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A review of the *Palaemon serratus* fishery: biology, ecology & management

Haig, J., Ryan, N.M., Williams, K.F. & M.J. Kaiser

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PURPOSE

This paper reviews the biology, ecology and management of the commercially fished shrimp species *Palaemon serratus*. The purpose of the review is to identify gaps in current knowledge so that we can identify the required research that will assist in assessing and managing *Palaemon* stocks to ensure their future sustainability.

INTRODUCTION

Palaemon serratus is a decapod crustacean that inhabits inshore coastal areas around the majority of the coast of the UK and Ireland. It is a relatively short-lived species with a life span of between two (Forster 1951) and five years (Cole 1958). *P. serratus* can be found in either shallow intertidal pools or deeper subtidal waters. They appear to be migratory; occuring in high abundances in shallow waters during summer months and in deeper water (up to 40m) during the winter. *P. serratus* has a number of historical synonymised names. It was first described by Pennant in 1777 as *Astacus serratus* and has since undergone several genera and species name changes up until 1950 (MarLIN & WoRMS, 2014). *P. serratus* is similar in morphology to other Palaemonid shrimp in northern temperate waters (e.g. *Palaemon elegans*, *P. longirostris* and *P. adspersus*), though *P. serratus* can be distinguished by the lack of dorsal teeth on the distal third of the distinctly upturned rostrum (González-Ortegon *et al*. 2006).

The *P. serratus* fishery does not occur across the full distribution. This may be explained by the spatial variability in abundance such that only a few regions are considered viable for fishery exploitation ("Fishers' Knowledge" interviews, EFF funded *Sustainable Fisheries in Welsh Waters* project, Bangor University). In the United Kingdom *P. serratus* is a commercially valuable species, providing income for pot trap fishermen during the winter months. In the British Isles, commercial fisheries began in the 1970s and since then effort has increased. Landings in Ireland were reported to have increased threefold in the early 1990s (Fahy & Gleeson 1996; BIM 2008). At present the fishery is unregulated, with little management in place to protect stocks from overexploitation. The exception to this is a closed season that is imposed from May to August in Ireland.

The aim of this review is to collate the information available on *P. serratus* throughout its commercial range, to identify current knowledge gaps, to compare fishery management approaches, and to identify biological differences that may occur between populations.

METHODOLOGY

The available literature was searched using the following protocol. A list of search terms was compiled that aimed to cover all aspects of the biology and ecology of *P. serratus* and the management of the fishery. Documents were considered if they were available in Microsoft word or PDF format. For peer reviewed literature, the title and/or abstract had to contain the search terms, and for grey literature the search terms needed to be in the title and/or the body text.

Search terms

The following search terms were used to search for both peer reviewed and grey literature:

"Palaemon*" AND "Larva*" OR "Development" OR "Life history" OR "Recruit*" OR "Reproduc*" OR "Habitat" OR "Connect*" OR "Taxonomy" OR "Population" OR "Phylo*geography/gen/genetic tree" OR "Trophic level" OR "Feeding" OR "Predation" OR "common prawn" AND "Manage*" OR "Legislat*" OR "Bye-law" OR "Fishery"

The following two research databases were searched: ISI Web of Knowledge and Science Direct along with two web-based search engines: https://www.google.co.uk/ and http://scholar.google.com. Specialist websites that may contain local reports or studies specific to the *Palaemon* fishery were also searched (Appendix 1). Preliminary searches identified that the first 30 hits were appropriate for examination. These hits were exported into the referencing software EndNote (©2014 Thomson Reuters) and assessed for relevance based on the search criteria. Titles and abstracts were read for appropriate content. For highly relevant papers (i.e. specific to biology or ecology of *Palaemon* spp.) the full text was read and the bibliographies were scanned for additional relevant articles.

BIOLOGY AND DISTRIBUTION OF *PALAEMON SERRATUS*

Palaemon serratus (Pennant 1777) is a short lived Palaemonid shrimp. It has a broad geographical distribution, ranging from the North-Western coast of the Atlantic in the UK and Ireland to as far south as the Mediterranean, the Black Sea and Mauritanian coast (Guraeo & Ribera 2000; BIM 2008). Depending on the season, it can be found on rocky shores, within estuaries and in deeper offshore waters (Forster 1951; González-Ortegón *et al.* 2006; Henderson & Bird 2010).

Research to date estimates a lifespan of between two and five years for *P. serratus* (Table 1). The variation in longevity among *Palaemon* species may relate to growth rates and temperature (Guerao *et al.* 1994). The variation in observed longevity for *P. serratus* could therefore be attributed to environmental variances throughout their distribution.

Table 1. Differences in the life span of *P. serratus* reported in the literature for different locations.

Lifespan (years)	**Location of study**	**Source**	**Year**
2	UK – Plymouth	Forster	1959
3	Spain –la Ría de Vigo	Figueras	1986
4	UK –Holyhead	Cole	1958
5	France -Roscoff	Sollaud	1916

P. serratus exhibits sexual dimorphism in both length and weight (Forster 1951; Guerao & Ribera 2000), with females generally larger and heavier than the males (Forster 1951). Growth in females slows down with the onset of reproduction as energy investment is focused on egg production rather than in growth increments during moults (Hartnoll 1985). Maximum growth (weight gain) was observed between July and

September for populations in Irish waters; and was attributed to the higher sea temperatures during this time (Fahy & Gleeson, 1996). Male *P. serratus* mature faster than females (Stamps & Krishnan 1997); reaching maturity at six to seven months old (females mature at nine to ten months) (Forster 1951). *P. serratus* will mate after the female moults and fertilisation is internal. The female will carry the fertilised eggs externally on her pleopods for around four months at temperatures between 9-11˚C (Guerao & Ribera 2000). Egg development has been found to be slower in colder inshore waters during the winter (Forster 1951; Fahy & Gleeson 1996).

Regional variation in reproductive traits for Palaemon serratus and relatives

Temperature may be the key factor underpinning the regional variation of reproductive patterns in shrimp (Forster 1959). For *Palaemon* species, there is considerable variation in spawning frequency; the time of spawning, and age at first spawning (see Table 2). For many crustaceans, mating occurs directly after a moult, thus creating a close link between reproduction and moulting patterns (Hartnoll 1985). The regional variation in intermoult period and colouration between French and Irish Sea populations are due to genotypic differences in their moulting hormones (Carlisle 1955). However, further molecular work is required to quantify these observed variances.

A number of gene flow, population structure and genetic selection studies on *Palaemon serratus* are currently underway at both the University of Coruña (lead by Dr Andrés Martínez Lage) and the University of Aberystwyth (lead by Dr Joe Ironside) with results anticipated by the end of 2014.

Table 2. Reproductive traits of *Palaemon* species, including field based and laboratory based experiments.

SPECIES	LOCATION	RECORDED TEMPERATURES	REPRODUCTIVE TRAIT	SOURCE
			Spawning frequency	
P. serratus	France	none available	3 per year	Cole 1958
P. serratus	Irish Sea	none available	1 per year	Cole 1958
			Timing of spawning	
P. serratus	North Wales	none available	Month spawned	Forster 1959
P. serratus	Plymouth	none available	Month spawned	Forster 1959
			Age at first spawning	
P. serratus	Plymouth	none available	0 & 1+	Forster 1959
P. serratus	North Wales	none available	1+	Forster 1959
P. elegans		none available	0 & 1+	Sanz 1986
P. pacificus		none available	0 & 1+	Ito *et al*. 1991
P. macrodactylus		none available	mostly 0+	Omori & Chida 1988
P. serifer		none available	mostly 1+	Ito *et al*. 1991
P. xiphius		none available	1+	Guerao *et al*. 1994
			Egg development	
P. xiphius	Laboratory	21	20 days	Guerao 1994
P. xiphius	Laboratory	28	12 days	Guerao 1994

Temperature and salinity influences habitat preference of different life stages

The seasonal migration of *P. serratus* from deep waters in winter to shallow inshore waters in summer is thought to be attributed to a susceptibility to cold temperatures and low salinities found inshore during winter when rainwater discharges are high near the coast (Forster 1951, Guerao & Ribera 2000, Rodriguez & Naylor 1972, Reeve 1969).

Estuarine habitats provide a valuable nursery habitat for *P. serratus* post larvae and juveniles as well as summer feeding habitats for adults (Kirkpatrick & Jones 1985; Rowe 2002). Estuaries can experience extreme fluctuations in temperature and salinity and the distrubution of shrimp within an estuary have been found according to their inherent tollerances (González-Ortegón *et al.* 2006). Salinity tolerance varies among *Palaemon* species (Table 3) and their distribution within an estuary may reflect the ideal salinity, temperature and food availability for a given species (González-Ortegón *et al*. 2006; Woolridge 1999; Rowe 2002). *P. serratus* were found to undertake small scale tidal and diurnal migrations; possibly in order to avoid variations in salinity levels (Forster 1951). *Palaemon* will undergo osmoregulation to survive in variable conditions (Spaargaren 1972; González-Ortegón *et al*. 2006; Courrat *et al.* 2009; González-Ortegón *et al.* 2010), and these osmoregulatory capabilities vary with size, sex and reproductive state (Kirkpatrick & Jones 1985; Panikkar 1941). Though, in extreme salinities osmoregulation is limited by low temperatures (Spaargaren 1972).

Table 3. Salinity tolerance ranges for *Palaemon* species (Kirkpatrick & Jones, 1985). Mixed refers to species that live in both open water and estuaries.

		Salinity	
Species	**Habitat**	Min	Max
Palaemon serratus	Mixed	16	39
P. elegans	Mixed	5	45
P. affinis	Mixed	5	43
P. macrodactylus	Estuarine	1	61.2
P. peringueyi	Mixed	10	50
P. intermedius	Mixed	5	39
Palaemonetes varians	Mixed	0	50

Adaptive tollerances to changes in the environment may be limited by metabolic capabilities. Physiological regulation places metabolic demand on animals. For small marine invertebrates, metabolic rate (estimated by oxygen consumption) varies with size. For example, small shrimp (80-260 mg) were found with higher metabolic rates than larger shrimp (1090-1140 mg) when exposed to temperature changes (5-20°C) in a laboratory (Dalla Via 1985), indicating that larger invertebrates deal with changes in temperature better than smaller ones. In the Mediterranean, marine temperatures range from 5 - 31°C, with monthly changes as much as 6–7°C (Marolla, 1980), and the metabolic rates at 15 and 20°C were lower than that of populations found in colder climates (Dalla Via 1985 & Alcaraz 1974). The latter finding indicates that *P. serratus* are adapted better to warmer rather than colder temperatures.

Ovigerous females have a lower tolerance to changes in salinity compared to non-ovigerous females and males (Panikkar 1941). Female *P. serratus* are found in deep open waters when they shed the larvae (Forster 1951). This is supported by the high proportion of ovigerous females in fisheries samples taken offshore during winter (unpublished data, Fisheries and Conservation Science Group, Bangor University). Female shrimp will shed their eggs at locations where they stand the best chance of dispersing and surviving until they settle as post larvae (Strathmann 1985).

Larval development and responses to variable environmental conditions

P. serratus exhibits four main life cycle phases (Figure 1). The larvae are called zoea and have thoracic appendages for swimming. There are several planktonic zoeal stages called instars, with the final instar metamorphosing into a post larval stage similar in morphology to the adult (Reeve 1969; Kelly *et al*. 2012). *P. serratus* are demersal during the juvenile and adult phases (Kelly *et al*. 2012).

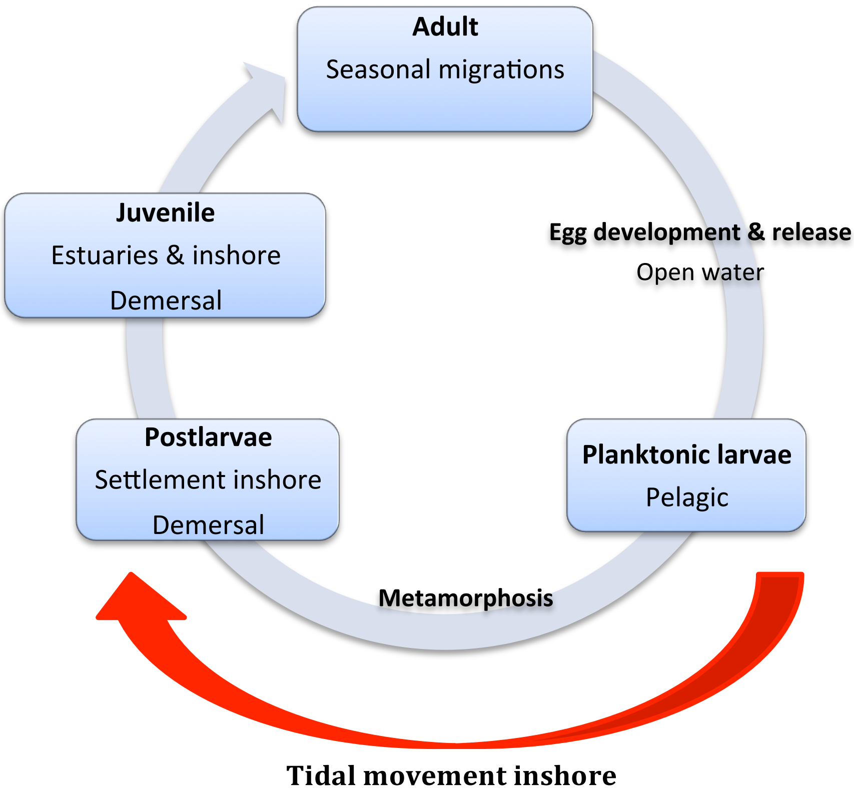

Figure 1. Lifecycle of *Palaemon serratus* showing life history stages and where they occur (Kelly et al 2012; Forster 1951).

The number of instars (stages when zoea moult and grow) is usually eight or nine (Fincham & Figueras 1986), but is dependent on environmental parametres such as temperature and salinity (Kelly *et al.* 2012), as well as resource (food) availability (Reeve 1969). Kelly et al. (2012) found that temperature positively influenced the number of instars prior to metamorphosis for *P. serratus*, however; nine larval instars have been reported for Irish populations (Kelly et al. 2012) while six instars have been observed in the Mediterranean populations (Fincham & Figueras 1986). If temperature was the main contributor to instar frequency we would anticipate Mediterranean populations to have a greater number of instars. This highlights the complexity of larval development. Additional larval stages (and typically smaller moult increments) can result from stressful conditions; comprehensive comparisons between locations would require more data such as the number of instars, the time between instars, growth increment, temperature, and salinity records.

Approximately one month after egg release, *P. serratus* metamorphose into post larvae (a stage ~10 mm long) which settles out of the water column between July and August. Post larvae settle out high in the littoral zone (Forster 1951; BIM 2008); in the low intertidal, rocky shore (Forster 1951; Guero & Ribera 1996). By mid-October *P. serratus* migrate to deeper waters (Kelly et al. 2012) and are of a size which can be caught in fishing gear.

Kelly *et al.* (2012) found that post larval (juvenile) *P. serratus* have a broader salinity and temperature tolerance compared to larvae. Similar tolerances were found in other Palaemonid species: *P. xiphas* and *P. adspersus* (Kelly *et al*. 2012). Rainfall and resulting river flow is the key determinant of the salinity and temperature of coastal and estuarine waters. In Ireland, the inter-annual variation in rainfall has meant that the conditions for development and survival are below the optimal levels for *P. serratus* (Kelly *et al.* 2012). Kelly *et al* (2012) suggested that due to the differences observed in environmental conditions and subsequent development and survival of larvae between Irish and Mediterranean waters, which local adaptations may be occurring. Further molecular studies are required to investigate the roles of phenotypic plasticity and genotype and how they vary over the geographic range of the species.

Trophic level and predator-prey relationships

P. serratus play an important role in ecosystems as they link micro- and macro-trophic levels (Henderson *et al*. 1992; Kelly *et al*. 2012; Smaldon 1993); grazing on diatoms and macrophytes, scavenging detritus, and predating on small crustaceans (Forster 1959). *P. serratus* is primarily a predator on benthic invertebrates; the type and size of prey consumed depend on the shrimp size (Guerao & Ribera 1996). Stomach content analysis of *P. serratus* caught in inshore waters revealed that they fed on mostly green-algae (Forster 1951). However, Guerao & Ribera (1996) sampled from an eelgrass bed in Spain and found that algae was only observed in the diet between 5-10% of the time and concluded that algae was accidentally consumed with invertebrate prey. In the English Channel, *P. serratus* diets were found to vary with depth and life history stage (Forster 1951). *P. serratus* were caught at increasing depths with handnets, traps and trawls and were observed to consume green, red and brown algaes respectively. In trawl catches, 0-group (zero to one year old) *P. serratus* were observed to consume ostracods almost exclusively and very little algae was observed in their diet. Inshore, similar patterns were observed with 0-group *P. serratus,* and interestingly, *P. adspersus* were found with no ostracods and consumed only algae and some forams indicating resource partitioning between co-inhabitant *Palaemon* species. *P. serratus* presumably is an important food resource for fish. *Scyliorhinus canicula* was found to predate on *P. serratus* (Smaldon 1993; Sims 2003). Fish species caught in prawn pots are often observed with distended bellies and preliminary gut analysis of by-catch supports the hypothesis that these species are targeting *P. serratus* as a food source (EFF funded *Sustainable Fisheries in Welsh Waters* project, Bangor University).

PALAEMON SERRATUS COMMERCIAL FISHERY

Distribution of the commercial Palaemon serratus fishery

Commercial fishing for *P. serratus* takes place in the Mediterranean and the northeast Atlantic (Guerao & Ribera 2000; BIM 2008). The Mediterranean fishery is based around the Iberian peninsula (BIM 2008), while the northeast Atlantic fishery most frequently occurs on the south and west coast of Ireland, the south of England and off the coast of Wales (Fahy *et al.* 2006). The shrimp fishery is similar throughout Europe and the UK; it is primarily a small-scale fishery consisting mostly of small fishing vessels utilising pot traps or using trawls. Fishing mostly occurs within 12 nm of the shore (BIM 2008). In the Mediterranean, the predominant fishing method is small scale trawls (Guerao & Ribera 1996).

The Palaemon serratus fishery in the United Kingdom

The majority of the *P. serratus* caught in UK waters are exported to markets in southern Europe, with very little retained for local markets. There is a considerable local market for shrimp and prawns in the UK, with shrimp and prawns accounting for the third highest seafood import into the UK in 2012, with 86,000 tonnes (MMO 2013). The main species imported to the UK are *Penaeus monodon*, which is a large farmed tropical species. The import/export pattern of shrimp and prawns is market driven and the larger penaeid prawns in demand and available all year round. *P. serratus* however, is a smaller species and is only available seasonally; further inclement weather may greatly reduce fishing effort and landings. *P. serratus* is exported live and commands a premium price in Europe so presumably there is also potential to develop a market locally in the UK. Local markets have smaller ecological footprints and enhance local economies; there is a potential for *P. serratus* to enter the local markets if the right processing and marketing infrastructure were in place.

P. serratus has been fished commercially in UK and Irish waters since the 1970s and has since become of particular economic importance (Fahy & Gleeson 1996) Advances in technology and catch capability since the 1990s have led to a considerable expansion of the fleet (Fahy & Gleeson 1996). *P. serratus* is fished in the autumn and winter in the UK (from October to May). The stock status of the *P. serratus* fishery is unknown and the fishery is considered "data poor". Some stock fluctuations have been observed through landings data. Ireland saw a dramatic decrease in landings in the 1980s with some recovery by the mid-1990s (Fahy & Gleeson 1996); the landings have since continued to fluctuate but have remained above the low levels observed in the 1980s (BIM 2008).

The Cardigan Bay Prawn Fishery

The Welsh *P. serratus* fishery extends from Milford Haven in the south to the Menai Strait in the north (Fahy & Gleeson, 1996) and is exclusively a static gear fishery (Figure 2) with most effort concentrated between Cardigan and Aberydyfi.

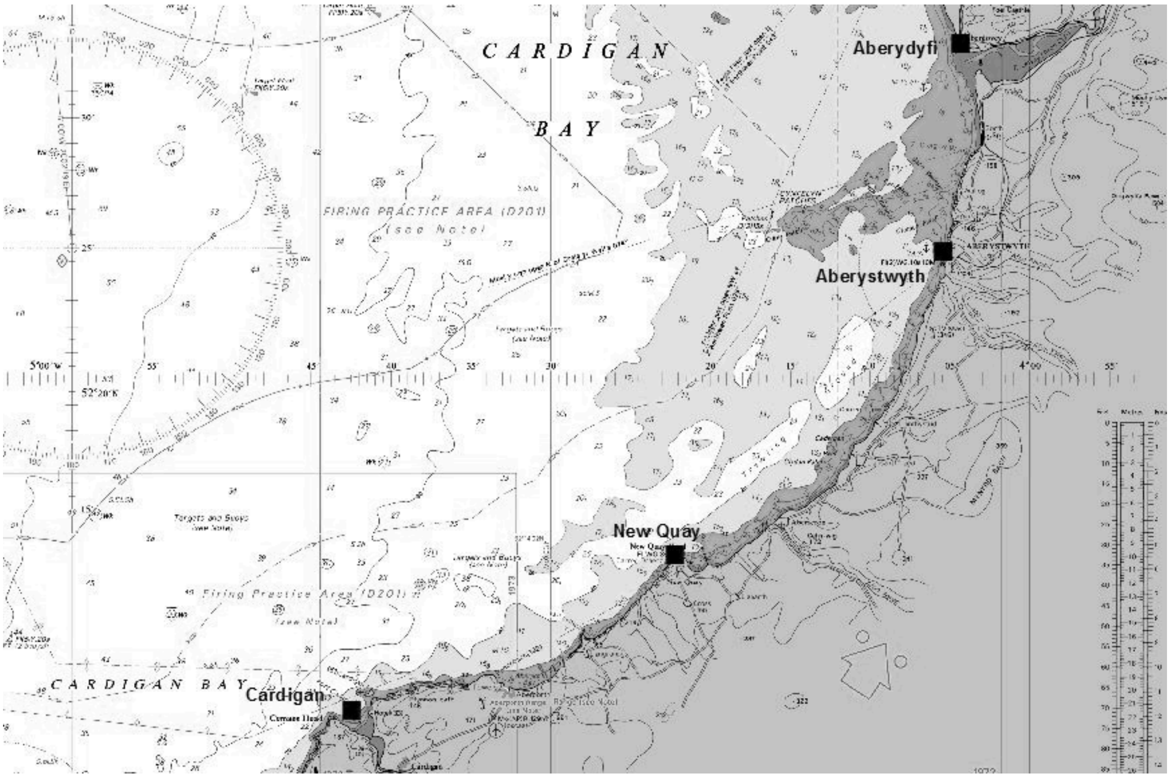

Figure 2. The locations of key ports in Cardigan Bay from which vessels prosecute *P. serratus*.

In Cardigan Bay, artisanal fishers target species that provide the greatest market value and are available for the given season (DEFRA 2006). Other species landed by these fishers include lobster, brown crab and spider crab. The Cardigan Bay pot fishery is an opportunistic fishery similar to that of many small-scale, regional fisheries that are of high socio-economic value. For example, the fisheries of the Galicia region of Spain support over 28,000 fishers and some communities within this region are entirely dependant on the fishing sector (Friere & Garcia-Allut 2000).

MANAGEMENT OF *PALAEMON SERRATUS*

Management of *P. serratus* is limited. The Irish fishery has a closed season between May and August (SI235 2006, Fisheries Management and Conservation Order; Kelly *et al.* 2012), and there is a shellfish licensing scheme currently in operation in the UK. This initiative limits the number of new vessels entering the fishery and requires all fishing vessels in the fleet to carry a license with a shellfish endorsement (Seafish 2009). Despite this scheme there is currently no specific legislation in place to manage the *P. serratus* fishery.

In more recent years, fishers in Cardigan Bay have adopted voluntary measures such as riddling the catch and increasing pot mesh size, to ensure that small prawns are returned to the sea. These measures have two main benefits to the fishers and the health of the stock.

By voluntarily grading their catch at sea, fishers ensure that immature prawns are returned to ideal habitats for survival and that the landed catch is larger and well sorted; which usually ensures a better or constant price from their buyer. Grading is done by two methods; either "on the ground" where a larger mesh size is used at the end of the trap allowing small prawns to escape when the traps are hauled; or a "riddle" is used. A riddle is a grader which permits only small shrimp to fall through and then the larger, kept prawns are typically hand sorted into up to five sizes (Fahy & Gleeson 1996; Garcia & le Reste 1981; Fahy *et al* 1998). Sex ratio estimates from catches indicate that many more females are present in landings, particularly during December (unpublished data, Fisheries and Conservation Science Group, Bangor University). This observation is supported by previous research in Cardigan Bay where a 10 mm riddle and a 9 mm end mesh was used (Huxley 2011). Due to the sexual dimorphism seen in *P. serratus*, the catch (when using a larger mesh size) would most likely contain a female bias. Long term removal of one sex more than the other can lead to a skew in the sex ratio in the population (Jennings *et al.* 2001; King 2007) resulting in mating mismatches and decreased molecular variance in a population.

Large numbers of shrimp are retained in the pots from 55 mm total length and larger. Shrimp are exploited in the highest numbers during their last phase before senescence (Fahy & Gleeson 1996). There has been some recorded mortality associated with riddling which needs to be investigated to justify its use as a management measure. 0-group prawns (in their first year) can still be sold, but they fetch very little on the market. Shrimp in their second year (1-group) are the most valuable and therefore are targeted by riddling (Fahy *et al*. 2006).

Discarded 0-group shrimp should then undergo their most significant growth phase and will reach ideal market size by the following year. By enhancing survival of riddled and discarded small shrimp the following year's yield and profits will increase (BIM 2008).

Identifying an appropriate stock management unit for cold temperate populations

Preliminary mitochondrial studies on Irish Sea populations show a distinct lack of genetic structure (Pers. Comm. Joe Ironside, Aberystwyth University). This presents some difficulty for management of the stock, as it falls within the jurisdiction of three countries. Currently, the direction of migration and gene flow is not well understood and more in-depth genetic analysis is required. Under a scenario that Irish populations of *P. serratus* are a significant source of larvae for the Welsh populations (or vice versa); then the management unit should include both Irish and Welsh stocks. However, if Welsh stocks are found to be "self-recruiting," then local stocks can be managed as such. Currently the Cardigan Bay Fisherman's Association is collaborating with Bangor University and Aberystwyth University to determine directional patterns of gene flow among populations of *P. serratus* in the Irish Sea.

STOCK ASSESSMENTS

Choosing an ideal stock assessment method

Effective stock management for the *P. serratus* fishery requires stock status data. The types of data collected and assessment varies between fisheries; the techniques used must be suitable for the species being assessed. Data collected can be fishery-dependant (working directly with the industry) and/or independent (working on research vessels/recruitment sampling in nursery grounds). More recently fisheries scientists employ the concept of ecosystem management; assessing the target species and also the impacts of the fishery on other species and the environment. The effect of gear on habitat, the amount and type of by-catch, and associated mortality are all examples of this concept.

Previous stock assessments

Catch per unit effort (CPUE) is calculated as an indication of the relative abundance of a species. CPUE assumes that the proportion of the species caught is constant. This does not take into account external influences to the catch such as environmental factors (i.e. weather) and technological advancements (BIM 2008). The stock assessment of the Irish *P. serratus* fishery used general linear modelling (GLM) to standardise catchability and effort rates (the CPUE data) (BIM 2008). GLM uses a series of variables (e.g. environmental factors) that are related to the response variable (CPUE). The variables used in the incidence of the Irish fishery include water temperature, tidal height and soak time, amongst others (Appendix 2). Stock assessments of Australian shrimp fisheries have collected CPUE data by using daily logbooks that record catch and effort; these were also verified using landings data obtained from processor records (Banks *et al*. 2012).

By collecting length data (either carapace length or total length) it is possible to determine size classes and identify spawning and recruitment events. By placing the shrimp into size classes it is possible to determine the number of cohorts within a population (King 2007). Length-frequency histograms show modes which can be interpreted as age classes as there is currently no reliable method to age invertebrates. Data on *P. serratus* in Ireland displayed distinctive hatching and recruitment periods with one cohort showing growth before the next cohort recruited to the fishery (BIM 2008).

Sex ratios in a population can be examined by comparing the number of males and females present. This is of particular importance in this species due to the sexual dimorphism seen between males and females. As most management measures involve targetting the larger individuals in a population, this could lead to a skew in the population in favour of the smaller sized males.

The presence of eggs on females is commonly used as an indicator of minimum size at maturity. Egg development should also be considered when using this method. Mature females who have shed their eggs may be incorrectly identified as immature. The recording of morphometrics of mature females may eliminate this problem. The side plates of the mature female abdomen are considerably wider to accommodate a brood of eggs (Forster 1951) and could easily be measured for non-gravid females.

Egg counts are used to estimate fecundity and typically displays a logarithmic relationship between body size and egg number. This relationship is dependent on the increase of carapace volume (Forster 1951).

CONCLUSION / OUTLOOK

The current status of the *P. serratus* fisheries in the UK is unknown and data is inadequate. Bangor University and the Cardigan Bay Fisherman's Association are hosting projects aimed at providing a better understanding of the stock status and the population trends of *P. serratus* in Welsh waters. We aim to gather baseline monitoring data for the Cardigan Bay fishery as well as describe the interaction of the fishery with other ecosystem parameters. Additionally, we are undertaking sampling that will enable us to model ideal post-larval recruitment habitats and provide the methods for a longer term monitoring program to develop a recruitment index for the fishery.

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Appendix 1

Specialist sources used during initial literature searches

Centre for Environment, Fisheries & Aquaculture Science – www.cefas.defra.gov.uk

Natural Resources Wales - http://naturalresourceswales.gov.uk

Department for the Environment, Food & Rural Affairs - https://www.gov.uk/government/organisations/department-for-environment-food-rural-affairs

Fisheries Research Service – www.scotland.gov.uk

International Council for the Exploration of the Sea – www.ICES.dk

Joint Nature Conservation Committee – www.jncc.defra.gov.uk

Marine Conservation Alliance – www.marineconservationalliance.org

Marine Stewardship Council – www.msc.org

Natural England – www.naturalengland.org.uk

Scottish Natural Heritage – www.snh.gov.uk

Appendix 2

Variables used to investigate causes of variation in shrimp CPUE data (BIM 2007)

Variable	Data type	Data Source
Vessel	Categorical	Fishing activity records
Week number	Categorical	Fishing activity records
Soak time	Categorical	Fishing activity records
Water temperature	Categorical	Marine Institute
Tidal height (Cobh, Co. Cork)	Categorical	www.pangolin.co.nz/tidecomp
Air pressure	Categorical	Met Eireann
Wind speed (Cork airport)	Categorical	Met Eireann
Wind direction (Cork airport)	Categorical	Met Eireann