Abundance and distribution of non-native species *Magallana gigas* and *Crepidula fornicata* on the Gat Sand mussel bed in The Wash

Eastern IFCA Research Report

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1.0 Introduction

The establishment and spread of invasive, non-native species has had a dramatic impact on the marine environment over recent decades. Non-native species can threaten native species and natural features, and can interfere with man-made structures and vital industries, including fisheries. The threat to native biodiversity comes in various forms, with non-native species able to displace or prey on native species, as well as to dominate their habitats or introduce new diseases or parasites into an environment (Defra, 2011). Two non-native species have been noted as present on the Gat Sand in The Wash and North Norfolk Coast Special Area of Conservation; the Pacific Oyster, *Magallana gigas* (previously classified as *Crassostrea gigas*), and the Slipper Limpet, *Crepidula fornicata*. The Gat Sand supports a natural mussel bed, which has value both for fishers and for the ecosystem functions it provides as intertidal biogenic reef.

1.1 Introduction of *Magallana gigas*

M. gigas (Figure 1) is a species native to north-east Asia and has been cultivated elsewhere to support shellfish industries where native oyster populations have declined (McKnight and Chudleigh, 2015). The species was introduced for commercial cultivation in the United Kingdom in 1964, when it was imported from British Colombia, Canada (Utting and Spencer, 1992; McKnight and Chudleigh, 2015). Until circa 2005, *M. gigas* was farmed in a small-medium scale operation in the south-west of The Wash (Clay Hole and Black Buoy), however this has not been practiced since. It has since spread around the estuaries and coastlines of the United Kingdom and North-West Europe (Spencer et al., 1994; Troost, 2010). The species have been reported to outcompete native oyster and mussel beds in many areas of Europe (Riese 1998; Nehls et al., 2006; Troost, 2010). This has had major implications for both marine biodiversity and the fishing industry.

Figure 1: Pacific oyster, *Magallana gigas*. © Baker, G. The Marine Biological Association of the United Kingdom. Image courtesy of the Marine Life Information Network (2008).

1.2 Biology of *Magallana gigas*

M. gigas are suspension-feeding bivalves that attach to hard substrates and form reef structures in high densities. They feed by filtering plankton and detritus from the water at a rate of 1.2 – 12.5 $l\ h^{-1}$ $individual^{-1}$ (Troost, 2010). The oviparous shellfish release gametes during periods of high water-temperatures (>20°C), generally in July and August in the Northern Hemisphere (Troost, 2010). The species reaches maturity at a shell length of approximately 50 mm, a size that can be reached within the first year of settlement.

1.3 Introduction of *Crepidula fornicata*

C. fornicata (Figure 2) is a species native to the Atlantic coast of North America. It has become widespread along the south coast of England, in the Bristol Channel, along the north-east coast of England and southern Ireland since being introduced in the United Kingdom for commercial cultivation in 1872 (Blanchard, 1997; The Conchological Society, 2014). The species have been located in ‘hot spots’ of high density along the south coast, particularly in estuaries such as the Solent and the Exe, and often coincide with other shellfish species (Devon Sea Fisheries Committee, 2008). In the Dutch Wadden Sea, a similar environment to The Wash, *C. fornicata* have persisted for over 70 years after introduction (Thieltges et al., 2003).

1.4 Biology of *Crepidula fornicata*

C. fornicata is a filter feeder that lives predominantly attached to hard living substrate, including oysters and mussels. In high densities, the species threatens native *Mytilus edulis*, with their attachment known to reduce survival and growth rates of the mussels. There is, however, little experimental evidence that indicates *C. fornicata* are a trophic competitor of *M. gigas* (Riera et al., 2002; Thieltges et al., 2003, Strasser and Reise, 2005), explaining the joint presence and success of the two species on the Gat Sand.

Figure 2: Slipper limpet, *Crepidula fornicata*. © Crown Copyright 2009 Image courtesy of the GB Non-Native Species Secretariat (2017).

2.0 Materials and methods

Eastern Inshore Fisheries and Conservation Authority (Eastern IFCA) officers have undertaken annual low-water foot surveys since 2014 to assess the density, size and distribution of *M. gigas* and *C. fornicata* within and around the Gat Sand mussel bed. A single earlier survey for *M. gigas* was also conducted in 2009.

2.1 Data collection

In 2017, the annual foot survey was undertaken between 11:00 and 14:00 on October 18 by three teams of two officers. As in previous years, five parallel 800 m east-west transects were walked, 400 m apart, to create a rectangular grid that covered approximately 0.32 km^2 of the Gat mussel bed. Within this grid, 42 circular stations (each with a diameter of 10m) were searched for *M. gigas* and *C. fornicata* during a two-minute timed search by two officers (Figure 5). Organisms found were collected and placed together for counting and measuring after the search ended.

Following the search, the number of individual oysters identified within the circle were counted and measured (length of shell from hinge to furthest point) (Figure 3). The number of slipper limpet stacks found during the search was also recorded, along with the number of individuals within each stack.

Figure 3: Eastern IFCA officer uses calipers to measure the length of a Pacific Oyster on the Gat Sand during the 2017 survey.

Additional information on substratum type was recorded for all 41 sample stations based on a visual assessment of sediment against a scale described in Table 1.

Table 1: Sediment scale used by Eastern IFCA for visual characterisation of sediment type during intertidal cockle and non-native species surveys.

Number	Sediment Description
1	Sand (Clean sand)
2	Silty Sand (Mainly sand, but contains some finer material)
3	Sandy Silt (Mainly fine silt but contains some coarser sand grains)
4	Silt (Fine silty mud)
5	Clay with a thin top veneer of sand (Clay sediments are more compact and solid than silt).
6	Clay with a thin top veneer of silt (Clay sediments are more compact and solid than silt)
7	Clay (Clay sediments are more compact and solid than silt)

Table 2: Materials used in the Pacific oyster and slipper limpet surveys.

Material	Specifications	Number required
Stakes		6
Rope	5m	3
Stopwatches		3
Callipers	Sufficient in size to measure Pacific Oysters	3
Handheld GPS		3
VHF Radios		3
Recording sheets		3
Pencils		3
Clipboards		3
Substrate sheets		3

2.2 Study area

The annual foot surveys were conducted on the Gat Sand in The Wash. The Gat Sand forms part of the intertidal mudflat and sandflat complex in The Wash embayment on the East coast of England. The Gat Sand is located on the western side of The Wash, and is bounded to the north and south by the Gat and Main End Channels and to the east by the waters of the central Wash (Figure 4). The Gat Sand harbours one of the largest mussel beds in The Wash; however, like many mussel beds in The Wash, it has shown a general decline in biomass in recent years (Eastern IFCA, 2014).

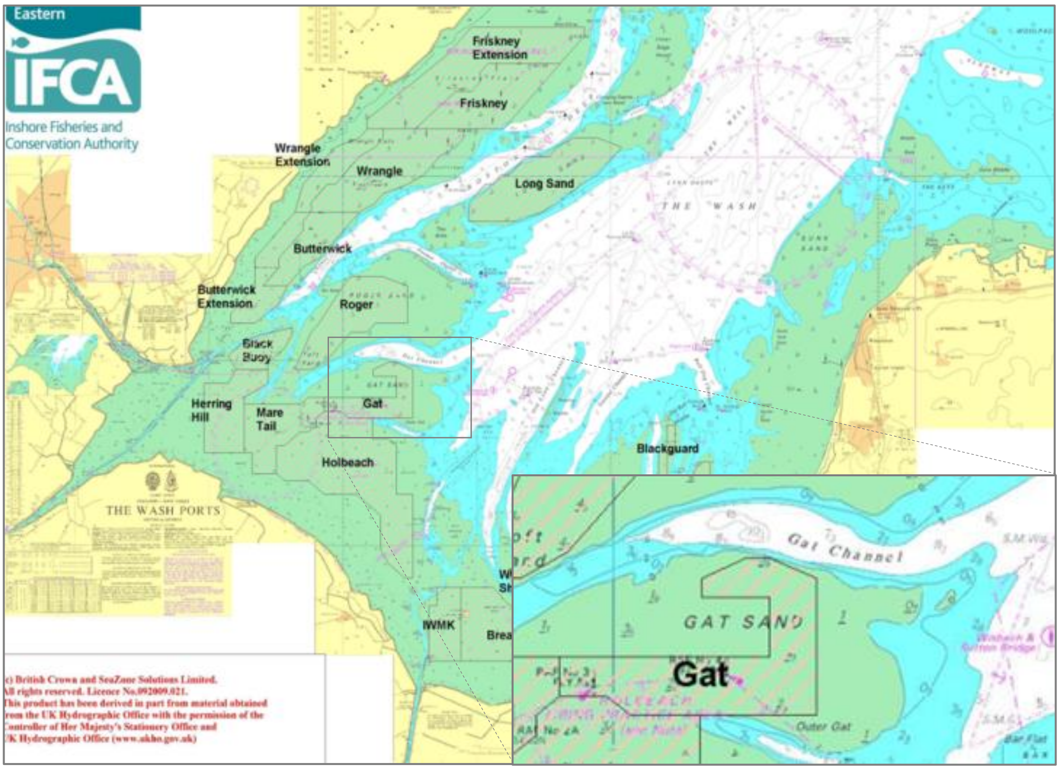

Figure 4: The Gat Sand study area (insert) within The Wash Embayment.

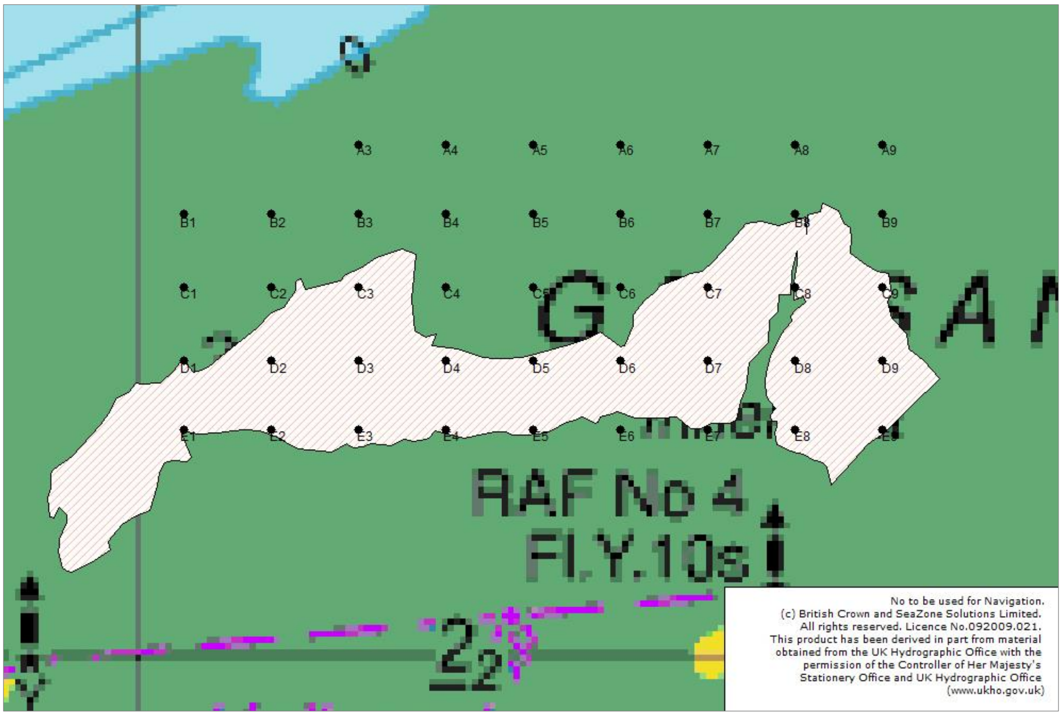

Figure 5: Stations on Gat Sand (A3:E9) searched for *M. gigas* and *C. fornicata*. Chart also shows the area of the sands covered by mussel beds in 2016 (cream). Please note in 2017 station B1 was underwater at the time of surveying and was therefore not studied.

2.3 Data compilation

Prior to processing the data collected in 2017, the data collected during annual surveys in 2014, 2015 and 2016 were compiled into one spreadsheet to allow for inter-annual analysis.

3.0 Results

3.1 Substratum composition

The annual surveys investigated the presence of *M. gigas* and *C. fornicata* in relation to substrate type using a substrate scale (Table 1). Excepting course sand (1), all substrate types were recorded as present on the bed in 2017 (Figure 6). Sandy and silty substrates (2, 3 and 4) were recorded to the north-east of the bed, with a general shift seen towards finer clay substrates (6 and 7) to the south of the bed.

3.2 *Magallana gigas*

The record of substratum type was used to ascertain whether M. gigas distribution was associated with ground type. *M. gigas* were logged on every substrate type recorded on the bed in 2017 (Table 3; Figure 7). The majority (54.0%) of *M. gigas* were found on sandy silt (27.6%) and silt (26.4%), despite this substrate type accounting for only 38.1% of the sampled area. Within the mussel bed, 70% of the stations surveyed supported *M. gigas*, compared to just 55% of stations surveyed outside the mussel bed. The stations surveyed within the mussel bed supported an average of 0.038 individuals m^{-2}. This differed significantly (two-sample t-test; $p < 0.05$) from those stations surveyed on sediment that did not support mussel bed, which supported an average of just 0.016 individuals m^{-2}. It is unclear whether this correlation is directly due to the presence of mussels, or because mussels bio-engineer sediment by depositing mussel mud and pseudo-faeces, which may in turn make finer sediment, more favourable for the settlement of *M. gigas*.

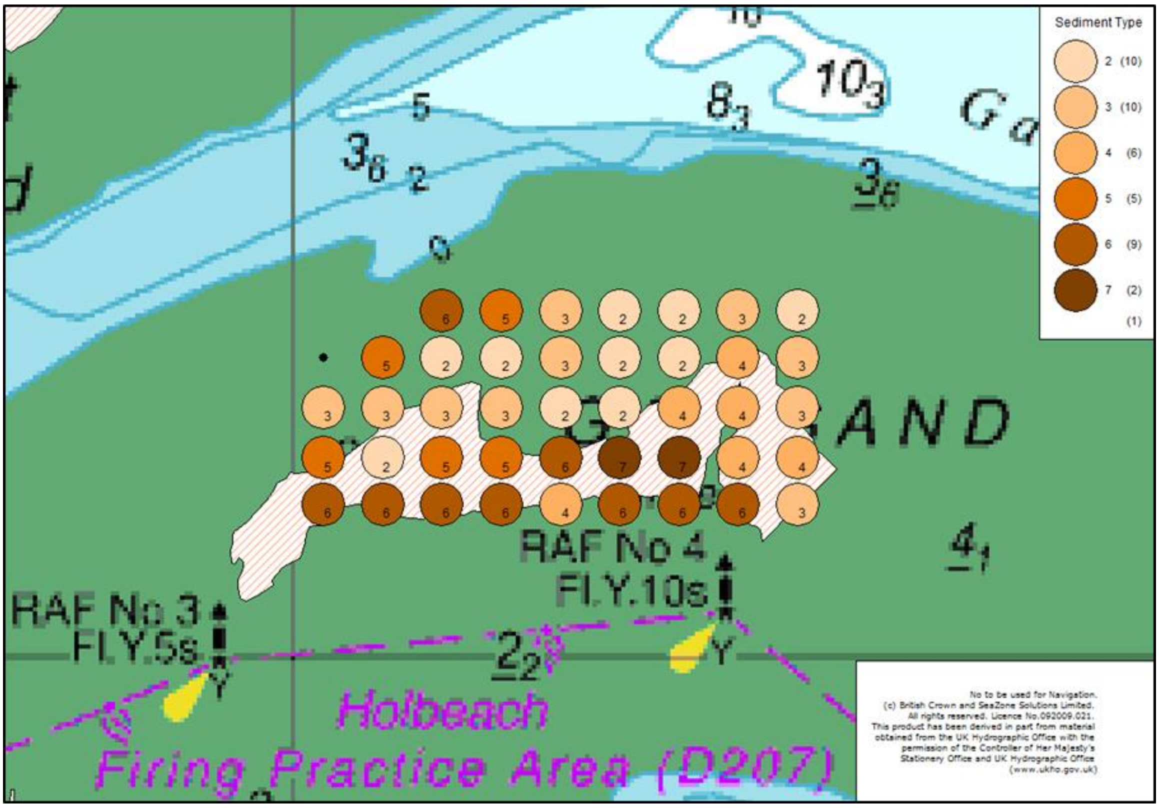

Figure 6: Substratum composition of the sampled stations on the Gat Sand (A3:E9). *N.B.* In 2017 station B1 was underwater at the time of surveying and was therefore not studied.

Table 3: Number and proportion of *M. gigas* recorded on each substrate type recorded in the sampled area of the Gat Sand during the 2017 survey.

Substrate type	Number of sites of each substrate type	Proportion of sites of each substrate type	Number of *M. gigas* recorded	Proportion of *M. gigas* population found on substrate type (%)
Course sand	0	0	0	0
Silty sand	10	23.8	15	17.2
Sandy silt	10	23.8	24	27.6
Silt	6	14.3	23	26.4
Clay substrate with sandy veneer	5	11.9	12	13.8
Clay substrate with silty veneer	9	21.4	9	10.3
Clay	2	4.8	4	4.6

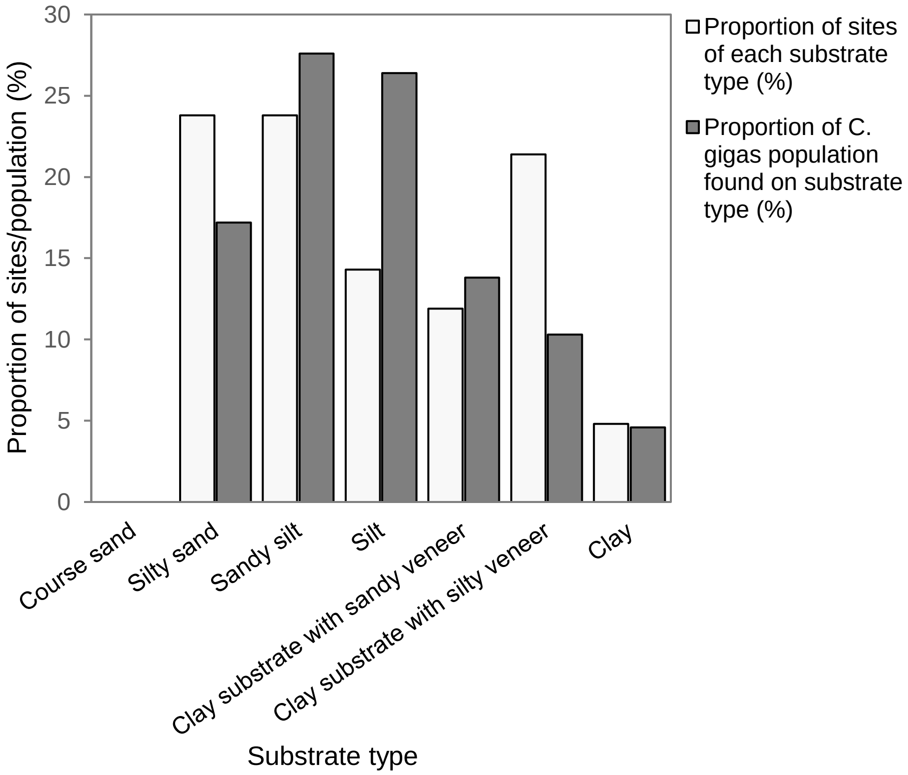

Figure 7: Number and proportion of *M. gigas* recorded on each substrate type recorded in the sampled area of the Gat Sand during the 2017 survey.

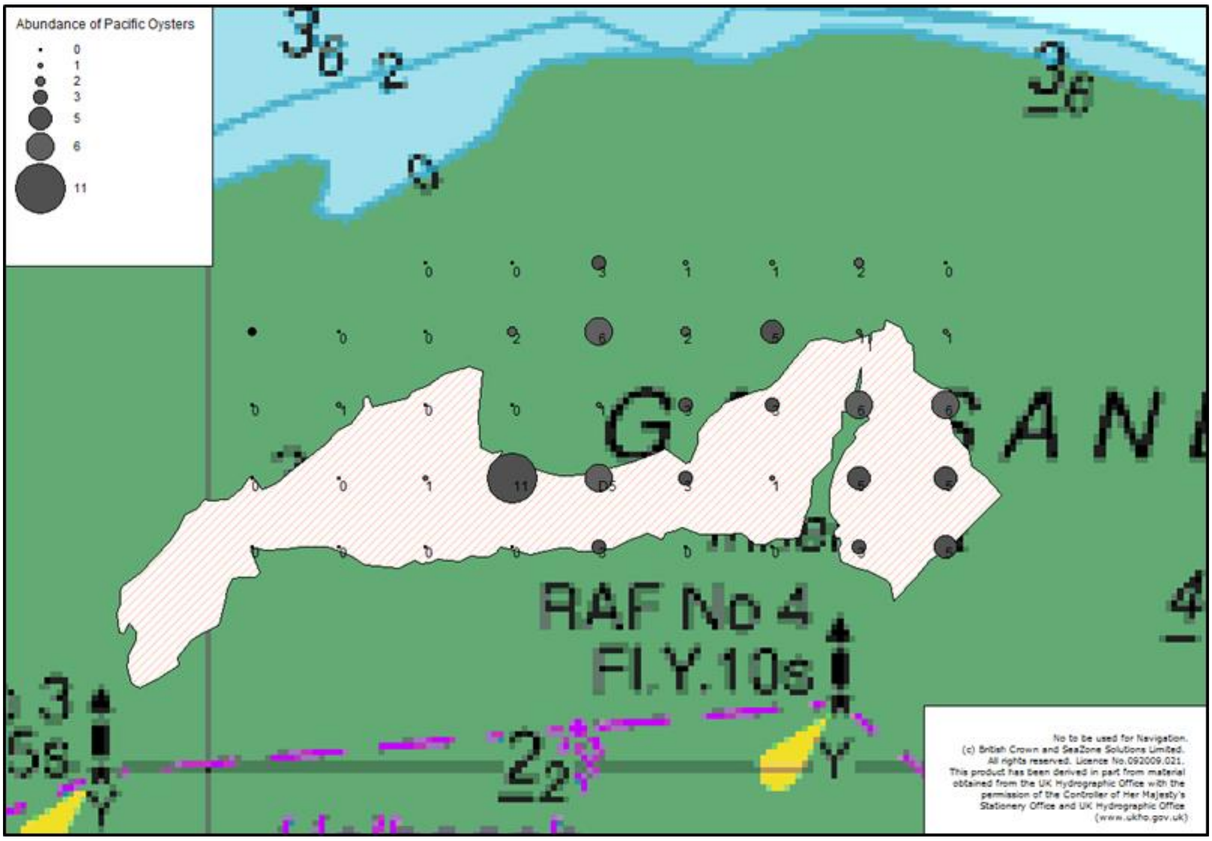

Figure 8: Abundance of *M. gigas* at each station on the Gat sand during the 2017 survey.

During the 2017 survey, 87 *M. gigas* were recorded at 42 stations on the Gat, measuring between 59 mm and 227 mm in length. There was a two-fold increase in *M. gigas* abundance in 2017 compared to 2016, when just 42 *M. gigas* were found in the same areas. There were also significantly more oysters recorded than in the 2014 and 2015 surveys, when 54 and 60 oysters were reported, respectively. Size ranges were similar to those recorded in previous years (2016: 45 - 240 mm; 2015: 70 - 227 mm; 2014: 38 - 204 mm) (Figure 9). However, the majority of the oysters in 2017 measured between 75 mm and 99 mm (29 individuals; 33.33% of population). This peak in size distribution was at much smaller length than those recorded in 2014, 2015 and 2016, when the majority of oysters measured between 125 mm and 174 mm. Coupled with the increase in abundance seen in 2017, this suggests there has been a recent successful settlement of *M. gigas* resulting in a change in the peak sizes caused by input of new recruits into the population. Based on the sizes of *M. gigas* reported, these were likely recruited into the population in 2015 or early 2016.

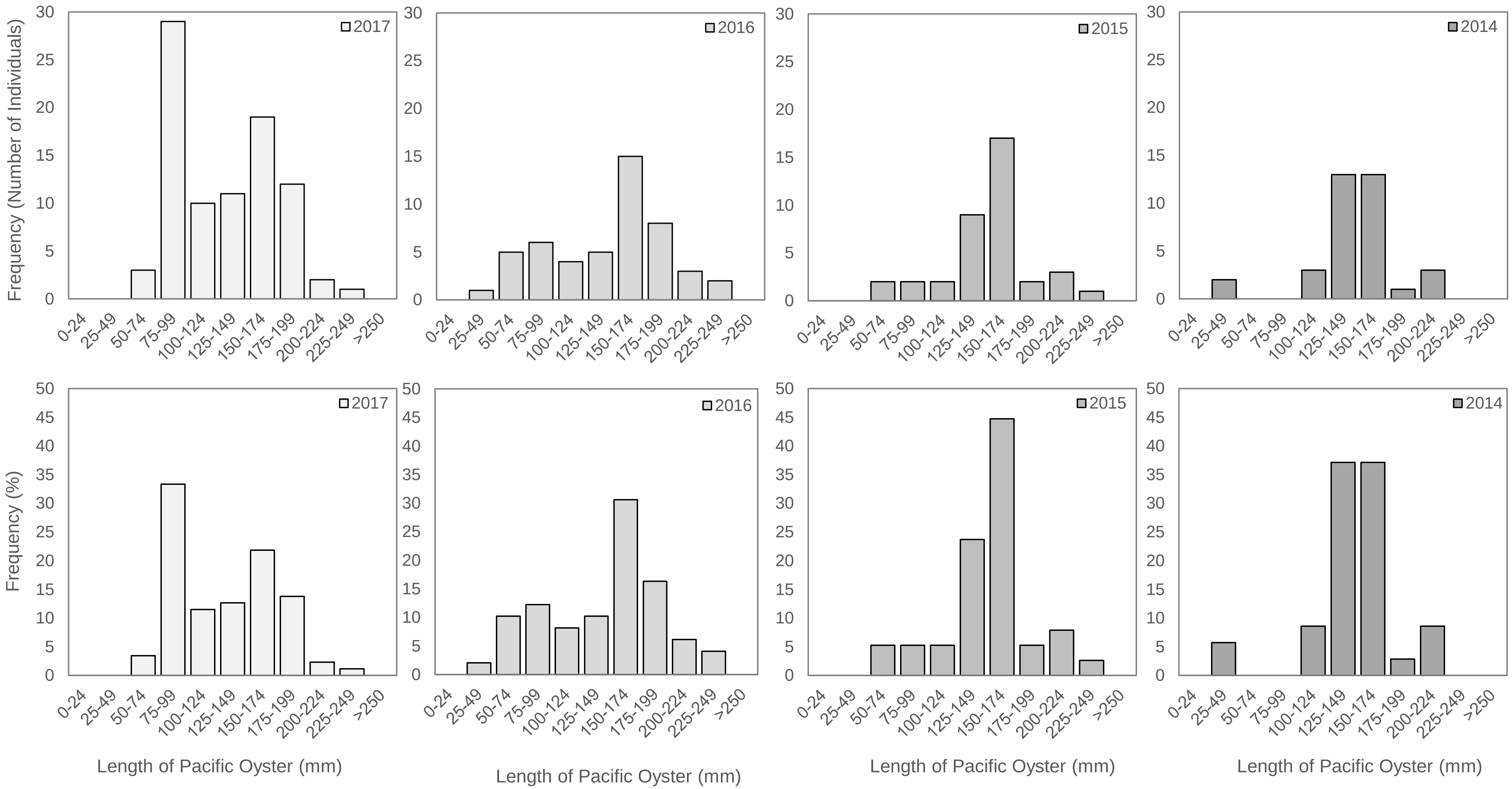

Figure 9: Length frequency distribution of *M. gigas* obtained on the Gat Sand in 2014, 2015, 2016 and 2017. Locations of stations sampled remained constant each year, although some years station B1 was inundated (2015, 2016 and 2017). Frequency displayed as percentage of total number of *M. gigas* recorded (top) and as number of individuals recorded (bottom).

3.3 *Crepidula fornicata*

In 2017, there were 117 *C. fornicata* recorded on the Gat over 32 stacks. These were irregularly distributed, with one sample site supporting a dense aggregation of 71 *C. fornicata* spread over 19 stacks. Average density of *C. fornicata* in sampled areas was 0.04 individuals m^{-2}, with sites supporting between 0 and 0.9 individuals m^{-2} each. An increase in abundance of *C. fornicata* was noted towards the south of the bed, with 105 of 117 individuals found in search areas on the southern-most transect (Figure 10). Apart from within this transect, no *C. fornicata* were found inside the boundaries of the mussel bed.

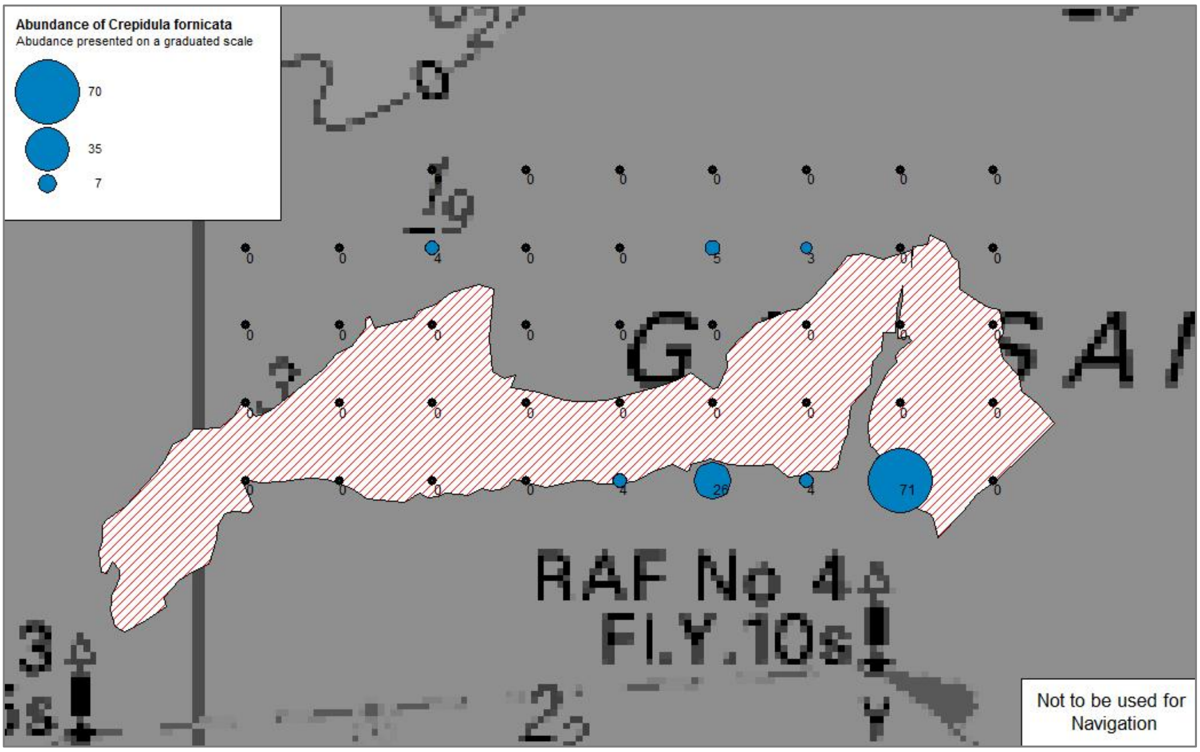

Figure 10: Abundance of *Crepidula fornicata*, presented on a graduated scale, at each survey point on and around the Gat Sand mussel bed (red striped) during the 2017 survey.

The 117 *C. fornicata* recorded in 2017 is significantly higher than any abundance of *C. fornicata* recorded in previous years, which ranged between 8 and 49 individuals over the entire surveyed area.

4.0 Discussion

Data collected in annual surveys of the Gat Sand has been used here to assess and compare the distribution and abundance of two key invasive species in The Wash. Results have shown that both *M. gigas* and *C. fornicata* have persisted in the area since 2009 and 2014, respectively, when Eastern IFCA first surveyed the bed for each species (Eastern Sea Fisheries Joint Committee, 2009; Eastern IFCA, 2014).

4.1 *Magallana gigas*

In 2008 an assessment concluded that there was a medium-high risk of *M. gigas* populations expanding in The Wash and North Norfolk Coast European Marine Site at the time. The species has no natural predators in The Wash, with its most likely predators the eider and oystercatchers unlikely to predate on *M. gigas* while *Mytilus edulis* are available. The assessment also identified, however, that certain local factors including the minimal parent stock and lack of hard settlement substrata could limit the spread of *M. gigas* (Eastern Sea Fisheries Joint Committee, 2009).

In 2009, average density of *M. gigas* across the entire survey area was 0.03 individuals m^{-2}, a density slightly higher than has been recorded in more recent surveys (Figure 11). It is however unclear to what extent the differing survey methods and areas studied could have influenced this result. In 2009 a greater area was surveyed, with a total of 99 survey stations over eight parallel east-west transects, compared with 42 stations over five east-west transects in more recent surveys.

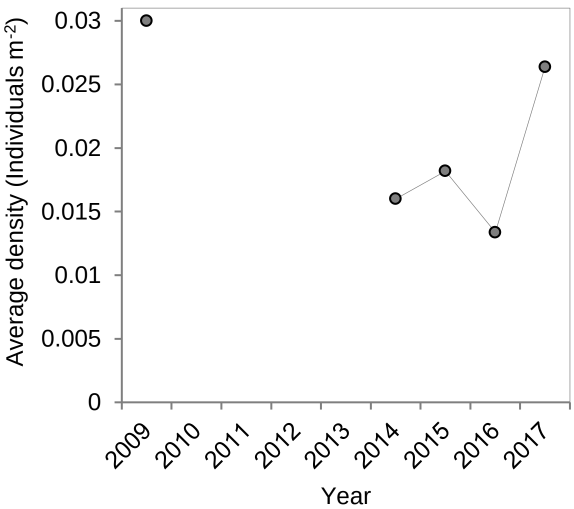

Figure 11: Average density of *M. gigas* within the surveyed area of the Gat Sand bed during each year surveyed (2009, 2014, 2015, 2016 and 2017). Please note survey methods differed between the 2009 survey and later surveys.

At the densities seen on the Gat Sand on each year surveyed, *M. gigas* are unlikely to be spatially-limited for growth as food available per individual is likely to remain high at these low densities (Hadley and Manzi, 1984; Honkoop and Bayne, 2002) and physical contact between individuals is limited (Honkoop and Bayne, 2002).

The Wash is a nationally and internationally important region for shellfisheries, and its mussel beds are of high industrial and conservation value. There has been concern over the health of the natural mussel beds since 2010, when after recovery from overfishing in the 1990s, high mortalities caused the biomass of the population to decline significantly. Populations have been fluctuating in biomass since 2010. The recent decline seems to be the result of a combination of poor recruitment coupled with high mortalities of three-year old mussels. The cause of the mortalities is currently unknown, but is thought to be linked to parasitic infection of mussels by *Mytilicola intestinalis* (Eastern IFCA, *pers. comm.*). Other possible causes of decline could be factors such as interspecific competition, parasitic infection, overfishing, and natural variation. If the *M. gigas* population increases to such levels that it forms reefs, as have occurred in other areas, they could pose a threat to the distribution of natural mussel beds.

4.2 *Crepidula fornicata*

Compared to the density of introduced *C. fornicata* in other areas of the United Kingdom and Northern Europe, the densities recorded on the Gat are extremely low and not currently problematic. Thieltges et al. (2003) recorded nearly 100 individuals m^{-2} in coastal waters off Denmark, Germany and Norway, remarking that these were low by comparison to superabundance recorded off the South Coast of England and the Dutch coast, which have supported several thousand individuals per metre squared in some locations. By comparison, the Gat was found to support a maximum density of 0.9 individuals m^{-2}, on the south east of the bed, with an average density across the sands of just 0.4 individuals m^{-2}.

Despite the species only occurring in relatively low numbers, sessile marine invertebrates like *C. fornicata* that have long-lived pelagic larvae are thought to be efficient colonizers that are able to spread quickly over large distances in the right conditions (Pechenik, 1999; Kinlan and Gaines, 2003; Viard et al., 2006). If the species began to settle at higher densities on the Gat, or spread rapidly to other areas, it could have major implications for native macro-benthic fauna and community composition (Thieltges et al., 2003; Viard et al., 2006). Continued monitoring of the abundance and distribution of the species is therefore crucial to maintaining the native mussel beds on the Gat. If the population of *C. fornicata* on the Gat continues to show rapid increases over time and/or spreads further into the mussel bed, Eastern IFCA may want to consider measures to manage the population.

4.3 Recommendations for biosecurity management on the Gat

4.3.1 Continuation of annual monitoring

Knowledge of the distribution and abundance of invasive non-native species is crucial to preventing and managing their spread within the district. Annual surveys should continue to monitor the presence of both species on the Gat.

4.3.2 Changes to methods used to monitor non-native species

In future surveys, conducting two separate searches, one for *M. gigas* and one for *C. fornicata*, may produce more accurate results for both species. Each officer involved in a two-minute search could look for one of the species.

To support the annual Gat sand surveys and to increase understanding of the distribution of invasive non-native species within the Eastern IFCA district, a biosecurity database accessible to all Eastern IFCA officers was set up in November 2017. This will be used on an opportunistic basis during other research and marine protection work to record sightings of invasive non-native species.

4.3.3 Biosecurity review

The Eastern IFCA 2018 review of biosecurity monitoring, management and contingency plans will reflect on the changes in abundance and densities of *M. gigas* and *C. fornicata* recorded in this study.

5.0 References

Blanchard, M., **1997**. Spread of the slipper limpet *Crepidula fornicata* (L. 1758) in Europe. Current state and consequences. *Science Marine*, 61, 109 - 118.

Department for Environment, Food and Rural Affairs, **2011**. Biodiversity Strategy 2020.

Eastern IFCA, **2013**. Eastern Inshore Fisheries and Conservation Authority Research Report. Available online at: http://www.eastern-ifca.gov.uk/wp-content/uploads/2016/03/Annual-research-report-2013.pdf Accessed 1 November 2017.

Eastern Sea Fisheries Joint Committee, **2009**. Pacific oyster in The Wash: A cause for concern? 1 - 7.

Hadley, N.H. and Manzi, J.J., **1984**. Growth of seed clams, *Mercenaria mercenaria*, at various densities in a commercial scale nursery system. *Aquaculture*, 36, 369 - 378.

Honkoop, P.J.C. and Bayne, B.L., **2002**. Stocking density and growth of the Pacific oyster (*Crassostrea gigas*) and the Sydney rock oyster (*Saccostrea glomerata*) in Port Stephens, Australia. *Aquaculture*, 213(1), 171 - 186.

Kinlan, B.P and Gaines, S.D., **2003**. Propagule dispersal in marine and terrestrial environments: a community perspective. *Ecology*, 84, 2007 - 2020.

Nehls, G., Diederich, S., Thieltges, D.W. and Strasser, M., **2006**. Wadden Sea mussel beds invaded by oysters and slipper limpets: competition or climate control? *Helgoland Marine Research*, 60, 135 - 143.

Pechenik, J.A., **1999**. On the advantages and disadvantages of larval stages in benthic marine invertebrate life cycles. *Marine Ecology Progress Series*, 177, 269 - 297.

Reise, K., **1980**. Pacific oysters invade mussel beds in the European Wadden Sea. *Marine Biodiversity*, 28(4), 167 - 175.

Spencer, B.E., Edwards, D.B., Kaiser, M.J. and Richardson, C.A., **1994**. Spatfalls of the non-native Pacific oyster, *Crassostrea gigas*, in British waters. *Aquatic Conservation and Marine and Freshwater Ecosystems*, 4(3), 203 - 217.

The Conchological Society of Great Britain and Ireland, **2014**. The current distribution of the American Slipper Limpet, *Crepidula fornicata* (L. 1758). Available online at: http://www.conchsoc.org/projects/crepidula-forn.php. Accessed 1 November 2017.

Thieltges DW, Strasser M. and Reise K., **2003**. The American slipper limpet *Crepidula fornicata* (L.) in the northern Wadden Sea 70 years after 1st introduction. *Helgoland Marine Research*, 5, 27 - 33.

Troost, K., **2010**. Causes and effects of a highly successful marine invasion: Case-study of the introduced Pacific oyster *Crassostrea gigas* in continental NW European estuaries. *Journal of Sea Research*, 64, 3, 145 - 165.

Utting, S.D. and Spencer, B.E., **1992**. Introductions of bivalve molluscs into the United Kingdom for commercial culture - case histories. *International Council for the Exploration of the Seas Marine Science Symposium*, 194, 84 - 91.

Viard, F., Ellien, C. and Dupont, L., **2006**. Dispersal ability and invasion success of *Crepidula fornicata* in a single gulf: insights from genetic markers and larval-dispersal model. *Helgoland Marine Research*, 60(2), 144.