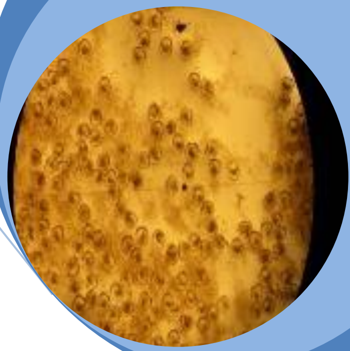


Loughs Agency
Gníomhaireacht na Lochanna
Factrie fur Loughs

Native Oyster Spawning Assessment Lough Foyle Summer 2019

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/Rory O'Donnell/Aine Thornton/ Tom Sheerin

Contents

List of Figures

List of Tables

Executive Summary

Monitoring of native oyster reproductive activity within the Lough Foyle native oyster fishery took place for the eighth successive year. Monitoring took place between June and September 2019 with sampling of adult oysters, plankton and environmental parameters being carried out weekly on five oyster beds until 19th September 2018.

Of the 27836 oysters examined, 119 (4.2% 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), 22.8% of the sampled population were reproductively active during the survey period. Although the numbers of reproductively active oysters were slightly less than in 2018, the findings of the native oyster autumn stock assessment and examination of spat collectors deployed in the lough indicate a limited spatfall in 2019. There were two peak periods for brooding – the main peak occurred in the first three weeks of July 2019 (the same week as the 2018 and 2017 peak); with a second more limited period in the middle of August. Average water temperature (16.4ºC ± 1.99) and salinity (30.8 psu ± 1.49) were both slightly higher than in 2018 and variation amongst the beds was minimal. Average temperatures peaked at 19.07ºC ± 0.27 in week 10 (16th July 2018).

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 2019/20 fishing season started on 8th October 2018.

This report outlines the findings of a survey undertaken between 7th May and 18th September 2019 to assess the spawning activity of *Ostrea edulis* (European native oyster) in Lough Foyle. The survey is now in its 9th 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.

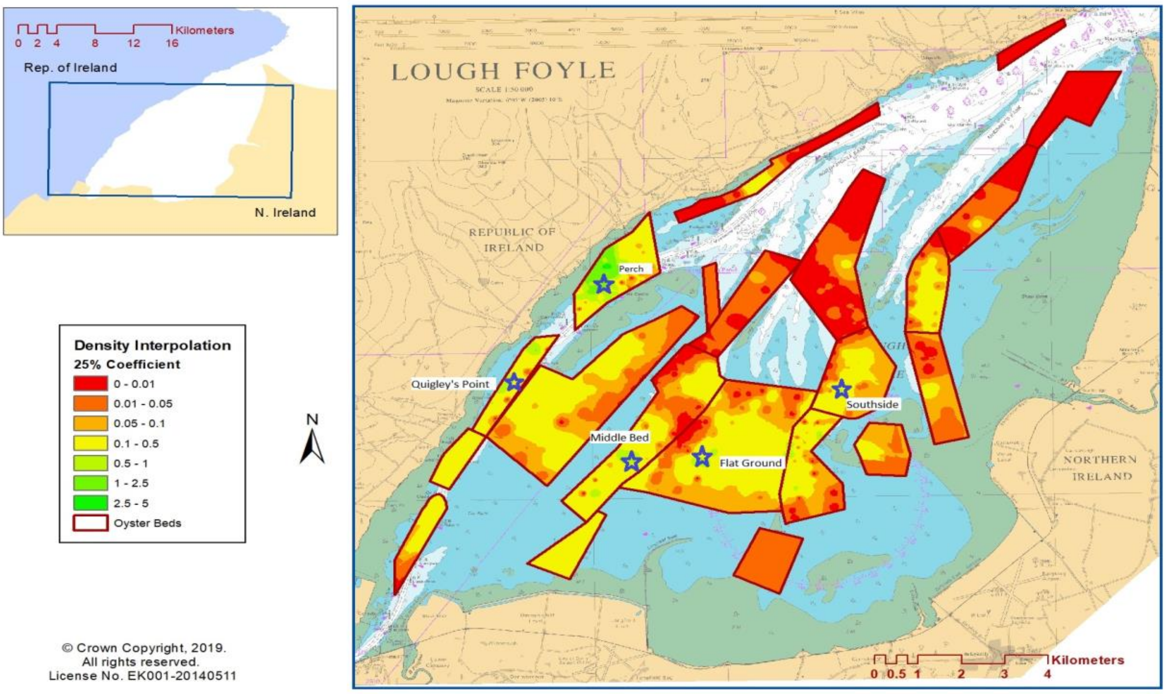


Figure 1: Oyster density in Lough Foyle Autumn 2019 and the 5 oyster beds sampled for this survey (stars donate approximate sample collection locations).

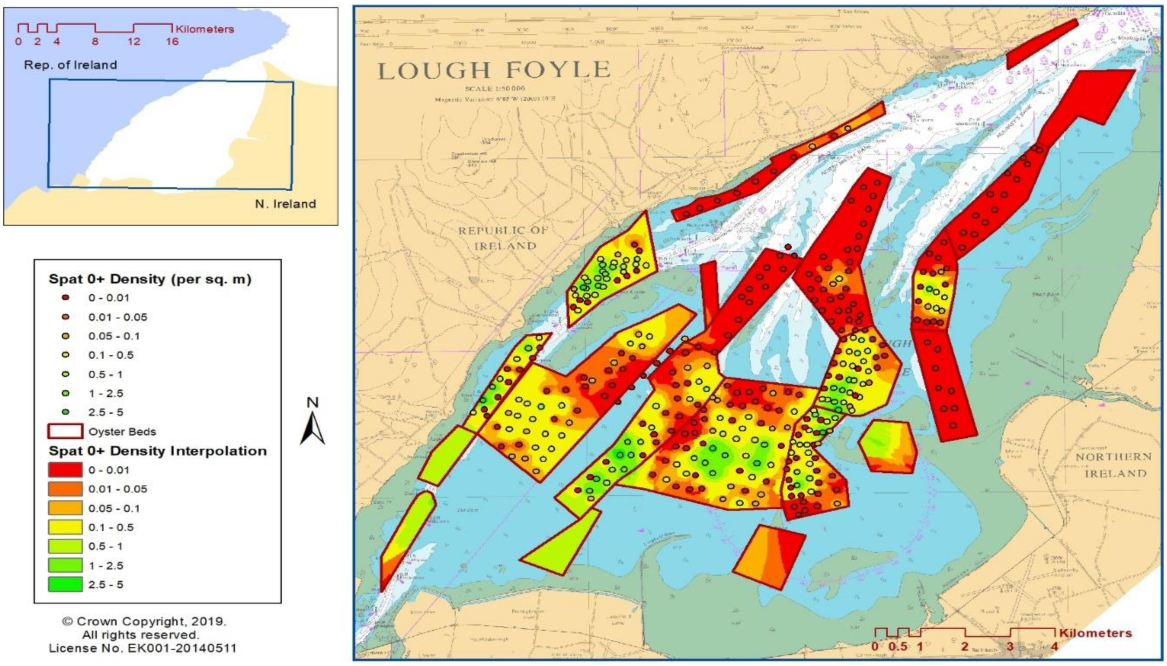


Figure 2: Spat Density Autumn 2019

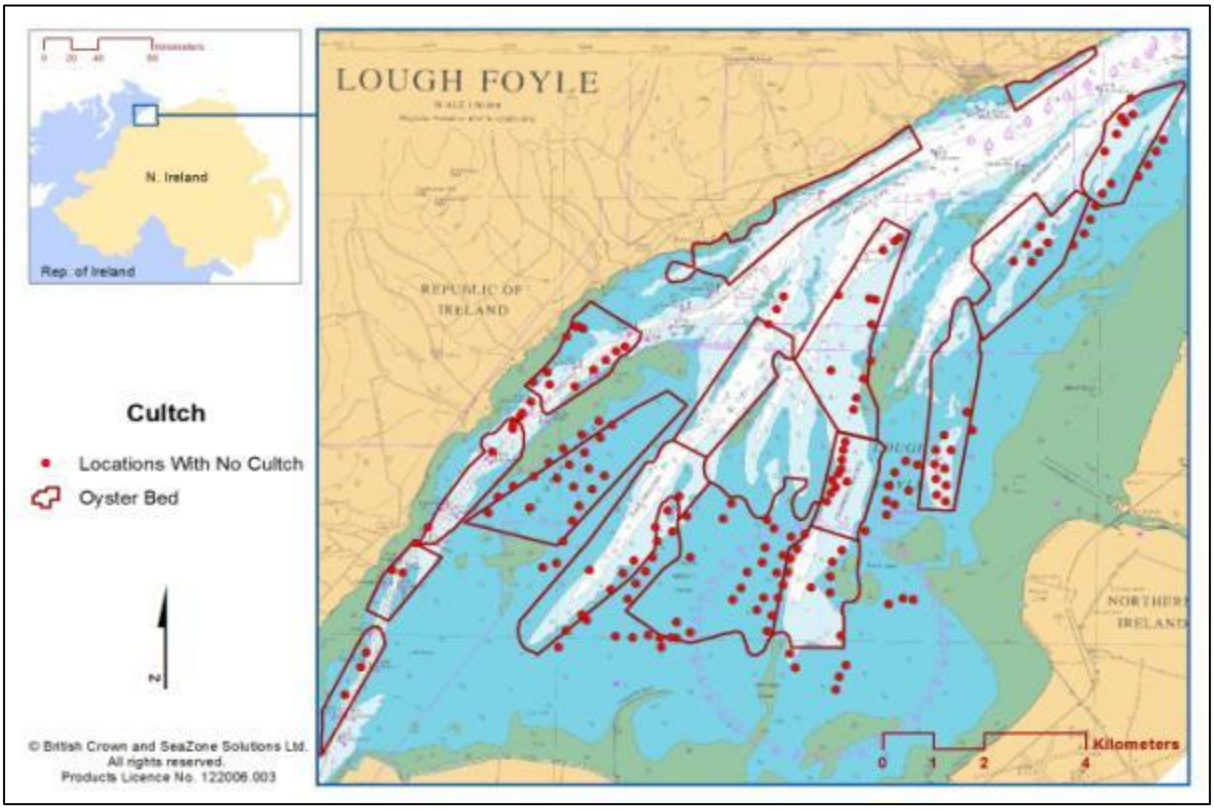


Figure 3 Location of areas without suitable cultch within the Foyle oyster fishery

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).

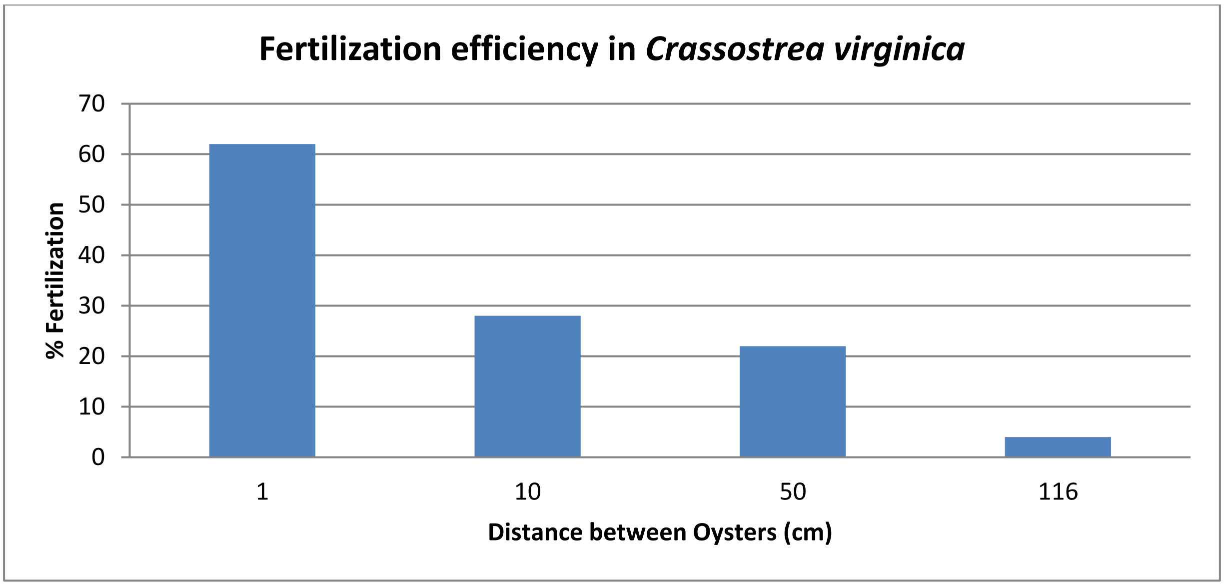


Figure 4 Fertilisation efficiency as a function of oyster population density (taken from Paynter, 2003)

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]

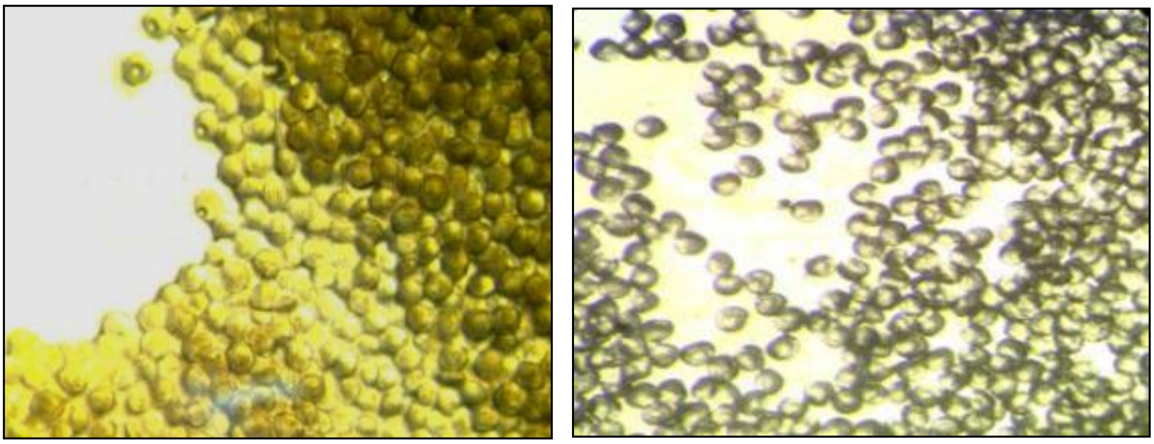


Figure 7 a-b: Native oyster larvae removed from a black sick brooding female (left) and grey sick female (right)

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 May 2019 and the survey was conducted over a period of 19 weeks, ending on 18th September 2019. 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 2836 oysters were collected and examined during the survey. Of these, 119 oysters were found to be brooding eggs or larvae, representing 4.2% of the sampled population. When combined with the number of oysters exhibiting spent gonads (indicating that they had released eggs or sperm), 22.8% of the sampled population were found to be reproductively active during the survey.

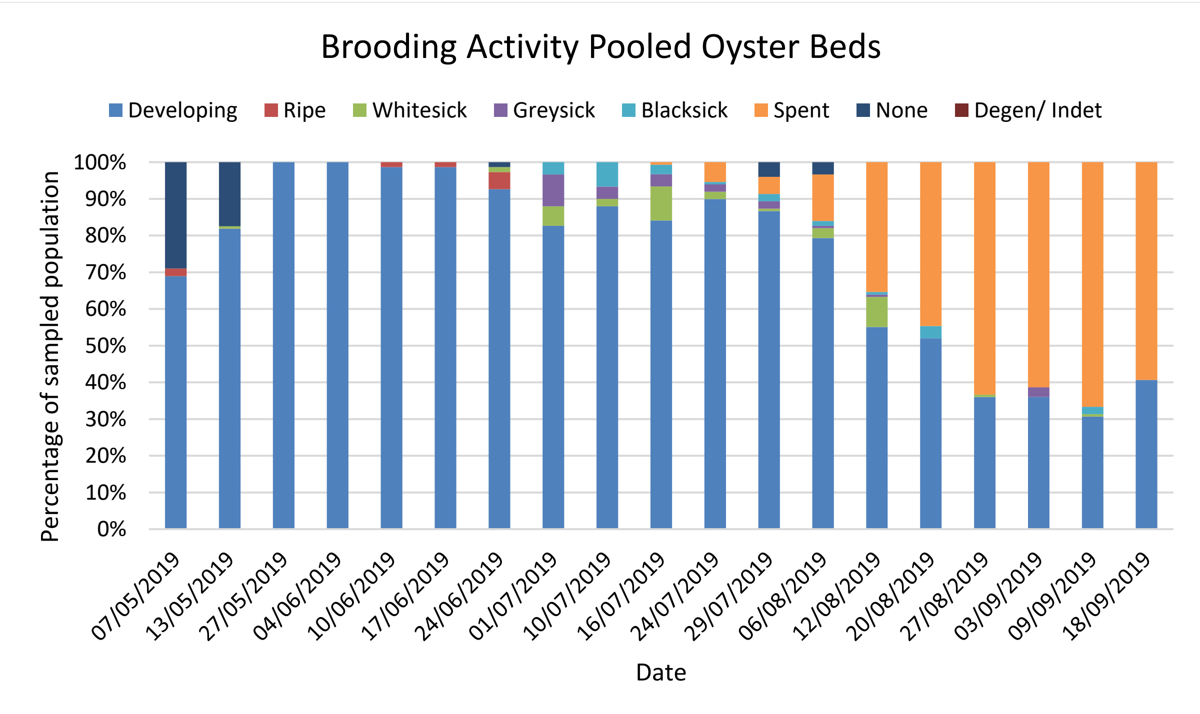


Figure 9 Reproductive activity in 2019, showing all oyster gonad and brooding development stages (pooled data – all beds).

The early summer period was characterised by relatively low water temperatures compared to the 2018 values. This may have had an impact on oyster conditioning and potentially delayed the onset of spawning in the oyster population in 2019. Brooding oysters were first recorded on 24th June 2019 (figure 9), when water temperatures had only just exceeded 15ºC. 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 10th July 2019. 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 6th August, 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 1st July 2019 (26 oysters or 17.3% of the sample) with relatively high numbers of brooding oysters on the beds for the first three weeks of July. A second smaller peak then occurred on 12th August, with 9.5% of the sampled oysters found to be brooding eggs or larvae. Mean water temperatures consistently exceeded 16ºC for much of July and August and reached a maximum of 19.07ºC in mid-July. A third, brief, smaller peak was recorded on 3rd September 2019, when 3% of the sampled oysters that week were found to be brooding. Combined with the number exhibiting spent gonads, 69.3% of the sampled population had been reproductively active. Brooding and reproductive activity then began to decrease as temperatures decreased to 14.5ºC at the end of the survey on 18th September 2019. Black sick oysters were recorded in the samples taken on 9th September. This is later than the traditional start date of the oyster fishing season in Ireland and close to the statutory 19th September opening date for the Lough Foyle fishery. No brooding oysters were recorded in the final week of the survey (18th September 2019).

Bivalve larvae (all species) were observed on each sampling occasion except the 27th May. Pooled mean larval density peaked on 12/08/19 (61,485m^3) and again on 20/08/19 (23,342/m^3). These peaks occurred following a maximum water temperature of 19°C in mid-July and sustained high water temperatures of over 16°C for most of July and August.

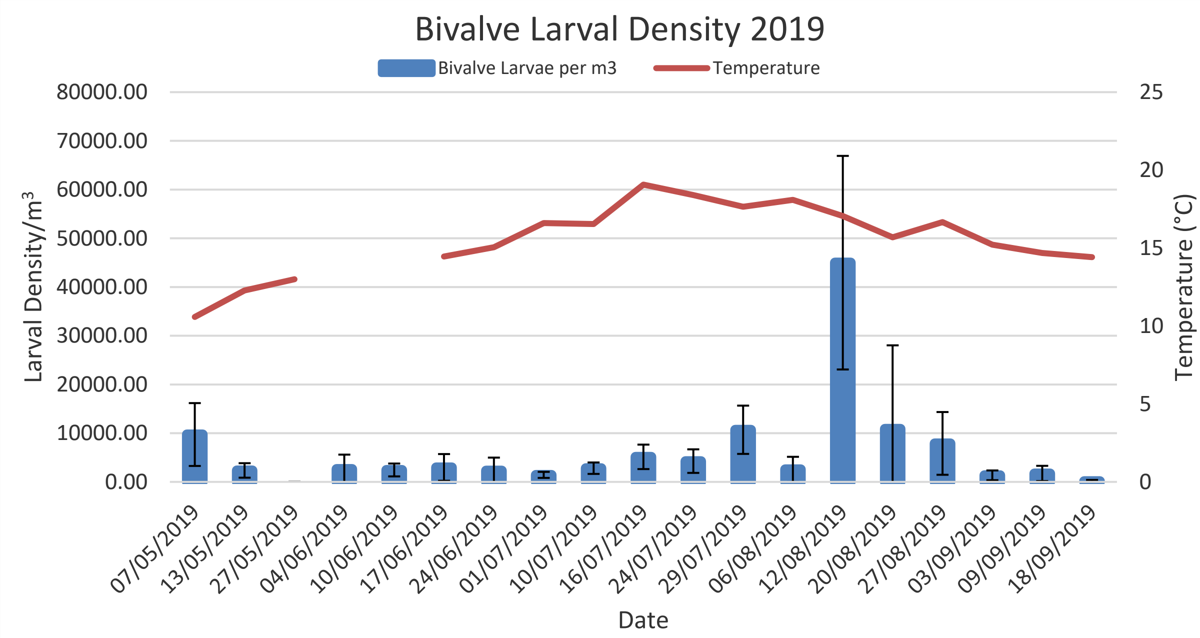


Figure 10 Weekly mean larval density and mean water temperatures (pooled data all sites).

The peaks in bivalve larvae occurred approximately 4 weeks after the peaks in brooding were observed. The peaks in larval numbers occurred on 12/08/19 (44,999m^3) and 20/08/19 (10.894/m^3), this followed a period when brooding within the sampled population had been over 9% on the 12/08/19.

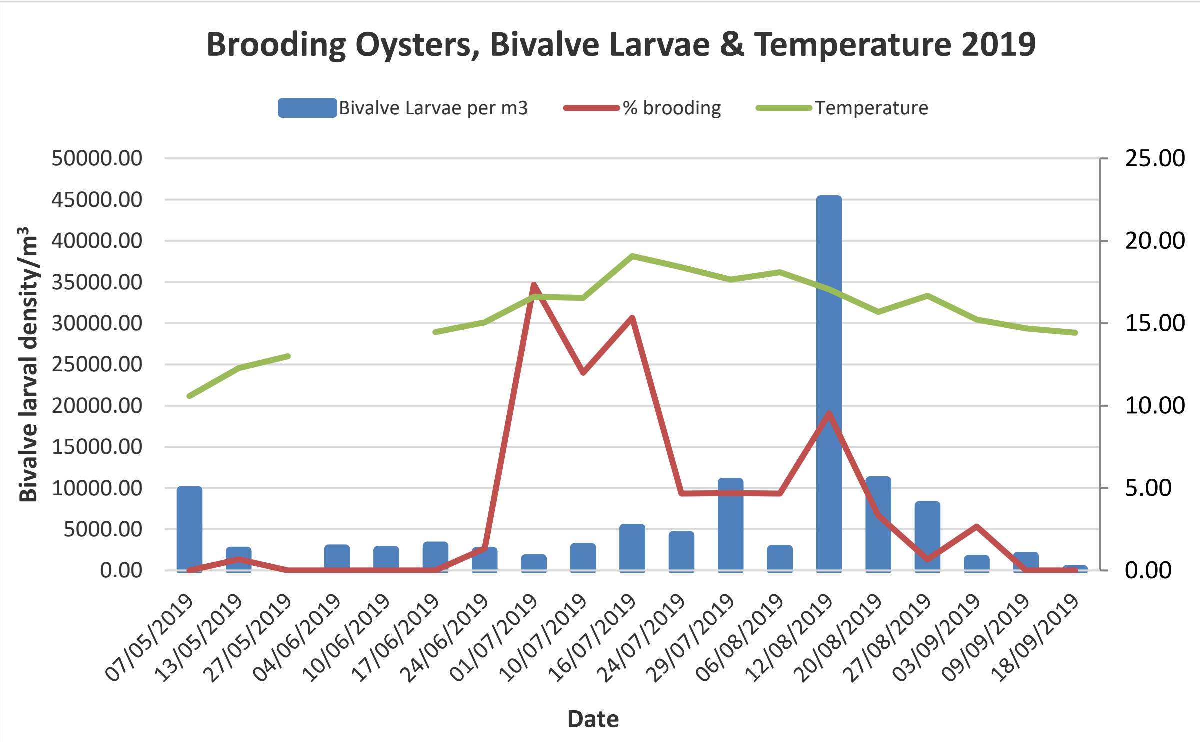


Figure 11 Weekly mean larval density, water temperatures and weekly proportion of brooding oysters (pooled data all sites).

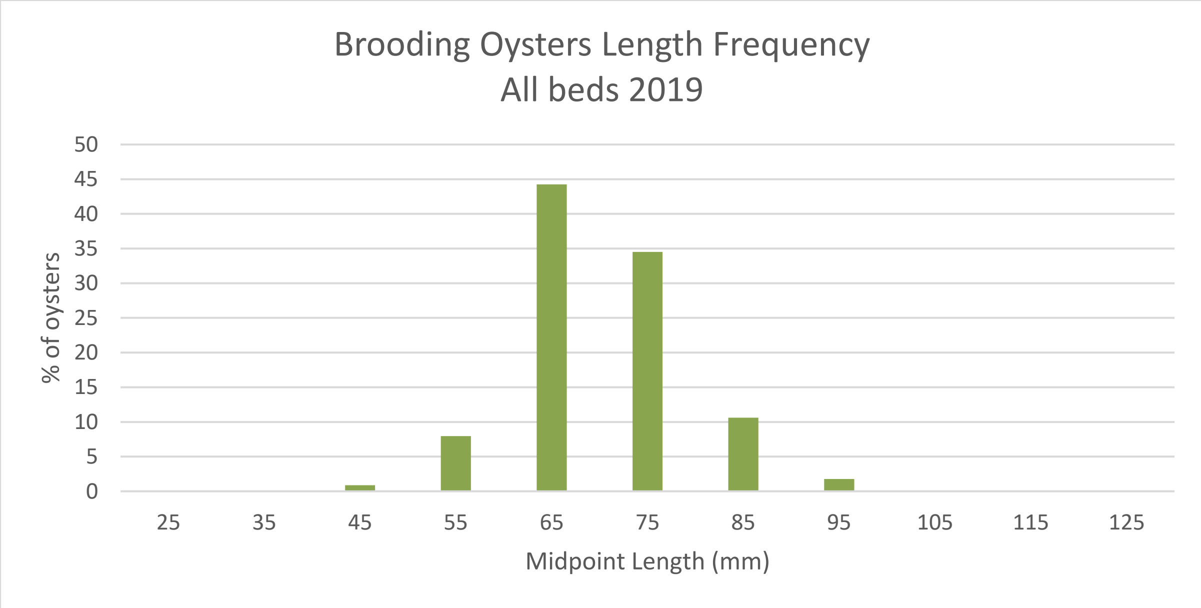


Figure 12 Length frequency of brooding oysters (pooled data all stations)

The length and weight frequencies for the sampled oysters show that oysters from 45mm and greater than 25g were recorded in the brooding phases. 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 reproductively active years.

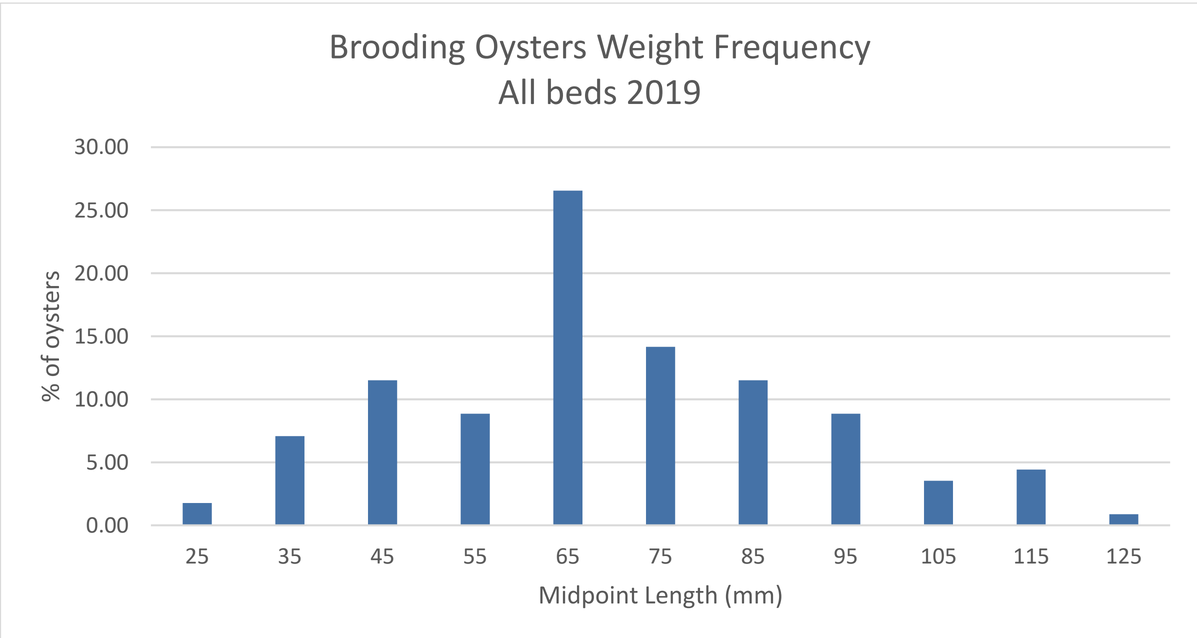


Figure 13 Weight frequency of brooding oysters (pooled data all stations)

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	10.73	19.12	164859.78	5.26	18.42	64.05	64.15
Middle Bed	10.50	18.91	41475.33	4.22	26.71	63.73	64.14
Perch	10.45	19.11	103731.99	3.87	25.31	67.13	67.21
Quigley's Pt	10.59	19.11	26943.38	5.15	24.69	64.37	63.14
Southside	10.62	18.84	42411.26	3.36	23.32	65.28	66.97

3.1 Flat Ground

Table 4: Flat Ground summary info

Bed Name	Flat Ground
Area (hectares)	970
Average Density (oysters/m2)	0.22
No. of Oysters	3,287,759
Total Biomass (t)	105

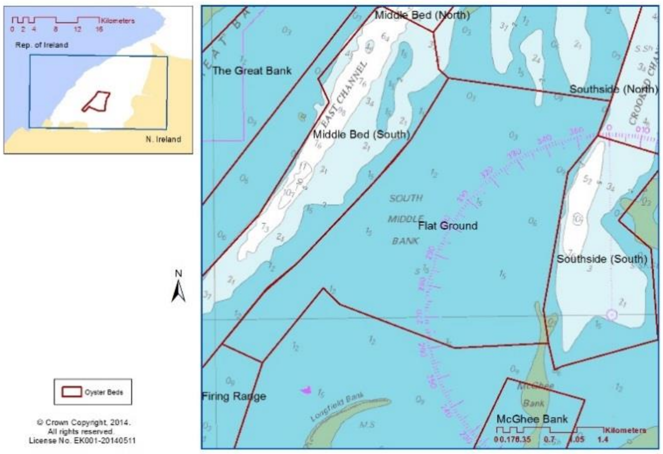


Figure 14: Location of Flat Ground

5.26% of sampled oysters on the Flat Ground were brooding during 2019. Flat Ground had the highest percentage brooding of all beds in Lough Foyle for a third successive year. Brooding commenced on 10th June and there was evidence of brooding each week until 10th September. Peak brooding occurred in Flat Ground on 1st July 2019 when 36% of the sample was observed with larvae in the white, grey or black stages. The number of spent oysters increased continuously from 6th August.

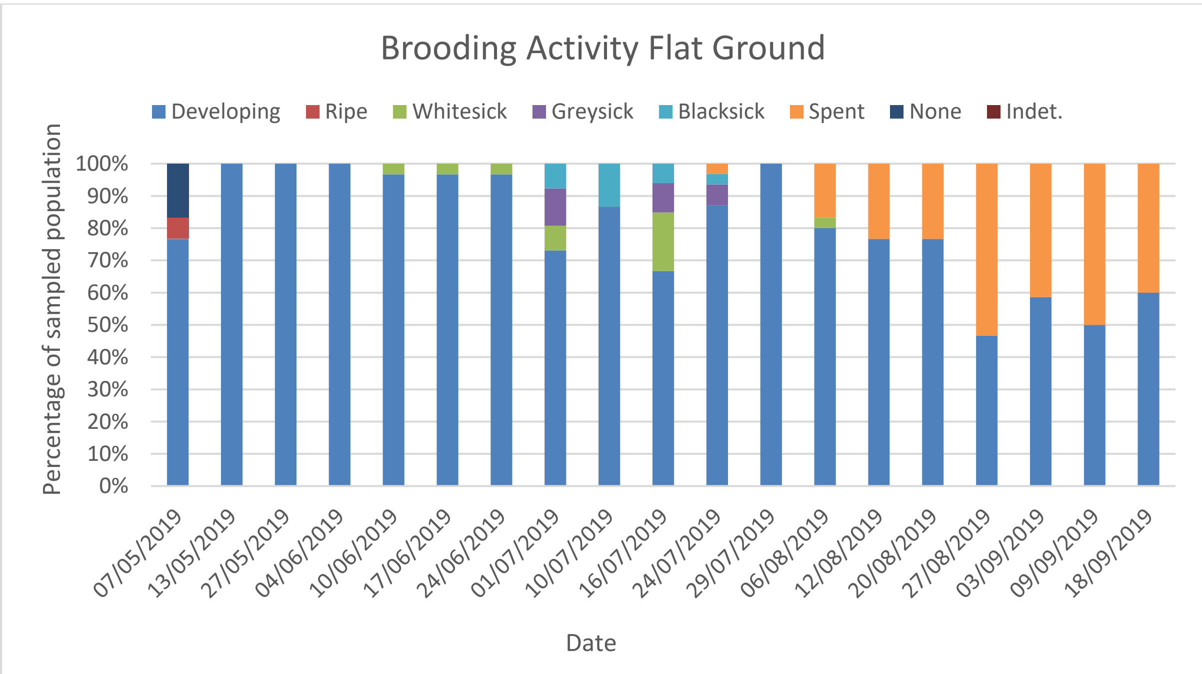


Figure 15: Spawning Stage Flat Ground 2019

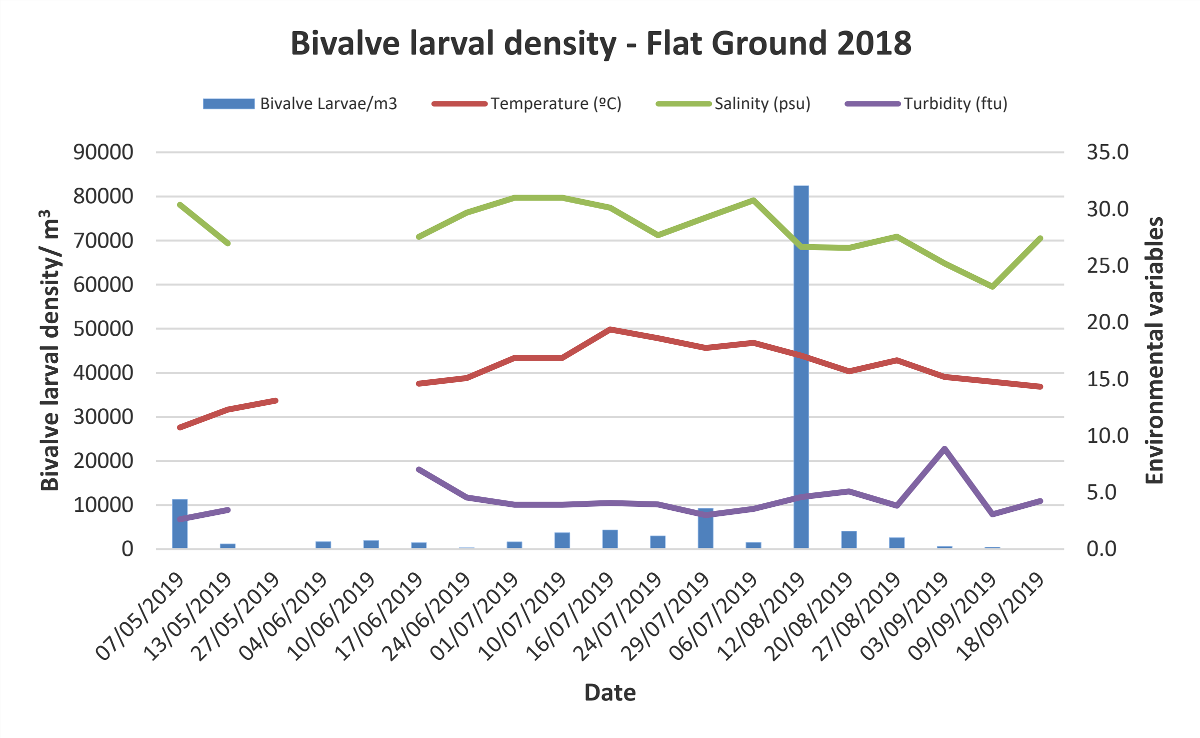


Figure 16: Larval Density and environmental variables - Flat Ground

Mean bivalve larval density was 6,922/m^3 with a peak on the 12/08/19 (82,429/m^3). This peak followed periods of sustained elevated water temperatures above 16°C and brooding activity of 36% and 26% respectively.

Mean water temperature on the Flat Ground was slightly higher than 2018 at 15.71°C (range 10.7-19.1°C). Mean salinity was 28.1 psu with a range of 23.1-31 psu showing relatively low freshwater inputs as was the case 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 64.05mm with a mean weight of all sampled oysters of 64.1g. Those oysters brooding eggs or larvae had a mean shell length of 66.7mm and a mean weight of 65.4g. 96% of the brooding oysters were less than the minimum landing size of 80mm. Oysters as small as 27.6g and as large as 110.1g in total wet weight were recorded as brooding showing the broad range of sizes that were spawning during 2019.

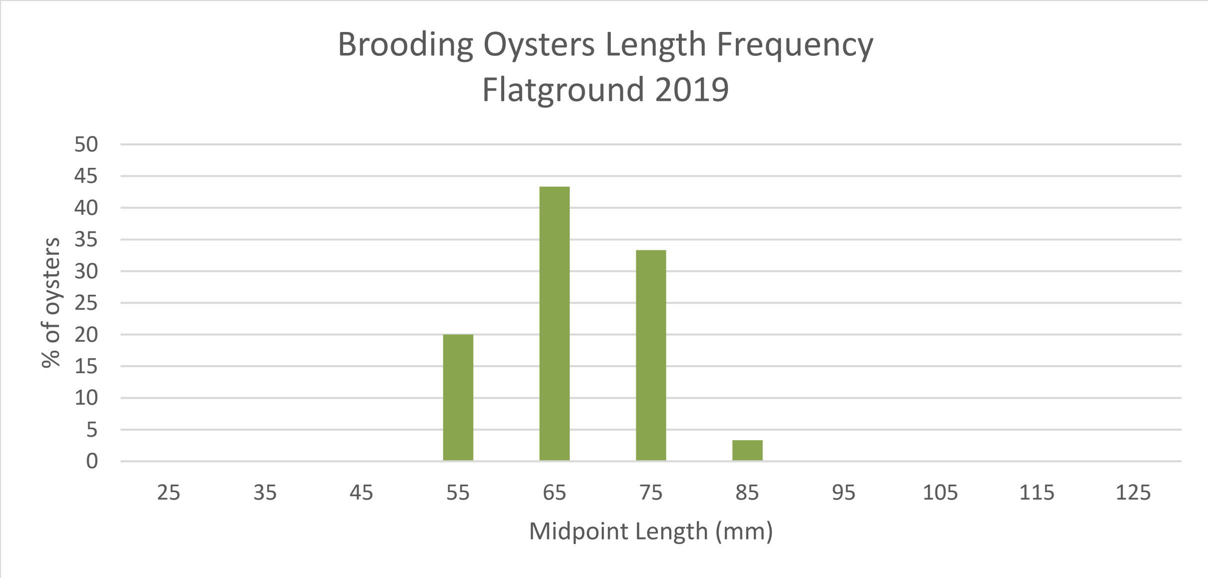


Figure 17: Length Frequency of Brooding Oysters - Flat Ground 2018

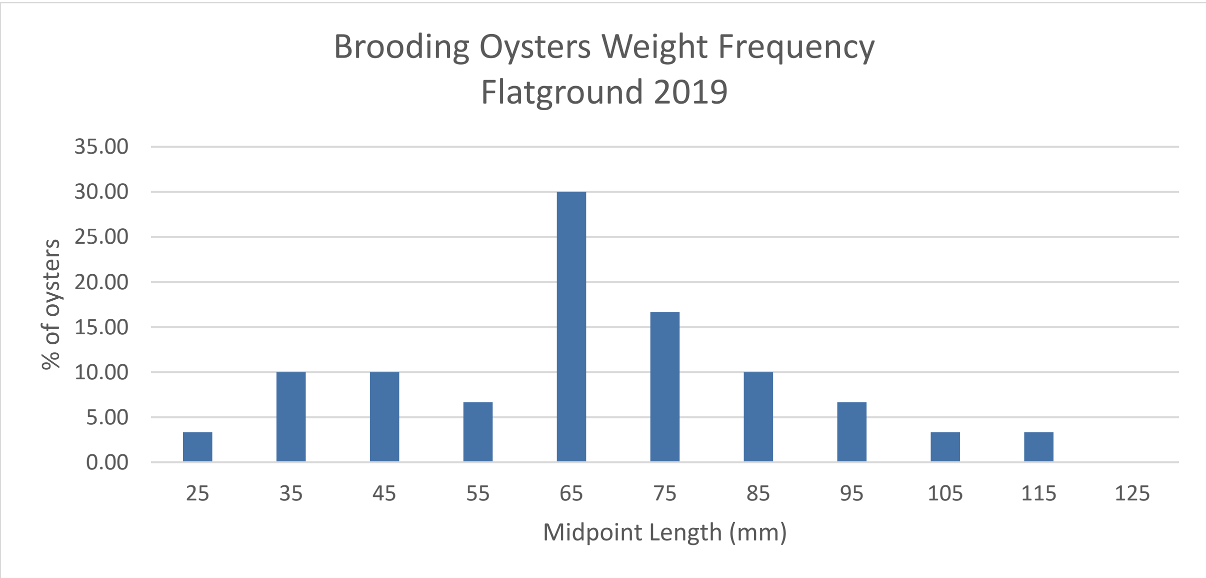


Figure 18: Weight Frequency of Brooding Oysters - Flat Ground 2018

3.2 The Perch Bed

Table 5: Perch summary info

Bed Name	The Perch
Area (hectares)	276
Average Density (oysters/m2)	0.30
No. of Oysters	2,852,992
Total Biomass (t)	68

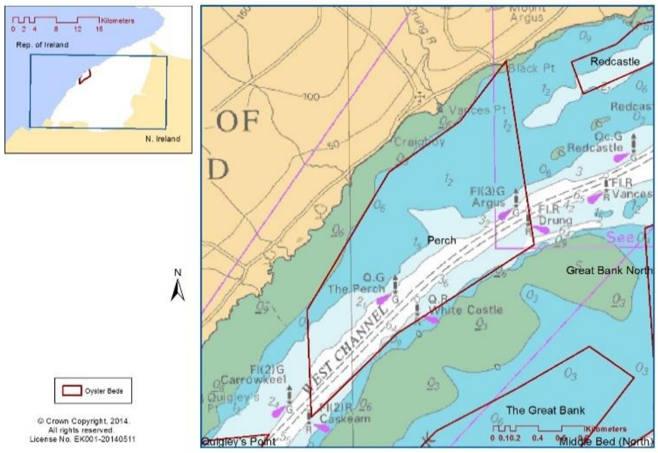


Figure 19: Location of the Perch

Brooding activity was observed from 24th 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.

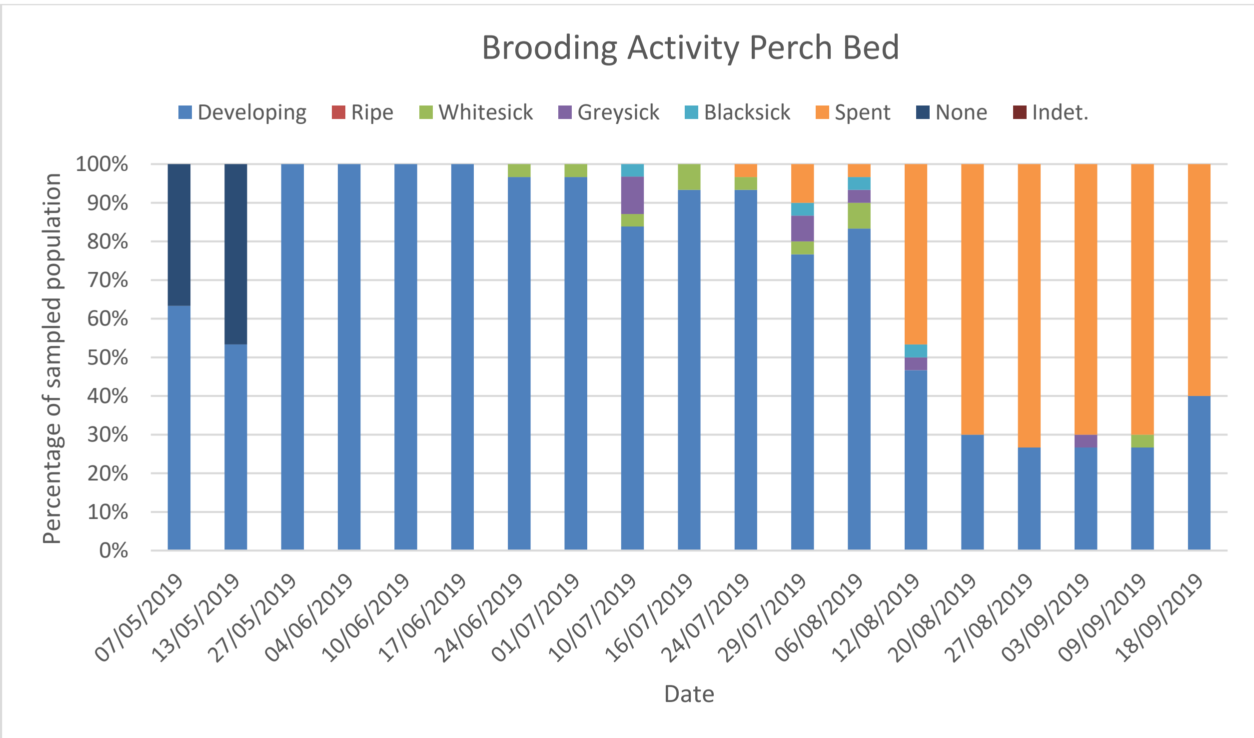


Figure 20: Spawning Stage Perch Bed 2019

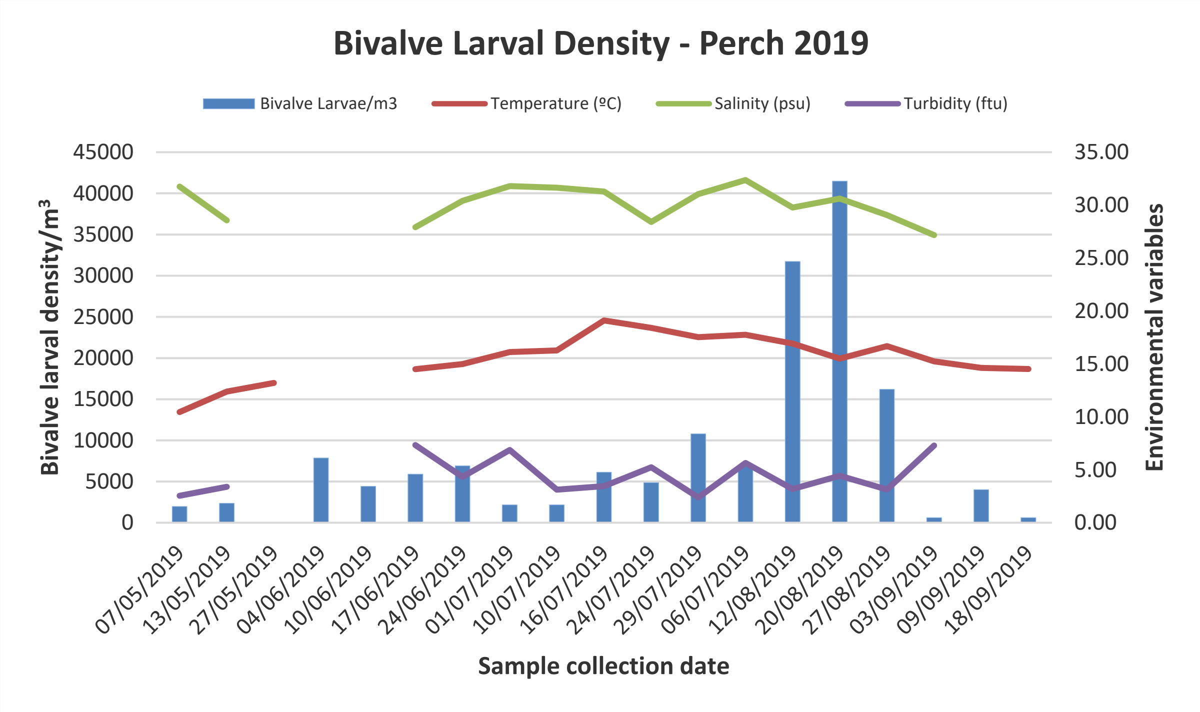


Figure 21: Bivalve larval density and environmental variables – Perch

Mean bivalve larval density for the Perch Bed was 8,270/m^3. A peak in bivalve larval numbers was observed in late August of 41,492/m^3. This peaks followed brooding levels of over 20% and 10% per week on this bed during late July and early August. Brooding was still evident on this bed in September as was the case in previous years.

Mean water temperature recorded in the Perch in 2018 was 15.5°C (range 10.4 – 19.1°C). Salinity ranged from 27.1 to 32.3 psu and turbidity averaged 4.3 NTU. Once again the relatively calm dry weather experienced during 2019 resulted in consistently high water temperatures, high salinity and low turbidity for much of the summer period.

Mean shell length of all sampled oysters in 2018 was 67.1mm and mean weight of oysters was 67.2g. 70% of all brooding oysters recorded during the survey were less than the 80mm minimum landing size.

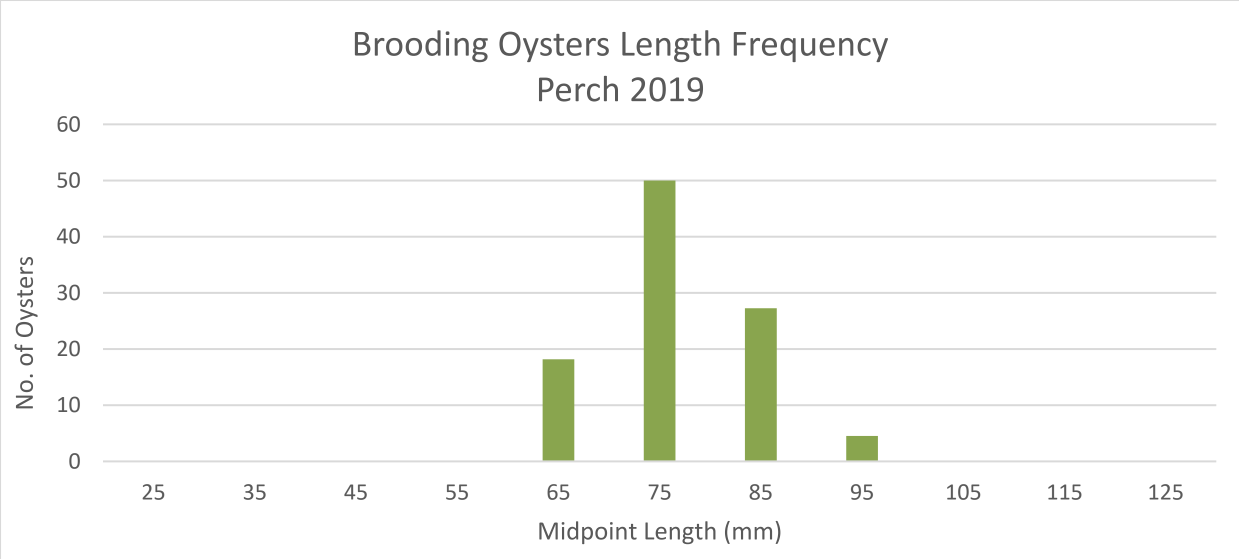


Figure 22: Length Frequency of Brooding Oysters - Perch

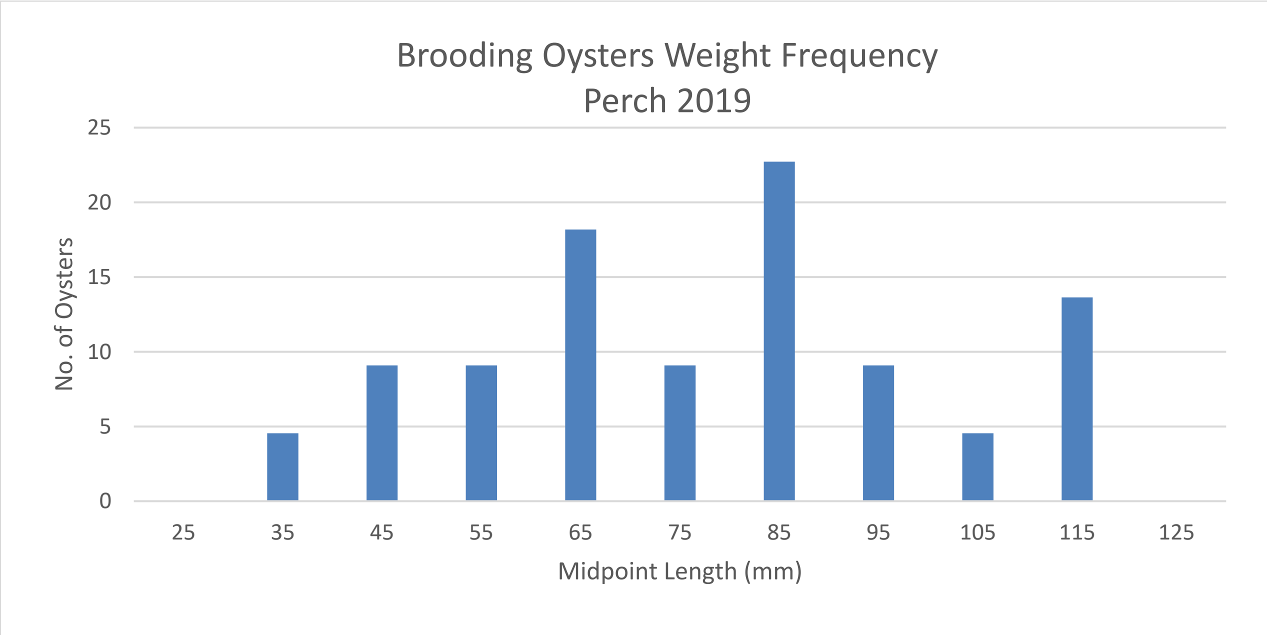


Figure 23: Weight Frequency of Brooding Oysters - Perch 2018

3.3 Quigley's Point

Table 6: Quigley's Point summary info

Bed Name	Quigley's Pt
Area (hectares)	140
Average Density (oysters/m2)	0.39
No. of Oysters	1,416,648
Total Biomass (t)	20

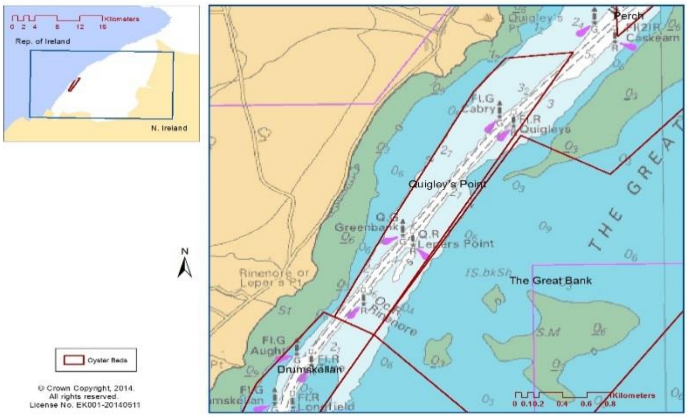


Figure 24: Location of Quigley's Point

Spawning activity was recorded on the Quigley's Point bed from 24 June onwards. Peak brooding was observed in Quigley's Point on 10th July when 23% of the sampled oysters were in the brooding phases. The numbers of spent oysters increased steadily from the end of July. In total 5.15% of the oyster samples were in the brooding phases during 2019.

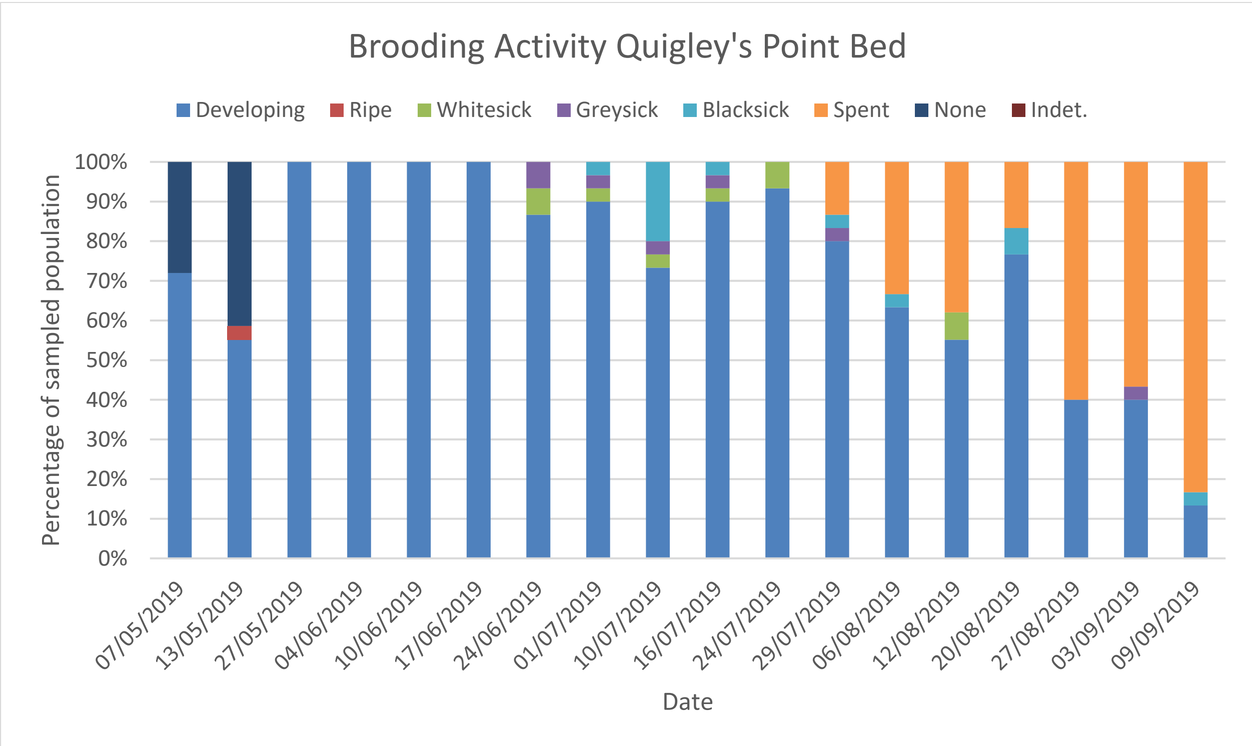


Figure 25: Spawning Stage Quigley's Point 2019

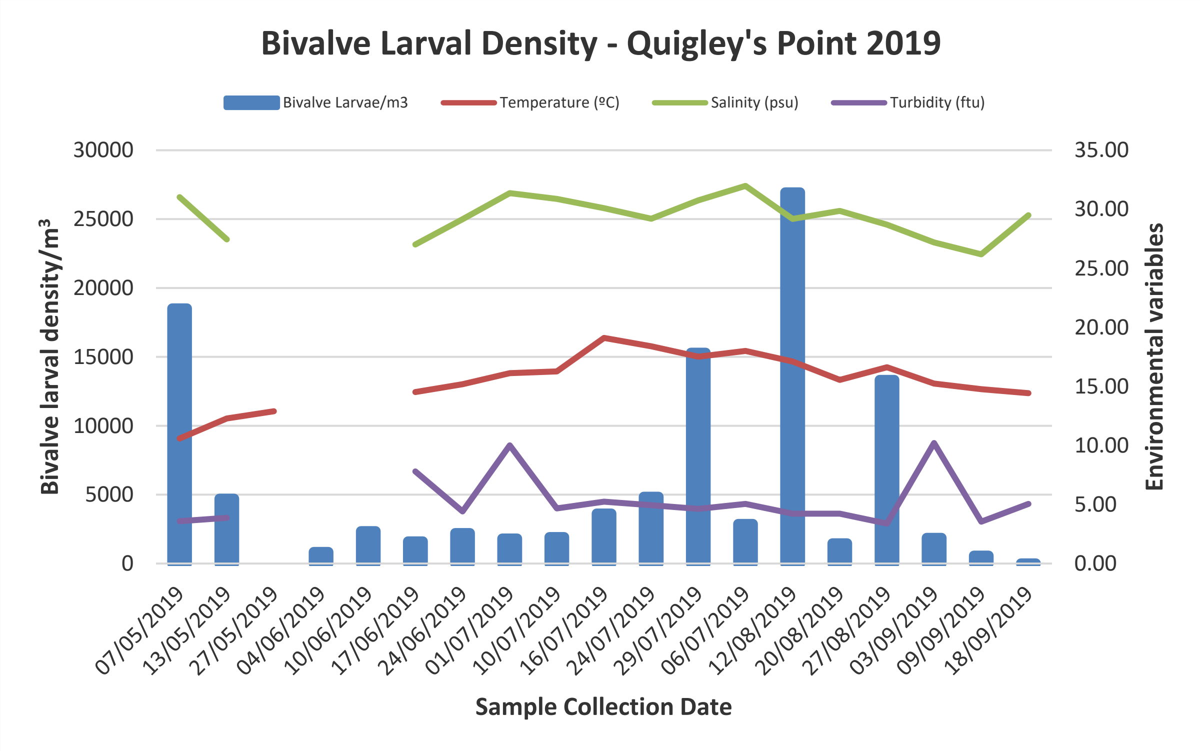


Figure 26: Bivalve larval density and environmental variables - Quigley's Point

Mean bivalve larval density on the Quigley's Point bed was 5,517/m^3. There were two notable peaks in the bivalve larval densities in late July (15,301/m^3) and mid-August (26,943/m^3). Bivalve larval peaks on this bed were twice as high as those observed on other oyster beds. Brooding peaks were observed in mid and late July and it is possible that the peaks in bivalve larval 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 15.5°C with a range of 10.5-19.1°C. Mean salinity value was 29.3 psu with a range of 26.1-31.9 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 64.3mm and mean weight was 63.1. Mean length of brooding oysters was 70mm and mean weight was 69.5g with a range of 32-110g.

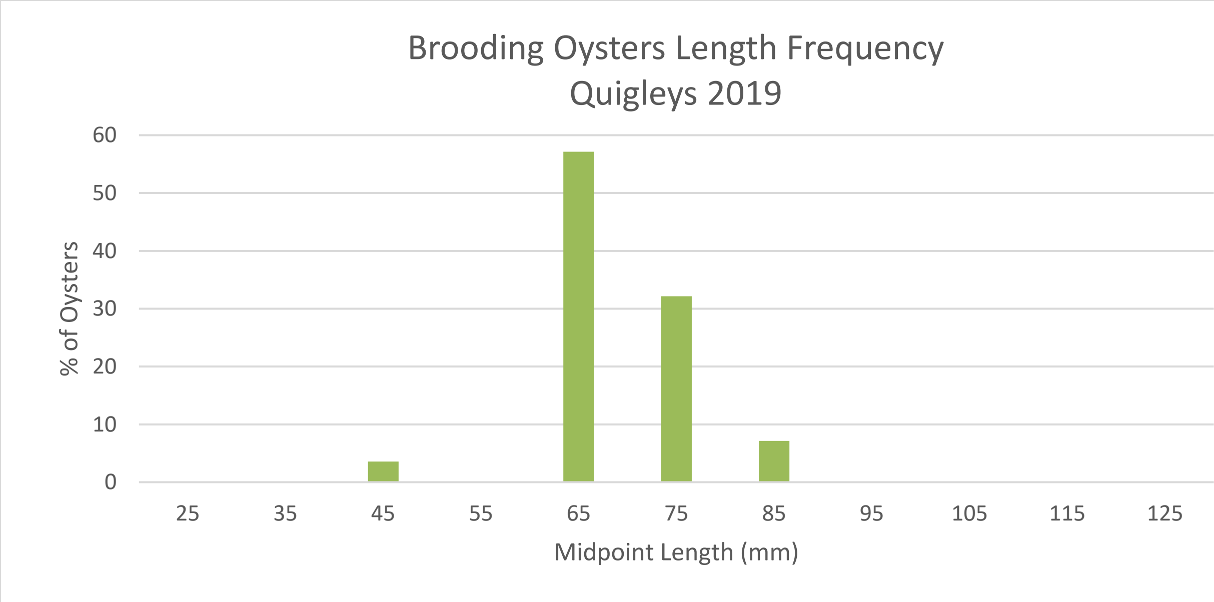


Figure 27: Length Frequency of Brooding Oysters - Quigley's Point

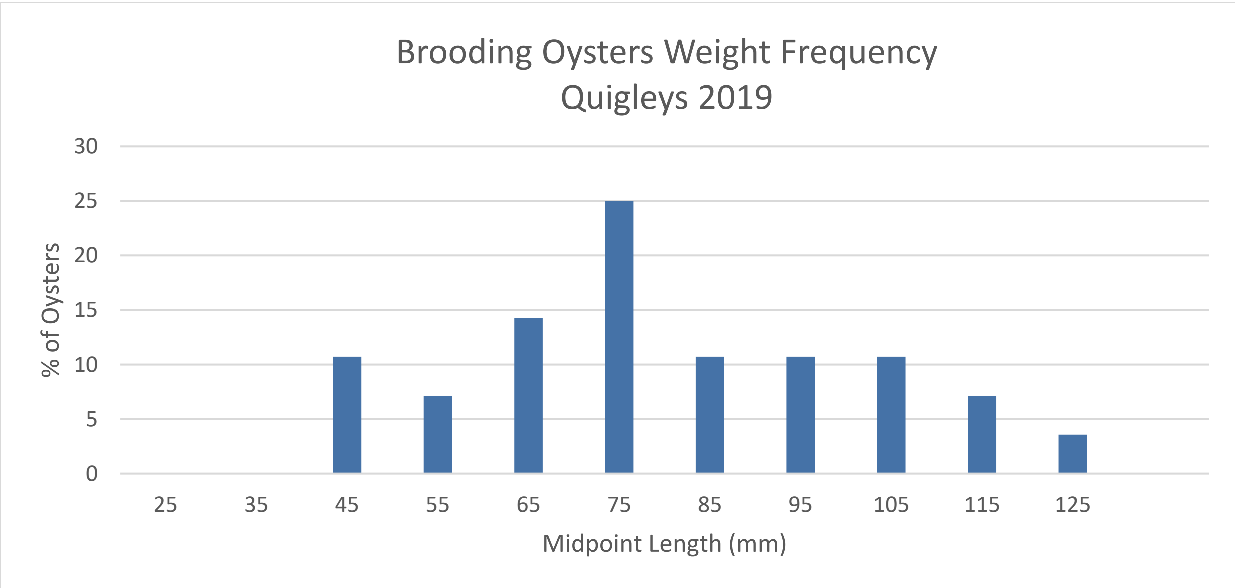


Figure 28: Weight Frequency of Brooding Oysters - Quigley's Point

3.4 Southside Bed

Table 7: Southside summary info

Bed Name	Southside
Area (hectares)	578
Average Density (oysters/m2)	0.48
No. of Oysters	3,877,109
Total Biomass (t)	82

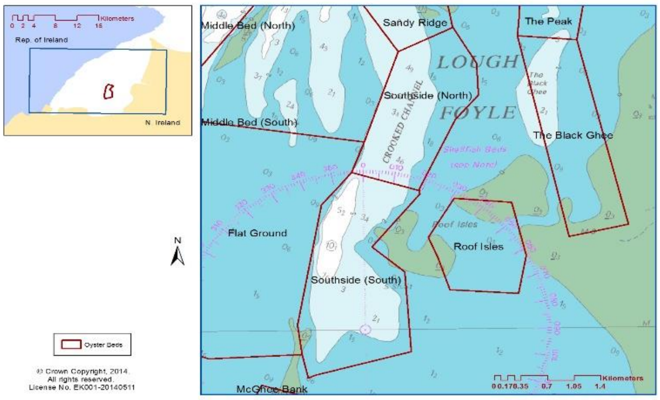


Figure 29: Location of Southside Bed

Brooding activity was observed from 1st July onwards on the Southside bed. As with the other beds, peak brooding occurred in Southside in the sample collected during the first week of July 2019. A second peak in the number of oysters found to be brooding eggs or larvae was recorded in the sample from 12th August 2019. 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 5.15% of the sampled population was brooding.

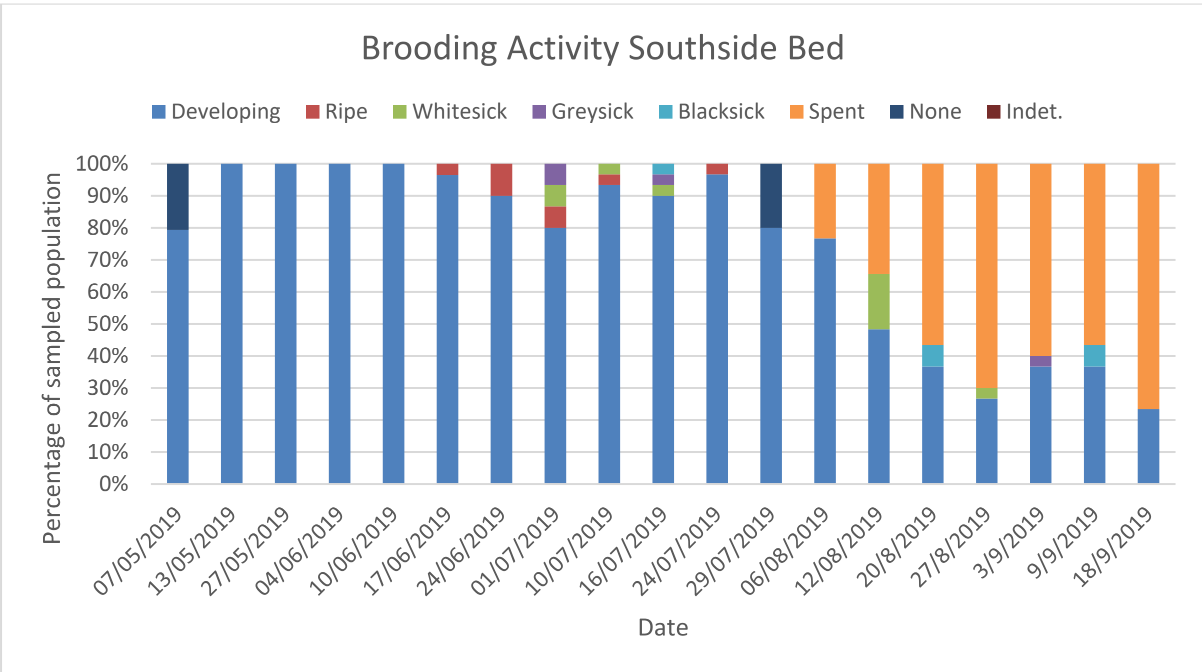


Figure 30: Spawning Stage Southside Bed 2019

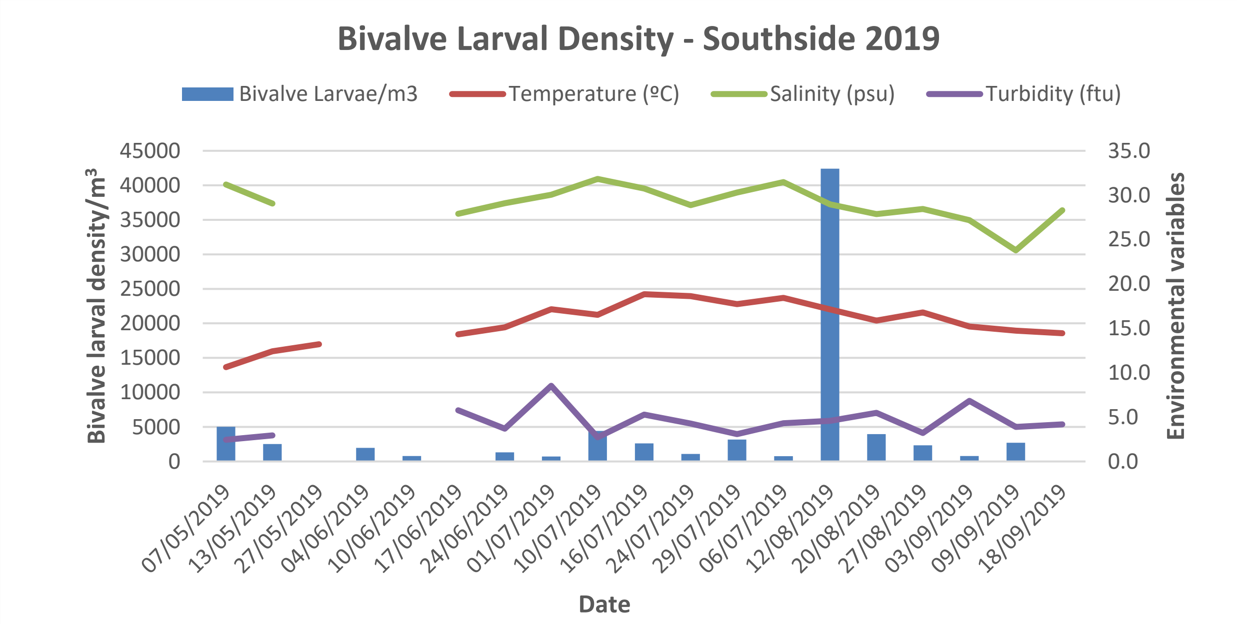


Figure 31: Bivalve larval density and environmental variables – Southside

Mean larval density on this bed was 4029/m^3. A peak in larval numbers was recorded on 12th August at 42,411/m^3. The brooding rates on this bed show a peak of 13% in early July and another peak of 17% in mid-August.

Mean water temperature on this bed was 15.72°C with a range of 10.6-18.8°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 29psu.

Mean length of the sampled population on this bed was 65.2mm with a mean weight of 66.9g. Brooding oysters ranged from 56-94mm in length and 41-129g in weight. 85% of the brooding oysters were less than the minimum landing size of 80mm.

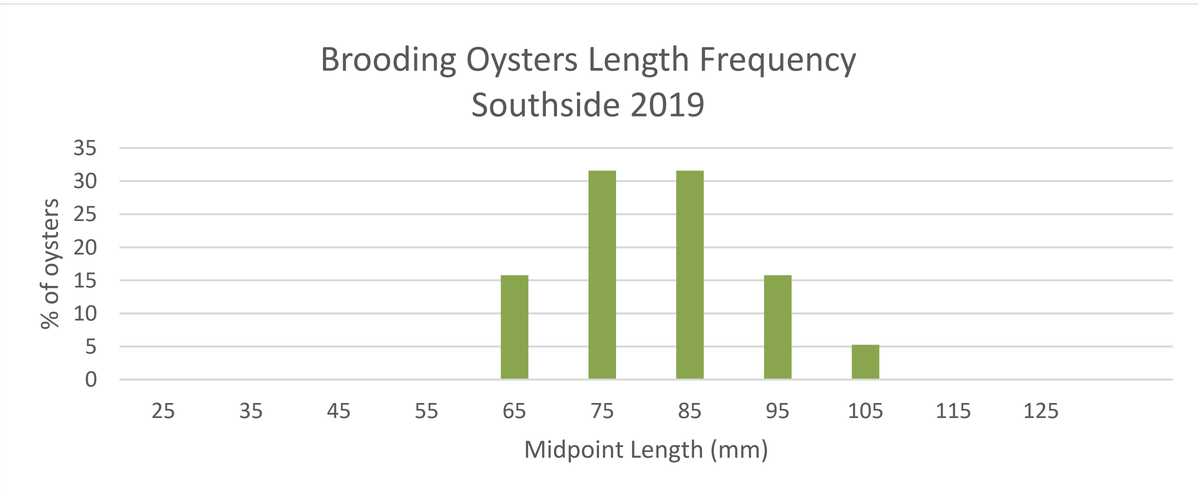


Figure 32: Length Frequency of brooding oysters - Southside

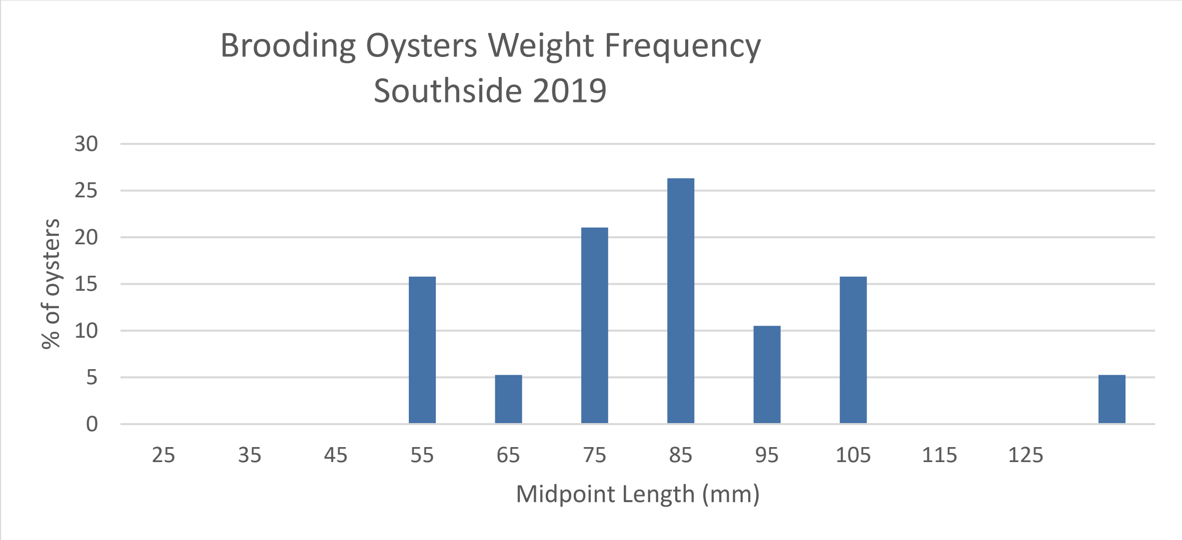


Figure 33: Weight Frequency of brooding oysters - Southside

3.5 Middle Bed

Table 8: Middle Bed summary info

Bed Name	Middle Bed
Area (hectares)	531
Average Density (oysters/m2)	0.41
No. of Oysters	2,964,596
Total Biomass (t)	74

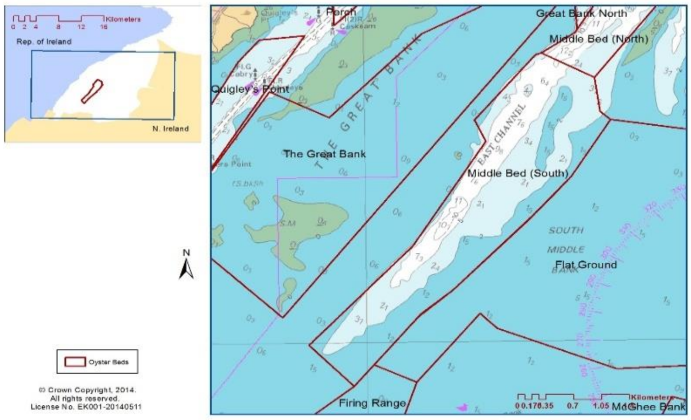


Figure 34: Location of Middle Bed

Brooding was first detected on 10th June with 3% of oysters from the sample in the white sick phase. The proportion of spent oysters progressively increased from the end of July onwards. Total brooding on this bed was 4.2%.

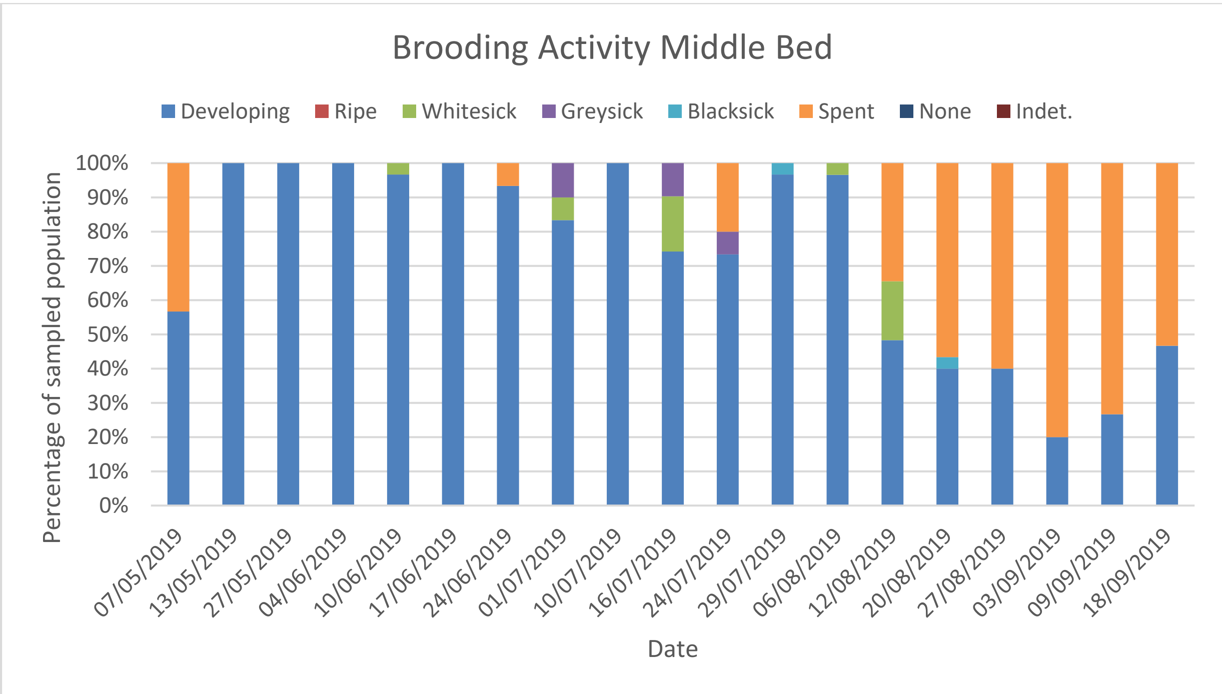


Figure 35: Brooding stage Middle Bed 2019

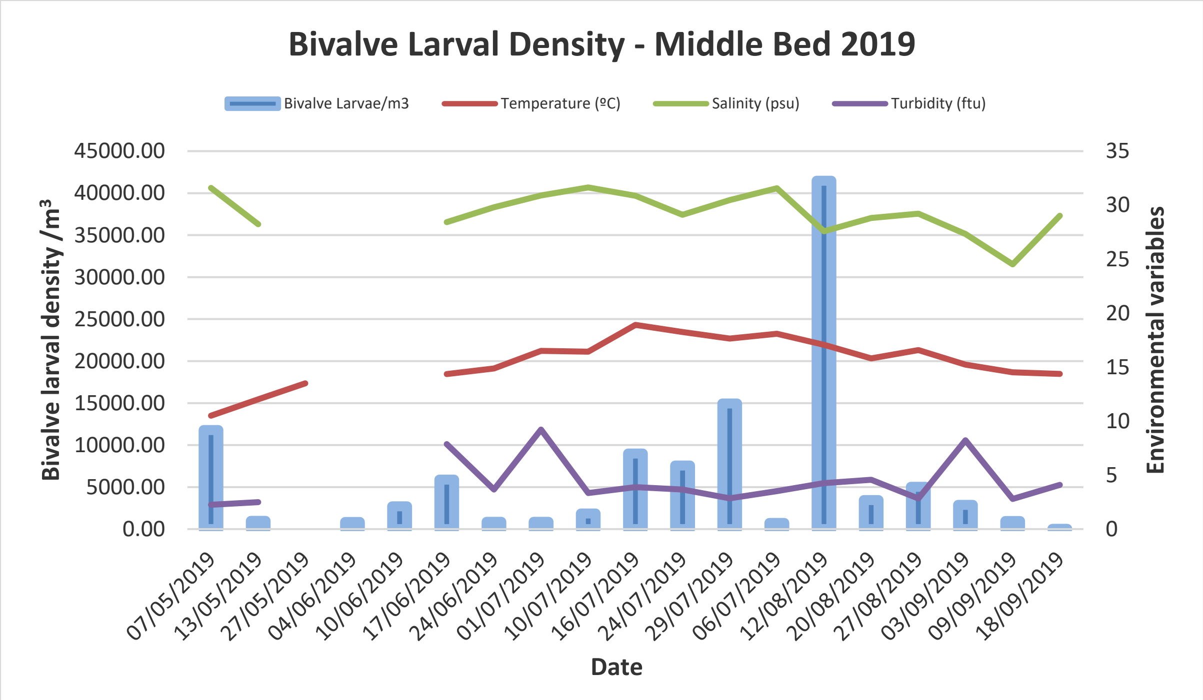


Figure 36: Bivalve larval density and environmental variables - Middle Bed

Mean bivalve density was 5,890/m^3. Bivalve larval peaks were observed in late July and mid August in keeping with many other oyster beds. Maximum larval density of 41.475/m^3 was recorded on 12th August.

Water temperatures remained consistently above 16°C for all of July and August only falling below this threshold on 20th August. Salinity was very stable once again thanks to the low rainfall levels during the period with a range of 24-31psu.

Mean length of all oysters sampled was 63.7mm and mean weight was 64.1g. Brooding oysters had a mean length of 68mm and a mean weight of 58.6g. 87% of the brooding oysters were less than the 80mm minimum landing size in the fishery and 90% were less than 70g in weight.

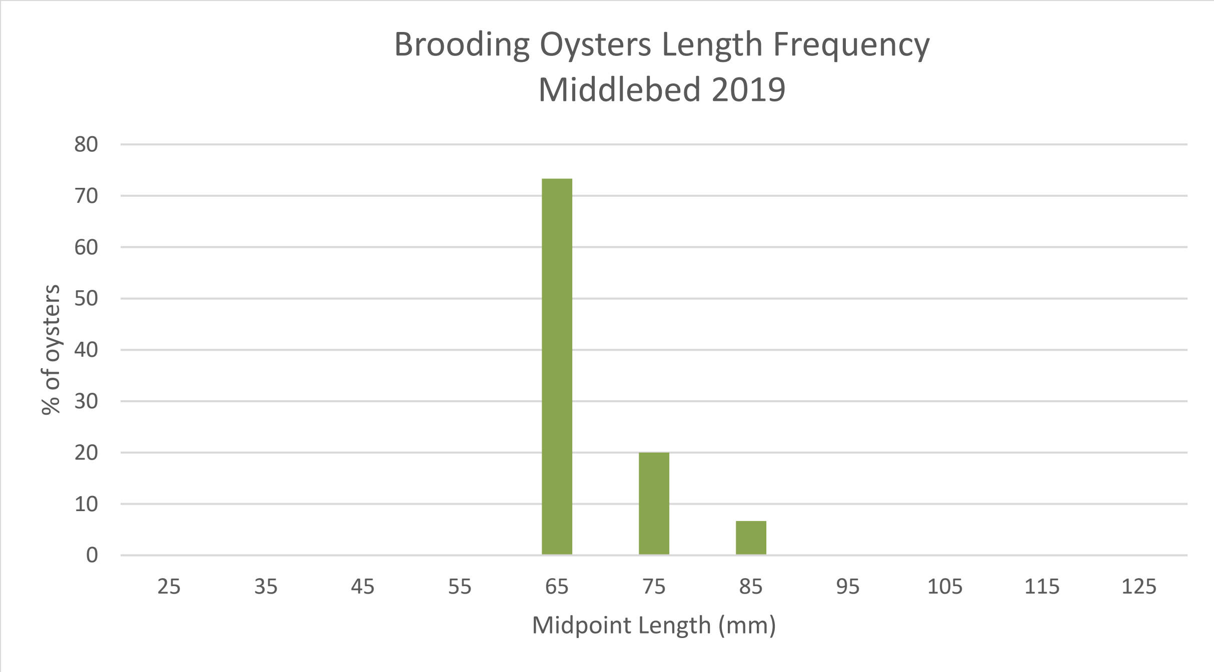


Figure 37: Length Frequency of brooding oysters - Middle Bed

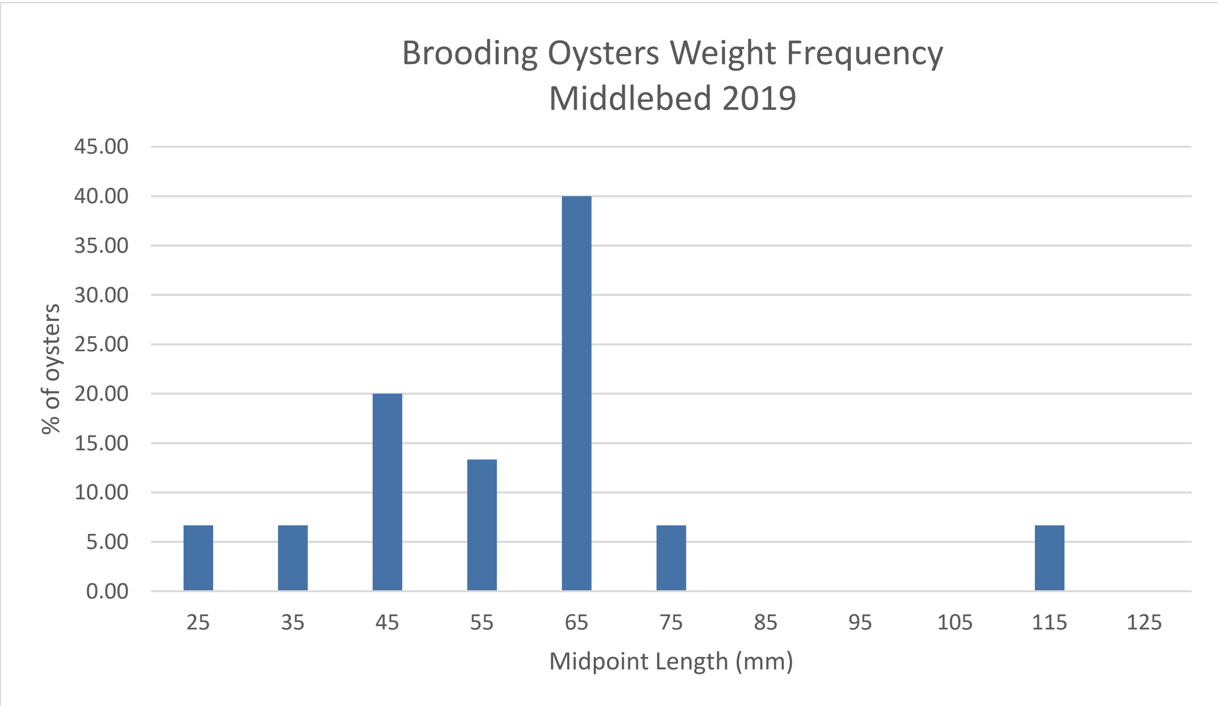


Figure 38: Weight Frequency of brooding oysters - Middle Bed

4.0 Discussion

Brooding in the Foyle oyster population appears to have been relatively slow to start in 2019 with very little spawning activity taking place in May and June. Water temperature was equally slow to rise in 2019 with mean temperatures on the beds being 2-3°C lower in June compared to the same period last year. This may have had an impact on gonad development within the stock and potentially meant that oysters were not in optimal condition for spawning in early July.

July and August 2019 was characterised by periods of relatively settled, warm, 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. Water temperatures remained consistently above 16°C throughout the July-August period and this provided optimal conditions for spawning and larval release and survival.

The observed rise in the proportion of brooding oysters in July is inconsistent with the observed larval densities and the presence of small spat (<15mm) in September. It is possible that larvae released during July when brooding was recorded did not survive well and that a secondary spawning event took place in mid-August when both brooding and larval numbers were relatively high. The results of the stock assessment would indicate that the spat settlement has been limited to the highest density areas within the oyster beds. This correlation between areas with high adult oyster density and spat settlement has been observed in previous years when spawning has been limited in nature.

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.

5.0 Conclusions

- The proportion of oysters brooding larvae within the population was lower than the previous 7 years however a spatfall did appear to take place late in the summer period on the high density areas within each oyster bed.

- 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 2019 represent < 10% of each year’s sampled population. Including oysters with spent gonads increases the percentage of the sampled 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.

- 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.

2. Investigate methods to enhance broodstock on low density beds to counteract the "Allee effect" and increase the chance of fertilisation success within the oyster population.

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

Beck, M. W., Brumbaugh, R. D., Airoldi, L., Carranza, A., Coen, L. D., Crawford, C., Defeo, O., Edgar, G. J., Hancock, B., Kay, M. C., Lenihan, H. S., Luckenbach, M. W., Toropova, C. L., Zhang, G., Guo, X., 2011. Oyster reefs at risk and recommendations for conservation, restoration and management. Bioscience 61: 107 – 116.

Bromley, C.A. (2015). Science-based management strategies for the commercial and environmental sustainability of the European oyster, *Ostrea edulis* L. PhD Thesis. The Queen's University of Belfast 226pp

Bromley, C.A., McGonigle, C., Ashton, E.A. & Roberts, D., 2015. Restoring degraded European native oyster, *Ostrea edulis*, habitat: is there a case for harrowing. Hydrobiologia published online 09 November 2015

Cole, H.A. (1956) Oyster Cultivation in Britain: A Manual of Current Practice. HMSO. London

Crisp, D., 1964. The effects of the severe winter of 1962-63 on marine life in Britain. Journal of Animal Ecology 33: 1: 165-210

Davidson, P. (1976) 'Oyster Fisheries of England and Wales' Ministry of Agriculture Fisheries and Food Directorate of Fisheries Research http://cefas.defra.gov.uk/publications/lableaflets/lableaflet31.pdf (22/09/2011)

Doak, D.F., Mills, L.S. and Soule, M.E. (1993) 'The keystone-species concept in ecology and conservation' BioScience, **43** (4): pp.219 http://bio.research.ucsc.edu/people/doaklab/publications/1993mills_soule_doak.pdf (04/10/2011)

Goulletquer, P. (2005-2011) 'Cultured Aquatic Species Information Programme. *Ostrea edulis*.' in: FAO Fisheries and Aquaculture Department, Food and Agricultural Organisation of the United Nations (FAO), Rome. Available from: http://www.fao.org/fishery/culturedspecies/Ostrea_edulis/en (10/10/11)

Hawkins, J.P., McAuslan, A.B., Roberts, C.M. and Thurstan R.H. (2008) 'Marine Reserves in Northern Ireland: The Way Forward' A University of York report for WWF and UWT http://www.ukmpas.org/pdf/NI_MPA_report_final.pdf (26/09/2011)

Helm, M.M., Bourne, N., Lovatelli, A**.** (2004) Hatchery culture of bivalves. A practical manual. FAO Fisheries Technical Paper. No. 471. Rome, FAO. 177p. http://www.fao.org/docrep/007/y5720e/y5720e09.htm (28/09/11)

Kennedy, R.J. and Roberts, D. (1999) 'A Survey of the Current Status of the Flat Oyster *Ostrea Edulis* in Strangford Lough, Northern Ireland, with a View to the Restoration of its Oyster Beds' Biology And Environment: Proceedings Of The Royal Irish Academy, **Vol. 99b** (2): 79-88
http://www.ecowin.org/smile/documents/StatusoftheflatoysterinStrangfordLough.pdf (28/09/2011)

Korringa, P., 1940. Experiments and observations on swarming, pelagic life and setting in the European flat oyster, *Ostrea edulis* L. Arch. Neerl. Zool. 5: 1-249

Korringa, P., 1957. Water temperature and breeding throughout the geographical range of *Ostrea edulis*. Annee Biologique 33: 1-17

Orton, J. H., 1937. Oyster Biology & Oyster Culture being The Buckland Lectures for 1935. Edward Arnold & Co., London 211pp

OSPAR Commission (2009) 'Background document for *Ostrea edulis* and *Ostrea edulis* beds' Biodiversity Series
http://qsr2010.ospar.org/media/assessments/Species/P00428_ostrea_edulis_and_beds.pdf (04/10/2011)

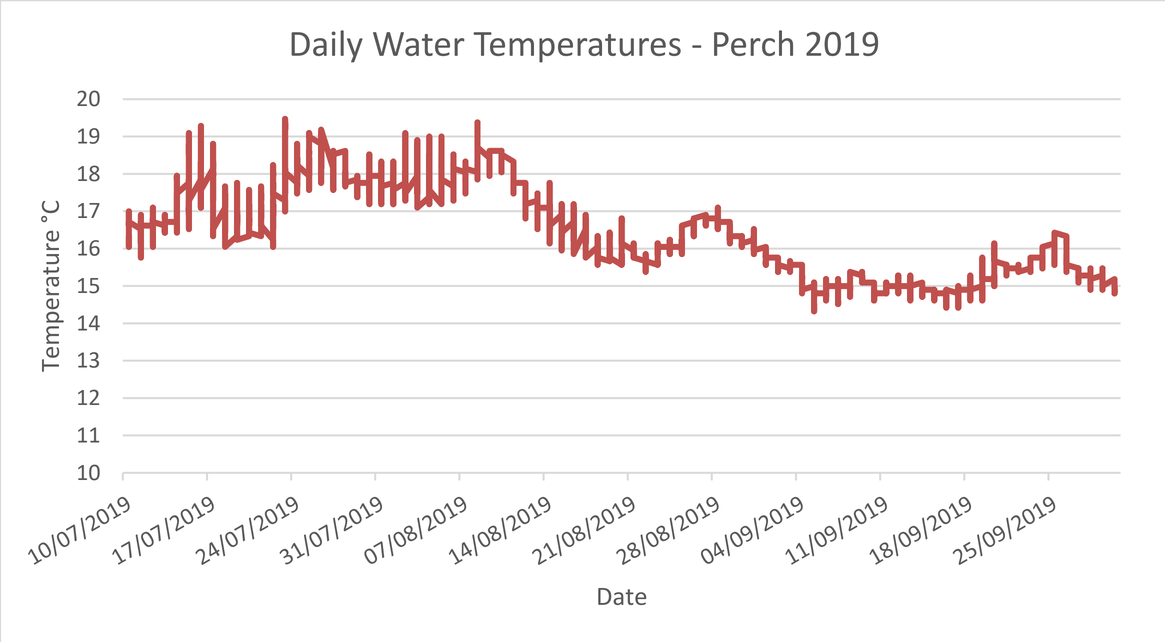
Paynter, K.T. (2003) Oyster Restoration and Management of the Chesapeake Bay Oyster Fishery in Maryland. Proceedings of the Loughs Agency Shellfish Management Workshop http://www.loughs-agency.org/archive/publications/Loughs%20Agency%20Shellfish%20workshop.doc (29/09/2011)

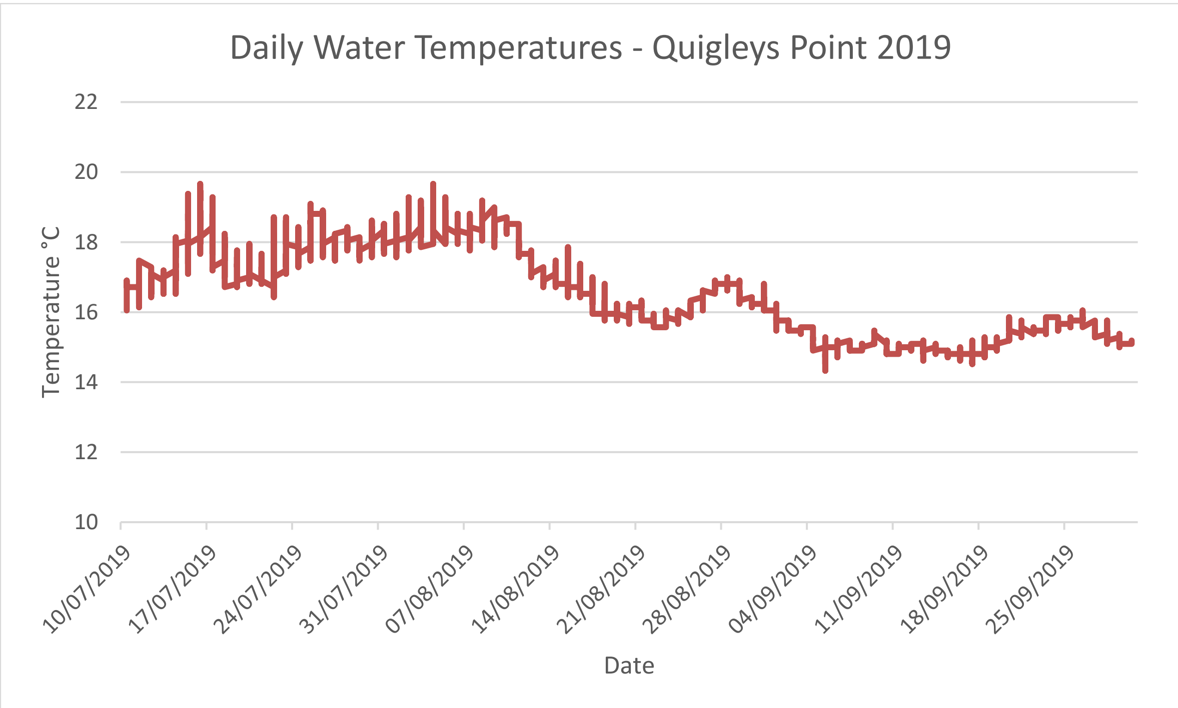
University Marine Biological Station Millport. (2007). Conservation of the Native Oyster *Ostrea edulis* in Scotland. Scottish Natural Heritage Commissioned Report No.251 (ROAME No. F02AA408).

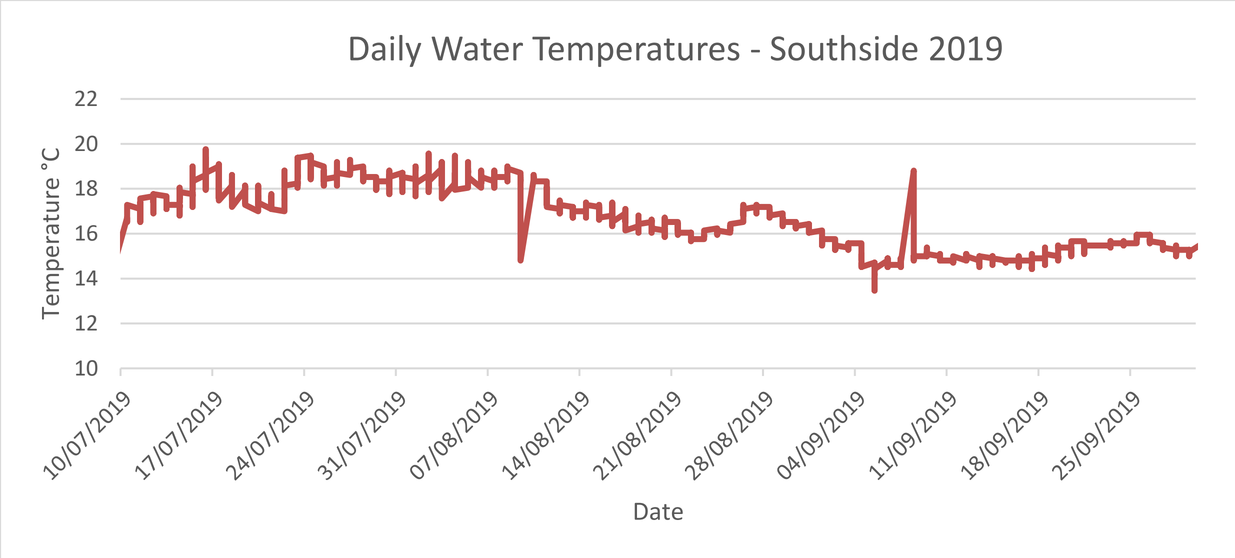
Walne, P. R. (1964). Observations on the fertility of the oyster (Ostrea edulis). JMBA 44: 293-310

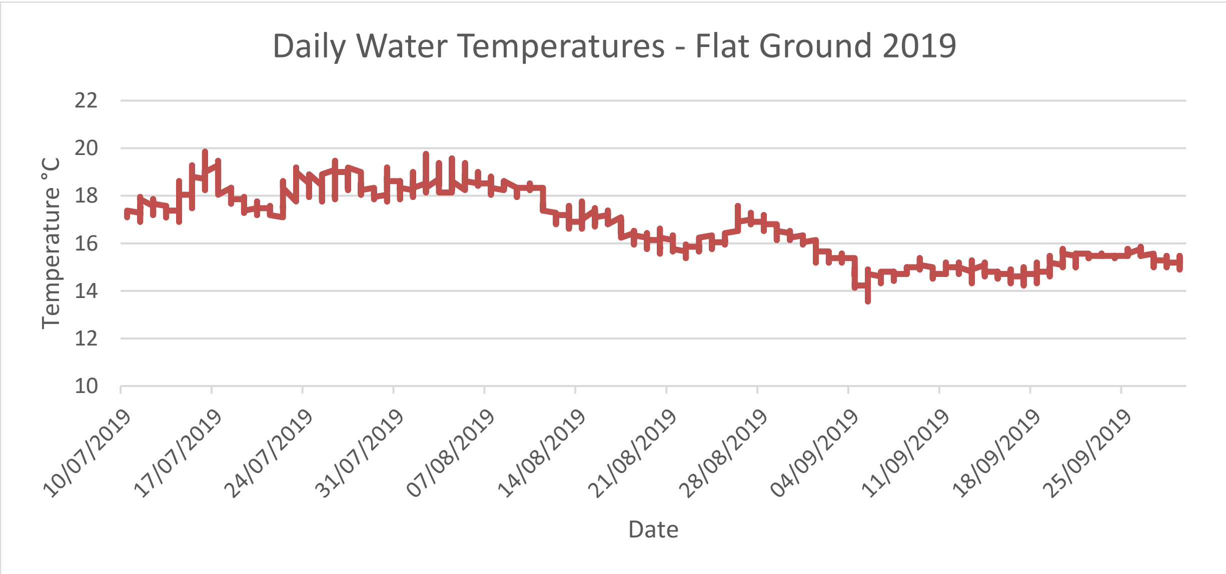
Walne, P.R. (1974). Culture of Bivalve Molluscs, The Buckland Foundation, London. 189 pp

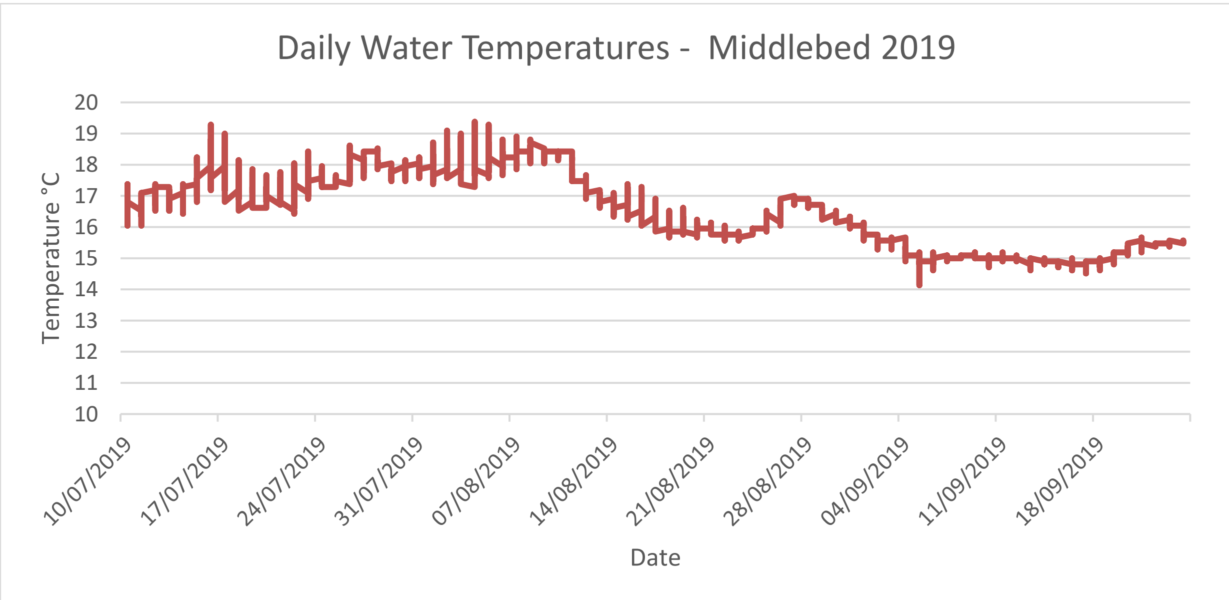
Appendix I – Daily Water Temperature Records



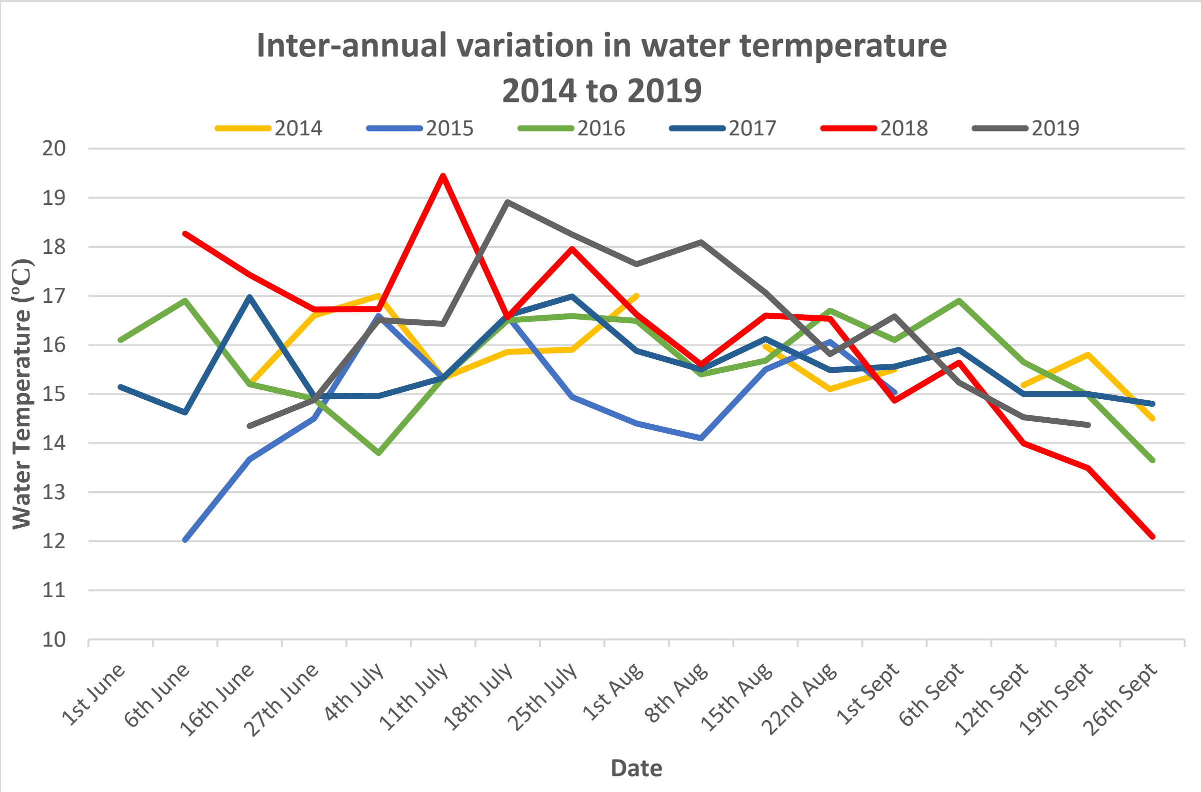



Daily Water Temperatures - Southside 2019
Temperature °C
22
20
18
16
14
12
10
10/07/2019
17/07/2019
24/07/2019
31/07/2019
07/08/2019
14/08/2019
21/08/2019
28/08/2019
04/09/2019
11/09/2019
18/09/2019
25/09/2019
Date

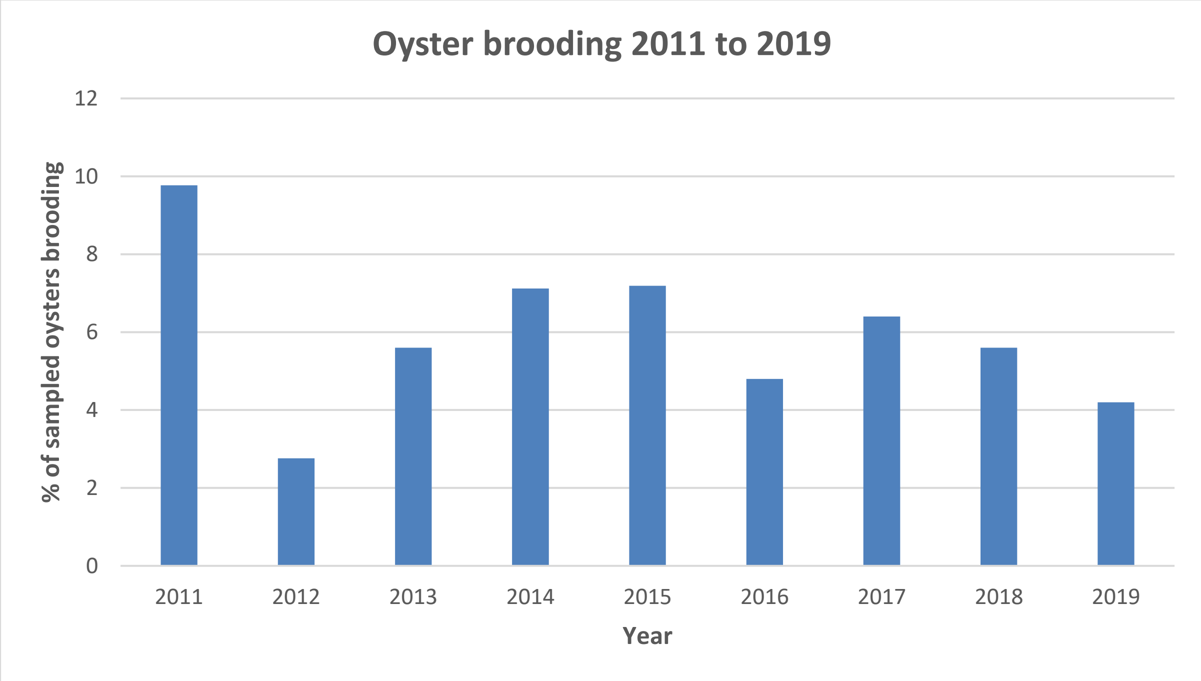

Daily Water Temperatures - Flat Ground 2019
Temperature °C
22
20
18
16
14
12
10
10/07/2019
17/07/2019
24/07/2019
31/07/2019
07/08/2019
14/08/2019
21/08/2019
28/08/2019
04/09/2019
11/09/2019
18/09/2019
25/09/2019
Date


Daily Water Temperatures - Middlebed 2019
Temperature °C
20
19
18
17
16
15
14
13
12
11
10
10/07/2019
17/07/2019
24/07/2019
31/07/2019
07/08/2019
14/08/2019
21/08/2019
28/08/2019
04/09/2019
11/09/2019
18/09/2019
Date

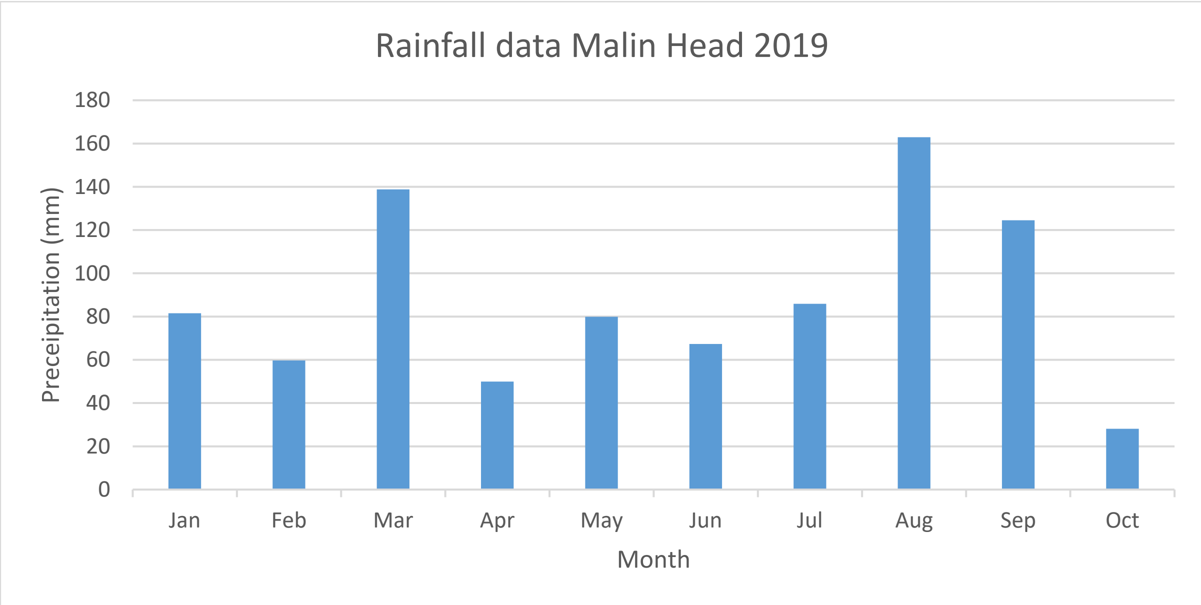
Appendix II Inter-Annual Variation in Water Temperature



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 2019

Introduction

In conjunction with the annual native oyster spawning survey, 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 ºC 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 on five of the higher density oyster beds (Perch, Middle bed, Southside, Quigley's Point and Flat Ground) within Lough Foyle in July 2019. Stock pots containing oyster shell (pacific and native), plastic coupelles and temperature loggers were deployed on each bed to monitor spatfall and water temperature over the spawning season. Each stock pot contained approximately 250 oyster shells and 30 plastic coupelles.

The pots were retrieved on 30th September 2019 and the data downloaded from the loggers.

100 Oyster shells and each of the 30 plastic coupelles were 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.

Results

Spat were observed on the shell within each collector examined. A total of 75 spat were collected from the five collectors. Spat had settled in the highest numbers on the Perch Bed (27).

Table 1: Spat counts from collectors examined

Collector	Spat count	No. of shells analysed	No. of coupelles analysed	Mean Length (mm)
1	27	100	30	8.4
2	15	100	30	7.6
3	3	100	30	7.5
4	15	100	30	9.2
5	15	100	30	8.7

The mean length of native oyster spat was consistent throughout the sites. Shell length ranged in size from 5.1mm to 13.3mm. There was no evidence of spat > 20 mm on any of the collectors indicating that spat did not settle out early in the summer period.

Discussion

Spat settlement took place only on the oyster shell cultch deployed during this trial. There was no evidence of any spat on the black coupelles deployed along with the shell however these have successfully attracted spat settlements in previous years. The addition of lime mortar to the plastic coupelles may have helped to attract settlements.

Native oysters were found to be brooding and releasing larvae from 13th 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 15ºC during the period of spat collector deployment. 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.