BANGOR UNIVERSITY, FISHERIES AND CONSERVATION REPORT NO.39

Palaemon serratus Fishery Report: 2013/14

Emmerson, J., Haig, J., Robson, G. & M. J. Kaiser

DECEMBER 2014

Y Gronfa Pysgodfeydd Ewropeaidd: Buddsoddi mewn Pysgodfeydd Cynaliadwy
European Fisheries Fund: Investing in Sustainable Fisheries

Cymdeithas Pysgotwyr Bae Ceredigion Cyf.
Cardigan Bay Fisherman's Association Ltd.

Llywodraeth Cymru
Welsh Government

Please cite as follows: Emmerson, J., Haig, J., Robson, G., & M.J. Kaiser (2014) *Palaemon serratus* Fishery Report: 2013 / 14. Bangor University, Fisheries and Conservation Report No. 39

CONTENTS

Summary

This report serves to provide a comprehensive update and progress-review of the Welsh Government funded "Cardigan Bay sustainable prawn fishery project". The focus is on data obtained from scientific pot sample returned during the period beginning October 2013 through to May 2014.

An introduction, along with project aims, provides a background to the fishery and important context to subsequent sections of the report. The methodological approach to data gathering and analysis are discussed, with acknowledgment of the barriers that prevented the best-possible data scenario from being possible. Results from data observations and statistical analysis are presented, which leads into a discussion on the possible implications and limitations of the data. Finally, a conclusion draws key findings from the report and highlights what the project requires from the next period of data collection in order to build upon what is evidently a limited but insightful baseline study of the *Palaemon serratus* fishery in Cardigan Bay.

Project aims

Funded by the Welsh Government, this collaborative project between the Cardigan Bay Fisherman's Organisation (CBFA) and Bangor University Fisheries & Conservation Science Group will underpin the Cardigan Bay prawn fishery with a robust evidence base, which aims to;

- Describe the current status of the stock in the region
- Build a picture of the temporal and spatial patterns of the species, including the recruitment of juveniles into the fishery.
- Inform the management and conservation of the stock by developing a monitoring methodology aimed at collecting relevant data for stock assessments
- Help safeguard the fishery against precautionary approaches to management that may jeopardise economic productivity

This will be delivered through provision of the following reports:

1. *Palaemon serratus* Fishery Report: Winter 2013/14
2. MSC pre-assessment Report
3. Final Report
    a. Cardigan Bay *Palaemon serratus* fishery 2013-15
    b. A contrast and comparison with historical data for *Palaemon serratus*
    c. Recruitment patterns of *Palaemon serratus* from summer 2014
    d. Guidance for management of *Palaemon serratus*

The collaborative approach to this project is particularly appropriate due to adoption of the Marine Strategy Framework Directive (MSFD) in 2008. The MSFD legislated the requirement of all European fisheries to address a number of environmental and stock status criteria, known as "Descriptors", with the requirement to achieve "Good Environmental Status" (GES) by 2020. Of particular concern to the Cardigan Bay prawn fishery are the requirements to;

- Ensure biological diversity is maintained (D1)
- Ensure commercial shellfish stocks are exploited within safe biological limits, exhibiting demographics of a healthy stock (D3)
- Maintain elements of marine food webs at levels where species are capable of retaining full reproductive capacity (D4)
- Ensure sea floor integrity is not adversely affected (D6)

(HM Government, 2012)

More recently, the EU Common Fisheries Policy has legislated a Landings Obligation for all fisheries within the EU that target quota-managed, i.e. total allowable catch (TAC), species. The requirement of EU quota fisheries to land all TAC species bycatch will begin in January 2015. Although these changes will not directly affect the Cardigan Bay prawn fishery, it is imperative that data is collected now on the diversity of bycatch, the abundance of each bycatch species and the survival of commercial (and in particular TAC) species. Addressing the requirement for this data prior to regulatory changes will ensure that precautionary measures, employed due to lack of data, will not be needed.

Finally, the project will provide a Marine Stewardship Council (MSC) pre-assessment report, which will outline the current position of the fishery in respect to being able to achieve MSC accreditation. In a similar way to the recent Seafish Project Inshore, which mapped all inshore fisheries in England against common sustainability criteria dictated by the MSC principles, it is expected that a pre-assessment report will provide valuable viewpoint from which to move the fishery towards sustainable practice.

The aim of the present report is to evaluate progress to date on the methods and results of the fishery stock-assessment from the 2013/14 winter fishing season.

1.0 - Introduction

1.1 - *Species background*

Palaemon serratus [1] (Pennant, 1777; MarLIN & WoRMS, 2014), known as the common prawn, is widely distributed within the inshore waters of Europe (Kelly *et al.* 2008). The geographical range of the species stretches from the Mediterranean in the South to the temperate coastal waters of the UK and Ireland in the North (Forster, 1951). The life-history of the species is characterised by seasonal migrations, found in rocky shore and estuarine habitats during summer and successively moving offshore into colder, deeper waters during the winter (Forster 1951; González-Ortegón *et al.* 2006). Although the longevity of the species has been speculated to be up to five years (*see difference in data interpretation from* Cole, 1958 *and* Forster, 1959), *P. serratus* are known to have a relatively short life span, with individuals now considered to typically survive no more than two to three years years (Forster, 1951; Fahy & Gleeson, 1996). Importantly, the growth traits exhibited by the species are thought to be largely driven by environmental factors that vary on a regional scale and have been shown to influence the form and behaviour of individuals from the larval phase to adulthood (Guerao *et al.* 1994).

1.2 - *The Palaemon serratus fishery*

The commercial exploitation of *P. serratus* does not occur across its full geographic range. The decision taken by fishers to actively exploit the species as a living marine resource can be said to be linked to a combination of ecological factors and economic factors, such as the spatial variability in its abundance and whether local infrastructure has the capacity to supply the market, which driven primarily by consumption in Southern Europe (Huxley, 2011; "Fishers' Knowledge" interviews, EFF funded *Sustainable Fisheries in Welsh Waters* project, Bangor University). The high level of market demand for good quality, live prawn from UK waters results in a relatively high price received by fishers for *P. serratus*, typically ranging between £20-23 per kilo (*pers. comms.* CBFA, 2014). The high price received for *P. serratus* in Europe is somewhat offset by the high capital

[1] Subphylum: *Crustacea*, Order: *Decapoda*, Suborder: *Pleocyemata*, Infraorder: *Caridae*, Superfamily: *Palaemonoidae*, Family: *Palaemonidae*, Subfamily: *Palamoniae*, Genus: *Palaemon*, Species: *Palaemon serratus* (Pan & Hay, 2010; MarLIN & WoRMS, 2014).

investment in the infrastructure and transport required to maintain a high quality and survival rate of the live product.

Within the UK, the economic importance of *P. serratus* fisheries varies by region. Fishers that target the species typically do so using static gear (pots) during the winter months only, with the Irish fishery also legislating a closed season from May until August (Kelly et al., 2008; Huxley, 2011). The fishery can provide essential income to static-gear fishermen during the winter months when catches of main target species, such as European lobster (*Homarus gammarus)*, are low (*pers. comms.* CBFA, 2014). Within the UK, the Welsh inshore fleet is particularly dependent on the *P. serratus* fishery, having dominated the UK landings figure by tonnage and value (Huxley, 2011).

1.3 - *The P. serratus fishery in Cardigan Bay*

Since the Cardigan Bay fishery for P. serratus began in the 1970s, the industry has undergone several periods of transition, such as the advent of live "viver" transport systems in the 1990's (Huxley, 2008). What began as a low-value winter supplement to the incomes of a minority of fishermen is now worth approximately £0.5 million per annum and a principal target species for half of fishermen in Cardigan Bay (Huxley, 2008). The financial reward for landing common prawn in Wales has resulted in improvements to capture technology along with a gradual increase in the fishing effort (Fahy & Gleeson 1996; Kelly et al. 2008; Huxley, 2008).

The fishery is characterised by small, artisanal fishing businesses, with vessels predominantly being under 10 m length overall. Although inshore fishers throughout Wales are known to target the species, fishers operating in Cardigan Bay are especially dependent upon the fishery. Contributing a significant socio-economic value to the local community by providing jobs and fishing related revenue, it is increasingly important to safeguard the fishery so that the industry remains ecologically viable in an increasingly uncertain economic climate.

Realising the importance of stock management and conservation, many Cardigan Bay fishermen have adopted voluntary practices in an attempt to protect the fishery in lieu of any legislated conservation measures. Voluntary measures include;

- Increasing the mesh size on the prawn pots from eight to between 10-14 mm, either on the pot-end or main-body as preferred by the fisher.
- Grading the catch by hand on a "Minimum Landing Size" (MLS) dictated by market preference.
- Grading the catch using a 10 mm riddle to a MLS dictated by market preference.

By sorting their catch into "sized" and "undersize", many fishers are able to return juveniles to the ecosystem. The sorting of catch benefits fishers both in the short-term, by landing larger prawns that return a consistent and higher price per kilogram, and in the long-term, by allowing returned juveniles the opportunity to mature prior to capture. There is an additional ecological benefit of using pots with larger mesh sizes; as they allow small prawns to escape directly to the seabed (Fahy & Gleeson 1996), thereby reducing the time required to sort the catch and minimising the stress and incidental mortality of captured juveniles.

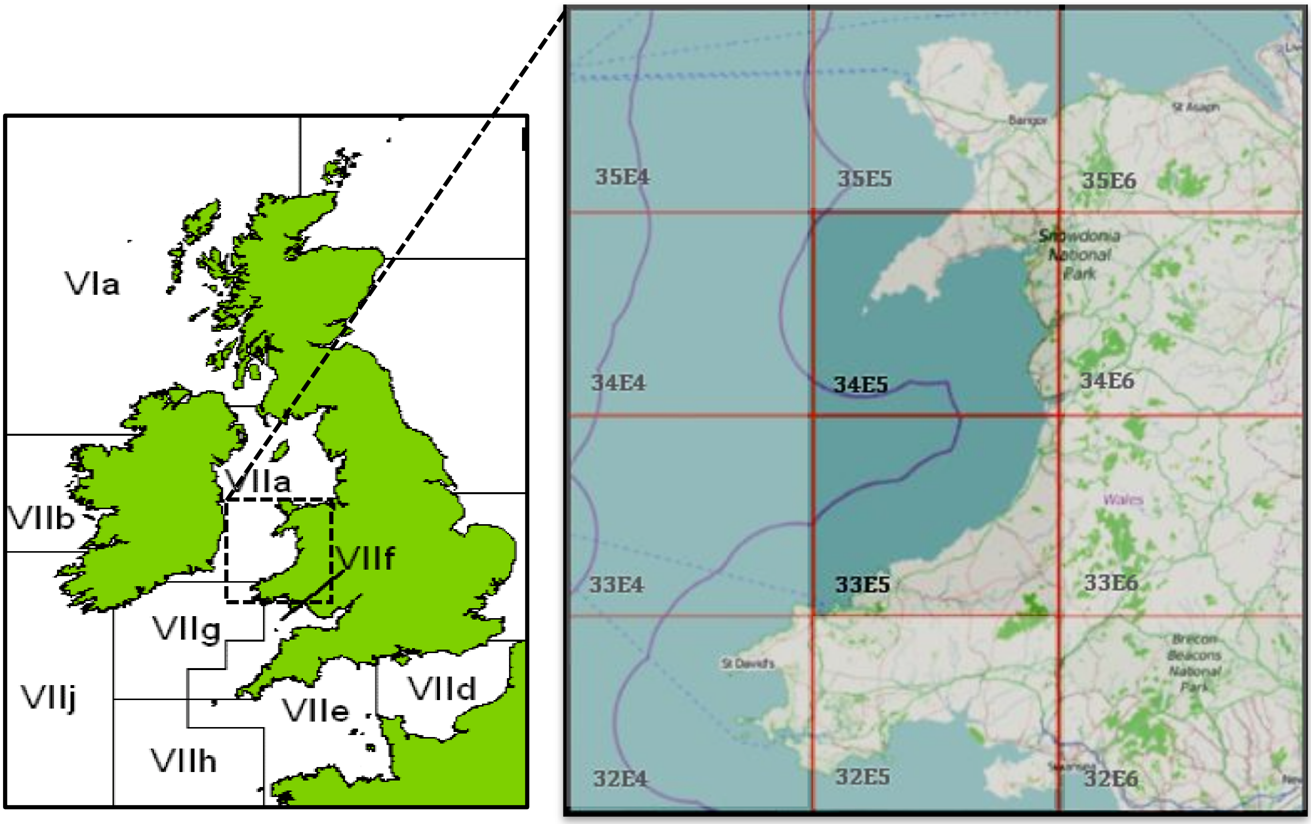
To date the *P. serratus* fishery is largely unregulated. There are no legislated conservation measures in place which aim to protect the stock of common prawn. Similarly, there is an absence of effort control both in terms of restricting access to the fishery and any form of vessel-effort control. In response to the knowledge-gap and imminent legislative requirements to prove sustainable practice, this project will create a scientific baseline of information from which the industry can move forward with sustainability at the forefront of the agenda.

This report will outline the methodological approach to the fishery analysis and critically examine the multiple sources of data available to this aspect of the project. Further, this report will present the baseline data obtained thus far and make preliminary observations from the statistical analysis on the 2013/14 fishing season. Finally, conclusions and recommendations will be discussed with the aim to move into a second round of monitoring during the 2014/15 fishing season.

2.0 - Methods

2.1 - *Industry collaboration*

All Cardigan Bay fishing businesses targeting prawn do so within ICES Area VIIa – "Irish Sea" (see Figure 2.1a). Typically, potting vessels fish within three nautical miles of the coast (*pers. comms.* CBFA, 2014) and operate out of several ports between the geographic co-ordinates of 52.00 latitude, -4.99 longitude at the southern-most extent of the fishery and 52.70 latitude, -4.02 longitude in the North. The vast majority of fishing effort therefore lies within the ICES Statistical Rectangle 33E5, with some vessels also fishing in ICES Statistical Rectangle 34E5 (see figure 2.1b).



a **b**

Figure 2.1 – **a**) ICES Areas around the British Isles, highlighting the area known as Cardigan Bay within Area VIIa. Figure cropped from online image taken from Scottish Sea Fisheries Statistics 2009 (Part 48) (The Scottish Government, 2009; p. 34). **b**) ICES Statistical Rectangles in the Irish Sea and Welsh waters. Note that the purple line demarks the boundary extent of Welsh Assembly Government (WAG) authority (12 nautical miles from territorial boundary). Figure adapted from an image taken using ICES online Interactive Map Viewer (ICES, 2014).

Six members of the Cardigan Bay Fisherman's Association are actively engaged with the project and operate out of the main ports in Ceredigion, namely Cardigan, New Quay, Aberystwyth and Aberdyfi. The locations of these home ports are presented in Figure 2.2.

These members have actively participated in project planning and data collection and the success of this project hinges upon their continued support.

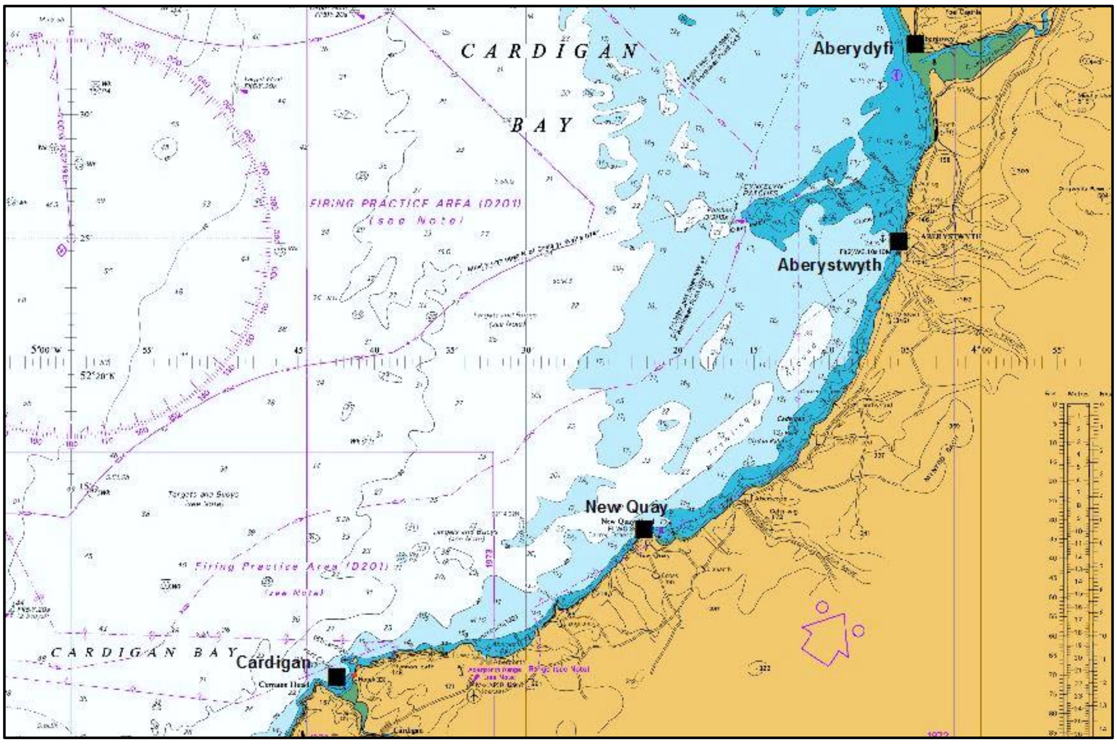


Figure 2.2 - The location of 'home ports' of CBFA members engaged with the project.

2.2 – *Formation of the Cardigan Bay prawn working group*

After some consultation between the CBFA members and Bangor University, a "prawn working group" was formed. The intended purpose of the group is to discuss the future of the Cardigan Bay prawn fishery. The group aimed to include representatives from the fishing industry members, processors, Welsh government, Natural Resource Wales and prawn researchers with scope to invite specialists if and when needed. This is an ideal forum to bring the current data to the table and discuss the future management options with all of the stakeholders in the prawn fishery. The aim of the group is to initiate industry led management and to enhance the transparency in the management processes and decisions. Members of the CBFA have expressed concern about the future prawn stocks and would like to know that their efforts in contributing to the science are leading to a sustainable future for the fishery. This group has the potential to eventually operate much the same as an ICES working group: initially identifying the data required for stock assessments and later bringing new data and monitoring methodology to the table to enhance future stock assessment methods for the prosecuted species.

2.2 - *Catch data (low-resolution)*

Without the resources to observe daily catches at sea, the project relies heavily upon logbook data. Initially, each fishermen was provided with a Daily Log Returns (Table 2.1).

Table 2.1 - Example of Logbook provided to fishermen.

Date	**Prawns Landed (kg)**	**Prawns Discarded (kg)**	**No. strings hauled**	**Av. No. pots per string**	**Total No. pots hauled**	**Baiting method *(species)***	**Soak time *(days)***	**GPS logger *(Tick if yes)***

With the above data, the project aims to detect spatial and temporal trends in abundance by evaluating the Catch per Unit Effort (CPUE) throughout the winter fishing season. This element is crucial in establishing reference points within the baseline data from which inter-annual comparisons can be made in the future. Further, accurate data returns from logbooks will allow this project to evaluate the anecdotal evidence that suggests a gradual opening of the fishery, with southern-most grounds detecting increases in CPUE early in the season but also being the first to observe decreases in the spring. This information may prove to be a highly valuable evidence-base if future management measures were ever to suggest seasonal closures, which could have an unequal impact on fishers depending on geographic location.

However, feedback from fishermen early in the project indicated that the logbook trial was unsuccessful. It is already a legislated requirement for fishermen to submit monthly "shellfish returns" and the doubling of paper-work was largely unpopular. The monthly shellfish returns, which are submitted to the Welsh Government, contains very similar information and data. In response, this element of the project now depends on obtaining accurate monthly shellfish prior to submission to the Welsh Government, with a copy being submitted to the CBFA offices where it will create a landings per unit effort dataset. Importantly, this dataset is kept secure and will remain inaccessible to anyone not working on the project. Furthermore, any analysis and presentation of results will ensure anonymity to those who submitted their shellfish returns.

2.3 - *Scientific pot sample data (high-resolution)*

The fishery is diverse in terms of the style of pot being used to target prawn, with fishers using a mix of "Roscoff", "Payne" or "Poly-pot" style pots within their fleet. Importantly, each of these pots vary in shape, but also in the mesh-size on the pot-ends and body. In order to standardise the data collection method, the fishermen engaged with the project were given three "scientific" pots, which can be fished alongside the fishers' regular pots in a string. The scientific pots are "Payne" pots with an 8 mm mesh on all sides with circular 35 mm entrances at both ends, as seen in Figure 2.3.

Figure 2.3 - A Scientific Prawn Pot

It was agreed that the entire contents of each pot are kept separate and stored frozen until Research Officers collect the sample from the fisher. Furthermore, the fisher would record the following details on a "SCIENCE POT data sheet" (see Appendix 1) that would be kept in a plastic bag with the sample;

- Date hauled & soak time
- GPS co-ordinates
- Water depth (m)
- Bait type
- Water Clarity (secchi disk measurement)
- Sea conditions
- Wind speed and direction

High-resolution catch data is an important data source, which aims to observe detailed offshore data for *Palaemon serratus*;

- Catch per unit effort
- Bycatch diversity and abundance
- Length distribution of catch from scientific pots (total length, carapace length and carapace width)
- Sex-ratio from scientific pots
- Size of functional maturity for females
- Fecundity at size

These observations will be analysed against environmental factors that have been highlighted in the literature as having an impact on the abundance, size and behaviour of common prawn. Environmental variables that are observed include;

- Geographical location
- Benthic habitat
- Turbidity
- Salinity
- Subsurface sea temperature

The subsurface sea temperature was recorded using "TinyTag" temperature loggers, which were attached to one of the scientific pots given to each fisher. The loggers were set to record the mean sea temperature every 10 minutes for the duration of the fishing season.

The samples collected from scientific pots during the 2013-14 winter fishing season were taken to the School of Ocean Sciences laboratories in Menai, where the data were recorded under a laboratory protocol (see section 2.5).

2.4 – *On-board observation data (medium-resolution)*

The on-board observation element of the project was unsuccessful during the 2013-14 winter fishing season. Extreme weather conditions, caused by the storm “St Jude”, dramatically reduced the number of opportunities for Research Officers to collect data on-board commercial fishing boats. The storms began in October 2013 with wind gusts of up to 100 mph, the storm did not ease until early 2014 and resulted in the most severe December weather conditions in 45 years with maximum gusts of 142 mph being recorded in the UK.

In total, three separate fishing trips were undertaken to develop a monitoring protocol. By observing the fishing practices and practicalities of working on a Cardigan Bay vessels, the project now has a practical and working protocol (Appendix 2) with appropriate data collection sheets (Appendix 3) for Research Officers to implement over the 2014-15 winter fishing season. The project aims to conduct two to three on-board observation trips per week from vessels working throughout the Cardigan Bay area and aims to bridge the gap between the fine-scale data taken from scientific pot samples and the large-scale data from logbooks by focussing on the following;

- Landed catch per string / pot
- Discarded catch per string / pot
- Bycatch per string / pot
- Environmental parameters for each string;
  - Benthic habitat type (using a drop down video)
  - Salinity (taking water samples where possible)
  - Turbidity (using secchi depth measurement)

By combining on-board observer data with pot sample data we are able to establishing the best possible data within a fisheries dependent sampling framework baseline to which future sampling and monitoring can be compared. The value of on-board observation data depends upon creating a continued time-series of repeated sampling throughout the fishing season and in following years.

2.5 – *Laboratory methods*

2.5.1 – *Palaemon* species identification

Three species of *Palaemon sp.* were most commonly identified during laboratory analysis, namely *P. serratus*, *P. varians*, and *P. elegans*. Individuals were identified using the illustrated guide in González-Ortegón and Cuesta, 2006. *P. serratus* can be recognised as distinct from other species of prawn due to the noticeably curved rostrum with a bifid tip and two teeth behind the eye orbit. Non *P. serratus* species are considered bycatch in this report.

2.5.2 - Morphometrics

Frozen pot samples (see section 2.3) were defrosted for at least an hour before proceeding with further analysis, with many samples being left in a refrigerator overnight to defrost gradually.

The total length (TL), carapace length (CL), and carapace width (CW), as defined below, were measured to the nearest 0.1 mm where possible using callipers (Figure 2.4):

- TL – From the tip of the rostrum to the end of the telson.
- CL – From the eye orbit to the posterior edge of the carapace.
- CW – The widest part of the carapace.

Using digital scales, the weight was recorded for each individual to the nearest 0.01 g.

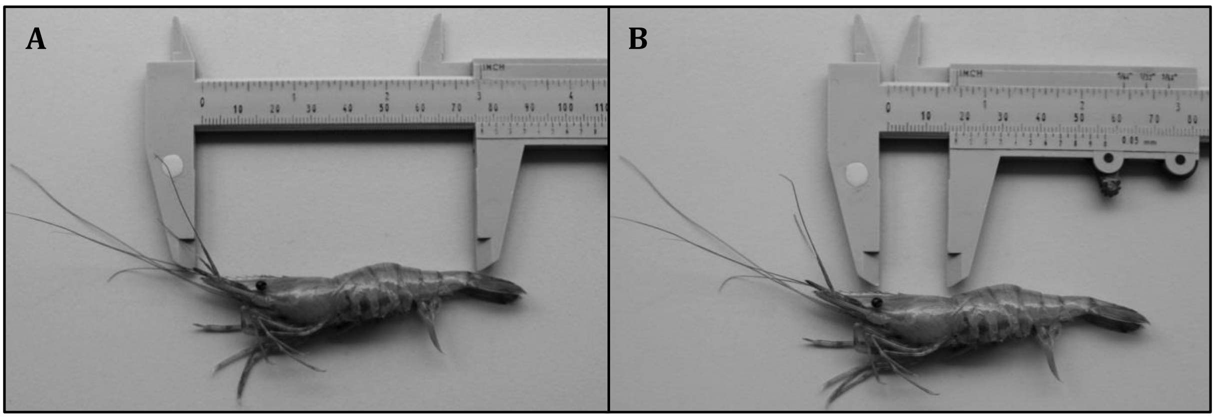
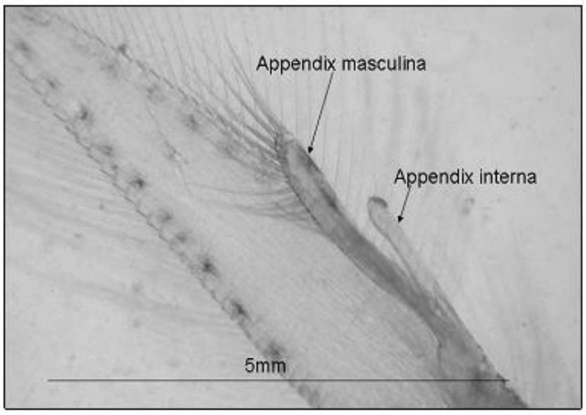


Figure 2.4 – Measurement of *Palaemon serratus* total length (A) and carapace length (B).

2.5.3 – Sex determination

The sex of *Palaemon* species was determined by removing the 2nd set of pleopods and observing them under a dissection microscope. Males have two appendages attached to the pleopods (an appendix masculina and an appendix interna), whereas females only have one (appendix interna) (Figure 2.5).

A note was made on the presence or absence of eggs on females individuals (see below for egg count protocol). Eggs were removed and placed on petri dish labelled with the sample number.



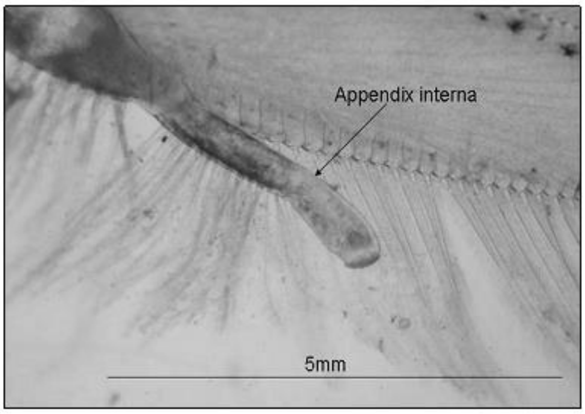


Figure 2.5 – Identification of male (left) and female (female) *Palaemon serratus* using a dissection microscope.

2.5.4 – Fecundity

Fecundity is analysed with the aim of investigating the relationship between the *P. serratus* morphometric measurements and number of eggs carried by females. The data-based estimations necessary to estimate fecundity are described in section 2.6.2.

The wet weight of the total egg mass carried by each gravid female was recorded using digital scales to the nearest 0.001 g. A small subsample of approximately 0.02 g was taken from the total egg mass and also recorded to the nearest 0.001 g. The eggs within the subsample were then placed on a gridded petri dish and counted using a dissection microscope (N.B. putting some sea water in the petri dish can help make the eggs less sticky and easier to separate and count).

Importantly, to ensure the subsample egg count and weight correspond with the total weight measurement and prawn sample number on data sheet so label the eggs straight, all subsamples were stored with a labelled note with the prawn ID number.

2.5.5 - Bycatch

Each species within the pot sample considered bycatch, including both teleost fish and crustaceans, were identified using field guides by Sterry and Cleave (2012) and Wood (2014).

The weight of each individual considered bycatch was measured using digital scales to the nearest 0.01 g. Teleost fish length measurements were recorded as the length between the snout and the posterior of the caudal fin to the nearest 0.1 mm. Length measurements of crab species were recorded as the carapace width at the widest point, whilst other crustaceans were measured as the total length from the tip of the rostrum to the end of the telson, both to the nearest 0.1 mm.

All bycatch were retained and re-frozen in sample bags with sample ID labels for potential future analysis.

2.6 – *Statistical analysis*

All data was entered into a central database on Microsoft (MS) Excel. Statistical investigation was carried out using the "R" software (version 3.1.0) (R Core Team, 2014), with the R-Studio interface (version 0.98.1091) (RStudio, Inc., 2014).

2.6.1 – Data-based estimations

Within MS Excel, several important variables were calculated *post-hoc* using existing data.

From the scientific pot samples, total number of eggs carried by each berried female prawn (fecundity; section 2.5.4) was calculated by taking a subsample and applying the following estimation equation:

$$Fecundity = \frac{Egg\ subsample\ count}{Egg\ subsample\ weight} \times total\ egg\ mass$$

Using the monthly shellfish return data, CPUE was calculated by applying the following equation:

$$CPUE = \frac{Total\ weight\ of\ daily\ catch (kg)}{Number\ of\ pots\ lifted\ that\ day}$$

2.6.2 – Length based analysis

The total length (TL), carapace length (CL) and carapace width (CW) data of all *Palaemon serratus* caught within the scientific pots are plotted on frequency histograms, which aid visualisation of the data according to spatial and temporal attributes including location and season. Due to the lack of regularity in data, season is chosen as the temporal scale of comparison rather than temporal comparison by month. The length-based frequency histograms are supported by boxplots, which show median average values ($\bar{x}$), Inter-quartile (IQ) ranges and 95% confidence intervals (CIs). All boxplots used for assessment between two or more data are generated with 'notched' boxes, which indicate 'strong evidence' of significant difference in median value if they do not overlap (Chambers *et al.,* 1983, p.62).

After assessing normality and homoscedasticity, both Kruskal-Wallis and analysis of variance (ANOVA) tests were performed to detect the spatial and temporal changes in the size of *Palaemon serratus*, whilst a *post-hoc* Tukey test was used to determine where differences occurred.

2.6.3 – Length-weight relationship analysis

After aggregating the data across all locations and throughout the time-series available, the relationship between length and weight of *Palaemon serratus* was investigated after having transformed weight-based data using a square-root transformation. A linear regression model investigated the degree of statistical significance of the relationship under the linear model assumptions.

2.6.4 – Sexual dimorphism

In order to explore the degree to which Male and Female *Palaemon serratus* are sexually dimorphic, i.e. they can be distinguished based on physical features alone, an analysis of Covariance method was used. By creating a linear model where CW ~ Sex + TL and comparing the ability of the model to explain the data against a CW ~ TL model, sexual dimorphism can be identified. Dimorphism can be said to occur if the sex-based models explain the data significantly better than the unvariate model.

2.6.5 – Sexual maturity and fecundity

The presence or absence of eggs on the pleopods of female *Palaemon serratus* was used to investigate the size at which females become sexually mature. Although the relative abundance (%) of berried females from within a sample may underestimate the relative abundance of mature females within the stock, this method has been used in many other studies (*see* Rodriguez, 1981) and is considered an inexpensive yet reliable method of determining functional maturity.

2.6.6 – Sex ratio

Testing the null hypothesis that there is no difference in abundance of Male and Female *Palaemon serratus* in the Cardigan Bay area, a G^2 test (likelihood ratio) was used to investigate whether the temporally and spatially aggregated data displayed an expected 1:1 ratio.

2.6.7 – Bycatch and discarding

Bycatch, in the case of the Welsh prawn fishery, can be defined as non-target species that are discarded due to lack of quota or commercial value. With regard to *Palaemon serratus* specifically, this report defines "target-species bycatch" as prawns that are caught in pots and are under-sized, crippled or damaged and subsequently discarded.

The bycatch and discard rate of *Palaemon serratus* was investigated by assuming that all individuals with a CW less than 10 mm would have been returned to the sea. The reasoning for this assumption is that fishers who voluntarily use a riddling device at sea usually use a 10 mm riddle (*pers. comms.* CBFA, 2014). This is expressed as both a % bycatch rate in terms of count and weight (kg) relative to total catch. The bycatch rate is investigated across time and geographic locations to examine spatial and temporal differences in the bycatch rate.

3.0 – Results

The return rate of catch data, in the form of shellfish landing returns (see section 2.2), was poor for the 2013/14 winter fishing season. Typically, the mandatory paperwork is completed a significant period of time after the fishing trip takes place and may therefore be subject to inaccuracies on important variables such as number of pots hauled. Consequentially, this report does not present CPUE data or resultant analysis on the low-resolution catch data. See section 4.1 for a discussion on probable causes of the poor data return rate.

Scientific pots were returned by fishermen operating out of three key ports; Aberystwyth, New Quay and Aberdyfi. The time period in which the scientific pots were hauled are shown in table 3.1.

Table 3.1 – The presence (**X**) and absence (-) of scientific pot returns by Month in each Location.

Season	Month	Aberystwyth	New Quay	Aberdyfi
Autumn	10	**X**	**-**	**-**
	11	**X**	**X**	**-**
Winter	12	**X**	**-**	**-**
Spring	3	**X**	**X**	**X**
	4	**-**	**X**	**X**
	5	**X**	**-**	**-**

3.1 – *Length-based analysis*

3.1.1 – Total length (TL)

A total of 712 individual *Palaemon serratus* were provided from scientific pot samples during the 2013/14 fishing season. The total length of individual *Palaemon serratus* sampled ranged between a minimum of 36.00 mm and a maximum of 115.17 mm. The mean total length was 79.42 mm ± 0.43 SE whilst the median was 78.00 mm.

The distribution of aggregated data was found not to be normally distributed (Shapiro-Wilk normality test, W=0.98, p <0.001) meaning the null hypothesis that the aggregated sample is normally distributed is rejected. The distribution can be visualised in Figure 3.1.

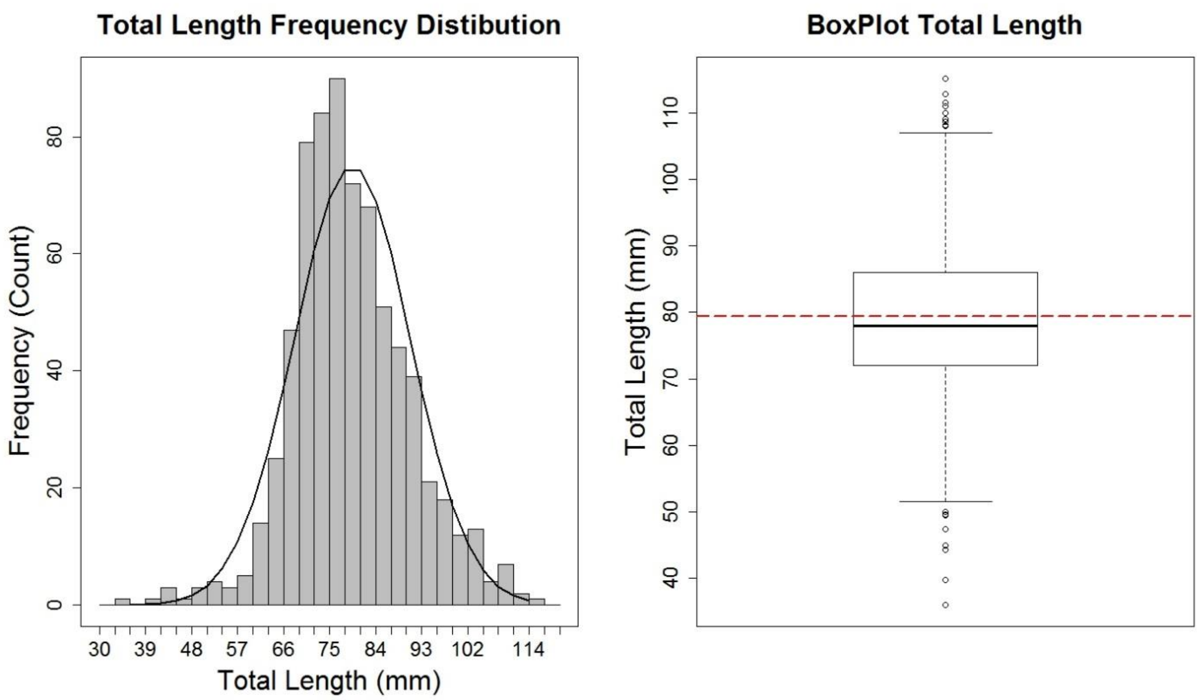


Figure 3.1 - Total length of *Palaemon serratus* (sp.) sampled using scientific pots 2013/14, Frequency plotted against a normal distribution curve. Red-dashed line represents mean value.

Figure 3.2 shows the available data and indicates some degree of variation in the total length distribution between sites and also a temporal change within locations by season. Table 3.2 provides summary statistics of total length by location and season.

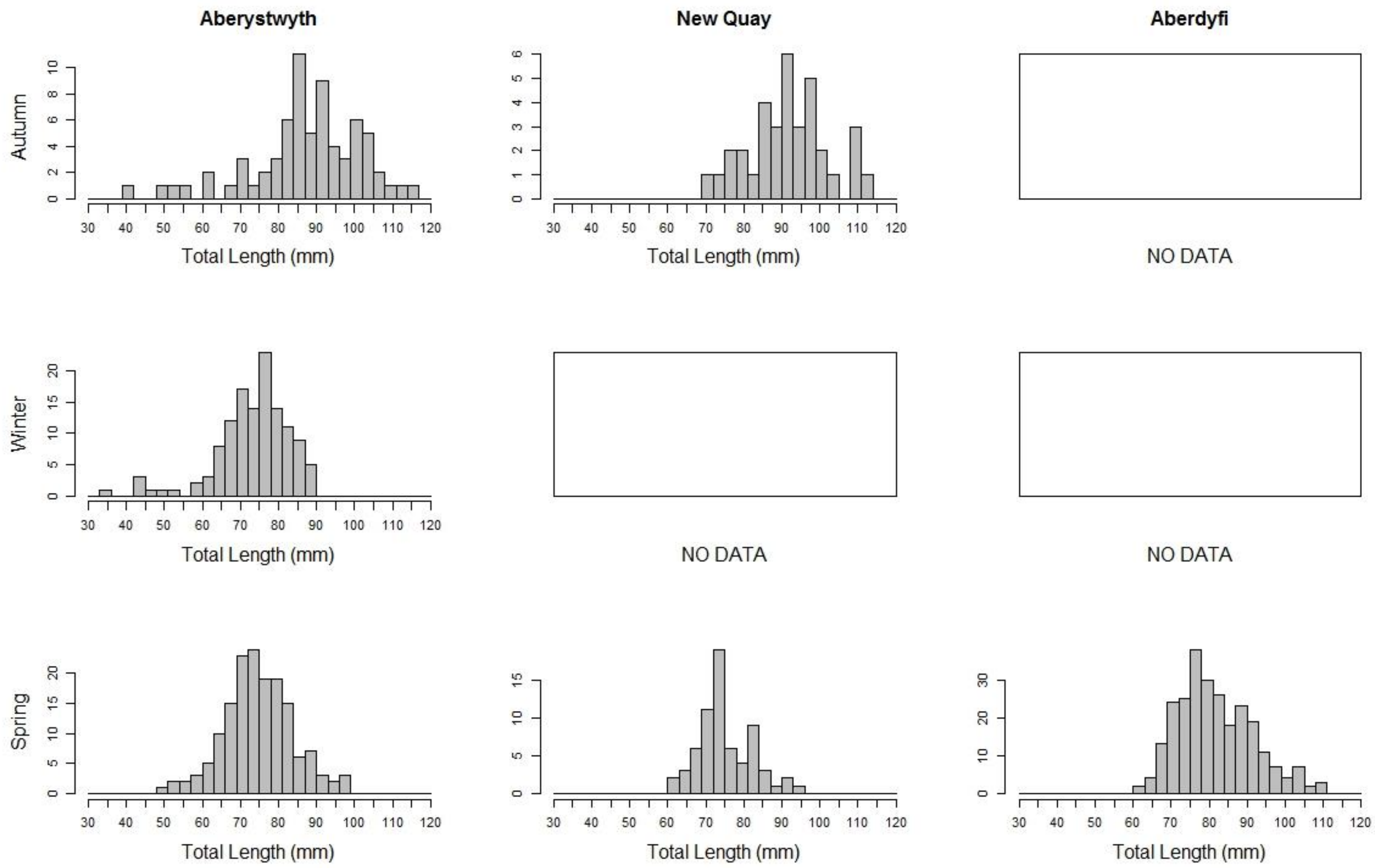


Figure 3.2 - The total length distribution of *Palaemon serratus* (sp.) from scientific pot returns by location and season. Blank plots represent a zero sample return rate.

Table 3.2 - Summary statistics of measured Total Length of *Palaemon serratus* (sp.) from scientific pot samples by Location and Season 2013/14. Min, minimum; Max, maximum; LQ lower quartile; UQ, upper quartile.

Location	**Total Length (mm)**				
Season	Min	Mean	Max	LQ	UQ
Aberdyfi					
Autumn	-	-	-	-	-
Winter	-	-	-	-	-
Spring	61.00	82.26	111.00	75.00	89.00
Aberystwyth					
Autumn	39.83	87.46	115.20	82.06	96.58
Winter	36.00	73.43	89.30	69.00	79.80
Spring	50.00	74.87	98.00	69.75	80.75
New Quay					
Autumn	70.50	91.71	112.80	86.37	97.44
Winter	-	-	-	-	-
Spring	62.00	75.75	95.00	71.00	80.00

From the data available, it is possible to conduct a comparison between sites for samples returned in spring. Furthermore, it is possible to investigate how the length distribution of *Palaemon serratus* changed through the season with samples retrieved from Aberystwyth.

Preceding further statistical analysis, the normality of total length data was reassessed on a Location~Season series of events using the Shapiro-Wilk test. The spring and winter samples from Aberystwyth were not normally distributed (Shapiro-Wilk normality test, $W = 0.94$, p-value = 0.004; Shapiro-Wilk normality test, $W = 0.91$, p-value < 0.001) whereas the spring sample was found to be normally distributed (Shapiro-Wilk normality test, $W = 0.99$, p-value = 0.47). Data from New Quay was normally distributed in the autumn (Shapiro-Wilk normality test, $W=0.98$, p-value = 0.78) and spring samples (Shapiro-Wilk normality test, $W = 0.966$, p-value = 0.06). Finally, the sample collected from Aberdyfi in spring was not normally distributed (Shapiro-Wilk normality test, $W = 0.97$, p-value < 0.001).

Homoscedasticity was assessed in order to test the null hypothesis, which assumes that the samples are of equal variance. This was done using Levene's test for all parameters. Total length was shown to have unequal variance between seasons (Levene's Test for Homogeneity of Variance [centre = median], df = 709, F = 5.33, p-value = 0.05). Contrastingly, data has equal variance between locations (Levene's Test for Homogeneity of Variance [centre = median], df = 709, F = 1.62, p-value = 0.20). Non-parametric tests were therefore used to conduct temporal comparisons, whilst ANOVA was employed to investigate spatial variations.

The total length distribution was significantly different in spring compared to autumn in New Quay (ANOVA, p-value < 0.001). The difference can be seen visually in Figure 3.2, but is emphasised in Figure 3.3.

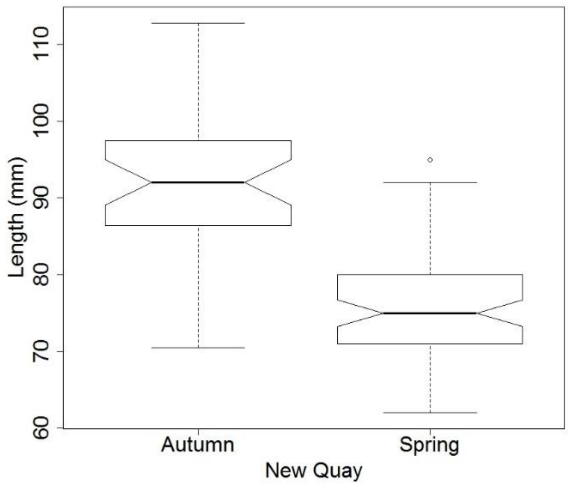


Figure 3.3- The total length distribution of *Palaemon serratus* (sp.) from New Quay samples in autumn and spring. ANOVA test reveals significant difference (p < 0.001).

The test was repeated for Aberystwyth, and revealed significant difference in the total length distribution between seasons (Kruskal-Wallis Rank Sum Test, χ^2 = 65.77, df = 2, p-value < 0.001). However, visual inspection of both Figure 3.2 and 3.4 shows that significant variation does not occur across all seasons, with winter and spring having similar total length distributions. This visual analysis is supported by the summary statistics presented in table 3.2.

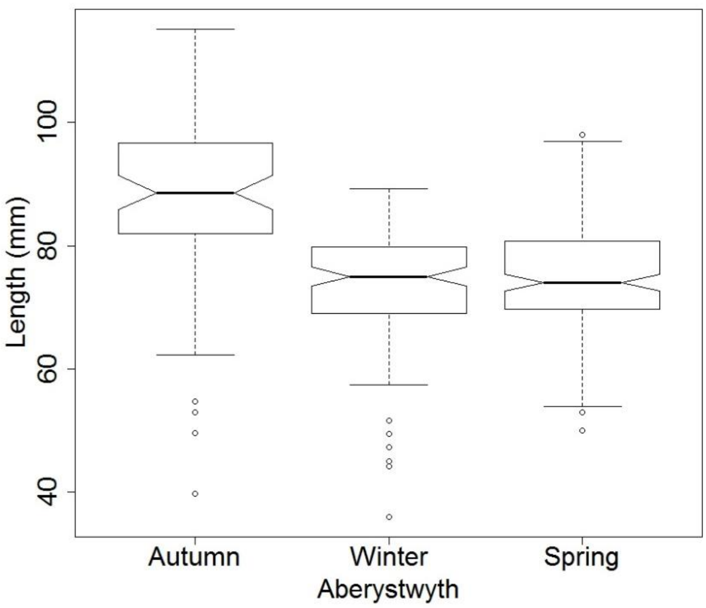


Figure 3.4 - The total length distribution of *Palaemon serratus* (sp.) from Aberystwyth samples in Autumn, Winter and Spring. Non-normal test shows significance (Kruskal-Wallis Rank Sum Test, = 65.77, df = 2, p-value < 0.001).

Total length varied between locations in spring, when samples were available from all three locations (ANOVA, p-value < 0.001), more specifically between Aberdyfi and both Aberystwyth (p < 0.01) and New Quay (p < 0.01). The difference in total length distributions can be observed in Figure 3.2 but is presented here in Figure 3.5 for clarity.

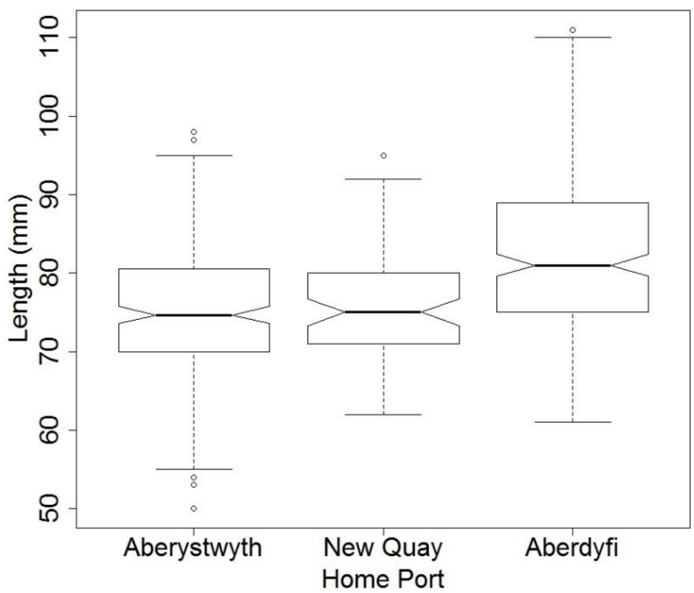


Figure 3.5 - The total length distribution of *Palaemon serratus* (sp.) samples taken from all locations in spring 2014.

3.1.2 – Carapace length (CL)

The carapace length (CL) of individual *Palaemon serratus* sampled ranged between a minimum of 6.00 mm and a maximum of 25.00 mm. The mean ± standard error (SE) was 17.72 ± 0.10 mm whilst the median was 17.98 mm.

The distribution of aggregated data was found not to be normally distributed (Shapiro-Wilk normality test, $W=0.98$, $p <0.001$) meaning the null hypothesis that the aggregated sample is normally distributed is rejected. The distribution can be visualised in Figure 3.6, with carapace length values presented in Table 3.3.

Carapace length analysis reflected the same relationships in the temporal and spatial comparisons as described by total length analysis (see section 3.1.1). The exception to this is the between-sites comparison in spring, where a significant difference in carapace length was only observed between New Quay and Aberdyfi (pair-wise TukeyHSD, $p = 0.003$), with remaining comparisons being non-significant.

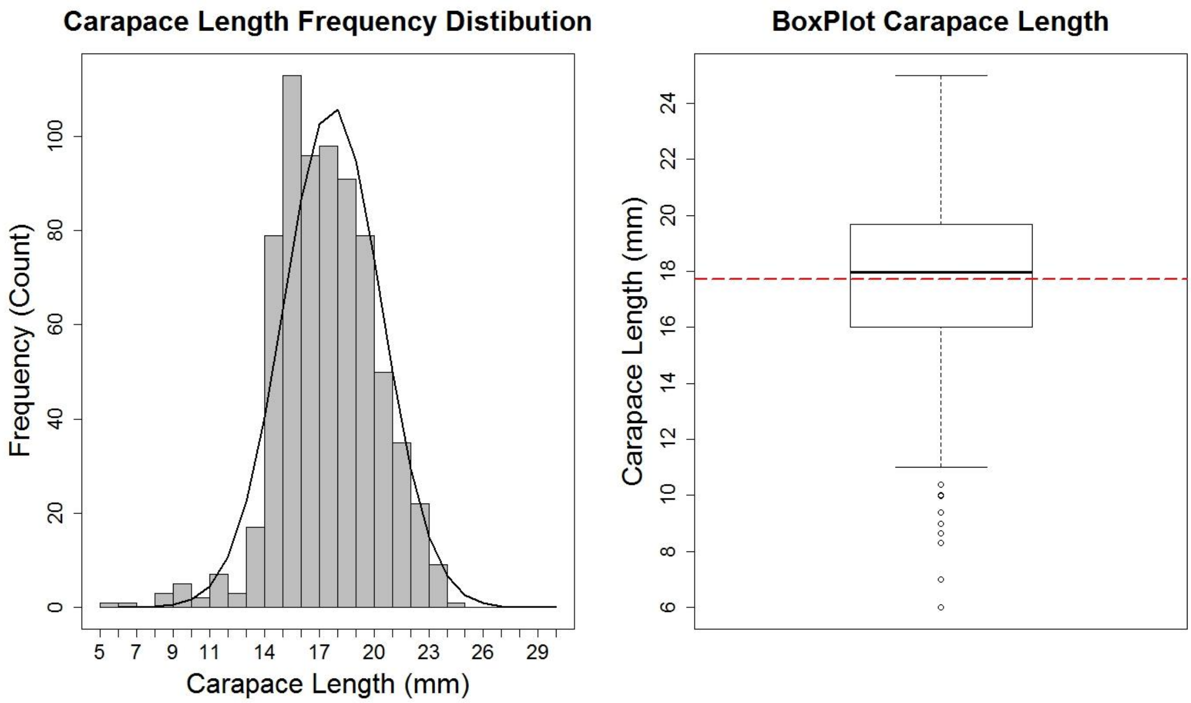


Figure 3.6 - Carapace length of *Palaemon serratus* (sp.) sampled using scientific pots, Winter 2013/14, Frequency plotted against a normal distribution curve. Red-dashed line represents mean average value.

Table 3.3 - Summary statistics of measured Carapace Length of Palaemon serratus (sp.) from scientific pot samples by Location and Season 2013/14. Min, minimum; Max, maximum; LQ lower quartile; UQ, upper quartile.

Location	**Carapace Length (mm)**				
Season	Min	Mean	Max	LQ	UQ
Aberdyfi					
Autumn	-	-	-	-	-
Winter	-	-	-	-	-
Spring	6.00	18.07	24.00	16.00	20.00
Aberystwyth					
Autumn	9.39	18.29	23.34	16.80	20.04
Winter	8.30	17.06	22.40	15.40	19.00
Spring	10.00	17.53	24.00	16.00	19.00
New Quay					
Autumn	8.66	18.74	20.11	18.12	20.11
Winter	-	-	-	-	-
Spring	7.00	16.91	25.00	16.00	18.00

3.1.3 – Isometric growth in *Palaemon serratus*

With length-based data, it is possible to assess whether the growth of *Palaemon serratus* is isometric. This was done with a linear regression model, which plotted carapace length (CL) against total length (TL) and addressed the null hypothesis that assumes the distribution in CL is not related to the distribution in TL. The fitted linear model is described by the function;

$$CL = 0.17\ TL + 4.165$$

The model produced a coefficient of determination (R^2) value of 0.53, explaining 53% of the variance in data. The relationship between TL and CL is significant ($p < 0.001$), which suggests with high confidence that *Palaemon serratus* growth is isometrically proportional, where CL ~ TL (Figure 3.7).

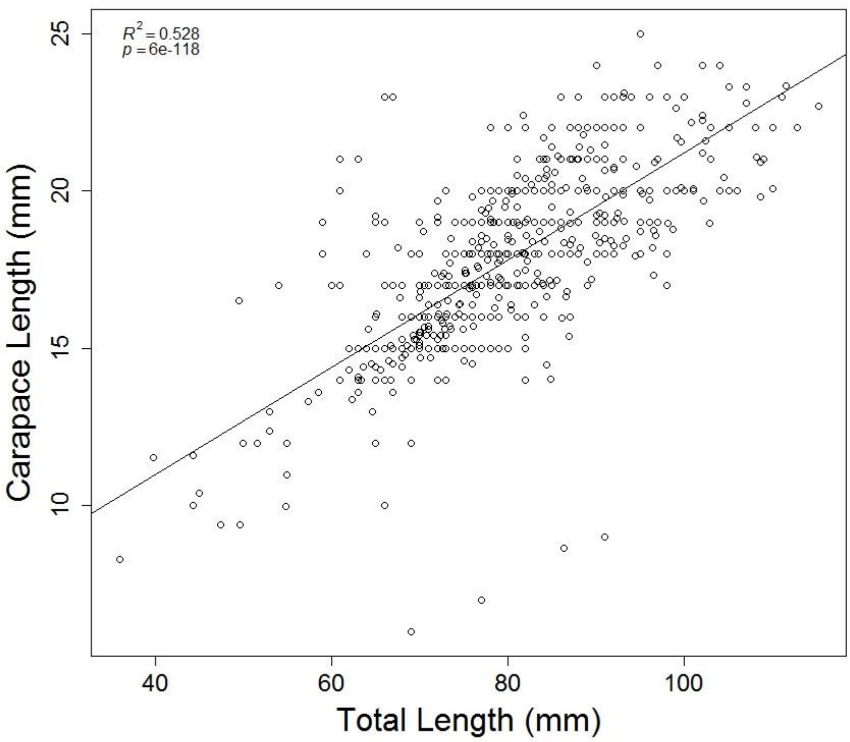


Figure 3.7 – A linear model explaining isometric growth in *Palaemon serratus* (sp.) from aggregated TL and CL data (CW = 0.17 TL + 4.165, R^2 = 0.53, p-value < 0.001)

To determine if the carapace width (CW) increased incrementally with length, a second linear model which fitted CW against TL was tested and produced a coefficient of determination (R^2) value of 0.56, explaining 56% of the variance in data ($p < 0.001$). The model is shown in Figure 3.8 and is described by the following equation;

$$CW = 0.124\,TL + 0.97$$

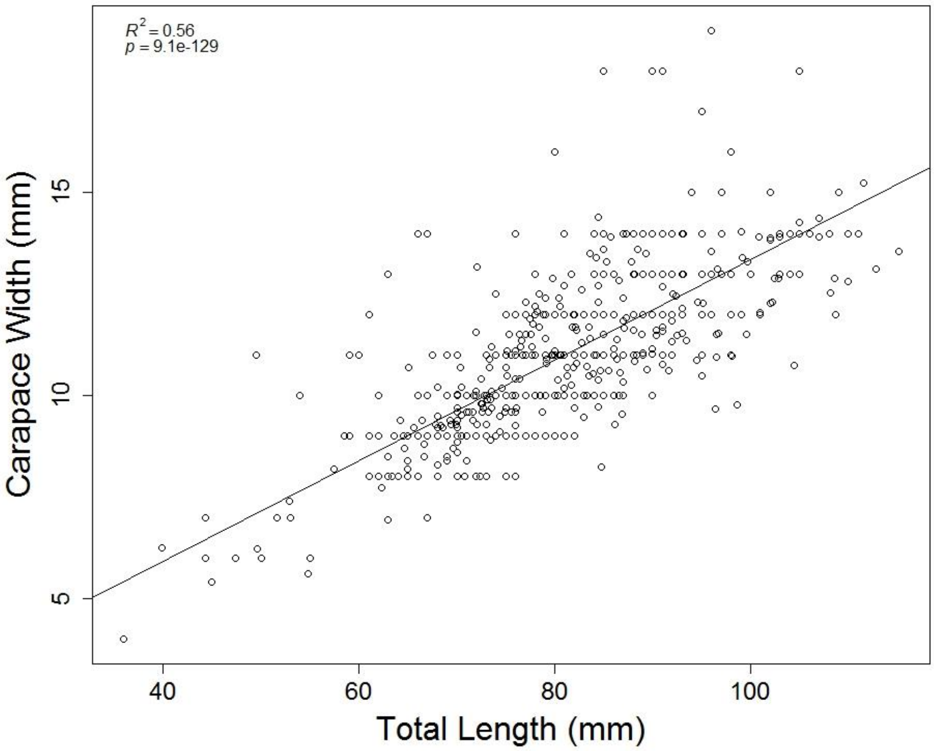


Figure 3.8 – A linear model explaining isometric growth in *Palaemon serratus* (sp.) from aggregated TL and CW data ($CW = 0.124\ TL + 0.97$, $R^2 = 0.56$, p-value < 0.001)

3.2 – Length-weight relationship analysis

The aggregated mean weight ± standard error (SE) of *Palaemon serratus* sampled by scientific pots was 5.579 g ± 0.087. The data exhibited a strong non-normal distribution with a positive skew. Transforming the data using natural log, square-root or inverse transformations did not shift the distribution sufficiently to return a non-significant p-value from a Shapiro-Wilk test. The closest transformation was square-root, shown in Figure 3.9.

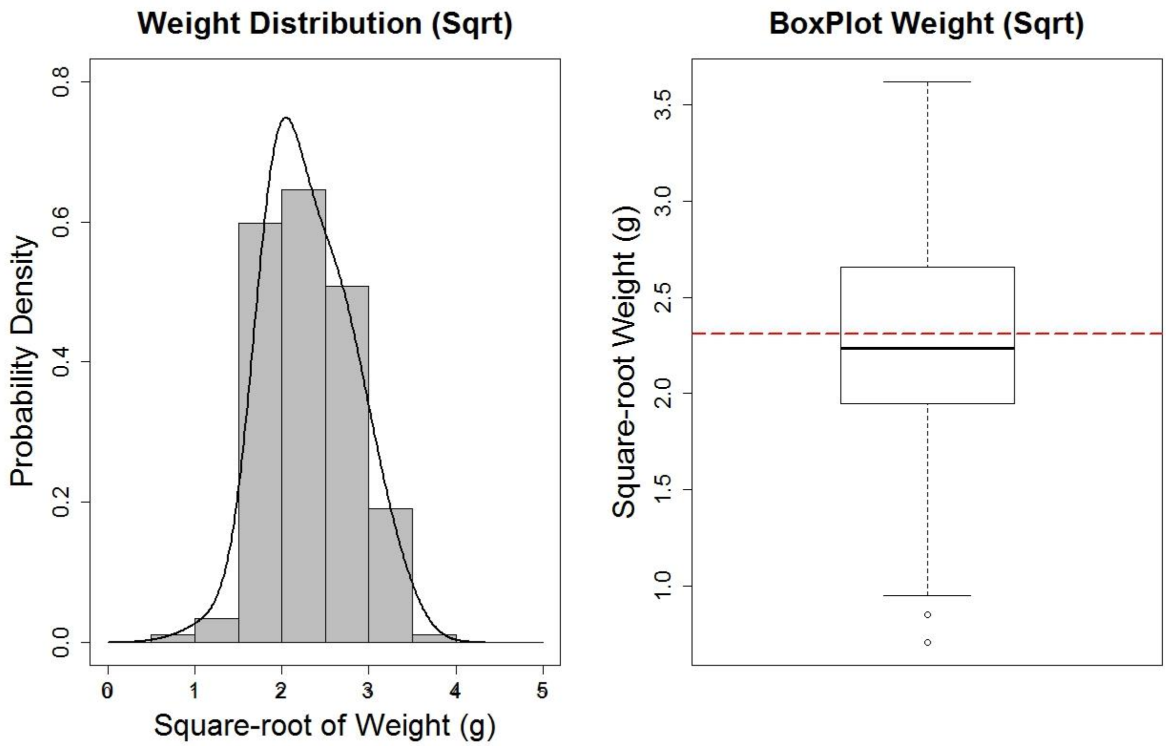


Figure 3.9 – Weight of *Palaemon serratus* (sp.) sampled using scientific pots, Winter 2013/14, Weight is transformed using a square-root function. Probability Histogram plotted against a density estimate line. Red-dashed line represents mean average value.

A linear model method was used to investigate the effect of total length and carapace length on the weight of *Palaemon serratus*.

A significant positive relationship existed for both TL and CL when modelled against √Weight. The $\sqrt{\text{Weight}} \sim \text{TL}$ model produced an R^2 value of 0.57, explaining 57% of the variance in data with a significance value of $p < 0.001$. The fitted relationship can be seen in Figure 3.10 and is defined by the equation;

$$\sqrt{Weight} = 0.032\ TL - 0.25$$

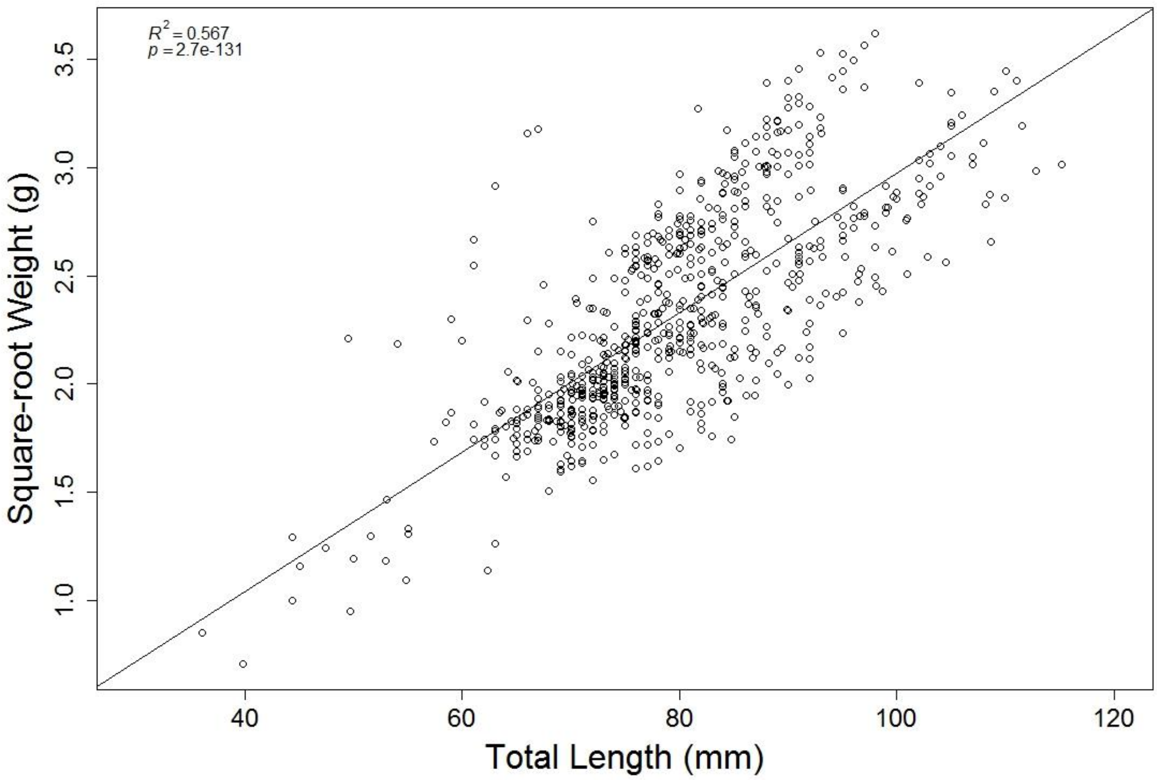


Figure 3.10 – A linear model explaining the length-weight relationship of *Palaemon serratus* (sp.) from aggregated TL and transformed Weight data ($\sqrt{Weight}$ = 0.032 TL – 0.25, R^2 = 0.57, p-value < 0.001)

However, results show that the model √Weight ~ CL is an improvement on √Weight ~ TL for explaining weight of *Palaemon serratus*, with an R^2 value of 0.74 (p < 0.001). The linear CL ~ √Weight model is defined by the equation;

$$\sqrt{Weight} = 0.16\ TL - 0.47$$

A Kruskal-Wallis test revealed no significant temporal or spatial change in the weight distribution of *Palaemon serratus* with the available data.

3.3 – Sexual dimorphism

Neither the aggregated male nor female total length (TL) data is normally distributed (Shaprio-Wilk normality test, W = 0.9605 (male), W = 0.9804 (female), $p < 0.001$). The mean ± standard error (SE) of aggregated TL data for male and female is 74.43 mm ± 0.43 and 85.89 mm ± 0.64 respectively. The TL distribution was different for male and female *Palaemon serratus* caught in scientific pots during the winter 2013/14 fishing season (Kruskal-Wallis Rank Sum Test, χ^2 = 206.77, df = 1, p-value < 0.001; Figure 3.11).

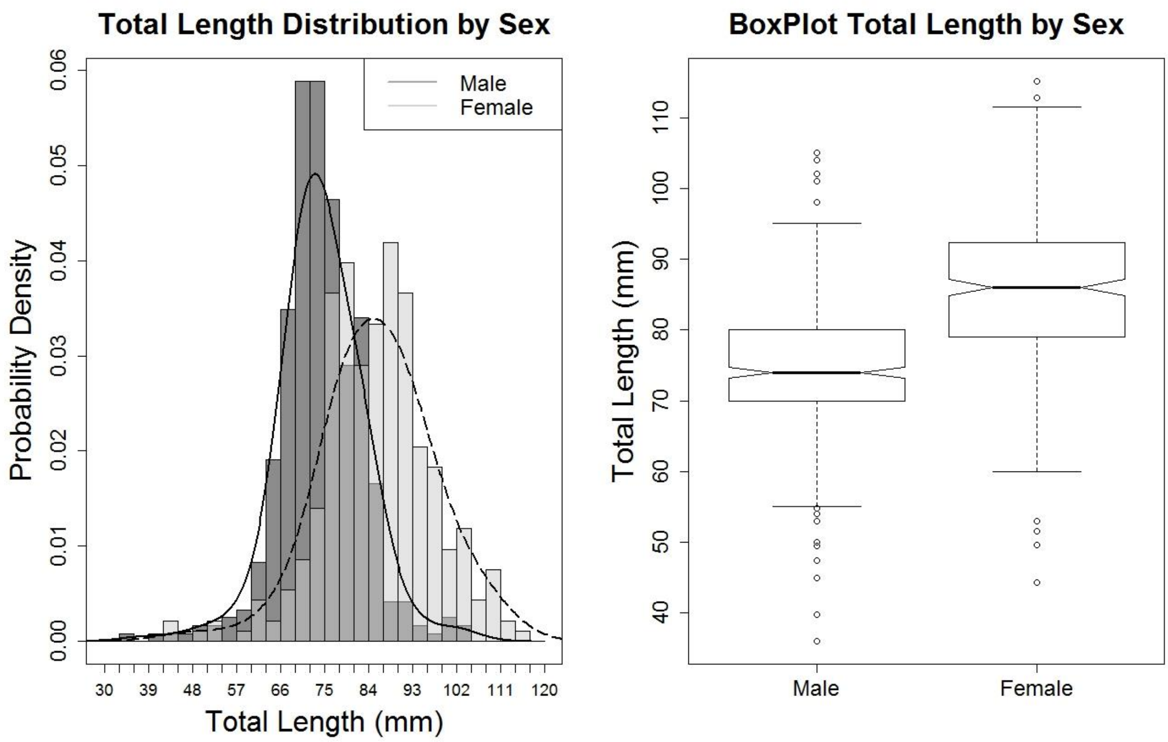


Figure 3.11 – TL of *Palaemon serratus* (sp.) by sex sampled using scientific pots, Winter 2013/14, Histogram fitted with a "smoothed" probability to curve to emphasise difference in distribution (solid = male, dashed = female). N.B, the medium grey colour represents overlapping distributions of male and female distributions.

Similarly, neither the aggregated male nor female carapace length (CL) data is normally distributed (Shaprio-Wilk normality test, W = 0.94 (M), W = 0.90 (F), $p < 0.001$). The mean average ± S.E of aggregated CL data for male and female is 16.35 mm ± 0.10 and 19.49 mm ± 0.14 respectively. The CL distribution is different for male and female *Palaemon serratus* caught in scientific pots during the winter 2013/14 fishing season (Kruskal-Wallis Rank Sum Test, χ^2 = 305.47, df = 1, p-value < 0.001), shown in Figure 3.12.

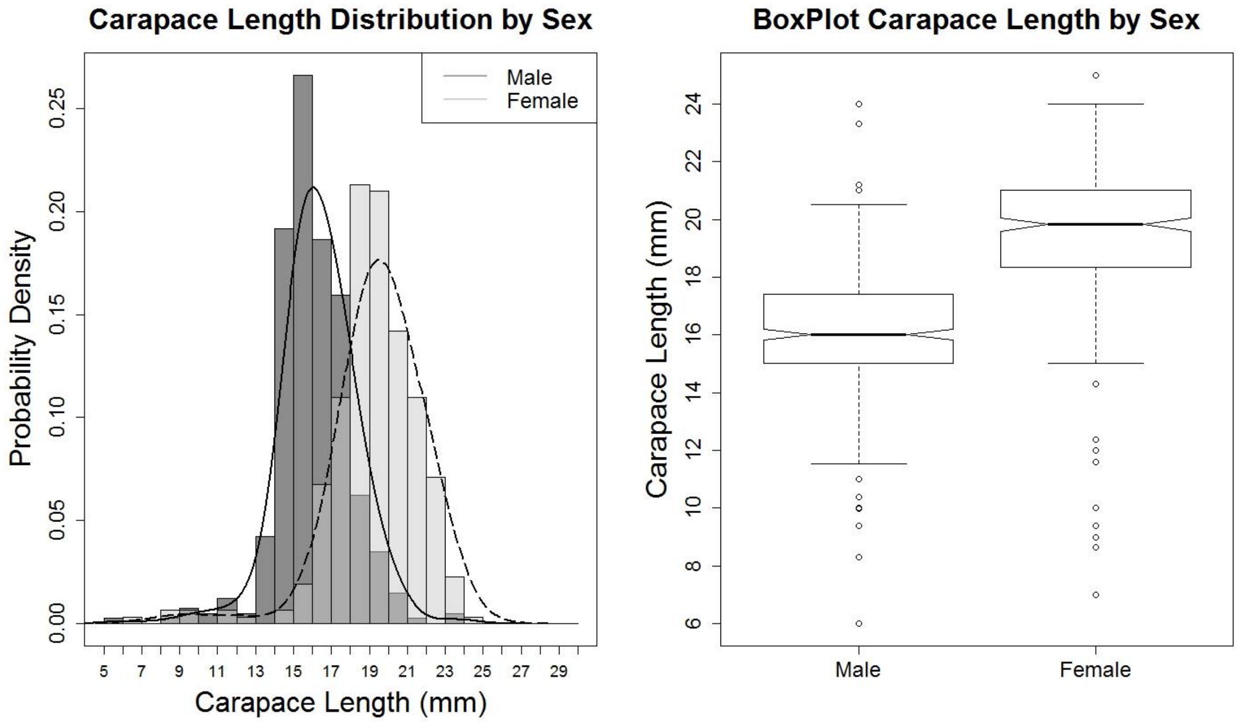


Figure 3.12 – CL of *Palaemon serratus* (sp.) by Sex sampled using scientific pots, Winter 2013/14, Histogram fitted with a "smoothed" probability to curve to emphasise difference in distribution (solid = male, dashed = female).

With the above findings, an Analysis of Covariance (ANCOVA) method was employed to investigate whether the relationship between TL and CW of *Palaemon serratus* is better described by including the additional independent binomial variable "Sex".

The ANCOVA analysis revealed that the CW is significantly determined by both TL (ANCOVA, $p < 0.001$) and Sex (ANCOVA, $p < 0.001$). The ANCOVA model found that the maximal model, where both slope and intercept are different for male and female models, was almost significant ($p = 0.06$) and rejected in preference of the minimal model. The multivariate model (CW ~ TL + Sex) has an R^2 value of 0.66 ($p < 0.001$), which is a 10% improvement on univariate model CW ~ TL (see Figure 3.10). The results of the ANCOVA analysis can be seen in Figure 3.13 and are described by the following two equations;

$$CW_{\ Male} = 0.093\, TL + 2.777$$
$$CW_{\ Female} = 0.093\, TL + 4.171$$

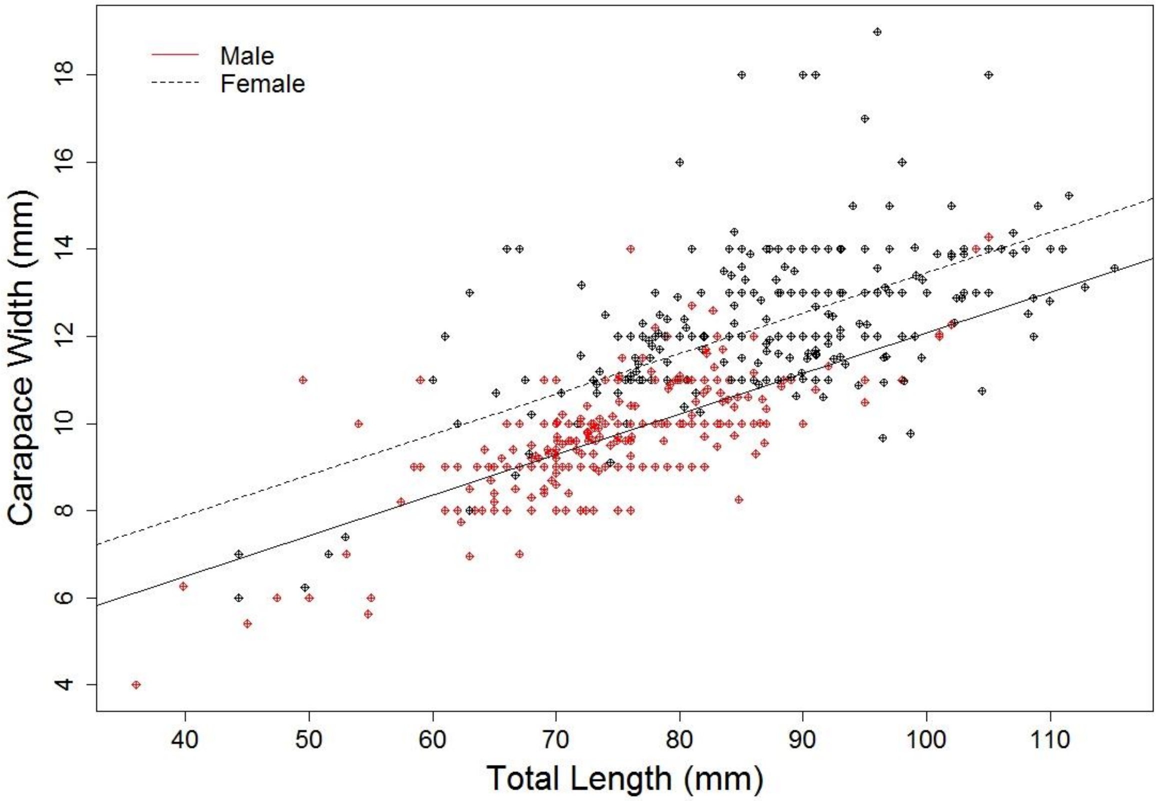


Figure 3.13 – Linear model of CW ~ Sex + TL of *Palaemon serratus* (sp.) sampled using scientific pots, Regression lines defined on previous page. Point characters indicate male and female observations, where red = male and female = black.

An ANOVA test was used to compare the multivariable and unvariate models. It found that there is a significant improvement in the ability to explain the data by including Sex with TL in a linear model against CW (Analysis of Variance, Sum of squares = 255.12, F = 212.8, $p < 0.01$).

3.4 – *Sexual maturity and fecundity*

3.4.1 – Sexual maturity

A total of 200 gravid females were sampled. The mean ± S.E of gravid female total length (TL) data is 87.10 mm ± 0.43. The smallest *P. serratus* caught during the sampling period had a total length of 60 mm. The gravid female TL data is not normally distributed (Shaprio-Wilk normality test, W = 0.98, $p < 0.0135$; Figure 3.14).

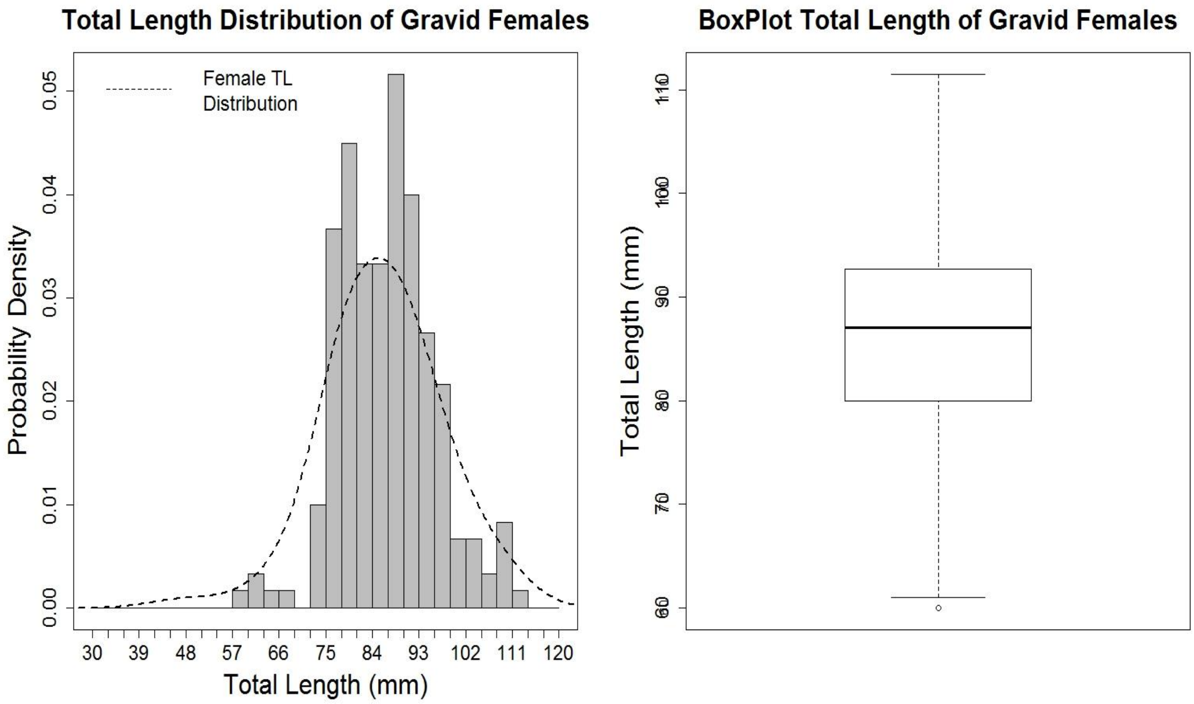


Figure 3.14 – TL of gravid *Palaemon serratus* (sp.) sampled using scientific pots. Histogram fitted with a "smoothed" probability curve of aggregate female TL for comparison (including non-gravid females).

The length distribution of gravid females varied significantly different between both location (Kruskal-Wallis Rank Sum Test, χ^2 = 14.82, df = 1, p-value < 0.001) and season (Kruskal-Wallis Rank Sum Test, χ^2 = 11.35, df = 1, p-value = 0.003), as seen in Figure 3.15 and 3.16.

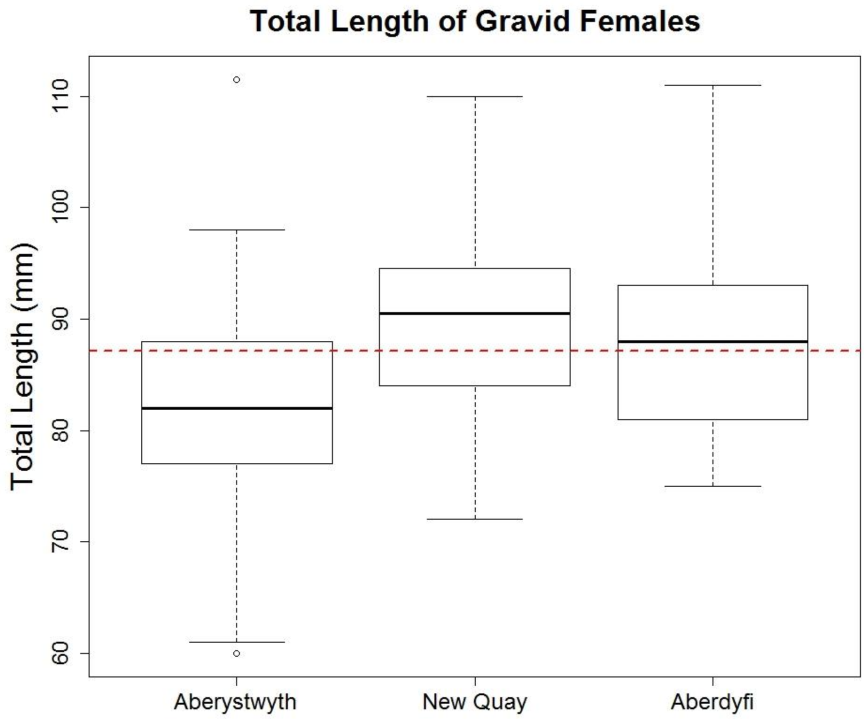


Figure 3.15 – TL of gravid *Palaemon serratus* (sp.) sampled using scientific pots by Location. Red-dashed horizontal line shows the mean average TL for gravid females (87.10 mm)

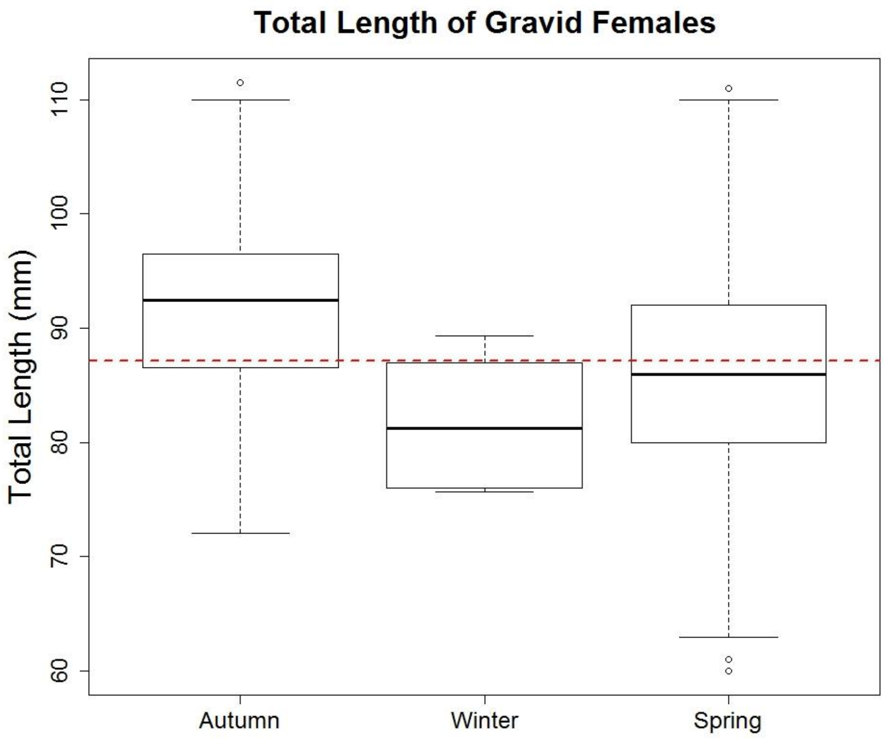


Figure 3.16 – TL of gravid *Palaemon serratus* (sp.) sampled using scientific pots by Season. Red-dashed horizontal line shows the mean average TL for gravid females (87.10 mm)

The total length data for gravid females showed equal variance between location (Levene's Test for Homogeneity of Variance [centre = median], df = 197, F = 0.05, p-value = 0.95) and season (Levene's Test for Homogeneity of Variance [centre = median], df = 197, F = 1.17, p-value = 0.31).

The mean total length of gravid females varied between locations (ANOVA, p < 0.001), more specifically between Aberystwyth and Aberdyfi (TukeyHSD, p < 0.001) and Aberystwyth and New Quay (TukeyHSD, p = 0.002). The mean total length of *P serratus* was also found to vary significantly between seasons (ANOVA, p < 0.001), specifically between autumn and spring (TukeyHSD, p = 0.03) and autumn and winter (TukeyHSD, p =0.01).

3.4.2 – Fecundity

The mean fecundity ± S.E of gravid females is 2009 ± 69. The maximum number of eggs estimated to have been carried by a *P. serratus* was estimated as 5,121 at a total length (TL) of 94.57 mm. The fewest eggs carried by an individual *P. serratus* was estimated to be 221 at a TL of 85 mm (Figure 3.17).

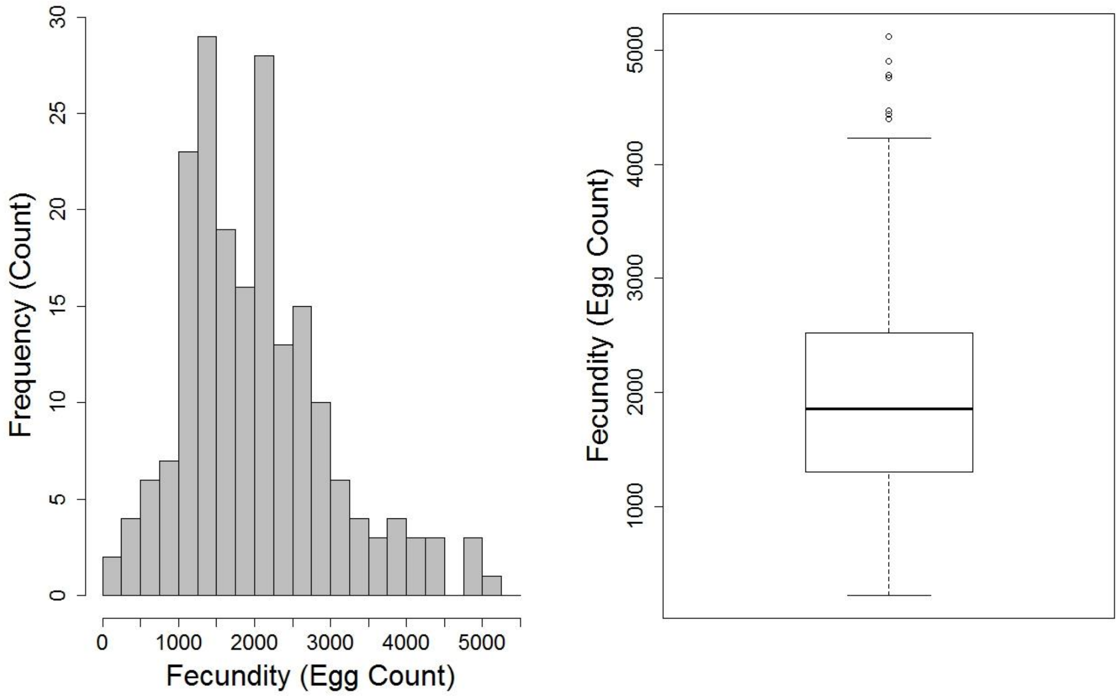


Figure 3.17 – Fecundity distribution of *Palaemon serratus* (sp.) sampled using scientific pots.

The data is not normally distributed (Shapiro-Wilk normality test, W = 0.95, p < 0.001). A square-root transformation adequately addressed the distribution (Shaprio-Wilk normality test, W = 0.99, p = 0.3112). The transformed distribution is shown in Figure 3.18.

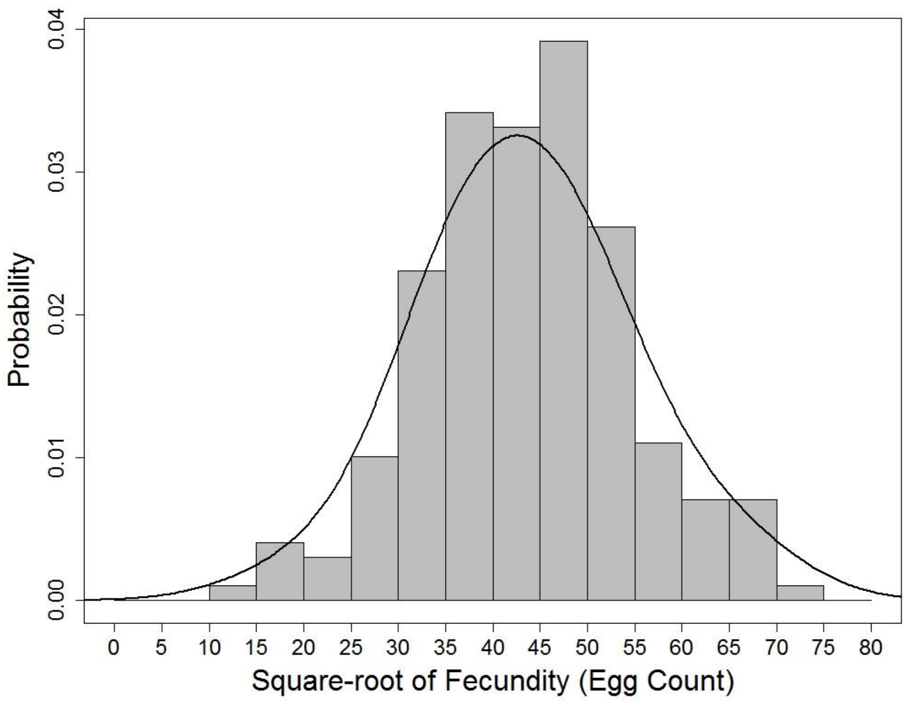


Figure 3.18 – Fecundity probability distribution of gravid *Palaemon serratus* (sp.) sampled using a square-root transformation. Normal distribution curve fitted for comparison.

The average fecundity of gravid females did not vary significantly by neither location (ANOVA, p = 0.18) nor season (ANOVA, p = 0.23).

TL and √Fecundity was shown to have a strong linear relationship from regression analysis ($\sqrt{Fecundity}$ = 0.322 TL + 15.51, R^2 = 0.07, p-value = 0.03) despite the linear model not being able to explain 93 % of the variation in data.

Despite carapace width (CW) and √Fecundity not having a significant linear relationship (R^2 value = 0.16, p-value = 0.188) visual interpretation of the relationship between fecundity ~ CW analysis is that, with the exception of one anomaly, all gravid females have a CW > 10 mm as shown in Figure 3.19.

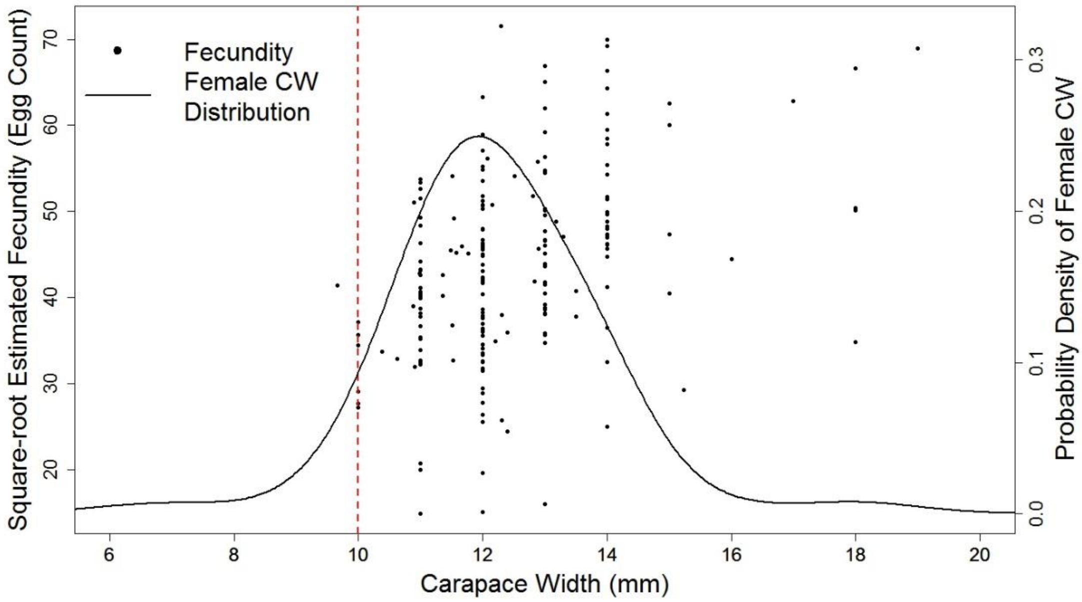


Figure 3.19 – Transformed fecundity (using square-root transformation) of *Palaemon serratus* (sp.) against CW. Probability density of female *P. serratus* CW distribution shows CW of gravid and non-gravid female CW. Red-dotted line at 10 mm CW represents typical riddling size of Cardigan Bay fishers.

The size at onset of maturity (SOM) can be estimated using the graphical representation above to be at CW = 10 mm. The size of maturity ogive calculated showed that approximately 35% of prawn were berried at a CW of 10 mm (Figure 3.20).

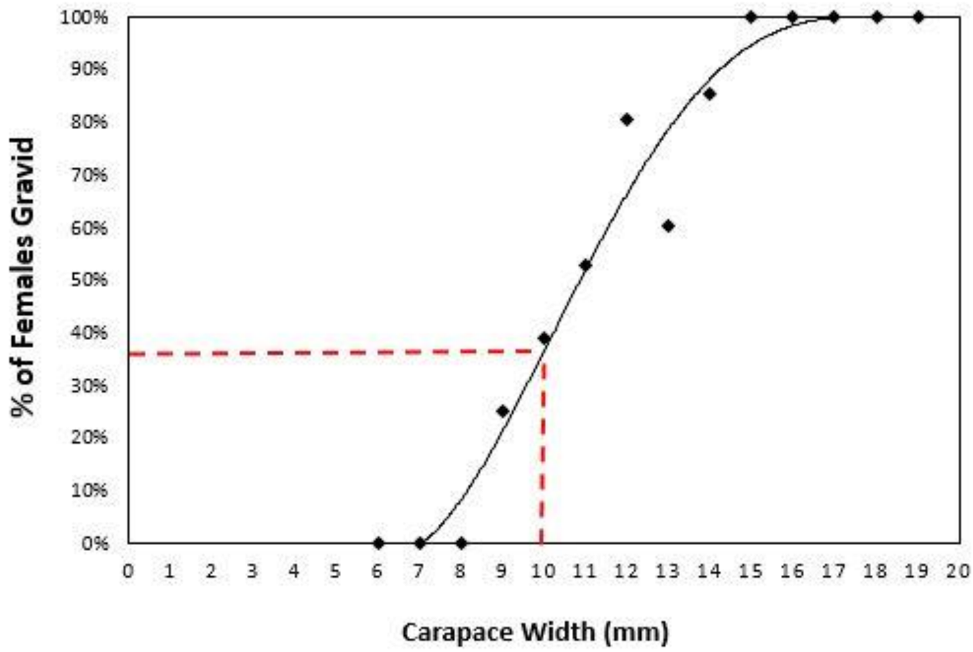


Figure 3.19 – The probability of maturity against size (in CW) displayed as the % of sampled females that were gravid at each carapace width value. Data from samples aggregated across all locations and throughout the fishing season.

3.5 – *Sex ratio*

Of the 712 *P. serratus* caught within scientific pots over the 2013 / 14 fishing season, the M : F sex ratio was approximately 9 : 7 (Male count = 402, Female count = 310). The aggregated sex ratio skew towards Male was significant ($G^2 = 11.66$, $p < 0.001$). Other significant sex ratio skews were found to occur in a number of temporal and spatial events, presented in table 3.4.

Table 3.4 –Significant sex ratio skews observed in P. serratus populations across spatial and temporal samples. Bold and underlined Male / Female counts highlight the skew direction.

Location	**Year**	**Season**	**Month**	**Female *n***	**Male *n***	**Exp.**	***G***	***p***
Aberystwyth	*Agg.*	*Agg.*	*Agg.*	145	**<u>212</u>**	178	12.27	< 0.001
Agg.	2013	Autumn	Nov	**<u>63</u>**	32	47.5	9.64	0.002
New Quay	2013	Autumn	Nov	**<u>33</u>**	2	17.5	33.19	< 0.001
Agg.	2014	Spring	Mar	83	**<u>204</u>**	143.5	51.75	<0.001
Aberdyfi	2014	Spring	Mar	38	**<u>85</u>**	61.5	18.42	< 0.001
Aberystwyth	2014	Spring	Mar	37	**<u>80</u>**	58.5	18.42	< 0.001
New Quay	2014	Spring	Mar	83	**<u>205</u>**	144	53.5	< 0.001
New Quay	2014	Spring	Apr	3	**<u>16</u>**	9.5	9.76	0.002
Aberystwyth	2014	Spring	May	15	**<u>28</u>**	21.5	3.99	0.046

3.6 – *Discards and bycatch*

Of the 712 *P serratus* sampled, 199 were found to have a carapace width < 10 mm. The composition of discarded *P. serratus* catch from data aggregated across temporal and spatial scales is shown in Figure 3.20.

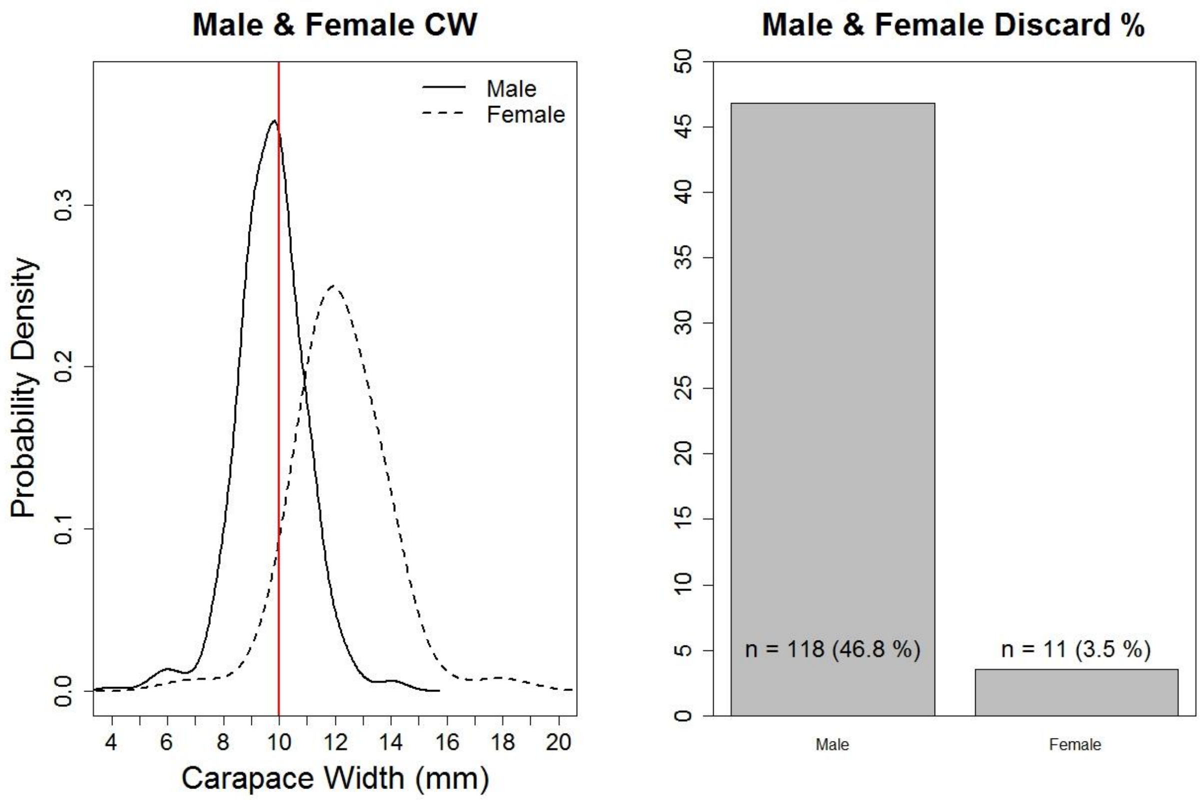


Figure 3.20 – The CW distribution of Male and Female *P. serratus,* showing the discarded catch to the left of the vertical red line (placed at 10 mm carapace width). Barplot show the Male and Female discard rate as a % of total male and female catch (n = number of male / female individuals with a carapace width < 10 mm).

The discard sex ratio is heavily skewed (M:F sex ratio of approximately 17:1) representing a significant deviation from the expected 1:1 ratio ($G^2 = 101.29$, $p < 0.001$) and occurred throughout the all seasons and locations.

The non-target species (bycatch) caught in scientific pots consisted of both crustaceans and finfish species. The diversity of bycatch from aggregated data included 16 separate species (Table 3.5). The diversity of bycatch species varied by site. Only two species were found to occur at all sites (Table 3.6).

Table 3.5 –Abundance and diversity of bycatch within the *P. serratus* fishery 2013/14 scientific pot samples. Underline highlights commercially valuable species.

Species name	Common name	Abundance (% total weight)
Crustaceans		
Carcinus maenas	Green crab	3.45
Crangon crangon	Brown shrimp	3.45
Liocarcinus depurator	Harbour crab	17.24
Liocarcinus holstatus	Swimming crab	3.45
Liocarcinus pusillus	Dwarf swimming crab	1.72
<u>*Necora puber*</u>	<u>Velvet swimming crab</u>	<u>24.14</u>
Pisidia lonogicornis	Porcelain crab	1.72
Pagurus bernhardus	Hermit crab	6.90
Palaemon sp.	Prawn sp.	5.17
Teleost fish (finfish)		
Gaidropsarus mediterraneus	Shore rockling	1.72
Gaidropsarus vulgaris	Three-bearded rockling	3.45
<u>*Merlangius merlangius*</u>	<u>Whiting</u>	<u>18.97</u>
Pholis gunnellus	Butterfish	1.72
<u>*Gadus morhua*</u>	<u>Cod</u>	<u>1.72</u>
Trisopterus minutus	Pouting	3.45
Gobiidae	Goby	1.72

Table 3.6 – Presence (**X**) and absence (-) of bycatch within the *P. serratus* fishery 2013/14 scientific pot samples by Location. Underline highlights commercially valued species.

Species name	Aberystwyth	New Quay	Aberdyfi
Crustaceans			
Carcinus maenas	**X**	-	-
Crangon crangon	-	-	**X**
Liocarcinus depurator	**X**	**X**	**X**
Liocarcinus holstatus	-	-	**X**
Liocarcinus pusillus	-	-	**X**
<u>*Necora puber*</u>	<u>**X**</u>	<u>**X**</u>	<u>**X**</u>
Pisidia lonogicornis	**X**	-	-
Pagurus bernhardus	**X**	-	**X**
Palaemon sp.	-	**X**	-
Teleost fish (finfish)			
Gaidropsarus mediterraneus	**X**	-	-
Gaidropsarus vulgaris	**X**	**X**	-
<u>*Merlangius merlangius*</u>	<u>-</u>	<u>**X**</u>	<u>**X**</u>
Pholis gunnellus	-	-	-
<u>*Gadus morhua*</u>	<u>-</u>	<u>-</u>	<u>**X**</u>
Trisopterus minutus	**X**	**X**	-
Gobiidae	**X**	-	-

4.0 – Discusssion

4.1 – Data gathering and industry collaboration

The current concern of fishermen is that shellfish returns forms are not being used to assess stocks. The lack of feedback on shellfish returns forms is the likely cause of this perception and perceived lack of communication between government and industry has led to disengagement from industry, in particular with the statutory shellfish data-gathering This project hopes to re-engage industry with management and science by making reports available and accessible at association meetings, where key findings shall be explained and discussed in the “prawn working group”. By delivering project outputs with a client-focussed attitude towards fishers data, the project hopes to improve upon the 2013/14 shellfish return effort. With more shellfish return records, project officers will be able to establish baseline CPUE data, which will be invaluable in ongoing monitoring of the fishery. It is absolutely essential that the 2014/15 *P. serratus* fishing season yields accurate monthly shellfish returns along with scientific pot samples.

Contrastingly, fishermen engaged with the project delivered very valuable data via the scientific pot samples, which have formed the bulk of evidence available to project officers to date. This is particularly notable considering the difficulty fishermen had getting days at sea with bad weather and the associated gear damage from storms. With the 2014/15 season already in progress, it is hoped that the number of possible temporal and spatial scales of comparison will be improved by gathering more scientific pot samples more consistently at all locations, including fishermen in Cardigan which did not manage to get gear in the water due to bad weather in 2013/14.

4.2 – Population structure

The *Palaemon serratus* from scientific pot catches has been shown to have a bell-shaped population structure, with the most abundant size-class of prawn found close to the mean. Total length data displays temporal shifts with a greater abundance of larger prawns (> 90 mm) caught in autumn from both Aberystwyth and New Quay, and fewer, smaller (< 85 mm) prawns caught in spring. The data suggests that a second cohort recruited into the fishery during the fishing season and was able to sustain catches until May, at which point fishermen ceased targeting prawn and returned to other target species predominantly the European lobster; *Homarus gammurus*.

Binomial distributions, which would represent two clearly defined cohorts of *Palaemon serratus* was not observed. The eight millimetre mesh size of the scientific pots likely permitted the escape of small prawns to a corresponding total length of around 57 mm. Although the smallest prawn caught was 36 mm, the capture rate of *P. serratus* below 57 mm by the pots was low.

The finding that the size-structure of *P. serratus* decreases through the season is counter-intuitive, since one would expect to find the average length of prawn to increase with time, not decrease approximately 12.6 mm total length. It is possible that fishing pressure contributes to the changing population structure; as large prawn are retained on-board during Autumn, the discarded prawn are released and are allowed to later recruit into a fishery that, although has a smaller average size-class structure, still has a high enough abundance to making fishing economically viable. This evidence could highlight the importance of riddling in sustaining catches later in the season.

However, the data is not comprehensive enough to make these conclusions. The decreasing size-structure of the population could be explained by the spring samples simply not fishing as well as the autumn sample. CBFA members point out that the prawn fishery is notoriously "patchy", meaning that a single sample from each month may not represent actual changes in the population structure within the ecosystem. Any conclusions drawn from temporal and spatial comparisons in population structure must therefore be taken into account with the limitation imposed by sampling such a naturally heterogenic species.

Palaemon serratus was shown to undergo isometric growth, which is important considering that the voluntary management measure of riddling individuals with a carapace width greater than 10 mm aims to ensure a minimum total length.

4.3 – Sexual dimorphism

The most important finding of this report is the evidence of dimorphism within the species. There exists two clear population structures of male and female *P. serratus*. Although not unusual in ecology, sexual dimorphism poses challenges to management, particularly when the fishery puts unequal pressure on the male and female populations.

Although the species undergoes isometric growth, females will have a smaller total length than males at 10 mm carapace width. The riddling of prawn catches with a 10 mm riddle will retain females 1.4 mm smaller (in total length) than the average male. Although the difference appears to be small, the dimorphic nature of the fishery means that the female population is subject to much heavier fishing pressure than the male population. Of the females caught, 96.5 % had a carapace width greater than 10 mm and are therefore of a size suitable to retain, whilst only 53.2 % of males would have been retained. This imbalanced pressure on females may explain why sex ratios changed from a relatively weak female-directed skew in the autumn (G = 9.64) to a heavy and very prominent male-directed skew in the spring (G = 51.75).

The heavy-pressure on the females of the population has an additional challenge when sexual maturity is taken into account.

4.4 – Sexual maturity and discarding

It is important to note that the 10 mm riddling practice does not aim to ensure the protection of immature *P. serratus*, but is a biologically-arbitrary minimum landing size (MLS) dictated by market preference for a prawn of a certain size. Results also reveal that, in addition to the female population being subject to much heavier fishing pressure than males, the practice of riddling prawn with a carapace width greater than 10 mm may not allow the majority of females to reach maturity before recruiting into the fishery. Only one gravid female with a carapace width of less than 10 mm was caught.

The data available suggests that there is approximately a 35% chance of females reaching maturity before recruiting into the fishery. It must be emphasised that this observation is drawn from data that is limited in capacity to investigate functional maturity and make conclusive observations. Despite the data limitations, evidence does present valuable insight into maturity analysis and suggests that if a minimum landing size based on protecting at least 50% of females from exploitation before reaching functional maturity, the riddle size should be increased by what can be estimated to be 1 mm. It is explicitly stated here that this report does support implementing this technical measure as a form of conservation management in the absence of robust data. Functional maturity is an element of investigation that will be explored further with the onset of data collection during the 2014 / 15 fishing season.

In contrast to the data presented in this report, Kelly et al. (2008) found there is over a 90 % probability that a female with carapace length of 14.9 mm (which corresponds to a 10 mm carapace width from the regression analysis in section 3.1 and 3.3) will have reached maturity (Figure 4.1). Consequentially, if the average Welsh *P. serratus* is assumed to reach maturity at the same point as an Irish *P. serratus*, the practice of riddling with a 10 mm carapace width may be a very valuable technical measure for conservation purposes without the need for adjustment.

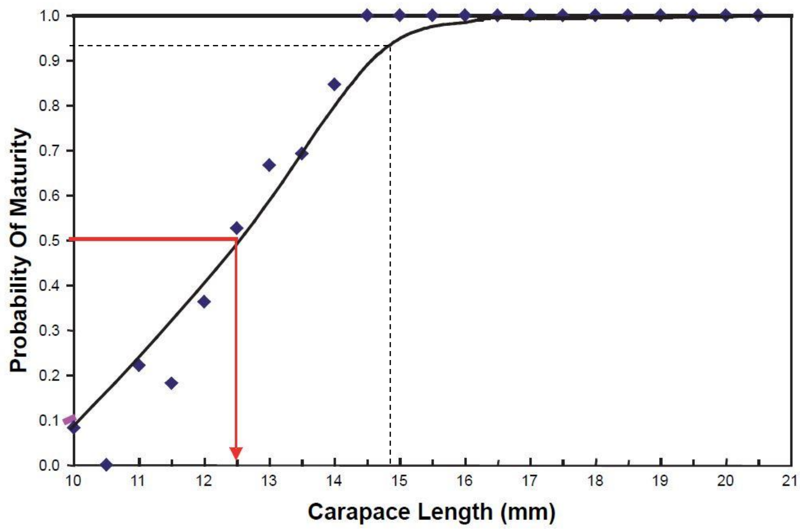


Figure 4.1 – The probability of maturity against carapace length for *P. serratus* sampled in the Irish fishery (data from the month of peak spawning only, i.e March). Red line shows the carapace length at which there is a 50 % chance of maturity (12.5 mm). Black dashed line represents the impact of riddling prawn in Welsh waters using a 10 mm riddle.

Nonetheless, the disproportionately heavy fishing pressure on the female population, coupled with the vulnerability of gravid females to exploitation, may have the potential to force juvenescence within the population, i.e. the maturation of females at an earlier point in their life cycle. Juvenescence is a conservation issue worth monitoring into the future, especially since studies of heavily exploited static gear fisheries suggests decapod crustacean species (e.g *Homarus* gammurus) offspring quality and recruitment are significantly affected by maternal influences (Moland et al., 2010). Continued monitoring should investigate whether juvenescence is occurring in the Welsh prawn fishery.

4.5 – Non *P. serratus* bycatch

The Cardigan Bay prawn fishery uses static gear, making it a relatively environmentally benign fishery in terms of physical impacts on the benthic assemblages (Coleman et al., 2013). However, like the majority of fishing methods, the fishery is susceptible to incidental bycatch of non-target species. The non-target species bycatch observed within the scientific pot samples constitutes 39 % of the total weight of all retained species. This may appear to be a relatively high bycatch rate, but is adequately explained by the fact the average weight of an individual *P. serratus* is just 5.6 g.

Furthermore, the majority of bycatch, both in terms of diversity and abundance, were crustaceans. Non-target crustacean species suffer very little mortality in static gear fishery and are very often returned live to the sea (*pers obs.*, 2014).

The survivability of returned teleost fish bycatch is expected to be lower as the experience of capture, sorting and release can endure stress that renders them unable to swim below the surface. At this point, bycatch is sometimes predated on by seabirds (*pers obs.*, 2014). At present, there is no data on the incidental mortality of bycatch in the Cardigan Bay fishery. However, observing the survivability of teleost fish is an explicit aim of the protocol adopted for on-board observations during the 2014/15 fishing season.

Bycatch is becoming an increasingly important issue for all fisheries that catch species with an assigned quota (or TAC species). For the Cardigan Bay fishery, bycatch quantification and analysis is an important element of the evidence base necessary to anticipate the potential conservation measures, which in lieu of scientific data may be delivered using a precautionary approach, resulting from the landings obligation.

5.0 – Conclusion

A total of 712 *P. serratus* were sampled from three locations over a period of eight months. This report highlights the results of the laboratory analysis along with several relationships and comparisons that were found to be statistically significant with reference to the length distribution.

Important findings include female *P. serratus* being subject to a much higher fishing pressure than males, perhaps explaining the shift from a female-skewed population to a heavy male dominated population towards the end of the season. Furthermore, the data suggests that a riddling size of 10 mm may not protect the majority of sexually immature females, contrary to other studies suggest there is over a 90 % chance that female *P. serratus* will reach sexual maturity before recruiting into the fishery.

Bycatch was shown to be dominated by crustaceans and the rate of mortality is expected to be very low for these species. Contrastingly, some teleost fish were subject to bycatch with an unknown rate of mortality. Data collection during the 2014/15 season will explicitly target this knowledge gap in readiness for the discard ban (i.e landings obligation), beginning in January 2015, for quota species such as Cod (*Gadus marhua*) and Whiting (*Merlangius merlangius*).

To conclude, considering the data available was limited by extreme weather events over the sampling period, this project has been able to evaluate key areas of both research and industry interest. With substantial gaps in the data, coupled with the high degree of natural variability in fishing success, conclusions made from scientific pot samples during this period should be met with an inquisitive caution. The samples already being returned by CBFA members during the 2014/15 season will provide much needed additional evidence for the fishery going forward with sustainable management. Finally, the absence of medium-resolution data from on-board observations shall be addressed in the coming fishing season.

6.0 – References

Chambers, J.M., Cleveland, W.S., Kleiner, B. and Tukey, P.A. (1983) *Graphical Methods for Data Analysis*. Wadsworth & Brooks/Cole.

Cole, H.A. (1958). Notes on the biology of the common prawn. Fisheries Investigations, London.

Coleman, R.A., Hoskin, M.G., Carlshausen, E. von and Davis, C.M. (2013) Using a no-take-zone to assess the impacts of fishing: Sessile epifauna appear insensitive to environmental disturbances from commercial potting. *Journal of Experimental Marine Biology and Ecology*, 440, p. 100-107.

Fahy, E., & Gleeson, P. (1996). The commercial exploitation of shrimp Palaemon serratus (Pennant, 1777) in Ireland. Irish Fisheries Investigations No. 1, Marine Institute.

Forster, G. (1951). The biology of the common prawn, Leander serratus Pennant. *Journal of the Marine Biological Association of the United Kingdom*, 30(2): 333-360.

Forster, G. R. (1959). The biology of the prawn, Palaemon (Leander) serratus (Pennant, 1777). *Journal of the Marine Biological Association of the United Kingdom*, 38(3): 621-627.

González-Ortegón, E., Pascual, E., Cuesta, J. A., & Drake, P. (2006). Field distribution and osmoregulatory capacity of shrimps in a temperate European estuary (SW Spain). *Estuarine, Coastal and Shelf Science*, 67(1): 293-302.

González-Ortegón and Cuesta, J. A. (2006). An illustrated key to species of *Palaemon* and *Palaemonetes* (Crustacea: Decapoda: Caridea) from European waters, including the alien species *Palaemon macrodactylus*. *Journal of the Marine Biological Association of the United Kingdom*, 67(1): 293-302.

Guerao, G. & Ribero, C. (1994). Growth and Reproductive Biology of *Palaemon xiphias* (Risso, 1816; Decapoda; Caridea; Palaemonidae). *Journal of Crustacean Biology*, 14(2): 280-288.

HM Government (2012) *Marine Strategy Framework Directive consultation: UK Initial Assessment and Proposals for Good Environmental Status.*

Huxley, R. (2008) The Cardigan Bay *Palaemon serratus* prawn fishery. BSc thesis. The University of Glamorgan, pp. 87.

Huxley, R. (2011) Population structure and morphology of the prawn *Palaemon serratus* (Pennant, 1777) in Welsh coastal waters with a consideration of two options for regulating the fishery. MSc thesis, The University of Glamorgan.

International Council for the Exploration of the Seas (ICES). (2014) Mapping Applications: ICES statistical rectangles. Available online at: [http://www.ices.dk/marine-data/maps/Pages/ICES-statistical-rectangles.aspx] Date Accessed: [05/12/2014].

Kelly, E., Tully, O., Lehane, B. and Breathnanch, S. (2008) The Shrimp (*Palaemon serratus* P.) Fishery: Analysis of the Resource in 2003-2007. Bord Iascaigh Mhara (Irish Sea Fisheries Board) Fisheries Resource Series, Vol. 8.

MarLIN (2014). The Marine Life Information Network, Available online at: [http://www.marlin.ac.uk/taxonomyidentification.php?speciesID=4019].
Date Accessed: [04/12/2014]

Morland, E., Olsen, E. M., Stenseth, N.S. (2010) Material influences on offspring size variation and viability in wild European lobster *Homarus gammarus*. *Marine Ecology Progress Series*, 400, p. 165-173.

R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available online at: [http://www.R-project.org/.] Date Accessed: [04/12/2014].

RStudio Inc. (2014) RStudio, Version 0.98.1091. Available to download at: [http://www.rstudio.com/products/rstudio/download/].

The Scottish Government (2009) Scottish Sea Fisheries Statistics 2009, A National Statistics Publication for Scotland. Available online at: [http://www.scotland.gov.uk/Resource/Doc/324719/0104567.pdf]. Date Accessed: [05/12/2014].

Sterry, P., Cleave, A. (2012) A photographic guide to every common species: Collins Complete Guide to British Coastal Wildlife. HarperCollins, London. ISBN: 9978 0 00 741385 0.

Wood (2014) The Diver's Guide to Marine Life of Britain and Ireland (2nd ed.) Wildlife Nature Press, Plymouth. ISBN: 978 0957394650.

7.0 – Appendices

Appendix 1 – "SCIENTIFIC POT" Data sheet.

Common Prawn (*Palaemon serratus*) SCIENCE POT Data Sheet

Date Hauled:____

Latitude: ____

Longitude:____

Water depth (m): _______________________________________

Soak time for this pot (circle number of days) or date of last haul

1 / 2 / 3 / 4 / other:__________**OR** date of last haul_________________

Secchi depth measure in segments: _______________segments =_____________metres

Appendix 2 – On-board Data Collection Protocol 2014/15

ON APPROACH TO POT FLEET

OBSERVER 1

As the vessel approaches the string:

1. Fill in the description details at the top of DATASHEET A including:
    a. Date
    b. Time On
    c. Fisher
    d. Location (Port)
    e. Whether the string has a Temperature Logger “Temp Logger”
    f. SST reading (if possible)
    g. String number
    h. GPS Mark (supplied by OBSERVER 2)
2. Prepare to lower the drop-down camera.
3. Begin to deploy camera when crew hook the end-buoy.
4. Alert the skipper that you are lowering the camera.

As the vessel begins to haul pots:

1. Continue to lower the camera until it reaches the sea floor.
2. Once you feel the camera frame make contact with the sea floor, haul it back onto the vessel deck.

Once the camera has been hauled to the surface:

1. Stow the camera away and make sure the equipment is switched off.
2. NOTE: stow it so that it poses minimal hazard / obstruction.

As the crew continues to haul pots:

1. Alert the skipper that the camera is stowed away.
2. Get permission from the skipper to lower a secchi disk.
3. Conduct a turbidity test with the Secchi disk.
4. Take a reading and record (DATASHEET A).
5. NOTE: Only conduct a secchi disk with permission of the skipper.
6. If the tide is to strong, take record visual note of turbidity.
7. Once the test is conducted and reported, haul the disk and stow away with the drop-down camera.

Begin to work on Pot SUBSAMPLES (High res. data):

1. There will be 3 or 4 subsamples from the first few pots ready to be recorded. They will be stored into seperate buckets.
2. Record the pot number from which the subsamples were taken. OBSERVER 2 will have this information (aiming to get the first 3 or 4 pots).

3. Separating each subsample into:
    i. LANDED CATCH
    ii. DISCARDED CATCH
    iii. BYCATCH (Non-target species)
4. Estimate the quantity of each in whatever form you are able. Preferably in count / kilos but in volume if necessary.
5. Record the subsample estimates onto datasheet A.
6. Record subsample BYCATCH diversity & abundance. If species ID is not possible, take a photo using the hand-held digital camera and make a note.
7. Take photos using the handheld camera of ALL the *Palaemon* in each subsample so that a length-distribution can be assessed using ImageJ software. NOTE:
    i. Place *Palaemon* in a white tray (one layer thick only) so ImageJ can detect outline & measure CL.
    ii. The camera position must be similar for each photo
    iii. There must be a reference measure in the photo.

By this point:

- The crew will be finished hauling the pots and may be shooting the rebaited fleet. When the string has been shot, note the time and record as "Time Off".
- OBSERVER 2 will be able to help with the subsample analysis.

Once finished with SUBSAMPLEs:

1. Return catch to skipper.
2. Record the total estimated catch (landed, discarded & bycatch) for that string by asking the skipper / using data recorded by OBSERVER 2.

OBSERVER 2

As the vessel approaches the string:

1. Take a GPS reading & tell OBSERVER 1 the GPS Mark #
2. Take a water sample using a vile in order to measure surface salinity.
3. Ask the skipper what style of prawn pot this string is made of and make a note on DATASHEET B.

As the vessel begins to haul pots:

1. Take all species caught from the first 3 or 4 pots (depending on conditions) to one side using buckets.
2. Stow them in chronological order, and make it clear to OBSERVER 1 which was the first.

As the crew continues to haul pots:

1. Using DATASHEET B, estimate the abundance of catch from each pot coming on board.
2. Estimate the *Palaemon* catch in kilos.
3. Ask the skipper to estimate how much was in each pot if it is difficult / not clear.

Once all the pots are hauled:

1. Help OBSERVER 1 with the SUBSAMPLEs from the first 3 or 4 pots (refer above).

Once finished with SUBSAMPLEs:

1. Return catch to skipper.
2. Make any other notes / observations on DATASHEET B.
    a. IMPORTANT: Make a note of what happens to discarded *Palaemon* and other Bycatch species, eg. Behaviour, mortality, stress, predation from gulls etc.
3. Finish entering any details into both datasheets.
4. Put datasheets away.
5. Prepare for next string of pots.

Appendix 3 – On-board Data Collection Sheets (A & B) 2014/15

ONBOARD DATA COLLECTION SHEET: CBFA PRAWN EFF PROJECT

DATASHEET A

Date: ____________________ Fisher: ____________________

Time On: ____________________ Location: ____________________

Time Off: ____________________ Video: Y / N Temp Logger: Y / N

String No.: ☐ Benthic Type: ☐

GPS Mark No.: ☐ Turbidity (m): ______ Salinity: Y / N ☐

STRING ABUNDANCE

Total Catch Est.: ____________ ☐ Vol ☐ Kg ☐ Count

Est. Q Landed: ____________ ☐ Vol ☐ Kg ☐ Count Est. Q Discard: ____________ ☐ Vol ☐ Kg ☐ Count

BYCATCH:

SUBSAMPLE ABUNDANCE

Pot No.: ☐

Total Catch Est.: ____________ ☐ Vol ☐ Kg ☐ Count Photo: Y / N ID: ________________

Est. Q Landed: ____________ ☐ Vol ☐ Kg ☐ Count Est. Q Discard: ____________ ☐ Vol ☐ Kg ☐ Count

BYCATCH:

ONBOARD DATA COLLECTION SHEET: CBFA PRAWN EFF PROJECT

DATASHEET B

Date: ____________________ **String No.:** [ ]

Observer: ____________________ **Pot Type:** ____________________

POT #	ABUNDANCE	COUNT / KG	BYCATCH spp. & Abundance
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			

NOTES (*Bycatch & Discard behaviour, mortality, predation etc...)*