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“Good news everyone”, the natives have returned: Assemblages of European flat oysters make a reappearance in Belfast Lough after a century of absence.

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1 **“Good news everyone”, the natives have returned: Assemblages of European flat oysters**
2 **make a reappearance in Belfast Lough after a century of absence**

3
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10
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12 recovery

13
14 **Abstract**

15 Belfast Lough in Northern Ireland like most estuarine systems in the UK and Europe once
16 supported a prolific *Ostrea edulis* fishery. However, the oyster was considered locally extinct
17 from the Lough by the early 1900s. Numerous ecological surveys over the next 100 years
18 failed to document one living specimen. Unsubstantiated sightings of solitary *O. edulis* along
19 the Loughs intertidal were recently conveyed to the author. It was considered necessary to
20 investigate these reports and as a result the presence of small assemblages of European flat

native oysters was confirmed. Hypotheses as to why the oysters have returned unaided are discussed with the aim to investigate these at depth in the future.

1. Introduction

The demise of the European native oyster *Ostrea edulis*, from that of a keystone species to an obscure bivalve, throughout the majority of its natural range has been well documented (Thurstan et al., 2013; Farinas-Franco et al., 2018; Pogoda et al., 2019). A number of factors have been associated with the demise of global estuarine oyster populations between the mid-1700s and late-1800s; industrial pollutants, coastal development, increases in sewage outflow and growing urbanization (Korringa, 1946; Maggenis et al., 1983). However, the most prominent drivers related to historical losses in native oyster populations have been identified as overfishing and disease (Yonge, 1960). The combination of these stressors devastated stocks to such an extent that the oyster still remains extinct from many of its historically prolific sites > 100 years after its disappearance (Pogoda, 2019). Instances whereby the native oyster has returned unaided are rare and those which have been documented were often the result of an aquaculture spawning event (Kennedy and Roberts 1999; 2006; Smyth et al., 2017). Pro-active interventions using stock augmentation are therefore considered vital if *O. edulis* is to make a return to its historic locations (Thurstan et al., 2013). As a result, numerous *O. edulis* restoration programmes are currently underway throughout the UK and Europe in an attempt to address the oysters decline (Pogoda et al., 2019).

Belfast Lough in Northern Ireland once accommodated a substantial population of native oysters (Mskimin, 1829). The first report of a recognised commercial oyster fishery in the Lough was in 1780 when it was stated that “the oyster is dredged from September to May by 27 boats and 123 fishers all of whom can read with the exception of two” (Mskimin, 1829).

The report also implied that oyster stocks were in a state of decline as a boat could dredge 800 to 1,200 large oysters a day at a price of 4-7 shillings per 100 in the year of 1800. However, by 1819, a boat was dredging between 100 and 300 oysters a day at a price of 8-18 shillings per 100 (Mskimin, 1829). Since the official closure of the Belfast Lough fishery in 1903 there have been no reports of wild *O. edulis*, no aquaculture stocks and no restoration attempts (Ferreira et al., 2007; CEFAS, 2017).

An investigation into the 1897, 1898 and 1901 enteric fever epidemics of Belfast City by the physician, Mair (1908) stated that, “the working class of Belfast were heavy consumers of shellfish including periwinkles, cockles, and mussels but not oysters as these have been practically extinct for many years”. The Irish Fisheries Commission considered the Belfast Lough oyster fishery officially closed in their report of 1903 (Browne, 1903; Kennedy and Roberts, 1999). The renowned malacologist N.F. McMillan did not record any living *O. edulis* specimens during meticulous surveys of the Lough between 1928 and 1929 (MacDonald, 1947). Gee and Wilson (1981) some fifty years later still failed to document the oyster on a comprehensive molluscan species list and more recently, in 1999, malacologists from the Ulster Museum Belfast could not detect any living native oysters during an extensive subtidal and intertidal investigation (Habitats.org). The 2002 Joint Nature Conservation Committee survey of the Lough was also unsuccessful in locating any live specimens and in 2017 the Sanitary Review of Belfast Lough only documented the presence of sub-fossil shell (Parr and Ager, 2003; CEFAS, 2017).

These historical accounts and surveys confirm the European native oyster as being absent from Belfast Lough for >100 years. However, the author was recently made aware of unconfirmed reports of solitary *O. edulis* along the intertidal zone of the Lough (pers. comm.

Gilmore, 2018; pers. comm. Hewitt, 2019). Consequently, it was considered necessary to investigate these unsubstantiated sightings of individual *O. edulis* to ascertain if an unassisted recovery had indeed occurred after more than a century.

2. Materials and methods

2.1 Site

Belfast Lough is a fully marine inshore body of water located on the east coast of Northern Ireland (Fig. 1). The Lough is a relatively shallow marine bay ~ 21 km long and 11 km wide, with a max depth of 23 m covering an area of 130 km² with annual seawater temperatures of between 2 to 21 °C (Johnson, 1956). The intertidal zones of both shores are characterised by a sandy mud substrate with high volumes of overlaying shell material. The three most abundant contributing species to substrate mixes are; *Mytilus edulis*, *Cerastoderma edule* and *Artica islandica* (Wilson and Lawlor, 1996). The main freshwater input into Belfast Lough is via the River Lagan, which contributes an average *E. coli* input loading of $2.1 \times 10^{12-d}$ at a mean flow of 8.521 m^{3-s} (CEFAS, 2017).

The River Lagan is impounded by a floodgate, the Lagan Weir, which typically only allows water exchange for 2 hr either side of high tide. According to the water balance index there is a clear dominance of the tidal dynamics against river dynamics in the Lough. Belfast Lough is also subject to intensive anthropogenic stressors. The major industrial shipping port at the head of the Lough manages > 80% of Northern Ireland's petroleum and oil imports. Furthermore, Belfast Port handles > 7000 vessels per year with an average freight through flow of 24.6 million tonnes. The inner lough accommodates 21 licensed blue mussel (*Mytilus*

edulis) mariculture beds which are fished by dredge. Fishing activity in the outer Lough focuses on pot fishing, scallop dredging and bottom-trawling for *Nephrops norvegicus* (Ferreira et al., 2007).

Fig 1. Intertidal survey sites, Belfast Lough 2020. Map generated using Arc Map 10.7.1 spatial analysis WGS84 coordinate geometry used throughout. Sites: 1. Shellbank, 2. Interval, 3. Whitehouse, 4. Gideon's Green, 5. Hazelbank, 6. Whiteabbey, 7. Jordanstown, 8. Greenisland, 9. Carrickfergus, 10. Kilroot, 11. Fujitsu, 12. Kinnegar Treatment, 13. Kinnegar Barracks, 14. Hollywood Yacht Club, 15. SeaPark, 16. RoyalNorth, 17. Rock Beach. (British Crown and OceanWise®, 2020. All rights reserved. Licence No. EK001-20180802. Not to be used for Navigation).

2.2 Surveys

In order to ascertain if *O. edulis* had settled along the intertidal zone of the Lough, both east and west shores were surveyed between May and June 2020 using belt transects of 5m carried out 1 m from the low water mark on tides < 0.8 m below datum chart. Ten x 1 km transects were completed along the west shore starting at Shellbank and finishing at Kilroot (Fig. 1). Dangerous sheer rock terrain and fine sand substrates limited the east shore survey to six x 1 km transects starting at, Fujitsu Shore and finishing at Rock Beach (Fig. 1).

If an oyster was recorded along a transect, a 20-minute timed search was carried out at the site of settlement within a 5 x 20 m survey plot as per Smyth et al. (2009). Substrate type was recorded at all sites and all oyster height measurements recorded *in-situ* using Vernier® callipers. Specimens were photographed using a Canon Powershot G16® on auto setting: 19mm focal length, ISO 100, 1/50 second at f/5.6. 16:9 aspect ratio with a reference in frame for scale. Images were calibrated using Coral Point Count® as per Carleton & Done (1995) to the suggested known overhead distance of (1 m). The image measuring application in CPC® was applied to each image to obtain morphometric data which could be applied to the shell age associations for *O. edulis* cited in Richardson et al. (1993).

As this was a baseline investigation, statistical analysis was limited. However, a t-test was carried out to examine the total number of oysters recorded on the east and west shores to determine if settlement was governed by location. In order to ascertain if a difference existed in the size of oysters recorded at each site a one-way PERMANOVA was carried out between site and size of individual oysters using PAST vr3.4® (<https://folk>).

3. Results

Within the intertidal zone of Belfast Lough, live *Ostrea edulis* were recorded at six sites. The west shore had five sites and the greatest number of oysters with 32 individuals, the smallest being 27mm in length and the largest 112 mm (Fig 2). The size and age variations between sites indicated that recruitment has been on-going within the Lough over the past 8-10 years. The average age of oysters on the west shore were between 3-4 years with an average shell height of 64mm as per estimations from Richardson et al., (1993) (Table 1). The east shore had one settlement site with nine individuals, the smallest being 33 mm and the largest 72 mm. The average age within the assemblage was 1-2 years with an average shell height of 50mm (Table 1). However, it must be emphasised that there may be variations within these age determinations as Richardson's research was based on *O. edulis* specimens from Essex which sits three lines of latitude below the sites in Belfast Lough.

Fig 2. Intertidal *Ostrea edulis* assemblages: 4. Gideon's Green, 5. Hazelbank, 6. Whiteabbey, 7. Jordanstown, 8. Greenisland and 13. Kinnegar Barracks. Map generated using Arc Map 10.7.1 spatial analysis WGS84 coordinate geometry used throughout. (British Crown and OceanWise®, 2020. All rights reserved. Licence No. EK001-20180802. Not to be used for Navigation).

A *t*-test was carried out using PAST vr3.4® between the total oyster abundance of west and east shore assemblages, no significant difference was detected ($p > 0.2$). Furthermore, PERMANOVA analysis did not detect any significant differences between oyster size and site ($F= 1.79, P> 0.1$).

A basic substrate description was assigned to each survey transects and live oyster sites (Tables 1). Substrate component percentages within site transects are displayed in pie chart

format (Fig. 3). *In-situ* digital stills of live oysters within the settlement survey plot are presented in (Fig. 4).

Fig 3. Substrate composition at survey sites. Oyster assemblages were recorded at sites 4-8 on the west and site 13 on the east. Map generated using Arc Map 10.7.1 spatial analysis WGS84 coordinate geometry used throughout. (British Crown and OceanWise®, 2020. All rights reserved. Licence No. EK001-20180802. Not to be used for Navigation).

164 Table 1. Intertidal survey site locations as per WGS84, transect substrate type, oyster
165 abundance, size and age as per Richardson et al., (1993).

Belfast Lough Survey 2020							
Site	Coordinates	Substrate type	No. Oysters	Size mm	Age in years min, max, mean		
1. Shellbank	54.640651 -5.900872	Sand/mud/ occasional mixed shell	0	0			
2. Interval	54.643780 -5.908124	Sand/mud/ occasional mixed shell	0	0	0	0	0
3. Whitehouse	54.647411 -5.907927	Sand/mud/ occasional mixed shell	0	0	0	0	0
4. Gideon's Green	54.657021 -5.899842	Sand/shell mix	2	37,112	0-1	>8	3-4
5. Hazelbank	54.662412 -5.898846	Sand/shell mix	7	60,63,81, 82,83,85, 87	2-3	4-5	3-4
6. Whiteabbey	54.667904 -5.896265	Sand/shell mix/bedrock/boulder	8	27,41,56, 56,73,80, 84,85	0-1	4-5	3-4
7. Jordanstown	54.675380 -5.890914	Sand/shell mix/cobble	6	38,38,42, 63,67,77	0-1	3-4	1-2
8. Greenisland	54.690979 -5.861021	Sand/shell mix/cobble	9	33,46,48, 51,57,64, 80,82,82	0-1	4-5	2-3
9. Carrickfergus	54.708104 -5.817230	Sand/mud/cobble/ occasional mixed shell	0	0	0	0	0
10. Kilroot	54.718930 -5.765505	Sand/mud/Fucus/ occasional mixed shell	0	0	0	0	0
11. Fujitsu	54.635956 -5.868799	Sand/mud/occasional mixed shell	0	0	0	0	0
12. Kinnegar Treatment	54.635771 -5.855509	Sand/mud/mixed shell	0	0	0	0	0
13. Kinnegar Barracks	54.639278 -5.849715	Sand/mud/mixed shell/concrete	9	28,35,42, 45,53,55, 56,61,72	0-1	2-3	1-2
14. Holywood Yacht Club	54.641671 -5.842687	Mud/sand/occasional mixed shell	0	0	0	0	0
15. SeaPark	54.648139 -5.828045	Sand/shell mix	0	0	0	0	0
16. Royal North	54.653253 -5.818363	Sand/shell mix	0	0	0	0	0
17. Rock Beach	54.659749 -5.804232	Sand/occasional mixed shell	0	0	0	0	0

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169 Fig. 4. Examples of settled *Ostrea edulis* at sites; A. Gideon's Green, B. Hazelbank, C.

170 Whiteabbey, D. Jordanstown, E. Greenisland and F. Kinnegar Barracks.

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4. Discussion

Unsubstantiated reports of solitary European flat oysters on the shores of Belfast Lough suggested that *Ostrea edulis* had returned to the waterway after more than a century of absence and the findings presented here have categorically shown that this is indeed the case. A total of 42 oysters were recorded with sizes ranging from 28–112mm indicating a population consisting of both 0-1-year juveniles and adults of > 8 years (Richardson et al., 1993). These variations in age are significant and indicate that recruitment had been taking place unnoticed within the Lough for at least 8-10 years.

While the number of oysters does not signify a sustainable population, it does raise questions as to; where did they come from and what allowed the settlement of larvae to occur? There have been no attempts at *O. edulis* aquaculture within the Lough's catchment and therefore the recent settlements must have been incidental. An understanding of recent abiotic and biotic changes within the Lough may offer some explanations as to how *O. edulis* has managed to make a return. An, important recent development within the Lough to be noted before assumptions are made occurred in 2016 with the dredging of the central channel. This was carried out to accommodate an increase in shipping traffic which had been steadily growing since 2000 when 5,336 vessels visited Belfast Port to > 6,800 in 2018 (DoT 2018). As a result, > 400,000m³ of dredge spoil were removed to widen the main shipping routes and accommodate deeper drafts and (BHA, 2018).

4.1 Possible pathways for *Ostrea edulis* introduction

The hypothesis that shipping ballast water spreads molluscan species has been postulated since the late 1800s (Sassi et al., 2005) and is now a well-documented route for invasive and native species into new areas (Endresen et al., 2004; Bailey, 2015). The transportation of the Pacific oyster *Magallana gigas* larvae has been periodically detected in ballast water sources (Patil et al., 2005). It has been hypothesised that ballast water transfer in the 1990s was the cause of *C. gigas* introductions into the east coast of Scotland as there had been no aquaculture ventures for the species in the region (Smith et al., 2014).

The increases in shipping to Belfast Port over the last decade offer the possibility for a ballast water induced spread via the transfer of pelagic larvae through ballast deposition. However, the reality of this is doubtful as the global sources of planktonic *O. edulis* larvae are extremely rare and mortalities within the pelagic stage of the life cycle are considerable (Korringa, 1941).

A more probable explanation is that adult oysters were introduced through the commercial Blue Mussel fishery. The Lough has 21 licensed subtidal *M. edulis* mariculture sites spread over a number of plots located either side of the shipping channel (CEFAS, 2017). The fishery plots are seeded with juvenile mussels dredged from various locations in the Irish Sea (Ferreira et al., 2007). It may be that within some of the dredged seed that a number of fecund *O. edulis* were collected and relayed (Wolff and Reise, 2002). However, the translocation of seed mussel has been carried out for > 30 years with no *O. edulis* settlements recorded. Therefore, if the mariculture plots have been the source of oyster larvae, it must have been from seed deployed within the last ten years. This is significant as records of the seed mussel site locations for the 2008, 2009 and 2010 relays may reveal a possible undiscovered Irish Sea population of native oysters.

In addition, abiotic or biotic changes within Lough over the last 10 years could have created conditions conducive to promoting the pooling and settlement of oyster larvae. Recent bathometric changes through the deepening of the central shipping channel and the resulting subsequent alterations to fine-scale hydrodynamics, may offer an explanation. However, fine-scale particle tracking and hydrodynamic modelling of the watercourse would be required to confirm this theory and unfortunately this was economically beyond the resources of our short survey.

4.2 Settlement

Belfast Port sits at the head of the Lough and is the largest commercial harbour in Northern Ireland. Anthropogenically introduced disturbances such as dredging are often associated with detrimental changes in marine habitats (Demes et al., 2012). However, in the case of Belfast Lough the increases in shipping and the subsequent dredging induced bathymetrical changes may have created a situation whereby the hydrodynamic regimen is now in a position to once again permit *O. edulis* larval settlements.

Increases in vessel activity and their subsequent wakes in particular have been shown to be instigators of environmental change within soft sediment benthic communities (Payne et al., 1999). Wake generated water velocity has led to instances of increased siltation in shallow estuarine systems and the subsequent smothering of bivalve beds and the burying of hard-shell substrates (Berghahn and Ruth, 2005). However, this is not always the situation and a number of factors need to be considered when assessing the effects of vessel wakes. Sediment composition, channel geometry, distance to shore, the number of successive vessels and their speed of passage can all influence wake effects (Gabel et al., 2017).

Demes et al., (2012) showed in British Columbia that primary production actually increased on rocky shore sites which lay favourable distances from intermittent ferry wake pulses. The distance from the wake's origin can have a significant influence on the degree of environmental stress. In some instances, *Crassostrea virginica* oyster reef systems in shallower estuarine regions were displaced by wakes with heights as shallow as 2cm (Campbell, 2014). However, wakes were shown to have had no impact on recruitment. Indeed, the dislodgement of oyster assemblages may have actually aided the geographical expansion of *C. virginica* within estuaries (Wall et al., 2005; Campbell, 2014).

The combined effect of regular wake travel to and from the shore can result in cleaning substrate surfaces of sediment through a washing effect (Koelh et al., 2013). This process can lead to increases in species abundance and richness along intertidal zones which are situated sufficiently far enough from the initial high velocity water pulse (Gabel et al., 2017).

The study presented here, revealed no oyster settlement close to the Port entrance even though shell substrate was substantial. Therefore, the speculation that the mariculture plots were a source of larvae becomes ever more likely as settlements were localised to sites within the boundaries of the mussel fishery lays and between 3-7 km from the head of the Lough. A distance which appears to have been suitably far enough from initial wake amplitude to allow shell substrates to remain clear of siltation, while tidal water retention remained sufficient to enable *O. edulis* pediveligers the opportunity to undergo cementation. The provision of clean settlement material and sufficient water retention have been recognised as optimal for larvae to settle and metamorphose (Cole and Knight-Jones, 1949; Waugh, 1972; Foster, 1994; Smyth et al., 2017).

The substrate mixes along Lough's intertidal zones provide some excellent settlement areas, however the findings of the survey identified assemblages in close proximities to each other. Suggesting, that the assumptions as to how the native oysters returned is not confined to one factor but to a combination of the proposed hypotheses. The unassisted reoccurrence of native oysters in Belfast Lough is undoubtably a unique event with many questions needing addressed before a pathway of re-establishment can be confirmed.

Conclusion

The 2020 documented settlements of *O. edulis* in Belfast Lough have raised a number of interesting hypotheses. Further research as to how the return of the oyster was induced is required. In-depth investigations into the effects of pollution and dredging impacts were practically and financially beyond the scope of this study. The main aim of this manuscript was to document that oysters are once again present in Belfast Lough after a century of absence. The initiation of future studies should be considered a matter of urgency, as a better understanding of abiotic and biotic parameters within the Lough could greatly benefit numerous European native oyster restoration projects which are currently underway.

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