



# Variations in the abundance and spatial distribution of *Palaemon serratus* (Decapoda: Palaemonidae) in the littoral zone of South Wales



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## ACKNOWLEDGEMENTS

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## **Variations in the abundance and spatial distribution of *Palaemon serratus* (Decapoda: Palaemonidae) in the littoral zone of South Wales**

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### **ABSTRACT**

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The abundance and spatial distribution of the prawn *Palaemon serratus* were studied in the littoral zone of South Wales in June and July, 2013. The study aimed to collect baseline data for *P. serratus* and establish a sampling methodology for the species within its inshore summer habitat. This research is the initial stage required for establishing a long-term monitoring programme to guide the future management of the currently unregulated commercial *P. serratus* fishery. The chosen sampling method involved timed searches conducted vertically along the shore using dip nets. The results indicated that *P. serratus* were sparsely distributed in the littoral zone of South Wales and that the species displayed highly site selective behaviour, since 68% of the total dip net catch was obtained at one site. Furthermore, there was a statistical difference in the total length of prawns between sites, indicating that site specific parameters influenced the population dynamics (Kruskal-Wallis,  $\chi^2 = 10.39$ ,  $p = 0.015$ ). However, the analysis was inconclusive as to whether environmental parameters drive *P. serratus* abundance; additional data collection is required to derive conclusions. Reference to previous research indicates that approximately 97% of the *P. serratus* caught in this study were O-group individuals. Thus, the findings suggest that the surveyed sites were nursery grounds for the species. By extending the spatial scope of the research through the addition of study sites, additional nursery grounds could be identified. It is also recommended that future sampling be undertaken monthly using the established standardised method in order to assess the seasonal abundance of *P. serratus* in the littoral zone. This preliminary study has provided the foundation for implementing a long-term monitoring programme for *P. serratus* which could enable the sustainable operation of the fishery through the development of effective management strategies.

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## **ABBREVIATIONS**

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ANOSIM – Analysis of similarity

ANOVA – Analysis of variance

CCW – Countryside Council for Wales

CL – Carapace length

CPUE – Catch per unit effort

DEFRA - Department of Environment, Food and Rural Affairs

GIS – Geographic information systems

GLM – General linear model

GPS – Global positioning system

HSI – Habitat suitability index

ITIS – Integrated Taxonomic Information System

JNCC – Joint Nature Conservation Committee

LSD – Least significant difference

MMO – Marine Management Organisation

PCA – Principal component analysis

SE – Standard error

TL – Total length

# 1. INTRODUCTION

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The common prawn *Palaemon serratus* (Pennant, 1777) is a commercially targeted species on the south and west coasts of Ireland, in southern England and in Wales (Fahy and Gleeson 1996; Fahy et al. 2006). In contrast to many other commercially fished species, the *P. serratus* fishery is unregulated throughout the British Isles, with the exception of a three month closed season in Ireland from May until August (Kelly et al. 2008). As a result of the lack of management for the species, there is a high potential for the fishery to become unsustainable due to overexploitation. The vulnerability of *P. serratus* to excess fishing pressure is further exacerbated by the species' short life span of only two to three years (Forster 1951; Fahy and Gleeson 1996). Thus, the depletion of a single year group, through fishing or natural causes, could substantially reduce the overall population size of the species and consequently lead to negative repercussions for the fishery. Furthermore, the short life span of the species suggests that there is a potential for growth overfishing to occur if management measures are not implemented to prevent this type of overfishing. Growth overfishing arises when "fish are caught in an inefficiently low age and weight group" (Quaas et al. 2013). Fishermen typically grade their catch by riddling to remove small prawns which could reduce the occurrence of growth overfishing. However, it is not guaranteed that the commercially undersized prawns are able to survive once returned to the water; therefore, the act of grading the catch does not ensure the problem of growth overfishing is avoided.

Proposed management options for the *P. serratus* fishery include implementing a minimum mesh size for prawn pots and enforcing a closed season (Fahy and Gleeson 1996; Huxley 2011). In order to design effective management strategies, data on the population dynamics of the stock are required (Sainsbury et al. 2000; Rademeyer et al. 2007). While the population dynamics of *P. serratus* have been studied in the British Isles to some extent (for example Forster 1951; Fahy and Gleeson 1996), insufficient research exists in order to produce robust models for assessing the potential success of proposed management techniques. Within the UK, it is of particular importance to obtain baseline data for *P. serratus* stocks in Wales because the Welsh fishery dominates the UK landings (Huxley 2011). Of the total landings of *P. serratus* into the UK in 2009, the tonnage and value landed by the Welsh fishery was 90 and 94% respectively (Huxley 2011).

Although the *P. serratus* fishery is unregulated, the fishery predominately takes place in the autumn and winter, while during the summer the fishery is voluntarily suspended (Kelly et al. 2008; Huxley 2011). The temporary cessation of the fishery is a result of the inshore migration of the species which occurs at the beginning of the summer (Forster 1951; Sterry and Cleave 2012). Consequently, the offshore potting for *P. serratus* in the summer months is commercially disadvantageous to fishermen; thus, pot fishermen target other species during the summer and return to catching *P. serratus* in the winter when the species returns to its offshore habitat (Huxley 2011).

The aim of this study was to develop and implement a sampling method for assessing the abundance and spatial distribution of *P. serratus* in the littoral zone during summer in South Wales. A baseline dataset was generated to determine if environmental variables influenced the abundance of *P. serratus*. Sampling methods were established with the goal of creating a repeatable inshore monitoring programme for *P. serratus* to assist with forming fisheries management strategies for the species.

### **1.1. UK FISHERY**

The UK Sea Fisheries Statistics 2011 report stated that UK vessels landed 600,000 tonnes of sea fish in 2011 into the UK and abroad, which equated to £828 million (MMO 2011). In the UK, the fishing industry is grouped into three categories: pelagic finfish, demersal fish and shellfish (MMO 2011; Smith 2013). Of the total landings by UK vessels into the UK in 2011, shellfish represented the greatest proportion by tonnage and value, at 37 and 45%, respectively (MMO 2011). Landings of pelagic fish comprised a slightly lower proportion of the total quantity, at 36%, while demersal fish made up 27% of the total quantity of landings in 2011 (MMO 2011).

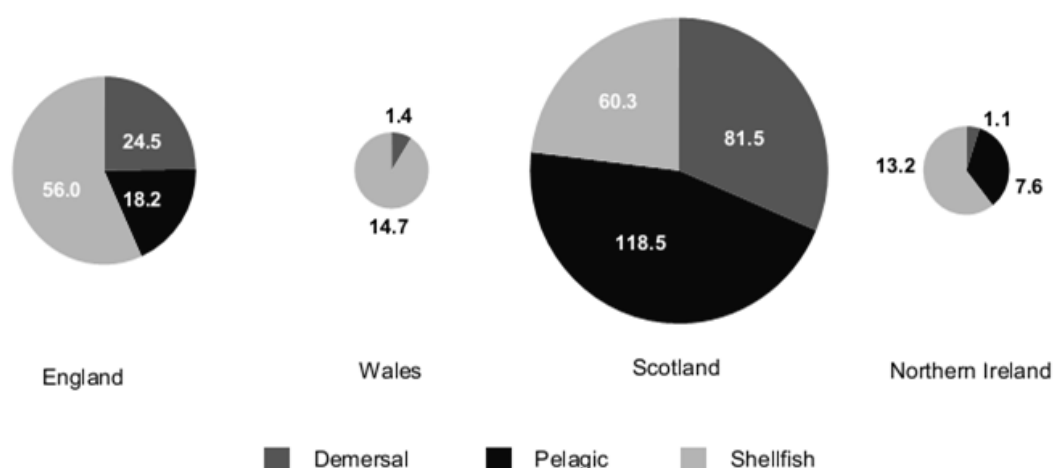
The UK fishing industry has evolved over time due to changes in technology, shifts in socioeconomic factors and the development of fisheries management practices (Smith 2013). Technological advances enabled the UK fishing industry to rapidly increase its fishing effort, which subsequently decreased many fish stocks and eventually resulted in overfishing becoming a widespread issue (Smith 2013). Consequently, fisheries management strategies were implemented in the UK in order to prevent the collapse of commercially important species; the principal management techniques included limiting access to fishing grounds and restricting landed quantities of targeted species (Steins and Edwards 1997; Smith 2013). In addition to declines in stocks due to overfishing, stringent management programmes also have the ability to reduce the total quantity of fish landed (Steins and Edwards 1997). As a result of these various factors, the total tonnage of sea fish landed into the UK decreased from 914,000 tonnes in 1960 to 471,000 tonnes in 2011, which represents a decline of almost 50% (MMO 2011). In addition, the species targeted by the UK fishing industry have shifted over time; during the past 50 years there has been a considerable decline in the quantity of demersal fish landed and an overall increase in the landings of both pelagic fish and shellfish (MMO 2011; Smith 2013).

Shellfish landings into the UK rose from 28,100 tonnes in 1960 to 152,400 tonnes in 2011, which represented a fivefold increase (MMO 2011). Since the fishing pressure on shellfish has rapidly intensified over the last fifty years, there is a pressing need for shellfish monitoring and management strategies to be implemented and enforced. For example, the limited management in place for the shrimp and prawn fishery was likely the leading cause of the observed 90% decline in landings by UK vessels from 2001 to 2011 (MMO 2011). This substantial decline in the catch of

shrimp and prawn is of significance to the shellfish industry, although the landings of shrimps and prawns comprising less than 1% of the total shellfish landed into the UK in 2011 (MMO 2011).

### 1.1.1. Welsh fishery

The value and quantity of sea fish landed varies considerably between the UK countries due to differences in the number of fishermen, the number and size of the fishing vessels and the species targeted (MMO 2011). In 2011, UK vessels landed the highest tonnage of sea fish into Scotland, at 260,300 tonnes (Figure 1) (MMO 2011). In comparison, the landings into Wales by UK vessels in the same year were substantially lower, at only 16,100 tonnes; consequently, landings into Wales in 2011 comprised only 4% of the total quantity of sea fish landed in the UK by UK vessels (MMO 2011). However, over 10% of the total quantity of shellfish landed into the UK in 2011 was landed into Wales, which indicates the importance of the Welsh shellfish industry to the UK (MMO 2011). Overall, 36% of the quantity of shellfish landed into the UK by UK vessels in 2011 was shellfish, which amounted to 144,000 tonnes (MMO 2011). Landings of shellfish into Wales had a higher than average contribution, at 91% of the total quantity of sea fish landed into Wales (MMO 2011). In comparison, the proportions of shellfish landed into England, Scotland and Northern Ireland were 56, 13 and 60%, respectively (Figure 1) (MMO 2011).



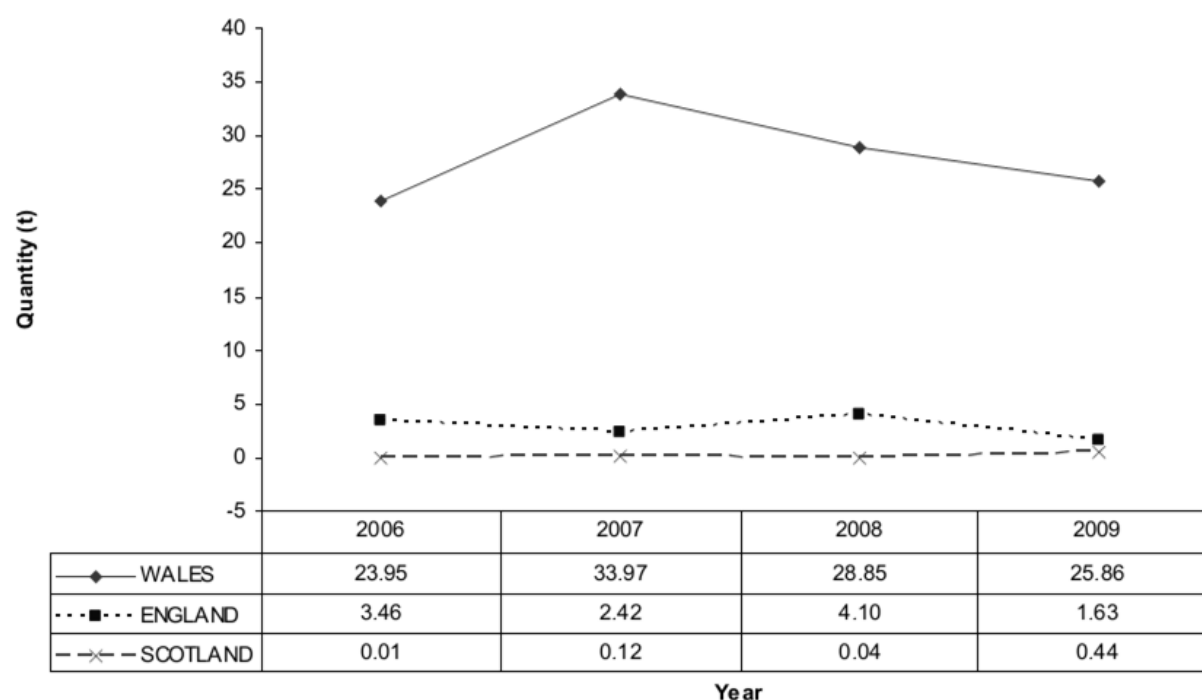
**Figure 1:** Landings in 2011 by UK vessels into the four UK countries. Landed quantities are divided by fish type and are recorded as '000 tonnes.

Source: MMO 2011

### 1.1.2. UK *Palaemon serratus* fishery

The *Palaemon serratus* fishing industry was established in the British Isles in the 1970s when trawl and lobster pot fisherman began obtaining commercially viable quantities of *P. serratus* bycatch in their gear (Fahy and Gleeson 1996). The industry steadily grew over the following twenty years and a rapid expansion of the fishery occurred in the 1990s (Fahy and Gleeson 1996). During this time, landings of *P. serratus* were consistently higher in Ireland than in Great Britain; in 1999, landings in Ireland reached a record high of 550 tonnes (Fahy and Gleeson 1996; Fahy et al. 2006;

Kelly et al. 2008). The landings in Great Britain were modest in comparison, with the maximum quantity landed in 2007 at 37 tonnes (Figure 2) (Huxley 2011 and references therein). Within Great Britain, 90% of the average quantity of landings between 2006 and 2009 were from Wales (Huxley 2011 and references therein). The average quantity of *P. serratus* landed into Wales during this four year period was 28 tonnes while average landings into England and Scotland combined amounted to only 3 tonnes (Figure 2) (Huxley 2011 and references therein).



**Figure 2:** Landings of *Palaemon serratus* into mainland UK between 2006 and 2009.

**Source:** Huxley 2011

### 1.1.3. Catch methods

Passive and active fishing gear types are used to catch prawns for both commercial and scientific purposes (Forster 1951; Boutillier and Sloan 1987; Kannupandi et al. undated). The dominant catch methods employed by the UK commercial prawn fishery are prawn pots (passive gear) and trawls (active equipment) (Forster 1951). In Wales, the most popular prawn pot type is the round “Roscoff” pot. They are deployed from fishing boats in “strings”, or groups of pots tied together on a lead line, and left for a designated period of time, known as the soak time (Huxley 2008). The catch efficiency of the pots is influenced their design; the mesh size and mouth diameter affect the escapement ratio while the pot saturation level is impacted by the pot volume and soak time (Boutillier and Sloan 1987; Yamane and Fujiishi 1992). In addition to potting, commercial beam trawls also catch prawns in the UK (Forster 1951). The mesh size, net mouth width and trawling speed of beam trawls alter the catch efficiency of this catch method (Schaffmeister et al. 2006).

The catch of prawns for scientific purposes, as well as for small scale prawn fisheries, relies on a wider range of gear types than those operated by the large-scale commercial prawn fishery (Forster 1951; Guest et al. 2003; Kannupandi et al. undated). Dip nets, seine nets and push nets are commonly used to catch prawns for scientific sampling, along with the more traditional use of beam trawls and baited prawn pots (Forster 1951; Guest et al. 2003; Kannupandi et al. undated). The type of gear that can be used is restricted by the water depth and the substrate type; for example, beam trawls have a minimum operating depth and push nets only function on relatively smooth sediments.

## **1.2. HABITAT**

The spatial range of *P. serratus* extends throughout the waters surrounding the British Isles as well as in the Mediterranean and Black Sea (Holthuis 1949). During the winter, *P. serratus* occupy offshore habitats to depths of 30 to 50m (Forster 1951; Guerao and Ribera 2000). The species undergo an inshore migration in early summer to the littoral zone of sheltered rocky shores (Forster 1951; Sterry and Cleave 2012) and estuaries (González-Ortegón et al. 2006; Henderson and Bird 2010). Prawns commonly inhabit seagrass beds, estuaries and intertidal rockpools as nursery grounds as well as adult feeding grounds (Forester 1951; Schaffmeister et al. 2006; Bilgin et al. 2008).

### **1.2.1. Rocky shores**

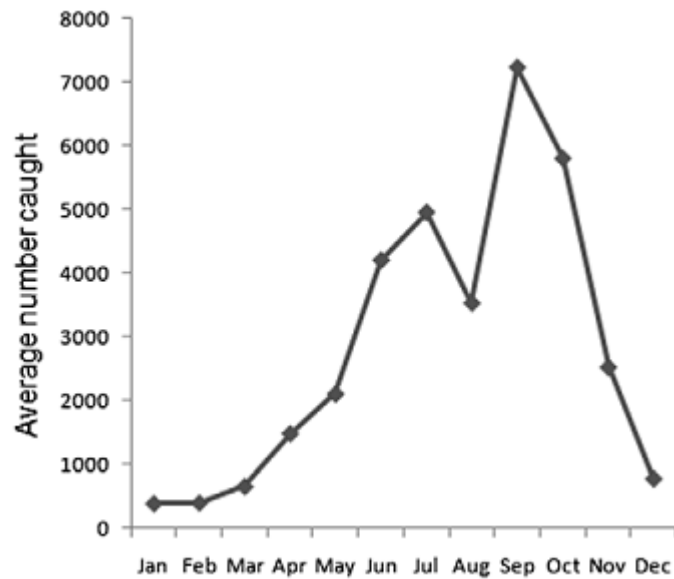
*Palaemon serratus* are present in rockpools on the mid- to low-shore as well as in the sublittoral waters on relatively sheltered coasts (Rodriguez and Naylor 1972; Sterry and Cleave 2012). In a study conducted in rockpools in South Wales in 1969, Rodriguez and Naylor (1972) concluded that *P. serratus* obtained the highest abundances in low-shore rockpools which were inundated by the tide at all times except for low water during spring tides. The dominant species of algae in these pools were *Laminaria digitata* and *Fucus serratus*; commonly observed faunal species included *Carcinus maenas*, *Cancer pagurus* and *Pilumnus hirtellus* (Rodriguez and Naylor 1972).

Of the habitats sampled by Forster (1951), the highest abundances of *P. serratus* caught in inshore habitats were along pier piles and in rock gullies. *Palaemon serratus* were also observed in rockpools starting at the end of March and the species maintaining relatively high abundances in the pools until late October (Forster 1951). Due to the absence of larvae observed during this study, it was assumed that metamorphosis occurred in the high littoral zone, where sampling was not conducted (Forster 1951).

During the winter months when *P. serratus* populate offshore habitats, the females have been found to prefer rocky bottoms while males typically occur in greater abundances on mud substrate (Forster 1951).

### 1.2.2. Estuaries

The abundance of *P. serratus* in estuaries increases in the summer, and typically peaks in September (Figure 3) (Forster 1951; Henderson and Bird 2010). Migrations into estuaries occur as a result of the active avoidance of *P. serratus* to relatively fresh, cold offshore waters in the winter and warm waters in the summer (Henderson and Bird 2010). Preliminary findings from the study conducted by Forster (1951) indicated that males migrate further into estuaries than females and that males also leave the estuaries in the autumn prior to the female offshore migration. By October, only a small proportion of the population is still present in estuaries and the abundance remains low throughout the winter (Figure 3) (Forster 1951; Henderson and Bird 2010).



**Figure 3:** Average number of *P. serratus* impinged on the intake pipe at Hinkey Point Power Station in Severn Estuary each month between 1981 and 2008.

**Source:** Henderson and Bird 2010

### 1.3. TAXONOMY AND MORPHOLOGY

*Palaemon serratus* (Palaemonidae: Decapoda) belongs to the Palaemoninae subfamily which is differentiated from the Pontoniinae subfamily by the number of posterior marginal spines; Palaemoninae have two pairs of spines and Pontoniinae have three (Chace 1992). Additional distinguishing physical characteristics of *P. serratus* include an upward curve of the rostrum with a bifurcated tip (Neal 2008; Sterry and Cleave 2012). The rostrum is toothed with 6 to 7 dorsal teeth, two of which are behind the eye socket, and 4 to 5 teeth on the ventral margin (Neal 2008; Sterry and Cleave 2012). The body is translucent with red to brown bands and sparsely distributed white chromatophores (Figure 4) (Carlisle 1955; Neal 2008). The pereopods are chelate with yellow and brown bands (Neal 2008; Sterry and Cleave 2012).



**Figure 4:** *Palaemon serratus* displaying bands of red to brown on its legs and translucent body. The upwards curve of the rostrum is also evident.

**Source:** Mark Thomas, [www.marlin.ac.uk](http://www.marlin.ac.uk)

#### 1.4. LIFE HISTORY STAGES

The life cycle of *P. serratus* includes four main life history stages: eggs, larvae, juveniles and adults. The fertilised eggs are attached to the pleopods of the female during embryonic development (Forster 1951; Guerao and Ribera 2000). The duration of the brood time, the period over which females carry their eggs, was found to be negatively correlated with the water temperature (Fahy and Gleeson 1996). In addition, Forster (1951) determined that the greater the total length of female *P. serratus*, the earlier spawning occurs; in a study conducted in Plymouth, females in the 7.7 to 8.4cm total length class spawned in December while females that were 5.5 to 6.4cm did not spawn until February. In general, ovigerous females first become present in the population in October, and most have spawned by June (Forster 1951; Fahy and Gleeson 1996; Kelly et al. 2008).

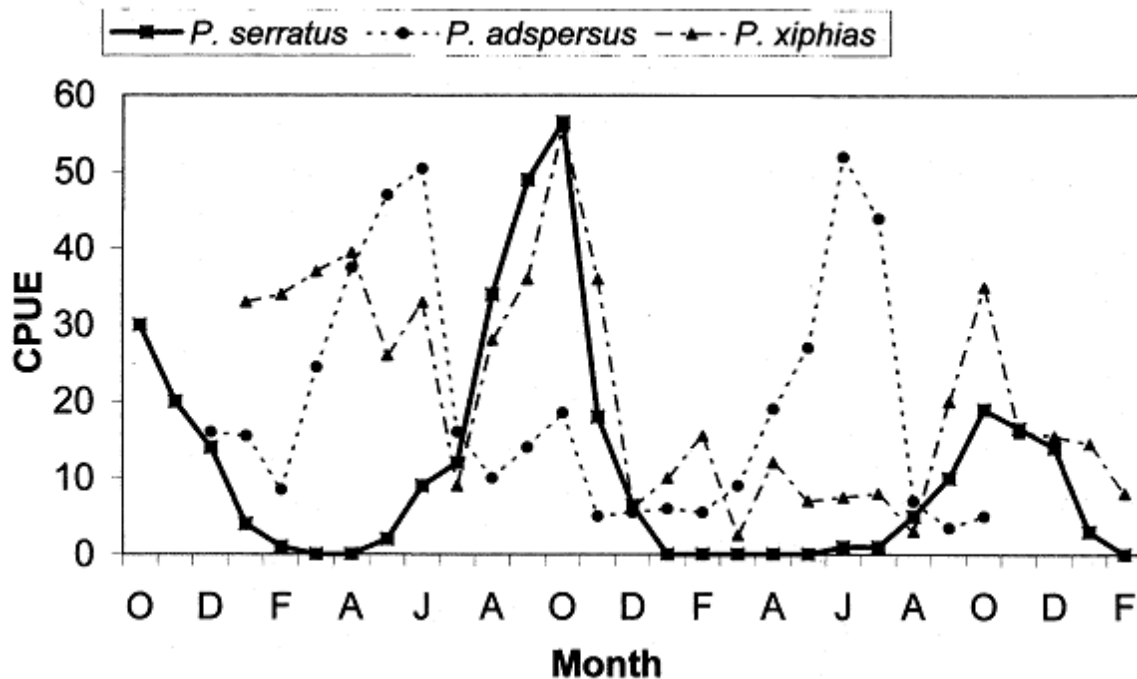
Upon hatching, the planktonic larvae inhabit the pelagic zone and undergo between 6 and 11 moults before metamorphosing into a post-larval state (Yagi et al. 1990; Reeve 1969). Laboratory studies indicated that *P. serratus* larvae were able to tolerate a range of temperature and salinity conditions; however, salinity was determined to have the greatest influence on larval mortality, while water temperature impacted the number of zoeal stages undergone (Kelly et al. 2012). Based on inshore sampling conducted in Plymouth, Forster (1951) speculated that metamorphosis occurs in the high littoral zone in July and August. However, the environmental conditions required for larval metamorphosis and settlement are not well understood and further research is needed to provide a comprehensive understanding of larval recruitment and population dynamics.

In contrast to the pelagic larvae, the juvenile and adult *P. serratus* life history stages are demersal (Kelly et al. 2012). In a laboratory study, the optimal temperature and salinity ranges for juveniles was found to be 15 to 17°C and 19 to 29‰, respectively (Kelly et al. 2012). Kelly et al. (2012) concluded that salinity had a greater influence than temperatures on juvenile mortality and the tolerance of juveniles to low salinities was relatively high (Kelly et al. 2012). As a result of high water temperatures, rapid growth is observed throughout the summer and autumn months while growth ceases in the winter (Forster 1951; Rodriguez 1981).

Juvenile and adult *P. serratus* have been observed to undergo seasonal migrations; the species migrates to coastal habitats during the summer and returns to deeper offshore waters in the winter (Figure 5) (Forster 1951; Guerao and Ribera 2000). It can be speculated that the summer inshore migration is a trend followed by the species regardless of its geographic location, since the seasonal migration has been detected in UK waters as well as in the Mediterranean Sea (Forster 1951; Guerao and Ribera 2000). The coastal phase of the species is important for the development of individuals since the summer is the dominant time when growth occurs (Forster 1951; Rodriguez 1981). While a conclusive explanation for the seasonal migration of *P. serratus* has yet to be drawn, it is hypothesised that low salinity in coastal waters is optimal for the species during its main growth period.



In addition to a seasonal migration, *P. serratus* have been observed to undertake tidal migrations (Forster 1951). Adult and juvenile *P. serratus* migrate to deeper water on the ebb tide and return to higher portions of the shore on the flood tide (Forster 1951).



**Figure 5:** Catch per unit effort (CPUE) as a measure of abundance for three prawn species: *Palaemon serratus*; *P. adspersus* and *P. xiphias*, from October 1989 to February 1992 in Alfacs Bay, Mediterranean Sea.

**Source:** Guerao and Ribera 2000

*Palaemon serratus* display sexual dimorphism, in relation to the total length, with females obtaining greater total lengths (Forster 1951). The mean total length for males and females is 7.5cm and 9.0cm, respectively (Forster 1951). Female-biased sexual dimorphism by size is typical of invertebrates (Fairbairn 1997). This form of sexual dimorphism is advantageous because female fecundity increases with body size (Shine 1989). In addition to size-based sexual dimorphism, the time taken to reach sexual maturity also varies by sex (Forster 1951). Male *P. serratus* become sexually mature 6 to 7 months after settlement while females take 9 to 10 months to obtain sexual maturity (Forster 1951). Research indicates that, in species which display sexual size dimorphism, the larger sex tends to take longer to mature; this is known as sexual bimartuation (Stamps and Krishnan 1997). Sexual bimartuation occurs because more time is needed for the larger sex to mature (Stamps and Krishnan 1997).

## 1.5. HYPOTHESES AND OBJECTIVES

A study was carried out to assess the abundance and spatial distribution of *Palaemon serratus* in South Wales in order to develop a repeatable sampling method for surveying the species in the littoral zone and to collect a baseline dataset. Throughout this study, the following hypotheses were focused on:

**H<sub>1</sub>:** Fishing gear type (Roscoff prawn pots or dip nets) has a statistical difference on the mean number of *P. serratus* caught in the littoral zone of rocky shores.

**H<sub>2</sub>:** There is a statistical difference between the abundance of *P. serratus* at different sites.

**H<sub>3</sub>:** Environmental variables cause significant variation in the abundances of *P. serratus* between sites.

**H<sub>4</sub>:** The abundance of *P. serratus* caught on the ebb and flood tides is statistically different.

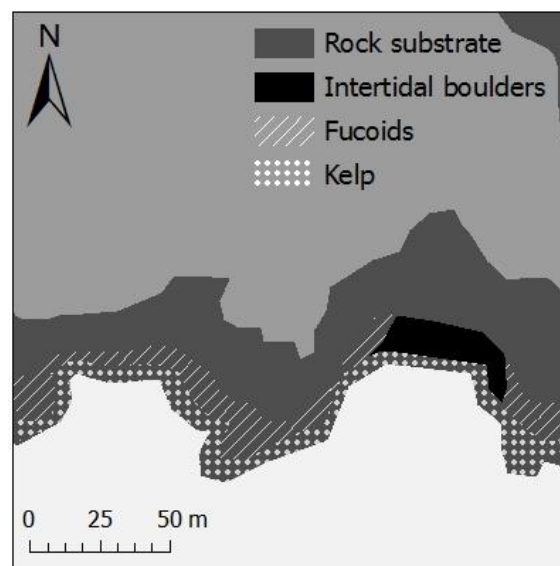
### 1.5.1. Objectives

1. To develop a repeatable methodology for assessing the abundance and spatial distribution of *P. serratus* in the littoral zone.
2. To quantify the variability in catch rates of *P. serratus* with different gear types (Roscoff prawn pot and dip net) used in the littoral zone.
3. To assess the length-frequency distribution of *P. serratus*, for males and females separately, at five sampling sites by measuring the total length of all specimens caught.
4. To identify environmental factors which influence the abundance and distribution of *P. serratus* in the littoral zone. Environmental metrics included bottom water temperature, salinity, algal cover, substrate type, exposure and turbidity.

## 2. METHODOLOGY

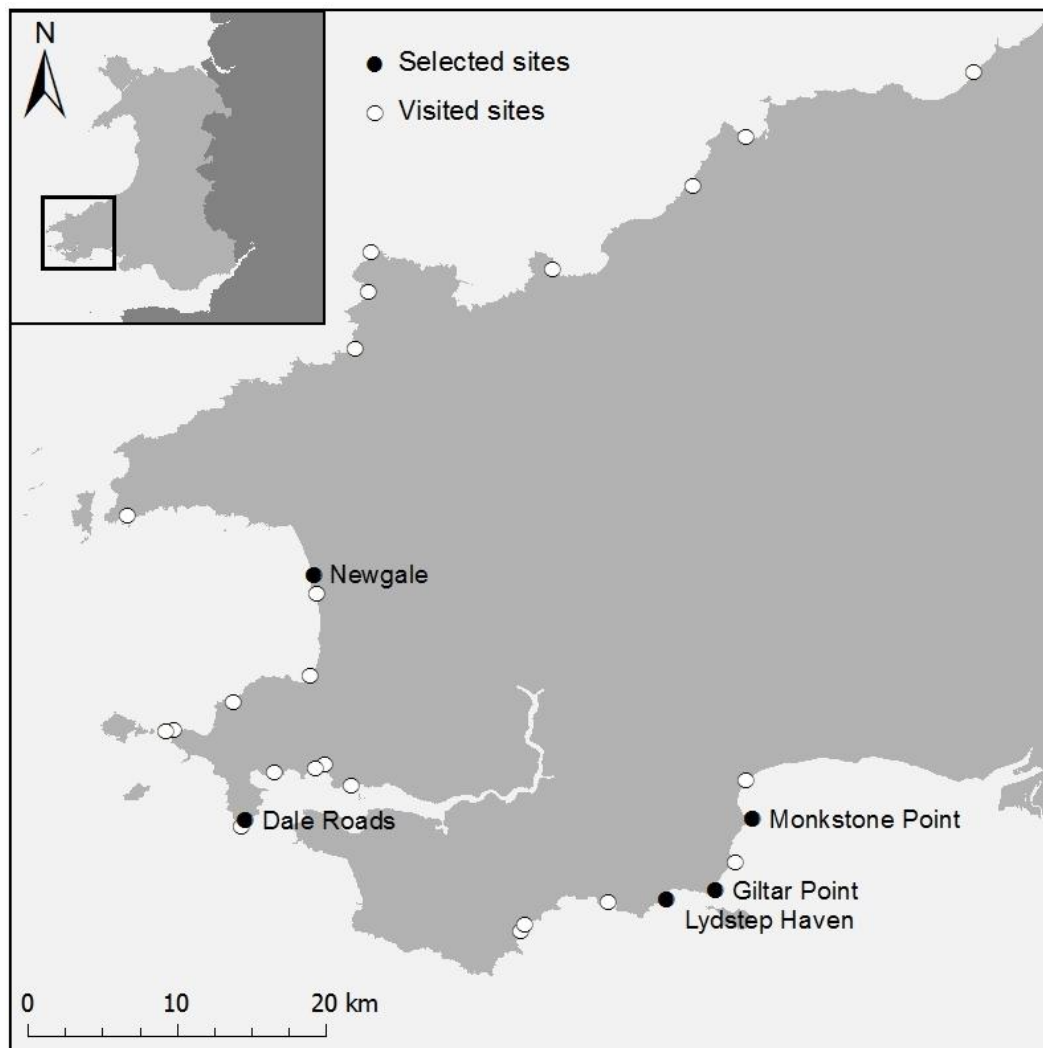
### 2.1. SITE SELECTION

Habitat maps were produced from geographic information systems (GIS) data provided by the Countryside Council for Wales (CCW) for the Marine Intertidal Phase 1 Biotope Mapping Survey (Wyn et al. 2006). These data layers were displayed in ArcMap 9.3 to illustrate areas of possible habitats for *Palaemon serratus*; to identify potential habitats, the data were categorised by substrates, such as intertidal boulder communities, and lifeforms, including kelp beds (Figure 6). In addition to using these GIS maps to select sites, Google Earth and ordnance survey (OS) maps were consulted to find appropriate habitats as well as to determine the accessibility of the sites.

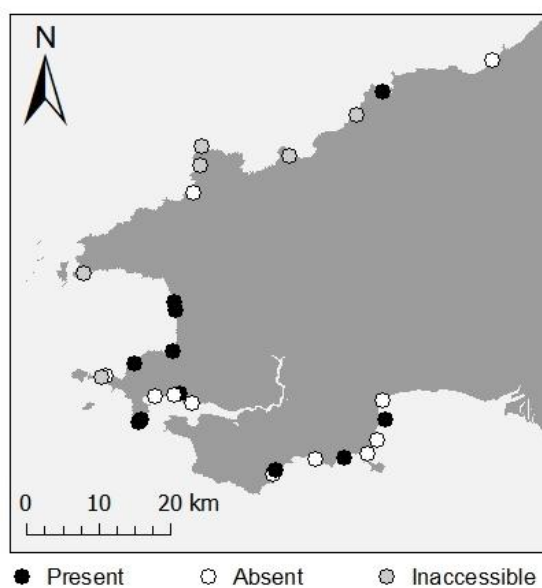


**Figure 6:** Example of GIS data layers used for identifying potential habitats for *P. serratus* to select sites to conduct preliminary sampling.

Thirty potential sites were visited during the spring tide in early June 2013 to determine which were appropriate to be used as sampling sites throughout the data collection period (Figure 7). A description and photograph were taken at each visited site to assess the suitability of the site for selection (Appendix I). Sites were immediately eliminated from the list if they were found to be unfeasible to reach for the purpose of this research (Figure 8). Accessible sites were sampled by conducting 20 minute timed searches using a dip net. The preliminary dip netting took place between two hours either side of the daytime low tide in a depth of 0.5m. During the dip netting, the net was frequently checked to determine if any *P. serratus* had been captured; specimens were not retained during the preliminary sampling period. The presence or absence of *P. serratus* was recorded to assist in the site selection process (Figure 8, Appendix I). Five sites were selected in South Wales based on the accessibility of the site and the presence of *P. serratus* during the preliminary sampling (Figure 7).



**Figure 7:** Sites visited in South Wales during the preliminary sampling survey, as well as sites selected to be included in the study.



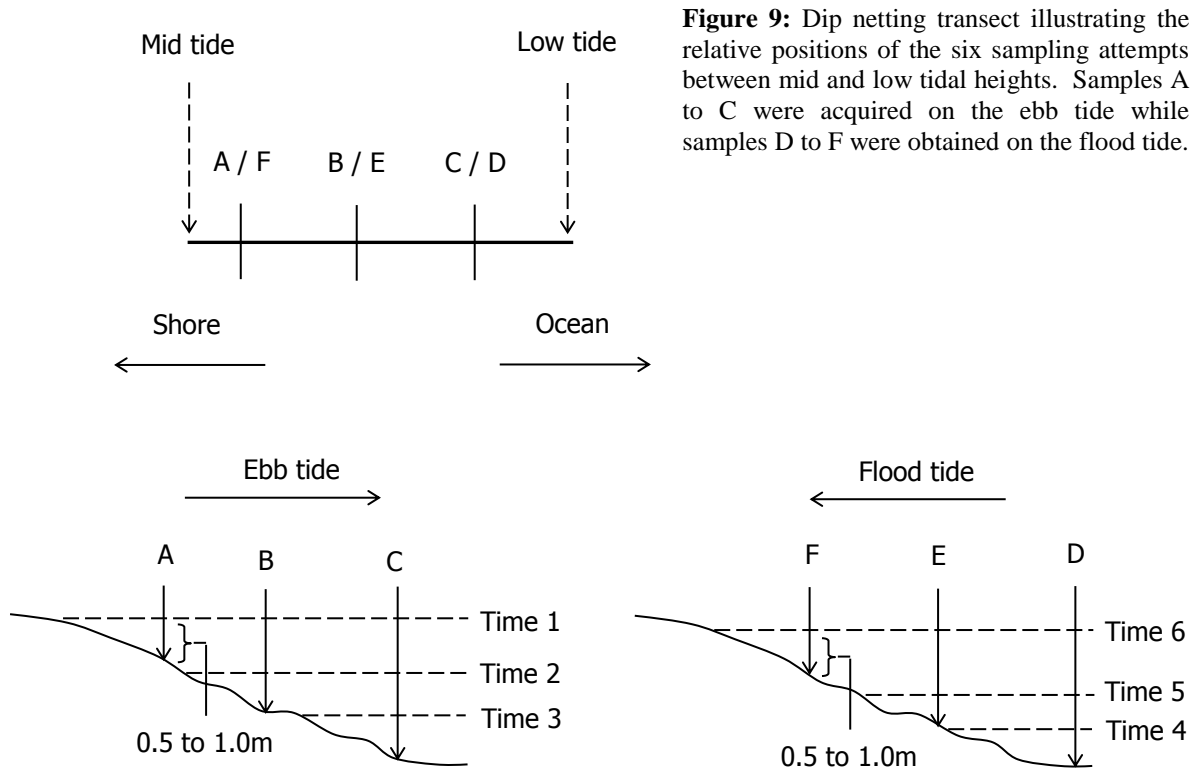
**Figure 8:** Identification of visited sites where *P. serratus* were present or absent during the preliminary 20 minute timed searches conducted in June 2013, as well as the sites which were inaccessible for the purpose of the research.

## 2.2. SAMPLING

Three sampling phases were undertaken between June and July 2013; sampling periods corresponded to spring tides to ensure that sampling could be conducted within the maximum tidal range possible. Each of the five selected sites was sampled on a separate day to ensure that all sampling occurred around the daytime low tide.

### 2.2.1. Littoral dip netting

A dip net with a mesh size of 5mm and catch area of 414cm<sup>2</sup> was used to collect prawns at the four main sampling sites: Dale Roads, Lydstep Haven, Giltar Point and Monkstone Point. Six sampling attempts, labelled A to F, were conducted at approximately hourly intervals to follow the ebb tide out, from mid to low tide, and then the flood tide back in, from low to mid tide (Figure 9 and 10). Sampling was performed along a randomly positioned transect which was aligned perpendicularly to the shore (Figure 9). Dip netting was carried out in water depths between 0.5 and 1.0m, unless the tidal conditions at the site prevented sampling at these depths (Figure 10). Consequently, the sampling locations were not spatially distributed in an even manner along the shore but were defined by the tidal conditions at the site (Figure 10). The latitude and longitude was recorded at the start position of each dip netting location using a Garmin eTrex global positioning system (GPS).



**Figure 10:** Cross sections of a shore displaying the positions of the six dip net sampling attempts, A to F, at hourly intervals, time 1 to 6, during the ebb and flood tides. All sampling attempts were conducted at depths between 0.5 and 1.0m, unless the tidal conditions at the site prevented sampling at this depth range.

Twenty minute timed searches were carried out with the dip net on either side of each sampling location, up to a maximum distance of 10m on either side of the transect. The distance over which sampling was conducted varied depending on the substrate; boulder substrate was time consuming to sample thus only a short distance was traversed while locations with sand typically were sampled to the complete 10m. During the timed searches, prawns were caught in the dip net by disturbing the substrate and algae. The net was frequently checked for prawns and all species caught were transferred into a labelled sample bag.

### 2.2.2. Rockpool dip netting

Due to the prevalence of rockpools at Newgale, dip netting was conducted in these pools rather than conducting a transect survey across the littoral zone as was detailed in 2.2.1. Rockpools were divided into two categories: high and low shore pools. On the ebb tide, any pools exposed at mid tide were defined as high shore pools while pools uncovered between mid and low tide were categorised as low shore pools. Three high shore rockpools and three low shore pools were randomly selected for sampling. Only pools which were greater in size than 50 by 50cm, with a depth of more than 5cm, were sampled to ensure that dip netting would be feasible. The length, width and depth of the pool were estimated and a photograph was taken to be referred to during the analysis.

### 2.2.3. Roscoff prawn pots

In addition to dip netting, *P. serratus* were also caught using Roscoff prawn pots (Figure 11). Each pot was 60.5cm in length with a diameter of 35.5cm and had an entrance funnel with a mouth diameter of 4cm. The body and funnel of the pots was covered with 8mm mesh. Each pot was baited with 100 to 200g of mackerel. Four pots were deployed at each site, in strings of two, and were weighted to prevent the pots being moved by the tide or currents (Figure 11).



**Figure 11:** A string of two Roscoff prawn pots with bricks for weights.

The pots were shot at low tide and hauled at the subsequent low tide, which resulted in a soak time of approximately 12 hours. The soak time was less at sites where the tidal conditions prevented the pots from being submerged at deployment. Pots were not deployed at Newgale because the access to this site was unsuitable for transporting pots to and from the shore.

Due to the very low numbers of prawns caught in the pots during the first period of sampling, this method of catching *P. serratus* was not continued for the subsequent sampling periods.

#### 2.2.4. Environmental variables

To determine the factors which contributed to providing a suitable habitat for *P. serratus*, a variety of biotic and abiotic variables were recorded. These environmental variables were substrate type, algal coverage, bottom water temperature, salinity, suspended matter content and the exposure level of the site.

Substrate types were classified by referring to the Udden-Wentworth grain-size classification scheme (Wentworth 1922). To enable the substrates to be classified in situ, the scheme was simplified to consist of five classification categories instead of the original eleven (Table 1). The substrate type was recorded for the areas for each dip netting attempt as well at the locations where the pots were deployed. Where multiple substrate types were observed, the dominant and secondary substrates were noted.

**Table 1:** Modified Udden-Wentworth classification scheme.

**Source:** Wentworth 1922

WENTWORTH CLASSIFICATION	GRAIN SIZE (MM)
Boulder	256
Cobble	64
Pebble	2
Sand	1 / 16
Silt / Clay	1 / 256

The percentage of algae cover at each dip netting location and at the areas where the pots were deployed was estimated. The total percentage of algae cover was estimated as well as the percentage cover of individual algal species; species were identified by referring to Collins Complete Guide to British Coastal Wildlife (Sterry and Cleave 2012).

Salinity was measured in situ using a refractometer, to an accuracy of  $\pm 1‰$ . Salinity measurements were taken at low tide during the second and third period of sampling. The salinity of the water in rockpools was recorded for all sampled pools except for those sampled during the first research period.

Bottom water temperature was measured using a Tinytag Aquatic 2 data logger. The logger was weighted and deployed at low tide during sampling and recovered on the subsequent low tide. Consequently, the bottom water temperature was logged for a period of approximately 12 hours. A temperature reading was recorded by the logger every three minutes and this data was used to calculate an average temperature for each site. The data logger was deployed at the sampling sites during the second and third sampling periods. Temperature was not recorded at the Newgale site because sampling was only conducted in rockpools.

The content of suspended matter in the water column was measured by collecting and filtering water samples. At each site during the second and third sampling periods, 3L of water was collected upon completion of the dip net sampling at the mid flood tide. From the water collected, three replicates were obtained which each had a volume of 1L. The replicates were filtered separately through three different GF/F microfiber filters, which had a pore size of 0.7µm, using a hand pump. The filters were frozen prior to being analysed in the laboratory.

The exposure level of each site was characterised as high, moderate or low based on the guidelines provided by Connor et al. (2004) (Table 2). The dominate species present on the upper, mid and low shore were recorded at each site to evaluate the exposure level by referring to the species list presented in Table 2.

**Table 2:** Guide for classifying the exposure level of sites based on the substrate and indicator species present on the upper, mid and low shore.

**Source:** Connor et al. 2004

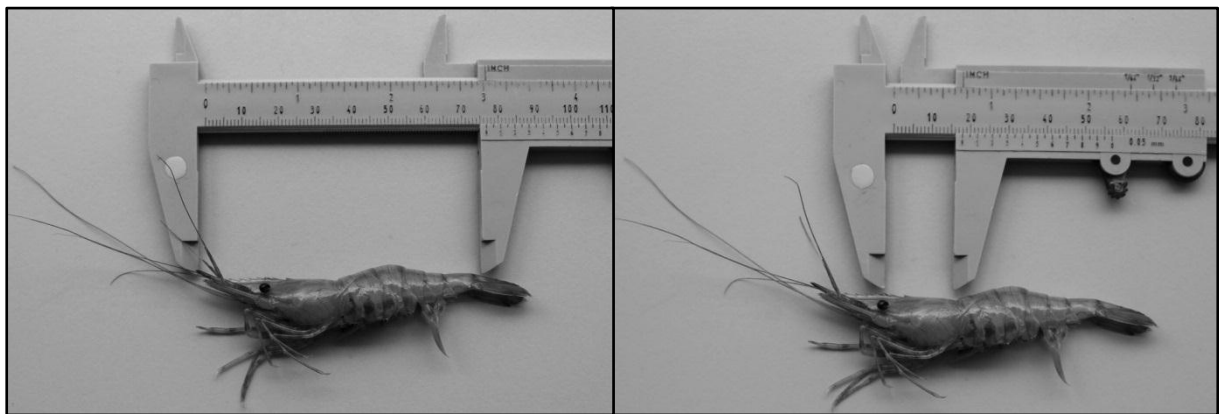
EXPOSURE LEVEL	SUBSTRATE	INDICATOR SPECIES BY SHORE HEIGHT		
		UPPER	MID	LOW
<b>High</b>	Bedrock Large boulders	<i>Mytilus edulis</i> <i>Chthamalus</i> spp. <i>Semibalanus balanoides</i> <i>Patella</i> spp. <i>Fucus distichus</i> <i>Fucus spiralis</i>	<i>Mytilus edulis</i> <i>Chthamalus</i> spp. <i>Semibalanus balanoides</i> <i>Patella</i> spp.	<i>Himanthalia elongate</i> <i>Corallina officinalis</i> <i>Mastocarpus stellatus</i> <i>Osmundea pinnatifida</i>
<b>Moderate</b>	Bedrock Boulders Cobbles	<i>Pelvetia canaliculata</i>	<i>Mytilus edulis</i> <i>Fucus vesiculosus</i> <i>Elminius modestus</i> <i>Littorina littorea</i> <i>Semibalanus balanoides</i> <i>Patella vulgata</i>	<i>Mytilus edulis</i> <i>Mastocarpus stellatus</i> <i>Elminius modestus</i> <i>Littorina littorea</i> <i>Fucus serratus</i>
<b>Low</b>	Bedrock Boulders Cobbles Pebbles Sand Mud	<i>Pelvetia canaliculata</i> <i>Littorina saxatilis</i>	<i>Ascophyllum nodosum</i> <i>Fucus vesiculosus</i> <i>Fucus spiralis</i> <i>Patella vulgate</i> <i>Littorina littorea</i>	<i>Fucus serratus</i> <i>Fucus spiralis</i> <i>Littorina saxatilis</i>



## 2.3. LABORATORY ANALYSIS

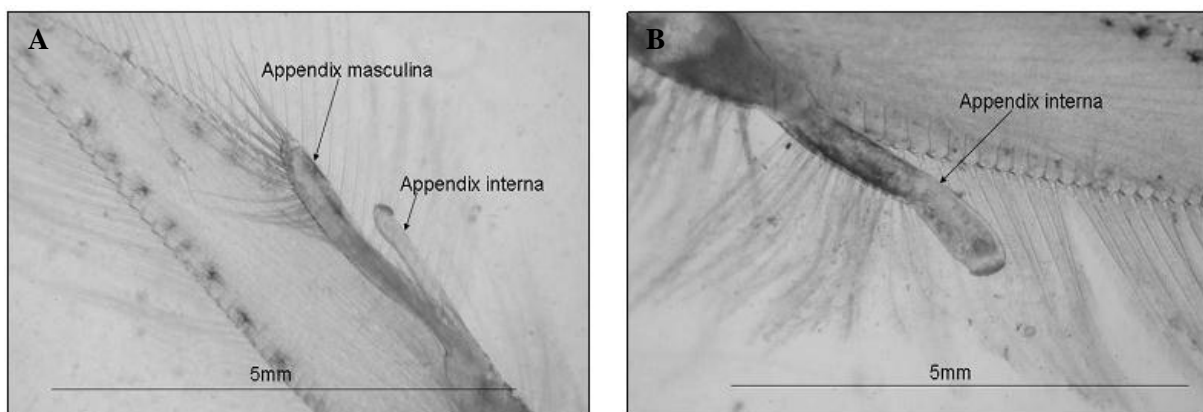
### 2.3.1. *Palaemon serratus*

All specimens were processed in the laboratory while fresh to prevent the need for using fixatives. The total length (TL) of each *P. serratus* specimen was measured, to the nearest 1mm, from the tip of the rostrum to the tip of the spines on the telson (Figure 12A). Before using calipers to measure the TL, the specimens were straightened against a ridged surface. In cases where the rostrum or telson was damaged, an estimate of the TL was made and the damage was noted. A subsample of *P. serratus* was randomly selected and the carapace length (CL) was measured, to the nearest 1mm, from the orbital margin to the dorsal posterior edge of the carapace (Figure 12B). The wet weight of each individual was determined, to the nearest 0.001g, using a digital scale.



**Figure 12:** Measurements recorded for the A) total length (TL) and B) carapace length (CL) of *P. serratus*.

Sex was determined by examining each *P. serratus* under a dissecting microscope to detect morphological differences outlined by Forster (1951). Male *P. serratus* contain an appendix masculina on the second pleopod, in addition to the appendix interna, while females lack this additional appendage (Figure 13) (Forster 1951). The presence or absence of eggs was also noted.



**Figure 13:** Second pleopod of A) a male *P. serratus* and B) a female individual, illustrating the presence and absence of the appendix masculina, respectively.

**Source:**( Huxley, 2011)

### 2.3.2. Suspended matter content

Prior to filtering the water samples, the GF/F filters were washed in distilled water and dried at 80°C for 24 hours in a drying oven. The start weight of the filters was measured, to the nearest 0.00001g, and the filters were stored in labelled plastic bags. After the water samples had been filtered, the filters were dried and weighed to determine the end weight. The start and end weights were used to calculate the weight of material collected on the filter and an average was calculated for each site.

### 2.4. DATA ANALYSIS

The dataset was produced in Excel and appropriate graphs were generated to display the general trends in the results. Outliers were identified by visually examining these graphs and any anomalous data points were removed in order to increase the accuracy of the analysis. Statistical analysis was undertaken using SPSS Statistics (v. 19) software and PRIMER (Plymouth Routines in Multivariate Ecological Research) (v. 6) statistical package.

An inspection of the dataset revealed that the data did not conform to the assumptions of parametric testing; consequently, non-parametric tests were undertaken for the majority of the statistical analysis. Due to the lack of replication in the experimental design of the study, it was necessary to use the three time periods as replicates to allow for the analysis to be undertaken.

A Kruskal-Wallis test was carried out in SPSS to assess whether there was a statistical difference in the abundance of *P. serratus* caught at the four main sampling sites. Multiple Mann-Whitney U tests were subsequently conducted to determine which sites were statistically different.

Length-frequency distribution graphs were generated in Excel for each of the four main sampling sites; the data were displayed for males and females separately as well as for ovigerous females. The total lengths of prawns were grouped into 5mm size classes and the percentage of *P. serratus* in each size class was calculated for each site. To assess whether there was a difference in the TL of prawns between the four main sampling sites, a Kruskal-Wallis test was performed and this was followed by Mann-Whitney U tests in order to determine where the differences lay. A Mann-Whitney U test was carried out on the complete dataset to evaluate whether there was a statistical difference in the TL of males and female to determine if the prawns caught in this study displayed sexual dimorphism by TL.

Principal component analysis (PCA) was undertaken to determine if the differences between samples were driven by the environmental parameters measured. A Draftsman plot was carried out in PRIMER to identify confounding variables. In instances where a correlation of 0.95 or higher existed between two variables, one of the variables was removed and the PCA analysis was repeated. The output from the PCA was used to generate hypotheses to be tested with data collected during future sampling periods. A component plot was produced to visually display the findings.

The analysis of the variation in abundance by shore height, as well as for the ebb and flood tides, was conducted using the data from Dale Roads since only this site provided sufficient data to effectively undertake statistical analysis. The data were log-transformed, because the non-transformed data were non-parametric, and a two-way analysis of variance (ANOVA) test was conducted. A *post hoc* least significant difference (LSD) test was carried out to identify which shore heights had statistically different abundances of *P. serratus*, as well as if a statistical difference in abundance occurred between the ebb and flood tides.

An analysis was conducted at Newgale to assess the abundance of prawns in the rockpools at this site. Length-frequency distribution plots were produced in Excel for *P. serratus* and *P. elegans* in high- and low-shore pools. Males, females and ovigerous females were displayed in 5mm total length classes. The statistical difference in TL of *P. serratus* and *P. elegans* was assessed using a Mann-Whitney U test. The existence of sexual dimorphism by TL was determined for both prawn species by conducting one-way ANOVA tests, because the TL data from the Newgale rockpools was found to be parametric. The TL of *P. serratus* in high- and low-shore pools was statistically compared using a one-way ANOVA test to determine if the mean TL varied by shore height.

The TL and CL data were plotted in Excel to visually determine if a relationship was present. The data were modelled using the straight line equation  $CL = m(TL) + c$ , where  $m$  is the slope and  $c$  is the y-intercept of the best-fit trendline. A linear regression analysis was conducted in SPSS to generate appropriate values for the parameters  $m$  and  $c$ .

The length-weight relationship of *P. serratus* was modelled using the equation  $W = aL^b$ , where  $a$  and  $b$  are constants (King 2007). Log-log plots were produced in Excel for males and females separately to illustrate the data. Trendlines of the equation  $\ln(W) = \ln(a) + b \ln(L)$  were fitted to each plot. In SPSS, linear regression analysis was undertaken, for males and females separately, to produce best-fit model expressions. A univariate general linear model (GLM) was run to determine if there was a statistical difference in the models produced for males and females. Since no difference occurred, the linear regression analysis was repeated using the combined data to produce a single length-weight model for *P. serratus*.

### 3. RESULTS

Over the duration of the sampling period, 229 *P. serratus* were caught by dip netting at the five sampling sites in South Wales (Table 3). A total of 197 individuals were caught in the littoral zone at the four main sampling sites while the remaining 32 *P. serratus* were caught in rockpools at Newgale (Table 3). Overall, 58% of the prawns caught were female and 4% of the total catch was ovigerous. The total length (TL) of specimens ranged from 16 to 93mm (mean TL =  $46.07 \pm 0.76$ mm SE) and the average weight of individuals was 1.28g ( $\pm 0.07$ g SE).

SITE	TOTAL ABUNDANCE
Newgale	32
Dale Roads	158
Lydstep Haven	26
Giltar Point	12
Monkstone Haven	1

**Table 3:** Total number of *P. serratus* caught by dip netting at five sites during the three sampling periods between June and July 2013.

#### 3.1. SAMPLING METHOD

Two gear types, Roscoff prawn pots and dip nets, were initially used to sample for *P. serratus* in order to determine which method was the most appropriate for the research. During the first period of sampling, 124 specimens were caught using the two gear types at the four main sampling sites (Table 4). Of the total catch during this sampling period, 85% of the individuals caught were obtained by the dip netting method (Table 4). While the catch of *P. serratus* by passive and active gear types cannot be directly compared, it was evident from the findings that the Roscoff prawn pots were less suitable for the purpose of this research than the dip netting method.

**Table 4:** Total number of *P. serratus* caught by dip netting and Roscoff prawn pots at the four main sampling sites during the first period of sampling.

SITE	DIP NET ABUNDANCE	POT ABUNDANCE
Dale Roads	92	8
Lydstep Haven	5	7
Giltar Point	9	3
Monkstone Haven	0	0

### 3.2. ABUNDANCE AND DISTRIBUTION OF *P. SERRATUS*

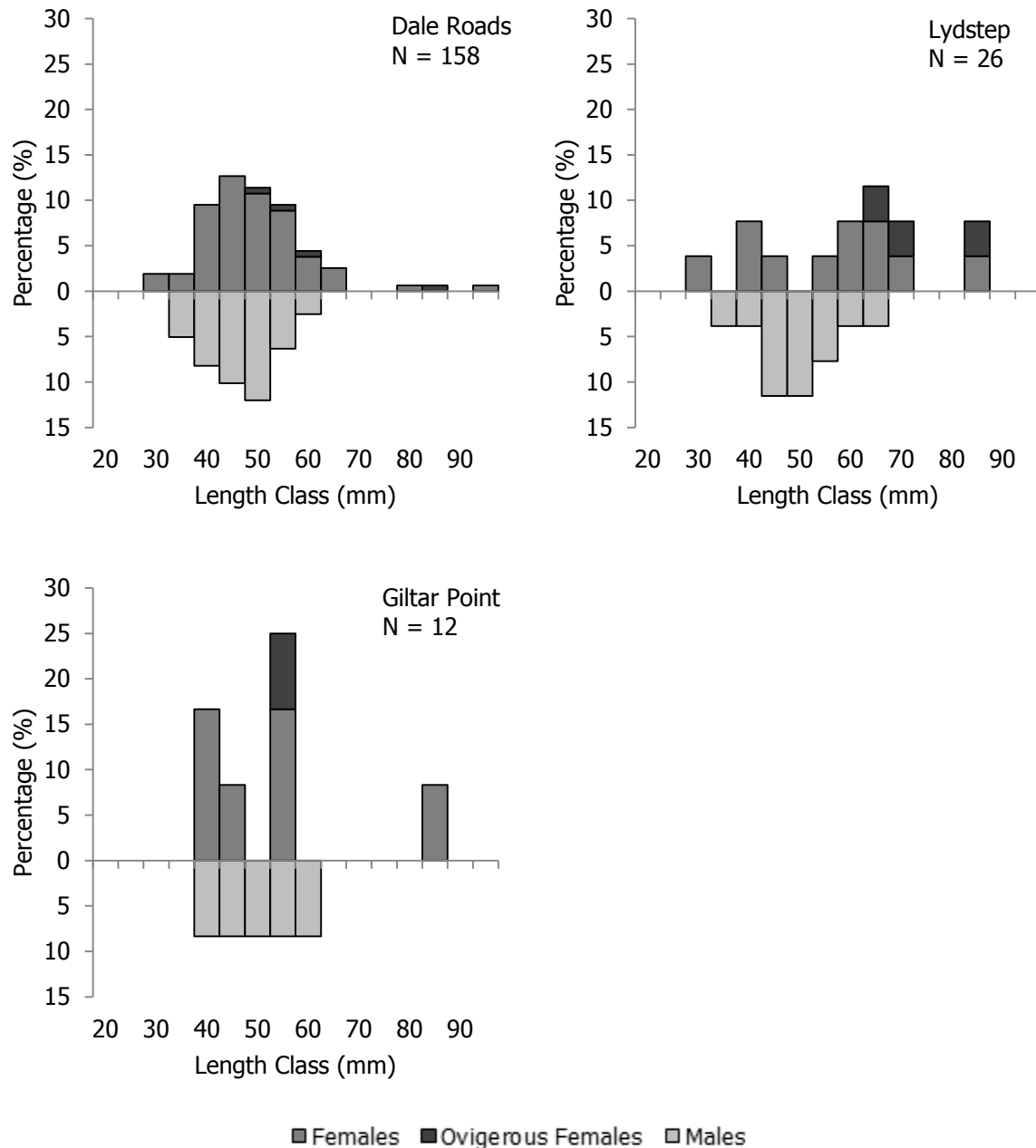
#### 3.2.1 Abundance between sites

The abundance of *P. serratus* caught varied substantially across the four main sampling sites (Table 2) (Kruskal-Wallis,  $\chi^2_3 = 29.07$ ,  $p < 0.001$ ). Of the 229 *P. serratus* obtained by dip netting, 158 were caught at Dale Roads which represented 68% of the total catch for the duration of the sampling period (Table 2). Consequently, Dale Roads displayed a significantly higher number of prawns caught than the other three sites (Mann-Whitney U test, Lydstep Haven:  $z = -3.15$ ,  $p = 0.002$ ; Giltar Point:  $z = -3.72$ ,  $p < 0.001$ ; Monkstone Point:  $z = -4.61$ ,  $p < 0.001$ ). In contrast, Monkstone Point displayed a significantly lower abundance of *P. serratus* than the other three main sites, with only one individual being caught throughout the sampling period (Mann-Whitney U test, Dale Roads:  $z = -4.61$ ,  $p < 0.001$ ; Lydstep Haven:  $z = -2.46$ ,  $p = 0.014$ ; Giltar Point:  $z = -2.11$ ,  $p = 0.035$ ). There was no statistical difference observed in the abundance of *P. serratus* caught at Lydstep Haven and Giltar Point (Mann-Whitney U test,  $z = -0.67$ ,  $p = 0.506$ ).

#### 3.2.2. Population structure between sites

In addition to variations in the overall abundance of *P. serratus* caught between the four main sampling sites, the population structure at each site also illustrated differences, as showed by the length-frequency distribution graphs in Figure 14. Statistical analysis demonstrated that there was an overall difference in TL between the four main sites (Kruskal-Wallis,  $\chi^2_3 = 10.40$ ,  $p = 0.015$ ). Further analysis illustrated that only the samples caught at Dale Roads and Lydstep Point showed statistical differences in TL (Mann-Whitney U test,  $z = -2.70$ ,  $p = 0.007$ ). *Palaemon serratus* at Dale Roads displayed the lowest average TL (mean TL =  $46.10 \pm 0.74$ mm SE) while the samples caught at Lydstep Point had a higher TL (mean TL  $53.15 \pm 2.69$ mm SE) (Figure 14). Although the sites displayed differences in population structures, the samples obtained all exhibited unimodal distribution (Figure 14).

Figure 14 shows that females obtaining a greater TL than males which suggests that sexual dimorphism by TL occurred at the four main sampling sites (Figure 14). However, statistical analysis indicates that there was no difference recorded in the TL of males and females (Mann-Whitney U test,  $z = -1.79$ ,  $p = 0.074$ ). Therefore, the data does not illustrate that sexual dimorphism by TL was observed in the samples obtained.



**Figure 14:** Length-frequency distribution plots of *P. serratus* caught at each of the four main sampling sites in South Wales between June and July 2013. The Monkstone Point plot was omitted because only one prawn was recorded at this site.

### 3.2.3. Environmental drivers

Principal component analysis (PCA) was undertaken to assess whether environmental variables had an influence on the differences in abundance between samples. Figure 15 illustrates that the weightings assigned by the analysis to the environmental variables result in a clustering of points by sites. This suggests that, to some degree, the environmental variables influenced the abundance of *P. serratus* caught. Table 5 lists the weightings assigned to each environmental variable during the analysis for components 1 and 2. Component 1 has the highest eigenvalue, at 2.07, which explains 30% of the variability between the samples, while component 2 explains 25% of the variability.

Consequently, these two components explain 55% of the variability between the samples. Based on the weightings assigned to each variable in Table 5, the following two hypotheses were proposed:

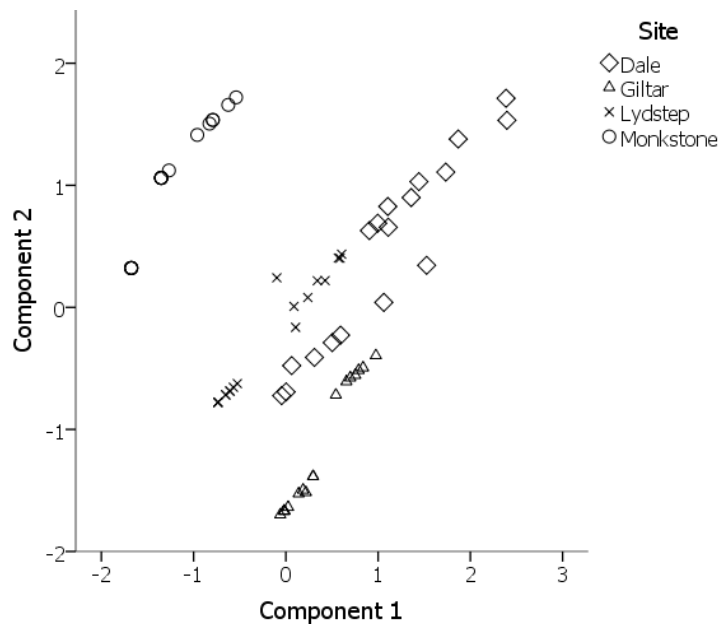
**H<sub>1</sub>:** Locations with high percentages of algae cover will result in high abundances of *P. serratus*

**H<sub>2</sub>:** Locations with low salinities and which are sheltered will lead to high abundances of *P. serratus*

Additional data collection is required to test these two hypotheses in order to form conclusions about the influence of environmental parameters on the abundance of *P. serratus*.

FACTOR	COMPONENT	
	1	2
Salinity	-0.537	0.579
Turbidity	0.361	-0.776
Exposure	-0.829	0.192
Dominant substrate	-0.359	-0.695
Secondary substrate	0.359	0.277
Percentage algae	0.545	0.340
Abundance	0.636	0.340

**Table 5:** PCA component matrix displaying the summary of weightings assigned to each environmental variable for components 1 and 2.

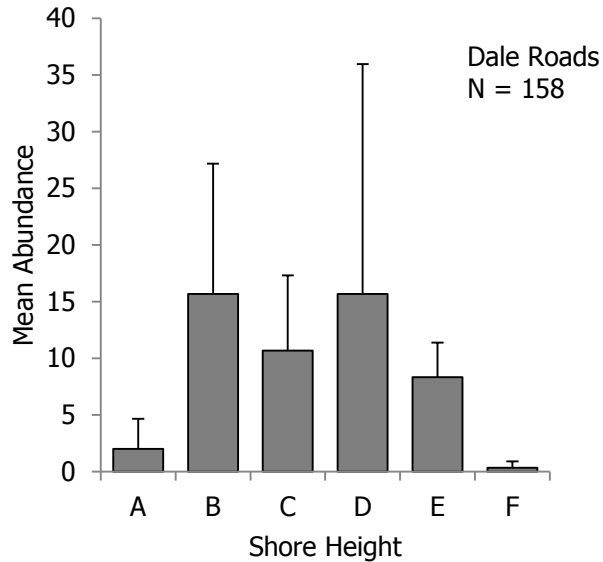


**Figure 15:** PCA component plot of the four main sampling sites and the influence of environmental parameters on *P. serratus* abundance.

### 3.3. ABUNDANCE AT DALE ROADS

The mean abundance of *P. serratus* caught at the six shore heights at Dale Roads is illustrated in Figure 16. The lowest mean abundances were obtained at sampling locations which were highest on the shore (A and F) (Figure 16). The analysis indicated that there was a statistical difference in the

abundance of *P. serratus* caught at the different shore heights (GLM,  $F_{2, 12} = 9.19$ ,  $p = 0.004$ ). *Post hoc* testing indicated that the abundances recorded at the mid-shore sampling locations (A and F), which were highest on the shore, were statistically lower than the abundances recorded on the other shore heights (GLM, B and E: SE = 0.21,  $p = 0.002$ ; C and D: SE = 0.21,  $p = 0.004$ ). There was no statistical difference in the abundance of *P. serratus* caught on the ebb and flood tides (GLM,  $F_{1, 12} = 0.76$ ,  $p = 0.399$ ) (Figure 16).

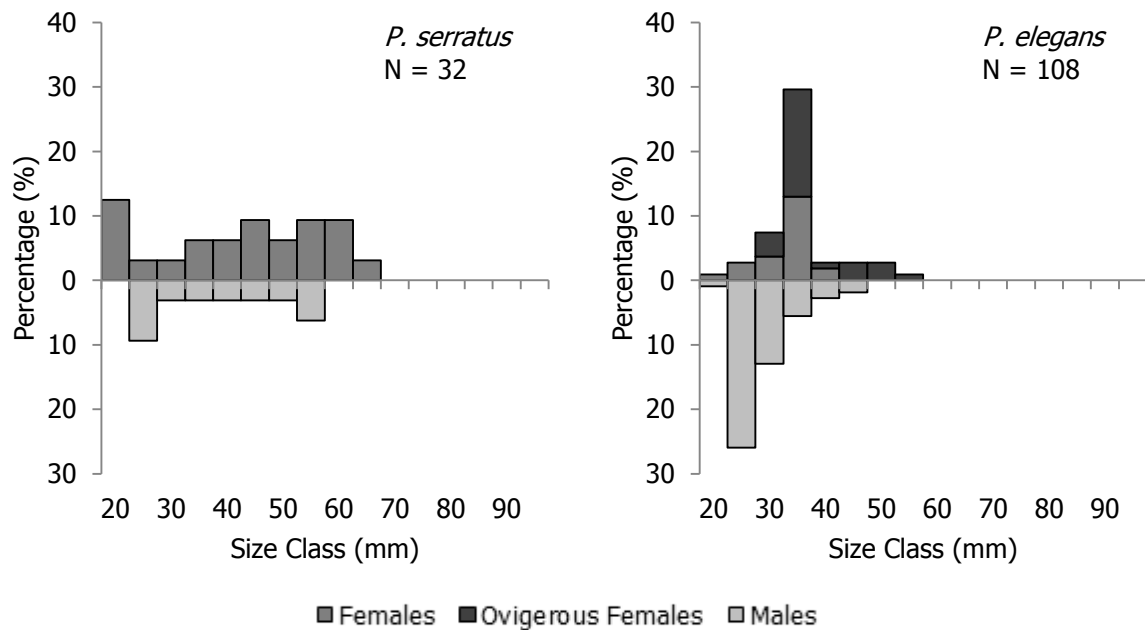


**Figure 16:** Mean abundance of *P. serratus* caught during the three sampling periods at each shore height for Dale Roads. Shore heights A to C were sampled on the ebb tide while samples D to F were obtained on the flood tide. Error bars illustrate the positive standard deviation.

### 3.4. ABUNDANCE AND DISTRIBUTION OF *PALAEMON* SPP. IN ROCKPOOLS

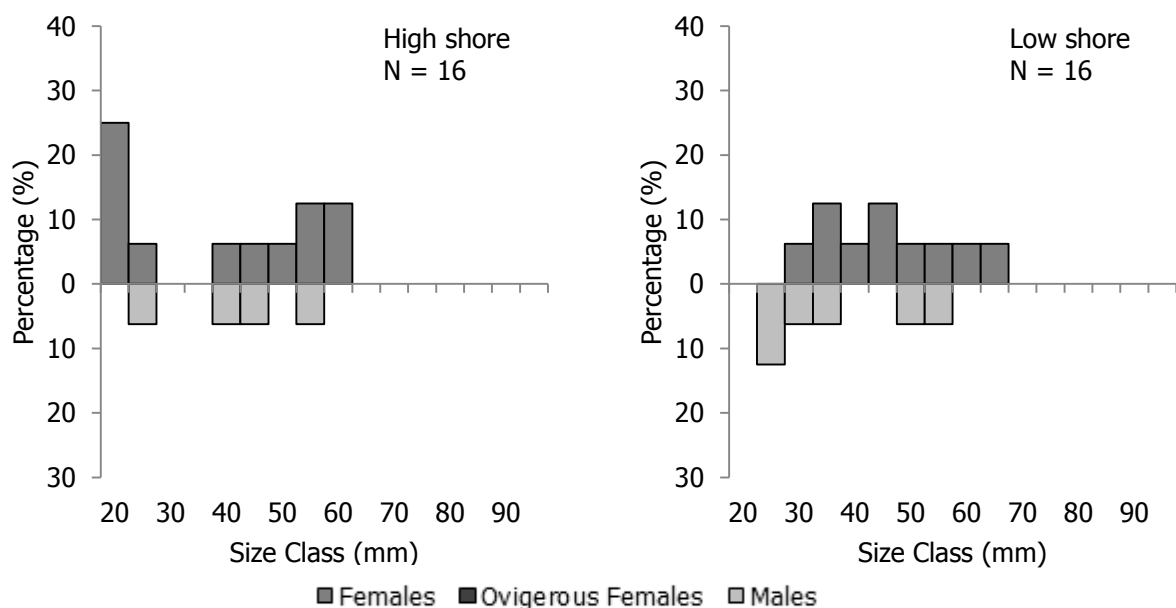
Dip net sampling in rockpools at Newgale resulted in the capture of 140 *Palaemon* spp. animals. Of this total catch, 25% were *P. serratus* and the remaining 75% were *P. elegans* (Figure 17). Ovigerous *P. serratus* were not observed in the rockpools while 22% of the catch of *P. elegans* was carrying eggs (Figure 17). The average TL of *P. serratus* (mean TL =  $38.97 \pm 2.49$ mm SE) was greater than that observed for *P. elegans* (mean TL =  $30.16 \pm 0.61$ mm SE) (Figure 17). Furthermore, this difference in TL between these two species was significant (Mann-Whitney U test,  $z = -3.34$ ,  $p = 0.001$ ). *Palaemon serratus* displayed a relatively uniform distribution across the size classes while *P. elegans* exhibited distinct peaks in TL for both males and females (Figure 17). Figure 17 illustrates that female *P. elegans* were most abundant in the 36 to 40mm TL size class while males dominated the 26 to 30mm class. Sexual dimorphism in TL was noted for *P. elegans* with females obtaining a statistically greater TL than males (mean TL females =  $33.13 \pm 0.81$ mm SE; mean TL males =  $27.19 \pm 0.70$ mm SE) (One-way ANOVA,  $F_{1, 106} = 30.79$ ,  $p < 0.001$ ). In contrast, sexual dimorphism was not observed in the catch of *P. serratus* in the Newgale rockpools (Figure 17) (One-way ANOVA,  $F_{1, 30} = 0.34$ ,  $p = 0.565$ ).





**Figure 17:** Length-frequency distribution plots for *P. serratus* and *P. elegans* obtained from dip netting in the rockpools at Newgale between June and July 2013.

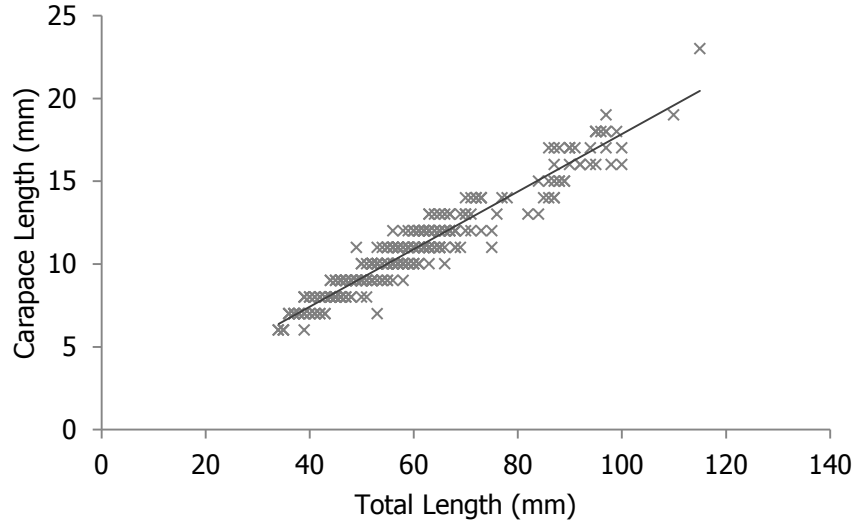
*Palaemon serratus* were equally distributed between high- and low-shore rockpools with 16 specimens observed in pools at each shore height (Figure 18). Conversely, 99% of *P. elegans* were caught in high-shore rockpools. The population structure of *P. serratus* displayed a similar distribution in both high- and low-shore pools; however, a higher abundance of females with TL of less than 25mm was observed in high-shore pools than those on the low-shore (Figure 18). On average, the TL of *P. serratus* was slightly greater in low-shore pools than high-shore pools but this difference was not significant (One-way ANOVA,  $F_{1,30} = 0.37$ ,  $p = 0.547$ ).



**Figure 18:** Length-frequency distribution plot of *P. serratus* in high- and low-shore rockpools at Newgale between June and July 2013.

### 3.5. RELATIONSHIP BETWEEN TOTAL LENGTH AND CARAPACE LENGTH

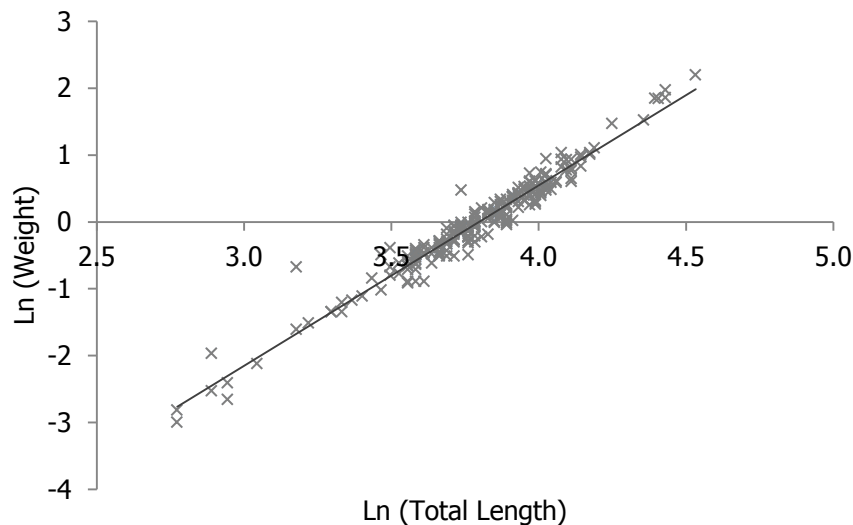
Figure 19 illustrates the linear relationship between the total length (TL) and carapace length (CL) of *P. serratus*. This relationship was modelled by the equation  $CL = 0.174 TL + 0.480$  (SE = 0.77,  $r^2 = 0.925$ ,  $F = 4095$ ,  $p < 0.001$ ).



**Figure 19:** Modelled relationship between total length and carapace length of male and female *P. serratus* in South Wales.

### 3.6. LENGTH-WEIGHT RELATIONSHIP

The length-weight relationships modelled for male and female *P. serratus* were not statistically different (GLM,  $F_{27, 153} = 0.62$ ,  $p = 0.930$ ). As a result, the male and female data were combined to produce a single length-weight model (Figure 20). The length-weight relationship for *P. serratus* can be described by the equation  $W = 3.52 \times 10^{-5} L^{2.70}$  (SE = 0.161,  $r^2 = 0.954$ ,  $F = 4753$ ,  $p < 0.001$ ).



**Figure 20:** Log-log plot modeling the length-weight relationship of male and female *P. serratus* in South Wales.

## 4. DISCUSSION

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### 4.1. SAMPLING METHOD

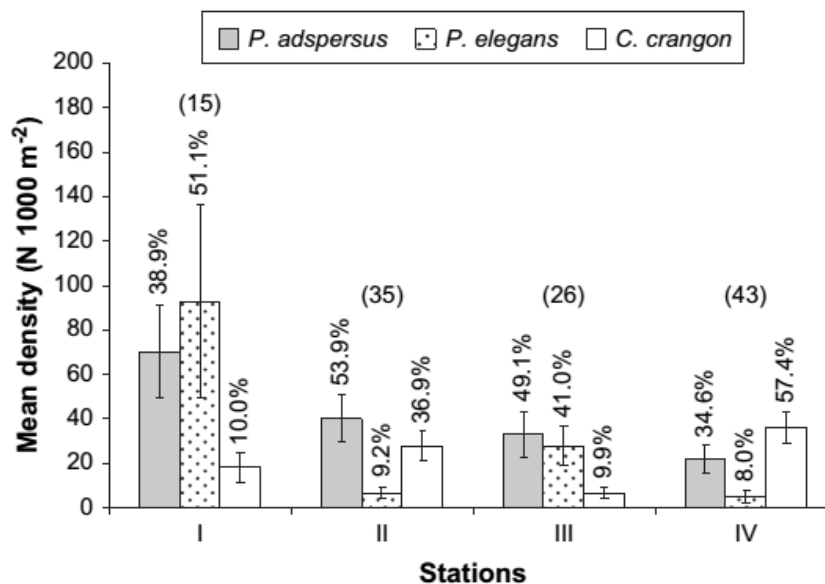
The results indicate that the dip netting method was more effective for sampling *P. serratus* in the littoral zone than the method of deploying Roscoff prawn pots. This finding is unexpected considering that Welsh commercial fisherman use pots as their main method for catching prawns. The low catches of *P. serratus* by prawn pots found in this study could be a result of the soak time being too short; pots were deployed for 12 hours in this study which is a considerably shorter period than the typical soak time of 2 to 5 days, which is utilised by fishermen (Huxley 2008). An additional explanation for the low catch efficiency of the pots is that *P. serratus* may not feed in the littoral zone. Forster (1951) analysed the stomach contents of *P. serratus* caught in Plymouth and determined that the food consumed varied by the habitat in which the prawns were situated in. However, this study was inconclusive and, to date, research has not been conducted to build upon the initial findings by Forster (1951). Consequently, it can only be speculated that the low catch efficiency of the pots was a result of the prawns not feeding.

While the dip netting method was more effective at catching prawns than the pots, it is unlikely that the dip net sampling was completely unbiased. Various species of prawns, including *P. serratus*, are known to be more active at night than during the day; thus, larger abundances of prawns are caught after dark than during daylight (Rodriguez and Naylor 1972; Anokhina 2005; Schaffmeister et al. 2006). Consequently, sampling only during the daytime could have caused the overall abundance of *P. serratus* to be underestimated. Furthermore, large prawns were potentially able to evade capture through rapid movement away from the mouth of the net (Schaffmeister et al. 2006). Thus, the dip netting method could have resulted in a low catch efficiency of large prawns. In contrast, it is less likely that small prawns were underestimated since the mesh size of 5 x 5mm would prevent the escape of most small prawns through the net.

### 4.2. ABUNDANCE AND DISTRIBUTION

During the preliminary sampling period, only half of the visited sites which were accessible were found to contain *P. serratus* during the 20 minute timed searches (Figure 8). These findings indicate that, during the summer, *P. serratus* are sparsely distributed in rocky littoral habitats in South Wales. Furthermore, 68% of the total dip net catch was obtained at Dale Roads, with the remainder of the catch divided between the four other sampling sites (Table 3). Thus, the abundance of *P. serratus* within a site is likely controlled by site specific parameters. Substantial differences in the abundance of *P. serratus* between sampling sites has been previously documented in Plymouth and Cardigan Bay (Forster 1951; Huxley 2011). However, the sampling intensity varied between the sites in these two studies; thus, the abundances of *P. serratus* caught could not be directly compared between the sampling locations (Forster 1951; Huxley 2011).

In addition, research has been conducted on the spatial distribution of other *Palaemon* spp. (Łapińska and Szaniawska 2006; Schaffmeister et al. 2006; Bilgin et al. 2008). These studies illustrate that the abundance of *Palaemon* spp. varies substantially within its spatial range (Łapińska and Szaniawska 2006; Schaffmeister et al. 2006; Bilgin et al. 2008). For example, Bilgin et al. (2008) detected a considerable difference in the abundance of *Palaemon adspersus* and *P. elegans* at four sampling stations in the southern Black Sea (Figure 21). In this study, there was a statistical difference in the species composition between stations (ANOSIM,  $r = 0.14$ ,  $p < 0.001$ ). Furthermore, the mean densities of *P. adspersus* and *P. elegans* were considerably higher at Station I than the other three stations, which indicates that the environmental conditions at this station were the most favourable for these two *Palaemon* spp. (Figure 21) (Bilgin et al. 2008). Therefore, previous research pertaining to the abundance and distribution of *Palaemon* spp. supports the present findings that *P. serratus* demonstrates a highly selective behaviour towards habitat preferences.



**Figure 21:** Mean densities ( $N\ 1000m^{-2}$ ) of *Palaemon adspersus*, *P. elegans* and *Crangon crangon* caught during monthly beam trawls samples obtained between February 2002 and January 2004 in the southern Black Sea. Standard error bars and percentages of densities within each station are illustrated along with the number of trawls conducted at each station shown in parenthesis.

**Source:** Bilgin et al. 2008

#### 4.3. POPULATION STRUCTURE

The length-frequency distribution plots demonstrated that *P. serratus* displayed a unimodal distribution at all five sites (Figure 14 and 17). It has previously been found that *P. serratus* populations exhibit a polymodal distribution, with peaks corresponding to different year-classes (Forster 1951; Guerao and Ribera 2000; Huxley 2011). Consequently, it can be concluded that the absence of a polymodal distribution in TL of the samples obtained in this study was likely because the majority of the catch was from a single age class: O-group individuals. This conclusion can be further strengthened by referring to the findings in Forster (1951); length-frequency distribution plots

of the population of *P. serratus* in Plymouth indicated that specimens with a TL of less than 70mm were O-group individuals. By using this TL as a proxy, it can be determined that approximately 97% of the *P. serratus* caught in this study were O-group prawns. However, this finding should be viewed with some caution since the population dynamics of *P. serratus* in South Wales are likely to be different than those in Plymouth. The minimal abundance of 1-group prawns collected in this study suggests that the littoral zone in South Wales is predominately a nursery ground for O-group *P. serratus*. However, additional research is required to verify this assumption.

Since the TL at maturity was not determined in this study, the data cannot be divided by maturity status to assess the population structure for immature and mature individuals separately. However, the maturity of *P. serratus* from other studies can be examined. Size at sexual maturity can be expressed as either the minimum size of ovigerous females (Forster 1951) or the size at 50% maturity (Béguet et al. 2010; Paschoal et al. 2013). In Plymouth, the minimum size of ovigerous females was found to be 55mm in total length (Forster 1951). The carapace length at 50% maturity for *P. serratus* in Cardigan Bay was found to be between 18 and 20mm (Huxley 2011). Using the CL-TL equation established in the present study, the total length at 50% maturity in the Huxley (2011) study was determined to be between 100 and 112mm. The considerable discrepancy in calculated TL at maturity from these two studies is due to the different locations that the studies were undertaken in as well as the different methods employed to calculate maturity. It was, therefore, deemed inadvisable to extrapolate the findings on maturity from other studies to provide estimates about the population structure of immature and mature *P. serratus* in South Wales.

The results indicated that sexual dimorphism by TL did not occur within the samples obtained, which conforms to previous research which specifies that sexual dimorphism is not evident in O-group individuals of *P. serratus* (Forster 1951). In contrast, sexual dimorphism by length has been noted for adult *P. serratus* (Forster 1951; Rodriguez 1981; Guerra and Ribera 2000) as well as other *Palaemon* species (Bilgin et al. 2009; Béguet et al. 2010; Paschoal et al. 2013). Consequently, sexual dimorphism by length may be apparent in the 1-group portion of the South Wales population of *P. serratus*; further data collection would be required to evaluate this hypothesis.

#### **4.4. *PALAEMON SERRATUS* IN NORTH AND SOUTH WALES**

A complementary study was conducted in North Wales at five sites around Anglesey and the Llŷn Peninsula by employing the same sampling method undertaken in this study (Jones 2013). Overall, the abundance of *P. serratus* was greater at the sampling sites in North Wales than in the south, with 827 and 229 individuals caught by dip netting, respectively (Jones 2013). These results suggest that the environmental conditions of the littoral zone in North Wales are more favourable for *P. serratus* than those in South Wales. However, due to the inconclusive analyses pertaining to the

environmental drivers of *P. serratus* abundance in both studies, the causes for the difference in abundance between north and south cannot be determined. In contrast, there was a statistical difference in the abundance of *P. serratus* caught at the different sampling sites in North Wales (Jones 2013) which parallels the findings for South Wales. Consequently, this strengthens the conclusion that *P. serratus* is highly site selective.

Both studies indicated that there was no statistical difference in the TL of males and females; however, females were slightly larger, on average, and were more prevalent at both the north and south sampling sites (Jones 2013). Furthermore, *P. serratus* caught in North Wales had a higher average TL (mean TL = 58mm) than the specimens obtained in South Wales (mean TL = 46mm). Accordingly, these two studies suggest that the population structure of *P. serratus* is not uniform throughout the littoral zone in Wales. From a fisheries management perspective, the variations in population structure between North and South Wales suggests that the spatial scale of management is a crucial factor to be taken under consideration if the *P. serratus* fishery is to operate in a sustainable manner. While a pan-Wales management strategy would be most straightforward to implement and enforce, this approach may not be effective due to the variations in the population characteristics over this relatively broad spatial scale.

#### **4.5. ENVIRONMENTAL DRIVERS**

The highly skewed distribution of the dataset prevented a thorough analysis to be conducted of the abundance of *P. serratus* in relation to the environmental parameters. As a result, no conclusions were drawn pertaining to the influence of environmental variables on *P. serratus* abundance. In order to evaluate the two hypotheses established based on the PCA, it is necessary that a new dataset be collected. In addition, the dataset would need to be obtained from sites which have relatively high abundances of *P. serratus* in the littoral zone so that adequate data are acquired for a comprehensive analysis to be conducted. Based on the proposed hypotheses, it is advised that sheltered sites with high algae cover and low salinities be targeted.

#### **4.6. ABUNDANCE BY SHORE HEIGHT AND TIDAL DIRECTION**

Tidal migrations are an endogenous characteristic of *P. serratus* which are synchronised daily by a combination of factors which include light intensity, temperature and pressure (Rodriguez and Naylor 1972). Common advantages of tidal migrations are an increased access to foraging grounds and reductions in predatory pressures (Gibson 2003). As a result of tidal migrations, the abundance of migratory species, including *P. serratus*, is known to vary by shore height (Forster 1951; Rodriguez and Naylor 1972; Sterry 2012). In this study, there was a statistical difference in the abundance of *P. serratus* at different shore heights, with the highest abundance of prawns collected on the low shore (Figure 16). The trend of elevated abundances at low water has also been noted for other caridean species which undergo tidal migrations (Al-Adhub and Naylor 1975; Coles 1979). The concentration

of *P. serratus* on the low shore is a direct result of the species only migrating up to the mid-shore level; 96% of the prawns collected for the shore height analysis in the present study were obtained below the mid-shore level. Although migrating into the intertidal zone on the flood tide provides benefits to tidal migrants, these species also expose themselves to the risk of stranding on the ebb tide (Rodriguez and Naylor 1972; Gibson 2003). Thus, by migrating into the intertidal zone only as high as the mid-shore, *P. serratus* are able to benefit from the advantageous intertidal conditions while minimising the possibility of stranding.

*Palaemon* spp. activity has been observed to increase on the ebb tide; it is theorised that this peak in activity is because during the offshore movement of water there is no risk of stranding (Forster 1951; Rodrigues and Naylor 1972). As a result, feeding can occur during the ebb tide without the prawns being carried to adverse heights on the shore (Rodriguez and Naylor 1972). In terms of the catch efficiency of prawns, an increase in activity typically corresponds to higher catch rates (Schaffmeister et al. 2006). In contrast to these findings, the present study observed no difference in the catches on ebb and flood tides. The non-significant difference between abundances caught on the ebb and flood tide could indicate that *P. serratus* activity was uniform through the sampling period at Dale Roads. Alternatively, it is possible that the sample size was inadequate to detect the difference in abundance by tidal direction.

#### **4.7. ABUNDANCE AND DISTRIBUTION OF *PALAEMON* SPP. IN ROCKPOOLS**

The analysis of *Palaemon* spp. in the rockpools at Newgale indicated that *P. serratus* were evenly distributed between high- and low-shore pools while *P. elegans* was confined to the high-shore pools. This conforms to the notion that *P. elegans* displays a preference for pools on the high-shore (Rodriguez and Naylor 1972; Sterry and Cleave 2012). In addition, the average TL of *P. serratus* (mean TL = 39mm) was determined to be statistically greater than for *P. elegans* (mean TL = 30mm), which corresponds to previous understandings of the two species (Sterry and Cleave 2012).

Furthermore, the results suggest that the reproductive cycles of *P. serratus* and *P. elegans* are not complementary; ovigerous *P. serratus* females were not collected at Newgale while 22% of the *P. elegans* catch was ovigerous. Thus, it can tentatively be concluded that the brooding period of *P. elegans* extends later into the summer than for *P. serratus*.

#### **4.8. LIMITATIONS AND FUTURE RESEARCH**

The study was temporally restricted to two month in the summer of 2013, which prevented the detection of the inshore and offshore migration of *P. serratus*. Previous research shows that the inshore migration period occurs as early as April, while the winter offshore migration typically takes place in October or November (Forster 1951; Guerao and Ribera 2000). Consequently, the temporal

scope of future research should be extended to include monthly littoral sampling from April to November, or preferably throughout an entire 12 month cycle, to assess the abundance of *P. serratus* over the duration of the species' residence time in the littoral zone. To further improve the understanding of the inshore phase of *P. serratus*, a long-term monitoring programme could be implemented to continually measure the abundance of *P. serratus* at key sampling sites in the littoral zone of South Wales.

Although Jones (2013) provided a complementary study of *P. serratus* in North Wales which improved the spatial scale of this research, additional studies could further improve upon the spatial coverage of the data. Firstly, neither study addressed sampling locations in mid-Wales, which led to a sizeable gap in the spatial extent of the findings. Additional sites should, therefore, be added in this central region; studying *P. serratus* in mid-Wales is of particular importance since the main *P. serratus* fishery in the UK is located in Cardigan Bay, mid-Wales (Huxley 2011). Secondly, the sampling sites in South Wales should be re-selected in an attempt to locate sites where *P. serratus* are abundant in order to increase the availability of data. Based on the observations from Jones (2013), as well as the present study, an adapted site selection criterion should be imposed which takes into consideration the presence of algae, salinity and the level of exposure of the sites.

In addition to extending the temporal and spatial scope of the research, the field and laboratory methodology could be modified to produce a more robust dataset. The process of replication should be incorporated into the experimental design to eliminate the problem of pseudoreplication that was incurred in this study. An added benefit of collecting true replicates is that time could be viewed as a factor, rather than used as a replicate, which would enable a temporal analysis of the data. The sampling could also be undertaken at night, when prawns are known to be more active, which would reduce the likelihood of the abundance of *P. serratus* being underestimated. However, sampling in the littoral zone at night is logistically more challenging than during the day and the benefits would probably only be marginal. To further strengthen the analysis, additional environmental measurements could also be collected such as meteorological conditions (Forster 1951), tidal currents (Coles 1979) and offshore fishing pressure. Determining the total length at 50% maturity by using the morphometric methodology described by Paschoal et al. (2013) would allow for a separate analysis to be undertaken for immature and mature *P. serratus*.

The data acquired by this study were insufficient to be used to predict suitable *P. serratus* habitat in the littoral zone. By undertaking the suggested improvements and generating a larger dataset, adequate data could be accumulated to establish a habitat suitability index (HSI) for the species. HSI modelling is a useful tool for enabling management bodies to make informed conservation decisions as it produces a broader temporal and spatial scope than can be acquired through fieldwork alone (Brown et al. 2000; Vinagre et al. 2006). Thus, the development of fisheries management regulations for *P. serratus* would be greatly aided by the availability of a HSI.



#### 4.9. CONCLUSIONS

This study enabled the development of a standardised method for sampling *P. serratus* in the littoral zone in order to determine the variations in the abundance and distribution of the species, as well as to identify key population characteristics. The analysis indicated that *P. serratus* was sparsely distributed throughout the littoral zone and displayed a highly site selective behaviour. Dale Roads was observed to host the highest abundance of prawns, which indicated that the habitat conditions at this site were more favourable than those at the other sampling locations. However, the study was unable to identify the causes for the significant differences in abundances between sites. The study, thus, demonstrated the substantial need for broadening the temporal and spatial scope of the research. In particular, further research is required to verify that the littoral zone in South Wales provides a nursery ground habitat for *P. serratus* in the summer months.

At present, the results are not comprehensive enough to effectively guide fisheries management strategies to allow for adequate conservation to be achieved for this commercially targeted species. However, this study presents a foundation for future research that has the potential to address the current data deficiency which is hindering the establishment of a sustainable *P. serratus* fishery.

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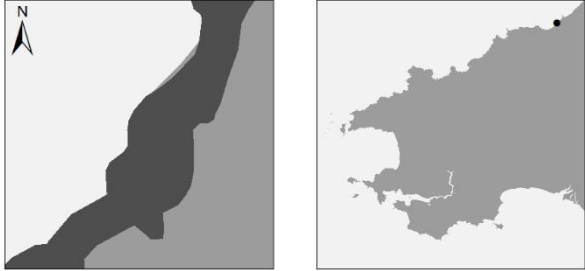
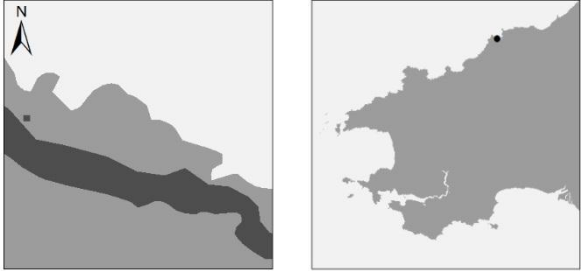
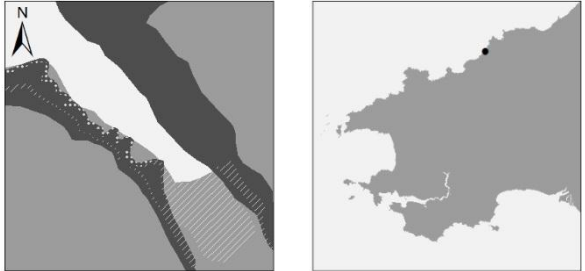
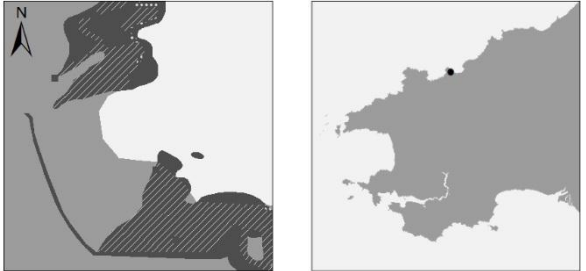
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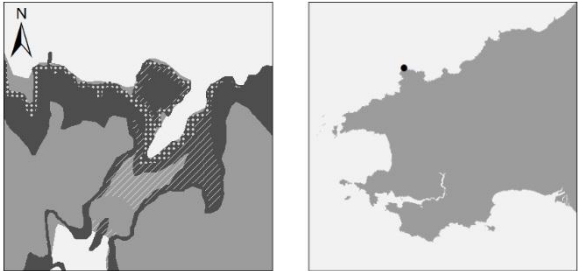
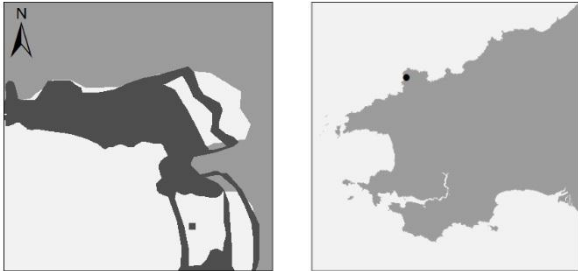

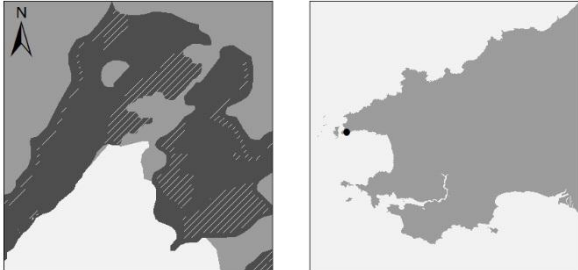
## APPENDICES

### APPENDIX I: SITE SELECTION

**Table Ia:** Maps and relevant information recorded at the visited sites during preliminary sampling.

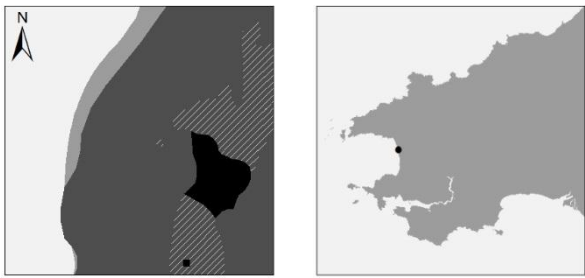
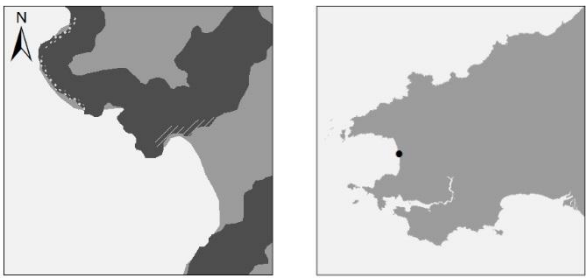
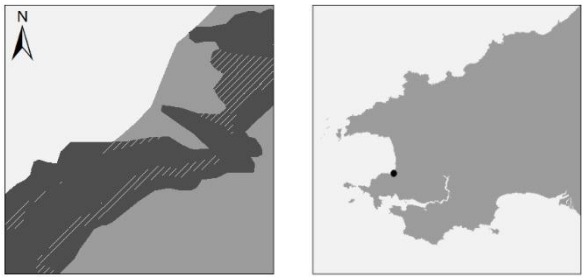
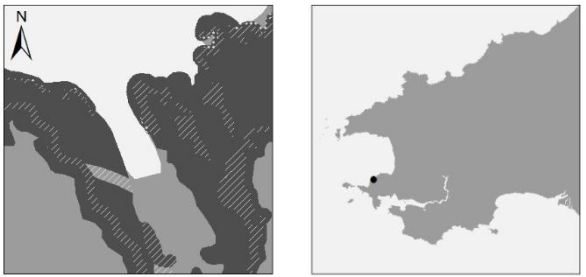
<p style="text-align: center;"><b>Aberporth</b></p>  <p><b>OS grid reference:</b> SN 260 512</p> <p><b><i>P. serratus</i> present:</b> No</p> <p><b>Substrate:</b> Boulders</p> <p><b>Algae:</b> Fucoids</p> <p><b>Accessible:</b> Yes</p>	<p style="text-align: center;"><b>Poppit Sands</b></p>  <p><b>OS grid reference:</b> SN 154 488</p> <p><b><i>P. serratus</i> present:</b> Yes</p> <p><b>Substrate:</b> Sand, bedrock</p> <p><b>Algae:</b> Green algae</p> <p><b>Accessible:</b> Yes</p>
<p style="text-align: center;"><b>Ceibwr Bay</b></p>  <p><b>OS grid reference:</b> SN 110 456</p> <p><b><i>P. serratus</i> present:</b> Did not sample</p> <p><b>Substrate:</b> Sand, bedrock</p> <p><b>Algae:</b> Fucoids</p> <p><b>Accessible:</b> Limited access</p>	<p style="text-align: center;"><b>Pig y Baw</b></p>  <p><b>OS grid reference:</b> SN 014 400</p> <p><b><i>P. serratus</i> present:</b> No</p> <p><b>Substrate:</b> Boulders</p> <p><b>Algae:</b> Fucoids</p> <p><b>Accessible:</b> Yes</p>

Rock substrate
  Fucoids  
 Intertidal boulders
  Kelp


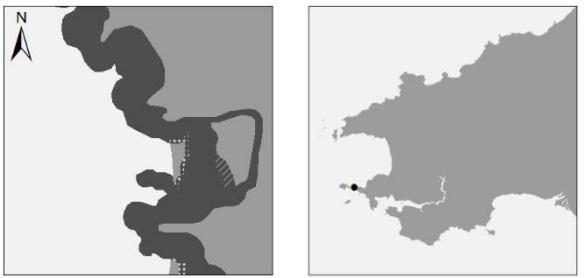
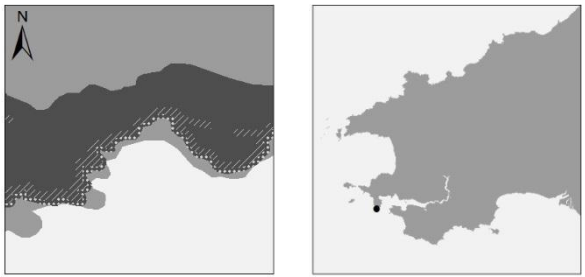
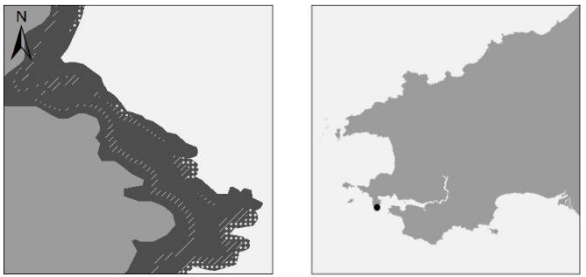
<p style="text-align: center;"><b>Strumble Head</b></p>  <p><b>OS grid reference:</b> SM 893 412</p> <p><b><i>P. serratus</i> present:</b> Did not sample</p> <p><b>Substrate:</b> Boulders</p> <p><b>Algae:</b> Fucooids, kelp</p> <p><b>Accessible:</b> No</p>	<p style="text-align: center;"><b>Pwll Deri</b></p>  <p><b>OS grid reference:</b> SM 894 410</p> <p><b><i>P. serratus</i> present:</b> Did not sample</p> <p><b>Substrate:</b> Boulders</p> <p><b>Algae:</b> Minimal</p> <p><b>Accessible:</b> No</p>
<p style="text-align: center;"><b>Aber Mawr</b></p>  <p><b>OS grid reference:</b> SM 881 346</p> <p><b><i>P. serratus</i> present:</b> No</p> <p><b>Substrate:</b> Boulders, sand</p> <p><b>Algae:</b> Green algae, patchy fucooids</p> <p><b>Accessible:</b> Yes</p>	<p style="text-align: center;"><b>Porthlysgi Bay</b></p>  <p><b>OS grid reference:</b> SM 725 235</p> <p><b><i>P. serratus</i> present:</b> Did not sample</p> <p><b>Substrate:</b> Sand, boulders</p> <p><b>Algae:</b> Patchy fucooids, green algae</p> <p><b>Accessible:</b> Limited access</p>

Rock substrate    
  Fucooids  
 Intertidal boulders    
  Kelp

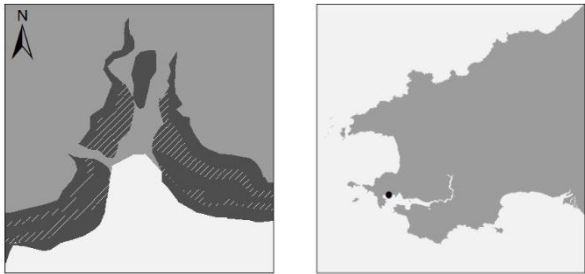
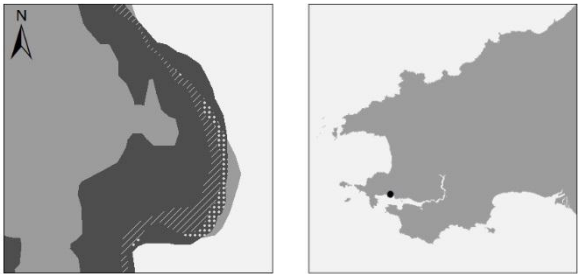

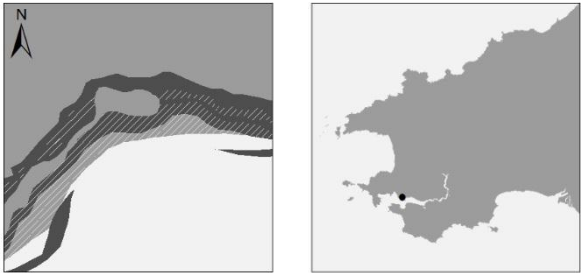


<p style="text-align: center;"><b>Newgale</b></p>  <p><b>OS grid reference:</b> SM 855 196</p> <p><b><i>P. serratus</i> present:</b> Yes</p> <p><b>Substrate:</b> Boulders</p> <p><b>Algae:</b> Fucoids, green algae</p> <p><b>Accessible:</b> Yes, but 1 mile across beach</p>	<p style="text-align: center;"><b>Nolton Haven</b></p>  <p><b>OS grid reference:</b> SM 859 185</p> <p><b><i>P. serratus</i> present:</b> Yes</p> <p><b>Substrate:</b> Sand, boulders</p> <p><b>Algae:</b> Patchy fucoids</p> <p><b>Accessible:</b> Yes</p>
<p style="text-align: center;"><b>Rook's Bay</b></p>  <p><b>OS grid reference:</b> SM 855 129</p> <p><b><i>P. serratus</i> present:</b> Yes</p> <p><b>Substrate:</b> Sand, boulders</p> <p><b>Algae:</b> Fucoids</p> <p><b>Accessible:</b> Yes</p>	<p style="text-align: center;"><b>St. Brides</b></p>  <p><b>OS grid reference:</b> SM 801 109</p> <p><b><i>P. serratus</i> present:</b> Yes</p> <p><b>Substrate:</b> Bedrock, boulders</p> <p><b>Algae:</b> Fucoids abundant, <i>Laminaria</i> sparse</p> <p><b>Accessible:</b> Yes</p>

 Rock substrate	 Fucoids
 Intertidal boulders	 Kelp

<p style="text-align: center;"><b>Martin's Haven</b></p>  <p><b>OS grid reference:</b> SM 760 091</p> <p><b><i>P. serratus</i> present:</b> No</p> <p><b>Substrate:</b> Boulders, sand</p> <p><b>Algae:</b> Fucoids abundant, <i>Laminaria</i></p> <p><b>Accessible:</b> Yes</p>	<p style="text-align: center;"><b>Mouse's Haven</b></p>  <p><b>OS grid reference:</b> SM 756 091</p> <p><b><i>P. serratus</i> present:</b> Did not sample</p> <p><b>Substrate:</b> Boulders, sand</p> <p><b>Algae:</b> Green algae, fucoids</p> <p><b>Accessible:</b> No</p>
<p style="text-align: center;"><b>Mill Bay</b></p>  <p><b>OS grid reference:</b> SM 809 035</p> <p><b><i>P. serratus</i> present:</b> Yes, scarce</p> <p><b>Substrate:</b> Sand, boulders</p> <p><b>Algae:</b> Green algae abundant, sparse <i>Laminaria</i></p> <p><b>Accessible:</b> Yes, 15 minute walk</p>	<p style="text-align: center;"><b>Dale Roads</b></p>  <p><b>OS grid reference:</b> SM 811 057</p> <p><b><i>P. serratus</i> present:</b> Yes, abundant</p> <p><b>Substrate:</b> Boulders, silt</p> <p><b>Algae:</b> Fucoids abundant, <i>Laminaria</i></p> <p><b>Accessible:</b> Yes</p>


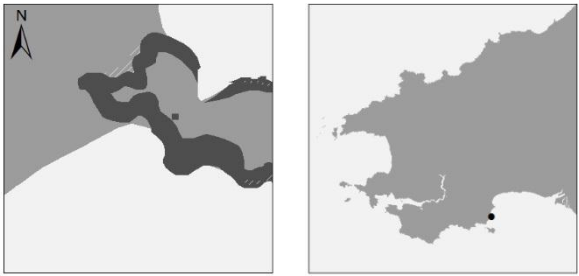
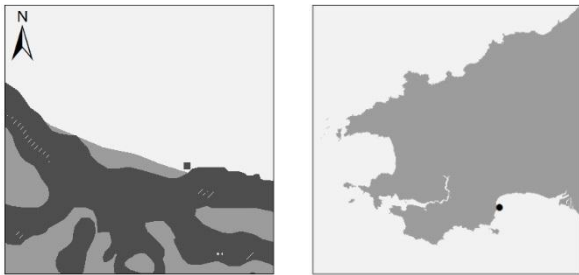
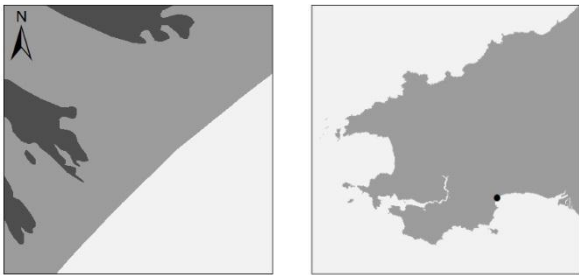
 Rock substrate	 Fucoids
 Intertidal boulders	 Kelp





<p style="text-align: center;"><b>Monk Haven</b></p>  <p><b>OS grid reference:</b> SM 828 064</p> <p><b><i>P. serratus</i> present:</b> No</p> <p><b>Substrate:</b> Bedrock, boulders</p> <p><b>Algae:</b> Green algae abundant, fucoids sparse</p> <p><b>Accessible:</b> Yes</p>	<p style="text-align: center;"><b>Sandy Haven boulders</b></p>  <p><b>OS grid reference:</b> SM 856 070</p> <p><b><i>P. serratus</i> present:</b> No</p> <p><b>Substrate:</b> Boulders</p> <p><b>Algae:</b> Green algae, fucoids sparse</p> <p><b>Accessible:</b> Yes</p>
<p style="text-align: center;"><b>Sandy Haven rockpools</b></p>  <p><b>OS grid reference:</b> SM 860 070</p> <p><b><i>P. serratus</i> present:</b> Yes, abundant</p> <p><b>Substrate:</b> Bedrock</p> <p><b>Algae:</b> Green algae, fucoids</p> <p><b>Accessible:</b> Yes</p>	<p style="text-align: center;"><b>Milford Haven</b></p>  <p><b>OS grid reference:</b> SM 905 056</p> <p><b><i>P. serratus</i> present:</b> No</p> <p><b>Substrate:</b> Boulders</p> <p><b>Algae:</b> Green algae, fucoids sparse</p> <p><b>Accessible:</b> Yes</p>

 Rock substrate	 Fucoids
 Intertidal boulders	 Kelp

<p style="text-align: center;"><b>Stackpole Quay</b></p> <div data-bbox="193 286 772 560"> </div> <p><b>OS grid reference:</b> SR 993 958</p> <p><b><i>P. serratus</i> present:</b> No</p> <p><b>Substrate:</b> Boulders, bedrock</p> <p><b>Algae:</b> Green algae, fucoids sparse</p> <p><b>Accessible:</b> Yes</p>	<p style="text-align: center;"><b>North of Stackpole Quay</b></p> <div data-bbox="813 286 1393 560"> </div> <p><b>OS grid reference:</b> SR 994 960</p> <p><b><i>P. serratus</i> present:</b> Yes, in rockpools</p> <p><b>Substrate:</b> Boulders</p> <p><b>Algae:</b> Green algae abundant, fucoids present</p> <p><b>Accessible:</b> Yes</p>
<p style="text-align: center;"><b>Manorbier Bay</b></p> <div data-bbox="193 1120 772 1393"> </div> <p><b>OS grid reference:</b> SS 059 976</p> <p><b><i>P. serratus</i> present:</b> No</p> <p><b>Substrate:</b> Bedrock</p> <p><b>Algae:</b> Green algae abundant, fucoids present</p> <p><b>Accessible:</b> Yes</p>	<p style="text-align: center;"><b>Lydstep Haven</b></p> <div data-bbox="813 1120 1393 1393"> </div> <p><b>OS grid reference:</b> SS 091 978</p> <p><b><i>P. serratus</i> present:</b> Yes</p> <p><b>Substrate:</b> Boulders, sand</p> <p><b>Algae:</b> Fucoids abundant, <i>Laminaria</i> present</p> <p><b>Accessible:</b> Yes</p>

Rock substrate	Fucoids
Intertidal boulders	Kelp

<p style="text-align: center;"><b>Giltar Point</b></p>  <p><b>OS grid reference:</b> SS 122 985</p> <p><b><i>P. serratus</i> present:</b> Yes</p> <p><b>Substrate:</b> Boulders, sand</p> <p><b>Algae:</b> Fucoids sparse</p> <p><b>Accessible:</b> Yes</p>	<p style="text-align: center;"><b>Tenby</b></p>  <p><b>OS grid reference:</b> SN 137 004</p> <p><b><i>P. serratus</i> present:</b> No</p> <p><b>Substrate:</b></p> <p><b>Algae:</b></p> <p><b>Accessible:</b></p>
<p style="text-align: center;"><b>Monkstone Point</b></p>  <p><b>OS grid reference:</b> SN 148 032</p> <p><b><i>P. serratus</i> present:</b> Yes, in rockpools</p> <p><b>Substrate:</b> Boulders, sand</p> <p><b>Algae:</b> Very sparse algae cover</p> <p><b>Accessible:</b> Yes, 15 minute walk</p>	<p style="text-align: center;"><b>Wiseman's Bridge</b></p>  <p><b>OS grid reference:</b> SN 145 060</p> <p><b><i>P. serratus</i> present:</b> No</p> <p><b>Substrate:</b> Sand, boulders</p> <p><b>Algae:</b> Green algae sparse</p> <p><b>Accessible:</b> Yes</p>

 Rock substrate	 Fucoids
 Intertidal boulders	 Kelp



**Table Ib:** Photographs of sites visited during the preliminary sampling stage to be used for site selection. Photographs not available for the following sites: Aberporth, Pig y Baw, Nolton Haven and Tenby.

**Poppit Sands**



**Ceibwr Bay**



**Strumble Head**



**Pwll Deri**



**Aber Mawr**



**Porthlysgi Bay**



**Newgale**



**Rook's Bay**



**St Brides**



**Martin's Haven**



**Mouse's Haven**



**Mill Bay**





**Dale Roads**



**Monk Haven**



**Sandy Haven boulders**



**Sandy Haven rockpools**



**Milford Haven**



**Stackpole Quay**



**North of Stackpole Quay**



**Manorbier Bay**



**Lydstep Haven**



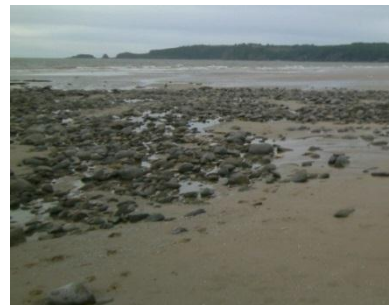
**Giltar Point**



**Monkstone Point**



**Wiseman's Bridge**



## APPENDIX II: GPS COORDINATES OF SAMPLE LOCATIONS

**Table IIa:** GPS coordinates of the dip netting sample locations for the first sampling period (June 22 to 26). Cells containing ‘-’ indicate sample locations when GPS coordinates were not recorder. Site codes are as follows: MOP = Monkstone Point, GIP = Giltar Point, DAR = Dale Roads, LYH = Lydstep Haven, NEW = Newgale.

DATE	SITE CODE	SAMPLE	LATITUDE	LONGITUDE
22/06/2013	MOP	A	51.69769	-4.67996
22/06/2013	MOP	B	51.69776	-4.67987
22/06/2013	MOP	D	51.69794	-4.67980
22/06/2013	MOP	E	51.69770	-4.67989
22/06/2013	MOP	F	51.69767	-4.67992
23/06/2013	GIP	A	-	-
23/06/2013	GIP	B	51.65431	-4.71197
23/06/2013	GIP	C	51.65440	-4.71168
23/06/2013	GIP	D	51.65432	-4.71184
23/06/2013	GIP	E	51.65454	-4.71279
23/06/2013	GIP	F	51.65427	-4.71309
24/06/2013	DAR	A	51.70680	-5.16705
24/06/2013	DAR	B	51.70704	-5.16692
24/06/2013	DAR	C	51.70743	-5.16544
24/06/2013	DAR	D	51.70727	-5.16521
24/06/2013	DAR	E	51.70696	-5.16611
24/06/2013	DAR	F	51.70676	-5.16610
25/06/2013	LYH	A	51.64683	-4.76004
25/06/2013	LYH	B	51.64701	-4.75915
25/06/2013	LYH	C	51.64705	-4.75866
25/06/2013	LYH	D	51.64706	-4.75863
25/06/2013	LYH	E	51.64714	-4.75926
25/06/2013	LYH	F	51.64709	-4.76006
26/06/2013	NEW	A	51.83472	-5.11417
26/06/2013	NEW	B	51.83480	-5.11404
26/06/2013	NEW	C	51.83427	-5.11427
26/06/2013	NEW	D	51.83227	-5.11516
26/06/2013	NEW	E	-	-
26/06/2013	NEW	F	51.83435	-5.11392



**Table IIb:** GPS coordinates of the dip netting sample locations for the second sampling period (July 10 to 15). Cells containing ‘-’ indicate sample locations when GPS coordinates were not recorder. Site codes are as follows: DAR = Dale Roads, GIP = Giltar Point, LYP = Lydstep Haven, NEW = Newgale, MOP = Monkstone Point.

DATE	SITE CODE	SAMPLE	LATITUDE	LONGITUDE
10/07/2013	DAR	A	51.70683	-5.16620
10/07/2013	DAR	B	51.70691	-5.16616
10/07/2013	DAR	C	51.70703	-5.16612
10/07/2013	DAR	D	51.70698	-5.16604
10/07/2013	DAR	E	51.70695	-5.16616
10/07/2013	DAR	F	51.70692	-5.16621
11/07/2013	GIP	A	51.65413	-4.71335
11/07/2013	GIP	B	51.65426	-4.71235
11/07/2013	GIP	C	51.65432	-4.71208
11/07/2013	GIP	D	51.65447	-4.71200
11/07/2013	GIP	E	51.65444	-4.71245
11/07/2013	GIP	F	51.65428	-4.71292
12/07/2013	LYH	A	51.64693	-4.75975
12/07/2013	LYH	B	51.64703	-4.75936
12/07/2013	LYH	C	51.64712	-4.75919
12/07/2013	LYH	D	51.64709	-4.75933
12/07/2013	LYH	E	51.64702	-4.75956
12/07/2013	LYH	F	51.64693	-4.76015
13/07/2013	NEW	A	-	-
13/07/2013	NEW	B	-	-
13/07/2013	NEW	C	-	-
13/07/2013	NEW	D	-	-
13/07/2013	NEW	E	-	-
13/07/2013	NEW	F	-	-
15/07/2013	MOP	A	51.69766	-4.68005
15/07/2013	MOP	B	51.69772	-4.68002
15/07/2013	MOP	C	51.69777	-4.68004
15/07/2013	MOP	D	51.69779	-4.68005
15/07/2013	MOP	E	51.69776	-4.67998
15/07/2013	MOP	F	51.69772	-4.68007

**Table IIc:** GPS coordinates of the dip netting sample locations for the third sampling period (July 22 to 29). Site codes are as follows: MOP = Monkstone Point, LYH = Lydstep Have, GIP = Giltar Point, DAR = Dale Roads, NEW = Newgale.

DATE	SITE CODE	SAMPLE	LATITUDE	LONGITUDE
22/07/2013	MOP	A	51.69776	-4.67979
22/07/2013	MOP	B	51.69795	-4.67944
22/07/2013	MOP	C	51.69819	-4.67868
22/07/2013	MOP	D	51.69816	-4.67912
22/07/2013	MOP	E	51.69780	-4.67974
22/07/2013	MOP	F	51.69766	-4.67982
22/07/2013	MOP	H	51.69748	-4.68021
26/07/2013	LYH	A	51.64668	-4.76015
26/07/2013	LYH	B	51.64684	-4.75908
26/07/2013	LYH	C	51.64702	-4.75866
26/07/2013	LYH	D	51.64684	-4.75824
26/07/2013	LYH	E	51.64695	-4.75898
26/07/2013	LYH	F	51.64706	-4.75989
27/07/2013	GIP	A	51.65413	-4.71311
27/07/2013	GIP	B	51.65426	-4.71236
27/07/2013	GIP	C	51.65423	-4.71206
27/07/2013	GIP	D	51.65436	-4.71205
27/07/2013	GIP	E	51.65426	-4.71226
27/07/2013	GIP	F	51.65425	-4.71281
28/07/2013	DAR	A	51.70672	-5.16627
28/07/2013	DAR	B	51.70690	-5.16616
28/07/2013	DAR	C	51.70694	-5.16626
28/07/2013	DAR	D	51.70694	-5.16634
28/07/2013	DAR	E	51.70693	-5.16623
28/07/2013	DAR	F	51.70684	-5.16626
29/07/2013	NEW	A	51.83457	-5.11361
29/07/2013	NEW	B	51.83432	-5.11390
29/07/2013	NEW	C	51.83417	-5.11413
29/07/2013	NEW	D	51.83434	-5.11533
29/07/2013	NEW	E	51.83508	-5.11501
29/07/2013	NEW	F	51.83453	-5.11504

### APPENDIX III: EXPOSURE INDEX

**Table III:** Indicator species situated on the upper, mid and low shores which aided in evaluating the exposure level of the four main sampling sites. Based on Connor et al. 2004.

SITE	SUBSTRATE	INDICATOR SPECIES BY SHORE HEIGHT			EXPOSURE LEVEL
		UPPER	MID	LOW	
DALE ROADS	Boulders Cobbles Pebbles Mud	<i>Pelvetia canaliculata</i>	<i>Ascophyllum nodosum</i> <i>Fucus vesiculosus</i> <i>Littorina littorea</i>	<i>Fucus serratus</i>	Low
LYDSTEP HAVEN	Boulders Cobbles		<i>Mytilus edulis</i> <i>Fucus vesiculosus</i> <i>Semibalanus balanoides</i> <i>Patella vulgata</i>	<i>Littorina littorea</i> <i>Mastocarpus stellatus</i>	Moderate
GILTAR POINT	Boulders	<i>Pelvetia canaliculata</i>	<i>Mytilus edulis</i> <i>Fucus vesiculosus</i> <i>Semibalanus balanoides</i> <i>Littorina littorea</i>	<i>Fucus serratus</i> <i>Littorina littorea</i>	Moderate
MONKSTONE POINT	Large boulders	<i>Mytilus edulis</i> <i>Chthamalus</i> spp. <i>Semibalanus balanoides</i> <i>Patella</i> spp.	<i>Mytilus edulis</i> <i>Chthamalus</i> spp.		High