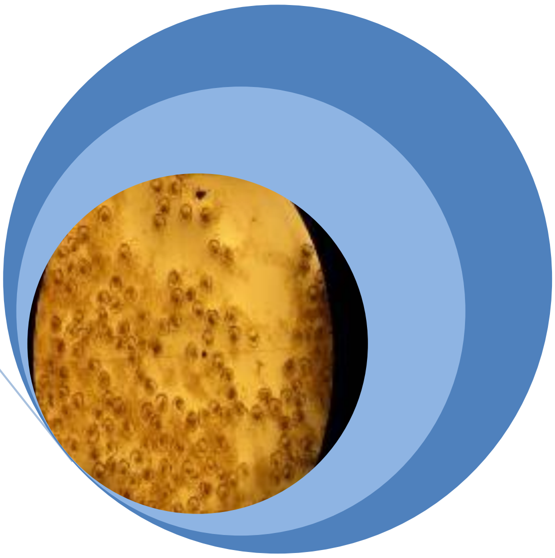

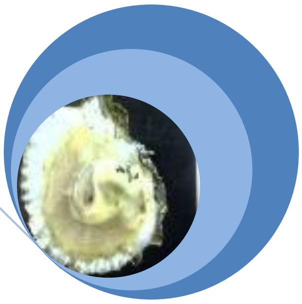

Native Oyster Spawning Assessment
Lough Foyle Summer 2018

An assessment of oyster spawning activity at 5 locations within the Lough Foyle oyster fishery employing spawning stage analysis, larval density counts and environmental monitoring.

Ciarán McGonigle/Cass Bromley/Luke Perry/ Tom Sheerin

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Executive Summary

Monitoring of native oyster reproductive activity within the Lough Foyle native oyster fishery took place for the eighth successive year. Sampling started in the Perch bed in April and May 2018 with limited sampling aimed at identifying the start of spawning. From 21st May 2018, sampling of adult oysters, plankton and environmental parameters was carried out weekly on five oyster beds until 24th September 2018.

Of the 2715 oysters examined, 154 (5.7% of the sampled population) were found to be brooding eggs (milky white mass visible on the gills) or larvae (grey or black mass). Including oysters exhibiting spent gonad material (showing that they have released eggs or sperm), 40.8% of the sampled population were reproductively active during the survey period. Although the numbers of reproductively active oysters were slightly less than in 2017, the findings of the native oyster autumn stock assessment and examination of spat collectors deployed in the lough indicate a significant, widespread spatfall in 2018. There were three peak periods for brooding – the main peak occurred in the first week of July 2018 (the same week as 2017's peak); with a second, more sustained period between the end of July and 20th August 2018; and a third, brief peak in the samples collected on 3rd September. This is consistent with observations of distinct size classes in settled spat (> 15 mm and < 6 mm.). Average water temperature (16.02ºC ± 1.99) and salinity (30.8 psu ± 1.49) were both slightly higher than in 2017 and variation amongst the beds was minimal. Average temperatures peaked at 19.5ºC ± 0.27 in week 6 (9th July 2018). Average turbidity remained below 8 FTU throughout the survey.

1.0 Introduction

1.1Background

The Lough Foyle oyster fishery is one of the last remaining productive native oyster fisheries in Europe. The fishery has been harvested intensively in the past and efforts to develop its full potential and manage the fishery in a sustainable manner historically failed due to a lack of legislation. In September 2008, the Loughs Agency of the Foyle Carlingford and Irish Lights Commission began to regulate the fishery for the first time. The Agency licenses oyster fishing vessels in Lough Foyle and they are permitted to operate from 19th September – 31st March. Regulations allow for postponement of the fishery to give recently settled spat an opportunity to become established and, for example, the 2018/19 season started on 9th October 2018.

This report outlines the findings of a survey undertaken between 9th April and 24th September 2018 to assess the spawning activity of *Ostrea edulis* (European native oyster) in Lough Foyle. The survey is now in its 8th year and has contributed to our understanding of reproductive activity in the Lough Foyle native oyster population. It also draws upon the knowledge acquired from previous reports and research work conducted during the IBIS research project on spawning activity, larval dynamics and fecundity (Bromley, 2015).

A stock assessment of the Lough Foyle native oyster fishery has been conducted either annually or bi-annually since 2007.   Adult and juvenile distribution and abundance is recorded during the surveys, as is the presence/absence of shell cultch (Figures 1 - 3). The results from these surveys have formed the basis of site selection for this reproductive assessment work. Oyster density, location of spatfall and availability of suitable cultch for larval settlement were the major factors that were considered during site selection, as well as logistical restrictions such as water depth and distance between beds.

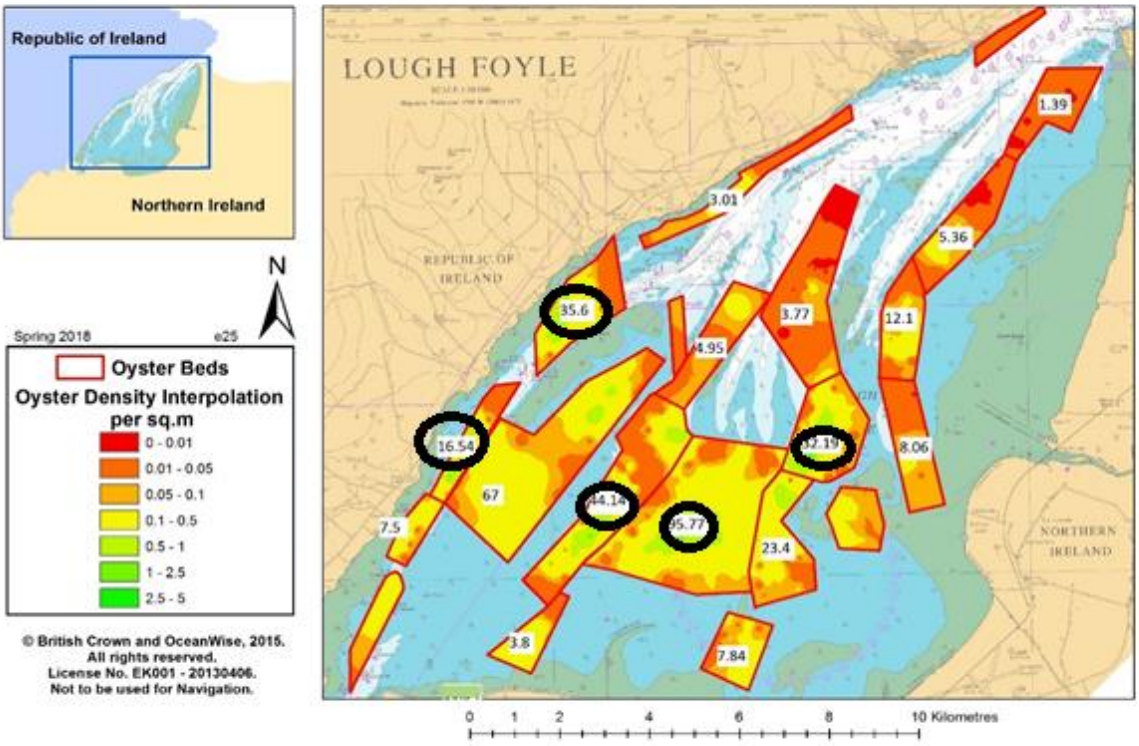

Figure 1: Oyster density in Lough Foyle Spring 2018 and the 5 oyster beds sampled for this survey (figures on each bed = harvestable biomass in tonnes).

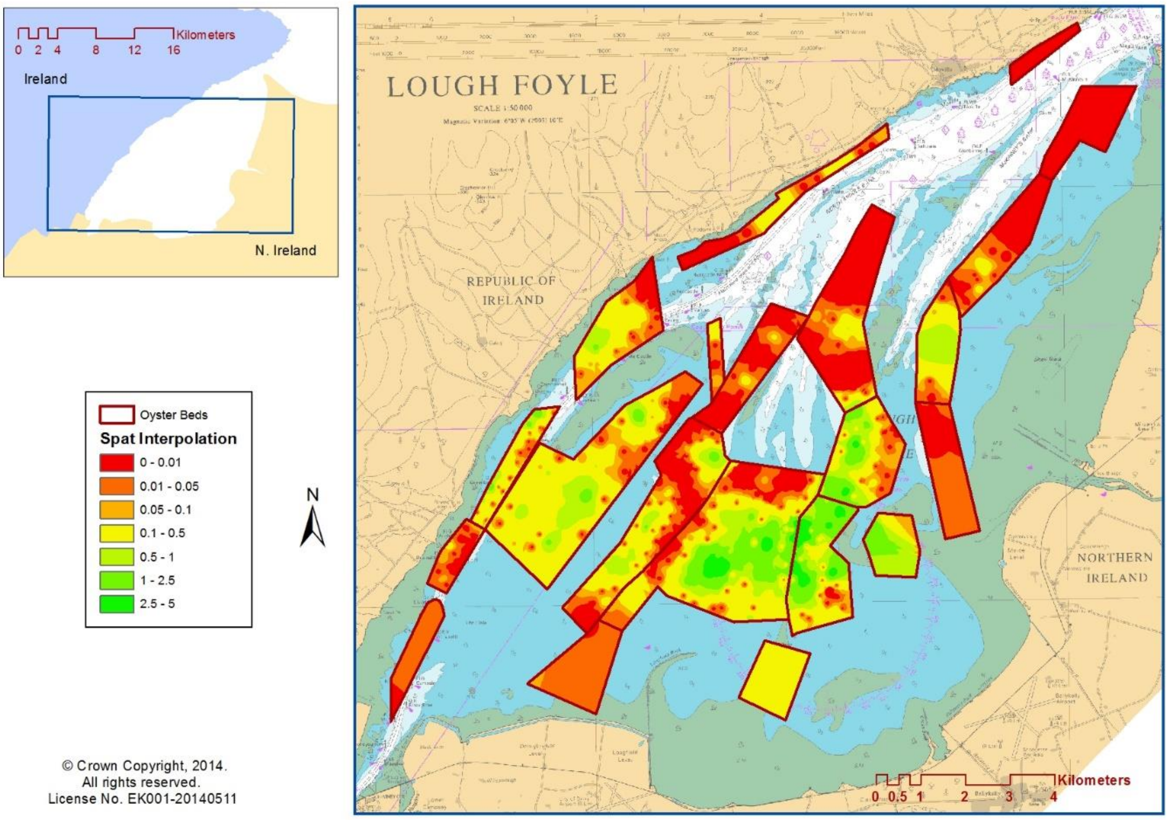

Figure 2: Spat Density Autumn 2018

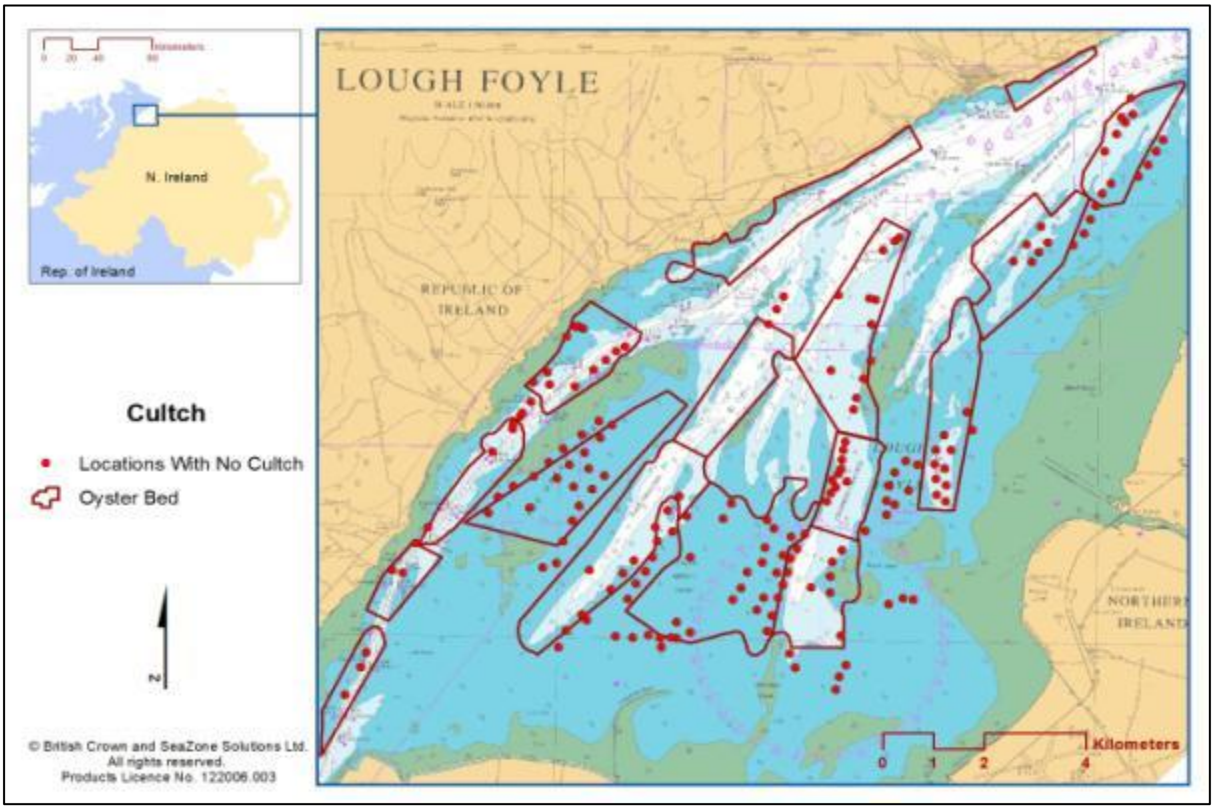

Figure 3 Location of areas without suitable cultch within the Foyle oyster fishery

1.2 Aims and Objectives

The aim of this project was to identify when and where there is an abundance of bivalve larvae present in the water column in Lough Foyle and to relate this to spawning activity in oysters and environmental drivers such as water temperature, salinity and turbidity.

Objectives:

- Record environmental variables (temperature, salinity, DO, turbidity) weekly at 5 oyster beds
- Assess larval density weekly at 5 beds
- Assess gonad stage and growth parameters of oysters weekly on 5 beds
- Record daily water temperatures at 5 beds

It is imperative to have a record of bivalve larval dynamics occurring on oyster beds for use as a baseline for potential enhancement projects. In areas where bivalve larvae are present but there is no suitable cultch and no notable spatfall occurring, mitigation may be needed to address the issues limiting success.

1.3 Native Oyster Spawning

Naturally occurring oyster beds are becoming increasingly rare throughout the world (Hawkins *et al.*, 2008; OSPAR Commission, 2009; Beck *et al*. 2011). It is estimated that 85% of oyster reefs worldwide have been lost (Airoldi *et al*, 2009). This is mostly as a result of overexploitation. However, the decline in stocks may also be attributed to severe winters such as the east coast of England fishery destroyed by severe winter conditions in 1962/ 63 (Davidson, 1976; Crisp, 1964). Food availability, climate change, invasive species (e.g. *Crepidula fornicata*), hydrodynamic regime changes, disease and availability of suitable habitat for juvenile settlement are all factors in the sustainability of these populations.

Native oysters are considered to be ecosystem engineers as a result of the role they play in the nutrient cycling process within estuaries and because they provide habitats and nursery areas for many other species. It is for this reason; along with the hugely important commercial value of the native oyster fishery to an area each year; that means of habitat regeneration, ways of promoting more sustainable fishing practices (such as an 80mm minimum landing size) and monitoring of disease (e.g. *Bonamia ostreae*) are adopted to promote sustainable fisheries (Goulletquer, 2005-2011).

Native oysters require between 4-8 weeks of good conditioning in early spring, with adequate food supply and correct temperatures, before spawning readiness will occur (FAO, 2004). The greater the conditioning prior to breeding season then the more probable that population-wide spawning events will occur simultaneously when optimum conditions (15-16˚C in previous studies in Lough Foyle), and good food supply are present. The European native oyster, *Ostrea edulis*, is larviparous. This means that instead of releasing eggs into the water column, fertilization is internal and females brood larvae within the mantle cavity which, after a period of up to 14 days, they then release into the water column. Larvae may then remain in the water column for up to 14 days before settling onto a suitable substratum. Whilst adult oysters may exhibit adaptations to local environmental conditions (ecotypes) and in some production areas are able to condition and spawn at lower temperatures than the 15 - 16ºC generally given as optimal conditions, studies, for example, Korringa (1940; 1957) have shown that the larval settlement stage is the most sensitive to temperature fluctuations and may need sustained temperatures of > 17ºC to successful settle and metamorphose into an oyster spat.

Table 1 shows an estimate of the average number of larvae released by oysters of a specified age (Walne, 1974). It illustrates that there is a relationship between age/size and the quantity of larvae brooded. However, this can be influenced by condition and there can be substantial variation within this relationship. This is a combination of the oyster being physically more capable of retaining greater numbers of larvae within the mantle cavity as it grows larger and increased conditioning in older/larger oysters resulting in older oysters being more valuable to the recruitment of the species annually. Recent local studies have suggested that these figures may not be fully representative of the true fecundity of oysters in Lough Foyle and this must be borne in mind when interpreting these results (Bromley, *pers. com*, 2016).

Table 1: Average fertility for successive age groups of oysters (Walne, 1974)

Approximate Age (years)	Mean Diameter (nm)	Fertility (number of larvae)
1	40	100,000
2	57	540,000
3	70	840,000
4	79	1,100,000
5	84	1,260,000
6	87	1,360,000
7	90	1,500,000

Successful spawning in native oysters is reliant on individuals being in close proximity and, for this reason, the highest density oyster beds are generally the most reproductively successful and have the largest spatfall events. In American (eastern) oysters (*Crassostrea virginica*), fertilisation efficiency has been shown to reduce by 50% when oysters are 10cm or more apart. This results in what is known as the “Allee effect”, where successful repopulation of the stock can become impossible even if fishing mortality is removed and stocks are protected (University Marine Biological Station Millport. 2007).

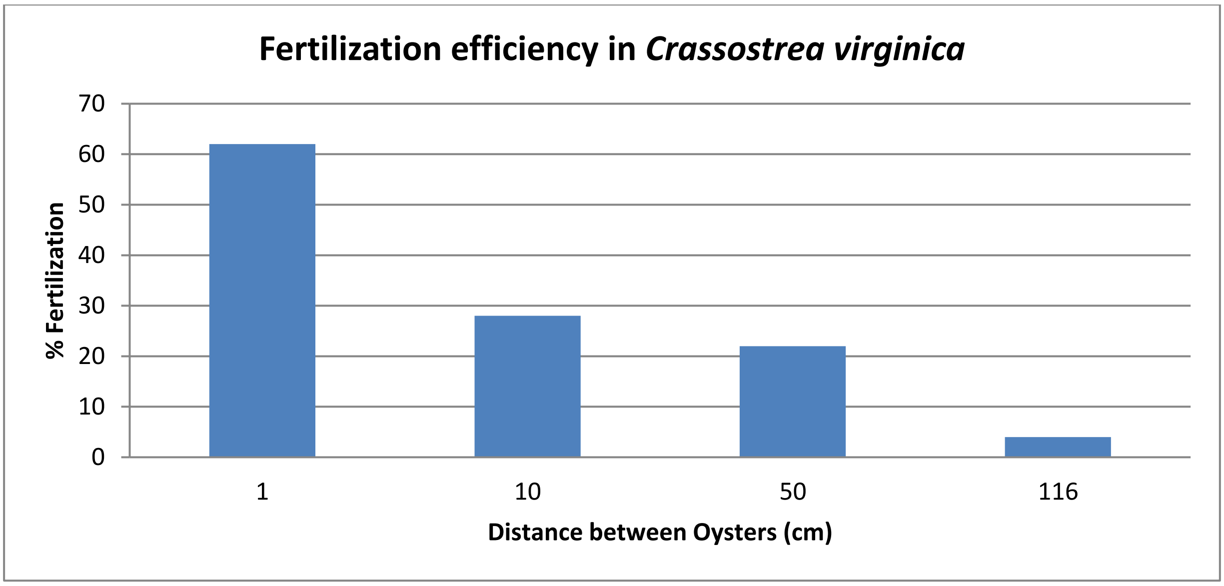

Figure 4 Fertilisation efficiency as a function of oyster population density (taken from Paynter, 2003)

2.0 Methodology

The 5 sites chosen for collecting samples for this project were Quigley's Point, Perch, Middle Bed, Flat Ground and Southside (Figure 1). These beds were selected based on the high densities of oysters present within them. The three methods of data collection and analysis are described in detail in sections 2.1-2.3.

2.1 Gonad Stage Analysis

Figure 5 a-c: Spawning stages of Native Oyster; (a) white sick; (b) grey sick; (c) black sick

A sample of 30 native oysters was collected using a traditional oyster dredge from 5 locations within the Foyle oyster fishery as identified in Figure 1. These 30 oysters were selected based on size and weight with oysters less than 50mm and 30g rejected from the samples. The first 30 oysters to meet these criteria were selected, labelled and stored in mesh bags. These samples were frozen immediately on return to the lab.

Samples were thawed completely on draining trays lined with paper roll to remove water content. Care was taken when opening the oysters to prevent losing any reproductive material. Oyster length and wet weight were recorded prior to shucking and weighing wet flesh weight and assigning reproductive stage class based on the classification of Helm *et al*. 2004.

Table 2: Description of Reproductive Stage for Native Oyster

Stage	**Description**
Mature/Developing	Gonad full or filling
White Sick	Gills covered in white mass (eggs) gonad empty
Grey Sick	Gills with visible grey shelled larvae present
Black Sick	Gills with visible black/purple shelled larvae
Spent Gonad	No gonad material remaining

2.2 Larval Counts

A plankton net of 300mm diameter and 100 micron mesh size was deployed vertically at each sample location. A manual flow meter was attached to the mouth of the plankton net and used to calculate the distance the net had travelled on each deployment. The sample was washed from the plankton net by using a seawater deck hose applied to the exterior of the plankton net and net bucket. The sample was collected in a 250 ml plastic bottle and labelled with site code and time and date information. The volume of water sampled at each site was calculated using the following formula;

$\Pi r^2 h$ – where r = radius of the net and h = distance towed.

Three 1ml sub-samples were taken from the 250ml sample using a 1ml sampling pipette following thorough mixing of the sample by hand. The sample pipette was changed between each sub-sample. The 1ml sample was transferred onto a glass Sedgewick Rafter counting cell on which all bivalve larvae were counted. Larval counts were averaged for the 3 sub-samples and these values were converted to density of larvae per metre cubed using the following formula:-

Figure 6 Plankton net

Bivalve Larvae in Sample = [(mean number per 1ml *Sample Volume ml) / (Volume of Water Sampled)]

Bivalve Larvae per m^3 = [Bivalve Larvae in Sample] / [Volume of Water Sampled m^3]

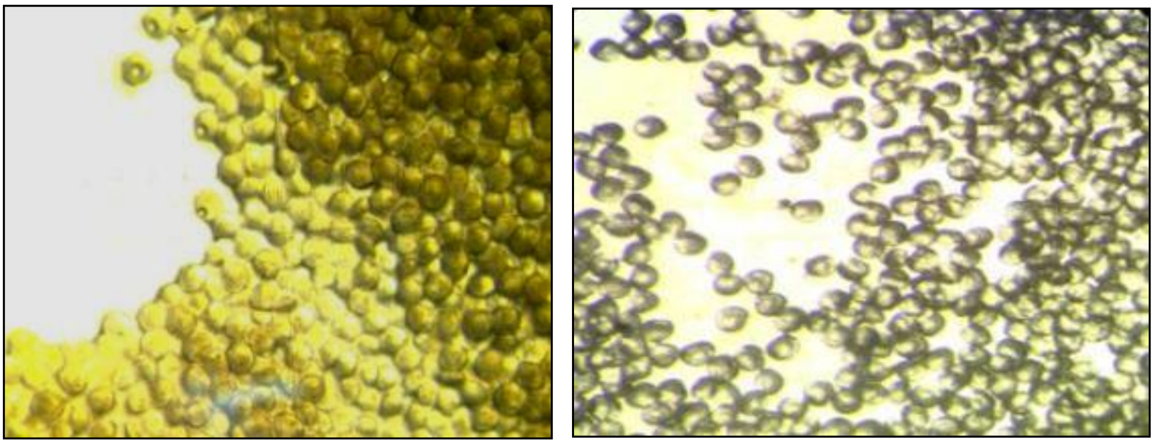

Figure 7 a-b: Native oyster larvae removed from a black sick brooding female (left) and grey sick female (right)

2.3 Environmental Monitoring

A Seabird 19+ CTD (Conductivity, Temperature, Depth) instrument was deployed at each of the 5 sample stations each time a plankton sample and oyster sample were collected. The water temperature, dissolved oxygen, salinity, turbidity and fluorescence were recorded on the downcast of this CTD with care taken not to disturb the seabed when lowering the unit. These data were converted to depth averaged data in 1m batches. The data were tabulated and graphed in MS Excel. Daily water temperature was recorded at each site using Onset® UA-001-64 HOBO temperature loggers.

Figure 8 Seabird 19+ CTD

3.0 Results

Monitoring began in April 2018 with collections from the Perch bed and a collection on 8th May 2018 from Perch, Quigley's Point and Middle bed. The main survey began on 21st May 2018 with collections from the Perch, Quigley's Point, Middle bed, Flat Ground and Southside sampling stations. The survey was conducted over a period of 18 weeks, ending on 24th September 2018. The survey started earlier than in previous years, with the aim of observing the onset of oyster spawning activity.

Average water temperature (16.02ºC ± 1.99) and salinity (30.8 psu ± 1.49) were both slightly higher than in 2017 and variation amongst the beds was minimal. Average temperatures peaked at 19.5ºC ± 0.27 in week 6 (9th July 2018). Average turbidity remained below 8 FTU throughout the survey.

A total of 2715 oysters were collected and examined during the survey. Of these, 154 oysters were found to be brooding eggs or larvae, representing 5.7% of the sampled population. When combined with the number of oysters exhibiting spent gonads (indicating that they had released eggs or sperm), 40.8% of the sampled population were found to be reproductively active during the survey.

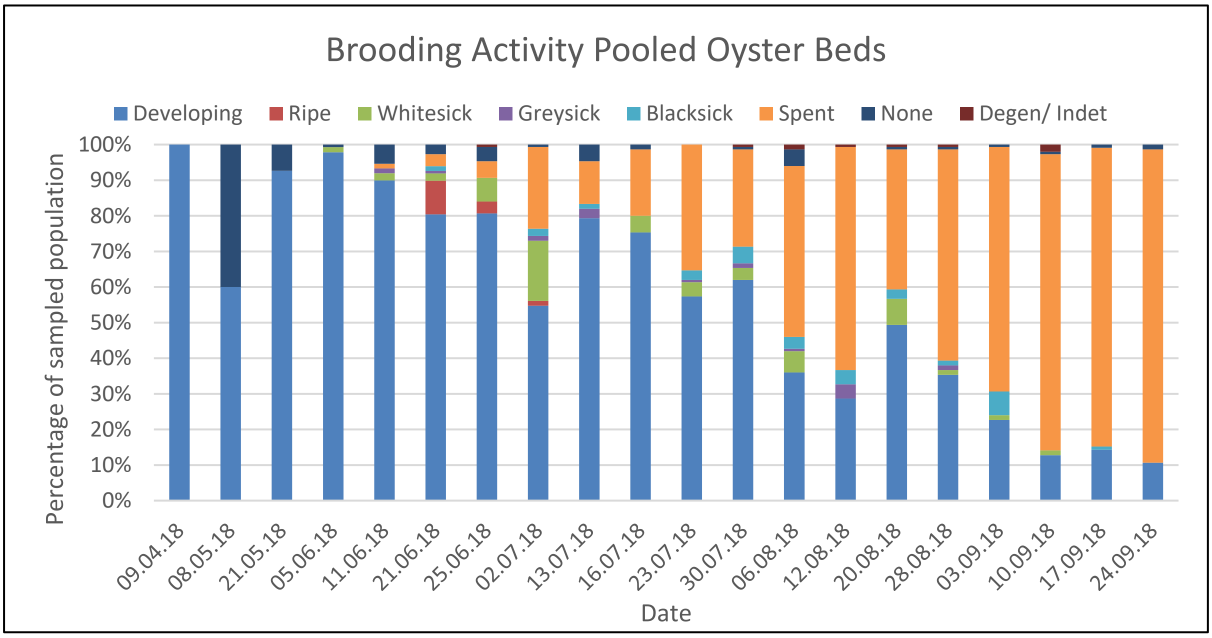

Figure 9 Reproductive activity in 2018, showing all oyster gonad and brooding development stages (pooled data – all beds).

Brooding oysters were first recorded on 5th June 2018 (figure 9), when water temperatures exceeded 18ºC. Of the three brooding stages, white sick (eggs) was the most frequently observed stage. The highest number of black sick (late stage, near-to-release larvae) in one week's samples was recorded on 3rd September 2018. Grey sick, the intermediate stage where eggs are developing into early stage shelled larvae, was the least frequently observed. The abundance of oysters developing gonad material was highest in each weekly sample from the beginning of the survey until the 16th July, after which point the number of oysters with spent gonads steadily increased until the end of the survey, when the majority of the sampled population were spent.

Peak brooding numbers were recorded on 2nd July 2018 (30 oysters i.e. 20.3% of the week's sample). A second, smaller, more sustained peak then occurred for almost a month between 23rd July and 20th August, where between 7.3 and 10% of the sampled oysters were found to be brooding eggs or larvae. This period coincided with mean water temperatures consistently exceeding 16.5ºC and reaching a maximum of 19.4 ºC. A third, brief, smaller peak was recorded on 3rd September 2018, when 8% of the sampled oysters that week were found to be brooding. Combined with the number exhibiting spent gonads, 76.6% of that week's oysters had been reproductively active. Brooding and reproductive activity then began to decrease as temperatures decreased to 12 to 13ºC at the end of the survey on 24th September 2018. Black sick oysters were recorded in the samples taken on 3rd September (after the traditional start date of the oyster fishing season in Ireland) and on 17th September (close to the traditional 19th September opening date for the Lough Foyle fishery). No brooding oysters were recorded in the final week of the survey (24th September 2018).

Bivalve larvae (all species) were observed in all weeks except the first week of the survey (08.05.18). Pooled mean larval density peaked on 25.07.18 (38026) and again on 22.08.18 (31957). These peaks occurred following water temperature peaks of up to 19°C and sustained high water temperatures of over 16°C.

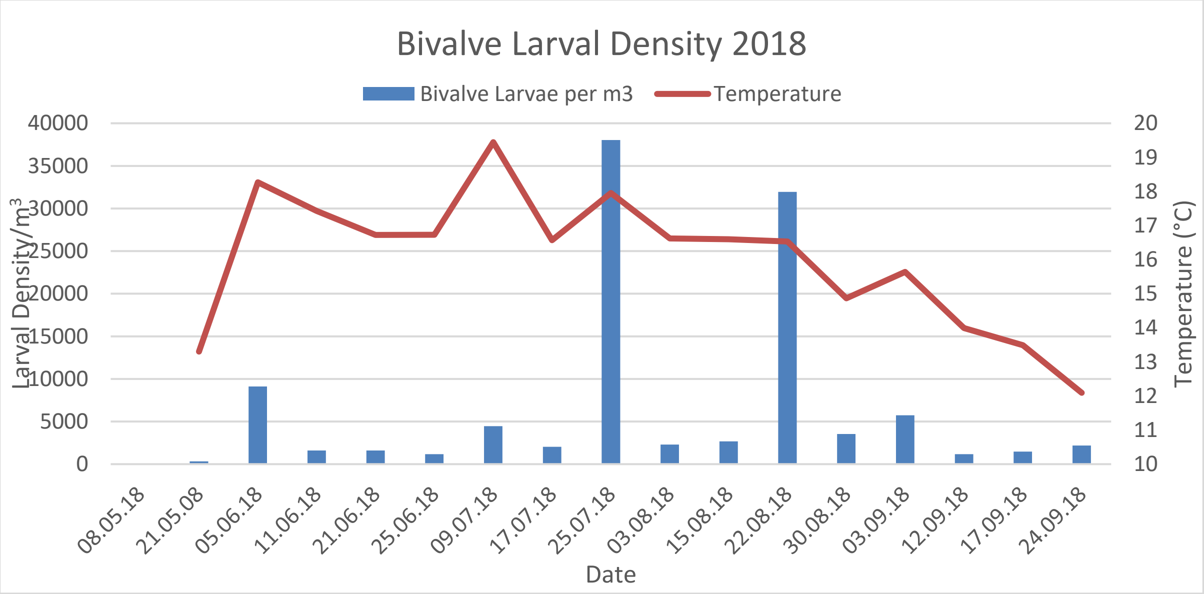

Figure 10 Weekly mean larval density and mean water temperatures (pooled data all sites).

The peaks in bivalve larvae occurred approximately 2 weeks after the peaks in brooding were observed. The first larval peak occurred on 25.07.18 (38,026m^3) and this followed a preceding period when brooding within the sampled population had been over 20% on the 09.07.18. A second peak occurred in the bivalve larvae on 22.08.18 and this followed sustained brooding activity of 8% per week or more during August.

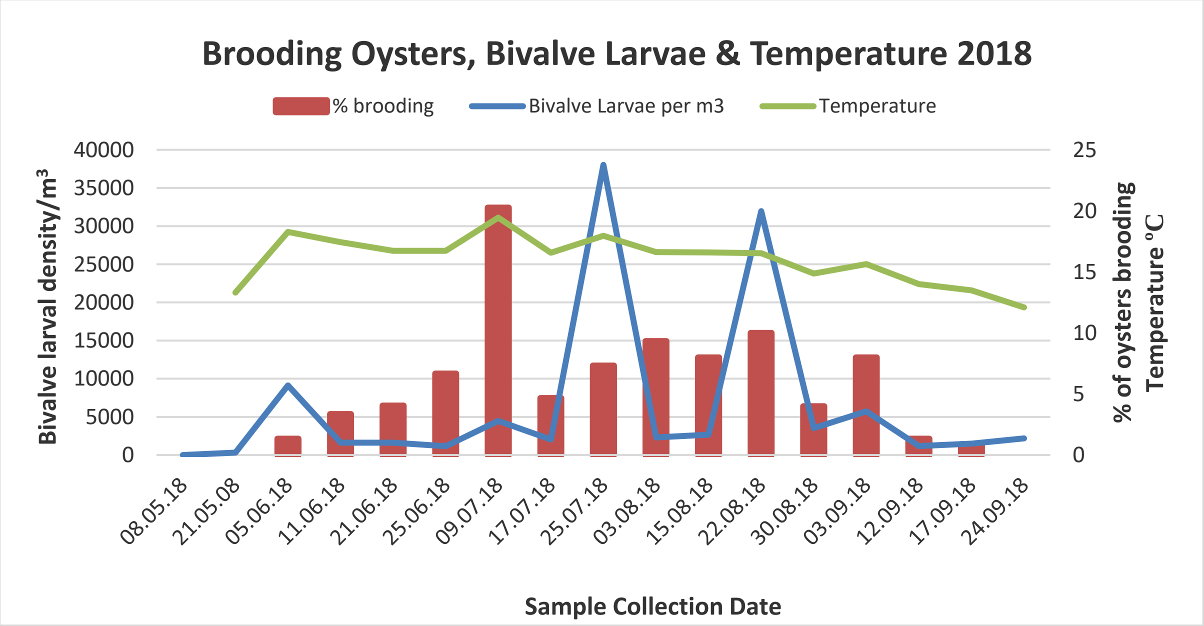

Figure 11 Weekly mean larval density, water temperatures and weekly number of brooding oysters (pooled data all sites).

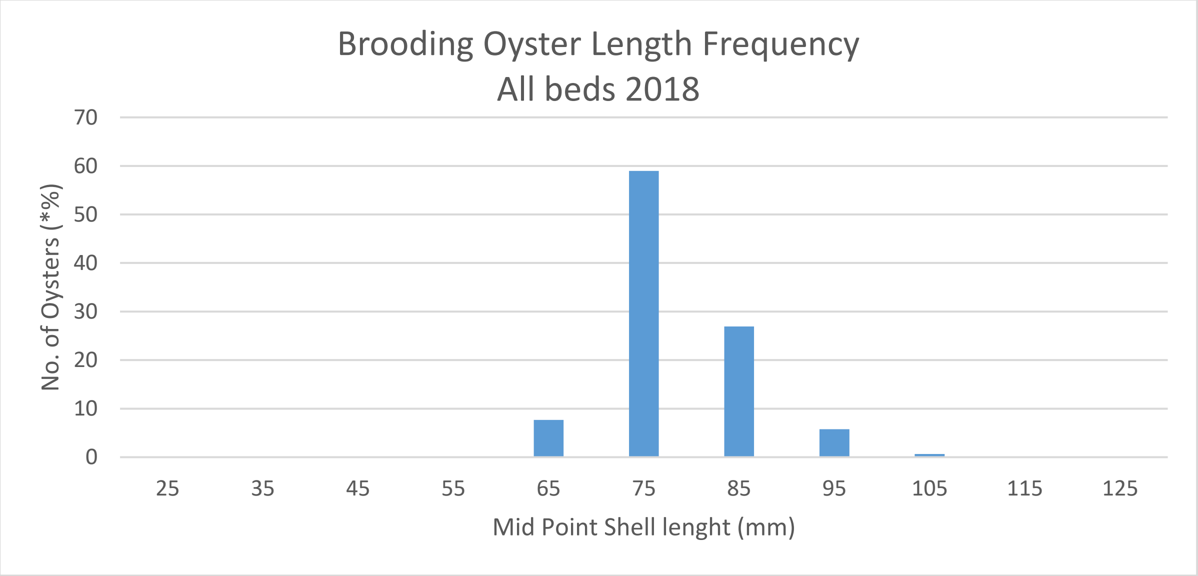

Figure 12 Length frequency of brooding oysters (pooled data all stations)

The length and weight frequencies for the sampled oysters show that oysters from 65mm and above 35g and over were brooding. This is important information for fishery managers as it gives us the evidence to show that the minimum landing size of 80mm is adequate to provide protection to the spawning oysters in their first and potentially second years. It must be noted that sampling bias may have resulted in the selection of larger oysters than in previous years.

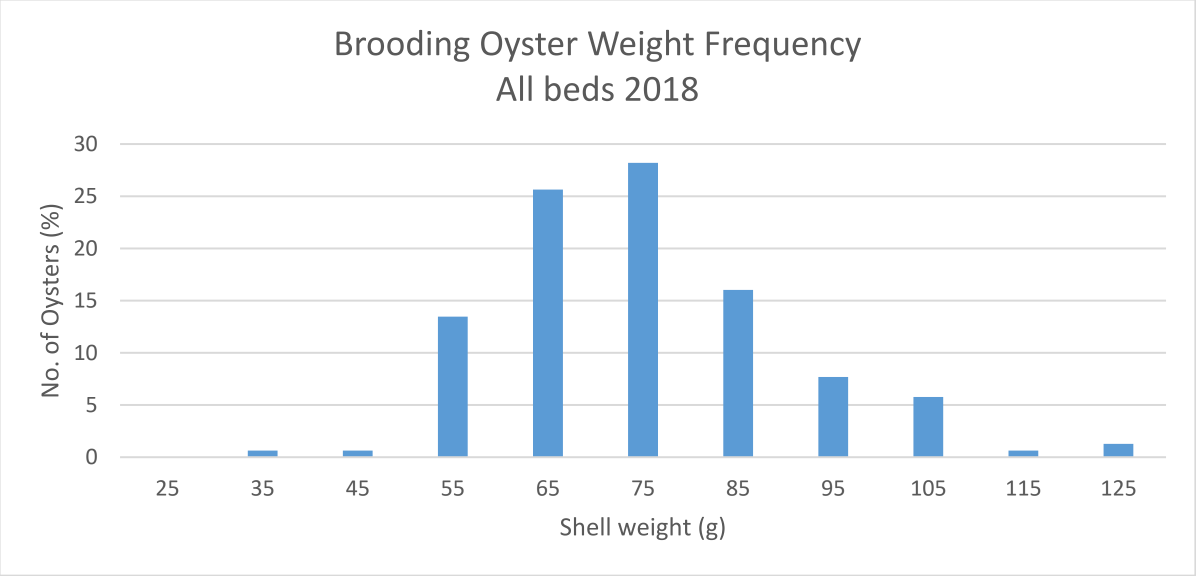

Figure 13 Weight frequency of brooding oysters (pooled data all stations)

Table 3: Summary data for all sites sampled 2018

Bed Name	Min Temp (˚C)	Max Temp (˚C)	Max Larvae per m^3	% Oysters Brooding	% Brooding & Spent	Mean Length (mm)	Mean Weight (g)
Flat Ground	11.98	19.66	33948	8.05	39.68	76.93	71.43
Middle Bed	11.97	19.24	15339	5.82	41.72	76.86	64.57
Perch	12.32	19.08	41257	4.52	36.68	77.69	75.30
Quigley's Pt	12.32	19.57	117877	5.55	41.29	77.83	70.33
Southside	11.85	19.66	9194	4.94	42.88	76.83	72.66

3.1 Flat Ground

Table 4: Flat Ground summary info

Bed Name	**Flat Ground**
Area (hectares)	**970**
Average Density (oysters/m2)	**0.32**
No. of Oysters	**3505758**
Total Biomass (t)	**238.3**

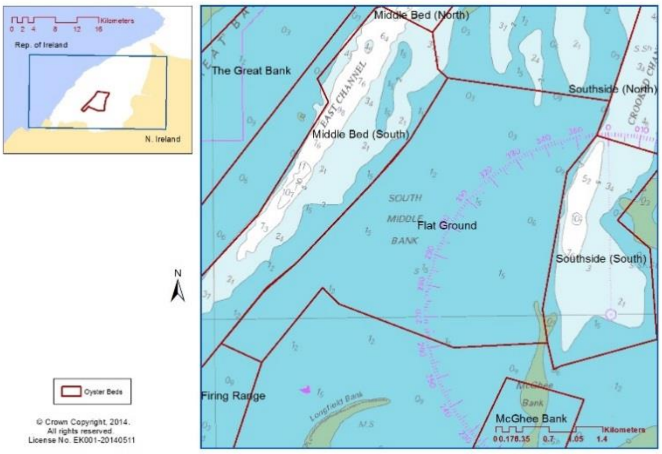

Figure 14: Location of Flat Ground

8% of sampled oysters on the Flat Ground were brooding during 2018. This was the highest brooding rate recorded throughout all oyster beds in Lough Foyle. Brooding commenced on 11th June and there was evidence of brooding each week until 10th September. Peak brooding occurred in Flat Ground on 2nd July 2018 when 26% of the sample was white sick. The highest number of black sick oysters recorded on this bed were found in the sample collected on 3rd September 2018. The number of spent oysters increased continuously from 20th August.

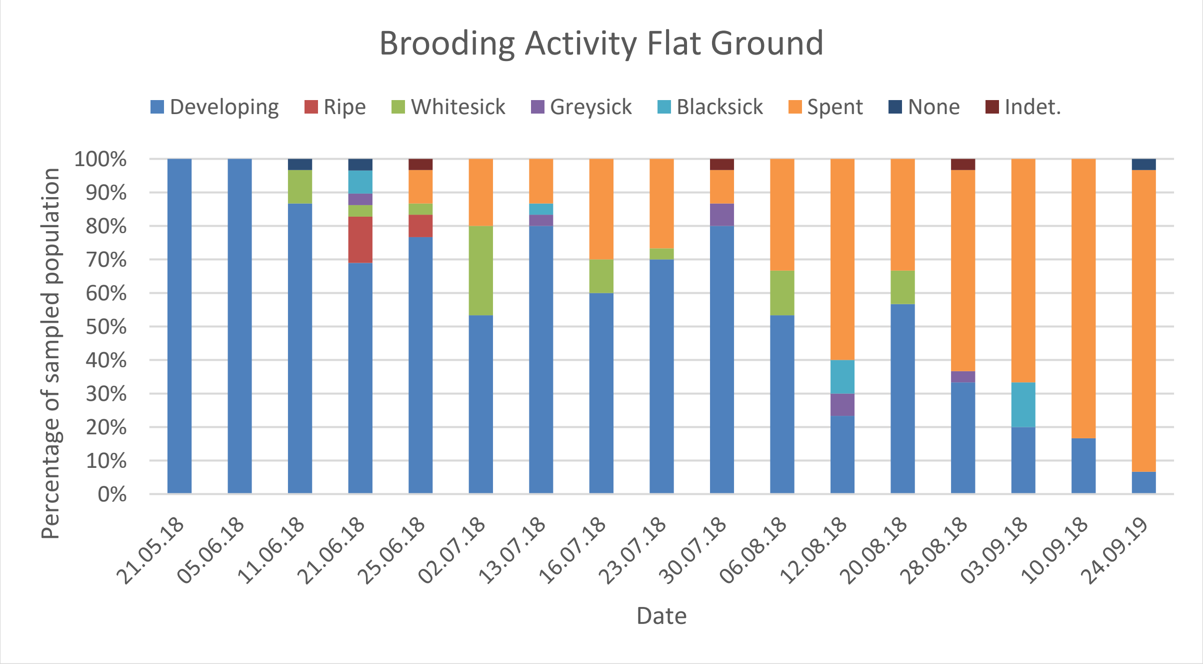

Figure 15: Spawning Stage Flat Ground 2018

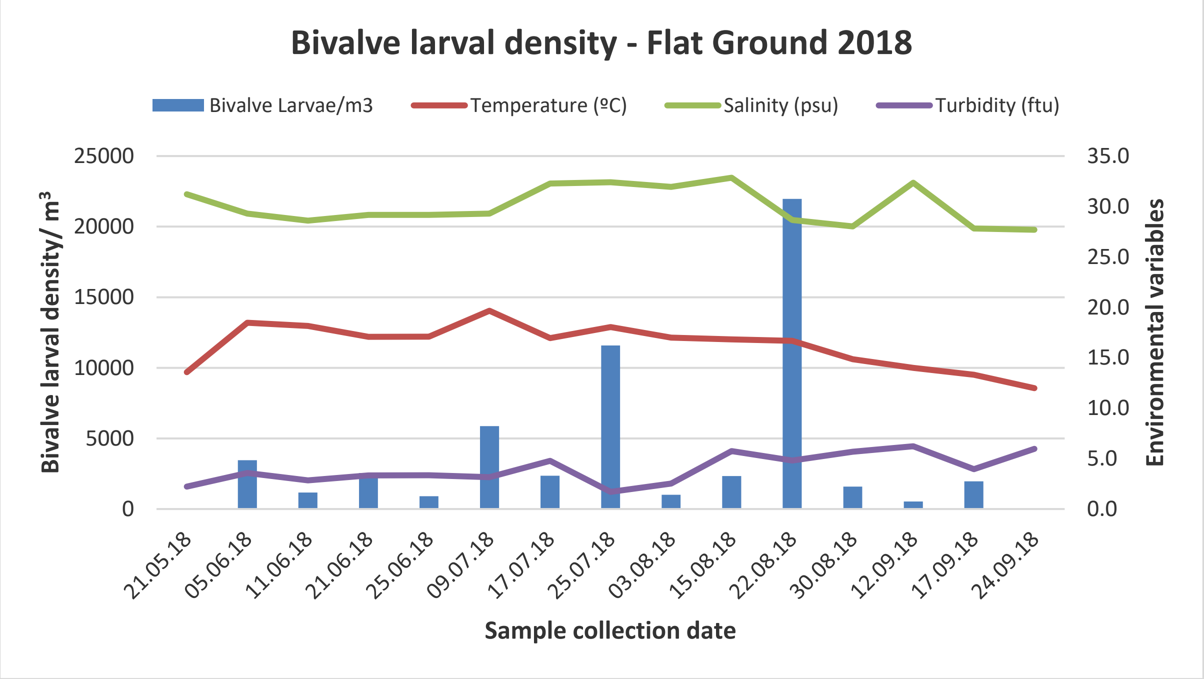

Figure 16: Larval Density and environmental variables - Flat Ground

Mean bivalve larval density was 3,820/m^3 with a peak on the 25.07.18 (11,580/m^3) and again on the 22.08.18 (21,966/m^3). These peaks followed periods of sustained elevated water temperatures above 16°C and brooding activity of 26% and 16% respectively. There was no larval peak in September following the slight increase in the numbers brooding in the samples on 3rd September suggesting that these larvae did not survive well or were exported from the bed.

Mean water temperature on the Flat Ground was 16.2°C (range 11.9-19.6°C). Mean salinity was 30 psu with a range of 27.6-32.8 psu showing how little freshwater input there was during the summer of 2018. Likewise turbidity was low relative to previous years thanks to the prevailing calm weather conditions for much of the summer period.

Mean length of all sampled oysters from the Flat Ground was 76.9mm with a mean weight of all sampled oysters of 71.4g. Those oysters brooding eggs or larvae had a mean shell length of 77.4mm and a mean weight of 76.5g. 73% of the brooding oysters were less than the minimum landing size of 80mm. Oysters as small as 39g and as large as 127g in total wet weight were recorded as brooding showing the broad range of sizes that were spawning during 2018.

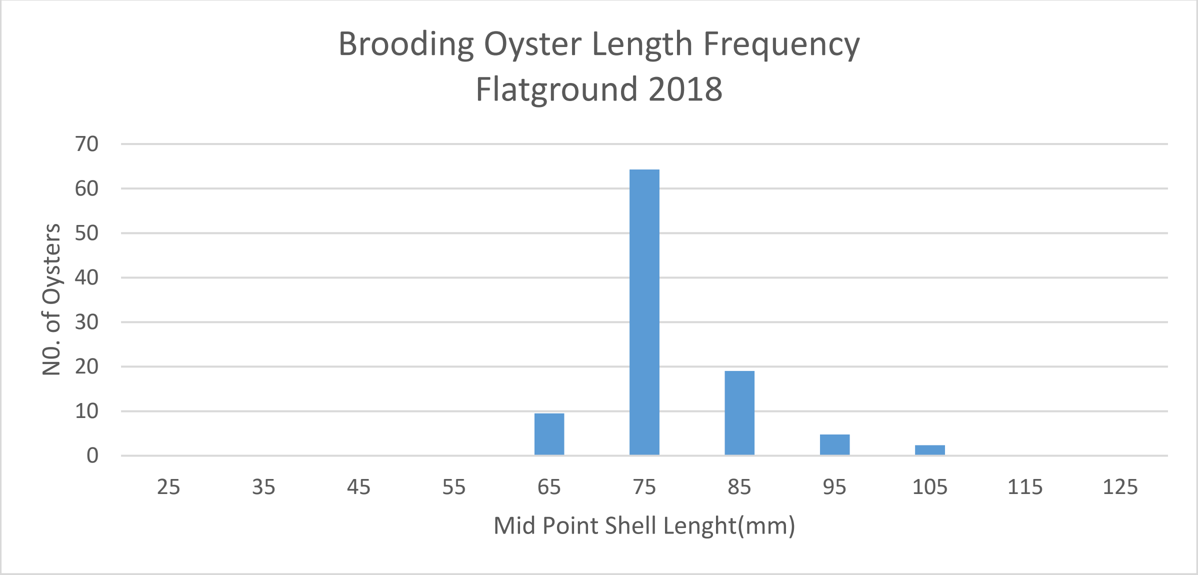

Figure 17: Length Frequency of Brooding Oysters - Flat Ground 2018

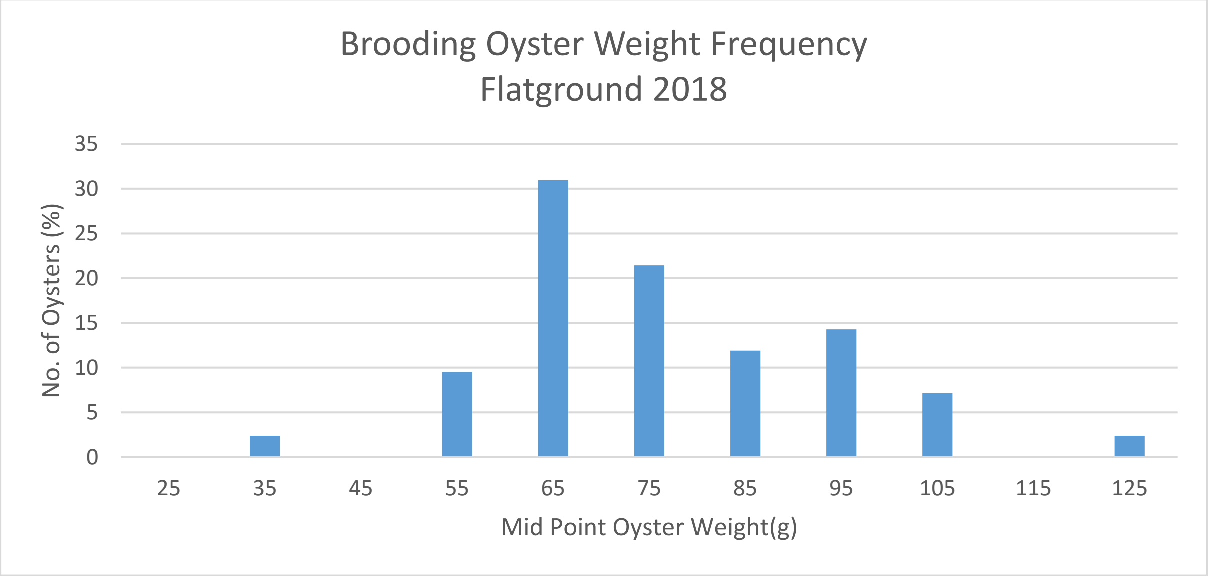

Figure 18: Weight Frequency of Brooding Oysters - Flat Ground 2018

3.2 The Perch Bed

Table 5: Perch summary info

Bed Name	The Perch
Area (hectares)	276
Average Density (oysters/m2)	0.20
No. of Oysters	501889
Total Biomass (t)	33.12

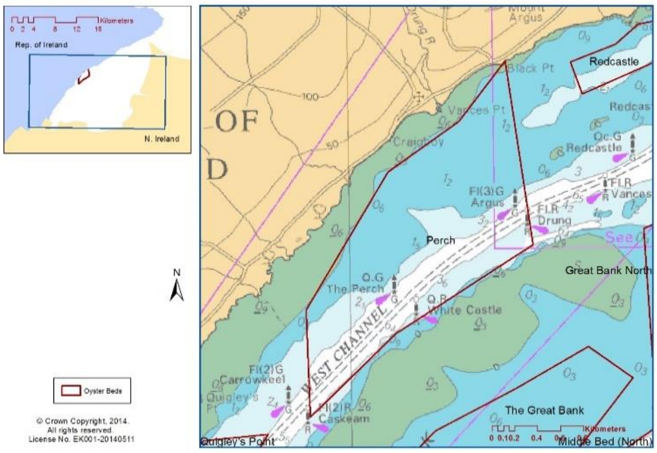

Figure 19: Location of the Perch

Brooding activity was observed from 25th June onwards on the Perch Bed. As with the other beds, peak brooding was observed in the Perch on 2nd July 2018 with 16% of the sampled population in the brooding stages. Only 4.5% of the sampled oysters were brooding during 2018. This was the lowest recorded brooding rate for all beds within Lough Foyle in 2018. The numbers of spent oysters in the samples was continuously rising from late July onwards.

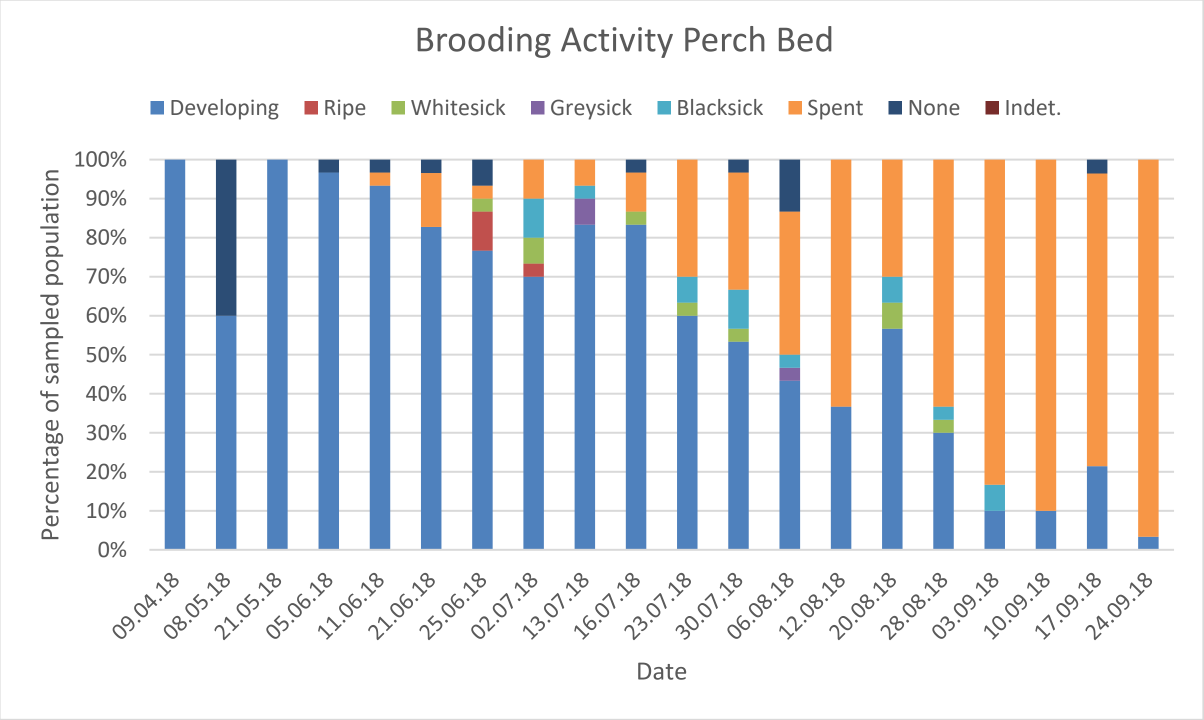

Figure 20: Spawning Stage Perch Bed 2018

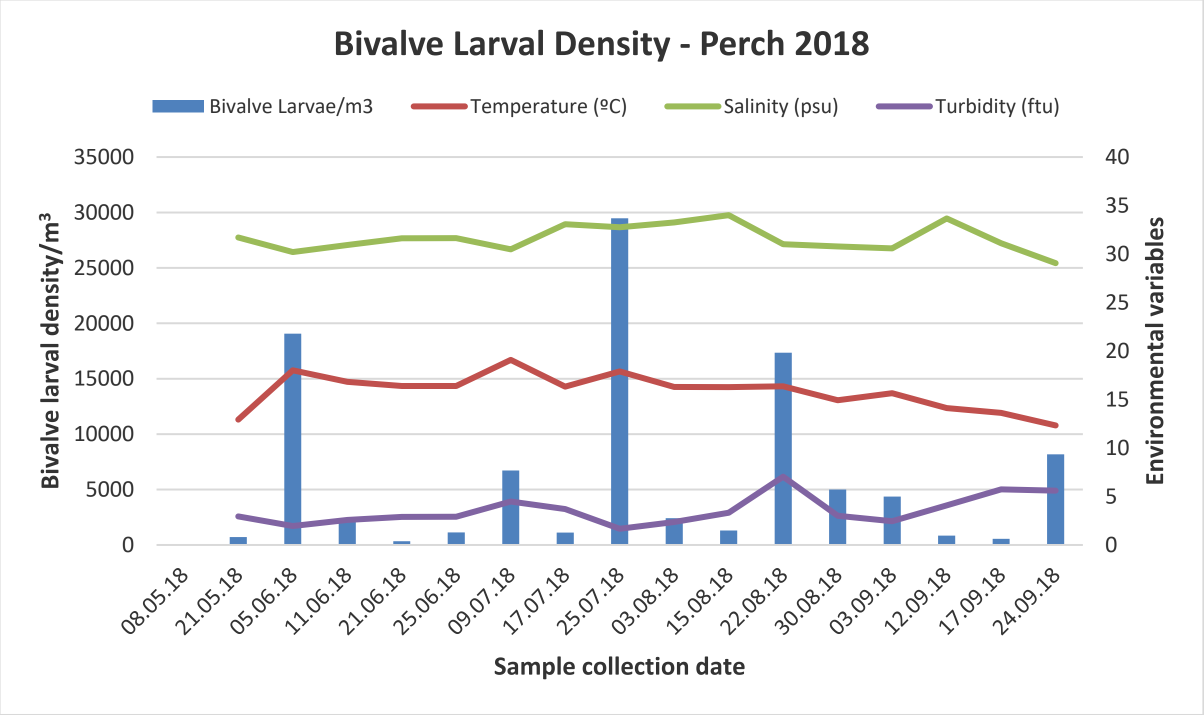

Figure 21: Bivalve larval density and environmental variables – Perch

Mean bivalve larval density for the Perch Bed was 5,938/m^3. Bivalve larval peaks were observed in early June (19,069/m^3), late July (29,469m^3) and late August (17,351/m^3). These peaks followed sustained brooding levels of over 10% per week on this bed during July and August. Brooding was still evident on this bed in September and this may account for the small peak in larval density on 24.09.18.

Mean water temperature recorded in the Perch in 2018 was 15.8°C (range 12.32 – 18°C). Salinity ranged from 29 to 34 psu and turbidity averaged 3.5. Once again the calm dry weather experienced during 2018 resulted in consistently high water temperatures, relatively high salinity and low turbidity for much of the summer period.

Mean shell length of all sampled oysters in 2018 was 77.6mm and mean weight of oysters was 74.4g. 60% of all brooding oysters recorded during the survey were less than the 80mm minimum landing size.

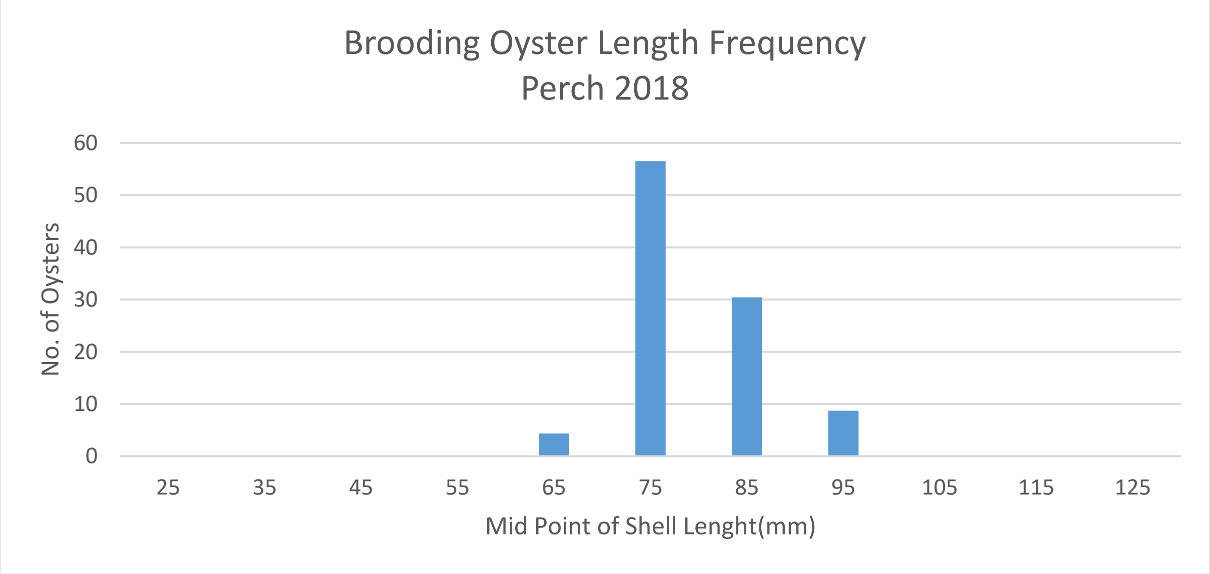

Figure 22: Length Frequency of Brooding Oysters - Perch

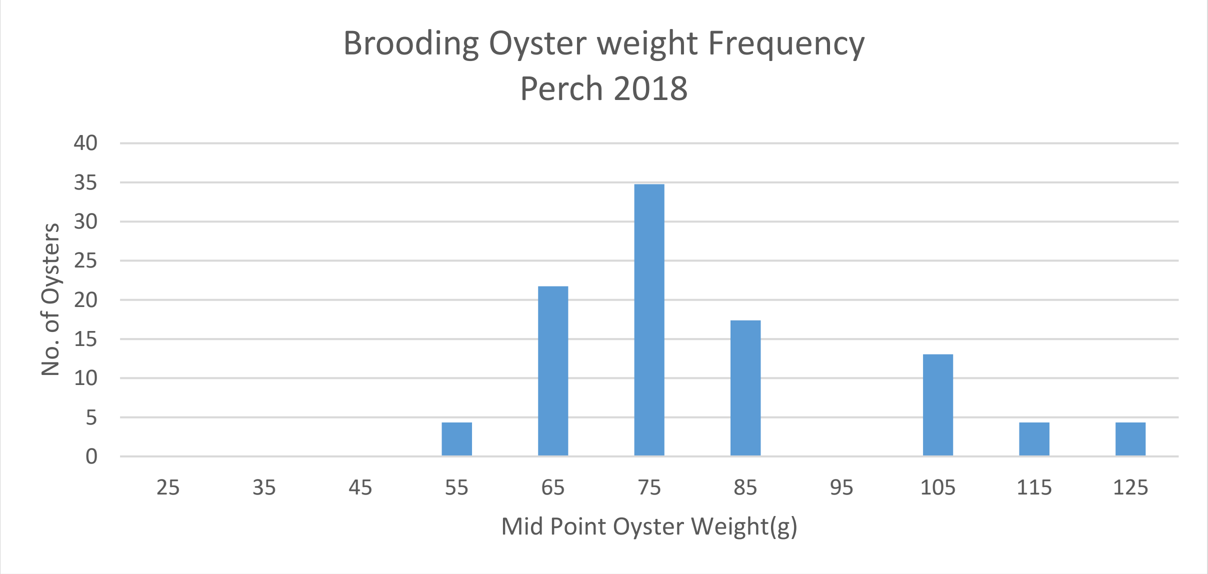

Figure 23: Weight Frequency of Brooding Oysters - Perch 2018

3.3 Quigley's Point

Table 6: Quigley's Point summary info

Bed Name	Quigley's Pt
Area (hectares)	140
Average Density (oysters/m2)	0.26
No. of Oysters	451881.9
Total Biomass (t)	26.2

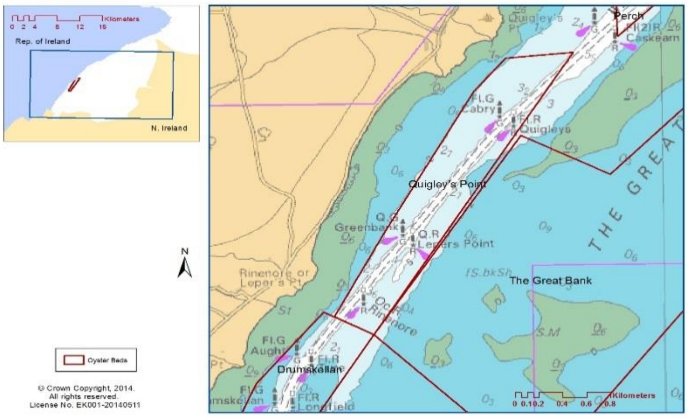

Figure 24: Location of Quigley's Point

Spawning activity was recorded on the Quigley's Point bed from 25 June onwards. Peak brooding was observed in Quigley's Point on 2nd July when 26% of the sampled oysters were in the white sick phase. The numbers of spent oysters increased steadily from the end of July. In total 5.5% of the oyster samples were in the brooding phases during 2018.

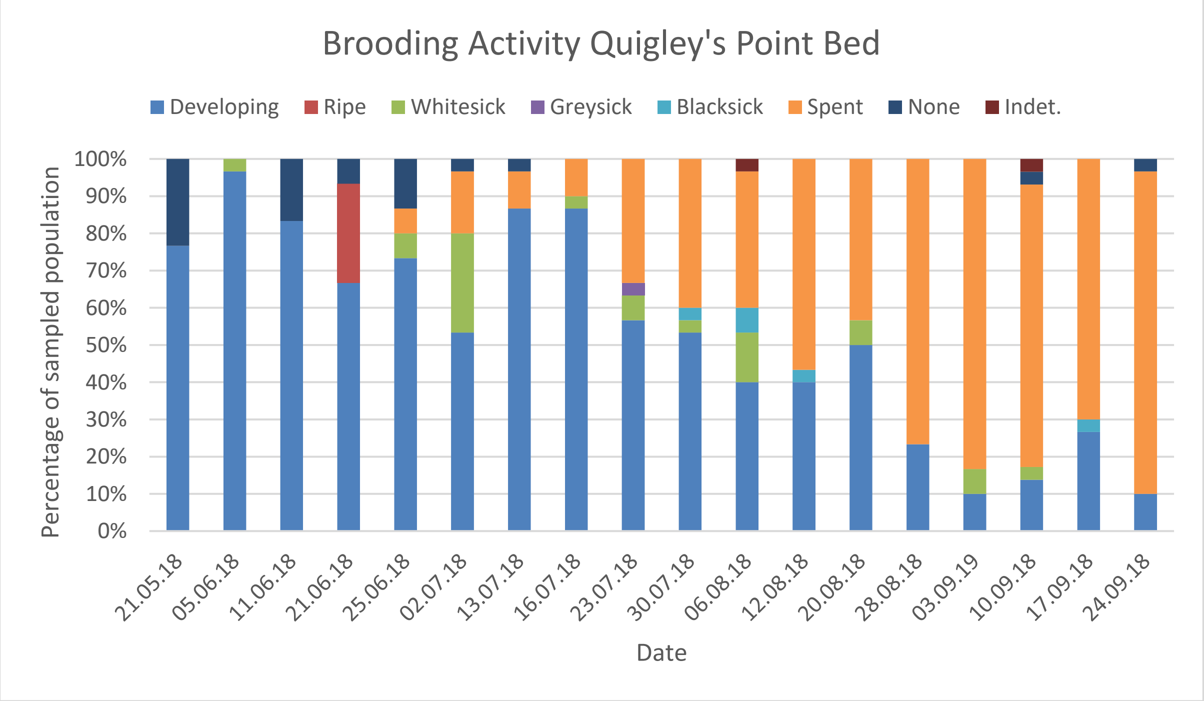

Figure 25: Spawning Stage Quigley's Point 2018

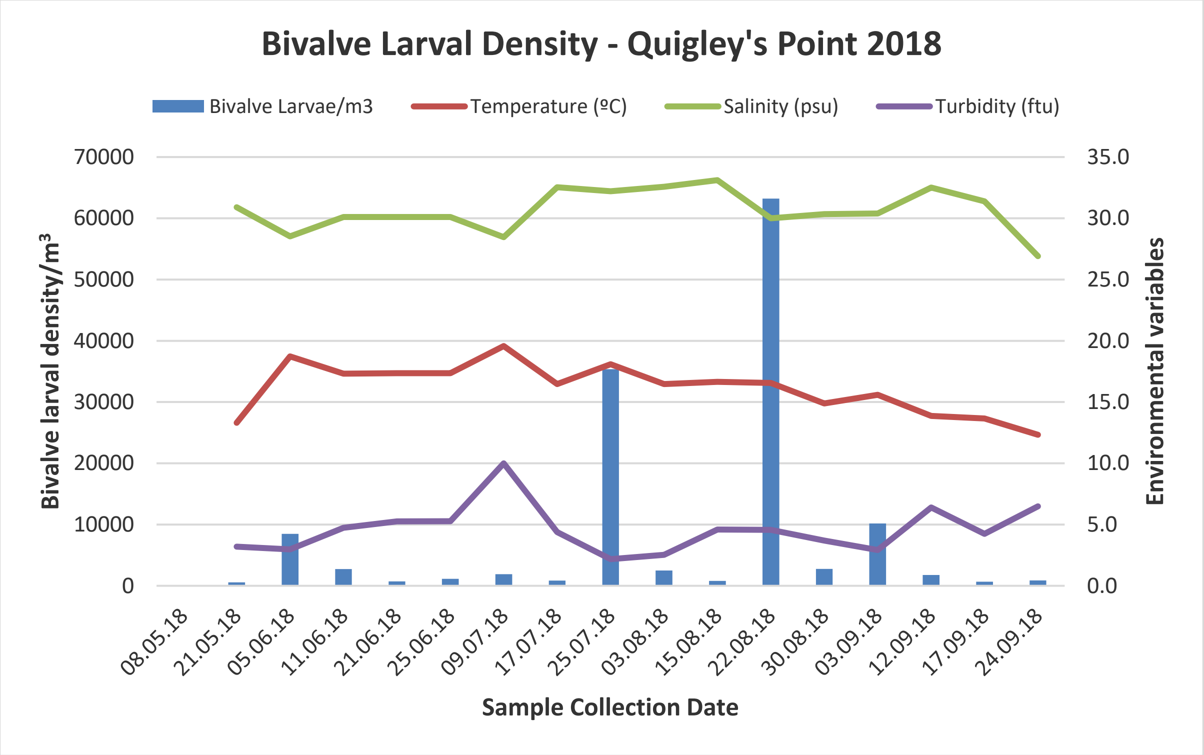

Figure 26: Bivalve larval density and environmental variables - Quigley's Point

Mean bivalve larval density on the Quigley's Point bed was 7,909/m^3. There were two notable peaks in the bivalve larval densities in late July (35,363/m^3) and late August (63,225/m^3). Bivalve larval peaks on this bed were twice as high as those observed on other oyster beds. Brooding peaks were observed in early July and early August and it is possible that the peaks in bivalve density are linked to this increased brooding activity. It is also possible that these bivalve larvae are those of other species and are not *Ostrea edulis* larvae.

Mean water temperature on the Quigley's Point bed during the sample period was 16.1℃ with a range of 12.3-18.7℃. Mean salinity value was 30.6 psu with a range of 26.9-32.5 psu. The relatively dry and calm summer conditions resulted in consistent water temperatures and very little freshwater influence on the salinity values for much of the summer period.

Mean length of all sampled oysters was 77.7mm and mean weight was 70.3g. Mean length of brooding oysters was 79mm and mean weight was 77.2g with a range of 56-92g.

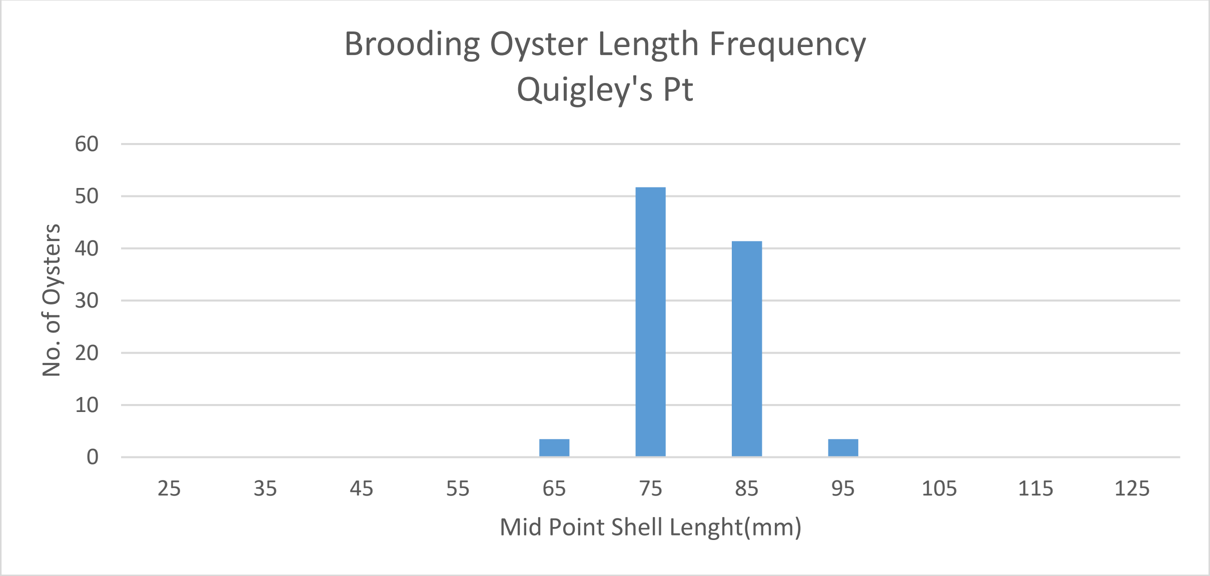

Figure 27: Length Frequency of Brooding Oysters - Quigley's Point

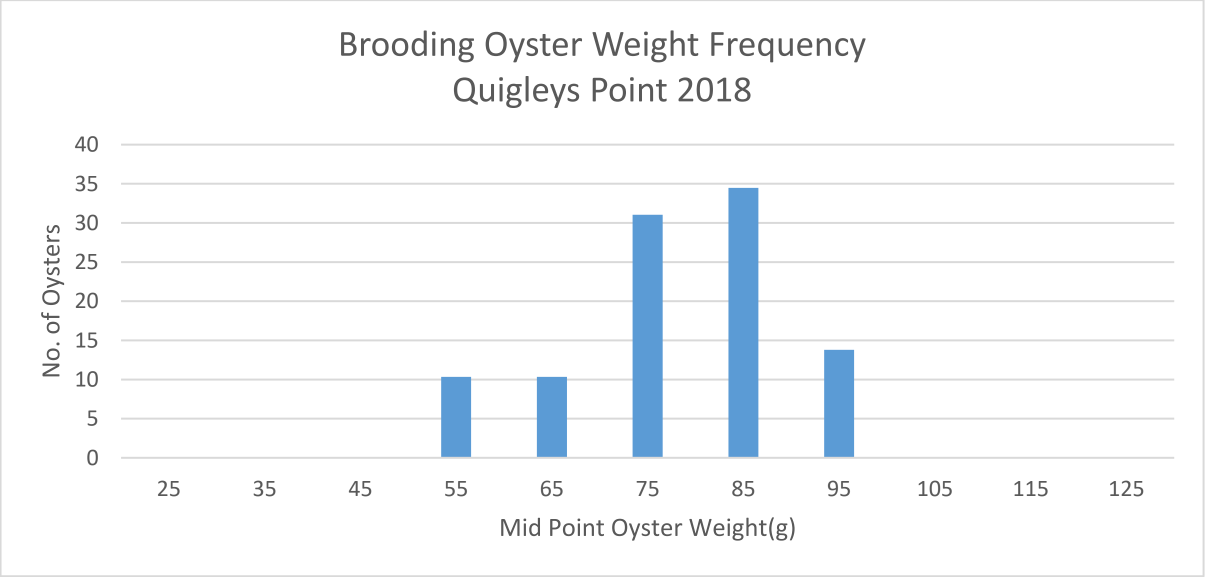

Figure 28: Weight Frequency of Brooding Oysters - Quigley's Point

3.4 Southside Bed

Table 7: Southside summary info

Bed Name	Southside
Area (hectares)	578
Average Density (oysters/m2)	0.36
No. of Oysters	2342175
Total Biomass (t)	156.4

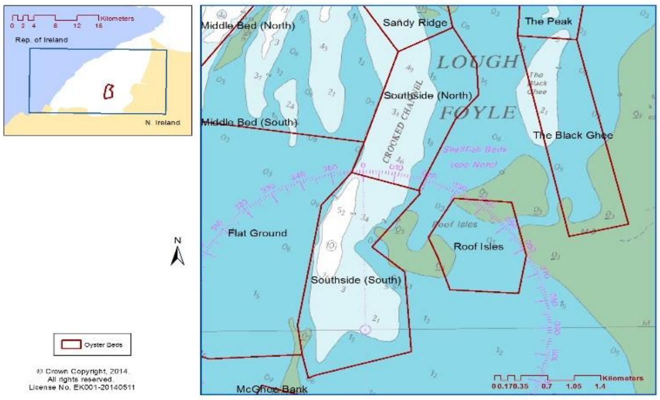

Figure 29: Location of Southside Bed

Brooding activity was observed from 5th June onwards on the Southside bed. As with the other beds, peak brooding occurred in Southside in the sample collected on 2nd July 2018. A second peak in the number of oysters found to be brooding eggs or larvae was recorded in the sample from 12th August 2018. Redevelopment appears to have occurred following the spawning events with almost 70% of the samples thought to be still developing in early September. In total 4.9% of the sampled population was brooding.

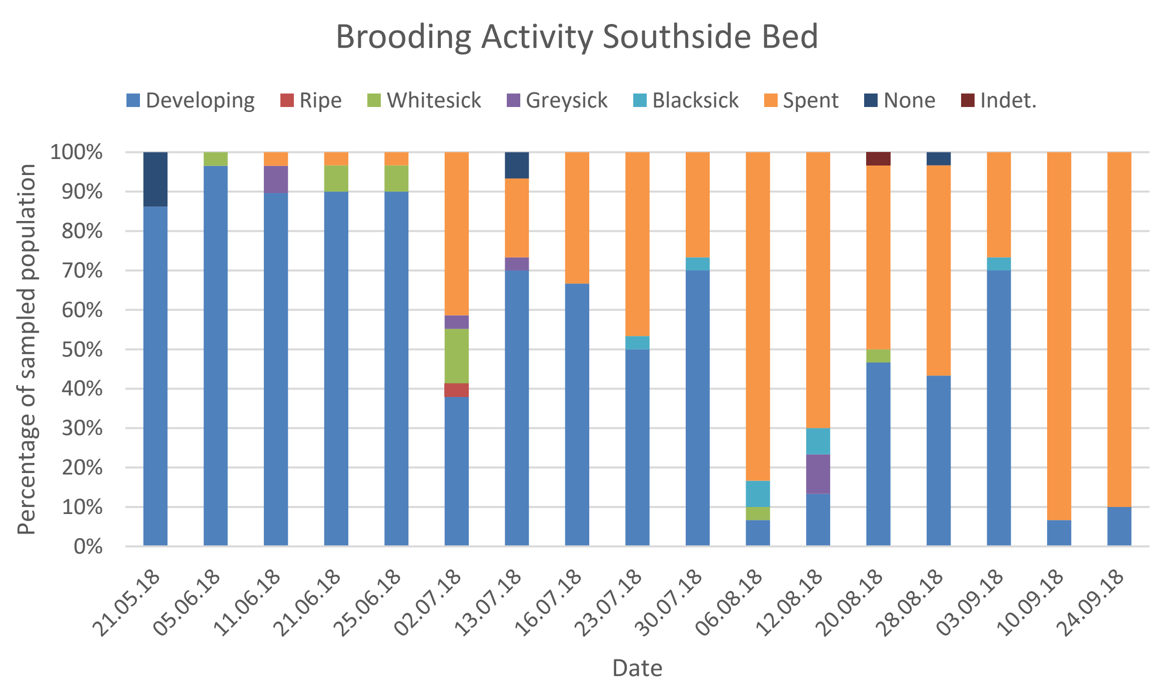

Figure 30: Spawning Stage Southside Bed 2018

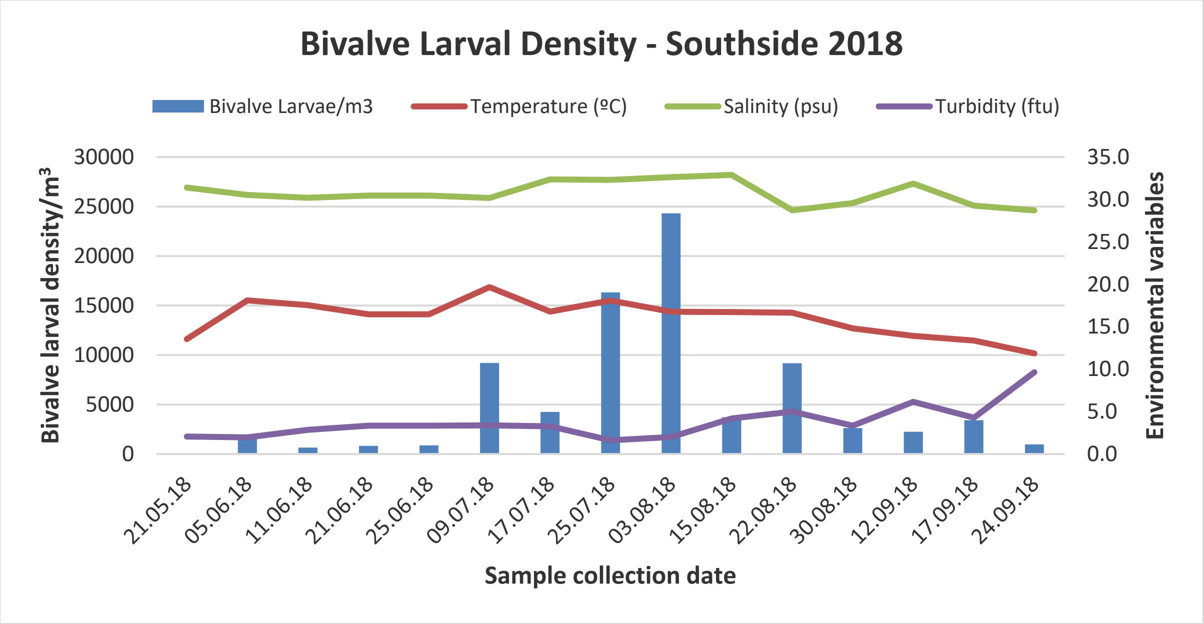

Figure 31: Bivalve larval density and environmental variables – Southside

Mean larval density on this bed was 5,351/m^3. Bivalve larval density remained relatively consistent on this bed for much of July and August, with values above 3,000/m^3. Peaks were recorded on 9th July (9,194/m^3), 25th July (16,328/m^3), and 22nd August (9,160)/m^3). The brooding rates on this bed show a peak of 16% in early July and another peak of 16% in mid-August.

Mean water temperature on this bed was 16.05°C with a range of 11.8-19.6°C. The sustained high water temperatures during the summer period provided the optimal conditions for oyster spawning. Low rainfall during this period resulted in a stable salinity regime with an average of 30.7psu and lows of only 28psu.

Mean length of the sampled population on this bed was 76.8mm with a mean weight of 72.6g. Brooding oysters ranged from 65-91mm in length and 57-95g in weight. 75% of the brooding oysters were less than the minimum landing size of 80mm and 45% were less than 70g in weight.

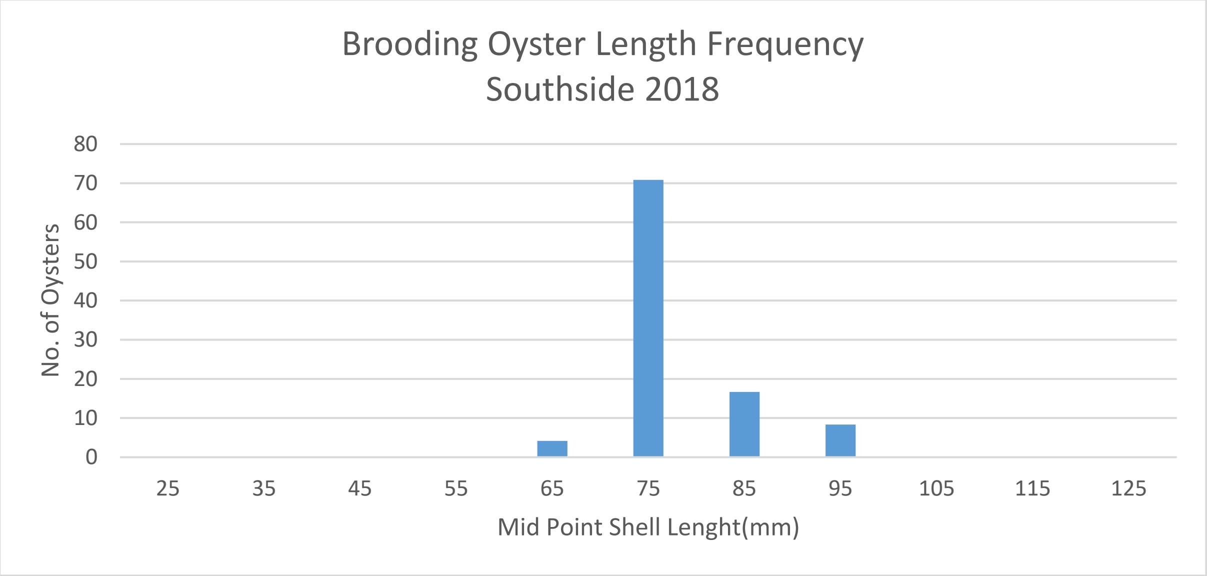

Figure 32: Length Frequency of brooding oysters - Southside

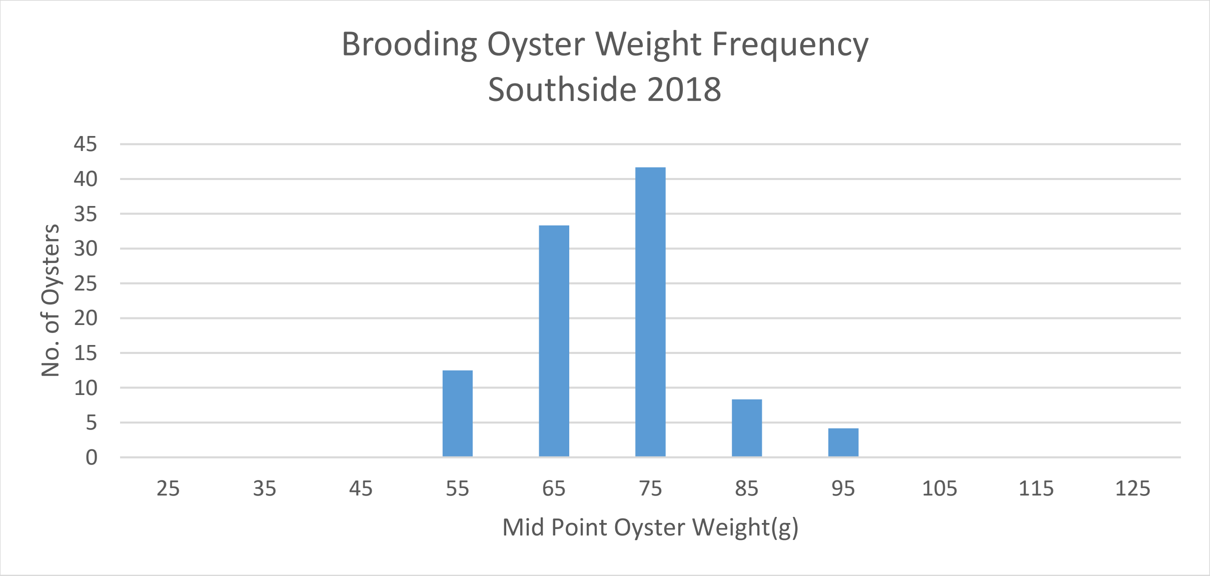

Figure 33: Weight Frequency of brooding oysters - Southside

3.5 Middle Bed

Table 8: Middle Bed summary info

Bed Name	**Middle Bed**
Area (hectares)	**531**
Average Density (oysters/m2)	**0.33**
No. of Oysters	**1744359**
Total Biomass (t)	**108.1**

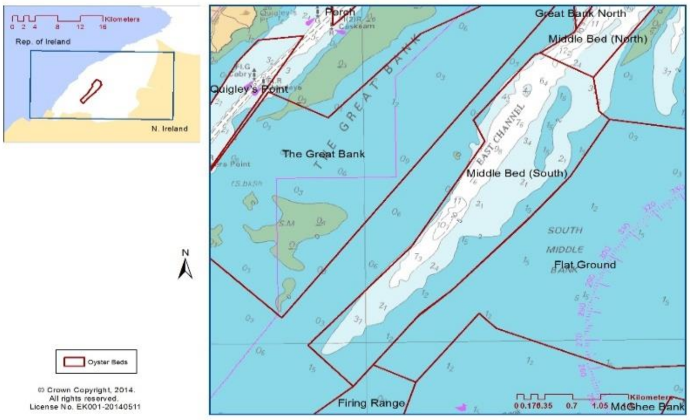

Figure 34: Location of Middle Bed

Brooding was first detected on 25th June with 13% of oysters from the sample in the white sick phase. Middle bed had relatively sustained levels of brooding oysters throughout July and August 2018 with levels of 10% or more for 7 weeks. The proportion of spent oysters progressively increased from the end of July onwards. Total brooding on this bed was 5.8% which was the second highest total brooding figure behind only the Flat Ground at 8%.

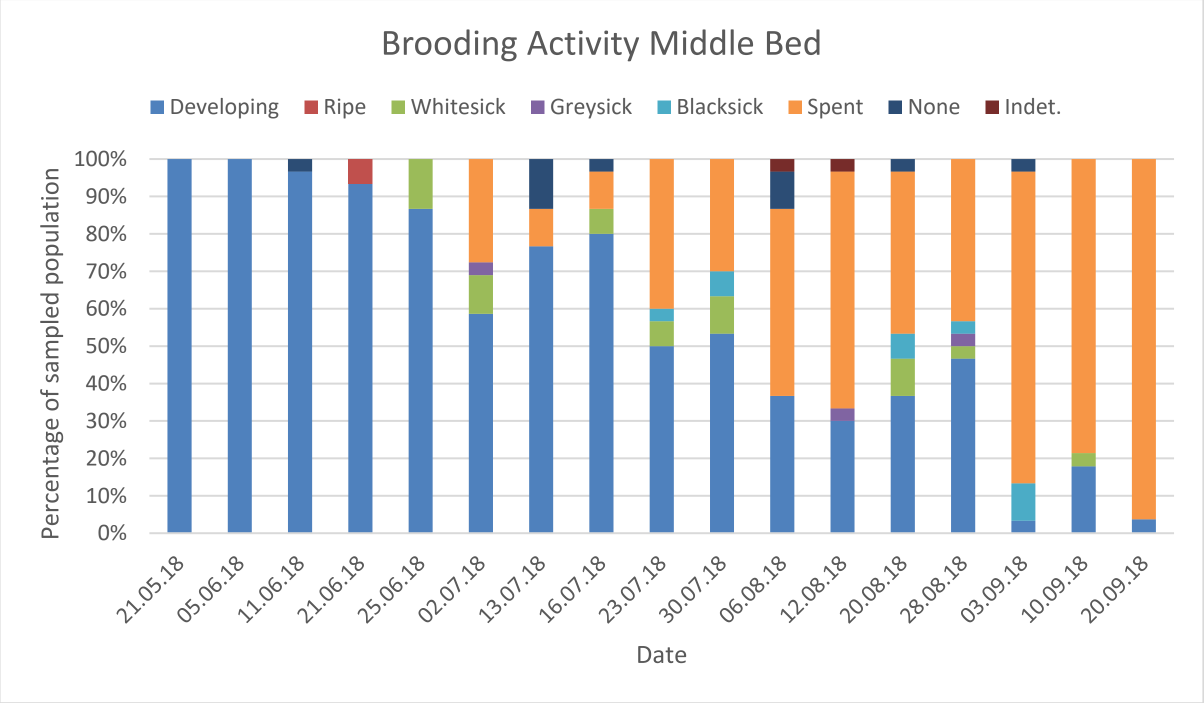

Figure 35: Brooding stage Middle Bed 2018

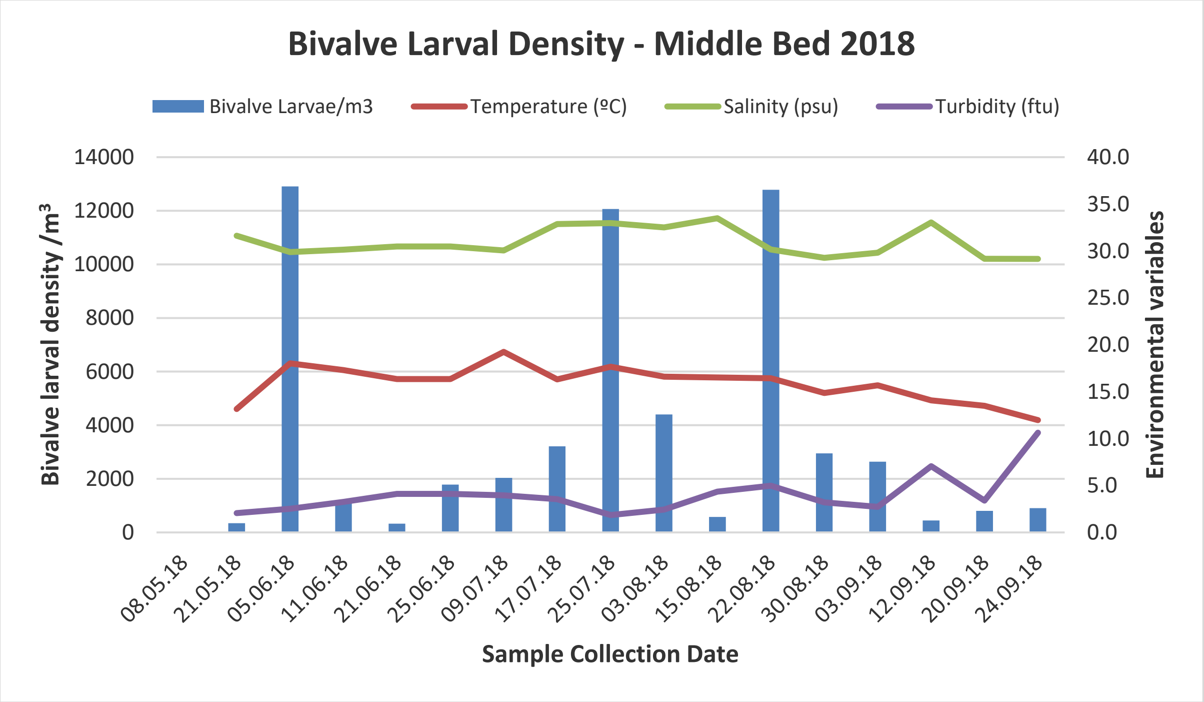

Figure 36: Bivalve larval density and environmental variables - Middle Bed

Mean bivalve density was 3.490/m^3. Bivalve larval peaks were observed in early June, late July and late August in keeping with many other oyster beds. Maximum larval density of 12,910/m^3 was recorded on 5th June and similar peaks were observed on 25th July and 22nd August.

Water temperatures remained consistently above 16°C for all of June and July only falling below this threshold on 30 August. Salinity was very stable once again thanks to the low rainfall levels during the period with a range of 29-33psu.

Mean length of all oysters sampled was 76.6mm and mean weight was 64.5g. Brooding oysters had a mean length of 75.6mm and a mean weight of 67.3g. 75% of the brooding oysters were less than the 80mm minimum landing size in the fishery and 67% were less than 70g in weight.

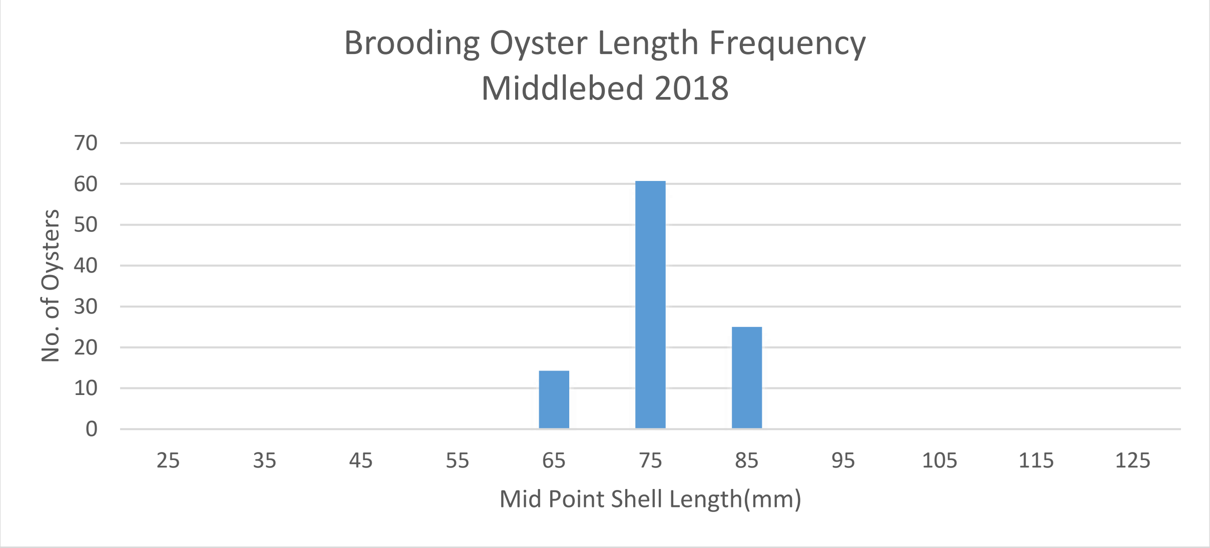

Figure 37: Length Frequency of brooding oysters - Middle Bed

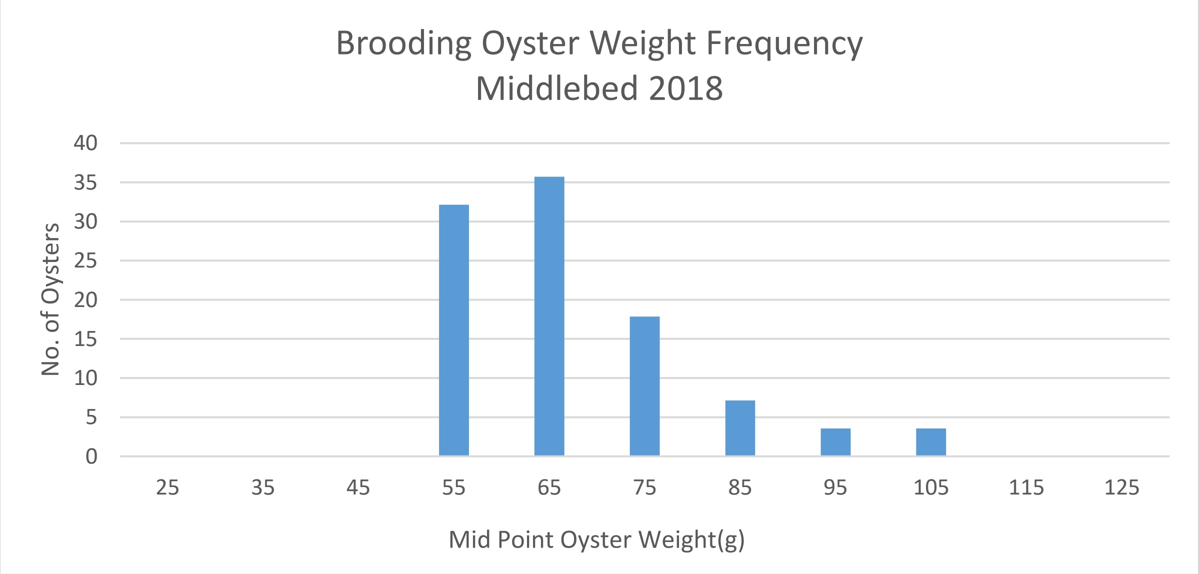

Figure 38: Weight Frequency of brooding oysters - Middle Bed

4.0 Discussion

Whilst in 2018 the percentages of brooding oysters and those showing evidence of reproductive activity were slightly less than those observed in 2017, the native oyster autumn stock survey and spat collector array data have provided evidence of a widespread spatfall in Lough Foyle in 2018.

2018 was characterised by longer periods of settled, hotter, drier weather – this influences water temperature, salinity and turbidity, which is especially influential in a dynamic estuarine environment such as Lough Foyle, where, for example, sudden large volume inputs of freshwater can rapidly decrease temperature and salinity and increase turbidity. For sedentary invertebrates such as native oysters and other commercial bivalve shellfish, changes in environmental conditions impact on all life processes, including feeding (and therefore condition and meat yield), mortality and reproduction. This demonstrates why it is important to carry out different types of monitoring surveys in order to gain a complete picture of the abiotic and biotic drivers of the population dynamics of Lough Foyle's native oysters.

Also from the collections for this survey and the native oyster stock assessment, it has been noticeable that the volume of the bryozoan, *Alcyonidium diaphanum*, has been significantly lower in 2018 than in previous years. As high volumes of the bryozoan attached to the substratum and the oyster themselves may inhibit spawning and settlement (interference/ spatial competition), this reduced abundance may have contributed to the observed native oyster spatfall. In some areas of the lough, however, a number of macroalgal species, including *Chorda* (bootlace weed) were abundant and may have negatively impacted native oyster spatfall in those areas. Understanding patterns and influences upon spawning and settlement success will assist with developing strategies to sustainably manage stocks and respond to environmental factors such as climate change.

The three observed peaks in brooding are consistent with the observed settlement in the lough of distinct spat sizes – those above 15 mm which would be expected to have settled in July; those between 6 and 15 mm which would have settled in the month between 23rd July and 20th August; and spat of < 6 mm settled during September. The high numbers of blacksick oysters recorded in the samples collected on 3rd September 2018 are also consistent with the observed intense spatfall during September.

It is important to note that the native oyster population in Lough Foyle was still reproductively active during September. Traditionally oyster fishing in Irish fisheries started on 1st September. The Lough Foyle fishery start date was moved to 19th September and then, in recent years, owing to observations of brooding around that date, has been delayed until the first week of October. The Tralee fishery, owing to similar observations of increased reproductive activity later in the breeding season, has also changed to an October start date. The results of this survey further support this move to starting fishing later than the traditional dates. Adult oysters need time to recondition after spawning and brooding and settled spat need time to “harden off”. Harvesting oysters whilst they are still reproductively active can lead to mortalities and lower quality oysters. This delay of the start of the fishing season is therefore essential for the conservation of the population and, indeed, is of benefit to the market. In native oyster populations with a breeding season running from June to September, the main settlement was traditionally expected to occur in July and August. Whilst peak brooding in the Lough Foyle population does occur during those months, in years where the water temperature is optimal for reproduction, we are starting to observe a trend for a tertiary peak of brooding leading to a widespread, intense spatfall in September. This trend requires continued monitoring as it may be indicative of climate change and will influence the future management of the fishery.

The results of the three surveys also demonstrate that the processes of successful gonad development, spawning and brooding in native oysters and a successful spat settlement may be somewhat decoupled. This is likely owing to differing environmental tolerances and resilience to change, especially sudden changes, between adults and juveniles.

Despite the observed spat settlement in the lough in 2018, larger, settlement stage bivalve larvae were notably recorded in low numbers in the plankton samples. This would therefore suggest that this is a result of sampling bias rather than true absence. It may be useful in future surveys to employ larval traps or similar sampling devices as larvae ready to settle would be expected to be closer to the seabed than earlier stage veligers.

From the observations of the stock survey, slightly fouled razor clam shell appeared to be attracting high levels of native oyster spat settlement. This may provide a potential additional source of cultch.

5.0 Conclusions

- This survey continues to demonstrate the need for long-term datasets in order to effectively monitor native oyster populations. It also helps to demonstrate the need to analyse the data collected from this type of survey in conjunction with the results of other surveys and experiments in order to build a fuller understanding of population and stock dynamics. This holistic approach assists with developing effective sustainable management strategies for sedentary, commercially exploited shellfish and to guide future restoration and enhancement work.

- A proportion of Lough Foyle's native oyster population successfully conditions and produces eggs and larvae each summer. Oysters observed to be brooding in the survey between 2011 and 2017 represent < 10% of each year's sampled population. Including oysters with spent gonads increases the percentage of the population that may have successfully produced larvae up to ca. 48%.

- Intensity of reproductive activity varies inter-annually depending upon a range of factors, including fluctuations in environmental variables such as temperature, salinity and turbidity.

- As only a proportion of the population successfully reproduces each year, broodstock areas may assist with diminishing "Allee effects" and increasing the effective population size.

- Lough Foyle's oyster population is reliant on smaller, younger oysters for reproduction, which influences brood size and recruitment. Precautionary approaches to fishery management need to be continued - oysters from both the smaller and larger size classes need to be retained in the fishery to ensure future sustainability.

- Evidence of reproductive activity in the adult oysters does not necessarily translate into successful settlement and metamorphosis of spat. As this influences population size and stock availability, extensive aquaculture techniques such as spatting ponds and growing systems need to be investigated to provide juveniles to mitigate for poor natural recruitment years.

6.0 Recommendations

1. Trial a cultch laying project on areas of commercial beds which have poor quality habitat to increase available space for spat settlement. From the results of the Autumn 2018 native oyster stock survey, it appears that slightly fouled shell, especially razor clam (*Ensis* spp.), may be the most effective in attracting spat in good settlement years.

2. Investigate methods to enhance broodstock on low density beds to counteract the "Allee effect"

3. Ensure densities do not reduce significantly on main oyster beds and aim to improve the density on the main oyster beds to >0.05 oysters/m^2

4. Investigate extensive aquaculture techniques such as spatting ponds to assist with breeding juvenile oysters to augment natural settlement.

5. Continue the annual reproductive survey to build a long-term dataset and provide information regarding inter-annual variation in reproductive success.

7.0 References

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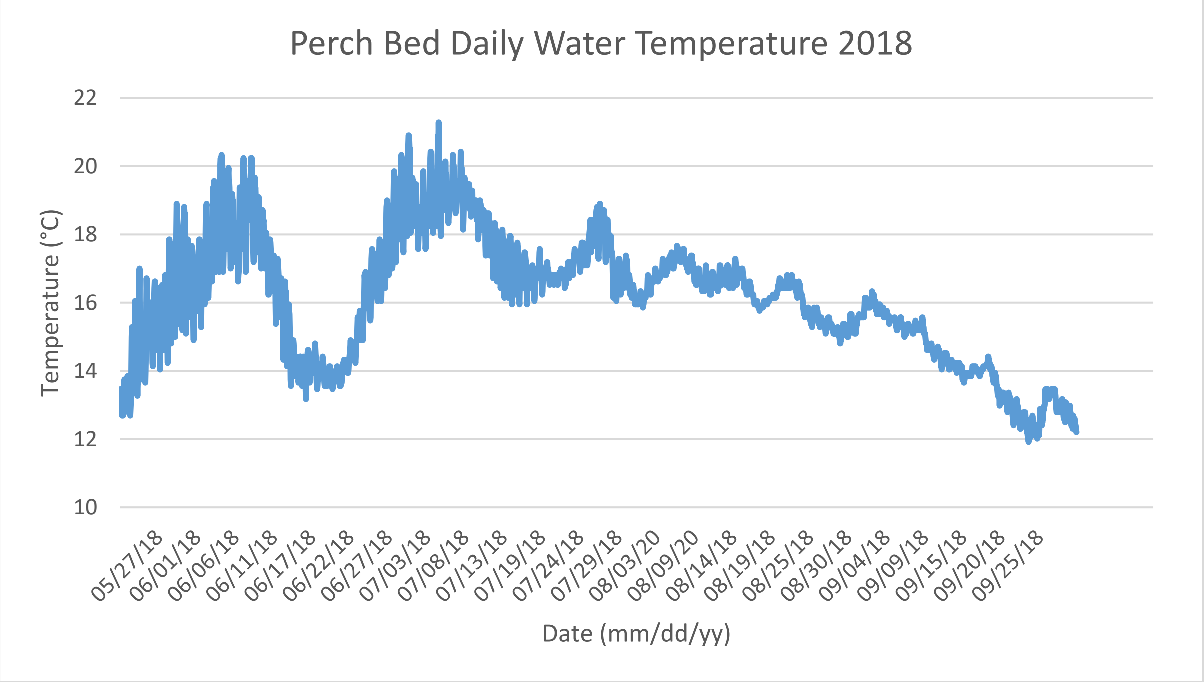
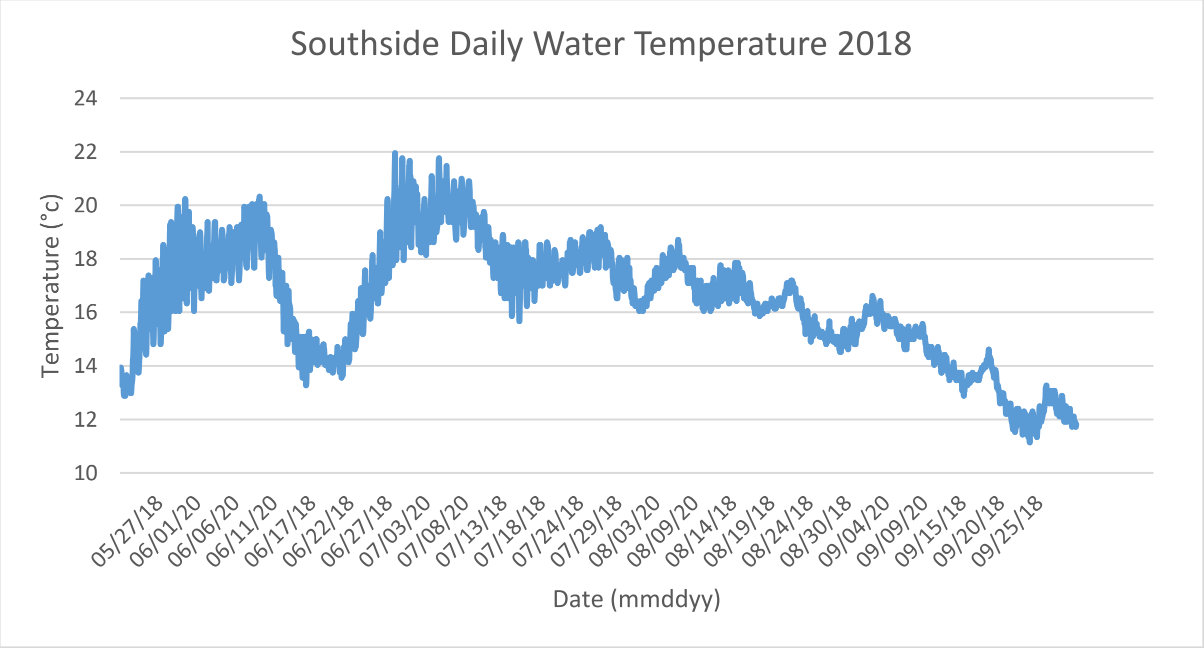
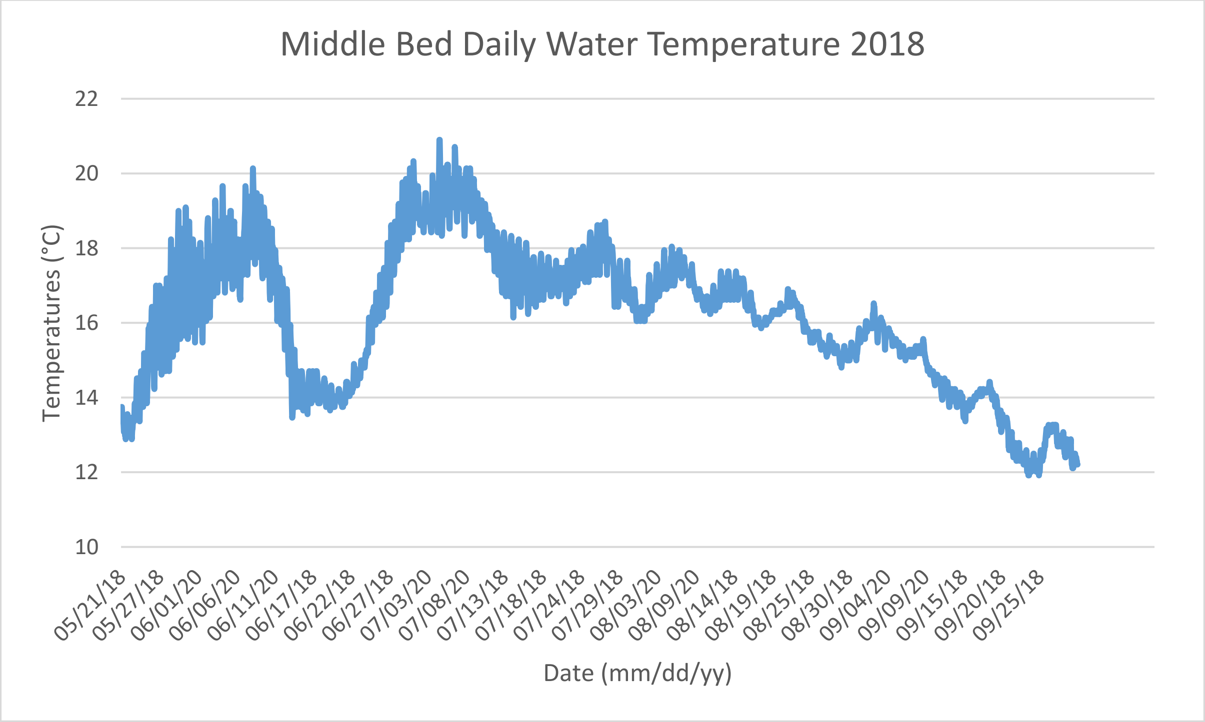
Appendix I – Daily Water Temperature Records






Middle Bed Daily Water Temperature 2018
Temperatures (°C)
22
20
18
16
14
12
10
05/21/18
05/27/18
06/01/20
06/06/20
06/11/20
06/17/18
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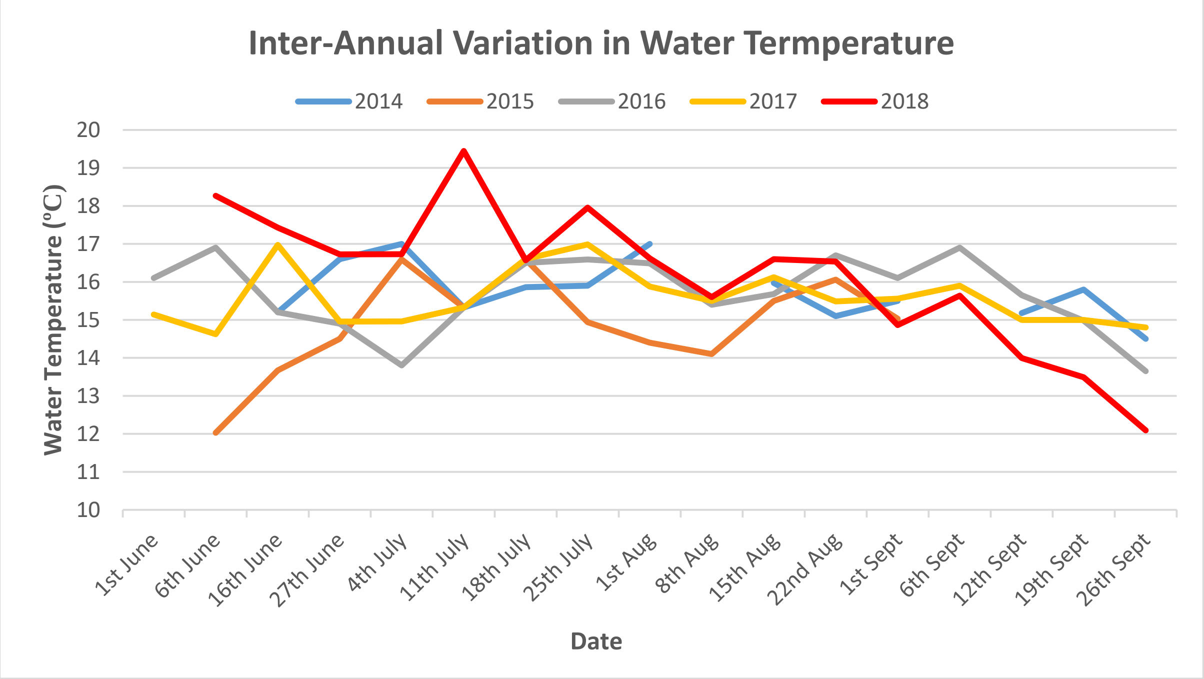
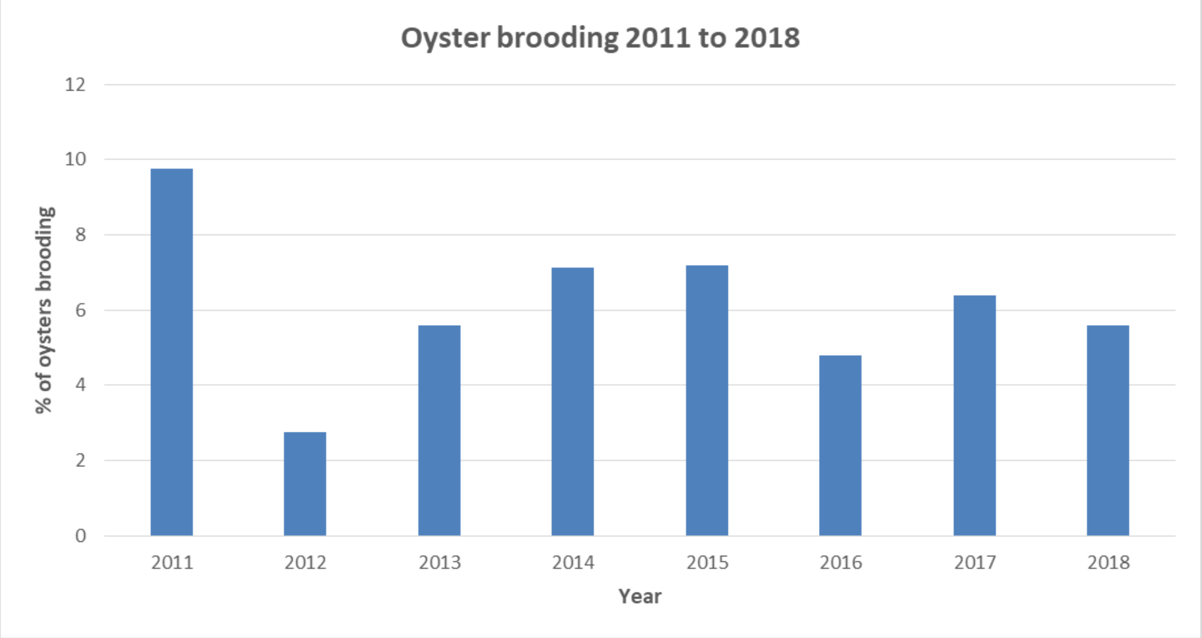
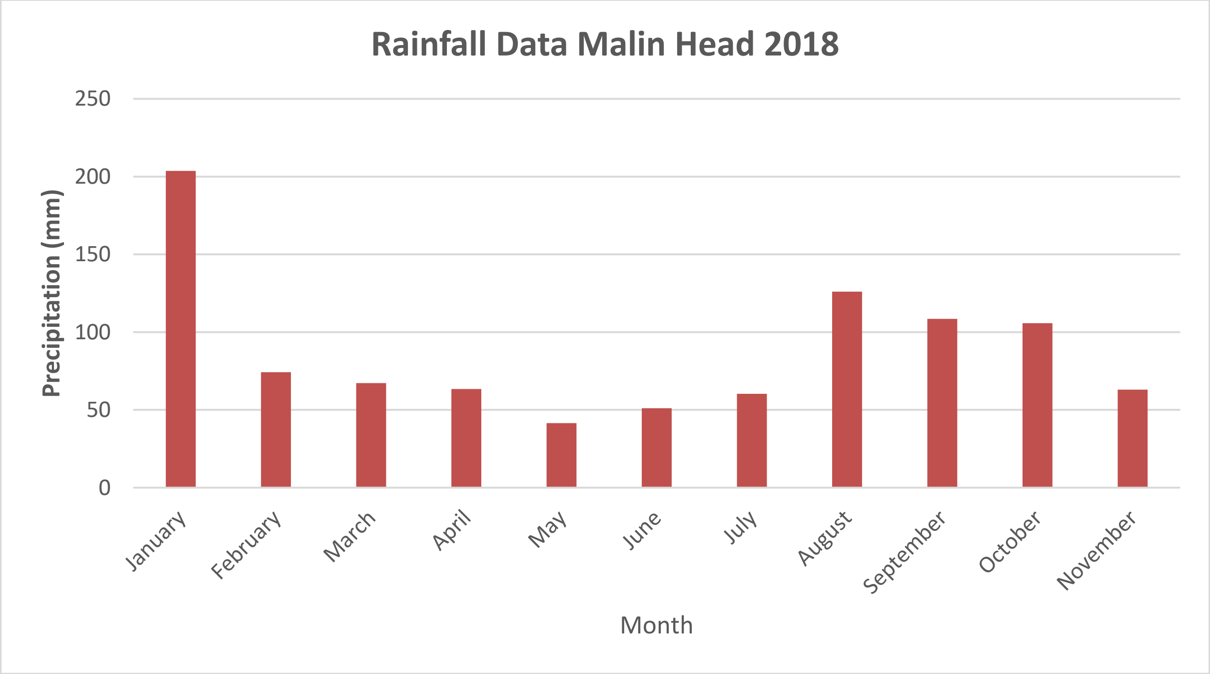
Appendix II Inter-Annual Variation in Water Temperature



Appendix III Oyster Brooding 2011 to 2018



Appendix IV Climate Data



Data from Met Eireann (https://www.met.ie/climate/available-data/monthly-data)

Appendix V Spat Collectors 2018

Introduction

In conjunction with the annual native oyster spawning survey, arrays of spat collectors were deployed on oyster beds in Lough Foyle with the aim of assessing spatfall (settlement of juvenile oysters) during the breeding season.

Despite at least a century of research, the causes of poor oyster settlement years remain poorly understood – drivers include habitat condition, climate, food quality and availability and adult spawning stock biomass. Key stages of the native oyster (*Ostrea edulis*) lifecycle are fertilisation of eggs within the female oysters' shells; brooding of eggs and larvae within the shell; release of shelled veliger larvae into the plankton; settlement of larvae; and metamorphosis of larvae into juvenile oysters. Each of these key stages is driven by a number of factors, including abiotic drivers such as temperature and salinity. Each stage is subject to specific tolerances - for example, it is generally understood that temperatures of between 14 and 16 °C are needed to enable oysters to condition and release gametes. Veliger larvae spend up to 14 days feeding in the plankton until they develop eyes and a foot (pediveliger) and descend to the seabed to actively seek out a suitable settlement substratum. Suitable substrata can be naturally occurring materials (e.g. live oysters or shell), or artificial surfaces (e.g. commercially produced spat collectors or limed ceramic tiles).

Collection of oyster spat for aquaculture purposes has been used since at least Roman times. When the French native oyster industry collapsed in the mid-1800s, they turned to collecting spat on wood and limed collectors to provide spat to be grown on in ponds and nurseries. Arrays of spat collectors are still used in production areas today.

Successful spatfall is key to maintaining a healthy population density, especially within an active fishery. These collectors were used to complement observations of spat settlement during dredge surveys in the lough.

Methods

Arrays of spat collectors were deployed in three of the higher density oyster beds (Perch, Middle bed, Flat Ground) within Lough Foyle in April 2017. Stock pots containing temperature loggers were deployed in the same bed to monitor temperature over the season.

One A frame constructed from Stainless steel and attached to a mooring line via shackles was deployed in each of the three sites. Each A frame carried 22 spat collectors, consisting of 47 coupelles threaded onto a 1.2 m long central pole and held in place with clips at each end (Fig. 1). The coupelles used were black, perforated plastic (Fig. 1 inset).

The pots were retrieved on 21st September 2017 and the data downloaded from the loggers. The loggers were re-programmed and the pots redeployed to enable monitoring of winter water temperatures. Spat collectors were retrieved on 28th September 2017.

The spat collectors were removed from the A frames once back on land and each coupelle examined for the presence of *Ostrea edulis* spat. Other taxa were also noted. Native oyster spat were removed from the coupelles and maximum shell length measured. The spat were then placed in storage containers and preserved in ethanol for future study, including possible genetic investigations.

Fig. 1: Spat collector array after retrieval and (inset) close up of coupelle surface.

Results

The array deployed in Southside was intact upon retrieval. The arrays in Perch and Flat Ground had suffered damage and a number of the collectors were not recovered. It appeared that both of these A frames had at some point been tipped over and, as well as some collectors being lost, the remaining collectors on one side of the frame were heavily fouled with mud. Owing to the loss of collectors, five collectors from each site were examined and the number of *Ostrea edulis* spat were counted on each coupelle on each collector and then averaged to allow comparison amongst the sites. The average for the collectors in each site have been used to project the estimated number of spat collected in each site.

Spat were observed on each collector examined. A total of 758 spat were collected from these collectors (see Table 1). Spat had settled in the highest numbers in Southside, with the least numbers retrieved from the Perch bed collectors. Occasional spat were also observed to have settled on the stainless steel A frames.

Table 1: Spat counts from collectors examined from Perch, Flat Ground and Southside oyster beds.

Bed	Spat count	Mean spat count/ collector	Standard Deviation (±)	Projected number of spat/ array
Flat Ground	252	50	27	1100
Perch	127	25	4	550
Southside	379	76	27	1672

The mean length of native oyster spat was consistent throughout the three sites – Flat Ground 8.6 mm ± 3.3; Perch 6.9 mm ± 3; and Southside 7.1 mm ± 2.5. Spat maximum shell length ranged in size from 2 mm to 18 mm. There was no evidence of spat > 20 mm on any of the collectors.

Juveniles of four other species of bivalve molluscs were recorded - saddle oysters (*Anomia ephippium*), mussel (*Mytilus edulis*), *Mya arenaria* and clam *sp*. Seed mussels were found in all three sites, with shell lengths ranging from 4 to 25 mm.

Settlement of any taxon was sparse other than sea squirts *Corella eumyota* and *Ascidiella* spp. and barnacles, mainly *Balanus* and *Chthamalus sp*. Keel worm (*Pomatoceros triqueter*) was rarely recorded. The sea spider, *Phoxichilidium femoratum*, was occasionally observed, associated with fine weed. Mobile macrofauna were mainly juvenile shore (*Carcinus maenas*), brown (*Cancer pagurus*) and porcelain crabs (*Porcellana platycheles*). Abundant in

2017, there were few observations of butterfish (*Pholis gunnellus*) and five bearded rockling (*Ciliata mustela*), and none of the squat lobster (*Galathea squamifera*).

Discussion

The black, perforated coupelles used are the type recommended for native oysters and experimentally shown to be more suitable than solid, orange plastic coupelles. The arrays are also rigged and deployed in a similar way to those used in commercial operations. For commercial use, the coupelles would need to be coated in lime to enable removal of the spat.

Whilst the Southside array remained intact in 2018, as happened in 2017, the arrays in Perch and Flat Ground appeared to have been lying on one side, leading to the coupelles on that side becoming clogged with muddy sand early in the season. Some coupelles were also lost from these arrays. The observations from previous years serve to demonstrate that settlement of sedentary marine organisms is cyclical and driven by the environmental and other tolerances of each species. In 2018, consistent with the observed widespread settlement within the lough, native oyster larvae had settled on the coupelles in abundance. In comparison, even though recorded reproductive activity in the oyster populations was slightly higher in 2017, there was little recorded spat settlement, either in the lough or on the spat collectors. In 2013 only saddle oysters and keel worm settled in high abundances, and in 2014 barnacle and native oyster spat were commonly to abundantly recorded on the collectors.

In 2018, the native oysters were found to be brooding and releasing larvae from 21st May right through to the end of the spawning survey at the end of September and average water temperatures did not fall below an average of 14ºC during the period of spat collector deployment. In comparison to the high rainfall and sudden, intense storm events of 2017, the weather in 2018 was generally hotter and more settled. This had a noticeable effect on brooding and larval numbers and appears to have influenced settlement. Sudden change in environmental conditions can have more impact on invertebrate biological processes and life history strategies than more gradual change. Oyster larvae have been shown to require temperatures above 17ºC to successfully settle and metamorphose – lower temperatures may delay or stop this process.

The type of taxa settling before the oyster larvae may also influence whether they settle on the collectors. Taxa such as other bivalves, barnacles or keel worm which all have shells or tubes constructed from calcium carbonate would be expected to potentially still attract oyster larvae to settle. The precise cues controlling oyster larval settlement in the natural environment remain poorly understood but it has been suggested that some fouling (bacteria, diatoms, hydroids) on surfaces may be more successful at attracting oyster spat than clean surfaces (Yonge, 1960; Walne, 1974). Timing of deployment is also important – too early (i.e. before oyster larvae are present in the water column) and collectors may become heavily fouled with other sessile organisms; too late and peak larval abundance may be missed (Matthiessen, 2001). Oyster larvae are also selective of settlement substrata but in years of high larval abundance may settle on any available surface, as suggested by finding spat attached to the frames of the spat collector arrays.

Long-term datasets are important for understanding trends and patterns in the marine environment. The data which is being compiled through deployments such as this, the spawning survey and other surveys are essential tools for managing an active fishery and for assisting with meeting environmental management obligations within UK, Irish and European law. Especially where there is an active, productive oyster fishery, there is a clear, demonstrable need for supplementing unpredictable, fluctuating natural spat settlement via extensive aquaculture techniques such as spatting ponds or a hatchery. Such techniques could be used to supply juveniles for on-growing within protected areas within the lough to assist with “smoothing” the historical boom and bust nature of native oyster populations.

Appendix VI Plankton Report 2018

Introduction

As part of the annual native oyster reproductive activity survey carried out in the Lough Foyle fishery in 2018, in addition to quantifying bivalve larval densities per m^3, the remainder of the plankton assemblage was also examined.

Together with benthic assemblages, plankton assemblages can provide important information relating to ecosystem health and often shows signs of the impacts of, for example, eutrophication and climate change, in advance of larger, longer lived organisms. Plankton underpins all marine food chains. Managers need therefore to recognise the importance of plankton in striving to meet the requirements for Good Environmental Status (GES) within the Marine Strategy Framework Directive (2008/56/EC).

Plankton is also of key importance to commercial shellfish production. Plankton assemblages and dynamics influence food availability and quality; carrying capacity; conditioning for spawning and for market; reproduction; settlement and growth; product quality; and consumer health. Bivalve shellfish such as native oysters, Pacific oysters and mussels all have a planktonic larval stage, as do many of their filter feeding competitors and predators. The successful survival and settlement of that stage is the key to a sustainable population, especially when commercially harvested. The theory of supply side ecology states that larval supply is an important driver of adult abundance and benthic community structure (Lewin, 1986; Young, 1987). In addition to larval quality and quantity, bivalve shellfish recruitment failure may be attributable to biotic (reproductively, pathogen or predation) or abiotic (temperature or tidal currents) drivers, individually or synergistically.

This report examines the phytoplankton and non-bivalve zooplankton identified during the annual native oyster reproductive activity survey mainly in terms of influences on the oyster population. Bivalve mollusc plankton has been included in the main survey report.

Methods

Plankton was collected from five of the highest density native oyster (*Ostrea edulis*) beds in Lough Foyle on a weekly basis between June and September 2018 (Figure 1). Non-bivalve plankton was included in the analyses of samples collected between 5th June and the end of the survey on 24th September.

Samples were collected using a plankton net of 300mm diameter and 100 micron mesh size deployed vertically at each sample location. The sample was washed from the plankton net by using a seawater deck hose applied to the exterior of the plankton net and net bucket. The sample was collected in a 250 ml plastic bottle and labelled with site code and time and date information.

A 1 ml subsample was then transferred via pipette to a Sedgewick-Rafter cell and examined via a Leica MZ7S dissecting microscope at 40 x magnification. Three subsamples were examined for each 250 ml sample. Bivalve larvae were quantified – the remainder of the plankton assemblage was identified to the lowest possible taxonomic level and assessed purely for presence/ absence (three subsamples combined).

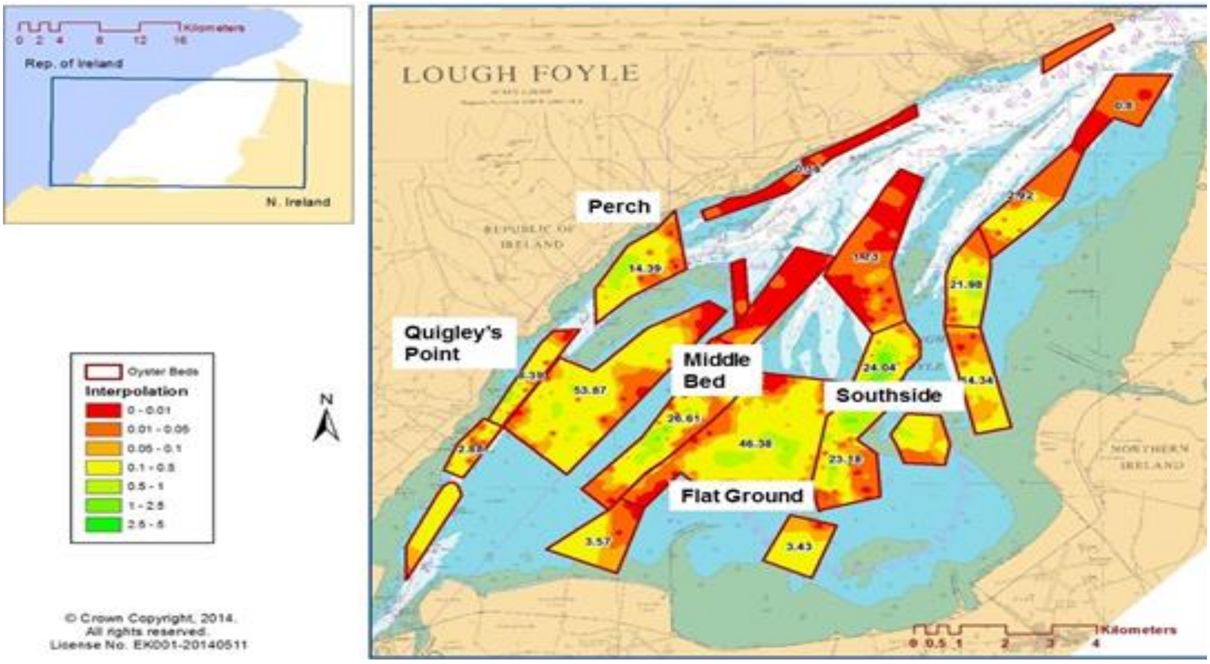


Figure 1: Locations of oyster beds used for plankton sampling during 2018

Results

47 phytoplankton and 85 zooplankton taxa were identified, together with crustacean exuvia, copepod faecal pellets, seagrass fragments, and other debris (anthropogenic and naturally occurring). A full list is provided in Appendices I to III. Zooplankton consists of both mero and holoplanktonic species. Mero plankton are organisms such as crustacean and echinoderm larvae which have a larval planktonic phase prior to settling and metamorphosing into benthic macrofaunal adults. Holoplankton are organisms such as copepods, jellyfish, ctenophores, some annelids, and Chaetognatha (arrow worms) which spend their entire lives in the water column.

Phytoplankton

Phytoplankton abundance and diversity was starting to decrease at the beginning of July. Diversity reached a peak at the end of the sampling period in late August early September. The Perch bed had the highest diversity of 21 separate taxa, noted in the final week of the survey. The diatom, *Rhizosolenia* sp., was the most commonly recorded taxon; found in 95% of samples (Figure 2a). Of the dinoflagellates, *Dinophysis*, *Noctiluca scintillans* and *Ceratium* were most commonly observed (Figure 2b/c).

Abundances and diversity had increased by the late September samples. At this time, the abundances of *Coscinodiscus* spp. and the chain forming diatoms such as *Thalassiosira* sp. (Figure 2e) and *Chaetoceros* spp. noticeably increased.

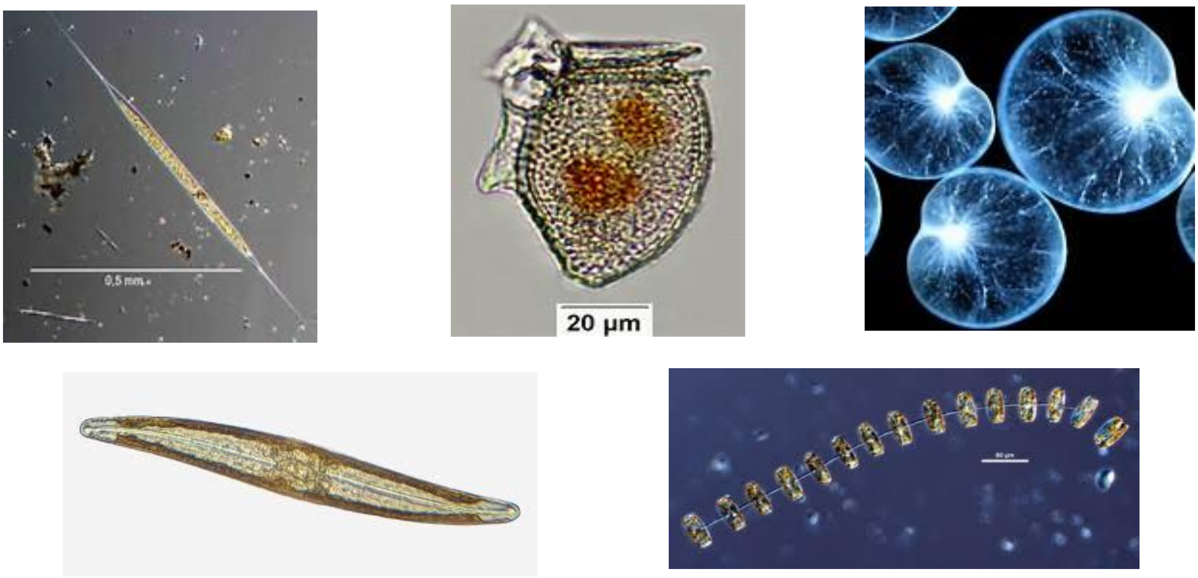


Figure 2: Phytoplankton (a) the diatom, *Rhizosolenia* sp.; (b) *Dinophysis* sp. (dinoflagellate); (c) *Noctiluca scintillans*; (d) benthic diatom, *Pleurosigma* sp.; (e) chain forming diatom, *Thalassiosira* sp..

Zooplankton

Calanoid copepods (Crustacea) were the most abundant zooplankters in the samples throughout the survey (Figure 3a). *Acartia spp.*, calanoids especially associated with estuarine habitats such as Lough Foyle, were recorded in 69% of the samples (Figure 3b). The cyclopoid, *Oithona* sp., was also frequently observed. Harpacticoid copepods, which occupy benthic habitats, were especially noticeable in samples collected after the flood event. Copepod nauplii and faecal pellets were recorded in all samples. Copepods carrying eggs or detached egg masses from harpacticoids and cyclopoids were frequently observed throughout the summer.

Figure 3: Calanoid copepods (a) such as *Acartia* spp. (b) were the most abundant zooplankters in all samples.

Figure 4: (a) barnacle cyprid larva ready to settle on a suitable substratum; (b) larva of the bivalve shell-boring polychaete, *Polydora*; (c) hermit crab, *Pagurus bernhardus*, larva

Barnacle nauplius larvae were recorded in 28% of the samples compared with 100% of the samples in 2017, with cyprid (settlement) phase being observed in 10% of samples in 2018 compared with 45% in 2017 (Figure 4a). Larvae of the polychaete, *Polydora*, the adults of which bore into oyster and other bivalve shells, were also frequently observed (69% of samples), (Figure 4b). The predatory Cladoceran, *Podon*, was recorded in 13% of samples and was especially frequent in the middle of August.

Hydroid medusa were more abundant than in 2014's samples. Decapod crustacean larvae including green crab (*Carcinus maenas*), shrimp (*Crangon crangon*), hermit crab (*Pagurus bernhardus*, Figure 4c) and porcelain crab (*Pisidia longicornis*), were occasionally observed as the summer progressed. Gastropod veliger larvae, including winkles (*Littorina littorea*) were commonly recorded in samples.

More rarely noted taxa included the larvacean, *Oikopleura*, bryozoan cyphonautes larvae (mostly *Membranipora*), anemone larvae, and echinoderm (sea urchin and brittlestar) pluteus larvae.

Tintinnids, rotifers, nematodes and mites were most often observed following periods of increased turbidity. Eggs of different taxa were observed in all samples and fish eggs were more frequently observed in samples than in 2014.

Other

Sand and pieces of vegetation were found in all samples. . Pieces of plastic filament and other plastic debris were recorded in 82% of the samples.

Discussion

Native oyster larvae are brooded within female oysters' shells until they have formed into shelled veligers. This is generally understood to be a strategy to (a) retain larvae closer to their natal habitat and (b) to reduce time in the plankton and therefore reduce mortality owing to predation during this period. After release from the adult's shell, larvae spend 10 to 14 days feeding in the water column, increasing in size by approximately 50% until they reach the pediveliger stage (larvae with a foot and eyes ready to settle) and actively seek suitable substrata upon which to settle and metamorphose into juvenile oysters (spat), (Orton, 1937).

Predation by planktivorous fish, crustacean larvae, Chaetognatha, the dinoflagellate, *Noctiluca*, and benthic filter and suspension feeding organisms (including oysters and mussels) can lead to high losses of larvae (Orton, 1937; Mackenzie, 1970). Suboptimal temperatures lengthen the duration of the planktonic larval stage, leaving larvae more vulnerable to predation or failure to settle (Korringa, 1940). It has been suggested that only 5 to 6 individuals from each brood can be expected to survive to successfully settle (Fowler, 1893; Davis & Ansell, 1962). In addition to this, oyster spat losses of up to 99% in Year 1 and 30% in Year 2 following settlement can be expected, especially where crabs, starfish and oyster drills are present. Whilst predatory crabs and starfish have planktonic larval phases, *Ocenebra erinacea* and other predatory neogastropods produce live juveniles from eggs laid on the substratum – eggs of this species, common whelks (*Buccinum undatum*) and dog whelks (*Nucella lapillus*) are all found within dredge samples in Lough Foyle. Some control of adult predators is operative in the lough - there is a substantial fishery for common whelks and green crab, and mussel growers regularly “mop” their lays to remove starfish. However, nothing can be done to control losses in the plankton.

When evaluating *Ostrea edulis* settlement dynamics, it is important to also consider the plankton assemblage. Tolerance and inhibition competition influence benthic community composition, with different timings in reproductive cycles, cyclical changes in abundance and differing tolerances to abiotic factors determining which taxa will be the first to settle on available substrata (Pillay *et al*., 2010). These pioneer settlers can outcompete other larvae either by inhibiting settlement or overgrowing/ dislodging those that do settle (Mackenzie, 1970). For example, keel worm (*Pomatoceros triqueter*) settled in such abundance on the spat collectors deployed in 2013 that it was plausible that greater than the five native oyster spat identified had settled and been overgrown. In 2017, it was apparent from the frequency of observation of the settlement (cyprid) phase, that a heavy settlement of barnacles could be expected.

Difficulty in identifying and quantifying spat mortality may lead to post settlement mortalities being underestimated (Gosselin & Qian, 1997). These high attrition rates at the larval and juvenile stages need to be taken in to consideration when assessing spatfall and spawning stock biomass to maintain a sustainable native oyster population.

The larvae of the polychaete, *Polydora ciliata*, were common to abundant and present in 77% of the plankton samples examined in both 2014 and 2017 and 69% of samples in 2018. The adults of this species bore into bivalve shells, creating a network of tunnels. This can cause shell damage and mortalities in spat and adult oysters and, together with heavy fouling, negatively influence oyster condition and market quality/ value.

The absence of some taxa may be an artefact of sampling (e.g. plankton net mesh size or time of day). Two notable taxa which were not recorded in either 2014 or 2017 were the arrow worms (Chaetognaths) and mysids, which are both often highly abundant in estuarine environments. Even in a largely shallow system such as the Foyle, some plankters will be more active or migrate to the surface waters at night and the absence of Chaetognatha and mysids in the samples may be explained in this way. However, the low abundances of some diatoms and the consistently high abundances of *Rhizosolenia* diatom species in the Lough Foyle samples in 2018 and 2018 require further investigation. This diatom’s morphology (long, cylindrical with long spines at each end) has previously been found to prevent *Magellana gigas* (Pacific oysters) ingesting this diatom as it could not pass through the gill lamina (Cooper & Gault, 2002). High abundances therefore of this diatom may influence bivalve filter feeding efficiency, with knock-on effects on growth and conditioning.

The increase in abundance and diversity of phytoplankton, especially the increase in diatoms such as *Coscinodiscus*, *Thalassiosira* and *Chaetoceros* spp., indicated that the autumn phytoplankton bloom started in mid-August 2018. In temperate Northern Hemisphere waters, there are generally two seasonal peaks in phytoplankton abundance, followed by increases in zooplankton – phytoplankton abundance then crashes as cells are grazed or use up available nutrients and minerals such as silica. Noting the timing of the onset of these spring and autumn phytoplankton blooms is important as this will influence zooplankton dynamics and therefore food availability for larval and adult oysters and conditioning of oysters for spawning and recruitment into the fishery.

Identification of phytoplankton species potentially responsible for shellfish poisoning and harmful algal blooms is important to protect consumer health and can also provide clues to perturbations in larval survival and settlement. This is carried out by scheduled shellfish health testing throughout the year. However, the samples from this survey could potentially also be useful as an additional “early warning system”. *Dinophysis* spp., is an occasional to common component of the plankton samples – this dinoflagellate produces toxins which can lead to Diarrhetic Shellfish Poisoning (DSP), even at low cell densities.

In 2012, there was a large bloom of *Karenia mikimotoi* which caused fish kills and shellfish mortalities along the west coast of Ireland and represented a significant cost to the industry. The Lough Foyle plankton samples showed that this dinoflagellate was present at that time but in low cell densities and it was concluded that the hydrographic regime in the Atlantic off the northwest coast helped to protect the lough from the effects of the bloom.

Pathogens such as *Bonamia ostreae*, a parasite which has been present in the Lough Foyle population since 2005, can negatively affect planktonic larval and settled spat survival (Arzul *et al*., 2011). It has been found in hatcheries that the bacteria, *Vibrio* spp. can negatively affect larval competence and survival (Wareing, 2015, *pers. comm*.). This is something that cannot be tested within the reproductive activity survey but does need to be considered and further investigated as there is currently little known about the effects of this in natural environments.

Monitoring plankton assemblages may also be used as indicators of ecosystem health to assist with meeting the requirements of European directives such as the Water Framework Directive (2000/60/EC) and Marine Strategy Framework Directive (2008/56/EC). Plankton abundance, biomass and community diversity are have been included as indicators of Good Environmental Status within the MSFD. The Continuous Plankton Recorder (CPR) survey, a near-surface plankton monitoring programme has been sampling in the North Atlantic since 1931. CPR data indicate that North Atlantic and North Sea plankton dynamics are responding to both climate and human-induced changes, presenting challenges to the development of pelagic targets for achievement of GES in European Seas. “The continuation of long-term ecological time series such as the CPR survey is crucial for informing and supporting the sustainable management of European seas through policy mechanisms” (McQuatters-Gollop, A., 2012). This is as equally relevant to the Lough Foyle ecosystem as to the North Atlantic as a whole.

Conclusions/ Recommendations

Phytoplankton and zooplankton, together with viruses and bacteria, form the basis of all marine food chains. As lifespans are generally of short duration, they are potentially important indicators of marine ecosystem health, short-term perturbations, and longer-term factors such as chronic pollution and climate change.

In terms of managing bivalve shellfish fisheries, in addition to monitoring bivalve reproduction, plankton assemblages are an important consideration in terms of food availability and quality; carrying capacity; conditioning for spawning and for market; and product quality.

It is therefore recommended that, in addition to monitoring native oyster reproductive activity, plankton assemblages should be included within the scope of the annual oyster spawning survey. Resources allowing, to better understand oyster conditioning, it would be useful to start CTD and plankton collections during the spring, as well as during the reproductive activity survey. Plankton sampling should also be carried out at other times of the year to provide a baseline for monitoring future change within the Lough Foyle ecosystem.

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Appendix I: Plankton taxa recorded during the 2018 survey

Phytoplankton

Rhizosolenia setigera

Rhizosolenia styliformis

Pseudo-nitzchia

Thalassiosira

Thalassionema

Chaetoceros 1

Chaetoceros 2

Chaetoceros 3 (very long setae)

Chaetoceros 4 (curls into semi circle or round)

Coscinodiscus

Coscinodiscus granii

Odontella regia

Odontella aurita

Odontella sinsensis

Ditylum

Proboscia

Pleurosigma

Plagiogrammopsis

Bellerochea malleus

straight line diatom

Striatella

Bacillaria

Stephanopyxis

Mediopyxis

Melosira

Podosira

Asterionellopsis glacialis

Lauderia

Guinardia

Leptocylindrus

Nitzchia longissima

Nitschia cf. reversa?

Raphoneis

dinoflagellate

Dinophysis

Noctiluca

Dissodinium

Pyrocystis

Ceratium

Ceratium (very long horns)

Ceratium (with curved stem)

Ceratium fusus

Ceratium furca

Triceratium

Neocalyptrella

Katodinium?

Eucampia

Zooplankton

radiolarian

Globigerina

shell foram

coil foram

leaf foram

tintinnid

ciliate

stalked ciliate

rotifer

Tubularia larynx

hydroid medusa

hydroid medusa (Phialella)

hydroid medusa (long/ narrow)

hydroid medusa (abundant tents)

hydroid medusa (Ceratium tent)

planula

anthozoan polyp

actinula

Aurelia aurita (moon jelly)

ctenophore (sea gooseberry)

ctenophore

platyhelminth

Spionid (Polydora)

trocophore

annelid (Dipolydora)

annelid

annelid

annelid with stolons

annelid (Lanice)

annelid (Syllidae/ Phyllodocida)

annelid (Capitellidae)

annelid (Sabellaria)

annelid trocophore (Owenia)

platyhelminth

playhelminth/ trematode (Heterophyidae?)

opisthobranch shelled

gastropod veliger

mite

copepod nauplii

barnacle nauplii

barnacle cypris

Acartia

Paracalanus

Temora

Calanus

Centropages

Oithona

Tisbe

Oncaea (harpacticoid)

harpacticoid (short ant)

harpacticoid (2 furca)

harpacticoid (3 furca)

ostracod

Podon

Evadne

amphipod

Cumacean

Crangon crangon larva

Carcinus zoea

Pagurus bernhardus zoea

Pisidia longicornis

decapod (unidentified)

bryozoan cyphonautes

Nemertean pilidium

Nemertean

nematode

Asteroidea brachiolaria (anchor) larva

early stage Echinodermata larva

pluteus (early)

pluteus (damaged - unidentified)

ophiopluteus (Ophiothrix fragilis)

ophiopluteus

Oikopleura

larvacean

salp

exuviae

barnacle exuvia

fish egg

egg

copepod egg mass

unidentified star shape (brittlestar disc?)

unidentified (Image No. 0052)

unidentified (Image No. 0054)

unidentified (Image No. 0066)

barnacle spat

Other

Bivalve disart. valve

bivalve shell articulated

barnacle cypris valve/s

bivalve shell

gastropod shell

cockle fragment

sand/ crystal

veg frags

seagrass frags

filamentous green algae

Ulva lactuca fragments

butterfly scale

copepod faecal pellets

sponge spicule

ctenophore ctene

plastic filaments/ fragments

hydroid stolons

Larvacean mucus house fragments

Moon jelly fragment/ tentacle

Pleurobrachia (ctenophore) tentacle

Seed

weed