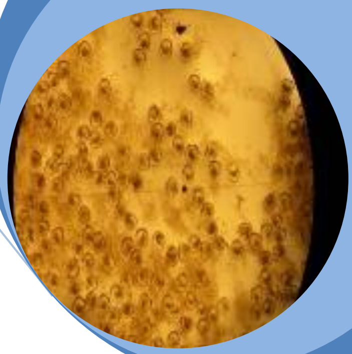

Native Oyster Spawning Assessment Lough Foyle Summer 2017

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.

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Executive Summary

Native oyster spawning was monitored weekly on five oyster beds within the Lough Foyle oyster fishery for 17 weeks from the beginning of June to the end of September 2017. Environmental conditions and bivalve larval density per m^3 were also recorded at these locations.

Of the 2430 oysters examined, 6.4% were in the brooding phase with eggs (milky white mass) or larvae (grey or black mass) visible on the gills. When combined with the number of oysters recorded with spent gonads, 48.8% of all oysters sampled showed evidence of larval release during the survey period. Water temperatures were consistently above 14ºC throughout the 17 weeks of the survey. Peak brooding week varied amongst the sampled beds, occurring between 03/07/17 and 24/07/17. Bivalve larvae of all species numbers peaked at a mean density of 35720/m^3 ± 15323 in week 10 (08/08/17), two weeks after water temperatures reached 17ºC. Although native oyster larvae were not observed in samples until week 5, native oyster larval numbers also peaked at the same time. Brooding oysters and native oyster larvae were recorded in samples taken the day before the 19th September, the traditional start date of the fishery. Brooding intensity, bivalve larval numbers, water temperatures and salinity all decreased and turbidity increased markedly following a major flooding event in late August 2017. Despite the numbers brooding and positive identification of larvae in the water column, this does not appear to have translated into a widespread spatfall in the lough in 2017. This needs to be taken into consideration when planning enhancement works and for future regulation of the fishery.

The adult oysters collected during the survey had a mean length of 77.7 ± 8.9 mm and mean weight of 60.4 ± 7.7 g. 64.8 % of the sampled oysters were below the 80 mm Minimum Landing Size. Of these, 71.6% measured between 70 and 79.99 mm and would be expected to recruit into the fishery for the 2017/ 18 season, given that sampled oysters noticeably increased in length and weight over the summer. This also means that the population is largely dependent upon smaller, younger oysters for reproduction.

The annual survey of reproductive activity in the Lough Foyle native oyster fishery has now compiled a 7-year dataset. This survey is one of the few of its kind carried out on an annual basis in Europe and it is important to continue with this work to assist with identifying change, inter-annual patterns and planning for future fishery regulation and enhancement works. This long-term data set will also enable the Loughs Agency and the Foyle fishery to contribute to European wide work to conserve *Ostrea edulis* populations.

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 2017/ 18 season started on 3rd October 2017.

This report outlines the findings of a survey undertaken between 2nd June and 25th September 2017 to assess the spawning activity of *Ostrea edulis* (European native oyster) in Lough Foyle. The survey is now in its 7th 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 2004. 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.

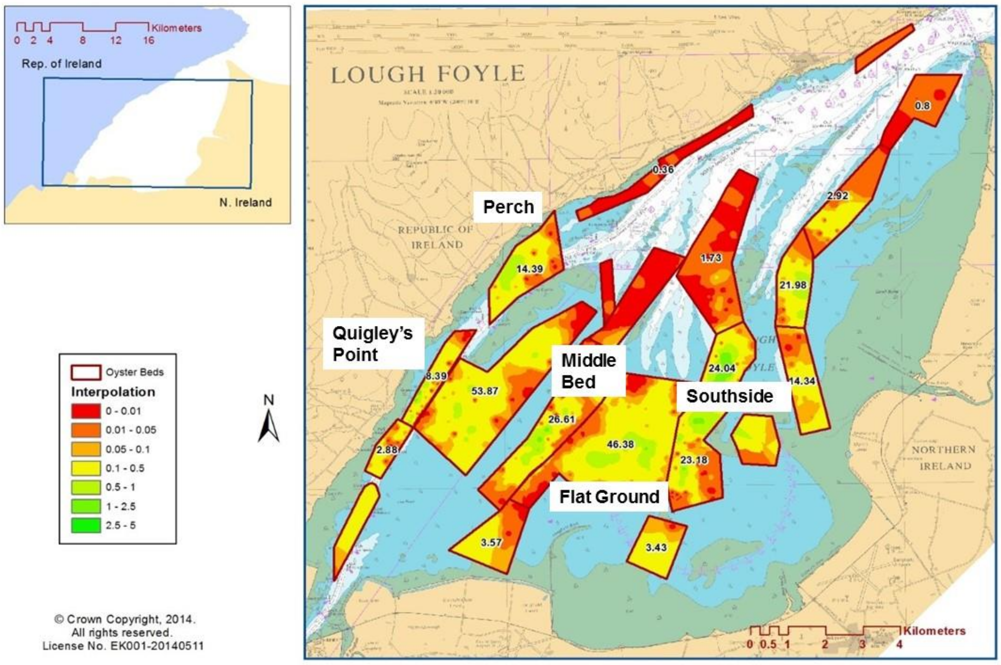

Figure 1: Oyster density in Lough Foyle Spring 2017 and the oyster beds sampled for this survey (figures on each bed = biomass in tonnes).

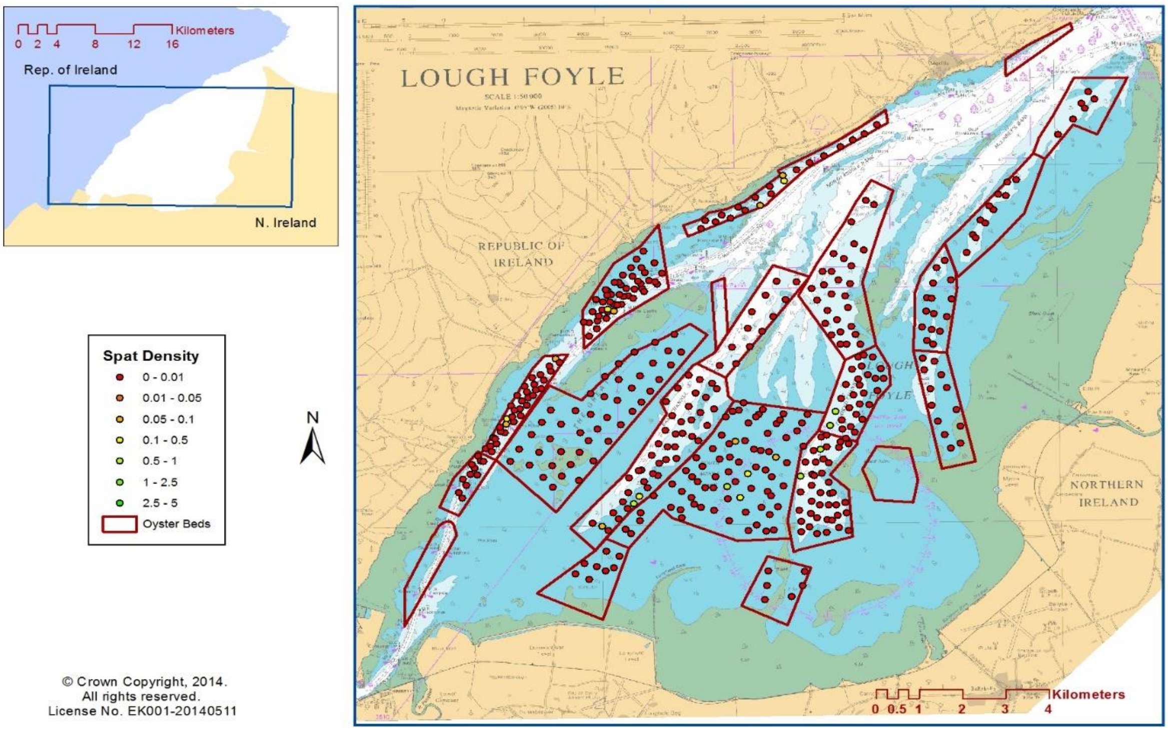

Figure 2: Spat Density Spring 2017 – red circles show areas with no spat settlement.

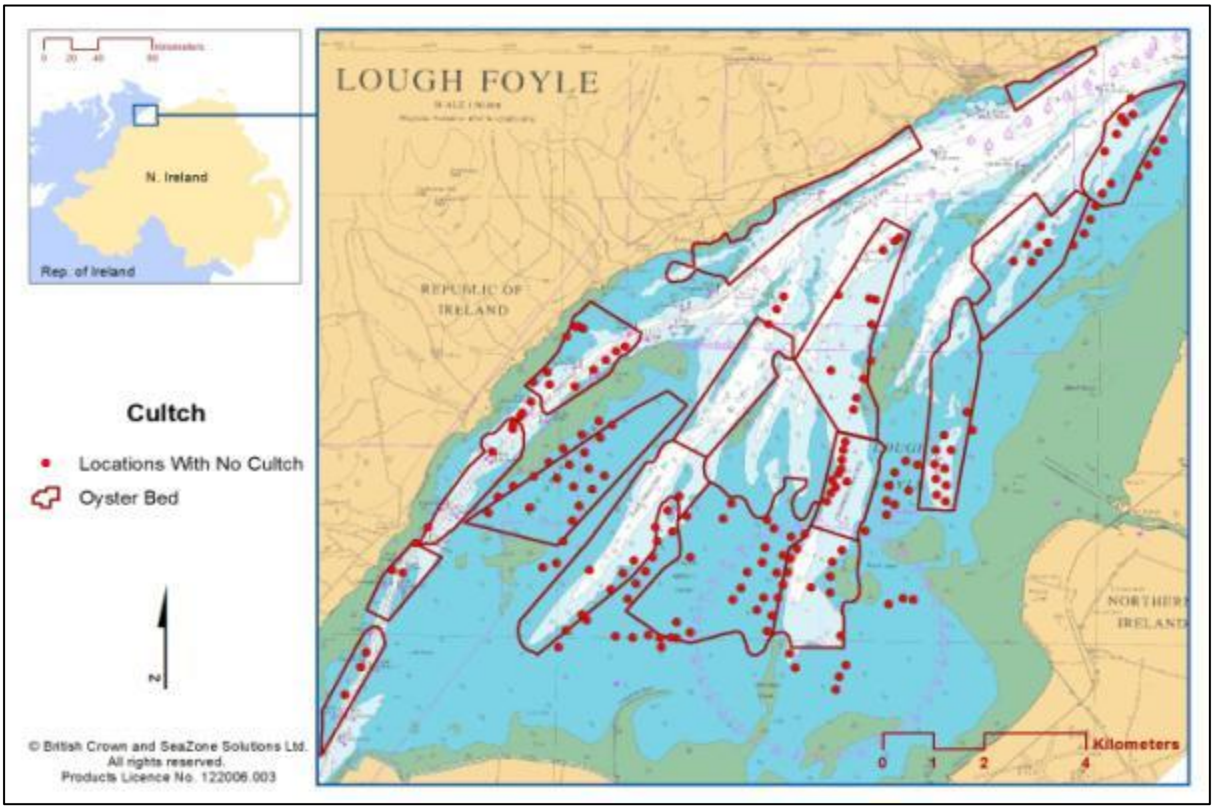

Figure 3: Location of areas without suitable cultch within the Foyle oyster fishery

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, fertilisation 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).

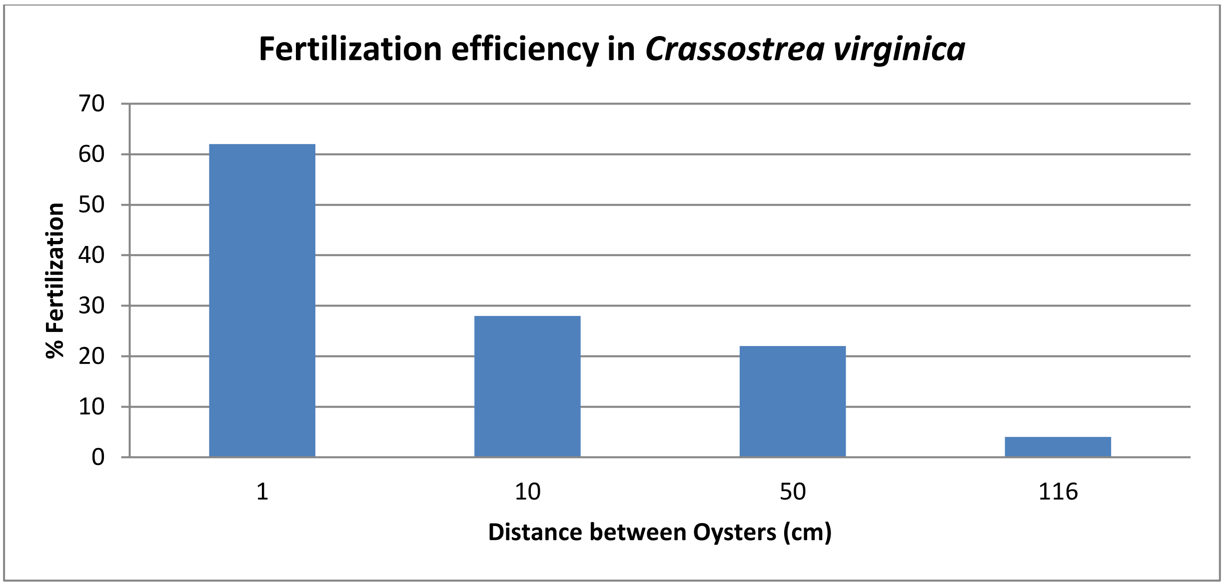

Figure 3: Fertilisation efficiency as a function of oyster population density (taken from Paynter, 2003)

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 4 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 Oysters

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 5: 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]

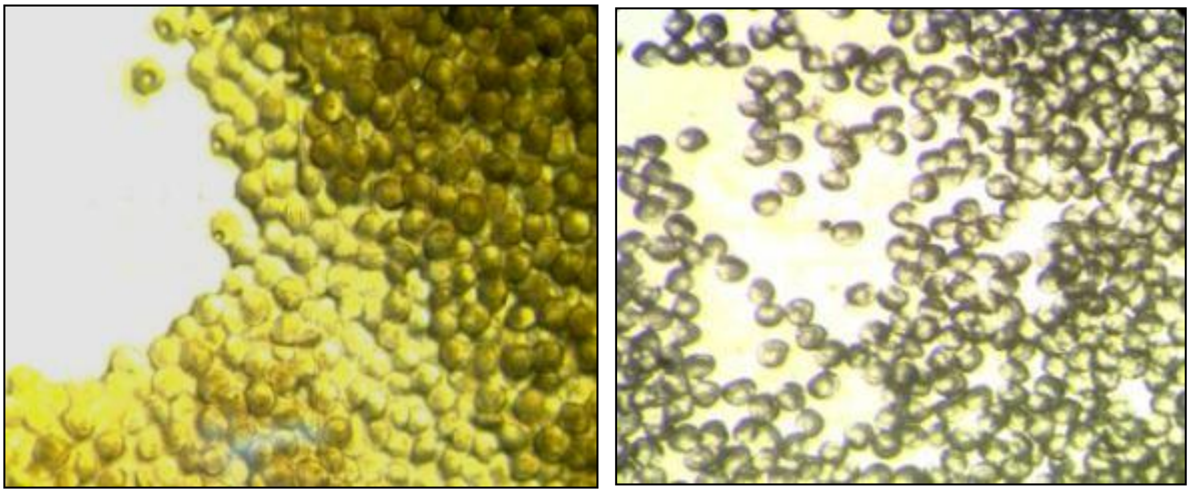

Figure 6 a-b: Native oyster larvae removed from a black sick brooding female (left) and grey sick female (right)

2.3 Environmental Monitoring

A Seabird 19+ CTD 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 7: Seabird 19+ CTD water sampler

3.0 Results

The survey was conducted over a period of 17 weeks, with plankton and environmental data being collected from all beds in all of the sampling weeks between 2nd June and 25th September 2017. Oyster samples were collected from the five beds from 12th June 2017 to 25th September 2017.

Mean water temperature for the period of the survey was 15.7 ± 0.7ºC (pooled data for all beds). Water temperature was less variable than in previous years' surveys and remained consistently above 14ºC during the survey period. The highest mean weekly temperatures of 17ºC were recorded in week 3 (19/06/17) and week 8 (24/07/17). Mean salinity was 30.2 ± 1.6 psu and mean turbidity 5.1 ± 2.7 FTU. A temperature drop of 2ºC followed the week 3 peak. Mean temperature and salinity decreased by ca. 4 psu and mean turbidity increased markedly in weeks 13 (29/08/17) and 14 (04/09/17), following a major flooding event in the Foyle catchment area in late August 2017.

A total of 2430 oysters were examined during the survey. Of these 6.4% (n = 156) were brooding eggs (whitesick) or larvae (grey or blacksick). Blacksick was the least often recorded brooding stage (n = 26), with the majority being whitesick (n = 90) and 40 greysick. Brooding oysters were recorded in all weeks except the final week of the survey (25/09/2017). 64% of the brooding oysters were recorded between week 5 (03/07/17) and week 8 (24/07/17), with a maximum of 28 oysters found to be carrying broods in week 5.

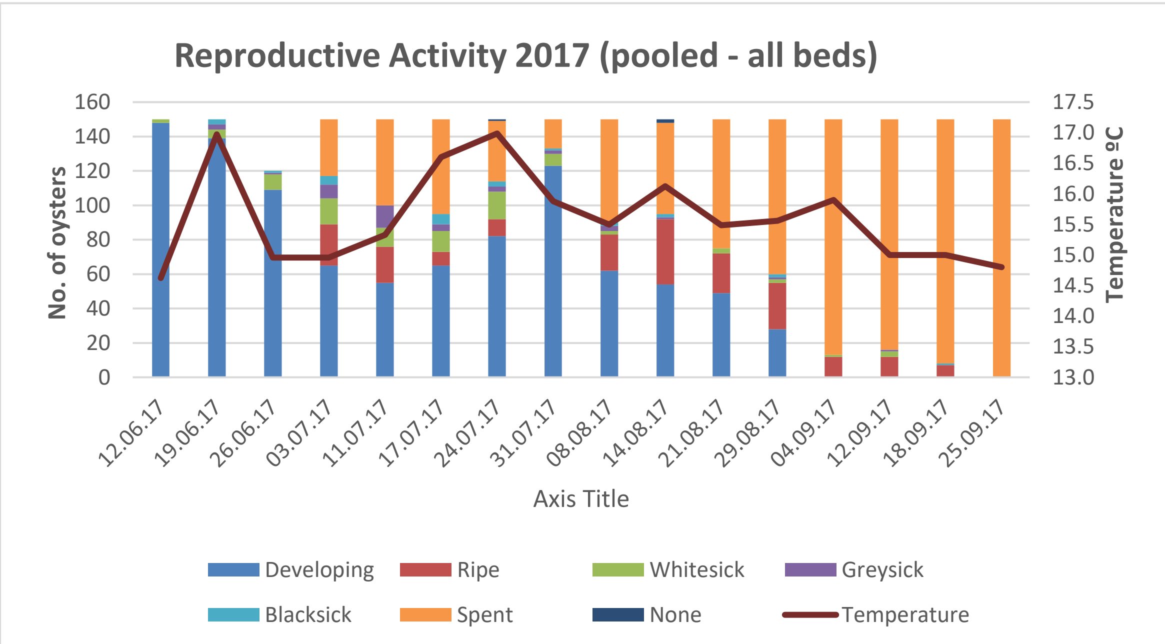

Figure 9: Reproductive activity in 2017, showing all oyster gonad and brooding development stages and weekly temperatures (pooled data – all beds).

The peak in brooding in week 5 was observed 14 days after mean temperatures for the beds reached 17ºC and mean turbidity was at its lowest. A blacksick oyster was recorded in the sample collected on 18/09/17, i.e. one day before the traditional oyster fishing season start of 19th September.

If we also include oysters with spent gonads, which shows evidence of having released eggs and larvae, then 48.8% of the sampled population was reproductively active between June and September 2017. Oysters with developing or ripe gonads accounted for 51% of the sampled population. Only 3 oysters were identified as having no gonad development. More oysters were seen to be developing gonad material than with spent gonads up to week 11 (14/08/17). From then on, oysters with spent gonads increased until 25/09/17, when 100% of the sampled oysters were recorded as having spent gonads.

Bivalve larvae (all species) were observed in all weeks except the first week of the survey (02/06/17). Pooled mean bivalve numbers for data from all 5 beds (35720/m^3 ± 15323) peaked in week 10 (08/08/17). A second, smaller peak of 12456/m^3 ± 2250 was observed in week 14 (04/09/17). These peaks occurred approximately 14 days after mean water temperatures reached 17ºC and following the peak period of observation of brooding oysters.

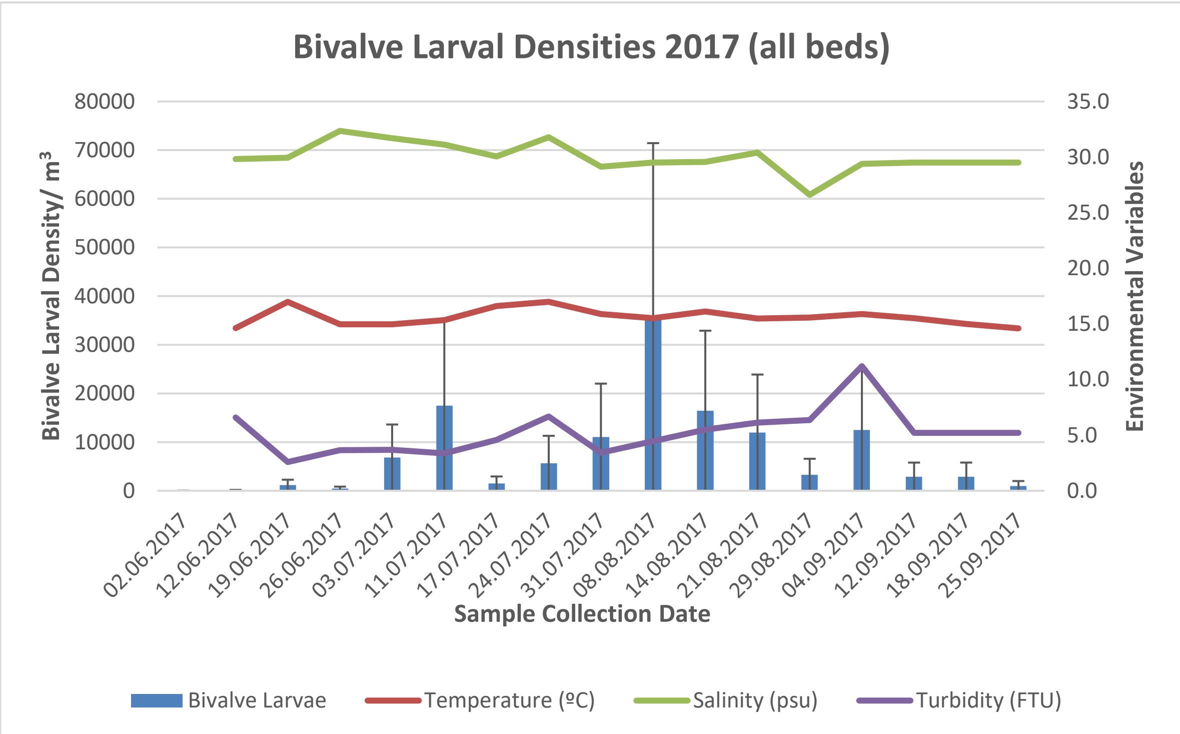

Figure 10: Weekly mean larval density and mean water temperatures (pooled data all sites).

Native oyster larvae were observed in samples from week 5 (03/07/17), coinciding with the start of the peak brooding period. The main peak in native oyster larval densities (8643/m^3 ± 1797) was observed 14 days after the end of the peak native oyster brooding period (24/07/17). This coincided with the peak density for all bivalve species in week 10 (08/08/17).

Large decreases in bivalve larval densities of all species were recorded in weeks 7 (17/07/17), 13 (29/08/17) and 15 (12/09/17), the latter following a sudden increase in turbidity (mean 11.2).

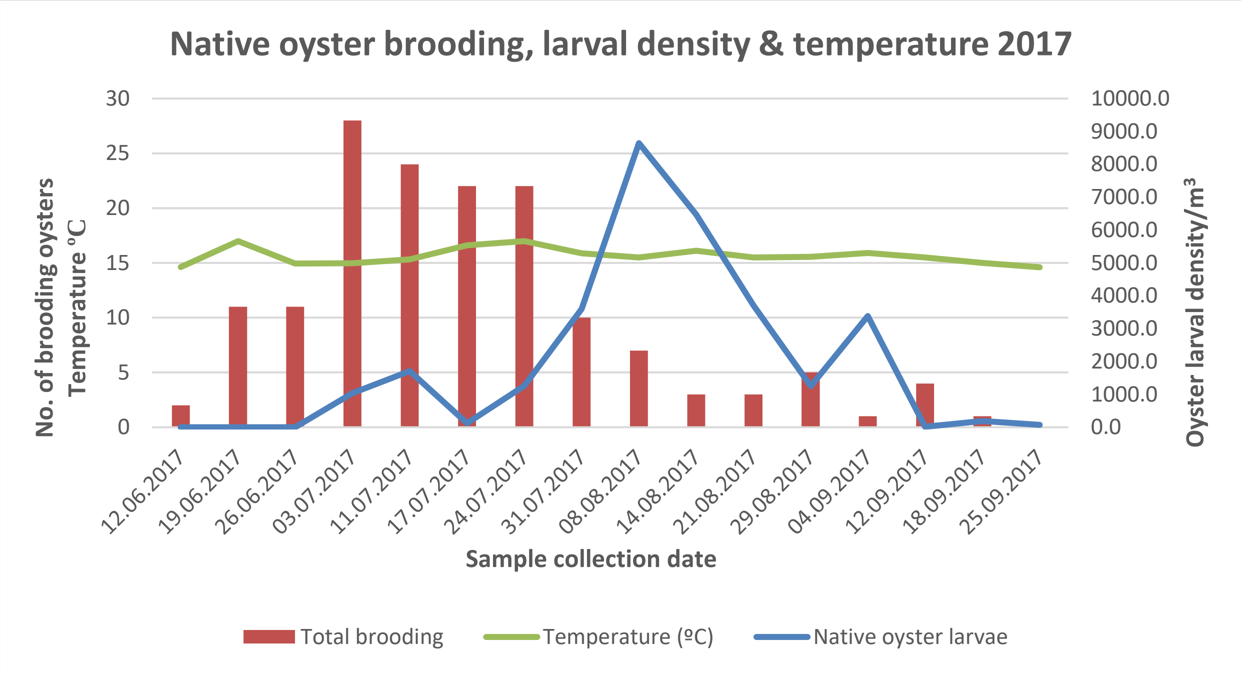

Figure 11: Weekly mean larval density and water temperatures, together with the weekly number of brooding oysters (pooled data all sites).

The mean shell length of the sampled oysters was 77.7 ± 8.9 mm (range 52.8 to 116.4 mm). The majority (64.8%) measured less than the 80 mm Minimum Landing Size (MLS). Of these, 71.6% were between 70 and 79.99 mm. The mean shell length of oysters from Flat Ground, Perch and Middle Bed was very similar (77.4 mm), with the sample from the Perch being slightly more variable. The mean shell length of oysters from Quigley's Point and Southside were also highly similar (78.2 ± 9.8 and 78.2 ± 8.5 mm). Brooding oysters measured between 56.4 and 103.2 mm (mean 76.3 ± 8.8g). The majority (73%) measured < 80 mm MLS – again, 73% of these were between 70 and 79.99 mm shell length. The mean length of brooding oysters was more variable amongst the different beds than in the overall sampled population. Oysters noticeably put on shell growth and weight as the weeks progressed.

Mean whole wet weight of all sampled oysters was 60.4 ± 17.7g (5.7 to 192.2 g). The majority (66%) weighed less than 65g. Oysters from the Perch had the highest mean whole wet weight (67.2 ± 22 g) amongst the five sampled beds - the heaviest oyster recorded in the survey (192g) was also collected in the Perch. Brooding oysters weighed from 20.2 to 131.9 g (mean 62.4 ±16.6g), with 62% being below 65g.

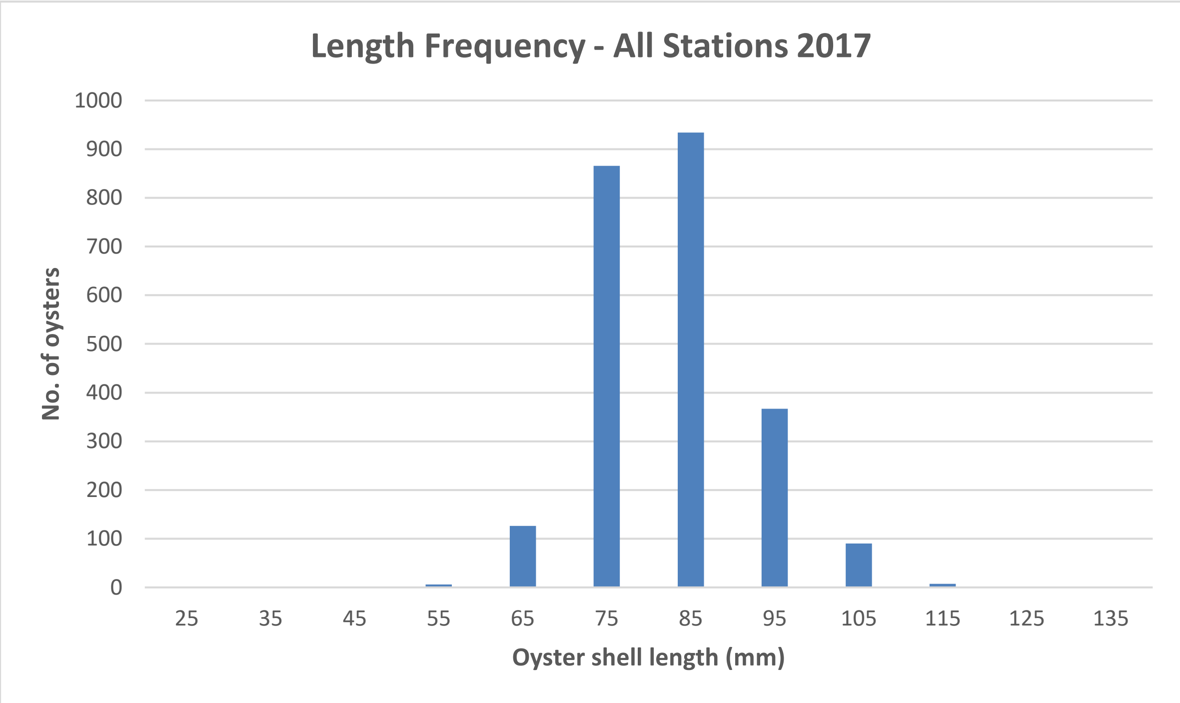

Figure 12: Length frequency of all sampled oysters (pooled data all stations). Mean shell length was 77.7 ± 8.9 mm. Mean shell length of brooding oysters was 77.4 ± 9 mm.

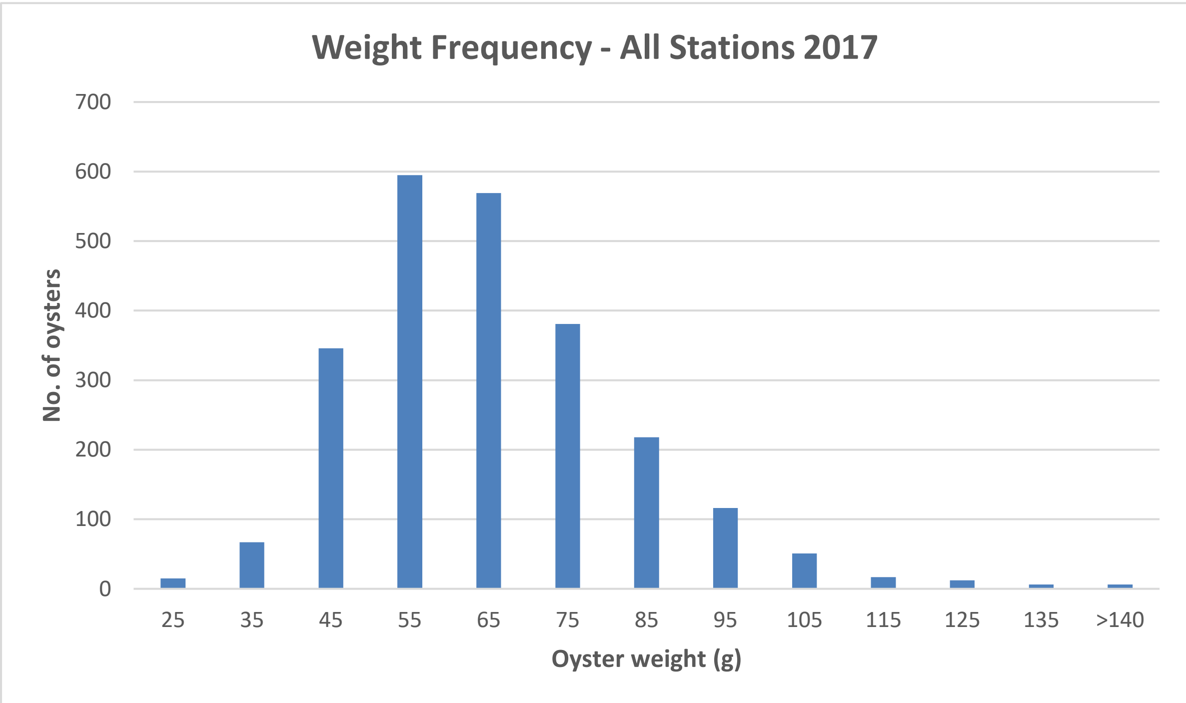

Figure 13: Weight frequency of all sampled oysters (pooled data all stations). Mean weight was 60.4 ± 17.7 g. Mean shell weight of brooding oysters was 62.4 ± 16.6 g.

Mean condition index was 15.3 ± 5.0 %. Condition index for all the sites reached a peak of 18.4 ± 5.2 % in week 2 of the survey (12/06/16); two weeks before the peak in brooding oysters was observed. Mean condition index of brooding oysters was 17.2 ± 7.0 %. Condition index decreased slightly as the summer progressed, especially after the flooding event, then showed a slight increase towards the end of September (consistent with indications of the autumn bloom of phytoplankton in the plankton samples).

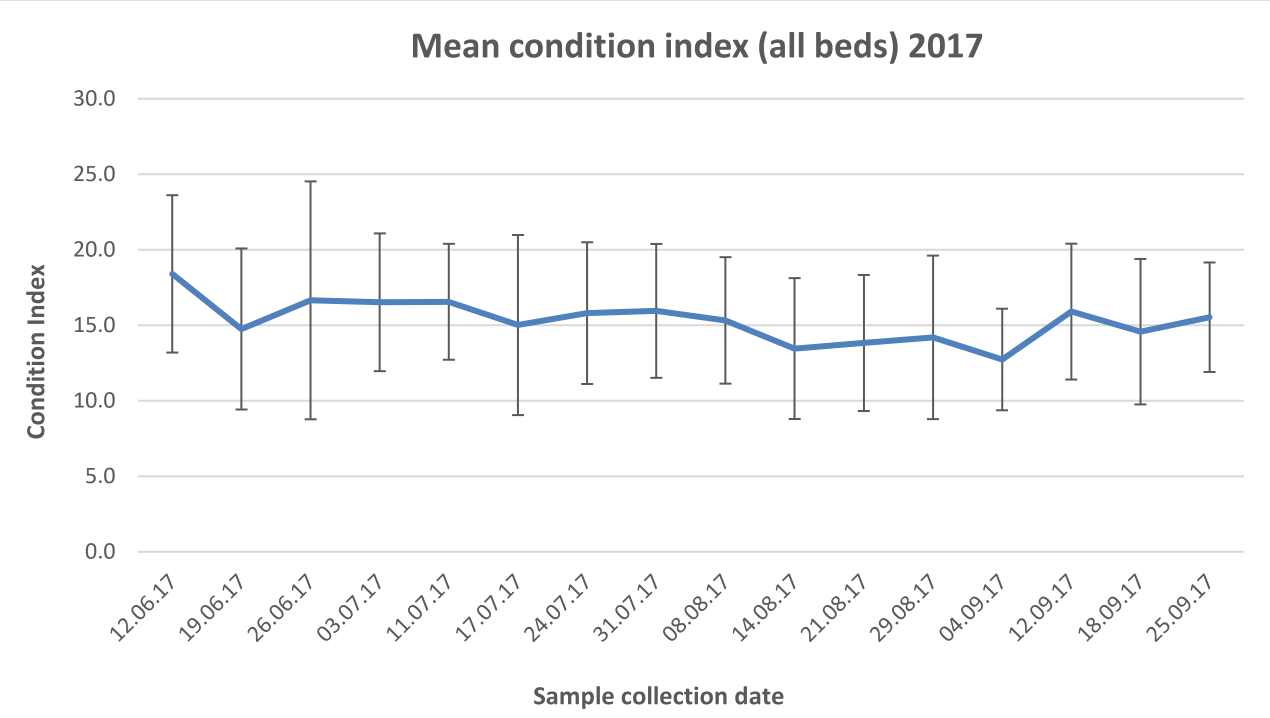

Figure 14: Mean weekly Condition Index 2017 (pooled data all sites).

Table 3: Summary data for all sites sampled summer 2017

Bed Name	Min Temp (˚C)	Max Temp (˚C)	Max Larvae per m³	% Oysters Brooding	% Brooding & Spent	Mean Length (mm)	Mean Weight (g)
Flat Ground	14.7	17.2	58377	7.3	51	77.3 ±8.5	57.8 ±14.2
Middle Bed	14.6	17.2	41748	4.9	48.4	77.4 ±9.0	56.7 ±16.9
Perch	14.6	16.7	39554	7.1	49	77.4 ±9.1	67.2 ±22.0
Quigley's Pt	14.5	17.0	17463	6.5	50.4	78.2 ±9.8	55.6 ±15.3
Southside	14.7	17.1	29547	6.7	51	78.2 ±8.5	64.6 ±16.1

3.1 Flat Ground

Table 4: Flat Ground summary info

Bed Name	Flat Ground
Area (hectares)	970
Average Density (oysters/m2)	0.93
No. of Oysters	6,893,899
Total Biomass (t)	206

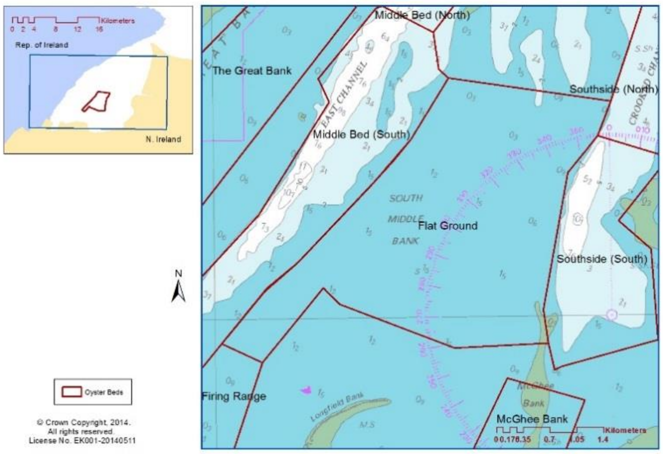

Figure 15: Location of Flat Ground

In 2017, of the five sampled beds, Flat Ground had the highest percentage of oysters carrying eggs or larvae (7.3%) - 21 whitesick, 7 greysick and 7 blacksick. The peak was recorded in week 6 (11/07/17) when 26.7% of that week's sample were carrying broods. Including oysters recorded with spent gonads, 51% of the population showed signs of active reproduction. Brooding was first observed on this bed in week 3 (19/06/17) and no brooding oysters were observed after week 15 (12/09/17). Oysters with developing or ripe gonad material were more numerous until week 12 (21/08/17), with increasing numbers with spent gonads after this and 100% of the sample being spent in the final week of the survey. No brooding oysters were observed in 6 weeks of the survey (weeks 2, 12, 13, 14, 16 and 17).

The mean density of bivalve larvae was 8945/ m^3 ± 14010.5. The earliest observation of bivalve larvae in the water column at any of the five sampled beds occurred in Flat Ground in week 2 (12/06/17). Peak larval density (58377/ m^3) was recorded in week 10 (08/08/17). Sharp declines in larval density were observed in week 7 (17/07/17) and week 13 (29/08/17), the week following a major flooding event in Counties Donegal and Londonderry. A lower magnitude peak was observed in week 15 (12/09/17). This bed had the most variation in bivalve larval numbers amongst weeks. *Ostrea edulis* larvae were first recorded in week 5 (03/07/17). Maximum native oyster larvae density (10665/ m^3) was recorded in the same week as for all bivalve species. Declines also followed the same pattern of sharp decreases in weeks 7 and 13. No oyster larvae were recorded in weeks 1 to 4, 7 or 16.

Mean water temperature in the Flat Ground was 15.8ºC ± 0.8 (range 14.7 to 17.2ºC). The highest temperatures were recorded in weeks 3 (19/06/17) and week 8 (24/07/17). Salinity ranged from 24.3 to 31.8 psu (mean 29.4 ± 1.9). The highest turbidity values (7.3 FTU) were recorded in weeks 13 and 14, i.e. after the major flood event in the Lough Foyle catchment area.

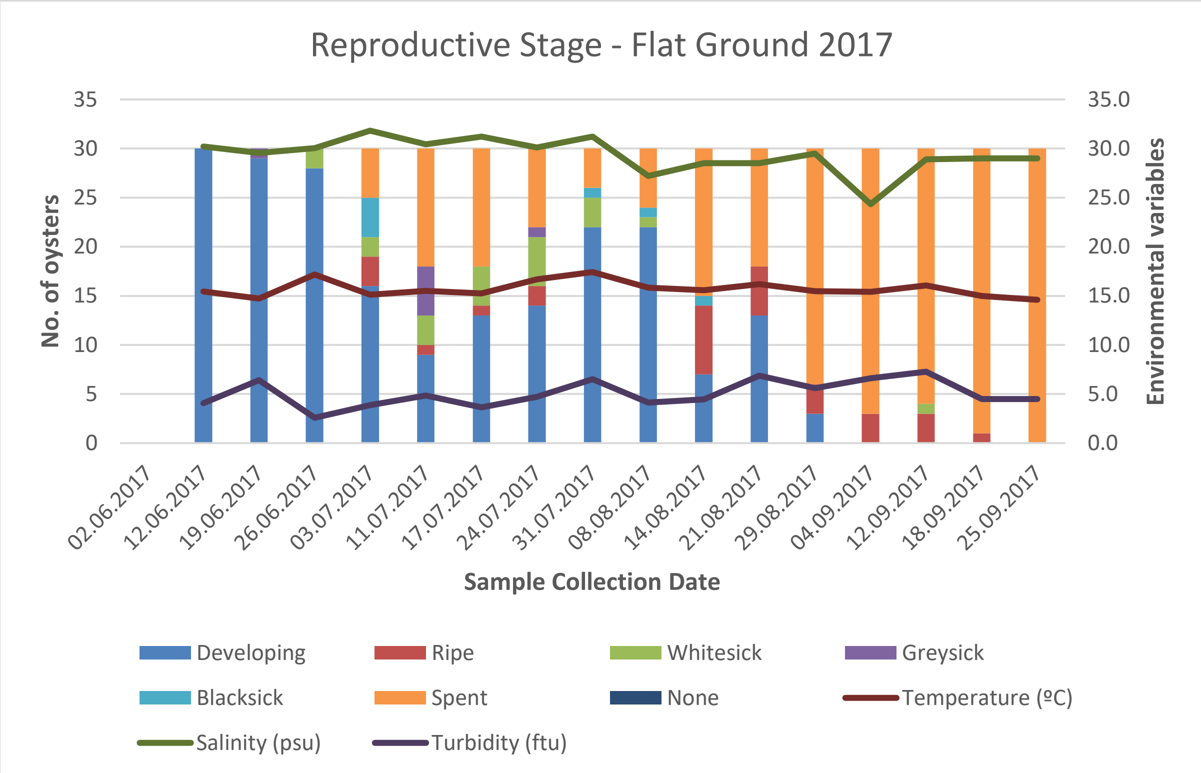

Figure 16: Spawning Stage and water temperature, Flat Ground 2017

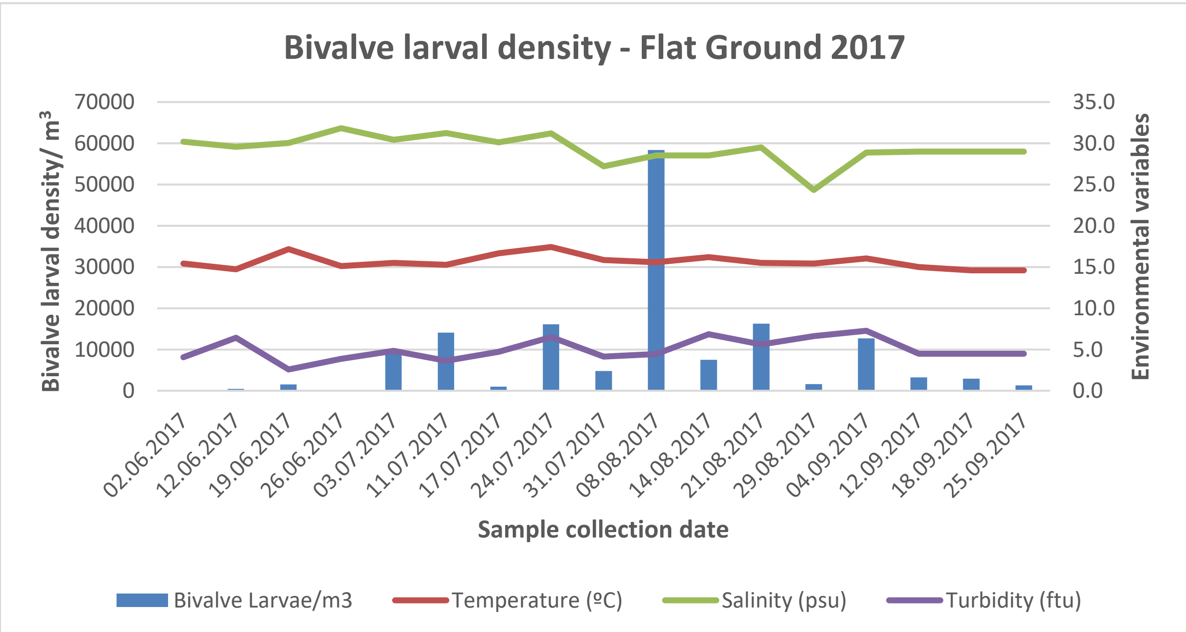

Figure 17: Larval Density (bivalve larvae/m³), water temperature, salinity and turbidity - Flat Ground

Mean water temperature in the Flat Ground was 15.8ºC ± 0.8 (range 14.7 to 17.2ºC). The highest temperatures were recorded in weeks 3 (19/06/17) and week 8 (24/07/17). Salinity ranged from 24.3 to 31.8 psu (mean 29.4 ± 1.9). The highest turbidity values (7.3 FTU) were recorded in weeks 13 and 14, i.e. after the major flood event in the Lough Foyle catchment

Mean length of all sampled oysters from the Flat Ground was 77.3 ± 8.5 mm, with 66.3% being below 80mm. Of these, 71.7% were between 70 and 79.99 mm. Mean weight was 57.8 ± 14.2g, with 29 % being > 65 g. Oysters brooding eggs or larvae had a mean shell length of 76.8 ± 8.3 mm and mean whole wet weight of 57.7 ± 12.6 g. 46% of the brooding oysters were above the 80 mm MLS and 79% of those below MLS were in the 70 – 79.99 mm size class. 62% of oysters brooding eggs or larvae weighed less than 65g.

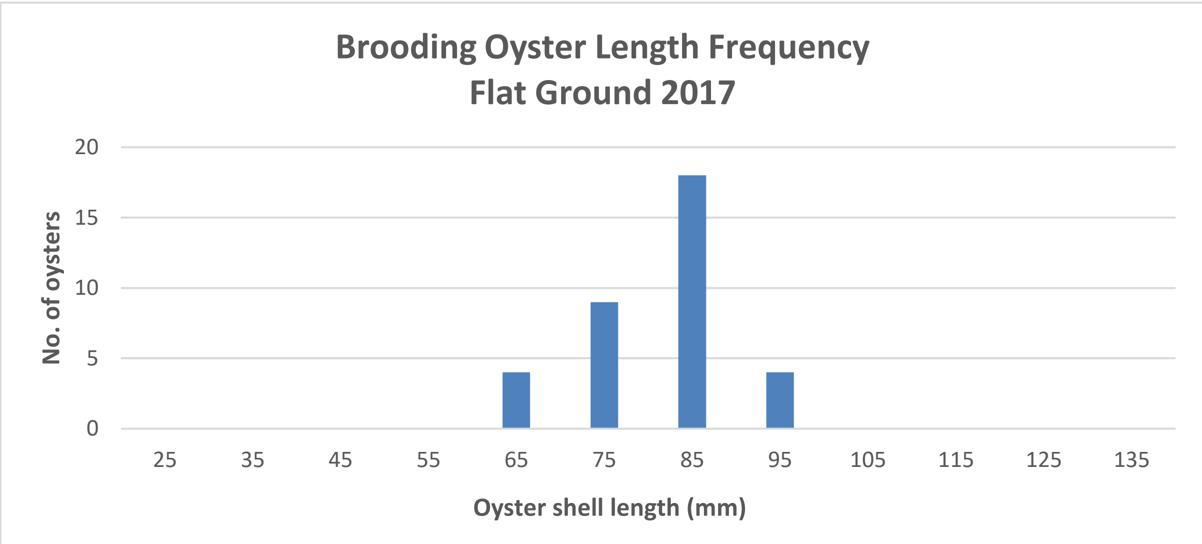

Figure 18: Length Frequency of Brooding Oysters - Flat Ground 2017

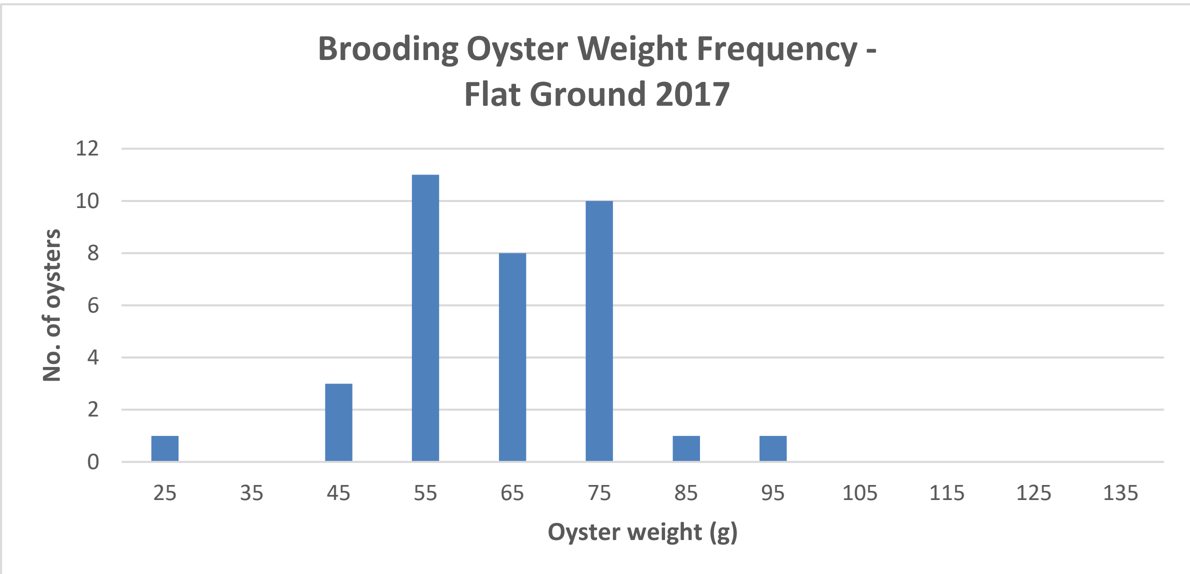

Figure 8: Weight Frequency of Oysters - Flat Ground 2017

Oysters from the Flat Ground had the highest mean Condition Index amongst the five sampled beds (17.4 ± 4.6 %). Condition was highest in week 2 of the survey and decreased in the samples collected on 17/07/17 and 04/09/17 after temperature decreases two weeks earlier.

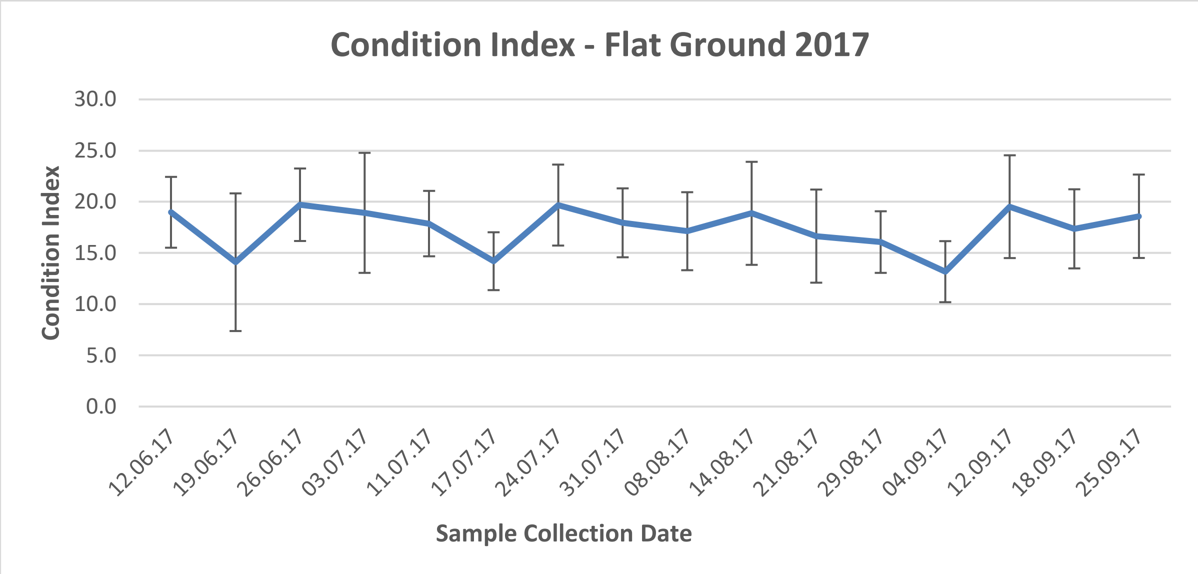

Figure 20: Condition Index - Flat Ground

3.2 The Perch Bed

Table 5: Perch summary info

Bed Name	The Perch
Area (hectares)	276
Average Density (oysters/m2)	0.40
No. of Oysters	829,618
Total Biomass (t)	37.3

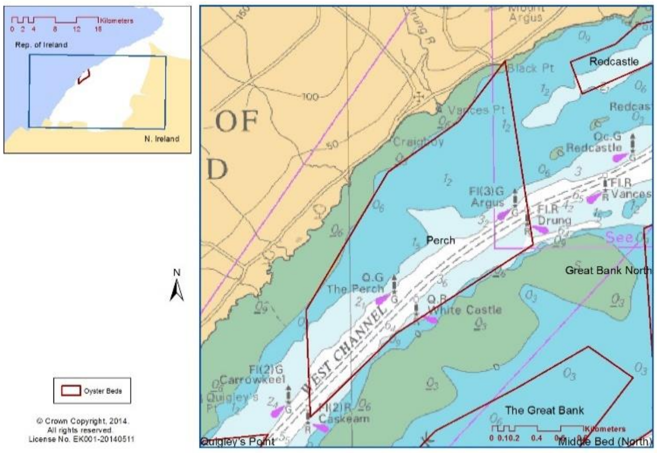

Figure 21: Location of the Perch

The second highest level of reproductive activity in 2017 was recorded in oysters sampled from the Perch bed. Of the 480 oysters collected, 7.1% (n = 34) were found to be brooding. Again, whitesick oysters (n = 17) were observed more frequently than greysick (n = 12) or blacksick (n = 5). With oysters recorded with spent gonads, 49% of the sampled population showed evidence of active reproduction. Peak brooding week occurred in week 5 (03/17/17) and brooding oysters were observed in samples until week 16 (18/09/17). Brooding was not observed in 5 weeks of the survey (weeks 2, 12, 13, 14 and 17, the latter when 100% of the oysters had spent gonads). Oysters with developing or ripe gonads outnumbered those with spent gonads until week 9 (31/07/17) – from then on, those with spent gonads increased until 100% of the sample were observed to be spent in the final survey week (25/09/17).

The mean density of bivalve larvae recorded for the Perch bed was 10436/m^3 ± 13764.6. The peak (39554/m^3) occurred in week 11 (14/08/17), with densities in the weeks before and after this peak being only slightly lower (30356/m^3 and 31465/m^3). Larvae were first observed in week 3 (19/06/17) and were recorded in samples throughout the rest of the survey. Sharp declines were recorded in weeks 7, 12 and 13. *Ostrea edulis* larvae were first recorded in week 5 (03/07/17). Maximum native oyster larvae density (14145/ m^3) was recorded in the same week as for all bivalve species. Sharp decreases were observed in weeks 7, 8 and 13. No oyster larvae were recorded in weeks 1 to 4, 8, 15 or 17.

Mean water temperature recorded in the Perch in 2017 was 15.6 ± 0.7 (range 14.6 – 16.7℃). Salinity ranged from 28.4 to 33.2 psu and turbidity averaged 4.8 ± 2.3 (again, salinity decreased and turbidity increased following the flood event in late August).

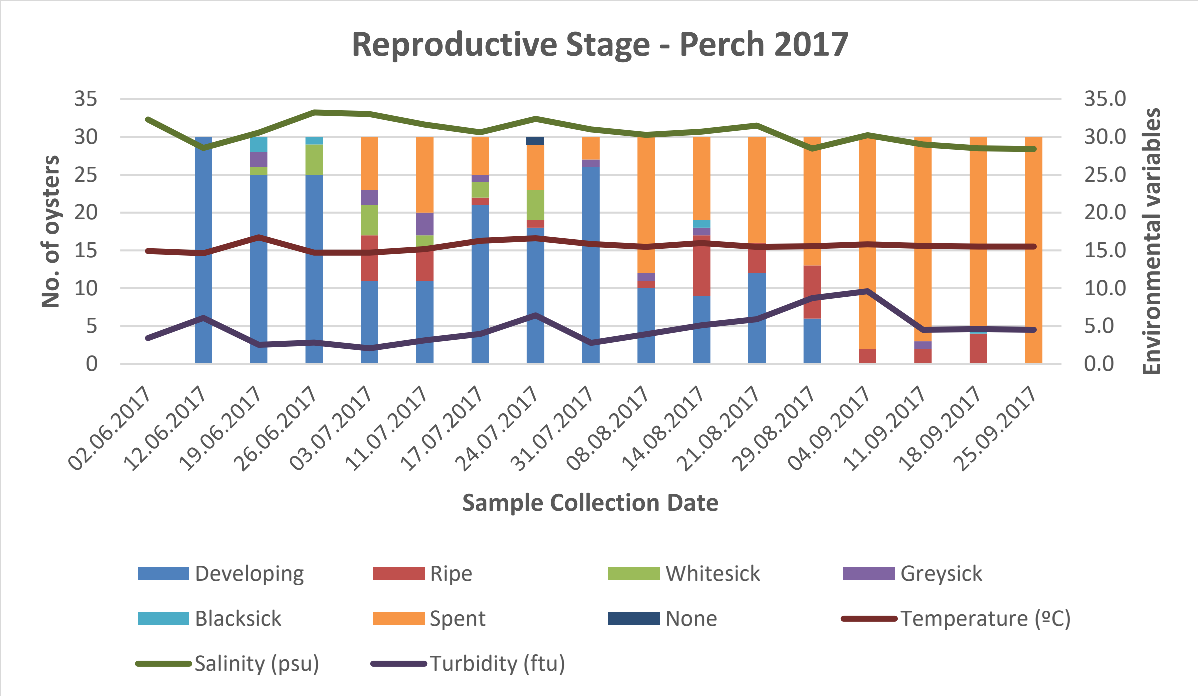

Figure 22: Reproductive Stage, temperature, salinity and turbidity - Perch

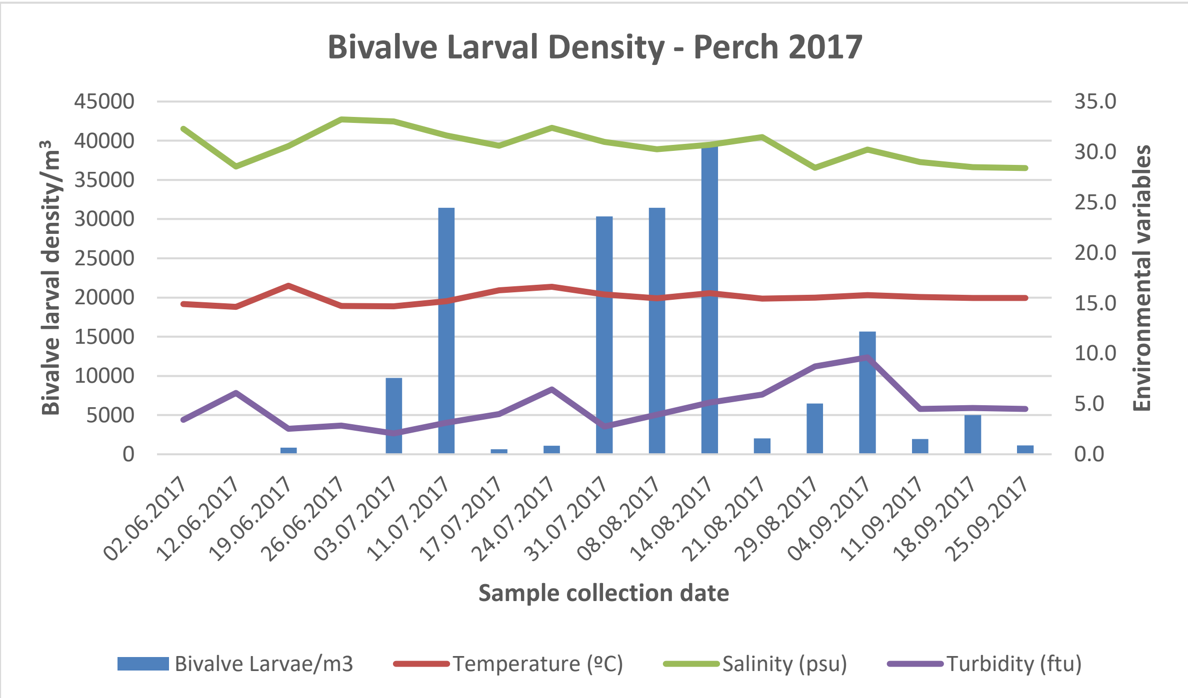

Figure 23: Bivalve larval density and environmental variables - Perch

Mean shell length of Perch oysters was 77.4 ± 9.1. 35% of the sampled population was above the 80 mm MLS, with 71% of the oysters below ring size falling into the 70 – 79.99 mm size class. Mean whole wet weight was 67.2 ± 22 g. The heaviest oyster recorded in the survey (192 g) was collected in the Perch. 45% of the sampled oysters were > 65 g. The majority (68%) of oysters brooding eggs or larvae in the Perch were less than the 80 mm ring size (mean 77.5 ± 10.9 mm); 65% of these occupied the 70 – 79.99 mm size class. Mean weight of brooding oysters in the Perch was 66.9 ± 21.5 g, with 53% below 65g.

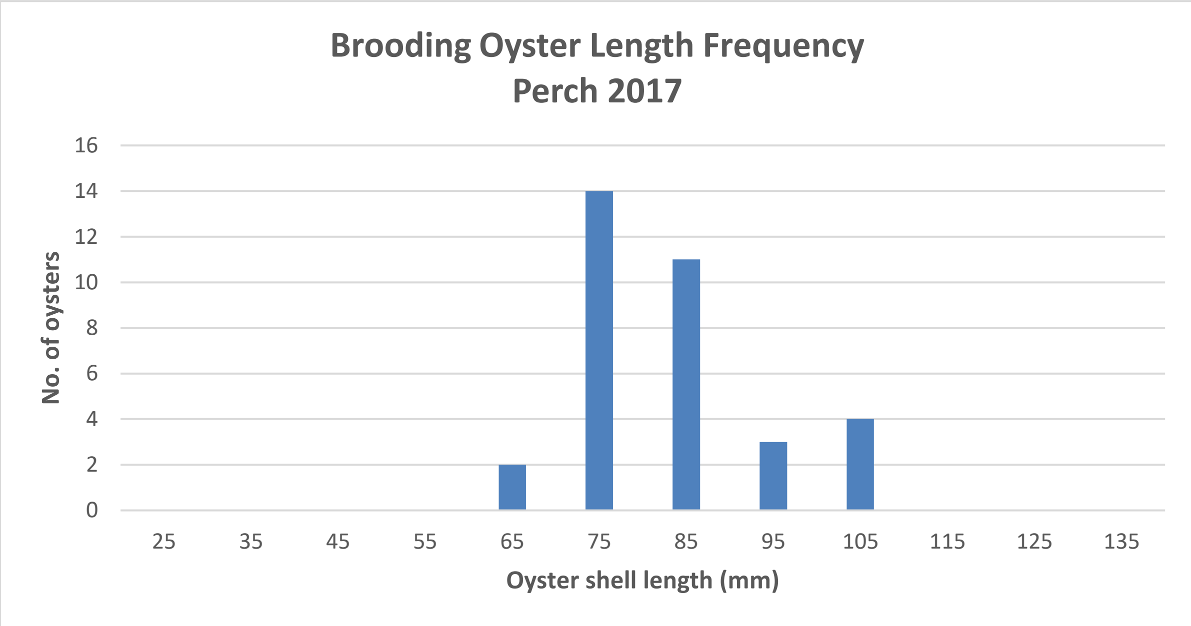

Figure 24: Length Frequency of Brooding Oysters - Perch

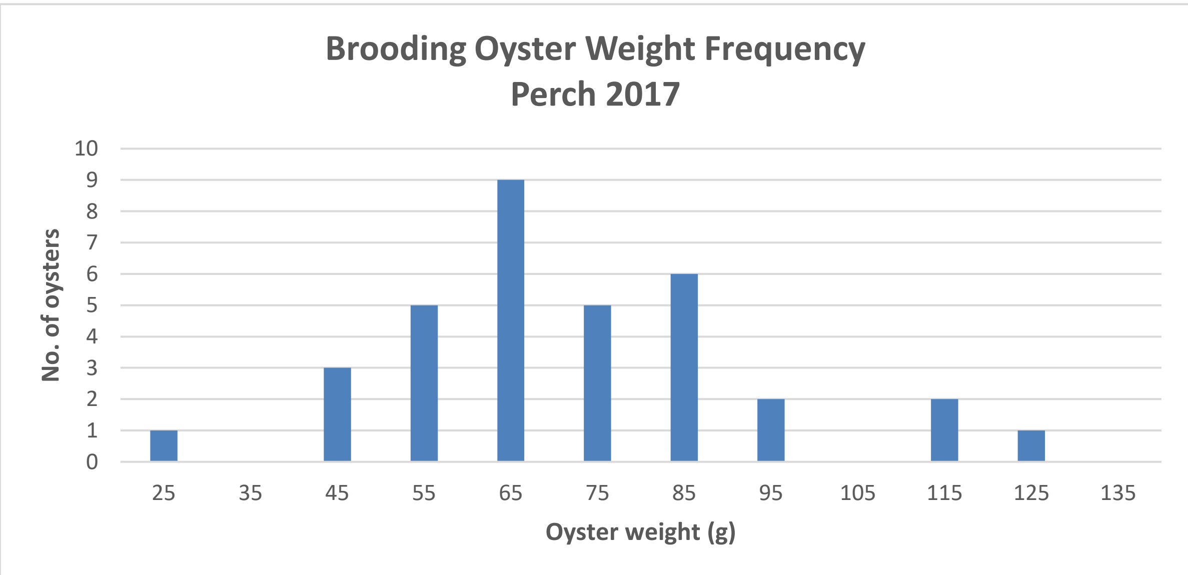

Figure 9: Weight Frequency of Brooding Oysters - Perch 2017

Condition Index in oysters from the Perch had the lowest mean value of any of the five sampled beds (13.0 ± 5.8). Condition was highly variable in the samples collected on 26/06/17 and 17/07/17, around the time of peak brooding, and fluctuated throughout the breeding season. Variation in condition decreased towards the end of the season as increasing proportions of the sampled oysters had spent gonads.

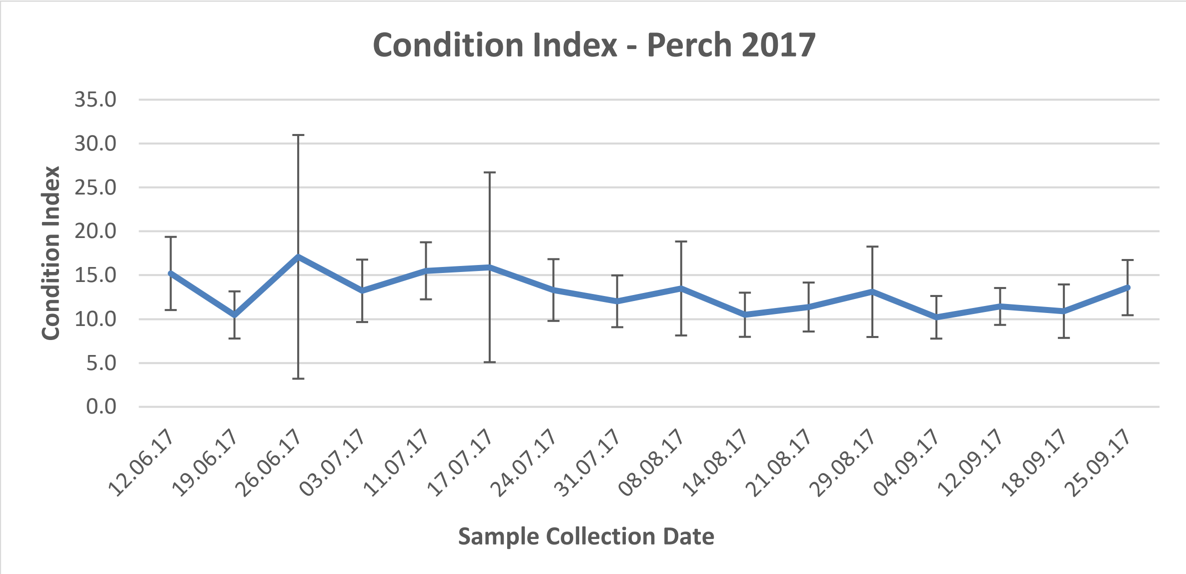

Figure 26: Condition Index - Perch

3.3 Quigley's Point

Table 6: Quigley's Point summary info

Bed Name	Quigley's Pt
Area (hectares)	140
Average Density (oysters/m2)	0.40
No. of Oysters	533,334
Total Biomass (t)	24

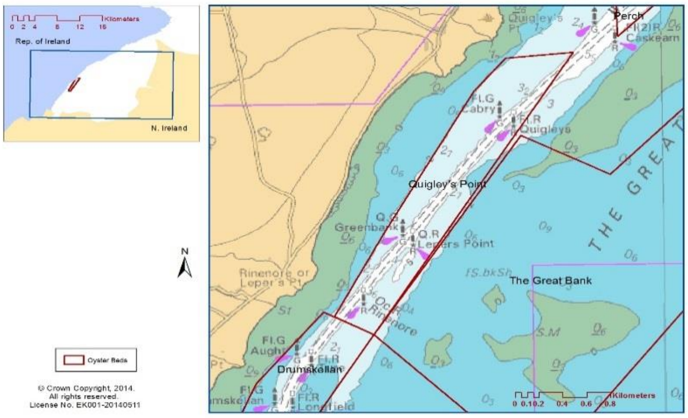

Figure 27: Location of Quigley's Point

Of the 480 sampled oysters, 6.5% (n = 31) were brooding eggs or larvae (14 whitesick, 9 greysick and 8 blacksick). Including oysters with spent gonads, 50.4% of the population was reproductively active in 2017. Only 3 weeks' samples contained no oysters with broods (weeks 11, 16 and 17). Brooding was first observed in week 2 (12/06/17) and no brooding oysters were observed after week 15 (11/09/17). Peak brooding week was week 7 (17/07/17, when 20% of the sample was carrying broods. Oysters with developing or ripe gonads were present in greater numbers than those with spent gonads until week 9 (31/07/17) – oysters with spent gonads then increased until 100% of the sample were recorded as spent in week 17 (25/09/17).

Less variation in bivalve larval densities was observed in the Quigley's Point samples, with generally lower densities than in those from the other surveyed beds. Mean density was 5019/ m^3 ± 5350.2. The first sample containing larvae was collected in week 3 (19/06/17), with larvae being observed in all weeks from then to the end of the survey. The peak density (17463/ m^3) occurred in week 10 (08/08/17). As with the other sampled beds, sharp declines in densities were observed in weeks 7 and 13. *Ostrea edulis* larvae were first recorded in week 7 (17/07/17). This occurred in a week when *Ostrea* and all bivalve larval densities had declined in the other beds. Maximum native oyster larvae density (10478/ m^3) was recorded in the same week as for all bivalve species. Again, a sharp decline occurred in week 13. No oyster larvae were recorded in weeks 1 to 6 or 15.

Mean water temperature in Quigley's Point bed was 15.7ºC± 0.8 (range 14.5 – 17.0ºC). The highest temperatures occurred in weeks 3 and 8 of the survey. Salinity ranged from 28 to 32.8

psu and turbidity rose to the highest value (18.4) recorded in any of the beds following the major flooding event in week 13 (29/08/17).

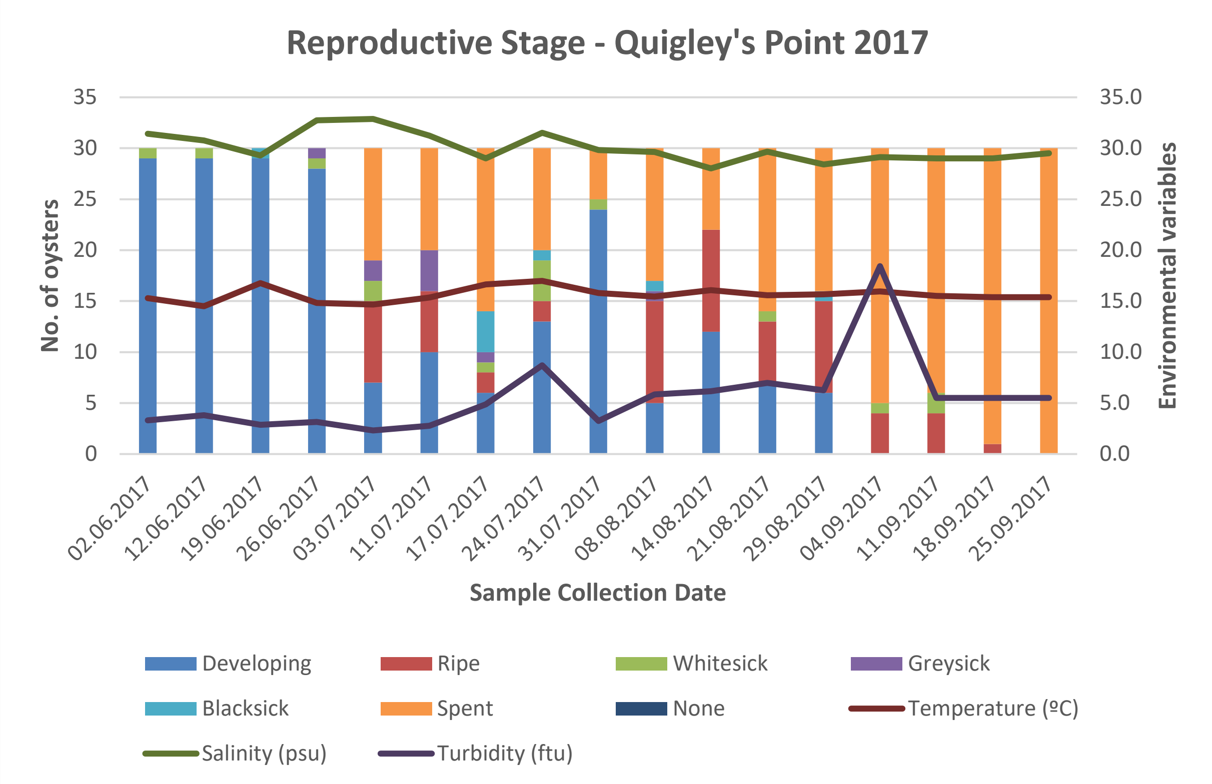

Figure 28: Reproductive stage, water temperature, salinity and turbidity - Quigley's Point

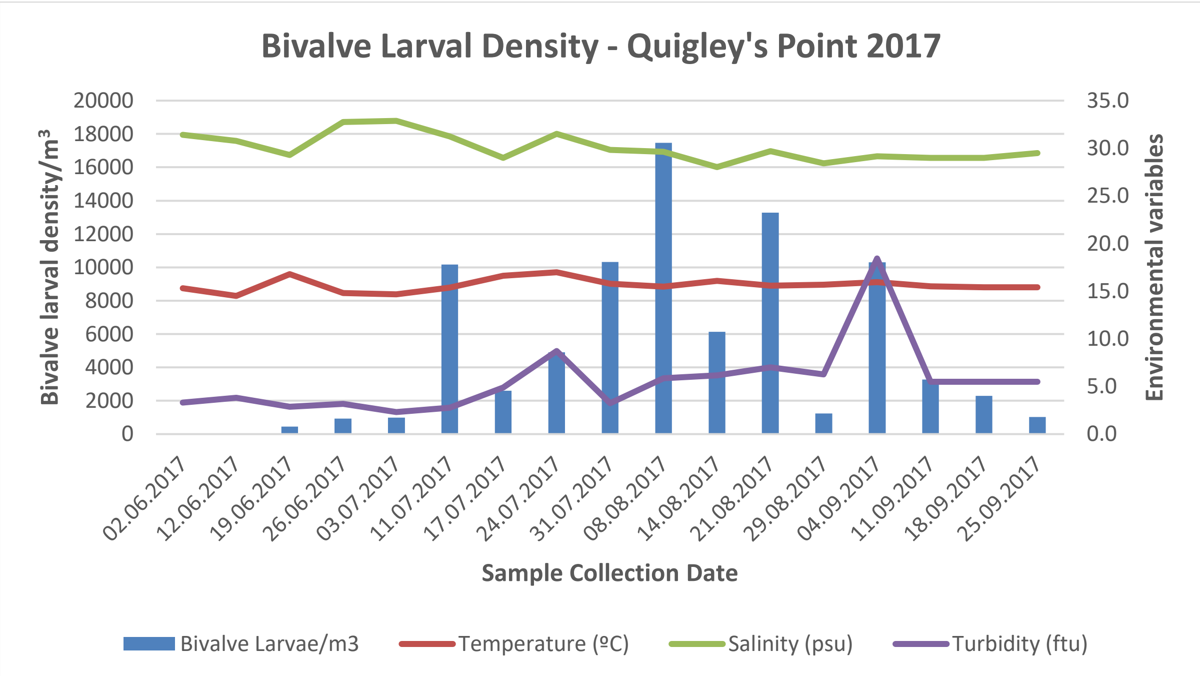

Figure 10: Bivalve larval density and environmental variables - Quigley's Point

Mean shell length of sampled oysters was 78.2 ± 9.8 mm, with 87% being above the 80 mm MLS. Of those below MLS, 68% were in the 70 – 79.99 mm size class. Mean whole wet weight was 55.6 ± 15.3, the lowest of any of the five beds. 78% of the sampled population were below 65 g. In the Quigley's Point samples, on average, brooding oysters measured 74.4 ± 7.6 mm and weighed 57.9 ± 11.3 g. 81% of the brooding oysters measured less than the 80 mm ring size, with 52% being within the 70 – 79.99 mm size class. Together with Southside, Quigley's Point had the least brooding oysters above MLS. 81% of the brooding oysters weighed less than 65g (mean 57.9 ± 11.3).

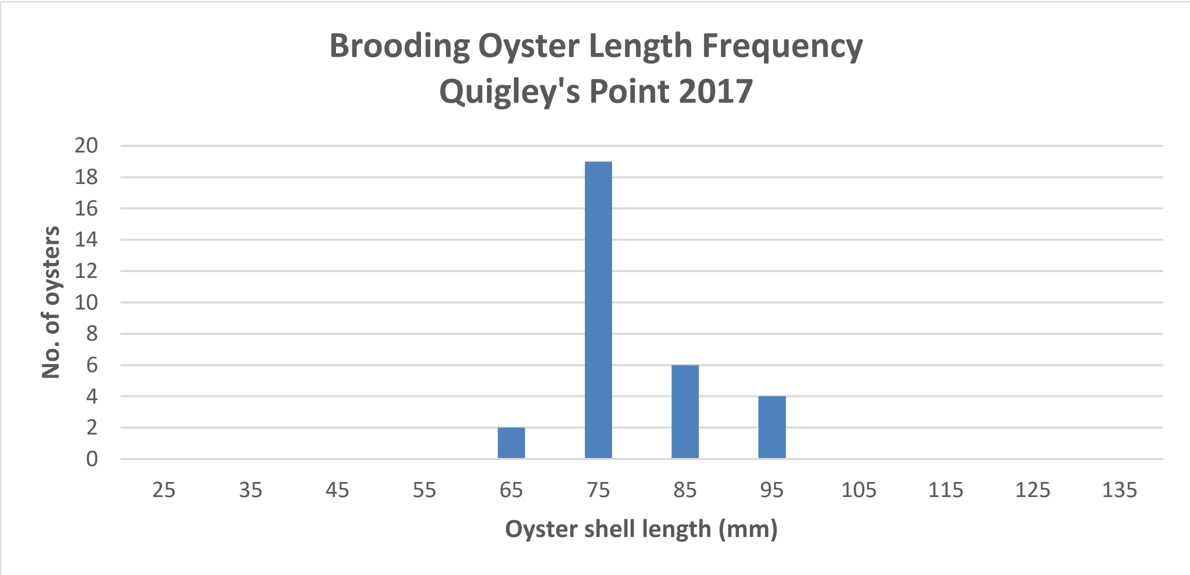

Figure 30: Length Frequency of Brooding Oysters - Quigley's Point

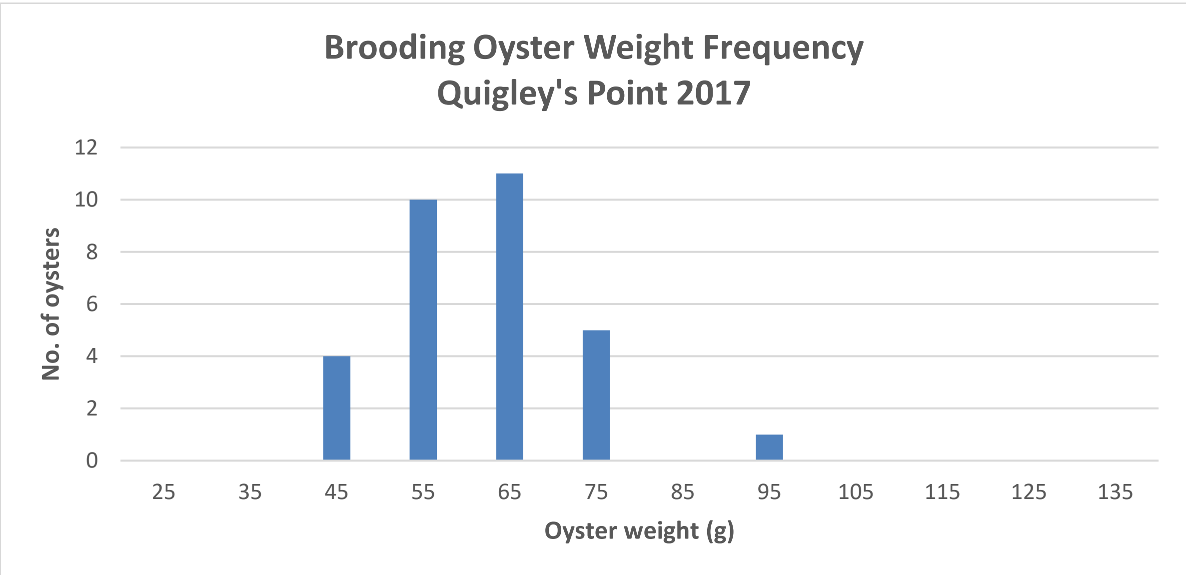

Figure 31: Weight Frequency of Brooding Oysters - Quigley's Point

Condition Index in Quigley's Point oysters was the second highest of the five beds (16.2 ± 5.2). As with the other beds except the Perch, CI was highest in weeks 2 and 3 (12/06/17). The lowest CI was recorded earlier than in the other beds on 14/08/17. CI was highly variable in the sample taken on 29/08/17, when turbidity had increased following the flood event.

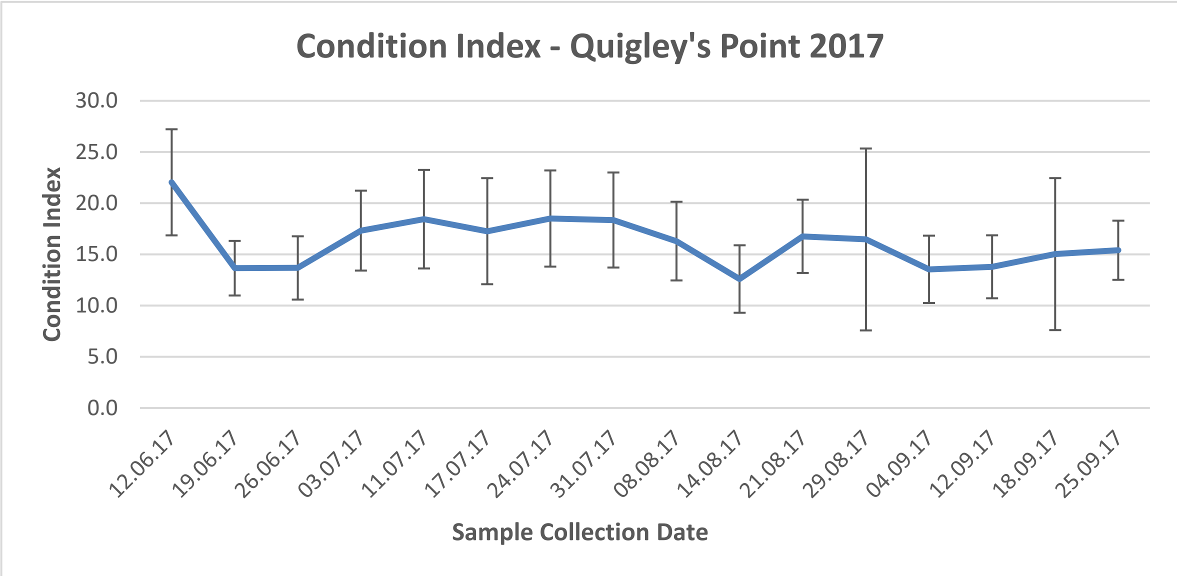

Figure 32: Condition Index - Quigley's Point

3.4 Southside Bed

Table 7: Southside summary info

Bed Name	Southside
Area (hectares)	578
Average Density (oysters/m2)	0.44
No. of Oysters	3,478,855
Total Biomass (t)	106

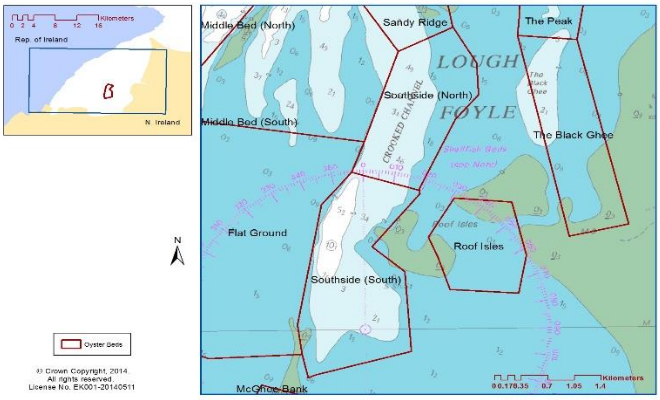

Figure 33: Location of Southside Bed

Of the 480 oysters examined, 6.7% (n = 32) were brooding eggs (n = 23) or larvae (6 greysick and 3 blacksick). Including oysters with spent gonads, 51% of the sampled population was reproductively active in 2017. Brooding was first observed in week 3 (19/06), with no broods being observed after week 13 (29/08/17). Peak brooding occurred in week 5 (03/07/17), when 30% of that week's sample (n = 24) were carrying broods. Brooding ended earlier than in the other beds and no broods were recorded in 6 weeks of the survey (weeks 2, 11 and all of September). Oysters with developing or spent gonads were recorded in greater numbers than those with spent gonads until week 9 (31/07/17).

Mean bivalve larval density for Southside was 6782/ m^3 ± 7758.9. The first sample containing larvae was collected in week 3 (19/06/17). The peak density (29547/ m^3) occurred in week 10 (08/08/17). As with the other sampled beds, declines in densities were observed in weeks 7 and 13, although these remained at higher densities than observed in the other beds. *Ostrea edulis* larvae were first recorded in week 5 (03/07/17). Maximum native oyster larvae density (6859/ m^3) was recorded in the same week as for all bivalve species. Declines also followed the same pattern of sharp decreases in weeks 7 and 13. No oyster larvae were recorded in weeks 1 to 4, 7 or 15 - 17.

Mean temperature in Southside was 15.8 ± 0.8 ºC. The lowest temperature was recorded in week 2 of the survey (12/06/17) and the highest temperatures, both above 17ºC, were recorded on 19/06/17 and 24/07/17. Salinity averaged 30.2 ± 1.5 psu, with the minimum recorded on 29/08/17, just after the flooding event. Turbidity averaged 4.7 ± 1.5 FTU, with the maximum of 6.8 FTU recorded following the flooding.

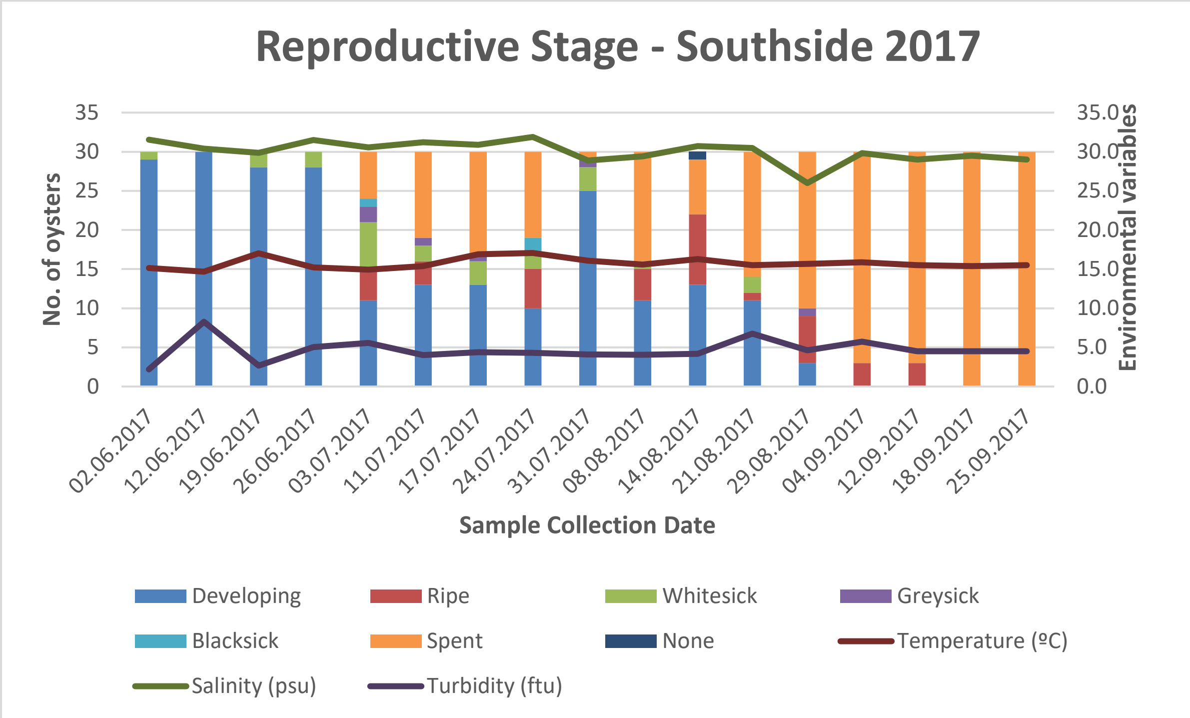

Figure 34: Reproductive stage, water temperature, salinity and turbidity - Southside

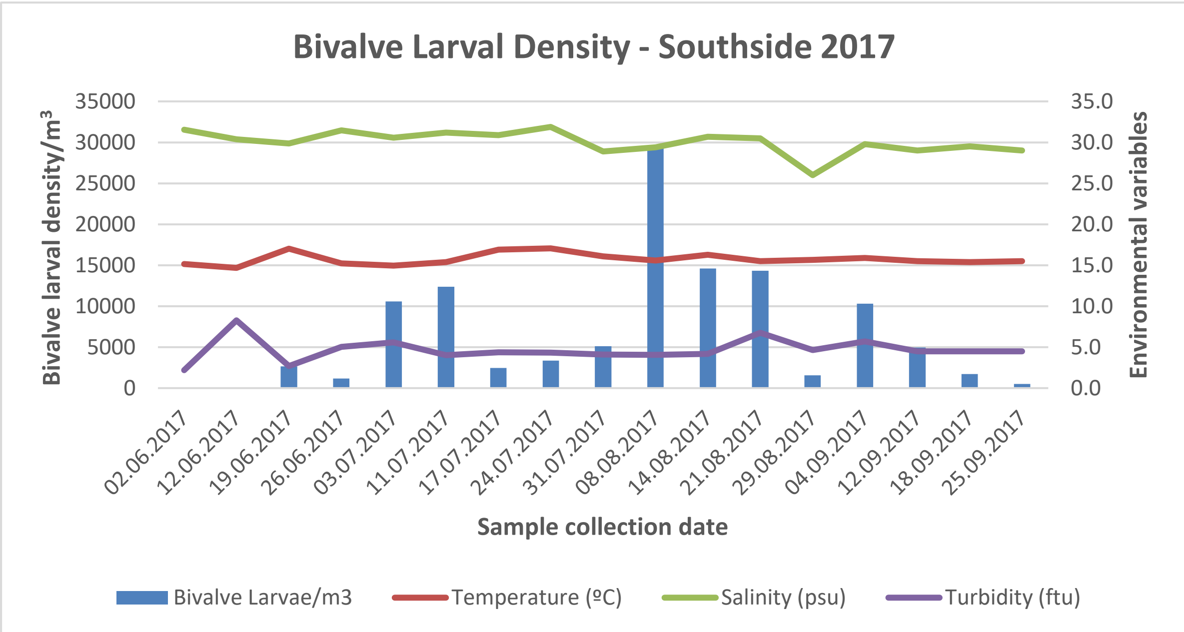

Figure 35: Bivalve larval density and environmental variables - Southside

Mean length of oysters collected in Southside was 78.2 ± 8.5, with 36% being above the 80mm MLS. 78% of those < 80 mm were in the 70 – 79.99 mm size class. Mean weight was the second highest of the five beds (64.6 ± 16.1 g). 46% of the sampled oysters weighed over 65g. Brooding oysters measured on average 75.0 ± 7.4 mm and weighed 64.1 ± 12.9 g. The majority

(85%) measured less than the 80 mm MLS, with slightly more brooding oysters weighing above 65g (52%) than the other beds. Together with Quigley's Point, Southside had the least number of brooding oysters above MLS.

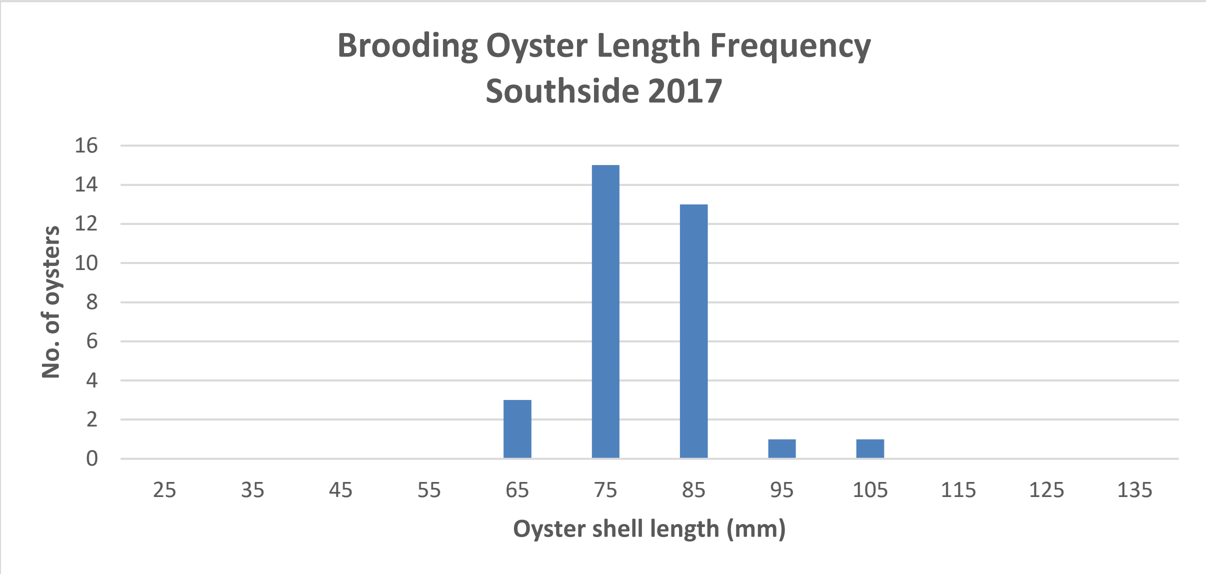

Figure 36: Length Frequency of brooding oysters - Southside

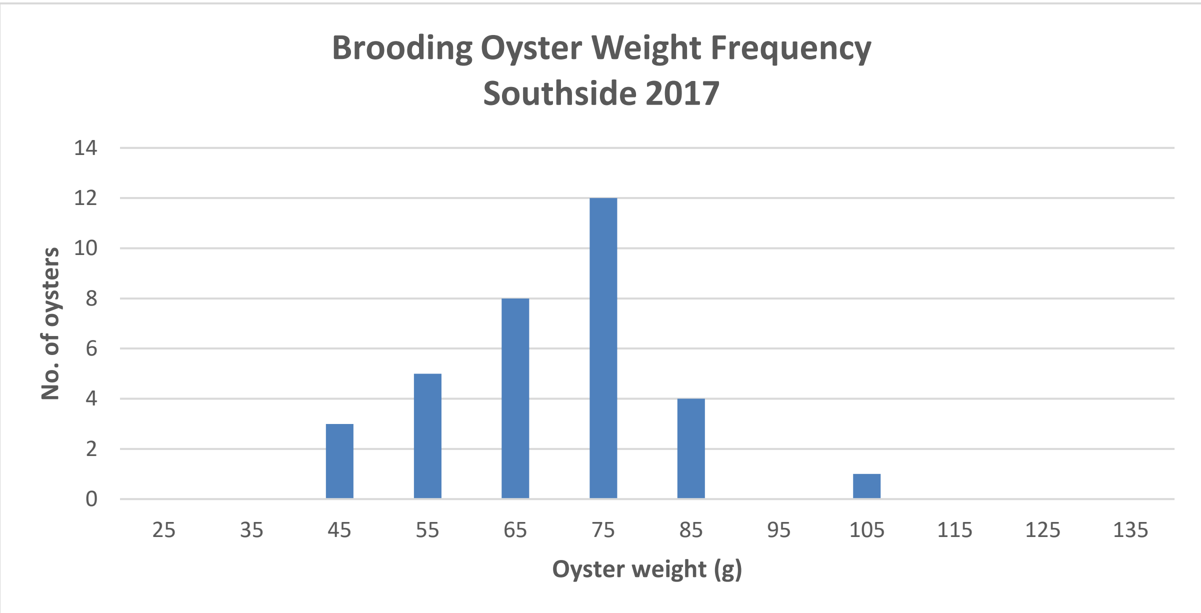

Figure 37: Weight Frequency of brooding oysters - Southside

Mean Condition Index in Southside was 15.1 ± 4.6 %. Again, the highest values were recorded at the beginning of the survey and the lowest value was recorded earlier than in the other beds (14/08/17).

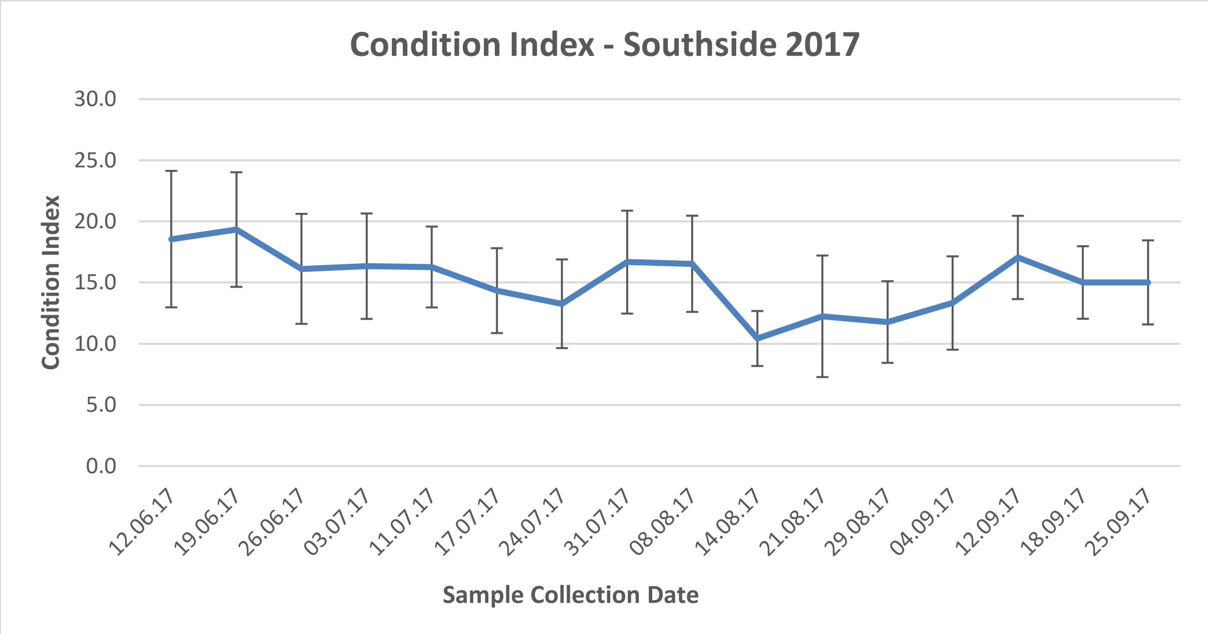

Figure 38: Condition Index - Southside

3.5 Middle Bed

Table 8: Middle Bed summary info

Bed Name	Middle Bed
Area (hectares)	531
Average Density (oysters/m2)	0.24
No. of Oysters	3,153,705
Total Biomass (t)	94.6

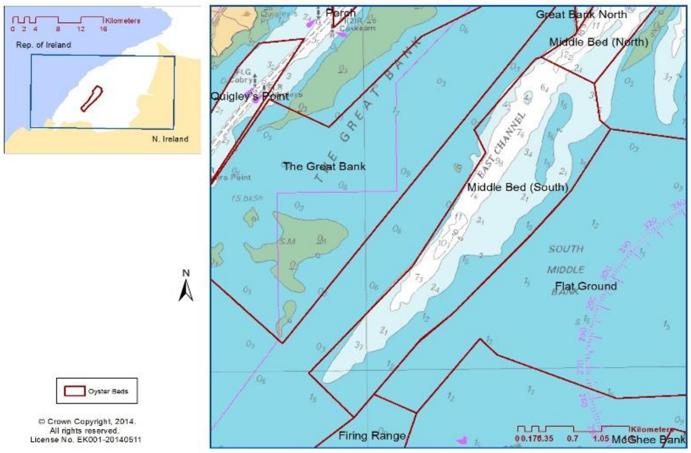

Figure 39: Location of Middle Bed

Middle Bed was observed to have the lowest number of brooding oysters of all the 5 sampled beds. The bed also had the highest number of weeks (7) where no brooding oysters were recorded (weeks 5, 11, 12, 14, 15, 16, 17). Of the 450 oysters collected, 4.9% (n = 22) were found to be carrying eggs (13 whitesick) or larvae (6 greysick, 3 blacksick). Together with oysters with spent gonads, 48.4% of the population showed evidence of releasing larvae. Brooding was first observed in week 2 (12/06/17), with no brooding oysters recorded after week 12 (29/08/17). Peak brooding week was week 7 (17/07/17), when 16.7% of the week's sample was carrying eggs or larvae. Oysters with developing or ripe gonads were more frequently recorded than those with spent gonads until week 11 (14/08/17). By week 17, all oysters in the sample had spent gonads.

The mean density of bivalve larvae observed in the plankton samples collected from the Middle Bed was 7259/m^3 ± 10817.6, with a maximum of 41748/m^3 observed in week 10 (08/08/17). First larvae were observed in week 3 (19/06/17). Sharp declines in numbers were again observed, as with the other beds, in weeks 7 and 13. *Ostrea edulis* larvae were first recorded in week 6 (11/07/17). Maximum native oyster larvae density (7859/ m^3) was recorded in the same week as for all bivalve species. Declines also followed the same pattern of sharp decreases in weeks 7 and 13. There was a slight recovery in densities in week 14 then numbers declined although larvae were recorded in samples at the end of the survey. No oyster larvae were recorded in weeks 1 to 5, 7 or 15.

Mean water temperature for Middle Bed in 2017 was 15.7°C (range 14.6 – 17.2°C). Salinity ranged from 25.8 to 32.5 psu. Turbidity showed a higher degree of variation than the other beds, with a mean of 5.3 ± 13.3 FTU. Turbidity rose to a peak of 14.8 FTU just after the flooding event.

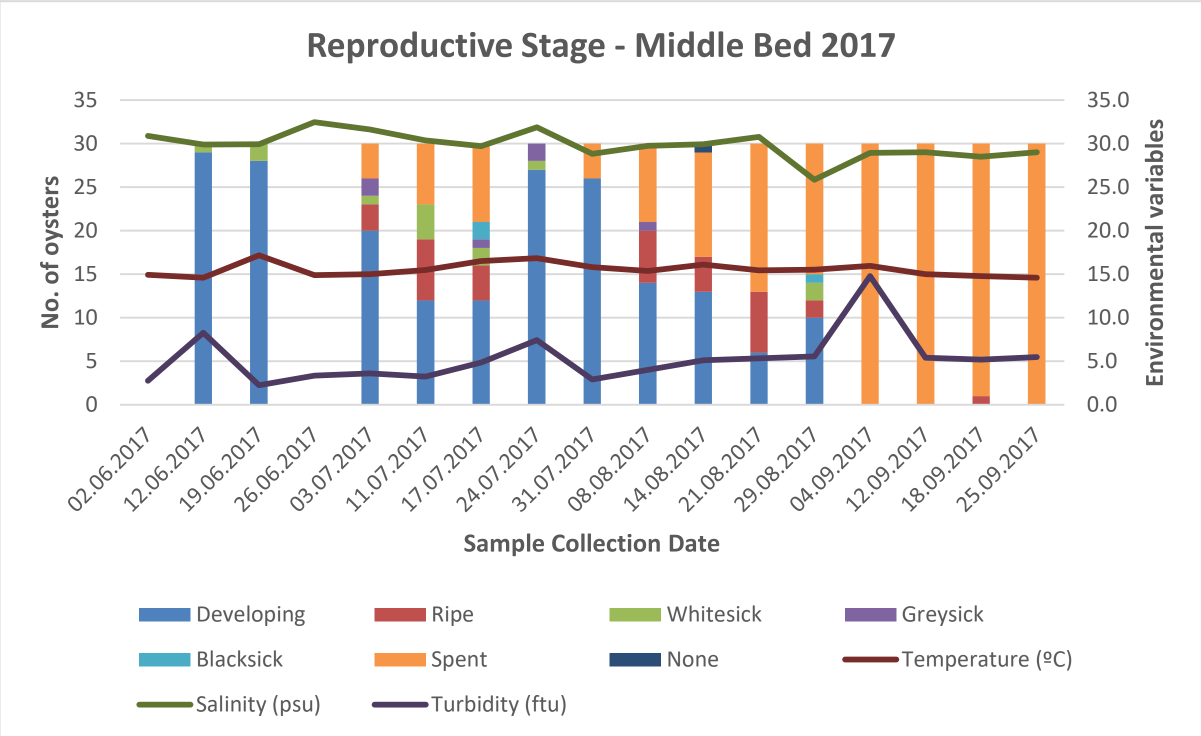

Figure 40: Reproductive stage, water temperature, salinity and turbidity - Middle Bed

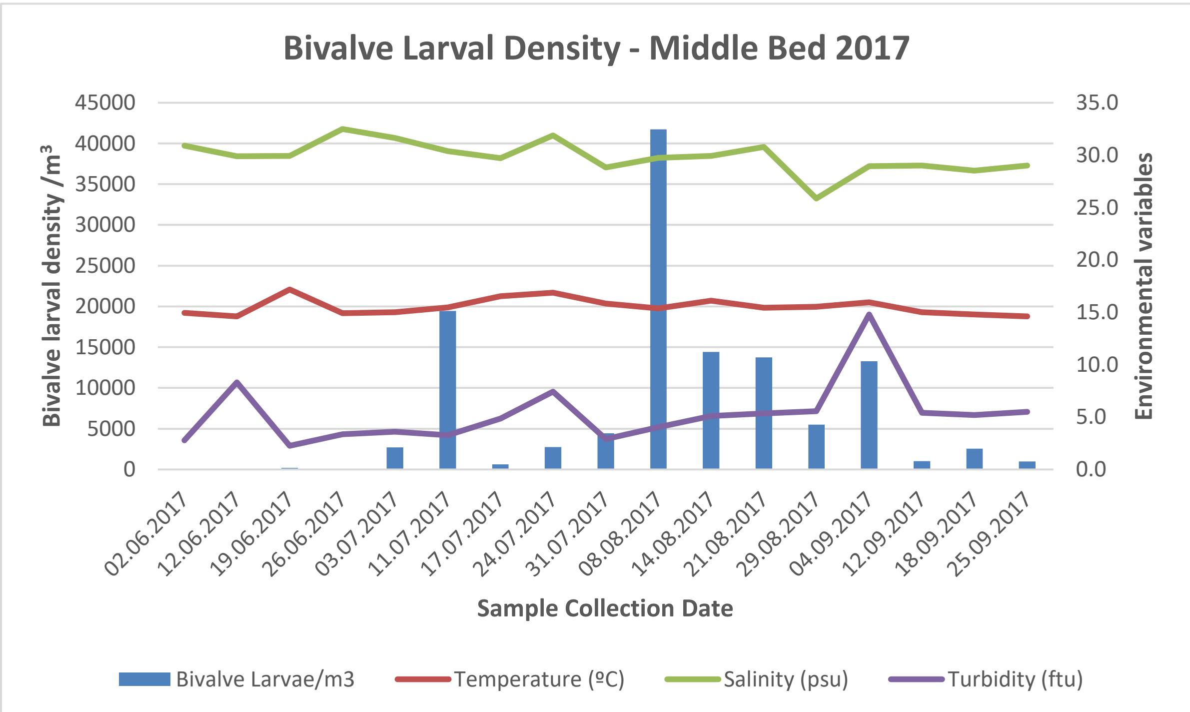

Figure 41: Bivalve larval density and environmental variables - Middle Bed

Mean length of the oysters collected from the Middle Bed was 77.4 ± 9.0 mm – the same mean length as those from Flat Ground and Perch. 35% of the oysters were above the 80 mm MLS, with 68% of those below MLS occupying the 70 – 79.99 mm size class. Mean weight (56.7 ± 16.9 g) was the second lowest of the sampled beds and 74% of the oysters weighed less than 65g. The mean length of brooding oysters in this bed was 78.2 ± 9.2 mm, with 32% above MLS. Of those below 80 mm, 87% occupied the 70 – 79.99 mm size class. Mean whole wet weight of brooding oysters was 67.0 ± 21.7 g, with 64% being < 65g. The heaviest brooding oyster (131.9 g) was recorded in this bed's samples.

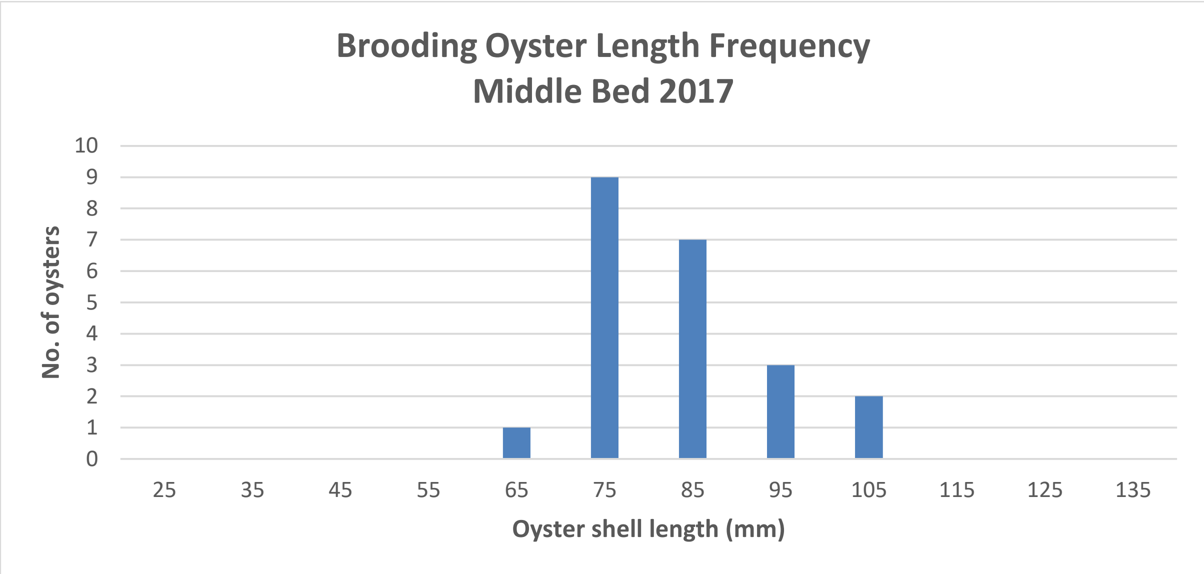

Figure 42: Length Frequency of brooding oysters - Middle Bed

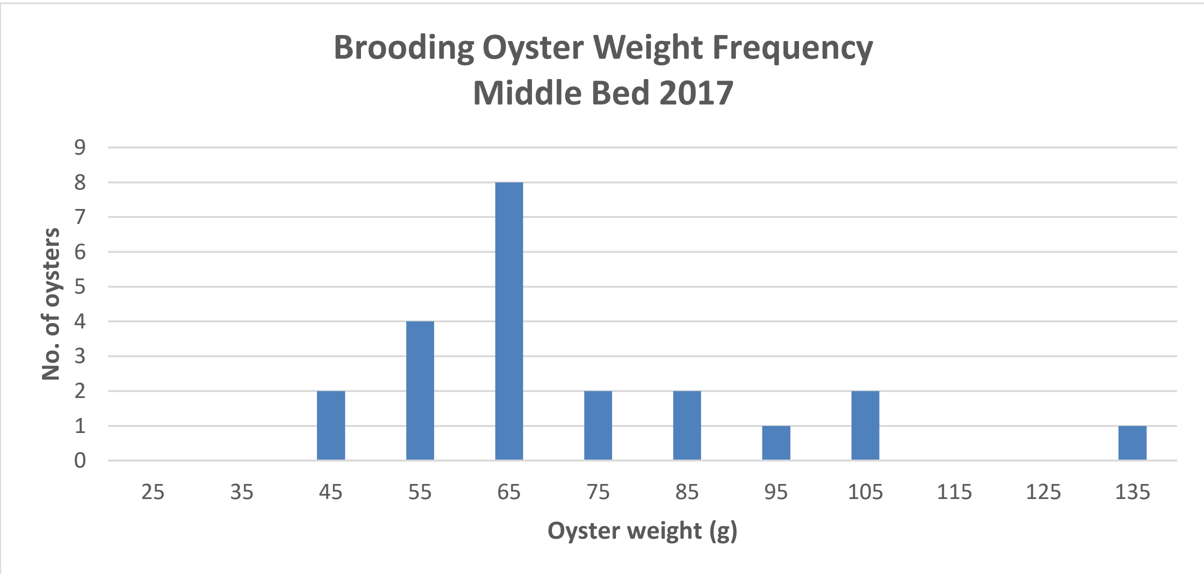

Figure 43: Weight Frequency of brooding oysters - Middle Bed

Mean Condition Index for Middle Bed oysters was 14.8 ± 3.7 %. As with the other beds except the Perch, oysters had the highest CI in week 2, together with another peak on 12/09/2017.

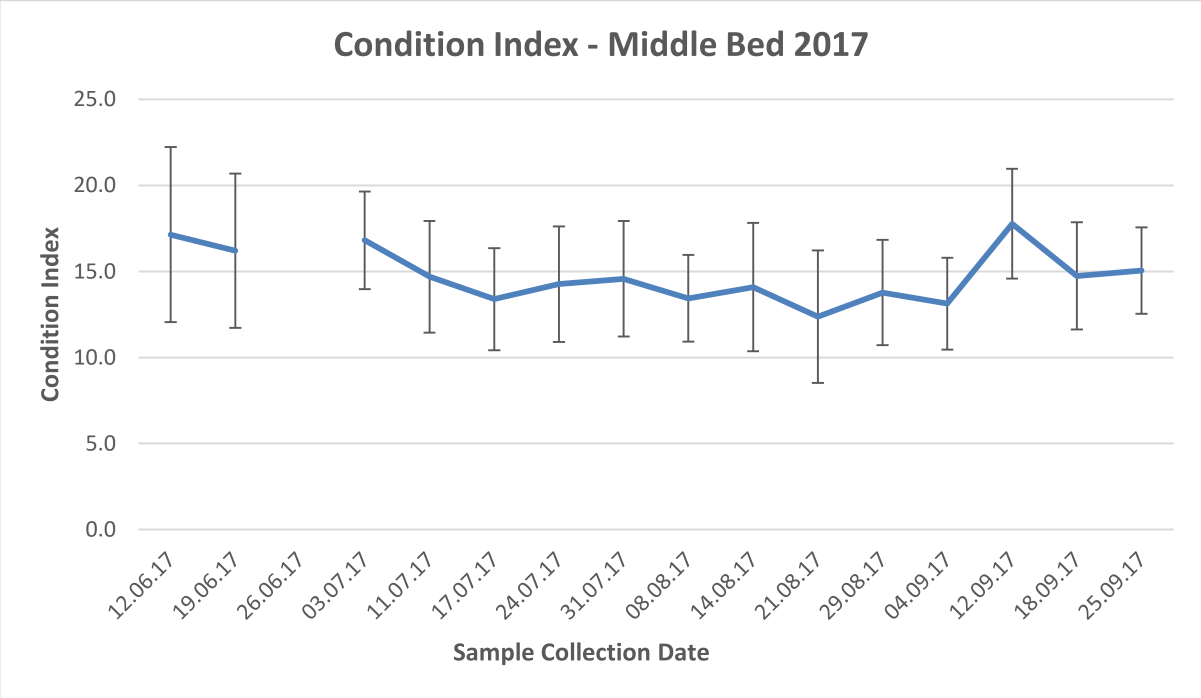

Figure 44: Condition Index - Middle Bed

4.0 Discussion

Lough Foyle's native oyster population had the fourth highest percentage of reproductively active oysters since this annual survey began in 2011. Despite this, there was limited evidence of spat settlement in 2017. Some evidence of settlement was observed during the native oyster stock assessment survey in September, but this was low compared to 2011 and 2014. There was no oyster spat recorded on spat collector arrays or pots containing cultch retrieved from the surveyed beds. Given that there was less variation amongst the samples in terms of oyster sizes and weights and environmental variables than in previous years, and temperatures staying consistently above 14ºC, spatfall was expected to be higher than observed. However, there were two notable periods which may have influenced reproductive success. The peak brooding period was slightly earlier than in previous years as oysters had conditioned well in the period leading up to the survey (Condition Index was highest in the first weeks of the survey). A sudden decrease in temperature following the 3rd July sampling came in the middle of this peak brooding period. There was then a marked decrease in temperature and salinity and sharp increase in turbidity in the weeks of 29th August and 4th September. This followed a major flooding event in the Foyle catchment area which was described as "a once in a hundred year event", leading to large volumes of freshwater and debris entering the lough. Oyster condition and larval densities certainly decreased during this period and may have influenced larval survival and ability to settle.

Whilst oyster populations have been shown to adapt to spawn in what would be considered as suboptimal conditions (e.g. temperatures < 14 - 16ºC), (Korringa, 1957; Bromley *et al.*, 2016), in adverse conditions, oysters can cease development of gonad material (Orton, 1927). The larval stage has been shown to be the most sensitive to decreases in temperature and salinity – when water temperature drops to less than 17 ºC, larvae may suffer from a decline in competence to settle and successfully metamorphose into spat (Korringa, 1941).

The results of this and other years' surveys have shown that larval densities of all bivalve species can effectively be used as a proxy for native oyster larvae, as they follow the same general patterns of increases and decreases in abundance, mostly linked to fluctuations in environmental conditions.

It is important to take into account the difference between actual and effective population size. Effective population is the proportion of the overall population that successfully reproduces each year. The survey results clearly demonstrate that low proportions of the spawning stock biomass are brooding at any one time during the breeding season. Some oysters will start the season ready to spawn as soon as conditions become favourable, whilst others will condition and spawn later in the season. Sudden fluctuations in environmental conditions can therefore perturb this process. Settled, optimal conditions such as those recorded in 2011 and 2014 contribute to a higher rate of reproductive success and spat settlement. Fertilisation success is influenced by population density - native oyster sperm can survive in water for ca. 10 minutes (compared to for example salmon sperm which lasts for approximately 1 minute in water), (Wilkins, 2017, *pers. com*.). This partially explains why oyster populations may not recover if the population density decreases beyond a certain level, even when other pressures are removed. It is therefore necessary to maintain a higher spawning stock biomass than might be expected to compensate for these factors.

Overall and for the individual sampled beds, a large proportion of the oysters measuring less than the 80 mm Minimum Landing Size were between 70 and 79.99 mm shell length. Given good growth conditions in 2017, it would be expected that the majority of these would recruit into the fishery for the 2017/ 18 fishing season. Fisheries are efficient at removing individuals above minimum landing size and is therefore heavily reliant upon oysters between 60 and 75mm for its spawning stock biomass. Investigations of oyster fecundity during the IBIS native oyster project found that Lough Foyle oyster broods were highly variable but generally the median number of larvae within a brood was lower than suggested by authors such as Walne (1964), (Bromley, 2015). Low densities can produce incomplete fertilisation and hatcheries tend to favour oysters over 10 years old to produce higher quality broods. The presence of the parasite, *Bonamia ostreae*, in a population can also reduce fecundity and egg quality. This could also influence successful larval survival and settlement. It is important therefore that precautionary methods to fishery management are maintained to ensure larger individuals are retained in the fishery to provide broodstock for the next breeding season.

Condition Index can be used as an indicator of stress and spawning activity. Condition index for all the sites reached a peak of 18.4 ± 5.2 % in week 2 of the survey (12/06/16); two weeks before the peak in brooding oysters was observed. Mean condition index of brooding oysters was 17.2 ±7.0 %. The percentages calculated for the sampled population are consistent with those expected for oysters but are generally towards the low end. When oysters put on significant shell growth, this can contribute to increased shell weight, potentially at the expense of flesh weight. Condition index decreased slightly as the summer progressed, especially after the flooding event, then showed a slight increase towards the end of September (consistent with indications of the autumn bloom of phytoplankton in the plankton samples).

In order to mitigate for factors that are not within regulatory control such as temperature and salinity and to assist with “smoothing” inter-annual fluctuations in spat settlement and stock sustainability, it would be necessary to adopt more extensive aquaculture techniques. These include cultch addition, where habitat availability may be a limiting factor for spat settlement. This is currently being trialled on a small scale in the lough. Spatting ponds can also be used to produce additional juveniles. Establishing broodstock areas with a higher density of oysters and protected from exploitation has been shown to positively enhance not only oyster growth and reproduction but also could assist with meeting environmental obligations under EU legislation.

The annual survey of reproductive activity in the Lough Foyle native oyster fishery has now built up a 7-year dataset. This survey is one of the few of its kind carried out on an annual basis in Europe. It is important to continue with this work as a long-term dataset will assist with identifying change, patterns and perturbations, planning for future fishery regulation and enhancement works, and will also enable the Loughs Agency and the Foyle fishery to contribute to the conservation of *Ostrea edulis*.

5.0 Conclusions

- 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.

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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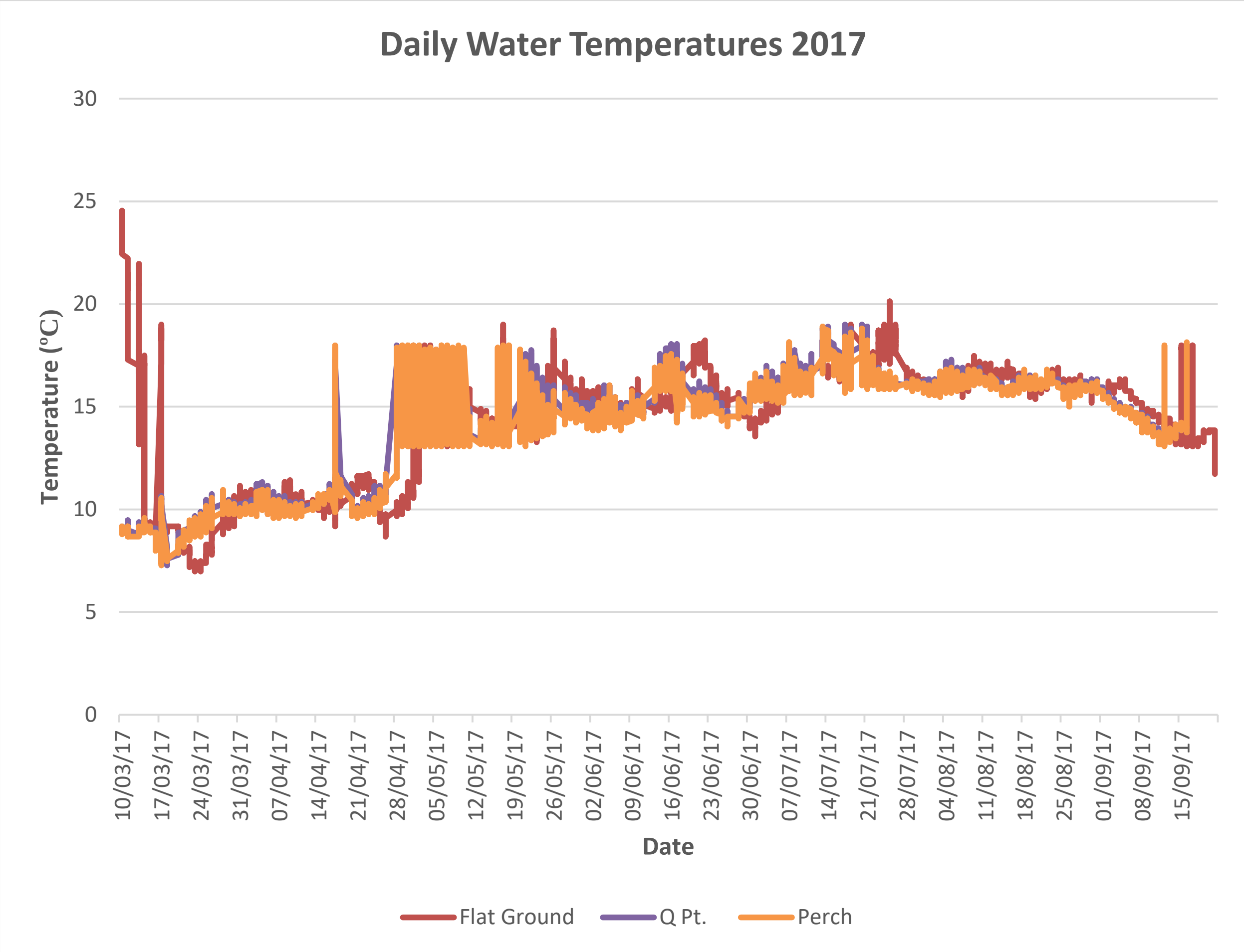
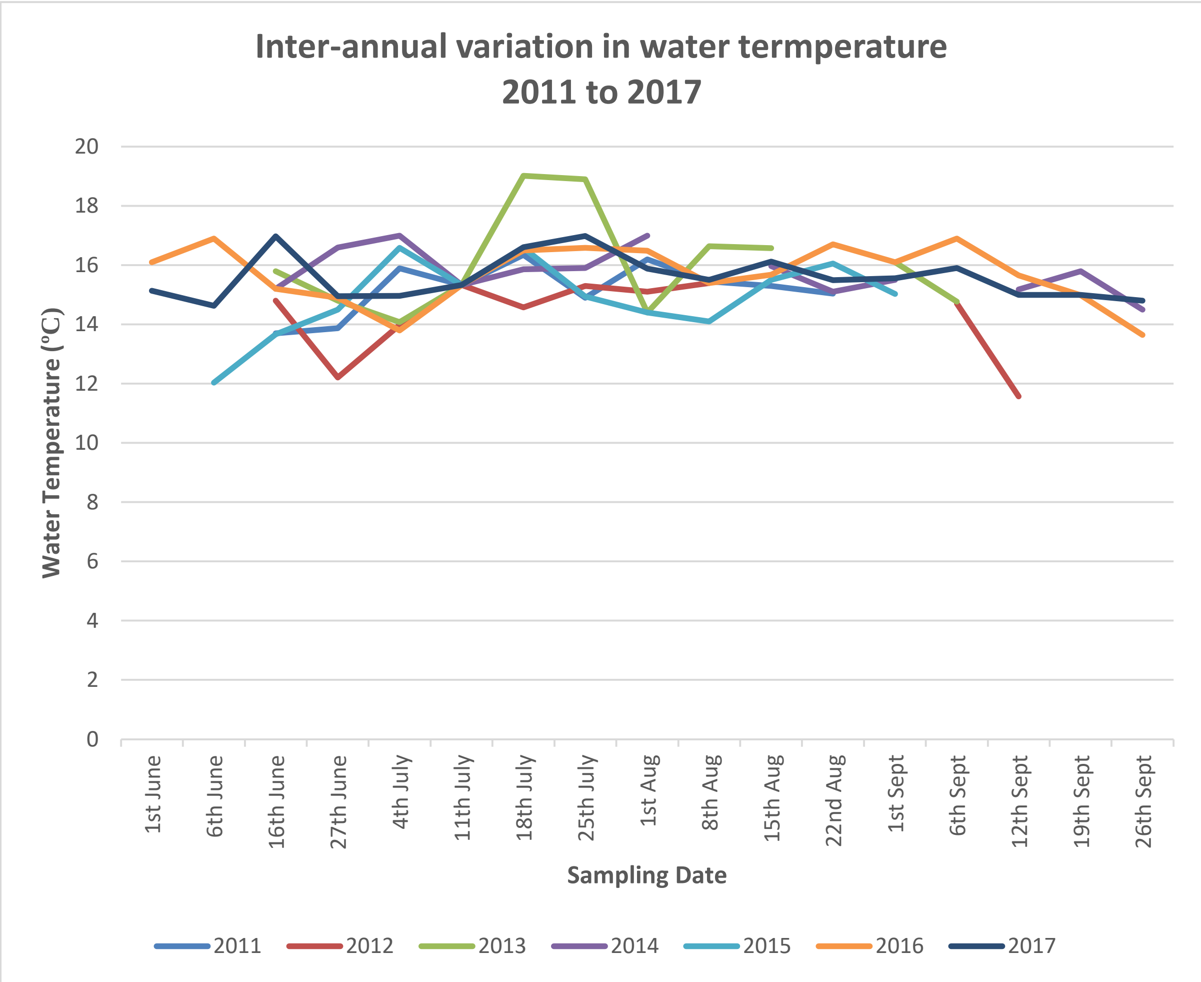
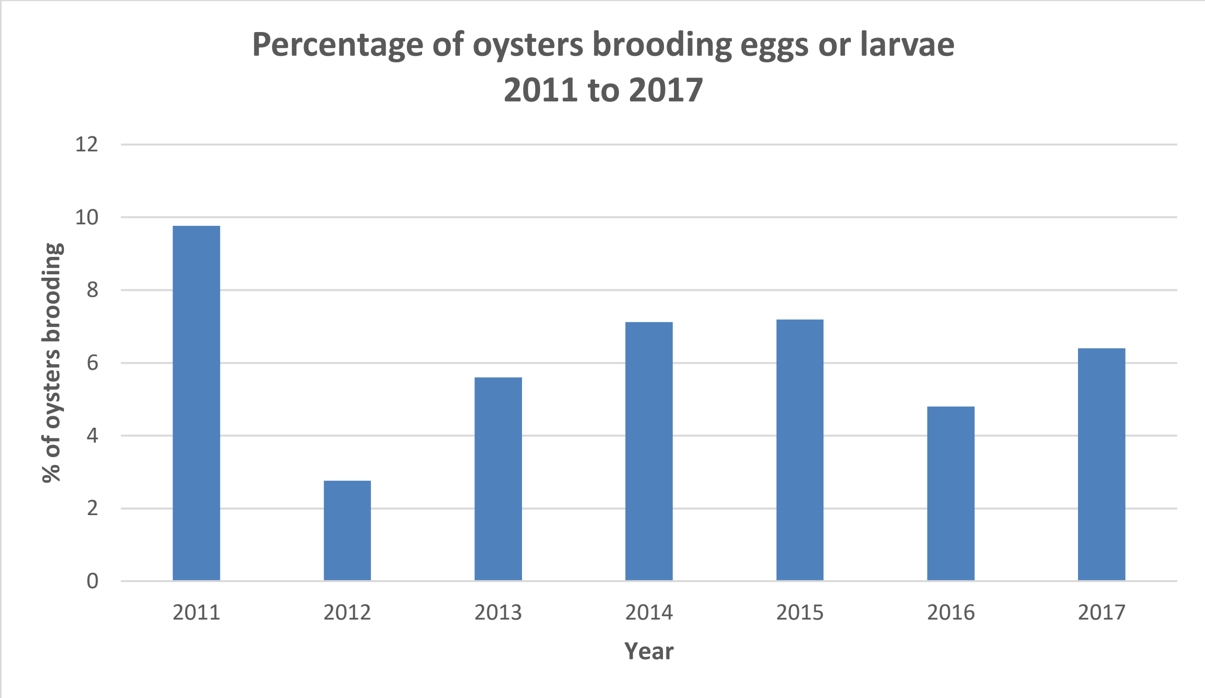
Appendix I – Daily Water Temperature Records

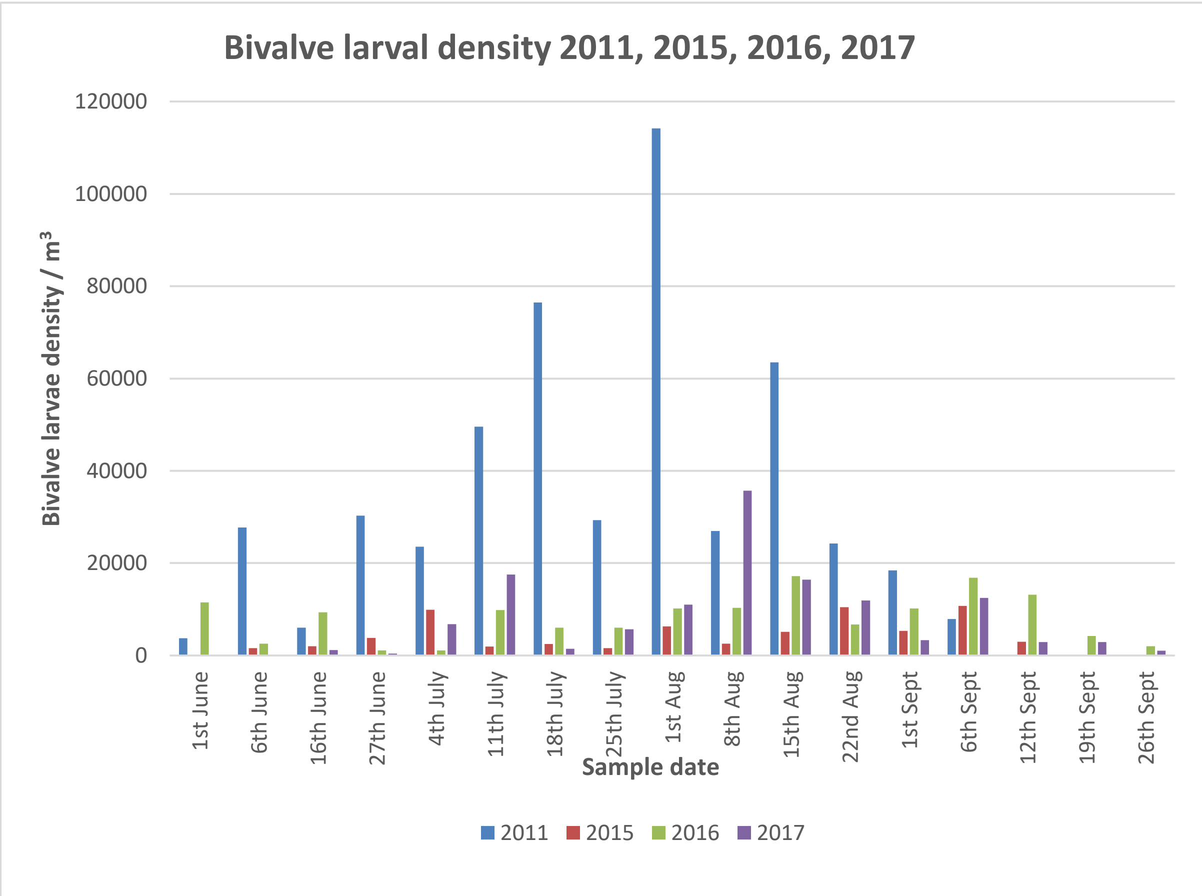


Appendix II Inter-Annual Variation in Water Temperature

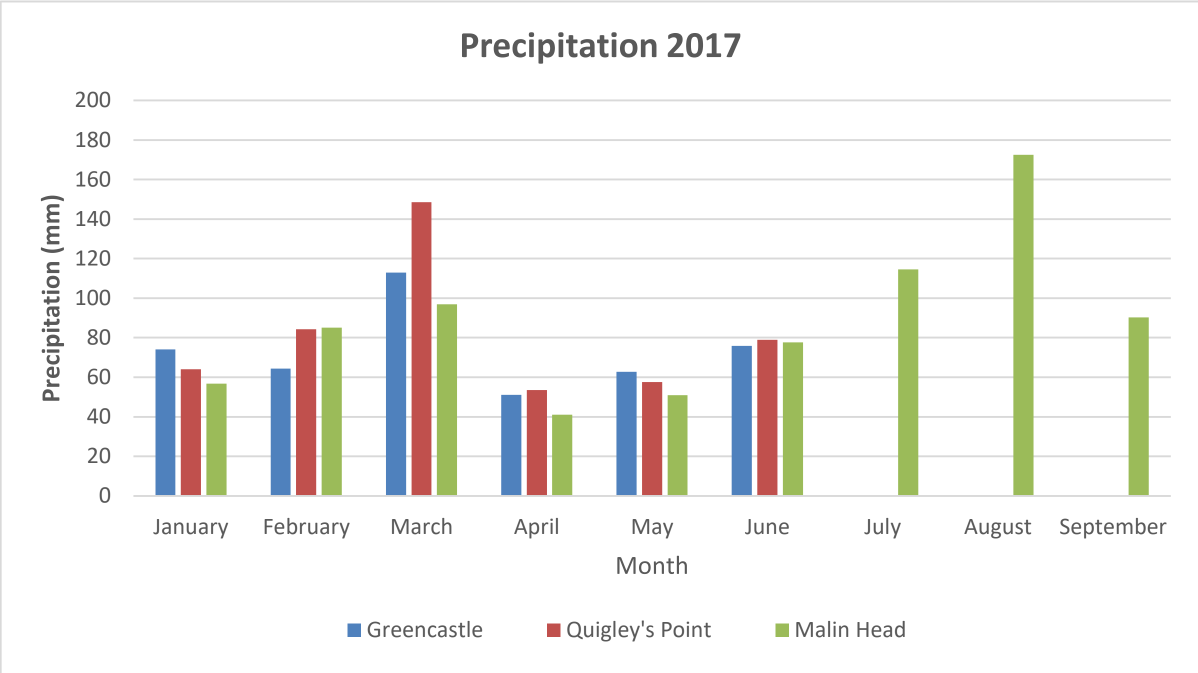


Appendix III Oyster Brooding Percentages 2011 to 2017 and Bivalve Larval Densities 2011/2015/2016/ 2017





Appendix IV Climate Data



Data from Met Eireann (http://www.met.ie/climate-request/)