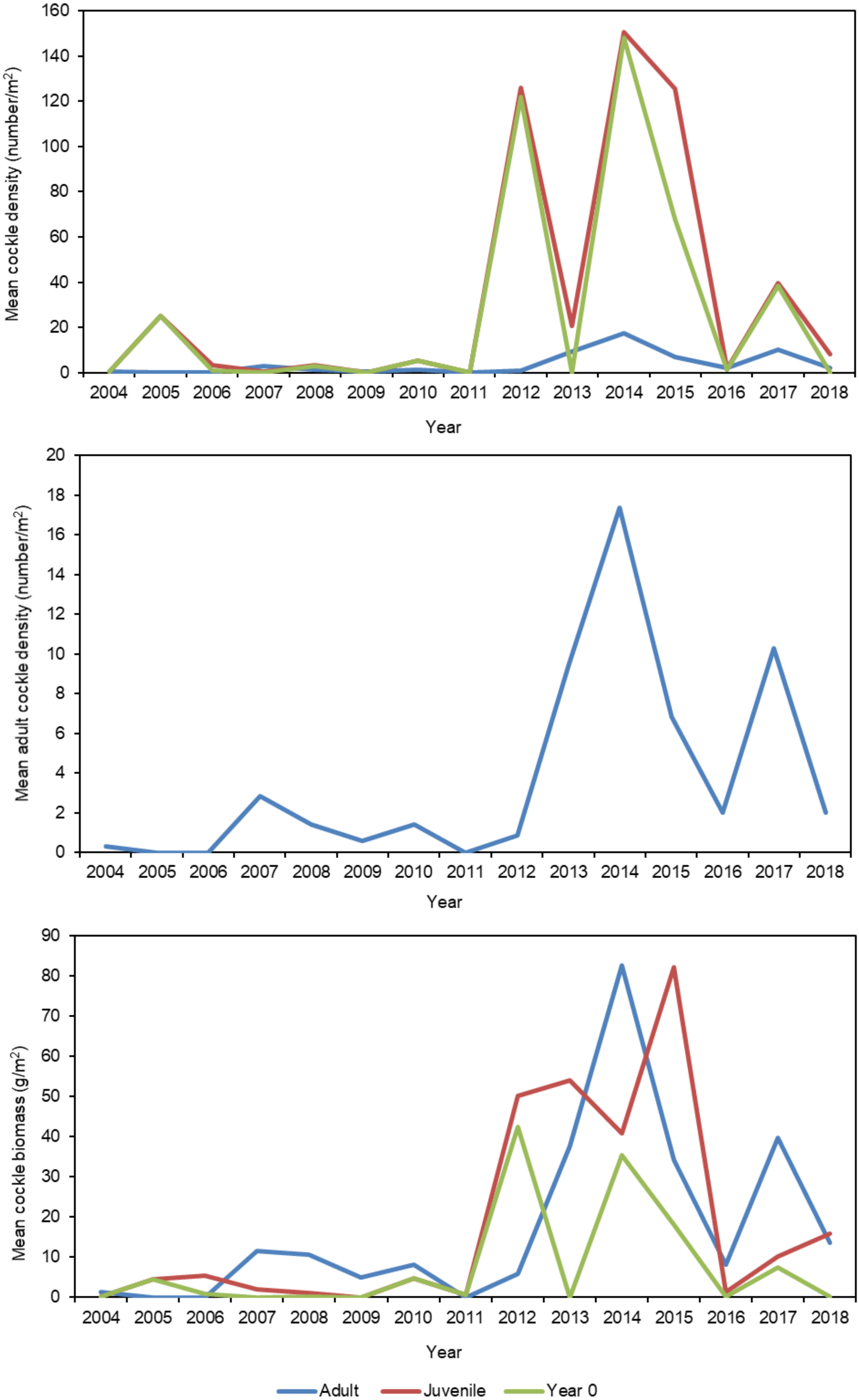


Mean cockle density (number/m2)
500
450
400
350
300
250
200
150
100
50
0
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
*
Year
Mean adult cockle density (number/m2)
40
35
30
25
20
15
10
5
0
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
*
Year
Mean cockle biomass (g/m2)
250
200
150
100
50
0
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
*
Year
Adult
Juvenile
Year 0

Daseleys

Pandora

A slow-growing bed (Jessop *et al*., 2013) not heavily targeted by the dredge fishery between 2001 and 2008 or the handwork fishery. Very low densities of year-0 cockles indicate poor spatfalls between 2004 and 2013, resulting in a crash in adult stocks in 2005, 2006 and 2011. However, a high spatfall in 2011 and 2013 appears to have resulted in recovery of the adult population over the last eight years.

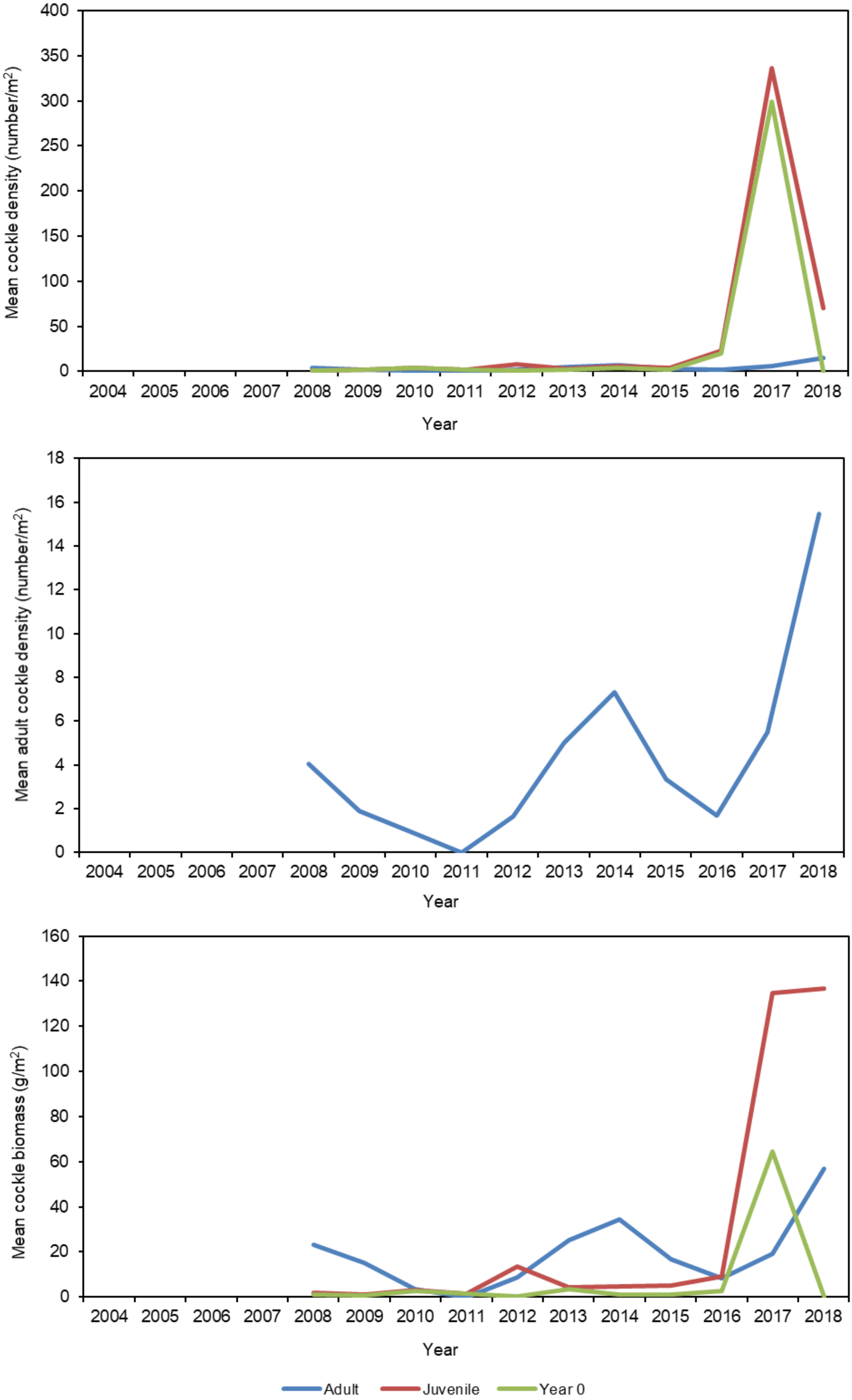


Mean cockle density (number/m²)
Year
Mean adult cockle density (number/m²)
Year
Mean cockle biomass (g/m²)
Year
Adult
Juvenile
Year 0

Pandora

Peter Black

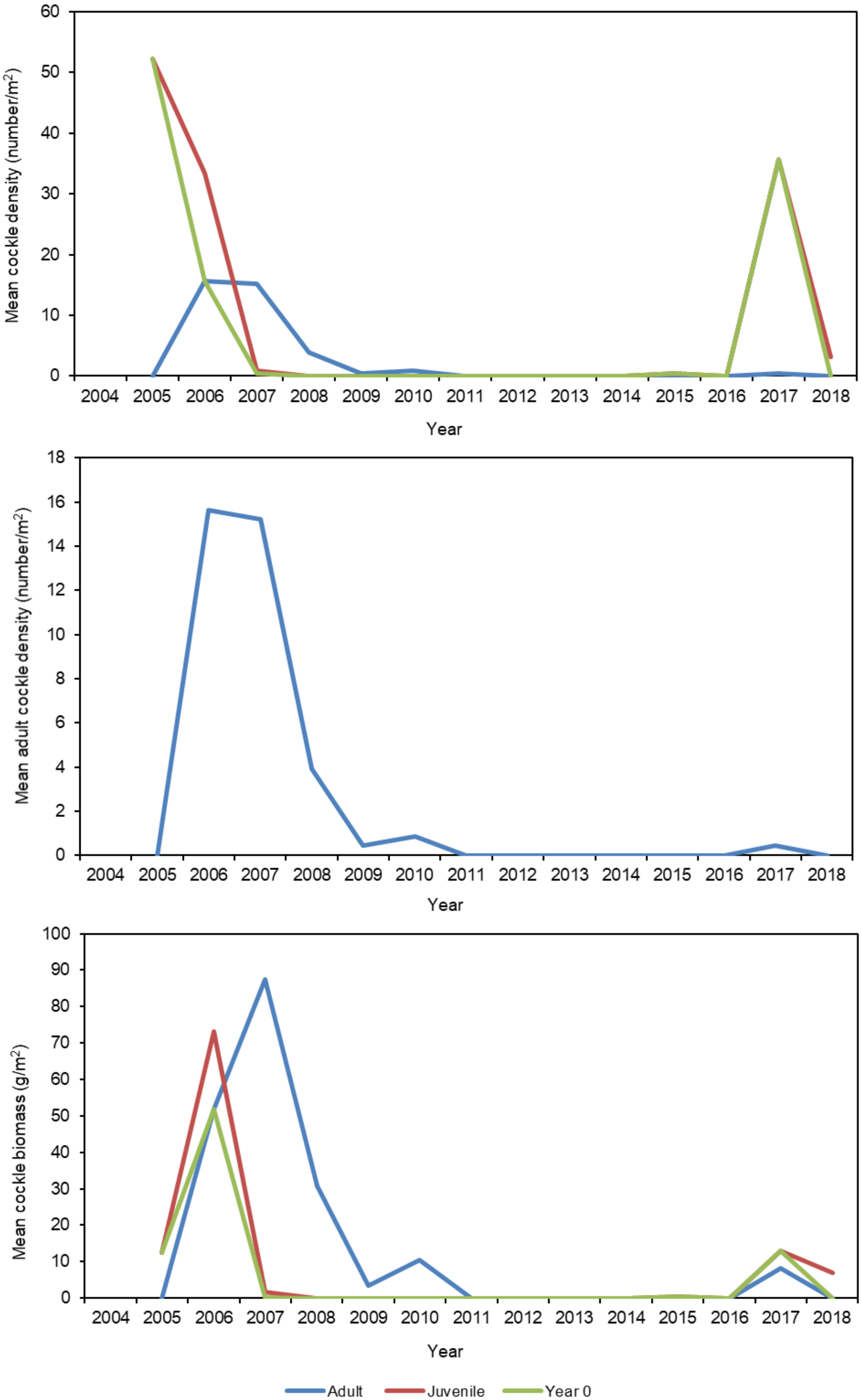
A slow-growing bed (Jessop *et al*., 2013) not heavily targeted by the dredge fishery between 2001 and 2008 or the handwork fishery. This bed has only been included in the cockle surveys since 2008 and so data is not available prior to this. Very low densities of year-0 cockles indicate poor spatfalls between 2007 and 2014, resulting in a crash in adult stocks in 2011. However, an increase in year-0's in 2017 indicate a large spatfall in which 2016 has resulted in an increase in adult stocks over the last couple of years.


Mean cockle density (number/m2)
400
350
300
250
200
150
100
50
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Mean adult cockle density (number/m2)
18
16
14
12
10
8
6
4
2
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Mean cockle biomass (g/m2)
160
140
120
100
80
60
40
20
0
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Adult
Juvenile
Year 0

Peter Black

Blackguard

A largely fast-growing bed (Jessop *et al*., 2013) not heavily targeted by the dredge fishery between 2001 and 2008 or the handwork fishery. Very low densities of year-0 cockles indicate poor spatfalls between 2006 and 2015 with large declines in adult and juvenile stocks in the years following. Despite a large spatfall in 2016, adult stocks have remained very low.

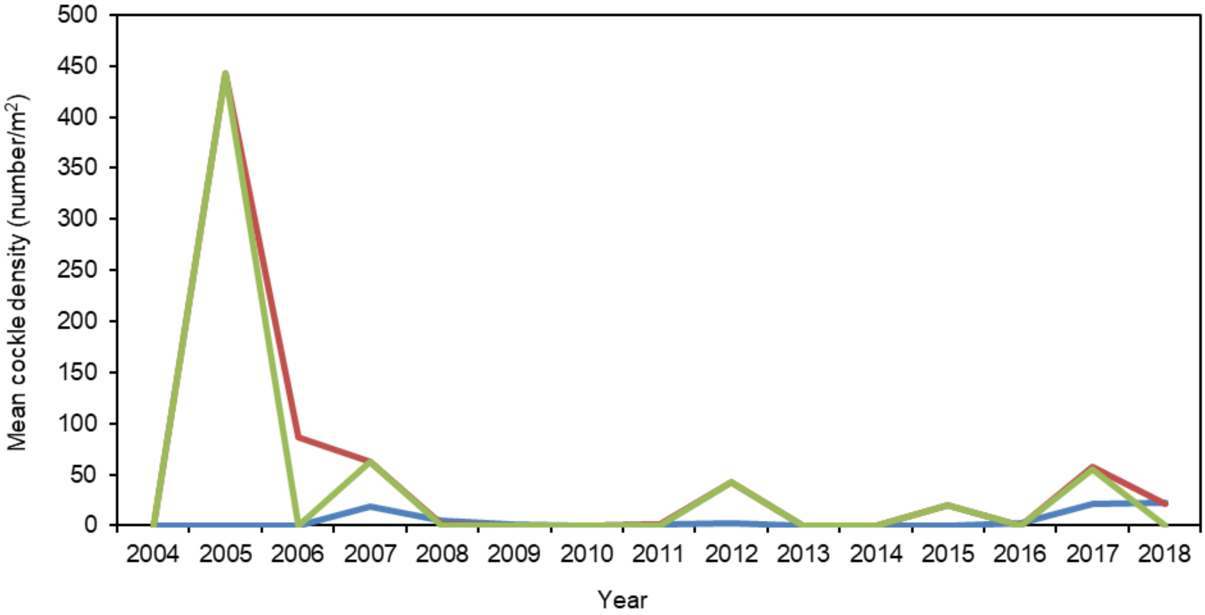


Mean cockle density (number/m^2)
Mean adult cockle density (number/m^2)
Mean cockle biomass (g/m^2)
Year
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Adult
Juvenile
Year 0

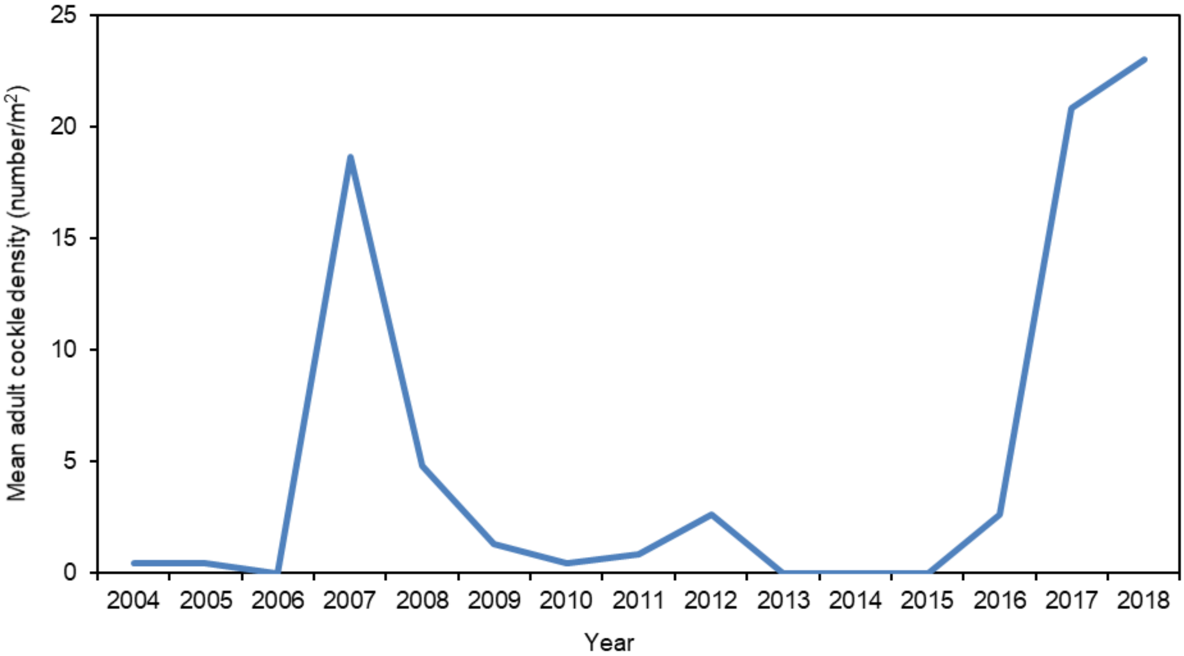
Blackguard

Styleman's

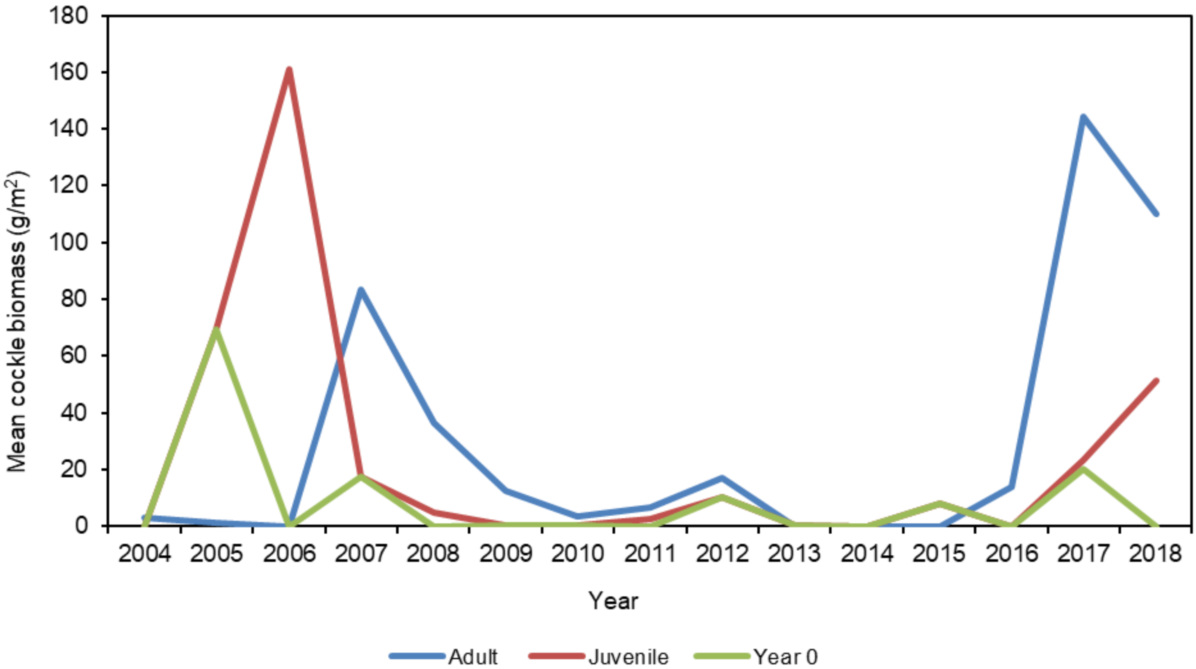
Styleman's was not heavily targeted by the dredge fishery between 2001 and 2008 or the handwork fishery. Spatfall and stock patterns are generally consistent with those observed across The Wash beds, however more recent spatfalls do not appear to have been as big as on some of the other beds.



Mean cockle density (number/m2)
Year



Mean adult cockle density (number/m2)
Year

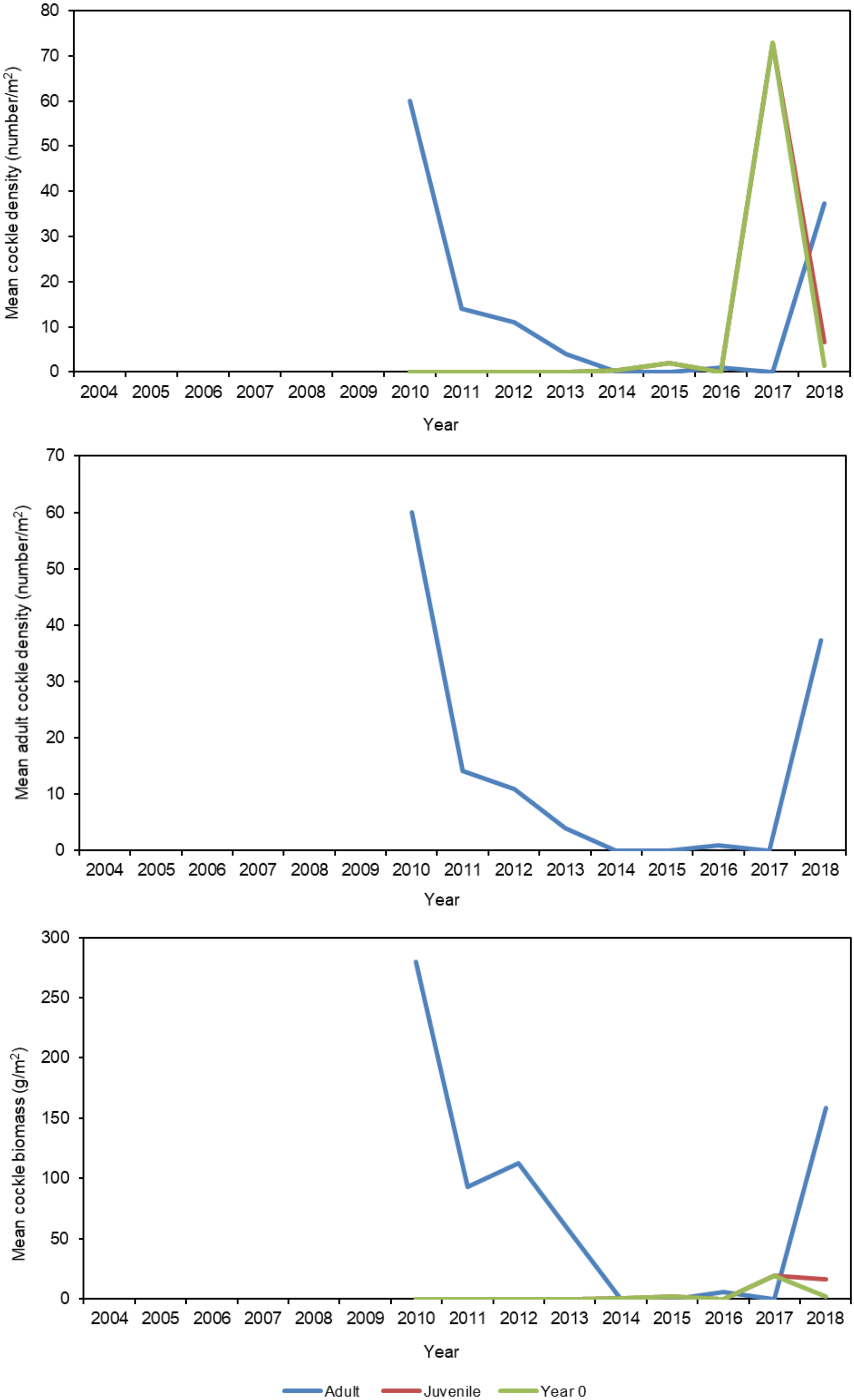


Mean cockle biomass (g/m2)
Year
Adult
Juvenile
Year 0

Styleman's

Whiting Shoal

A relatively fast-growing bed (Jessop *et al*., 2013) not heavily targeted by the dredge fishery between 2001 and 2008 or since the handwork fishery. This bed has only been included in the cockle surveys since 2010 and so data is not available prior to this. Very low densities of year-0 cockles indicate poor spatfalls between 2009 and 2016, resulting in a crash in adult stocks in 2014. However, a large spatfall in 2016 has resulted in an increase in adult stocks over the last couple of years.



Whiting Shoal

Appendix 8: Re-analysis of 2007-2008 Holbeach and IWMK cockle survey data

In 2007 an area of Holbeach was opened to the dredge cockle fishery whilst the rest remained closed due to substrate being predominantly composed of stable muddy sediment. This provided an opportunity to investigate the effects of the dredge fishery on cockle stocks in the open areas of Holbeach, with the closed areas providing a control for comparison (Jessop *et al*., 2007)[22]. In addition to this, the Inner Westmark Knock (IWMK) cockle bed, which is situated close to Holbeach, exhibited similar stock composition and growth rates to those on Holbeach and was also closed to dredging in 2007, providing a further control. Whilst this bed was open to the hand-work fishery in 2007, it was not targeted heavily by the fishery (*Pers. Coms.* Senior Marine Science Officer, Eastern IFCA). Further to the annual spring survey conducted in May 2007 an additional survey was conducted in December 2007 to further investigate the effects on stocks on both Holbeach and IWMK beds.

The data collected from these surveys have been reanalysed by Eastern IFCA to include data collected in the 2008 annual spring survey[23]. In this analysis, only stations which were sampled across all three surveys have been included (May 2007, December 2007 and April 2008), this amounted to 37 stations in the closed area of the Holbeach bed, 90 in the open area of the Holbeach bed and 34 in IWMK (closed to dredging); a total of 151 stations (Figure 1). The mean biomass and density of year-0, juvenile (<14mm) and adult (≥14mm) cockles in the different areas have been plotted across years to investigate differences between closed and open areas.

During the fishery all participating vessels were required to use a riddle screen that had a maximum bar spacing of 14mm and were tested to ensure their equipment damaged no more than 10% of cockles captured.

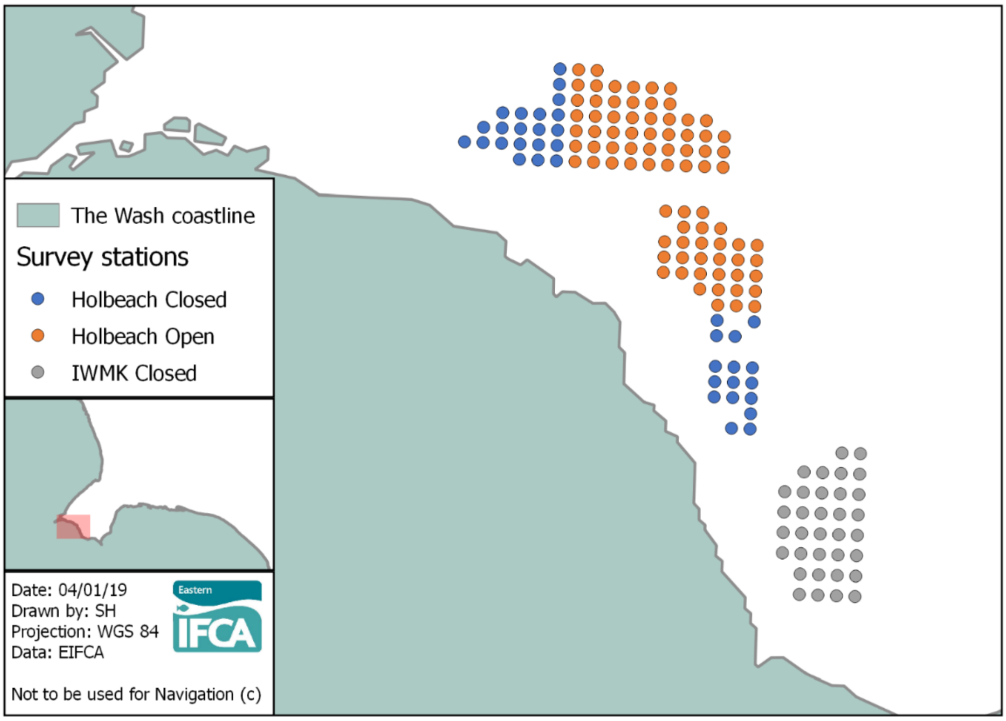


Figure 20 Chart showing the location of the 151 stations sampled across May 2007, December 2007 and April 2008 that were used in the re-analysis of the Jessop et al., (2007) Holbeach and IWMK study into fishery impact on stocks.

[22] It is important to note that whilst the dredge fishery on Holbeach was not conducted in an experimental manner the enforcement of the fishery ensured that dredging only occurred in the open area of the bed. Holbeach was closed to hand-working in 2007.

[23] Re-analysis also included stations with zero cockles (previously omitted in the Jessop *et al*., 2007 study) and removed any stations incorrectly recorded with zero's due to no samples being collected.

Results

Year-0 cockles

High numbers of year-0 cockles during the May 2007 surveys suggest a good spatfall during 2006, followed by a poor spatfall in 2007 (Figure 2). This follows the biennial spatfall patterns generally observed in The Wash, indicating the poor 2007 spatfall is unlikely a result of dredging activity in the open areas in 2007. This is further supported by similar results across both open and closed areas on Holbeach and IWMK beds.

It is important to note that although the charts in Figure 2 show no year-0's in April, this does not mean there was poor recruitment in 2008. The annual spring surveys are carried out in spring before spat have settled; thus, at the time of the 2008 survey, the year-0's would still be the 2007 cohort. The absence of that cohort in both surveys helps to confirm they had not just been missed in one of the surveys.

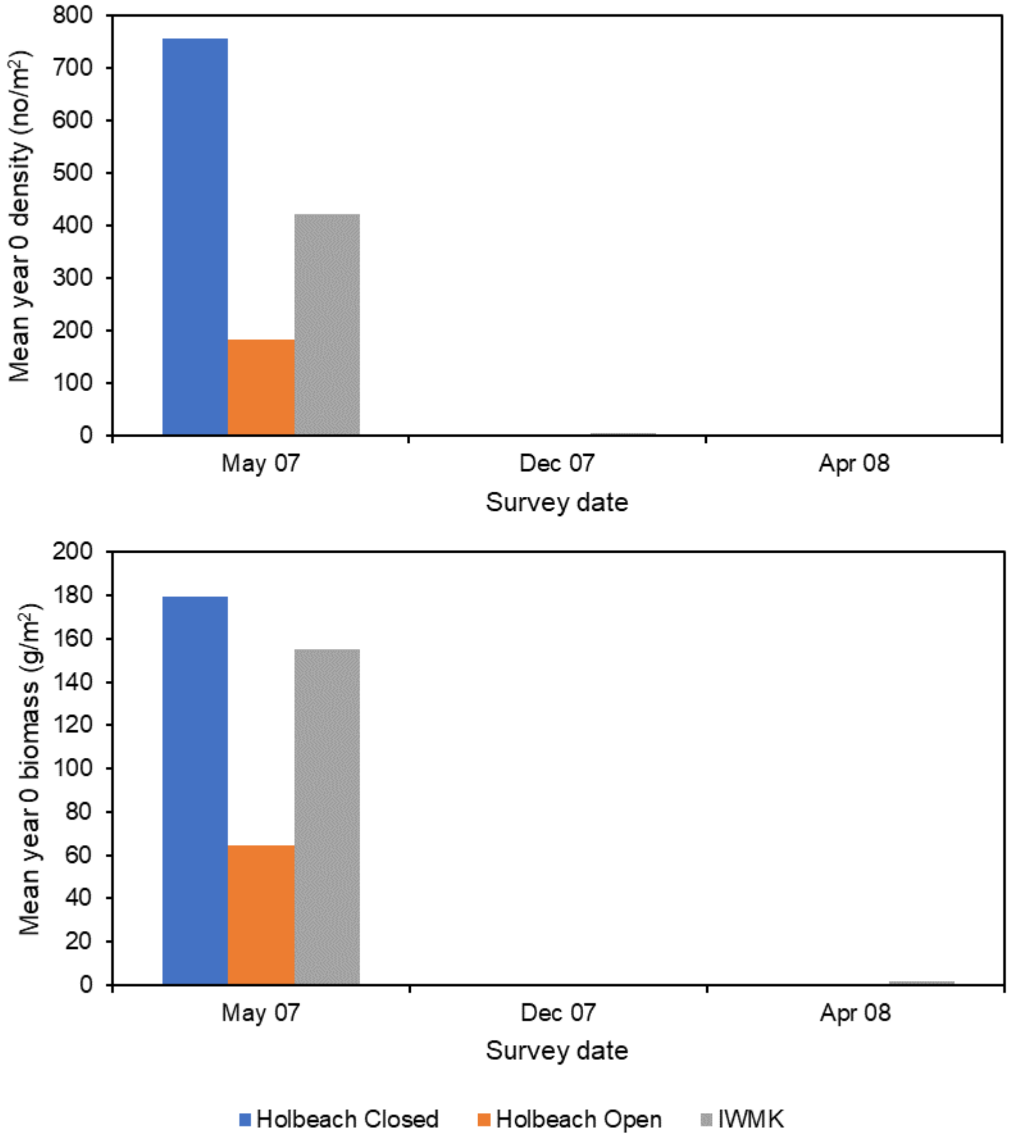


Figure 21 Mean density (no./m^2) and biomass (g/m^2) of year-0 cockles in open and closed areas of the Holbeach and IWMK (closed) in The Wash during May 2007, December 2007 and April 2008 cockle surveys conducted by ESFJC.

Juvenile cockles (<14mm)

Observed decreases in densities of juveniles between May and December 2007 are similar between the open and closed areas of Holbeach and thus has likely resulted from recruitment to the adult population and natural mortality through ridging out, rather than an effect of dredging (Figure 3). The observed increases in biomass in closed areas are likely to reflect growth over summer; however, there appears to be little change in biomass in the open area of Holbeach over time. Fishing mortality and recruitment to the adult population could be having an effect on these stocks, cancelling out any increase in biomass that may have resulted from growth of juveniles.

On IWMK stocks appear much more stable. An increase in biomass over summer indicates growth but a relatively stable density suggests low natural mortality during the summer.

The similarities in stock patterns between the open and closed areas of Holbeach suggests dredging is not the primary cause of declines. However, when comparing effects with those observed on IWMK, it could be postulated that dredging in the open areas of Holbeach could have indirect effects on adjacent sands which may receive increased sediment loads in the water column following dredging events. Such effects are unlikely to impact the stocks on IWMK which are further away. Alternatively, these observed differences between beds could in fact be the result of different environmental and hydrodynamic conditions that act on the beds resulting in different levels of natural mortality.

Decreases in biomass and density between December 2007 and April 2008 are only observed at IWMK indicating low overwinter mortality of juvenile cockles. Overwinter mortality of cockle spat is generally predicted to be high in The Wash as spat are known to provide an import prey resource for an internationally important population of Knot which overwinter in The Wash. During the December 2007 surveys the mean width of juvenile cockles at Holbeach and IWMK was 10mm and 9mm, respectively. Cockles of this size are at the top end of the size range preferred by knot, but at the lower end of the size range preferred by Oystercatcher, possibly reflecting the low mortality observed between December 2007 and April 2008.

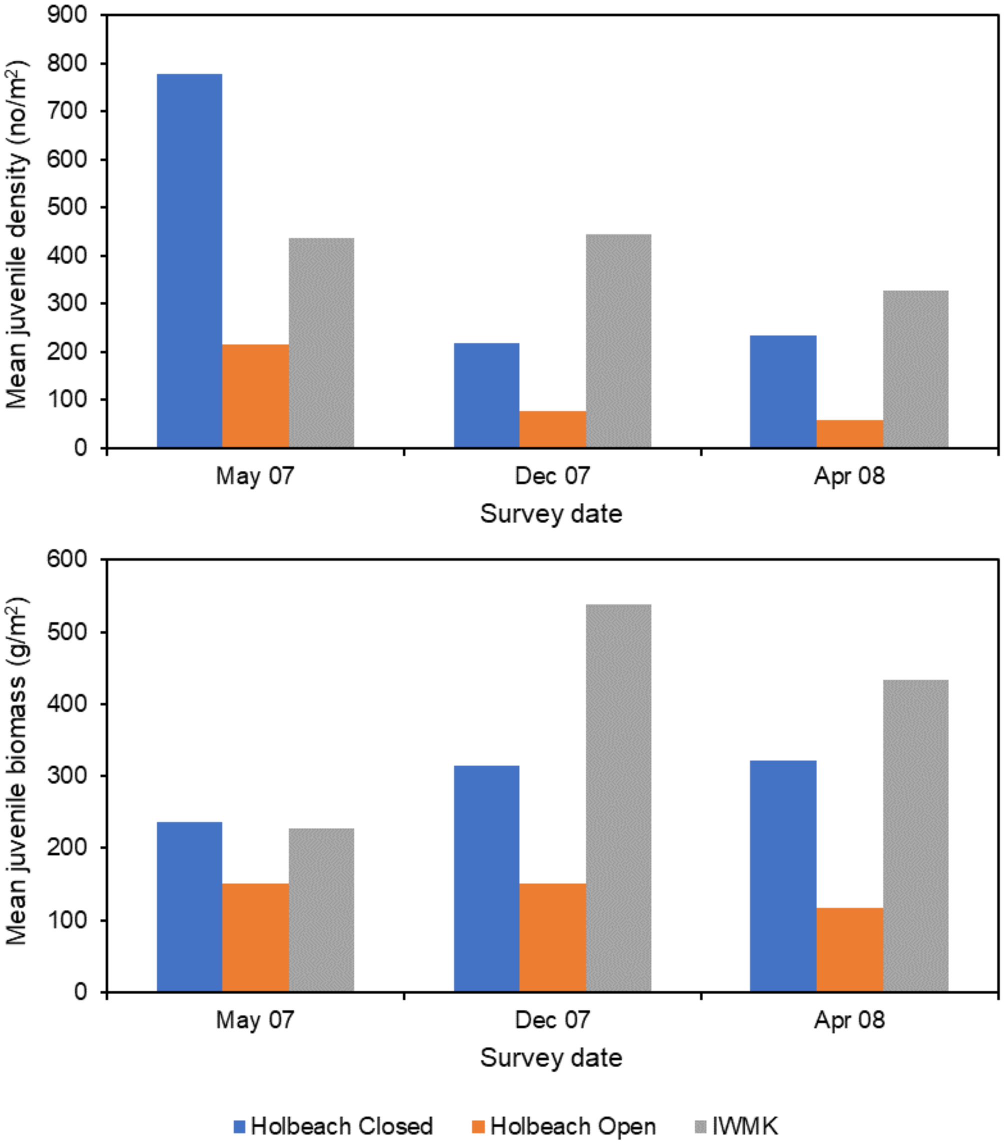


Figure 3 Mean density (no./m²) and biomass (g/m²) of juvenile cockles (<14mm) in open and closed areas of the Holbeach and IWMK (closed) in The Wash during May 2007, December 2007 and April 2008 cockle surveys conducted by ESFJC.

Adult cockles (≥ 14mm)

Similar to the juvenile stocks, decreases in adult cockle density and biomass were observed between May and December 2007 in both open and closed areas of Holbeach but also on the IWMK bed (Figure 4). The observed decreases were similar in the open and closed part of Holbeach, but slightly lower on IWMK. Dredging targets cockles ≥ 14mm so it is expected that fishing mortality of adult cockles will be high in areas open to dredging; however, the similarities observed here, between open and closed areas, suggest other mortalities have a greater impact on adult stocks on both Holbeach and IWMK beds. These impacts are likely to result from natural mortalities such as ridging out or severe weather conditions over summer. At both beds most adults observed during the May 2007 surveys were from the 2004-year class (Jessop *et al*., 2007). Observations over summer on IWMK indicated adult cockles ridging out, likely, forced out of the ground by dense beds of growing juvenile stocks and explain the observed declines in adults in December 2007. This likely also explains the declines observed at Holbeach. In contrast, overwinter mortality appears low across all areas. Internationally important populations of Oystercatcher are known to utilise and overwinter in The Wash and are the main predators of adult cockles that may contribute to high overwinter mortality.

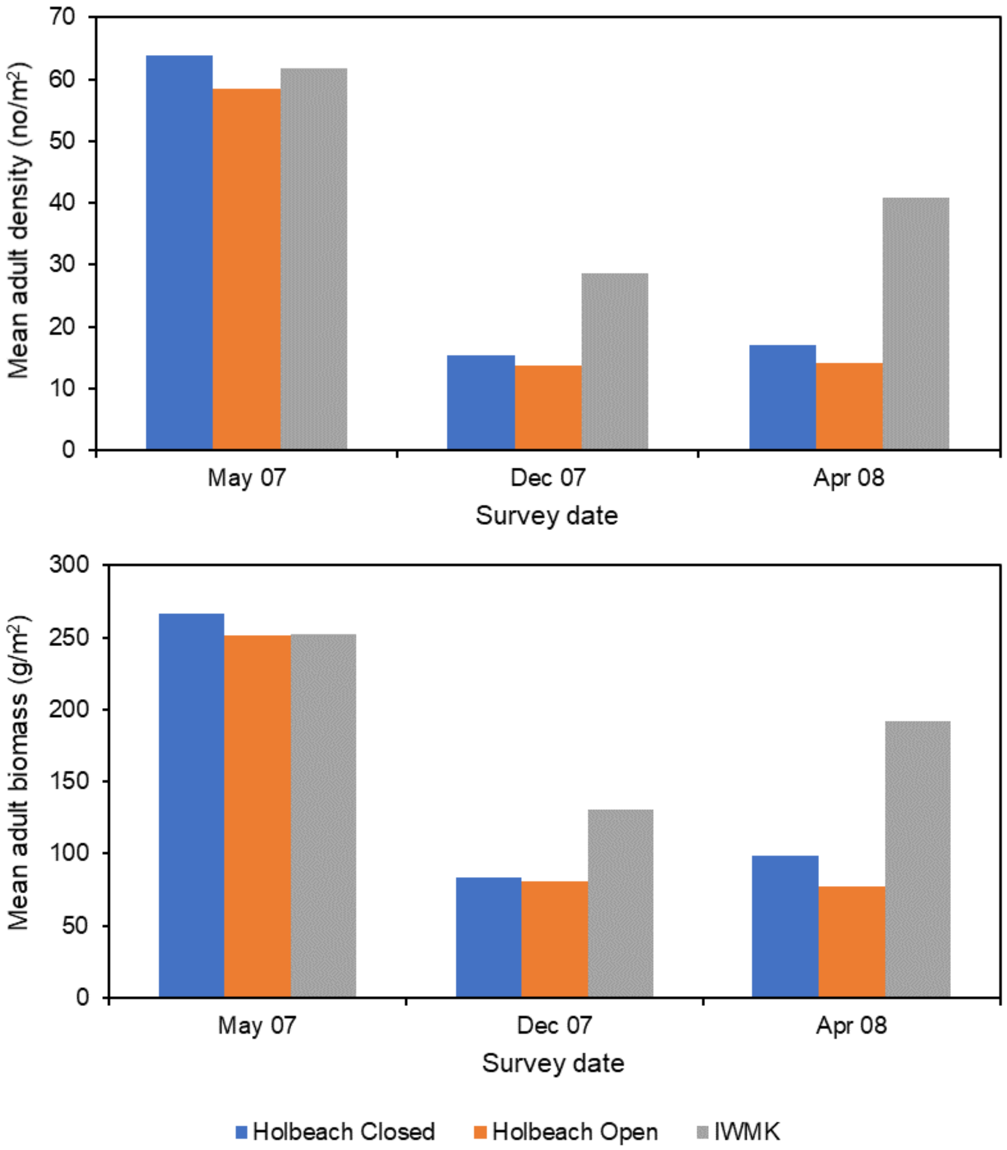


Figure 22 Mean density (no./m²) and biomass (g/m²) of adult cockles (≥14mm) in open and closed areas of the Holbeach and IWMK (closed) in The Wash during May 2007, December 2007 and April 2008 cockle surveys conducted by ESFJC

2006 Year class cockles

Decreases in densities were observed in open and closed areas of Holbeach between May and December 2007 but appeared to remain relatively stable the following winter (Figure 5). A steeper decrease in density was observed in the closed Holbeach site compared to the open area. This is likely due to higher densities to start off with, resulting in increased ridging out and natural mortality. Fishing mortality may also contribute to the declines seen in the open area between May and December 2007.

Increases in biomass are observed in the closed and open areas of Holbeach, at similar rates over the three surveys. IWMK showed a much higher rate of increase in biomass between May and December 2007 but a decrease between December 2007 and April 2008. Decreases in density overwinter are likely a result of natural mortality from bird predation or severe storms. Whilst increases in biomass over summer likely result from growth and lead to increased competition for food and space results in ridging out and decreased densities.

Densities on IWMK appear much more stable than on Holbeach with a small decrease over winter likely caused by natural mortalities and resulting in the observed decrease in biomass during this period.

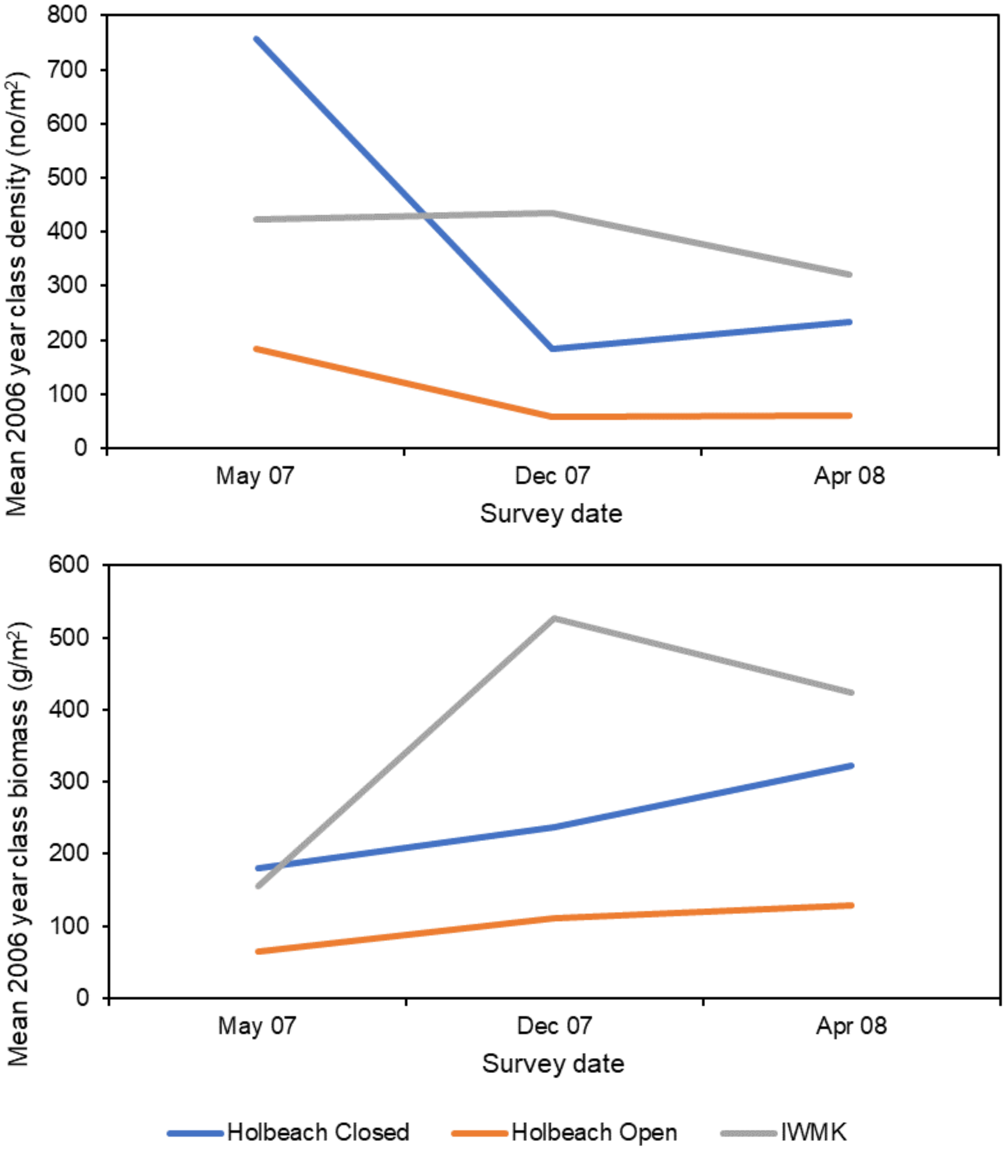


Figure 23 Mean density (no./m²) and biomass (g/m)²of 2006 year class cockles in open and closed areas of the Holbeach and IWMK (closed) beds in The Wash during May 2007, December 2007 and April 2008 cockle surveys conducted by ESFJC.

Conclusions

The results suggest that cockle stocks are much more stable on IWMK than on Holbeach and that natural mortalities are the most likely cause of stock declines observed between May and December 2007. Results show no clear indication of negative effects that could be directly attributed to dredging on juvenile or adult cockles or on the settlement of spat. There is a possibility that dredging in the open areas of Holbeach could have had indirect effects on adjacent sands that are closed, because of increased sediment loads in the water column, however, the observed differences between the two beds could also be a direct result of the different local hydrodynamic conditions that act upon them.

It is important to note that the analysis of this data only provides us with a snapshot of information. The 2009 spring cockle surveys indicated a spatfall in 2008 on Holbeach and IWMK beds. Whilst on both beds these were not as high as previous biennial peaks (2004 and 2006 spatfalls) which were considered very good spatfalls, the 2008 spatfall was considered relatively normal (Appendix 7) (*Pers. Coms.* Senior Marine Science Officer, Eastern IFCA). Furthermore, Holbeach and IWMK beds were both heavily targeted in 2004 by the dredge fishery, the good spatfall observed this year provides further evidence that dredging has not had an effect on spat settlement.