Report on the possible expansion of the invasive, non-native slipper limpet population (*Crepidula fornicata*) on Wash Fishery Order 1992 shellfish lays

E. S. Quinn, May 2018

1. Summary

On April 3, 2018 Marine Science Officers conducting a cockle survey near the Wash Fishery Order Toft Lays reported unusually high densities of the invasive slipper limpet *Crepidula fornicata*, at greater numbers than previously known in The Wash. Blue mussel (*Mytilus edulis*) beds in The Wash are known to support a widespread, but low density, population of the invasive species. A foot survey of the lays was undertaken on May 1, 2018 to further assess the situation of slipper limpets on the lays. Following on from this survey management options will be investigated, as required.

2. Slipper limpets: their introduction and success in the UK

The American slipper limpet *Crepidula fornicata* (Fig. 1) is a highly successful, invasive non-native marine gastropod that was unintentionally introduced to Great Britain in the late 1800s. The species, which is listed under Schedule 9 of the Wildlife and Countryside Act 1981 and is listed on the IUCN list of problematic alien species, is now well established around the British coast (Fig. 2 Records of Crepidula fornicata presence in the UK (map from National Biodiversity Network Gateway UK, 2011). Adults live on the seabed on a variety of surfaces, often attached to the shells of hard-shelled invertebrates such as mussels, whelks and crabs (Fig. 1). The species has been known to reach extremely high densities in wave protected muddy areas (GB Non-Native Species Secretariat, 2016), and are well studied in the Wadden Sea, the Solent, the Salcombe estuary and other muddy marine environments.

Fig. 1 Stacks of the American slipper limpet *Crepidula fornicata* attached to an empty blue mussel *Mytilus edulis* shell (left) and a live common cockle *Cerastoderma edule* (right) in The Wash. Photographs taken by Eastern IFCA officers in early 2018.

The success of the slipper limpet can be attributed to several biological characteristics that aid rapid population development and increase the species tolerance to new environments. The species is characterised by colony formation, hermaphroditism, long egg-laying period, pelagic larvae, generally strong reproductive viability[1], and a tolerance of a wide range of environmental conditions (including temperatures and salinities) (Diederich et al., 2011; Schubert, 2011; Blanchard, 2009). Furthermore, the species has high potential for both natural and anthropogenic dispersal[2], and their success is spread by an absence of natural predators of the species in British waters.

[1] Slipper limpets are protandrous hermaphrodites that start their lives as males before subsequently changing sex. Breeding can occur between February and October, with peak activity in May and June when 80%-90% of females spawn. Most spawn twice a year (Rayment, 2008). Females can lay >12,000 eggs per spawning event (Deslou-Paoli and Heral, 1986; Richard et al., 2006; Rayment, 2008).

[2] Anthropogenic dispersal is highly likely. It can occur via discharge of ballast water (larvae), hull fouling (juveniles and adults), and movements of shellfish for aquaculture (juveniles and adults) (Bohn, 2012).

At low levels, slipper limpets pose little threat to fisheries or the environment (Fitzgerald, 2007). At high concentrations, however, slipper limpets may be considered as threats to native mussels in The Wash, which provide the main substrate for the species to settle on. The ecological and fisheries impacts of *C. fornicata* settlement include:

- Reduced growth rate and survival of blue mussels. Thieltges et al. (2005) reported a fourfold to eightfold reduction in the survival of mussels fouled with slipper limpets and reported shell growth in surviving mussels with attached *C. fornicata* was three to five times lower than in unfouled individuals.
- Modified trophic structure of benthic communities where dense populations of slipper limpets settle (Hily, 1991; Chauvaud et al., 2000; Thieltges et al., 2003)
- Changes in sediment composition and near-bottom currents and dynamics due to the accumulation of pseudofaeces and fine sediment because of the filtration of slipper limpets as well as individuals protruding in stacks into the water column (Thieltges et al., 2003)
- Changed microbenthic community composition (Barnes et al., 1973; De Montaudouin and Sauriau, 1999; De Montaudouin et al., 1999; Thieltges et al., 2003)
- Requirement for expensive cleaning operations of landed mussels to remove slipper limpet fouling (Blanchard, 1997; Thieltges et al., 2003)

2.1. Known distribution and extent slipper limpets

The Wash currently supports a relatively small but widespread population of the invasive slipper limpets, with sightings of the species recorded on a number of mussel beds over the 2017/2018 winter[3] (Fig. 3), and anecdotal evidence from fishers suggesting the species are present throughout The Wash, although at varying densities. Habitat for organisms requiring hard substrate within The Wash is mainly restricted to natural mussel beds and private mussel lays, with slipper limpets regularly recorded on both dead and live mussel shell. The annual WFO cockle survey in 2018 brought up cockle on the Holbeach bed that supported a stack of three slipper limpets, the first indication that the species could pose a threat to cockles as well as mussels within The Wash. There have also been sightings nearby on the North Norfolk Coast of *C. fornicata* settled on landed common whelks *Buccinum undatum* and edible crabs *Cancer pagarus*. These are mobile species that can act as natural vectors for the transport and spread of slipper limpets.

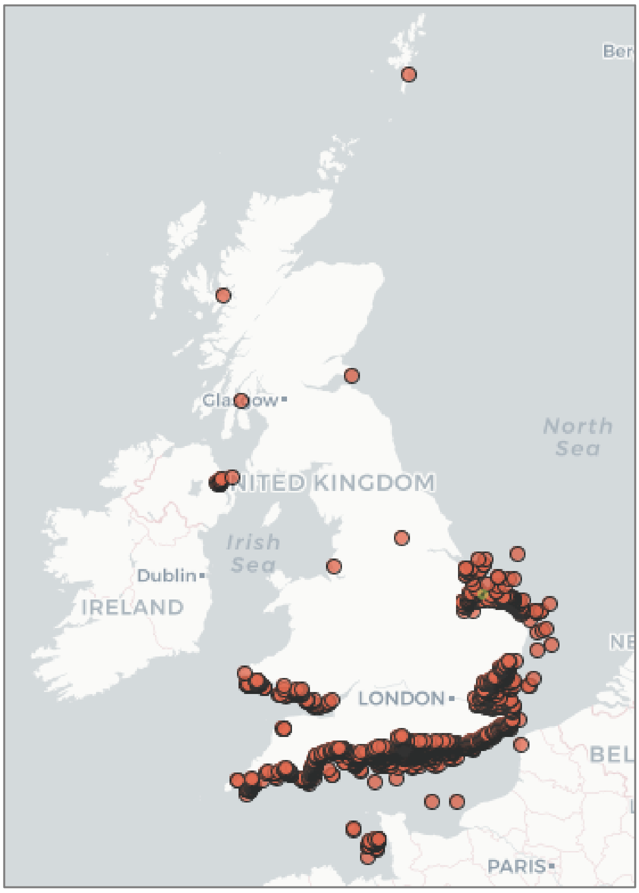

Fig. 2 Records of *Crepidula fornicata* presence in the UK *(*map from National Biodiversity Network Gateway UK, 2011*).*

[3]Sightings of invasive species have been recorded on an opportunistic basis during research and marine protection work by Eastern IFCA officers since late November 2017.

Thus far in The Wash, the slipper limpet population has been thought to be small enough that it has posed little threat to fisheries or the environment (Fitzgerald, 2007). Annual surveys of the Gat mussel bed to the west of The Wash supported the assumption that the species only existed at low densities, with the bed supporting <1 slipper limpets m^{-2} (Fig. 4) (Eastern IFCA, 2017), compared to problematic numbers of >100 individuals m^{-2} in coastal waters off Denmark, Germany and Norway (Thieltges et al., 2003). Despite the species only occurring in relatively sparse numbers thus far, 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). At higher densities, slipper limpets could threaten mussel beds in The Wash. A foot cockle survey near the Toft lays on April 3, 2018 indicated much higher abundances than previously known on the private lays in the area. If this is the case, it could have major implications for native macro-benthic fauna and community composition (Thieltges et al., 2003; Viard et al., 2006). A survey was planned for May 1, 2018 to assess the distribution and abundance of slipper limpets on the private mussel lays.

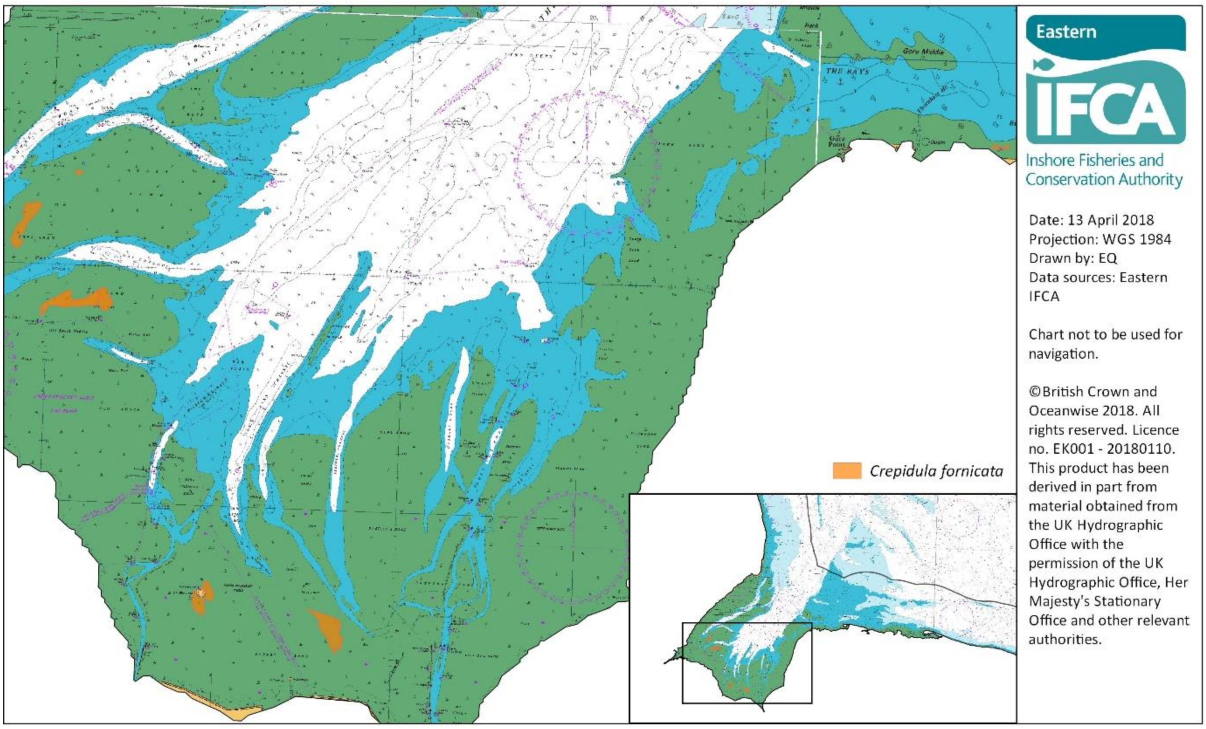

Fig. 3 Blue mussel beds known to support populations of American slipper limpets (orange) according to sightings recorded over the 2017/18 winter period. *N.B*. The true distribution of the species is thought to be much broader.

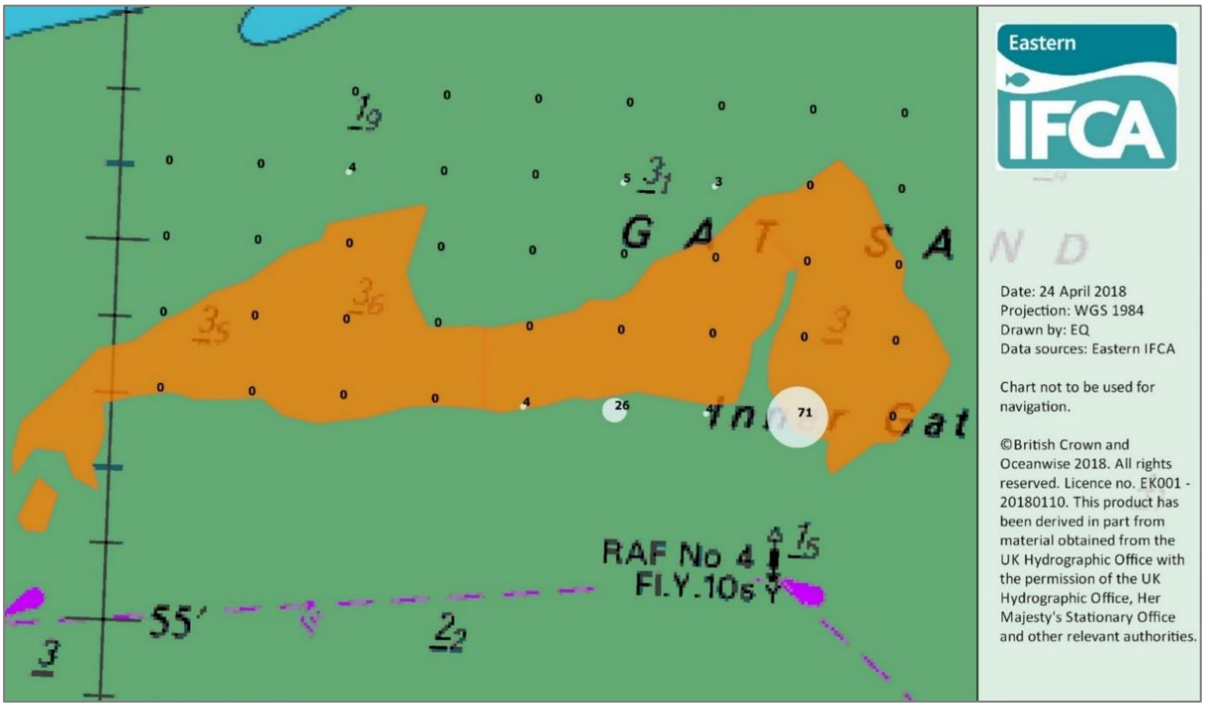

Fig. 4 Abundance of slipper limpets (white) on the Gat Sand mussel bed (orange) in August 2017, presented on a graduated size scale. Survey stations were 10 m in diameter (Eastern IFCA, 2017).

3. Distribution and abundance of slipper limpets on the Northern Toft Lays

We found that *C. fornicata* occurred in high densities to the east of the lays, reaching a maximum of 88 *C. fornicata* 0.1m^{-2}. However, the species were only found in relatively low densities (≤19 *C. fornicata* 0.1m^{-2}) within the lays (Fig. 8). Patches outside the lays were found settled on mostly dead mussel and slipper limpet shells in gullies, while within the lays slipper limpets were settled on relatively healthy-looking mussel (e.g. Fig. 5).

Fig. 5 Quadrats from stations surveyed outside (top) and within (bottom) the lays

Average density at stations surveyed outside of the lays was 39 ± 28 *C. fornicata* 0.1m^{-2}, while within the lays it was just 4 ± 9 *C. fornicata* 0.1m^{-2} (Fig. 7). This included 6 of the 13 stations sampled on the lays that supported no slipper limpets at all.

The population showed signs of reproductive activity, and therefore the ability to further expand. Several slipper limpets were collected to look closer at on RV *Three Counties*. One of these supported a large egg mass found attached to the substratum below the foot of the animal (Fig. 6).

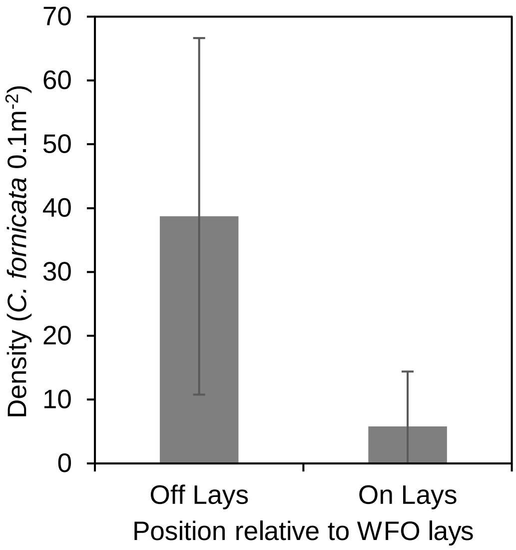

Fig. 7 Average density of *C. fornicata* surveyed within and outside of the WFO lays on the Roger Sand

Fig. 6 Slipper limpet found during the foot survey on the lays supporting a yellow egg mass, found between the foot of the animal and the substratum on which the animal was attached

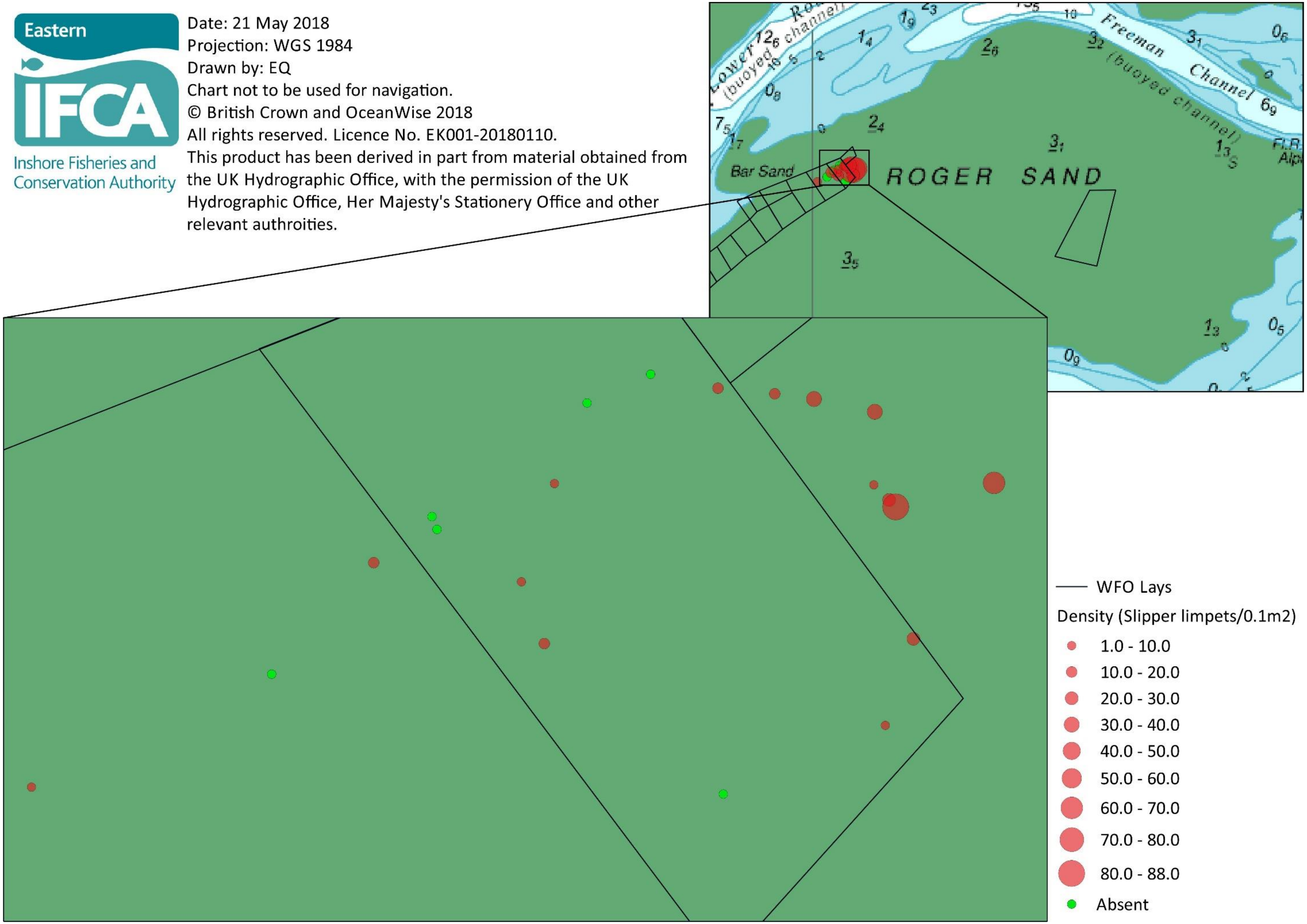

Fig. 8 Density of *C. fornicata* at 21 stations sampled using a 0.1 m^2 quadrat on and around the WFO Toft Lays at the north of the Roger Sand (Insert – Top right). Bright green markers indicate an absence of *C. fornicata*, while red markers present density of *C. fornicata* (individuals 0.1m^{-2}) on a graduated scale.

4. Management options

Total eradication of slipper limpets from infested areas is not currently known to be possible, however limiting their expansion can still provide important benefits to ecology and the fishing industry. There are a number of potential means to manage the population of slipper limpets in The Wash where numbers start to increase to high densities.

4.1. Mechanical removal by Baird dredging

Dredges used on The Wash mussel lays are of the “Baird” design, a dredge consisting of a mesh or net held open by a frame the bottom edge of which consists of a blade ‘with or without teeth’, which dislodge mussels from the surface of the mussel bed. These typically penetrate between 2.5 cm and 5 cm into the sediment (Senior IFCO, *Pers. comm.*), and could be used to fish slipper limpets established on the surface of the beds as a method of mechanically removing the species from the area.

One of the few known successful programmes of eradication of slipper limpets was in major mussel culture area in the Menai Strait, North Wales, after a transfer of mussel seed inadvertently introduced slipper limpets into the culture area. This led to “urgent remedial action having to be taken by the industry which involved removing the infested mussel seed and then smothering of any remaining slipper limpets with new slipper limpet free seed” (Syvret and Fitzgerald, 2008). While this seems a simple and successful approach, the success of the programme can be attributed to the rapid response of the industry to the introduction. Furthermore, if the species had established in the Menai Strait, it would have become the northernmost population along the west coast of Britain, so there is no proving that the eradication was not aided or due to the suitability of the habitat.

Despite the possible advantages of dredging, Blanchard (2009) attributed a rapid expansion in the slipper limpet population in the Bay of Mont-Saint-Michel in the Western Channel, France, to anthropogenic dredging activities. This was partly due to the sorting of catch from dredging and trawling, which results in slipper limpets thrown overboard. This would not be the case if dredging were to be used as a management measure, as slipper limpets would be specifically targeted and therefore retained for disposal on land. However, the study also reported that the use of bottom-towed gear has the ability to aid the spread of slipper limpets as it cuts and divide slipper limpet chains, can break shells – creating settlement structures, and can create bottom furrows well-suited to slipper limpet settlement (low velocity, high biodeposition, high accumulation of dead shell).

Fig. 9 Slipper limpets collected in high concentrations in a gulley to the north east of the Toft lays as an example of a location that could be hand raked for slipper limpets

4.2. Manual collection by hand working

Areas of high density outside of the mussel lays could be specifically targeted by Eastern IFCA officers and hand worked to remove dense populations from the area and reduce risk of the expansion of the population within the lays. RV *Three Counties* could be laid on the sand to allow officers to walk out and use rakes and nets to collect and remove slipper limpets.

It is however time consuming, and therefore costly, it would be an ineffective measure over large areas – but in the small, highly infested areas identified to the east of the lays, where slipper limpets have collected in gullies (e.g. Fig. 9) it could be an effective method of controlling the population. Furthermore, it would not have any of the potential adverse side effects associated with dredging.

5. Sediment burial and smothering

Recent evidence suggests that slipper limpets may be poorly adapted to sediment burial (Powell-Jennings and Callaway, 2018). Laboratory experiments have indicated that 81.5% of C. fornicata died in burial treatments, although the probability of mortality increased with increasing thickness of the sediment layer. While some *C. fornicata* buried in 2 cm of sediment were able to re-emerge after seven to 20 days, no *C. fornicata* re-emerged after burial under 6 cm or more of sediment as the species is poorly adapted to adjust its vertical position in the sediment. Confidence in these laboratory findings were strengthened by field surveys in Swansea Bay that found no *C. fornicata* in 6.1 km of dredge tows at dredge spoils grounds. This was compared to a nearby site where a single 309 m tow brought up 97 *C. fornicata* (Powell-Jennings and Callaway, 2018).

Sediment in The Wash tends to be highly mobile – influenced by wave energy higher than experienced in most UK estuaries. This characteristic could easily render any attempts to reduce the spread of slipper limpets purely through sediment burial unsuccessful, as wave and tidal action could quickly uncover buried slipper limpets or reduce the thickness of the sediment layer, increasing survival.

Despite this caveat, smothering should not be ignored as a possible management option. It could perhaps be used in The Wash in combination with other management. For example, it could be used after hand working to limit the likelihood of survival of any slipper limpets that were not seen and collected. This would take time, however where slipper limpets have collected in high concentrations in small areas (e.g. Fig. 9), it would be feasible to fill these areas in after collection using nearby sediment.

6. Draft recommendations

We propose an integrated approach to managing areas where slipper limpets have settled in high densities. In this case, it is suggested that a combination of hand-raking of slipper limpets and infested mussels, and subsequent sediment burial of raked areas is used. Regardless of the control mechanism used, resettlement is likely to be an issue. The only effective treatment is likely to be regular harvest to maintain the population at a minimum density. Furthermore, it would be an interesting research opportunity to monitor the quantities of slipper limpets currently in the area, their removal, and subsequent resettlement.

7. Disposal of slipper limpets

By-products associated with the removal of slipper limpets from the area would come under Category 3 of the Regulation (EC) No. 1069/2009 of the European Parliament and of the Council laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No. 1774/2002 (Animal by-products regulation). Slipper limpets and mussels that require disposal will be categorized such because they suit the following descriptions:

- Aquatic animals, and parts of such animals, except sea mammals, which did not show any signs of disease communicable to humans or animals;
- Aquatic and terrestrial invertebrates other than species pathogenic to humans or animals.

GOV.UK (2018) guidance on disposal of Category 3 animals and animal by-products states that you can only dispose of these as follows:

Category 3

You can only dispose of category 3 ABPs by:

- Incineration or co-incineration
- Sending them to landfill after they've been processed
- Processing them, if they're not decomposed or spoiled, and using them to make feed for farm animals (where allowed by the TSE/ABP regulations)
- Processing them and using them to make pet food
- Processing them and using them to make organic fertilisers and soil improvers
- Using them in composting or anaerobic digestion
- Ensiling (turning them into silage) if they come from aquatic animals
- Applying them to land as a fertiliser, in some cases
- Using them as fuel for combustion
- Using them to make cosmetic products or medical devices

Of these, the only suitable method available for Eastern IFCA with these animal by-products would be incineration.

Eastern IFCA are currently in discussion with waste management groups to investigate the most appropriate and cost-effective method of disposing of slipper limpets (and the mussel that would come with them).

8. References

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9. Appendix 1: Raw data and photographs from the intertidal survey of the Toft Lays and Roger Sand

Position of *RV Three Counties*: 52.961133, 0.174375

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	1
Photograph No.	P5010007
Latitude	52.959236
Longitude	0.172925
Photographs	
Number of slipper limpet stacks	14
Total number of slipper limpets	34
Comments	Line of slipper limpets in gulley

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	2
Photograph No.	P5010008
Latitude	52.958949
Longitude	0.172927
Photographs	
Number of slipper limpet stacks	5
Total number of slipper limpets	8
Comments	Patches of slipper limpets in holes

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	3
Photograph No.	P5010009 – P5010015
Latitude	52.958891
Longitude	0.173028
Photographs	  
Number of slipper limpet stacks	14
Total number of slipper limpets	30
Comments	Large patch in gulley 6 m x 1.5 m

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	4
Photograph No.	P5010016
Latitude	52.958864
Longitude	0.173072
Photographs	
Number of slipper limpet stacks	25
Total number of slipper limpets	88
Comments	Rows of limpets in gullies ~40 m wide

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	5
Photograph No.	P5010017
Latitude	52.958965
Longitude	0.173709
Photographs	
Number of slipper limpet stacks	26
Total number of slipper limpets	62
Comments	Rows of limpets in gullies ~40 m wide

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	6
Photograph No.	P5010018
Latitude	52.958347
Longitude	0.173202
Photographs	
Number of slipper limpet stacks	7
Total number of slipper limpets	27
Comments	Just off the edge of TOA (lay)

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	7
Photograph No.	P5010019
Latitude	52.958005
Longitude	0.173029
Photographs	
Number of slipper limpet stacks	2
Total number of slipper limpets	4
Comments	

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	8
Photograph No.	P5010020
Latitude	52.957724
Longitude	0.171983
Photographs	
Number of slipper limpet stacks	0
Total number of slipper limpets	0
Comments	

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	9
Photograph No.	P5010021
Latitude	52.958303
Longitude	0.170801
Photographs	
Number of slipper limpet stacks	10
Total number of slipper limpets	19
Comments	

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	10
Photograph No.	P5010022
Latitude	52.958544
Longitude	0.170645
Photographs	
Number of slipper limpet stacks	2
Total number of slipper limpets	3
Comments	

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	11
Photograph No.	P5010023
Latitude	52.958932
Longitude	0.170849
Photographs	
Number of slipper limpet stacks	1
Total number of slipper limpets	1
Comments	

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	12
Photograph No.	P5010024
Latitude	52.958744
Longitude	0.17009
Photographs	
Number of slipper limpet stacks	0
Total number of slipper limpets	0
Comments	

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	13
Photograph No.	P5010025
Latitude	52.958609
Longitude	0.169682
Photographs	
Number of slipper limpet stacks	4
Total number of slipper limpets	12
Comments	

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	14
Photograph No.	P5010026
Latitude	52.958164
Longitude	0.169031
Photographs	
Number of slipper limpet stacks	0
Total number of slipper limpets	0
Comments	Mussels younger and cleaner

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	15
Photograph No.	No photograph
Latitude	52.957704
Longitude	0.167481
Photographs	No photograph
Number of slipper limpet stacks	2
Total number of slipper limpets	2
Comments	

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	16
Photograph No.	P5010031
Latitude	52.958794
Longitude	0.170056
Photographs	
Number of slipper limpet stacks	0
Total number of slipper limpets	0
Comments	

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	17
Photograph No.	P5010032
Latitude	52.959251
Longitude	0.171052
Photographs	
Number of slipper limpet stacks	0
Total number of slipper limpets	0
Comments	

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	18
Photograph No.	P5010033
Latitude	52.959368
Longitude	0.171462
Photographs	
Number of slipper limpet stacks	0
Total number of slipper limpets	0
Comments	

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	19
Photograph No.	P5010034
Latitude	52.959318
Longitude	0.171902
Photographs	
Number of slipper limpet stacks	6
Total number of slipper limpets	13
Comments	

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	20
Photograph No.	P5010035
Latitude	52.9593
Longitude	0.172272
Photographs	
Number of slipper limpet stacks	7
Total number of slipper limpets	13
Comments	

Survey Title	Toft Lays Slipper Limpet Assessment
Date	1 May 2018
Waypoint	21
Photograph No.	P5010036
Latitude	52.959282
Longitude	0.172528
Photographs	
Number of slipper limpet stacks	8
Total number of slipper limpets	34
Comments	