Bord Iascaigh Mhara
Irish Sea Fisheries Board

The Shrimp (*Palaemon serratus* P.) Fishery: Analysis of the Resource in 2003-2007

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Fisheries Resource Series

Foreword

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Technical and scientific contributions to the ***Fisheries Resource Series*** are invited, from internal and external sources, which primarily promote the sustainable development of the Irish sea fisheries sector and, in addition, support its diversification in the coastal regions so as to enhance the contribution of the sector to employment, income and welfare both regionally and nationally.

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The Shrimp (*Palaemon serratus* P.) Fishery: Analysis of the Resource in 2003-2007

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Preface

The Management Framework for Shellfisheries was established in 2005 to oversee the sustainable development and management of the shellfisheries sector in Ireland. The Framework is a co-operative management model between state and industry centred around four Species Advisory Groups (SAGs). This report has been compiled for the Shrimp Species Advisory Group and its constituent Local Advisory Committees (LACs) and outlines the current status of shrimp stocks and fisheries in Ireland at the end of the 2007 fishing season. The report is a working document, which will be developed periodically as the appropriate data and assessment methods become available.

NATIONAL DEVELOPMENT PLAN

FINANCIAL INSTRUMENT FOR FISHERIES GUIDANCE

Bord Iascaigh Mhara
Irish Sea Fisheries Board

Martin Ryan Institute
Institiúid Mhairtín Uí Riain

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Summary

The trap fishery for *Palaemon serratus* in Ireland dates back to the early 1970s. Annual landings between 1990 and 2006 varied from 150 to 550 tonnes. At a value of €15 per kg the total annual value of the fishery varies from €2.25 to €8.25 million. Approximately 300 vessels take part in the fishery operating approximately 117,000 traps. The fishery is regulated by a closed season between May 1st and August 1st. Despite the economic and social importance of this fishery, the stocks have not routinely been assessed and methods for their assessment are poorly developed.

Although stock structure is unknown it is likely to be local (i.e. bay) or regional in scale. Data are reported here for 4 coastal regions in Ireland. Daily catch and effort and associated data were provided by a sample of vessels in the fleet. A separate age length sampling programme was undertaken, also with the assistance of the fleet.

Catch rate varies annually and within season. In one location, where a time series was available, nominal catch rate data varied 2 fold over an 8 year period. Nominal catch rates were generally low at the beginning of the season and increased between August and November. Recruitment of the 0+ cohort to the fishery occurred in October. The catch was dominated by female shrimp aged 1+ with varying contributions of the 0+ and 2+ cohorts depending on the time of year. There was no evidence of any geographic variation in growth rate.

Catch and effort data from the fishery were standardised by general linear modelling. This analysis revealed high variation in catch rate between vessels and within and between fishing seasons. A depletion estimate of the 1+ female cohort was derived from the commercial catch rate data to estimate fishing mortality and exploitation rates. Fishing mortality estimates were compared to yield and egg per recruit reference points. Estimated mortality rates varied from 50-60% per annum and in general did not breach egg or yield per recruit reference points. Significant improvements in yield and egg per recruit accrued from size selective harvesting by grading the catch. Post grading discard mortality was estimated to be less than 6%. Gains in economic yield per recruit were proportionally higher than gains in yield in weight, for any given size selective harvest strategy, because price is size related. Predicted gains in yield, egg and earnings per recruit are sensitive to values of natural mortality used in the assessments.

Monitoring and research priorities are highlighted. Research to identify stock structure should be undertaken. The effects of environmental temperature and salinity on recruitment should be modelled and related to fishery performance. A complete census of catch and effort and improved standardisation of the catch rate index would provide an invaluable fisheries monitoring and assessment tool and allow exploitation rates to be estimated using depletion analysis.

The stock is exposed to a number of risks which management should seek to address. These include lack of information on stock structure, no input or output controls, anecdotally, increased fishing mortality on over-wintering mature female shrimp and poor capacity to adjust harvest rates when environmental conditions for recruitment are poor.

Introduction

Three hundred and twenty two tonnes of shrimp were landed in Ireland in 2006. The vast majority of the annual catch is composed of *Palaemon serratus*. Less than 1% of shrimp catches in Ireland may be *P. elegans* according to Fahy *et al*. (1998b). The value of this catch was approximately €4.5 million at first point of sale (Anon., 2007), making shrimp the third most important crustacean fishery in Ireland after brown crab *(Cancer pagurus)* and lobster *(Homarus gammarus)*.

This report is the first attempt to draw together all relevant information on shrimp stocks and fisheries in Ireland. The ultimate objective is to provide reliable fisheries management advice that will assist in the sustainable development of the fishery. In this context the report is produced for the Shrimp Species Advisory Group, which is a constituent committee of a co-management advisory framework that provides recommendations to the licensing authority (The Department of Agriculture, Fisheries and Food) on matters relevant to the management of shellfisheries. Shrimp fisheries are not presently subject to any particular management regime other than a closed season between May 1st and August 1st (Statutory Instrument (SI) 235 of 2006). The fishery is in open access and there are no catch, effort or size limits. Effort is generally increasing while landings fluctuate annually both nationally and locally.

Available data on Irish shrimp stocks have typically resulted from individual projects that supplied information for a limited period of time in certain geographic areas and were usually collected as part of university postgraduate projects or to service short term national or EU funded projects. Such project based work extends back to the late 1970s (McPadden, 1979), through the 1990s (Fahy and Gleeson, 1996) and up to recent times (O'Cuaig, 2004). There is no national monitoring program, although since 2004 increasing amounts of good quality catch and effort data have been provided voluntarily by the fleet through the BIM Fishing Activity Record (FAR) programme. These data are used in the present report to assess variability in catch rates within and between seasons, and to compare the catch rates reported from different coastal areas. The main body of biological data presented in this report was the result of a sampling program on the south and west coasts from 2003 to 2006. Information on growth and mortality was extracted from these samples and was used in a yield per recruit assessment to investigate whether the shrimp stocks are being harvested in a manner that makes the best use of the resource. Information on maturity and fecundity was also used in an egg per recruit assessment to determine whether the stock was at risk of recruitment over-fishing. The present report is constrained by data limitations, however sufficient biological and fishery information is provided to help progress the management of shrimp stocks in Ireland.

The Biology of Shrimp

1. Commercial distribution

P. serratus occurs in the Mediterranean and coastal areas of the north east Atlantic Ocean (Holthius, 1950). Commercially exploited stocks occur in the Mediterranean, in Iberia, France, UK and Ireland. In the Mediterranean, Gurney (1923) noted its occurrence off the coasts of France, Italy, Greece, Turkey and Algeria. It is considered common around the coast of Britain up to a diagonal line extending from the Clyde to the Wash (Reeve, 1969a). It is also common around the Irish coastline, and although DeBhaldraithe (1971) noted its absence in the north west, commercial fishing has occurred in this region in recent years. The northern limit of *P. serratus* is probably set by temperature (Richard, 1978). It is commonly found on rocky shores, in pools or amongst algae on the lower shore. It extends offshore into water as deep as 60m (McPadden, 1979) and is also known to enter the lower reaches of estuaries (Smaldon, 1993).

2. Biology

P. serratus is a relatively short-lived decapod crustacean, with a lifespan of approximately two years with a very high mortality in the summer of the third year. Growth is rapid with females increasing their weight by 50% between the months of August and September in their second year. Males grow at a slower rate and achieve a smaller overall size. Females begin to carry eggs in October and November and by December the majority are berried. The time required for embryo development is dependent on the ambient water temperature and generally takes 2.5 to 3 months in Irish waters (Philips, 1971). By the start of April half of the mature females have hatched their eggs. The planktonic larvae remain in the water for approximately one month before metamorphosing into post larvae and settling into intertidal and shallow subtidal habitats at a total length of approximately 1cm. These young shrimp grow rapidly during their 1st summer and recruit to the fishery in October at a total length of approximately 5cm. A 1.5g female can carry approximately 1,600 eggs while a 4g shrimp can carry 2,000 eggs (Reeve, 1969a). Mature berried females undertake small scale migrations to deeper waters during the winter months and they return to shallow inshore areas and estuaries prior to larval release (DeBhaldraithe, 1971).

Shrimp Fishing in Ireland

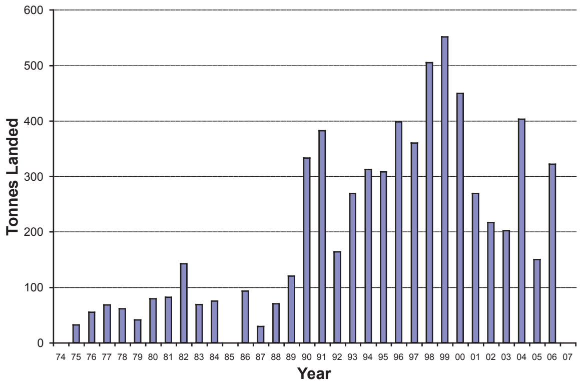
Records of national landings of *P. serratus* into Ireland go back to 1975 (Figure 1). Landings remained at around 100 tonnes until the late 1980s. There was a rapid expansion of the fishery over the following decade, with a maximum of 551 tonnes landed in 1999. Landings subsequently declined and a 10 year low of 202 tonnes was recorded in 2003. Since then the landings have fluctuated with higher landings in 2004 and 2006 than in 2005.

The increase in landings in the late 1990s coincided with an increase in fishing effort (Fahy and Gleeson, 1996). The fishing gear consists of a cylindrical trap, which is covered with 7.5mm rigid plastic mesh with a conical entrance at either end. These traps are usually baited with fish and left submerged for at least one night before being hauled. However, this soak time can be much longer. The latest figures compiled in 2006 by BIM estimated that there are approximately 117,000 shrimp traps being fished in Ireland (Table 1). Over 70% of this fishing effort occurs in counties Galway and Cork (Figure 2).

The type of fishing vessels most commonly used in shrimp fishing are small half-decked boats and open punts or currachs. These vessels are typically less than 9m in length. A smaller number of vessels between 9 and 13m in length are used to follow the shrimp migration offshore during the autumn. In 2006 there were approximately 300 boats involved in the fishery with an average of 400 shrimp traps per boat. However, trap numbers ranged from 150 to 1500. The number of vessels targeting shrimp and the amount of fishing gear is generally increasing and fishing is also extending to deeper water later in the fishing season, especially on the south coast. Mature female shrimp over winter in these deeper water areas and belong to the same stock as that exploited inshore during the summer months.

Landings and catch rates are prone to failure at a local scale. Given that shrimp have a short life span and the fishery is heavily reliant on a single year class local fishery failures are probably due to local failure in recruitment. The relative contributions of fishing mortality and environmental effects on recruitment are unknown. The relationship between spawning stock biomass and recruitment is unknown. Unfavourable conditions of temperature and salinity during early life history may have a strong impact on recruitment (Kelly, 2008).

Figure 1: National landings of *Palaemon serratus* in Ireland, 1975 to 2006



(Source of data: Department of Agriculture, Fisheries and Food)

Figure 2: Distribution of fishing effort by county in Ireland during 2006

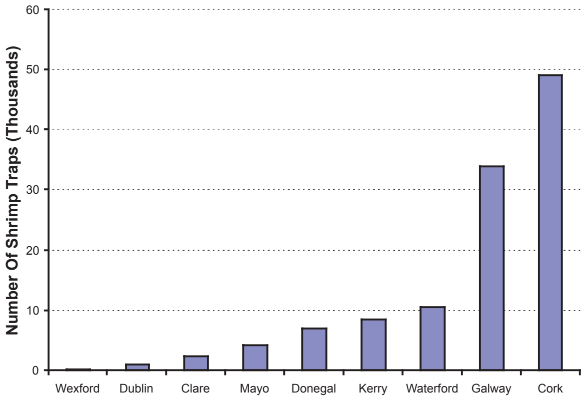


Table 1: Numbers of boats and pots fished in Irish shrimp fisheries in 2006

County	Area	Boats	Shrimp Traps
Donegal	Burtonport	16	3,000
Donegal	Inner Donegal Bay	10	2,500
Donegal	Lough Swilly	5	1,500
Mayo	Blacksod Bay	4	700
Mayo	Achill	5	600
Mayo	Clew Bay	12	3,000
Galway	Connemara	66	25,000
Galway	Galway Bay (East of Casla)	15	9,000
Clare	North Clare	4	900
Clare	Shannon Estuary	3	1,500
Kerry	Portmagee	10	5,000
Kerry	West of Kenmare	10	3,500
Cork	West Cork	40	22,000
Cork	Dunmanus to Galley Head	32	18,000
Cork	East of Galley Head	25	9,000
Waterford	Dunmore	10	3,000
Waterford	Dunbrattin	3	1,150
Waterford	Helvick	15	6,100
Waterford	Ardmore	3	300
Wexford	Rosslare	2	300
Dublin	Dublin Bay	3	1,000
Total		**293**	**117,050**

Current Management Measures

The shrimp fishery in Ireland is regulated by the following measures:

1. Each vessel must be licensed and registered in either the polyvalent general or polyvalent potting segments of the Irish fishing fleet.
2. There is a prohibition on 'fishing, attempting to fish for or being in possession of shrimp' between 1st May and 1st August (SI 235/2006).

Shrimp can be captured recreationally without licence but the catch cannot be sold commercially.

In addition to the obligatory management measures described above the industry have introduced voluntary measures, such as collection of catch and effort data and live-grading of catch at sea. The rationale behind grading at sea is that the early period of the fishing season (August to October) coincides with the main growth period of shrimp. Delaying the time of first capture allows shrimp to attain a greater size, which may result in an overall increase in yield from the stock.

Previous Research and Monitoring Activity

As mentioned in the introduction, the available data on shrimp stocks in Ireland have typically come from individual projects that supplied information for limited periods of time in localised geographic areas. The first investigation on *Palaemon serratus* in Ireland was carried out by Gibson (1959) who described the distribution of the species on the south and west coasts. DeBhaldraithe (1971) studied the general biology and distribution of the species on the west coast while McPadden (1979) described the distribution of the stock in relation to depth and time of year, and assessed the feasibility of establishing a commercial fishery. Further investigations on the biology and fishery for this species were completed by Kearney (1997), Power (1996) and O'Cuaig (2004).

The first investigation of the fishery for *P. serratus* in Ireland was carried out by Fahy and Gleeson (1996). This investigation looked at the size structure of the catch and other biological factors such as the reproductive cycle and the length to weight relationship. An annual catch per unit effort (CPUE) index was developed for the years 1977 to 1984 which showed a downward trend. These data were sourced from processors' records, rather than directly from fishing trips. Although this report made recommendations on delaying the start of the fishing season from its current date of 1st August, no particular starting point was identified. In any case, until the present work, no information on growth and mortality existed that would have enabled an assessment of the optimum date to open the season. Further work was carried out on the selectivity of various mesh sizes on the traps by Fahy *et al.* (1998a) and on possible performance indicators for the fishery by Fahy *et al.* (2006).

Given the new impetus for management of shrimp stocks in Ireland following the publication of the framework for shellfisheries in Ireland (Anon., 2005), there is increased urgency to provide fishery managers with scientific data and assessments of shrimp stocks. In particular, as there are no readily agreed assessment methods for shrimp, development and demonstration of methods that could use fishery-dependent data is important. In addition, given the biology of the species, understanding the relative effects of fishing activity and environmental factors on recruitment is crucial to designing fishery monitoring and management measures.

Data Sources

1. Landings

Since 2007 the Sea Fisheries Protection Authority (SFPA) has compiled national landings data on shrimp. Previously this was done by various government departments which held the fisheries brief from 1975 to the present.

2. Fishing Activity Records

Fishing Activity Records (FARs) have been maintained on a voluntary basis by shrimp fishermen since 2004. These provide daily summaries of catch and effort. Information is also given on the approximate fishing location, soak time, wind direction, wind speed and any other variable of interest such as bait, water depth, ground type etc. The fine spatial and temporal resolution of these data makes them particularly useful as a monitoring tool.

Three FARs were available for the 2004-2005 season representing 162 daily catch and effort summaries. Six returns were obtained in 2005-2006 from Co. Cork representing 342 fishing days. Fifteen were returned in 2006-2007 representing a total of 480 fishing days. In 2007-2008 6 books were returned from Co. Donegal, 6 from Co. Galway, 4 from Co. Kerry, 2 from Co. Mayo and 14 from Co. Cork. This represented a total of 1037 daily catch and effort summaries. In addition 1 vessel from Baltimore Harbour, Co. Cork provided a time series of catch and effort covering the period 1998-2005 including 506 fishing days. At the time of writing the catch and effort database represented a total of 2021 records of daily catch and effort (Table 2).

Table 2: Number of fishing days for each area where catch and effort data were available

County	Bay	2004/2005	2005/2006	2006/2007	2007/2008	Total
Cork	Ballycotton Bay	-	-	14	8	22
	Baltimore Bay	57	59	-	45	161
	Bantry Bay	-	-	-	38	38
	Cork Harbour	55	283	99	-	437
	Courtmacsherry Bay	-	-	15	-	15
	Kenmare Bay	-	-	59	41	100
	Kinsale	-	-	123	23	146
	Roaringwater Bay	-	-	137	345	482
	Youghal Bay	-	-	15	-	15
Cork Total		**112**	**342**	**462**	**500**	**1416**
Donegal	Dungloe Bay	-	-	-	250	250
	Lough Foyle	-	-	-	24	24
Donegal Total					**274**	**274**
Galway	Bertragh Buí Bay	-	-	-	36	36
	Gorteen Bay	-	-	-	43	43
	Greatman's Bay	-	-	18	16	34
	Killary Harbour	-	-	-	26	26
	Roundstone Bay	50	-	-	19	69
Galway Total		**50**		**18**	**140**	**208**
Kerry	Fenit	-	-	-	54	54
	Tralee Bay	-	-	-	33	33
Kerry Total					**87**	**87**
Mayo	Clew Bay	-	-	-	27	27
	Doohoma Bay	-	-	-	9	9
Mayo Total					**36**	**36**
Grand Total		**162**	**342**	**480**	**1037**	**2021**

3. Biological sampling program

A biological sampling program was carried out, from 2003-2006, in order to provide information on the age structure, growth, mortality and reproductive biology of shrimp on the south and west coast of Ireland. Over this time 289 random 1 kg samples of the catch were collected by the skippers of the vessels. Each sample contained an average of 240 individuals and a total of 71,500 shrimp were measured. During the 2003-2004 fishing season 139 samples were taken from ports in Co. Cork (Figure 3). This sampling regime allowed spatial variability in the size structure and growth of shrimp to be assessed. The 2004-2005 sampling program in Co. Cork provided a total of 63 samples from the 6 ports. Work also began in Connemara, Co. Galway in 2004 where 34 samples were taken from 4 bays (Figure 4). In 2005-2006 33 out of the 38 samples taken on the south coast were from Cork Harbour. In Galway only 11 samples were collected in 2005-2006 from 3 bays (Tables 3 and 4). The vast majority (87%) of the samples were collected during the fishing season (1st August to 1st May) although 39 pre-season samples were also taken. The earliest sample from the 2003 season was taken on the 4th July, while during the 2004 and 2005 seasons the earliest samples were on the 1st July and 4th July respectively. Although the shrimp fishing season does not officially finish until the 1st May, very few fishermen fish for shrimp after January and consequently it proved difficult to obtain samples after this period. The latest sample was taken on the 2nd March 2005.

The samples were collected from fishermen and brought to the laboratory for analysis. During this analysis each individual shrimp was classed as male or female, measured and weighed. Female sexual maturity was determined by the presence or absence of eggs on the abdomen.

Figure 3: Bays sampled on south coast 2003-2006

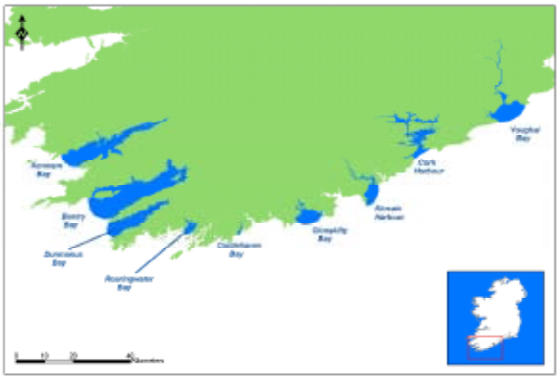


Figure 4: Bays sampled on west coast 2003-2006

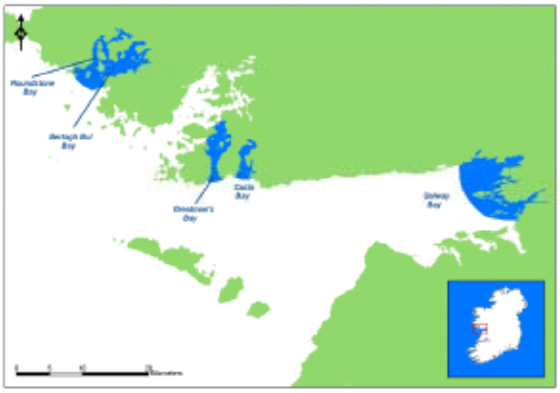


Table 3: Summary of the sampling program in Co. Cork 2003-2006

Co. Cork	2003/2004	2004/2005	2005/2006	Total
Bantry Bay	17	14	-	31
Castlehaven Bay	14	-	-	14
Clonakilty Bay	6	-	-	6
Cork Harbour	9	15	33	57
Dunmanus Bay	6	13	-	19
Kenmare Bay	6	-	-	6
Kinsale Harbour	4	-	-	4
Roaringwater Bay	68	21	5	94
Youghal Harbour	9	-	-	9
Total	**139**	**63**	**38**	**240**

Table 4: Summary of the sampling program in Co. Galway 2003-2006

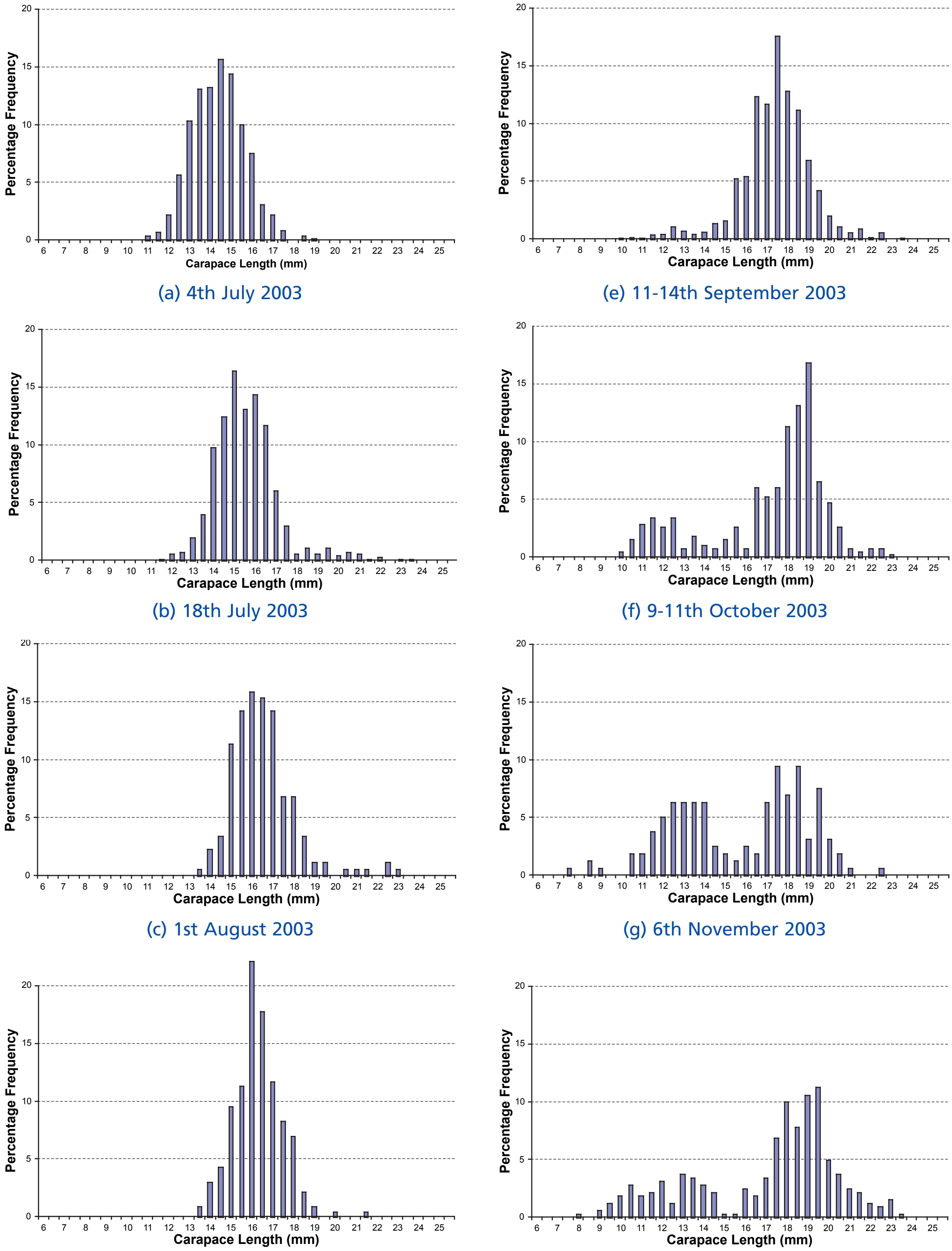
Co. Galway	2003/2004	2004/2005	2005/2006	Total
Bertragh Buí Bay	1	-	3	4
Casla Bay	-	7	-	7
Galway Bay	3	4	-	7
Greatman's Bay	-	4	-	4
Kilkieran Bay	-	-	4	4
Roundstone Bay	-	19	4	23
Total	**4**	**34**	**11**	**49**

4. Derivation of age structure

Age structure was investigated by the construction of length frequency histograms for each of the samples. For illustrative purposes the length-frequency series for Roaringwater Bay female shrimp during the 2003-2004 season is shown in Figure 5. These charts generally displayed bimodal distributions from October onwards. Increase in size is evident from the progression of cohorts on the size axis over time. The NORMSEP function in the FiSAT (Food and Agriculture Organisation, FAO) software was used to separate modes in the length frequency data. This process was carried out separately for male and female shrimp because of sex specific growth rates. The presumption that the modes in the length-frequency distribution represent age classes is probably valid for *P. serratus* as there are distinct hatching and recruitment periods in this species, which result in growth of one cohort before the next cohort is recruited. Two such cohorts will therefore be separated in size, and appear as different distributions in a size frequency histogram. This method has been previously used by Anderson (1981) and Cormier and Labonte (1980) to separate 3 to 4 age classes in *Pandalus borealis* in Alaska and Nova Scotia.

The inputs for the NORMSEP function were the expected number of age-groups and approximate mean lengths. The program was seeded with these starting values for each cohort present in the histogram. The results were not found to be sensitive to input values. The outputs from the NORMSEP function can be seen in Figure 6. These are i) the calculated mean lengths for each age class, ii) the numbers in each age class, iii) the standard deviations of the mean lengths-at-age and iv) a Separation Index (SI) for the groups identified, which indicated how successfully the distribution mixture had been resolved. In general an SI value of less than 2 indicates that the modes have not been successfully separated (Gayanilo *et al.* 2005). The SI value in Figure 6 is 6.02. After separation of the cohorts the numbers attributed to each were summed by month in each of the areas in order to show the monthly age structure.

Figure 5: Length frequency distributions for female shrimp from Roaringwater Bay in 2003/2004



(a) 4th July 2003

(b) 18th July 2003

(c) 1st August 2003

(d) 22nd August 2003

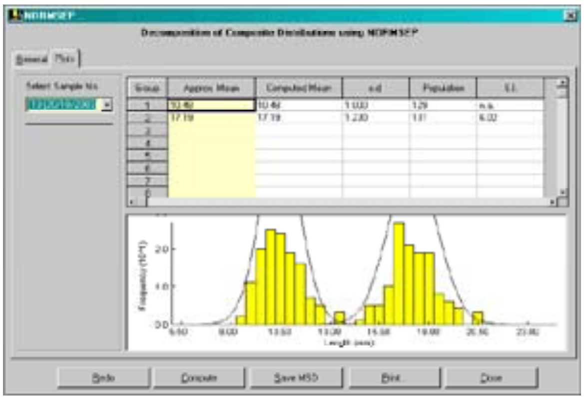
(e) 11-14th September 2003

(f) 9-11th October 2003

(g) 6th November 2003

(h) 21st January 2004

Figure 6: Separation of two age classes in a sample of *Palaemon serratus* using the NORMSEP function in the FiSAT program



Modelling growth rate

The average size at age for each age class in each sample derived from the NORMSEP analysis were used to model the growth rate. In order to maximise the number of data points the available data for all sampling years were combined. The resultant growth model therefore ignores potential variation in growth between years.

Before calculating the growth parameters, it was necessary to assign a relative age to each normal distribution (age class) in each sample. Shrimp that recruit to the fishery in October were presumed to be the result of a hatching event sometime earlier in the same year and were therefore classed as 0+. Successive groups were deemed to be 1 or more years older than the 0+ group. A more accurate estimate of age was produced by counting the number of weeks after a birth date, which was taken to be the period of peak egg hatching. In this case the date of birth was taken to be week number 16.

Growth of individuals is a major determinant of the productivity of a population. Several models have been used to express growth using simple mathematical equations, however, the von Bertalanffy growth equation has been most commonly used in studies on marine species (Beverton and Holt, 1957). When fitted using least squares residuals this curve represents the average growth of the individuals in the population. The model, in terms of length, is:

Equation 1

$$L_t = L_\infty\left(1 - e^{[-K(t-t_0)]}\right)$$

Where:

L_t is the length (mm) at age t

L_∞ (pronounced 'L-infinity') is the theoretical maximum length

K is the rate at which L_∞ is reached

In temperate climates such as experienced in Irish waters, where water temperature fluctuates seasonally, the growth of many organisms, including shrimp, is not uniform throughout the year. In such cases it is necessary to modify the growth model so that the seasonal effects on growth can be taken into account. One method is to add a sine wave function which allows the growth curve to fluctuate seasonally above and below the non-seasonal growth curve (Pitcher and MacDonald (1973) in Haddon, 2001):

Equation 2

$$L_t = L_\infty\left(1 - e^{-\left[C\sin\left(\frac{2\pi(t-s)}{52}\right) + K(t-t_0)\right]}\right)$$

Where:

C is related to the magnitude of the oscillations of the seasonal growth curve and

s is the starting point in time for the sine wave function.

Note that the sine wave function is divided by 52 so that the time scale of events is in weeks.

Assessment Methods

1. General linear modelling of catch rate data

If catch per unit effort (CPUE) data are to be used as an index of abundance of a fish population, then changes in the index must be directly proportional to changes in the actual abundance of the stock. However, this assumes that the catchability, or the proportion of the population caught by one unit of fishing effort, is constant. This is rarely the case because catch rates are often affected by variables other than abundance. These include technological advances in fishing technique (Quinn and Deriso, 1999) and environmental and physiological factors (Hilborn and Walters, 1992). It is therefore necessary to account for changes in catchability before using catch rate data as an index of abundance.

The General Linear Model (GLM) is commonly used to standardise fisheries catch and effort data. This technique (Nelder and Wedderburn, 1972) is similar to multiple linear regression in that a combined set of explanatory variables is linearly related to the observed values of the response variable, which in this case is the CPUE data series. Since their first use in fisheries assessment in the early 1980s (Gavaris, 1980), GLM methods have been used to standardise commercial CPUE data in a wide range of finfish and shellfish fisheries e.g. walleye pollock in the Bering Sea (Battaile and Quinn, 2004), Icelandic cod (Brynjarsdottir and Stefansson, 2004), bluefin tuna in the Mediterranean Sea (Ortiz and Serna, 2000), Australian northern prawns (Bishop *et al.*, 2004) and Irish brown crab (Tully, 2006).

The number and type of explanatory variables that are included in a GLM is generally determined by the biology of the species, the type of fishery or anecdotal evidence from fishermen. These variables can be broadly divided into two groups; those related to the fishing operation i.e. vessel and soak time, and those related to the environment i.e. water temperature, tidal height, air pressure, wind speed and wind direction. As part of the GLM an analysis of variance (ANOVA) was carried out to identify the significant sources of variation in the CPUE data due to the variables listed in Table 5. Only the significant variables were included in the final GLM.

Table 5: Variables used to investigate causes of variation in shrimp CPUE data

Variable	Data Type	Data Source
Vessel	Categorical	Fishing Activity Records
Week Number	Categorical	Fishing Activity Records
Soak Time	Continuous	Fishing Activity Records
Water Temperature	Continuous	Marine Institute
Tidal Height (Cobh, Co. Cork)	Continuous	www.pangolin.co.nz/tidecomp
Air Pressure	Continuous	Met Éireann
Wind Speed (Cork Airport)	Continuous	Met Éireann
Wind Direction (Cork Airport)	Categorical	Met Éireann

2. Depletion methods

Depletion methods were originally formulated by Leslie and Davis (1939) and DeLury (1947). The application of these methods in fisheries has been discussed by Hilborn and Walters (1992) and Smith and Addison (2003). The general principle behind the Leslie estimator is to examine how cumulative removals from the population by fishing influence the rate of catch of the remaining population. Assuming that there is no recruitment or migration in the period of investigation, and that CPUE is a true index of abundance, the aim is to predict the removal that would be necessary in order to drive the catch rate to zero and therefore what the total population size is. For example, if the average catch rate recorded in a bay was 2kg of shrimp per pot, and after a total removal of

2500kg the CPUE was subsequently reduced to 0.8 kg per pot then, by extrapolation, the removal required to reduce the CPUE index to zero would be 4000kg. This is an estimate of the original stock size. In such a case the harvest rate is the removal divided by the stock estimate i.e. 2500/4000 = 62.5%.

In order to carry out a valid depletion assessment, it is necessary that a large proportion of the stock is removed from an area over a short period of time. As shrimp stocks are located in enclosed bays and are often subject to high fishing effort, over a relatively short fishing season, it was considered likely that these conditions may apply. However, valid application of the model also requires that a number of other conditions are met.

The depletion model assumes a closed system where there is no change in the biomass of the stock over the course of the study period due to immigration, emigration, recruitment or growth. This is obviously not true for the Irish fishery for *P. serratus* which occurs during the autumn and winter, when shrimp are growing rapidly and during which time the recruitment of the new year class takes place. To minimise violations of these assumptions, the original abundance index (kg of shrimp per pot hauled) was modified using the information on stock structure from the sampling program, so that only the 1+ females, expressed in numbers, were included in the model. The isolation of the 1+ cohort removed the effect of the recruitment event that occurs in the middle of the fishing season. Separation of the females from the males accounted for the fact that the ratio of males to females was not consistent over the course of the fishing season possibly due to sex specific patterns of migration and recruitment. The average weights of shrimp in each size class, were used to convert from weights to numbers to control for the effects of individual shrimp growth on the catch rate. Finally, the data on numbers of 1+ female shrimp per pot were standardised using a GLM to account for the variation in catch rate that was not related to abundance but due to differences in catchability. This method of modifying the abundance index by applying knowledge of the stock structure is similar to an open system depletion model (Allen 1966, Smith and Addison 2003).

An additional problem in using the CPUE data in a depletion model was the offshore winter migration of female shrimp to deeper waters (McPadden, 1979). This behaviour corresponds to the onset of sexual maturity (DeBhaldraithe, 1971) and it seems likely that the timing of this migration is related to a decline in water temperatures in shallow inshore waters, as temperatures of less than 8°C are thought to inhibit spawning (Cole, 1958). This migration violates the closed population assumption of the depletion model as the offshore movement of mature female shrimp late in the season reduces the stock available to the fishing gear. In the depletion model this would lead to an underestimate of the original stock size and an overestimate of the harvest rate. In order to account for this the data series used in the depletion model was limited to those fishing events that took place prior to week number 48 and, therefore, before the outward migration had started (DeBhaldraithe, 1971).

Data were not available for every skipper involved in the fishery, and as a result the total removals of shrimp from each area were not known. Consequently it was not possible to use the depletion method to estimate the absolute pre-season abundance of shrimp in any area. The use of such partial data also means that the catchability estimate associated with the CPUE index will be overestimated relative to the whole population i.e. if only 10% of the catch is monitored, then the catchability coefficient will refer to only 10% of the total population and thus will be 10 times too large. Therefore estimates of the catchability coefficient are not reported. Finally, it is assumed that the pattern of removals is similar between the monitored and unmonitored groups of fishermen.

3. Yield and egg per recruit analysis

If the yield from shrimp recruiting to a stock is to be optimised losses in biomass due to mortality must be balanced against the gains due to individual growth. This optimal yield can be identified if the growth rate and rate of natural mortality is known. An extension of this yield per recruit (YPR) analysis is to identify the harvest size and harvest time that manages the risk of recruitment failure by maintaining egg production potential per recruit (EPR) above a given value. Although the stock recruitment relationship for Irish stocks of *P. serratus* is unknown information from other fisheries and species suggest what the EPR should be given the biological characteristics of this species.

The YPR was modeled as described in Haddon (2001). As the actual number of shrimp recruiting to each area during each year was unknown, an arbitrary number of 1000 recruits was entered into the model at an age of 19 weeks old for males, and 23 weeks old for females. These were the ages that male and female shrimp were first seen to recruit to the fishery, and were the smallest sizes observed in the samples (age was calculated assuming a birth date of Julian week number 16 when hatching was observed to peak). The 1000 recruits were subjected to natural (M) and fishing (F) mortality rates in weekly time steps until the cohort disappeared from the population at an age of 97 and 127 weeks for males and females respectively. The total weight of the catch under each simulated exploitation regime was calculated and divided by the number of initial recruits to get an estimate of the yield on a per recruit basis. The YPR model can be described mathematically as:

Equation 3

$$\frac{Y}{R} = \sum_{t=t_c}^{t_{max}} W_t . N_F$$

Where:

Y is the total yield across all age-classes,

R is the number of initial recruits,

W_t is the average weight at age,

N_F is the numbers caught in the fishery,

t_c is the age at first capture and

t_{max} is the maximum age observed in the catch.

The EPR model builds on the YPR model by adding data on female maturity and fecundity to allow the impact of fishing mortality on the reproductive capacity of the stock to be quantified. The relative EPR (R_{EPR}) is the ratio of the EPR at the current fishing mortality ($F_{current}$) to the EPR when there is no fishing (F_0).

Fecundity was estimated using the relationship of Reeve (1969a). The size at maturity was estimated for the month at which peak spawning occurred as indicated by the peak in the percentage of females that were berried (Figure 7) The size maturity ogive , thus calculated, in March (Equation 4) showed that 50% of shrimp were berried at a CL of 12.45mm (Figure 8) .

Equation 4

$$\textit{Probability of Maturity} = \frac{1}{\left(1 + e^{(0.8933.\,(\textit{Carapace Length (mm)} - 12.45mm))}\right)}$$

Regression of the proportions of ovigerous and non-ovigerous females were plotted against week number to estimate the week of peak hatching for inclusion in EPR modelling. In the same way the decline in the percentage of egg bearing females was used to estimate the time when 50% of the mature females had hatched their eggs. This was estimated to be julian week 16.1.

Figure 7: Proportion of 1+ females carrying eggs by month (Numbers represent individuals inspected)

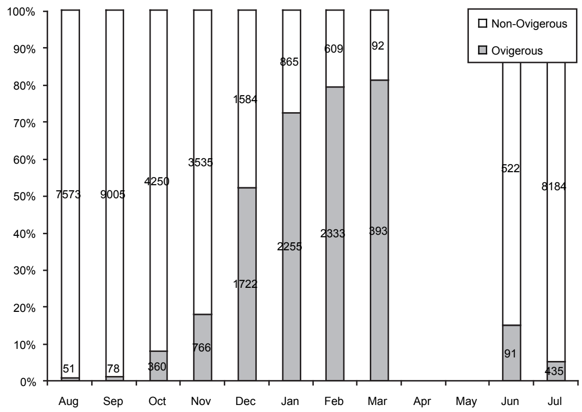
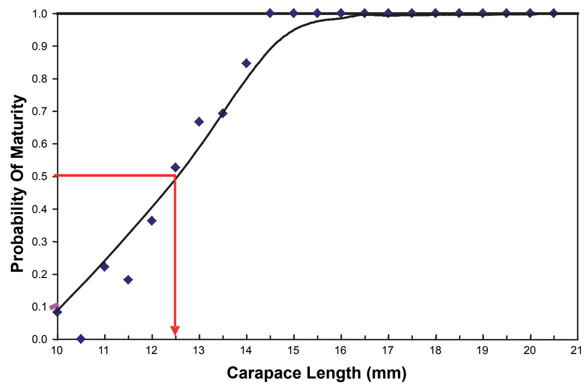


Figure 8: Probability of maturity against size for 1+ females (Data from the month of peak spawning only i.e. March)



$F_{current}$ was estimated from the harvest rates calculated in the depletion model. In Co. Cork and the south west in 2005 and 2006 total mortality was estimated to range from 0.6 to 2.5% per week (Tables 12 to 15). In order to ensure that the likely exploitation scenarios were covered, the YPR values were calculated for a wide range of harvest rates from 0% to 7.4% per week. No independent estimates of M were available in the literature for *P. serratus*, however, a study on the related species, *Palaemon adspersus* by Conides *et al.* (1992), estimated M to be <1% per week. Berenbojm *et al.* (1992) estimated M to be 1.5 to 1.6% per week for *Pandalus borealis* in the Barents Sea. Fu and Quinn II (2000) provide estimates of M for *P. borealis* ranging from 1.5 to 2.8% per week. To cover the likely rates of M for *P. serratus* the YPR assessment was run at values of M equivalent to 1.0%, 1.9%, 2.8% and 3.8% per week. The final condition in the YPR model was to include the closed season of May 1st to August 1st by applying an F of zero during this period.

Maximising the gross weight of the catch is likely to be a less important objective for the participants in the fishery compared to maximising the economic return. In reality the price obtained by fishermen for their catch is related to the average size of shrimp landed. Market price data (€/kg shrimp of each grade) were collected during the 2006-2007 fishing season. Information was given for ungraded, 8mm graded, 9mm graded and 10mm graded shrimp. The average price per kg for each grade was then used to rescale the YPR results from grams per recruit to € per recruit.

4. Reference points and performance indicators

The YPR model of Beverton and Holt (1957) is used in fisheries assessment to provide management advice on F that optimises yield from a cohort under different conditions such as size at recruitment or time of harvesting. This model assumes that the population is in a stationary state, in other words that the stock is not changing over time with respect to age structure, growth rate, mortality or recruitment. Under this assumption the total annual yield from the population at any one time is the same as that from the entire lifespan of any one of its component year classes. However, shrimp populations are rarely in a stationary state (Garcia, 1984), recruitment may be environmentally driven and M may be high. Simulation of growth and mortality processes may, therefore, suggest an unreasonably high F to optimise yield per recruit. In this circumstance offering management advice on adjusting F to optimise yield may be unsafe. Nevertheless it is useful to compare management reference points that are in widespread use, with the current position of the shrimp fishery. Some evaluation of the appropriateness of $F_{current}$ is required and even if this is not used to change F in the short term comparison of reference point ratios over time with trends in performance of the fishery may provide useful information to adjust F.

Recruitment overfishing reference points depend on the parameters of the Stock-Recruitment (S-R) relationship, or more precisely on the slope at the origin of this relationship. As the S-R relationship in shrimp is unknown, a precautionary approach, based on information from other species and life histories, may be followed (Mace and Sissenwine, 1993). The end result of a YPR or EPR assessment is an evaluation of the yield or egg production for a given level of natural mortality, age/size at first capture and fishing mortality. The fishing mortality rate that maximises the YPR or EPR is defined as F_{max}. The marginal yield criterion which is usually denoted as $F_{0.1}$ (Hilborn and Walters, 1992) is more precautionary than F_{max}. The use of $F_{0.1}$ for fisheries management was introduced by Gulland and Boreman (1973) and is the fishing mortality rate at which the slope of the YPR curve is 10% of the slope at the origin.

$F_{current}$ for *P. serratus* were estimated by depletion analysis for four bays on the south coast of Ireland during the 2005 and 2006 fishing seasons and compared to the values for $F_{0.1}$. EPR reference points were defined in relative terms as the relationship between EPR at $F_{current}$ to what it would be at F_0 ($F_{current}$ / F_0). In cases where the stock-recruitment relationship is not known, it is generally recommended that the reproductive potential of the stock should not be reduced to less than 30% of its unexploited capacity (Mace and Sissenwine, 1993).

5. Size selective harvesting

The optimum size at which to harvest shrimp depends on the balance between increase in biomass due to individual growth and decrease in biomass due to natural mortality. An optimum age/size at first capture can be implemented in a number of ways such as by opening the fishing season at a later date, by controlling the within season fishing mortality rate or by using size selective fishing gear or other grading devices. The latter option was investigated here by the use of grading devices. These graders were composed of two interconnecting components (Figure 9). The first section was a light-weight, fiberglass-reinforced polyester box 70 x 50 x 40cm in dimension. The second section was an interchangeable plastic panel with 8mm, 9mm or 10mm bar spacings. The overall weight of the box and grid together was 4.5kg.

Figure 9: Grading device from www.catvis.com

To estimate the appropriate grading size for *P. serratus*, a subset of data was extracted from the size distribution database for Co. Cork for the months of August to November 2003, and length frequency charts were drawn for each month. From October onwards the size structure of the shrimp population was bimodal, the smallest mode representing the 0+ cohort with a mean carapace length of 15mm. Initial YPR estimates suggested that the optimum harvest strategy should exclude this cohort from the landings. To estimate the selectivity necessary to exclude 0+ shrimp (on the basis of the maximum carapace width), the carapace length and carapace width of 224 shrimp were correlated. As the catch made at sea is composed of a mixture of males and females a combined-sex regression of carapace length and carapace width was used. In any case this relationship was similar for males and females. From this regression a carapace length of 15mm corresponded to a carapace width of 10mm and as a result the largest grader used in the trial was 10mm in width. The effects of grading at 8mm and 9mm were also investigated.

Selectivity trials of the 8, 9 and 10mm graders were undertaken at sea. Approximately 1 kg of shrimp was used in each test. The grading panel was shaken until no more shrimp fell through, a process that usually lasted no more than 1 minute. Each grid was tested in triplicate and the graded shrimp were returned to the laboratory for measurement.

Using the methodology in King (1995), the proportion retained by the grading device was calculated as the number of individuals retained at each size-class, divided by the total number at each size class. This proportion was then plotted against length, and a logistic curve (Equation 5) was drawn through the points.

Equation 5

$$\text{Probability of retention} = \frac{1}{\left(1 + e^{(-r(L - Lc_{50}))}\right)}$$

The constant r in this equation determines the steepness of the curve and was estimated by transforming the above equation into a straight line (y = a + b.x) of the following form:

Equation 6

$$L_n\left(\frac{1-P}{P}\right) = rLc_{50} - rL$$

r = -b   Where b is the slope of the regression line

$Lc_{50} = \frac{a}{r}$ Where a is the y-axis intercept

By plotting the natural log of the proportion released over the proportion retained against length, it was possible to estimate the steepness of the curve (r) and the mean size at retention, Lc_{50}.

The effect of grading on the survival of both retained and discarded shrimp was also investigated. This was undertaken at Bréizon Fisheries (Rossaveel, Co. Galway, Ireland). Only the 9mm grader was used. The trial was conducted in triplicate. Following grading the shrimp were placed in separate rigid plastic holding trays (40 x 30 x 21cm dimensions) with rectangular mesh (17.5 x 6.5mm) and re-immersed in flow-through seawater tanks. The shrimp were then checked after 24 hours and 96 hours. Dead individuals were removed and measured and mortality levels calculated.

The length at which an individual shrimp has a 50% chance of being retained (Lc_{50}) for each of the grading devices was estimated by plotting the logarithm of the proportion retained against size. This analysis produced Lc_{50} values for the 8mm, 9mm and 10mm graders, of 13.53mm, 15.54mm and 17.44mm carapace length respectively (Table 6 and Figure 10). The fit of these linear models was good with R^2 values of >0.94 and slope values of -2.32 for the 8mm grader, and -1.33 and -2.18 for the 9mm and 10mm graders respectively. Using a combined-sex length to weight regression, the Lc_{50} values corresponded to individual weights of 2.79g, 4.07g and 5.57g. In commercial terms this corresponded, on average, to 358 shrimp per kg for the 8mm grader, 246 per kg for the 9mm grader and 180 per kg for the 10mm grader.

Table 6: Regression coefficients for 8mm, 9mm and 10mm graders

	8mm	9mm	10mm
R^2	0.94	0.94	0.98
N	541	538	491
y-int.	31.4	20.7	38.1
Slope (-r)	-2.3201	-1.3325	-2.1841
Lc_{50}	13.53	15.54	17.44

The Lc_{50} values for each grade were used in Equation 5 to construct the selectivity curves in Figure 11.

Figure 10: Estimates of mean size retained by 8mm, 9mm and 10mm graders

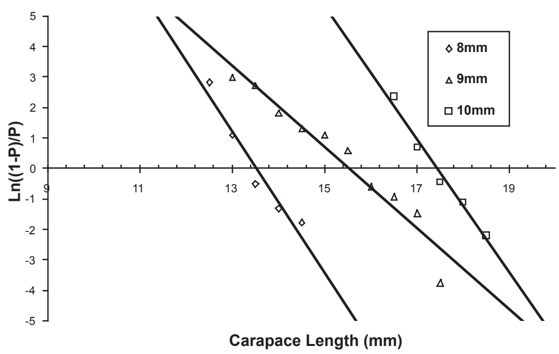
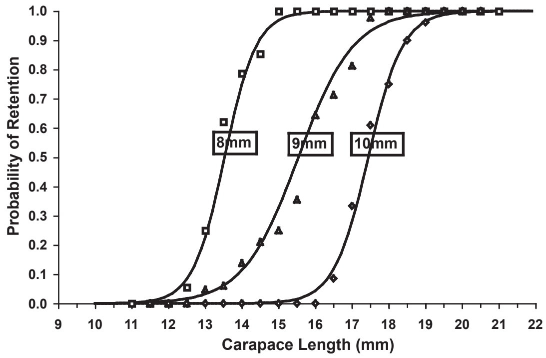


Figure 11: Selectivity curves for 8mm, 9mm and 10mm graders



The logistic functions defining the probability of capture (P_c) and the selectivity properties of each grader are:

Equation 7

$$P_c \text{ 8mm grader} = \left(\frac{1}{\left(1+e^{(-2.3201*(L-13.53))}\right)}\right)$$

Equation 8

$$P_c \text{ 9mm grader} = \left(\frac{1}{\left(1+e^{(-1.3325*(L-15.54))}\right)}\right)$$

Equation 9

$$P_c \text{ 10mm grader} = \left(\frac{1}{\left(1+e^{(-2.1841*(L-17.44))}\right)}\right)$$

The square-mesh in the commercial shrimp traps is composed of rigid plastic mesh of approximately 7.5 x 7.5mm. This mesh has a selectivity effect on the average size of shrimp in the catch prior to grading, as some very small shrimp may escape before the pots are hauled. To investigate this effect, Fahy *et al.* (1998a) compared the size of shrimp retained in a fine mesh trap (2.5mm mesh size) and a normal commercial trap. Using the alternate hauls method, as described in King (1995), the logistic equation for the selectivity curve of the commercial trap was determined to be

Equation 10

$$P_c \text{ commercial trap} = \left(\frac{1}{\left(1+e^{(-0.7268*(L-10.96))}\right)}\right)$$

From Equation 10 the mean size of shrimp retained by commercial traps was estimated to be 10.96mm carapace length, which corresponds to a weight of 1.57g, or 637 individuals per kg. The size selectivity is also lower than the Catvis grader as shown by the lower r value in Equation 10 compared to Equation 7 to Equation 9. Fahy *et al.* (1998a) also found that only 277 shrimp out of 2844 (9.7%) had escaped from the commercial pots in his study.

Over 96hrs, mortalities of shrimp that had been passed through the 9mm grader were 7.9%, 4.8% and 5.9% in the three separate trials. In comparison the mortality rates of those retained were 0.7%, 5.6% and 3.8% respectively.

After the positive reception of the Catvis grader by shrimp fishermen during the 2006-2007 fishing season, BIM invested in the construction of a new grader, specifically designed for use in the shrimp fishery (Figure 12). The dimensions of this new grader were 73.5 x 48.5 x 16.5cm with a weight of 3.3kg. It was manufactured in 8mm, 9mm and 10mm sizes with a collection box and pregrader of 20mm also produced in order to select out crabs and fish from the shrimp catch. These devices were stackable in order to facilitate sequential grading through the panels and to minimise the space they occupy when not in use. They were distributed with Fishing Activity Records prior to the 2007-2008 shrimp fishing season.

Figure 12: Shrimp grading device designed by Bord Iascaigh Mhara

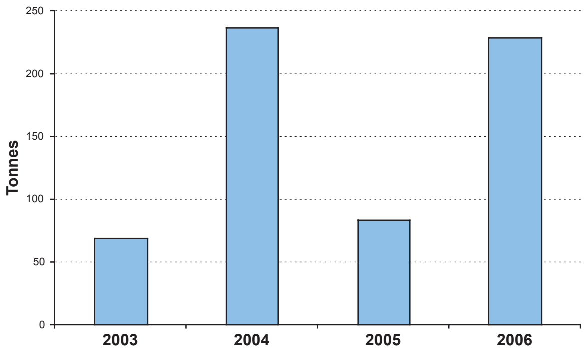
(Produced by JFC Ltd., Tuam, Co. Galway, Ireland)

The South West Fishery

1. Landings

In 2006, 40% of active shrimp fishing vessels, 49% of the fishing effort and 72% of the landings in Ireland were from the south west region (Table 1 and Figure 2). Annual landings vary substantially (Figure 13). In 2004 and 2006 landings were double those of 2003 and 2005. The reason for this variation is not known but it may be due to fluctuations in the population size due to annual changes in recruitment success. The fleet also responds to poor recruitment and stock biomass by reducing fishing activity or deciding not to fish.

Figure 13: Shrimp landings from the south west of Ireland from 2003-2006



2. Analysis of CPUE data

Cork Harbour 2005-2006

The sample data set for Cork Harbour in 2005-2006 consisted of 283 daily catch and effort summaries (Table 7). Fishing in this area began at the start of August and finished in the first week of November. However, one skipper continued fishing until mid February. The average number of days fished per vessel over this period was 57 with a minimum of 36 and a maximum of 84. In total 38,451 pot lifts were recorded, resulting in a catch of 6,618 kg. The average soak time used by each skipper ranged from 1.0 to 2.3 days.

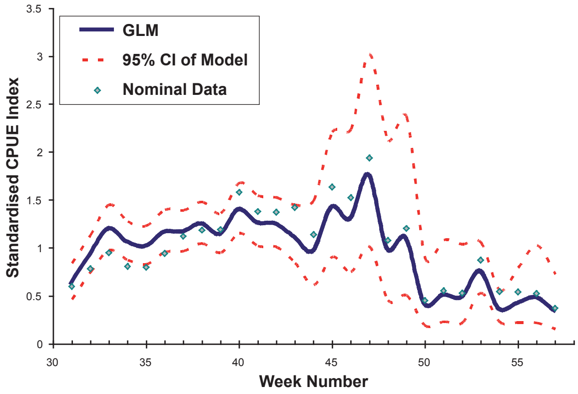
Table 7: Summary statistics for fishing activity records for Cork Harbour 2005-2006

Skipper	Start Week	End Week	Days Fished	Pots Lifted	Total Catch (kg)	Ave. Soak Time (Days)
1	32	39	52	5200	376	2.0
2	32	43	69	9660	2352	1.0
3	31	57	84	13641	2901	2.8
4	31	43	36	1550	469	2.3
5	31	43	42	8400	520	2.1

Analysis of Variance (ANOVA) showed that 74% of the variance in catch rate was explained by vessel and week number. The effects of the other variables were non-significant. A General Linear Model (GLM) was run to standardise for vessel effects to produce a standardised weekly catch rate series. The standardised series was smoother than the nominal data up to week 48 (Figure 14).

After week 48 nominal and standardised data showed a similar pattern. The confidence intervals of the model show that the variation was greatest in November, during the middle of the fishing season, when the abundance index was at its highest.

Figure 14: GLM standardised CPUE data for Cork Harbour in 2005-2006



South West 2006-2007

Sixteen FARs representing a total of 481 daily catch and effort summaries were collected from the south west region in 2006-2007 (Table 8). The main fishery took place between the second week of August and early December. However, 3 out of the 15 skippers continued fishing until the end of February 2007. The average number of days fished per vessel was 31 and ranged from 4 to 77. The average gear soak time ranged from 2.3 days to 6.1 days.

As with the standardisation procedure for Cork Harbour in 2005, the fishery data were merged with environmental data i.e. wind speed, wind direction, water temperature, air pressure and tidal height. As the vessel effect was the most significant variable in the 2005-2006 assessment, the areas for which more than one FAR was available were extracted from the database so that the vessel effect could be accounted for. There were 5 FARs returned from Kinsale Harbour, 3 from Cork Harbour and 2 from Roaringwater Bay.

ANOVA showed that vessel and week number were significant in Cork Harbour and Kinsale while in Roaringwater Bay soak time and week number were significant. The variation accounted for by these factors was then removed using the GLM (Figures 15 to 17). Despite the differences between bays, the three data series showed some similarities with some coincident periods of higher catch rates. The first of these peaks occurred between Julian weeks 40 to 43 and probably corresponded with the annual recruitment of the new year-class into the fishery. After this period the catch rate declined. Towards the end of the year there was a second increase which was probably due to fishermen moving their gear seaward to follow the off-shore migration of adult shrimp. Catch rates subsequently declined towards the end of the season.

Table 8: Summary statistics from fishing activity records for the south west in 2006-2007

Skipper	Bay	Start Week	End Week	Days Fished	Pots Lifted	Total Catch (kg)	Ave. Soak Time (Days)
1	Ballycotton	40	49	14	3600	913	3.8
2	Cork Harbour	39	63	45	8802	3287	5.9
3	Cork Harbour	39	51	9	900	551	9.9
4	Cork Harbour	30	42	45	10370	1080	3.1
5	Courtmacsherry	35	44	15	2167	497	4.5
7	Kenmare	33	62	59	17510	2787	5.9
8	Kinsale	40	42	4	920	145	2.8
9	Kinsale	34	55	33	8500	2583	6.1
10	Kinsale	33	54	42	8030	1343	3.8
11	Kinsale	36	55	30	5934	1668	6.0
12	Kinsale	47	63	15	2640	984	3.9
13	Roaringwater	32	51	60	17110	2268	2.5
14	Roaringwater	31	51	77	33980	4304	2.3
15	Youghal	41	49	15	2410	622	2.7

Figure 15: GLM standardised CPUE series for Cork Harbour 2006

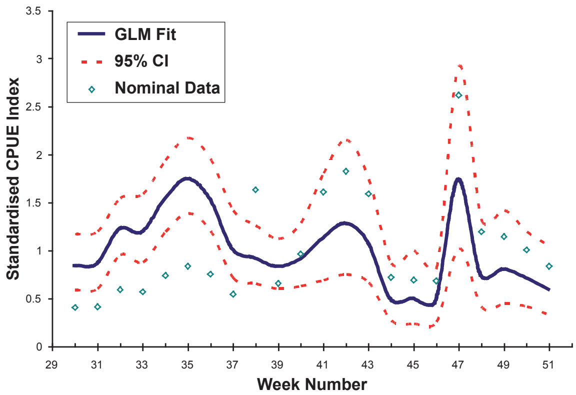


Figure 16: GLM standardised CPUE series for Kinsale Harbour 2006

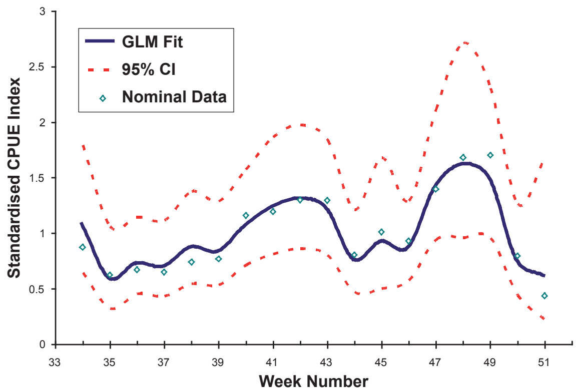
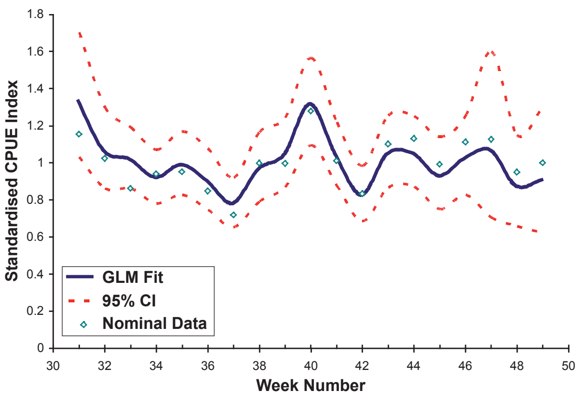


Figure 17: GLM standardised CPUE series for Roaringwater Bay 2006



South West 2007-2008

Eighteen FARs and a total of 546 daily records of catch and effort were recorded in 2007-2008 (Table 9). The fishery occurred from early August to early December. However, 4 of the 18 skippers continued fishing into 2008. The average number of days fished per vessel was 34 (range 5 to 66). The range in average soak times for each skipper was larger than in previous years with a minimum of 1.4 days and a maximum of 8.3 days.

ANOVA of the data from the 6 skippers in Roaringwater Bay showed that vessel and week number were significant as in the previous analyses, however, soak time was also highly significant. This may be due to the greater range of soak times in the 2007-2008 dataset than in any of the previous years. In contrast to the previous years GLM standardised and nominal data did not show peaks between weeks 40 and 43 (Figure 18).

The CPUE data for bays in the south west region for 2007-2008, where data for only 1 vessel per bay was available, showed significant variation between areas (Figure 19). In all the bays, except Kinsale, there was a general downward trend in the observed catch rates as the season progressed.

Table 9: Summary statistics for fishing activity records for the south west in 2007-2008

Skipper	Bay	Start Week	End Week	Days Fished	Pots Lifted	Total Catch (kg)	Ave. Soak Time (Days)
1	Ballycotton	48	55	8	1840	748	6.0
2	Baltimore	32	43	45	9000	1294	1.8
3	Bantry Bay	32	56	38	15350	1350	5.0
4	Fenit	41	51	12	1660	315	5.5
5	Fenit	39	50	24	4660	729	4.5
6	Fenit	35	47	18	6150	869	4.7
7	Kenmare Bay	50	52	5	850	117	4.4
8	Kenmare Bay	41	61	36	15740	1999	5.4
9	Kinsale	38	56	23	5000	1139	8.3
10	Roaringwater Bay	32	46	50	13345	1440	1.9
11	Roaringwater Bay	32	48	66	29500	2987	2.4
13	Roaringwater Bay	32	40	49	23065	2611	1.9
14	Roaringwater Bay	32	41	35	6700	722	2.1
15	Roaringwater Bay	32	42	50	24850	3403	2.1
16	Roaringwater Bay	30	43	54	24970	2556	1.4
18	Tralee Bay	34	55	33	12080	2637	6.0

Figure 18: GLM standardised CPUE series for Roaringwater Bay 2007

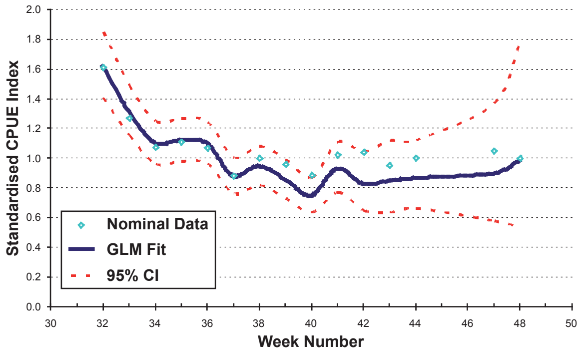
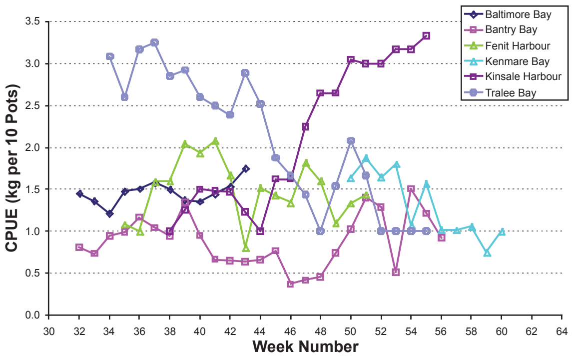


Figure 19: CPUE data from south west region 2007-2008



3. Inter annual trends in CPUE data

Catch and effort data, for the period 1998-2005, were obtained from one skipper fishing in Roaringwater Bay, Co. Cork (Table 10). This skipper fished an average of 63 days each season, with a maximum of 81 days in the 1998/1999 season and a minimum of 53 days in the 2000/2001 season. On average he lifted 21,320 pots and landed an average of 1,470kg per season. Information on soak time was only available for 2004 and 2005. ANOVA showed that temperature, wind speed, year and week number were significant in determining the catch rate. Year and week interactions were also significant showing that the weekly pattern was not the same each year.

As in the previous analyses, standardised abundance indices were produced, for the single vessel time series, by removing the effects of the significant factors from the data series in a GLM (Figures 20 and 21). The within season, weekly catch rate declined until week 37, after which it increased reaching a peak between weeks 49 and 50. In 1998, 1999 and 2001 fishing activity extended into the new calendar year and the catch rates decreased towards the end of the season. There was a twofold difference in the annual average nominal catch rate over the 8 year period.

Table 10: Catch and effort data for Roaringwater Bay time series (1998-2005)

Fishing Season	Start Week	End Week	Days Fished	Pots Lifted	Total Catch (kg)	Ave. Soak-Time (Days)
1998/1999	29	54	81	24300	1822	-
1999/2000	26	53	76	22800	1638	-
2000/2001	31	48	66	19800	1315	-
2001/2002	30	51	53	15900	746	-
2002/2003	34	49	59	17700	1385	-
2003/2004	32	45	53	15900	1265	-
2004/2005	32	43	57	23480	1691	1.5
2005/2006	33	44	59	30680	1899	1.5
Total			**504**	**170560**	**11760**	

Figure 20: GLM Standardised CPUE Index for Roaringwater Bay 1998-2005

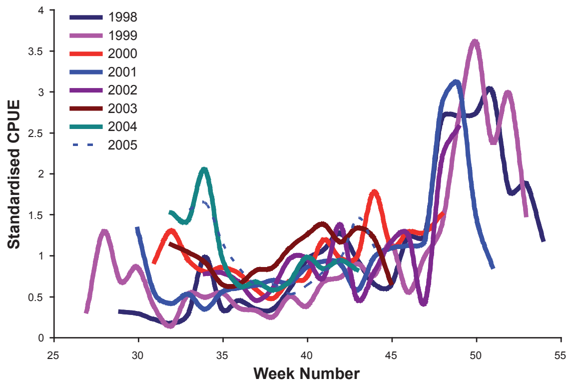
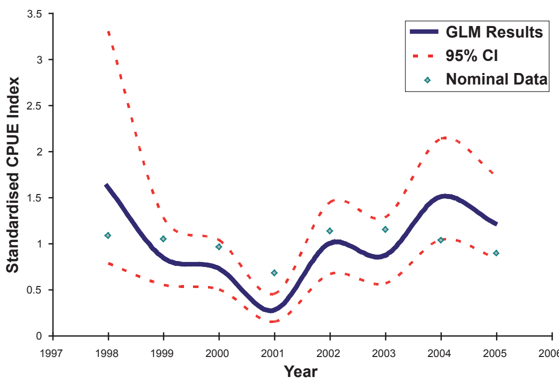


Figure 21: GLM Standardised Annual CPUE Indices for Roaringwater Bay (1998-2005)



4. Age structure of the stock

The general age structure of the shrimp populations in the south west, over the course of the fishing season, was found to be similar across all the areas sampled. A new year class recruited to the fishery in the autumn and the proportion of the catch represented by this year class increased over the second part of the season. Growth was estimated separately for females (Figures 22 to 25) and males (Figures 26 to 29). Males recruited to the fishery in September while females recruited in October. The population then consisted of the 0+ and 1+ age-classes until the end of the fishing season. The 0+ age class overwintered, reached 1+ in April (assuming an April birth date based on peak in egg hatching), and by the following July/August was usually the only age class in the samples. However, in Roaringwater Bay in 2003 females of the 2+ cohort were still present until September (Figure 25).

The main geographic difference in age structure was seen in Bantry Bay, Co. Cork in 2004 (Figure 26). In this instance no recruitment event was observed and the samples were unimodal during the fishing season, containing only 1+ shrimp.

Figure 22: Age structure of female shrimp in Bantry Bay (Co. Cork)

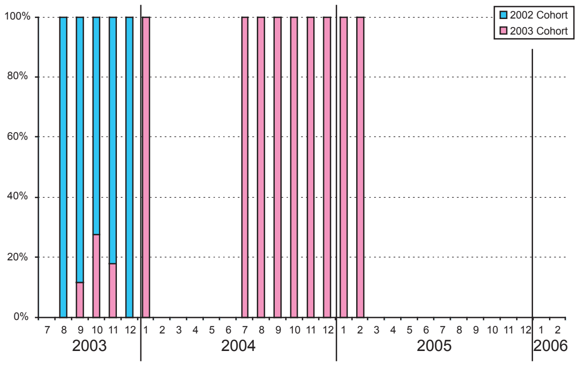


Figure 23: Age structure of female shrimp in Cork Harbour (Co. Cork)

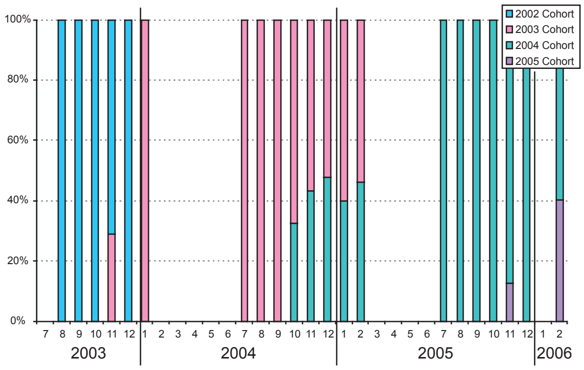


Figure 24: Age structure of female shrimp in Dunmanus Bay (Co. Cork)

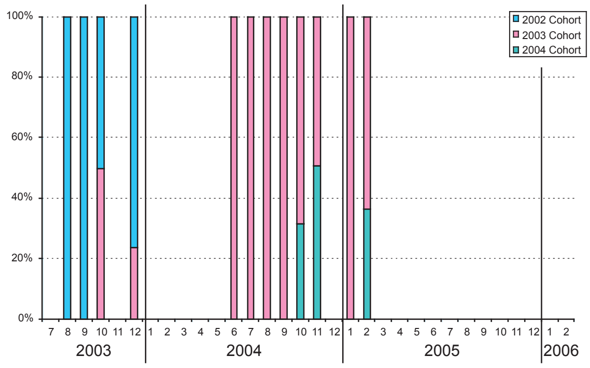


Figure 25: Age structure of female shrimp in Roaringwater Bay (Co. Cork)

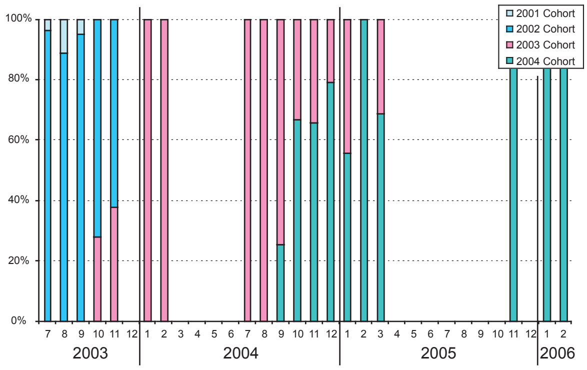


Figure 26: Age structure of male shrimp in Bantry Bay (Co. Cork)

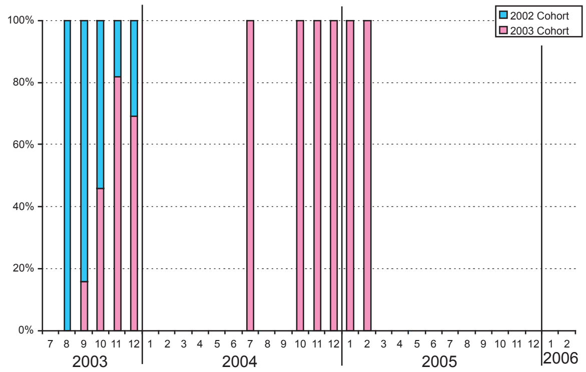


Figure 27: Age structure of male shrimp in Cork Harbour (Co. Cork)

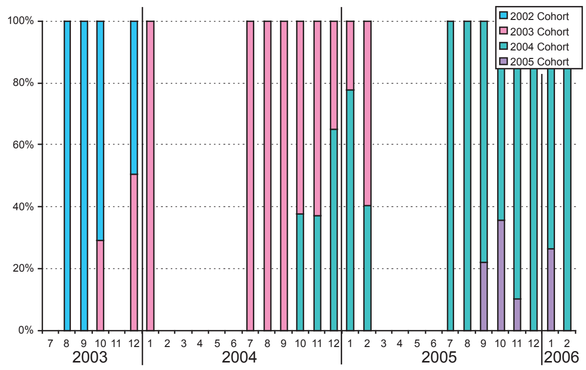


Figure 28: Age structure of male shrimp in Dunmanus Bay (Co. Cork)

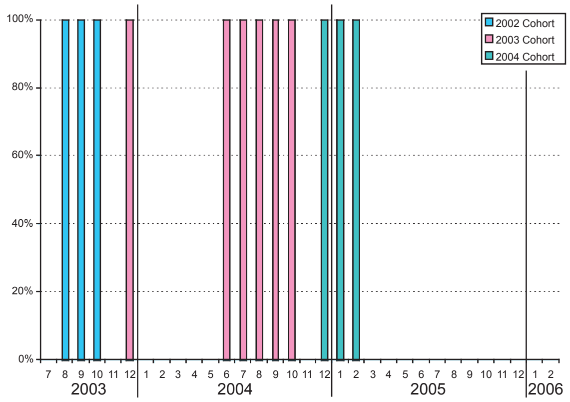
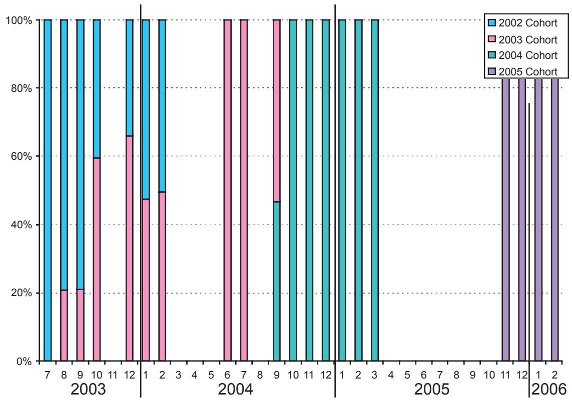


Figure 29: Age structure of male shrimp in Roaringwater Bay (Co. Cork)



5. Sex structure of the stock

In 2003 and 2005, the proportion of male shrimp in the samples increased as the fishing season progressed (Figure 30). Females dominated the 1+ cohort in every area with an average of 65% over the fishing season (Table 11). The sex ratio for the 0+ cohort was more complicated with males dominating in Bantry Bay and Cork Harbour while females dominated in Dunmanus Bay, Roaringwater Bay and Youghal Harbour. However, the combined sex ratio for all areas, for the 0+ cohort, was almost equal at 51:49 females to males.

Figure 30: Sex structure of the shrimp stock from the south west region

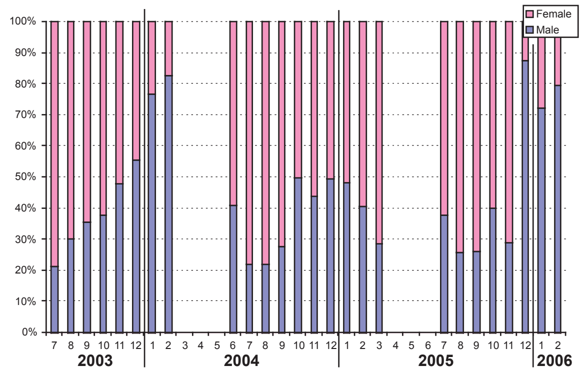


Table 11: Average sex ratios of each age class between August and January

	Female (Numbers)		Male (Numbers)		M:F	
	0+ Cohort	1+ Cohort	0+ Cohort	1+ Cohort	0+	1+
Bantry Bay 2003/04	342	1486	464	840	1.36	0.57
Bantry Bay 2004/05	0	1099	79	639	-	0.58
Cork Harbour 2003/04	126	1064	254	313	2.02	0.29
Cork Harbour 2004/05	313	1051	579	705	1.85	0.67
Cork Harbour 2005/06	142	2917	207	754	1.46	0.26
Dunmanus Bay 2003/04	182	750	102	306	0.56	0.41
Dunmanus Bay 2004/05	265	1070	212	711	0.80	0.66
Roaringwater Bay 2003/04	-	4048	-	3221	-	0.80
Roaringwater Bay 2004/05	1123	801	637	124	0.57	0.15
Youghal Bay 2003/04	208	673	79	295	0.38	0.44

6. Modelling the depletion in catch rate

Cork Harbour 2005-2006

The proportion of the shrimp catch that was 1+ female was estimated from the age structure data and converted from weight of 1+ female shrimp per pot into numbers of 1+ female shrimp per pot. An ANOVA was carried out on these data to identify which factors had the most important influence on catch rate of 1+ female shrimp. This analysis revealed that the factors week number and vessel were significant and a GLM was then used to account for variation in catch rate due to these factors. The resultant standardised CPUE index for the numbers of 1+ females (Figure 31) showed that there was an increase in the index from week 31 to 32 after which the index was stable or decreased while the nominal catch rate index did not decrease. No depletion signal was observed in the standardised CPUE data for the male 1+ group.

Depletion analysis of the numbers of 1+ females in the catch was carried out by plotting the declining section of the standardised CPUE data from week number 32 to 43 for the 5 Cork Harbour skippers against their cumulative catch in numbers. By calculating the intercept of the linear regression on the x-axis, it was estimated that the removal necessary to reduce the stock to zero was 3.235 million shrimp (Figure 32). As the total removal of shrimp by all fishermen operating in Cork Harbour was not known, this stock estimate is only relative to the cumulative catch of the 5 skippers for which data were available (i.e. it is not an estimate of the total size of the 1+ cohort of females in Cork Harbour). Nevertheless, by comparing the known removal of 948,000 shrimp by the 5 skippers to the stock size estimate from the depletion model, the annual mortality rate was estimated to be 29 ±3% (95% Confidence Interval). This corresponds to an instantaneous mortality (Z) of approximately 0.35 ±0.03 per year or 0.0067 ±0.0006 per week (Table 12).

Figure 31: Isolation of 1+ female shrimp from the Cork Harbour 2005 CPUE index

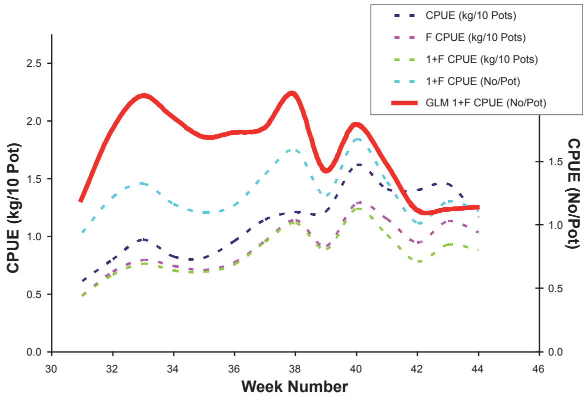


Figure 32: Depletion estimation of harvest rate on 1+ female shrimp from Cork Harbour in 2005

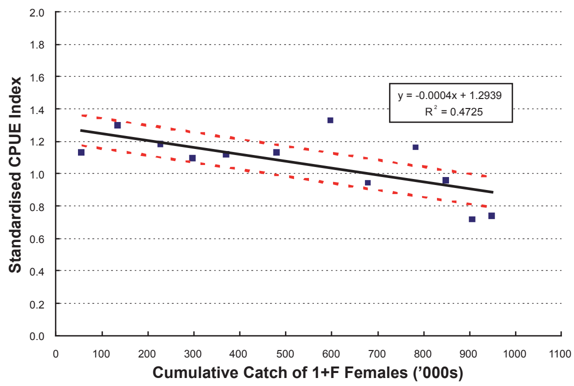


Table 12: Estimate of fishing mortality rates on 1+ female shrimp from depletion assessment in Cork Harbour 2005

	Stock Estimate ('000s)	Stock Removal ('000s)	% Annual Mortality Rate	Total Mortality Per Year	Total Mortality Per Week
Model Fit	3235	948	29	0.35	0.0067
Upper 95% CL	3002	948	32	0.38	0.0073
Lower 95% CL	3467	948	27	0.32	0.0061

South west 2006-2007

Data for 16 vessels in 8 bays were available for analysis from the 2006-2007 season. Catch and effort data from each of these bays were processed in the same way as for 2005 so that only the numbers of 1+ female shrimp were considered. After this step was completed, depletion signals were found in the standardised abundance indices from Kenmare Bay (Figure 33), Kinsale Harbour (Figure 34) and Roaringwater Bay (Figure 35). ANOVA found the week number effect to be significant in all areas. In addition vessel, soak time and wind speed were found to be significant in Kinsale, while soak time was significant in Roaringwater Bay. The mortality rate for 1+ female shrimp was estimated to be highest in Roaringwater Bay at 66% ±4% (95% Confidence Interval). Kinsale Harbour was similar at 67% ±5% while Kenmare had the lowest mortality rate of 53% ±3% (Figures 36 to 38, Tables 13 to 15).

Figure 33: Isolation of 1+ Females from Kenmare Bay 2006 CPUE index

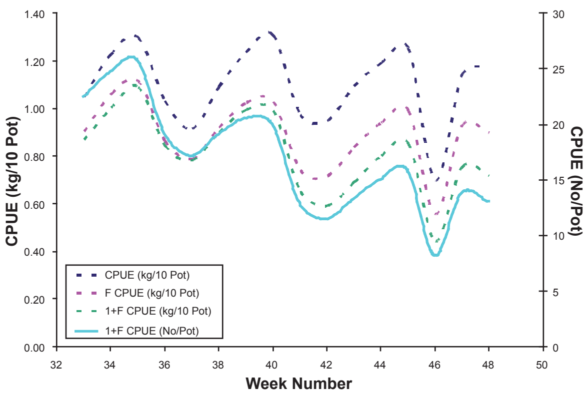


Figure 34: Isolation of 1+ Females from Kinsale Harbour 2006 CPUE index

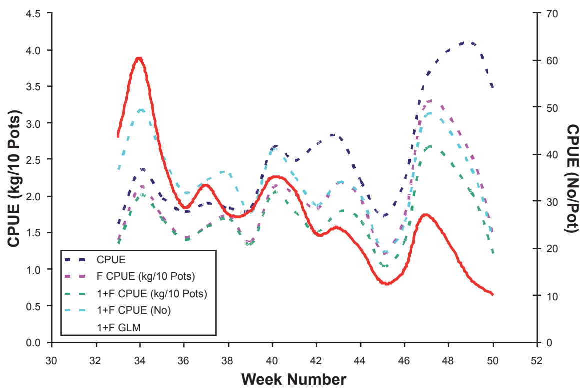


Figure 35: Isolation of 1+ Females from Roaringwater Bay 2006 CPUE index

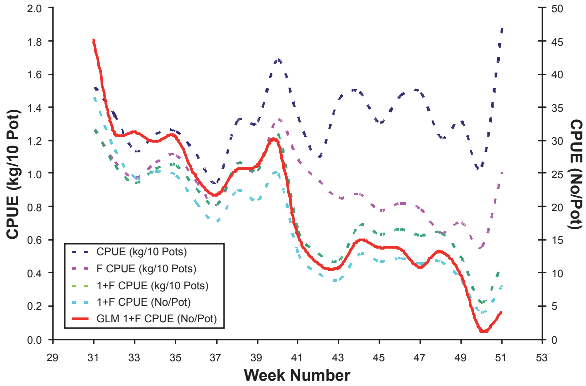


Figure 36: Depletion estimate of harvest rate on 1+ year old female shrimp from Kenmare Bay in 2006

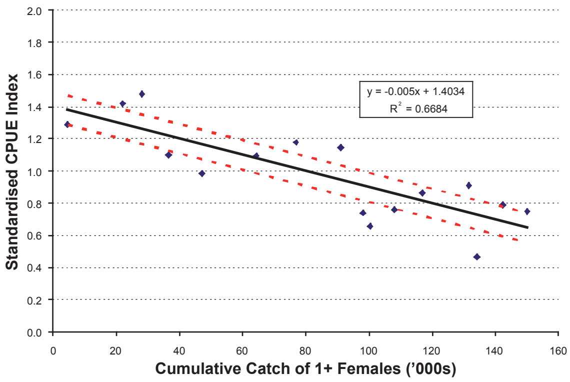


Figure 37: Depletion estimate of harvest rate on 1+ year old female shrimp from Kinsale Harbour in 2006

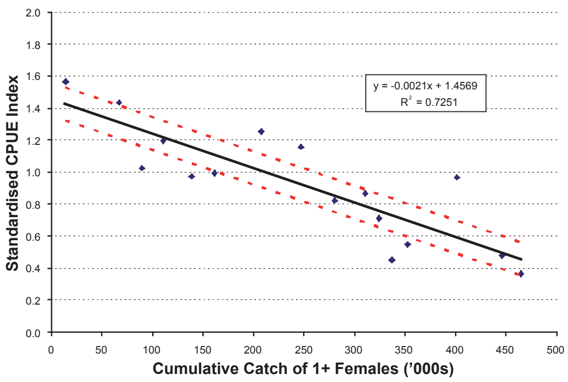


Figure 38: Depletion estimate of harvest rate on 1+ female shrimp from Roaringwater Bay in 2006

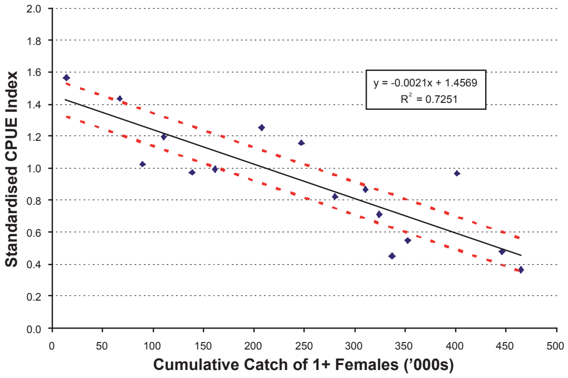


Table 13: Estimates of fishing mortality rates on 1+ female shrimp from depletion assessment for Kenmare Bay 2006

	Stock Estimate ('000s)	Stock Removal ('000s)	% Annual Mortality Rate	Total Mortality Per Year	Total Mortality Per Week
Model Fit	281	150	53	0.76	0.0147
Upper 95% CL	262	150	57	0.85	0.0164
Lower 95% CL	299	150	50	0.70	0.0134

Table 14: Estimates of fishing mortality rates on 1+ female shrimp from depletion assessment for Kinsale Harbour 2006

	Stock Estimate ('000s)	Stock Removal ('000s)	% Annual Mortality Rate	Total Mortality Per Year	Total Mortality Per Week
Model Fit	694	465	61	1.11	0.0213
Upper 95% CL	645	465	72	1.28	0.0245
Lower 95% CL	743	465	63	0.98	0.0189

Table 15: Estimates of fishing mortality rates on 1+ female shrimp from depletion assessment for Roaringwater Bay 2006

	Stock Estimate ('000s)	Stock Removal ('000s)	% Annual Mortality Rate	Total Mortality Per Year	Total Mortality Per Week
Model Fit	1370	903	66	1.08	0.0207
Upper 95% CL	1294	903	70	1.20	0.0230
Lower 95% CL	1445	903	62	0.98	0.0189

7. Estimation of growth parameters

The seasonal von Bertalanffy growth models were fitted to the size data for the areas where a sufficient time series of data was available i.e. Bantry Bay, Castlehaven Bay, Cork Harbour and Roaringwater Bay in Co. Cork. The resulting growth curves for males are shown in Figures 39 to 42 and for females in Figures 43 to 46. The parameters of these growth curves are given in Tables 16 and 17 for males and females respectively. The estimated maximum size (L_∞) for male shrimp ranged from 14.00mm Carapace Length (CL) in Bantry Bay to 14.75mm CL in Castlehaven Bay. For females estimated L_∞ ranged from 17.49mm CL in Castlehaven to 20.85mm CL in Cork Harbour.

Figure 39: Seasonalised von Bertalanffy growth model for males from Bantry Bay

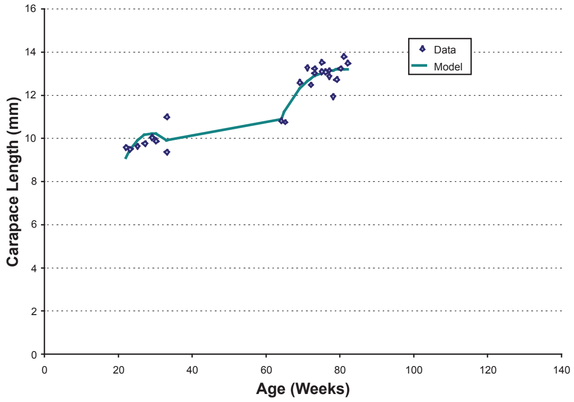


Figure 40: Seasonalised von Bertalanffy growth model for males from Castlehaven Bay

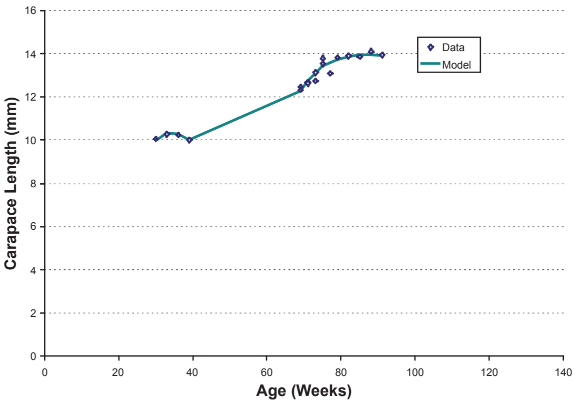


Figure 41: Seasonalised von Bertalanffy growth model for males from Cork Harbour

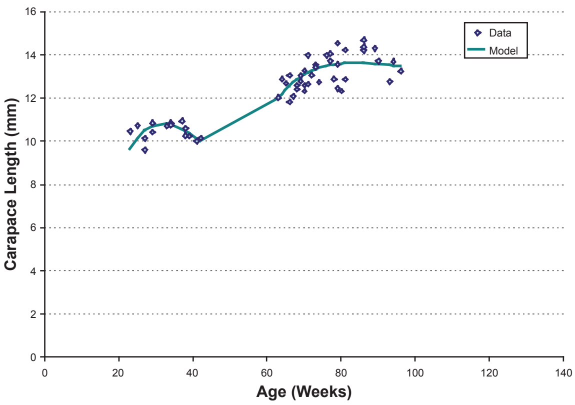


Figure 42: Seasonalised von Bertalanffy growth model for males from Roaringwater Bay

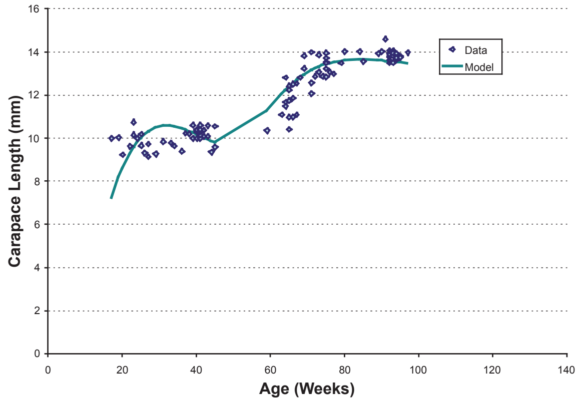


Figure 43: Seasonalised von Bertalanffy growth model for females from Bantry Bay

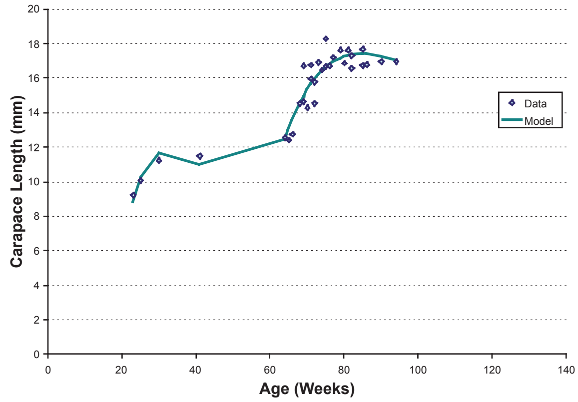


Figure 44: Seasonalised von Bertalanffy growth model for females from Castlehaven Bay

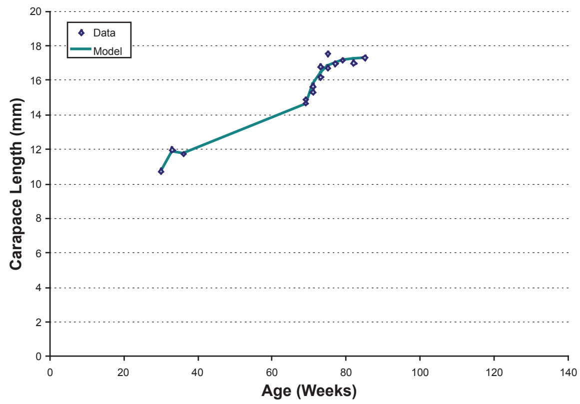


Figure 45: Seasonalised von Bertalanffy growth model for females from Cork Harbour

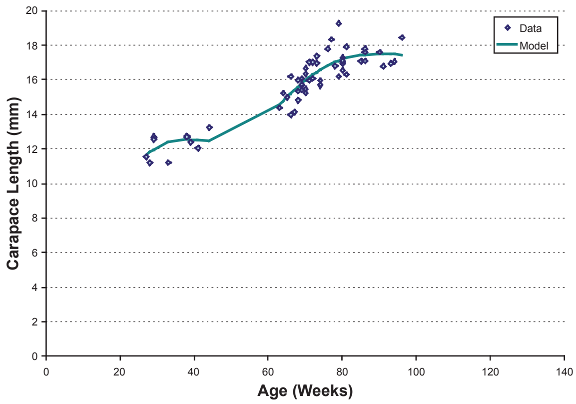


Figure 46: Seasonalised von Bertalanffy growth model for females from Roaringwater Bay

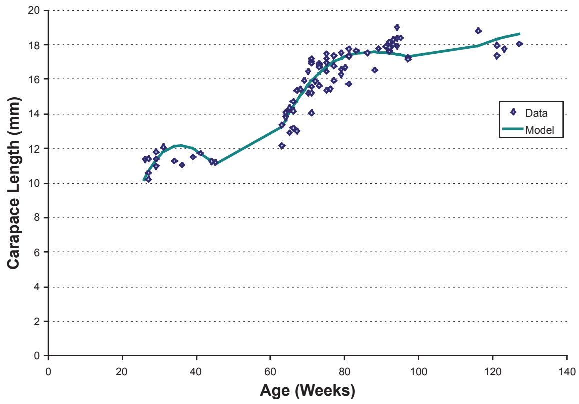


Table 16: Seasonalised von Bertalanffy growth parameters for males

	Bantry Bay	Castlehaven Bay	Cork Harbour	Roaringwater Bay
L_∞ (mm)	14.00	14.75	14.20	14.46
W_∞ (g)	3.19	3.69	3.31	3.49
K	0.030	0.033	0.035	0.030
t0	9.75	13.36	3.64	-0.79
c	0.78	0.59	0.53	0.41
S	13.17	17.38	66.26	65.75
N	26	18	52	107
SD predicted CL	0.46	0.19	0.55	0.66
R^2	0.92	0.98	0.87	0.91

Table 17: Seasonalised von Bertalanffy growth parameters for females

	Bantry Bay	Castlehaven Bay	Cork Harbour	Roaringwater Bay
L_∞ (mm)	18.77	17.49	20.83	19.22
W_∞ (g)	6.75	5.53	9.03	7.20
K	0.030	0.067	0.017	0.028
t0	15.91	38.53	-10.71	11.44
c	0.62	1.55	0.16	0.40
S	16.76	18.17	15.75	17.33
N	31	15	60	83
SD predicted CL	0.46	0.19	0.55	0.66
R^2	0.91	0.98	0.85	0.85

8. Size selective harvesting

Prior to the 2006-2007 fishing season, 40 Catvis© grading devices, each with interchangeable 8mm, 9mm and 10mm grids, were distributed to fishermen. Selectivity parameters for the grading panels were derived as described in the section on assessment methods. Fishing Activity Records (FARs) were also distributed in order to record fishing activity, grading practices and discarding. Twelve FARs were returned from Co. Cork and one from Co. Kerry. In total 305 fishing days, during which the graders were used, were reported (Table 18). The 9mm grader proved most popular with fishermen from this region, and it was used in 189 out of 305 days (62%), while the 8mm and 10mm grids were used for 88 days (29%) and 28 days (9%) respectively. The proportions of the catch retained and returned over the course of the season were calculated for each grader from the data on landings and discards in the FARs (Figure 47). Use of the 8mm grader resulted in an average discard rate of 30.5% of the catch in weight, while the 9mm and 10mm discarded 33.3% and 58.2% of the catch respectively.

In the 2007-2008 season 14 FARs were returned from Co. Cork and 4 from Co. Kerry. In total, 289 grading days were reported (Table 19). In the previous year the 9mm grader was the most popular in this region and was used on 62% of fishing days. In contrast during 2007-2008 the 8mm grader was the most popular and was used on 56% of fishing days, while the 9mm and 10mm grids were used for 36% and 8% of fishing days respectively. The proportions of the catch retained and returned over the course of the season were 22.7%, 43.9% and 39.0% for the 8mm, 9mm and 10mm graders respectively.

Table 18. Summary of shrimp fishing days in the south west during 2006-2007 on which the catch was graded

Bay	8mm	9mm	10mm	Grand Total
Ballycotton Bay (Co. Cork)	4	2	-	6
Cork Harbour (Co. Cork)	3	51	-	54
Courtmacsherry Bay (Co. Cork)	14	1	-	15
Kenmare Bay (Co. Kerry)	4	-	-	4
Kinsale (Co. Cork)	1	94	28	123
Roaringwater Bay (Co. Cork)	47	41	-	88
Youghal Bay (Co. Cork)	15	-	-	15
Grand Total	**88**	**189**	**28**	**305**

Table 19. Summary of shrimp fishing days in the south west during 2007-2008 on which the catch was graded

Bay	8mm	9mm	10mm	Grand Total
Ballycotton (Co. Cork)	-	6	-	6
Baltimore (Co. Cork)	30	-	-	30
Kenmare Bay (Co. Kerry)	4	-	-	4
Kinsale (Co. Cork)	-	-	23	23
Roaringwater Bay (Co. Cork)	123	21	-	144
Fenit (Co. Kerry)	5	44	-	49
Tralee Bay (Co. Kerry)	-	33	-	33
Grand Total	**162**	**104**	**23**	**289**

Figure 47. Proportion of catch discarded by weight using 8mm, 9mm and 10mm graders in the south west during 2006-2007

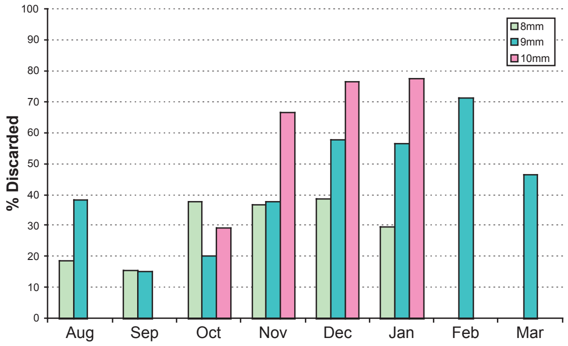
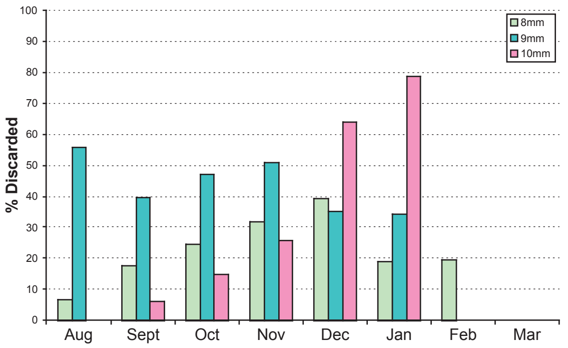


Figure 48 Proportion of catch discarded by weight using 8mm, 9mm and 10mm graders in the south west during 2007-2008



9. Yield per recruit assessment (YPR)

YPR results were sensitive to natural mortality (M) and grading (Figures 49 to 52). Maximum YPR (F_{max}), with no grading, and assuming M of 1% per week was 1.7g at F of 4.1% per week. Grading at 8mm increased this yield by 33% to 2.2g, while grading at 9mm increased YPR by 41% to 2.4g. Grading at 10mm produced a 5% decrease in yield. At the higher levels of M, yield was lower for any given grading pattern, and YPR optima were often not observed over the range of fishing mortalities investigated. Grading of males did not improve the yield under any of the exploitation scenarios investigated because of low growth rate. Male YPR results are not shown in this report.

At $F_{0.1}$ grading at 8mm produced an increase in yield of between 38% (M = 1% per week) and 17% (M = 1.9% per week) (Tables 20 to 23). Grading at 9mm produced improvements in yield of 69% and 33% at M of 1% and 1.9 % per week respectively. No improvements in yield occurred at M >2.8% per week.

Analysis of the depletion in catch rate indicated that shrimp stocks in Cork Harbour in 2005 and Kenmare, Kinsale and Roaringwater Bay in 2006 had mortality rates of 0.007, 0.015, 0.021 and 0.021 per week respectively. All of these estimates are lower than $F_{0.1}$ for females suggesting that higher F would improve yield. However, this conclusion is sensitive to M and does not take into account impacts on spawning potential and recruitment.

Figure 49: Female YPR with weekly M of 1.0%

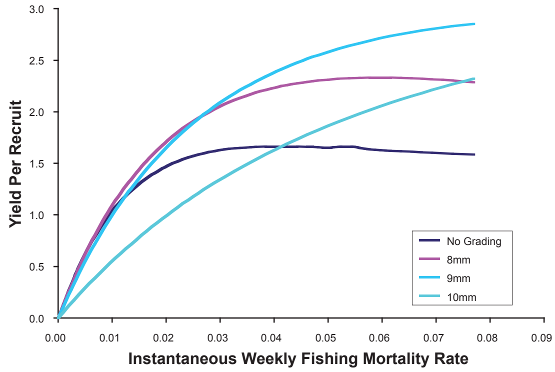


Figure 50: Female YPR with weekly M of 1.9%

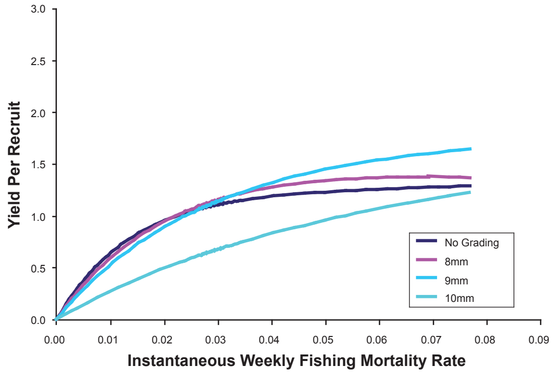


Figure 51: Female YPR with weekly M of 2.8%

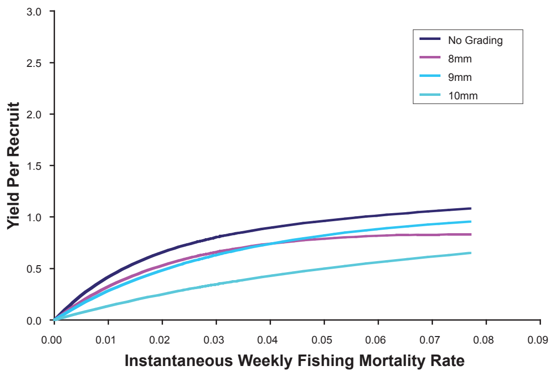


Figure 52: Female YPR with weekly M of 3.8%

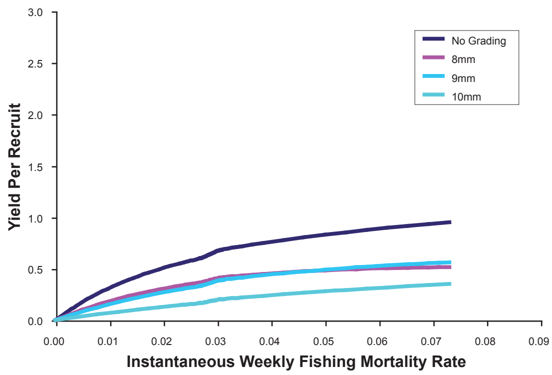


Table 20: Female YPR values at $F_{0.1}$ (M = 1.0% per week)

	$F_{0.1}$ (Per Week)	YPR at $F_{0.1}$	Increase in YPR
No Grading	0.029	1.6g	-
8mm	0.040	2.2g	37.5%
9mm	0.060	2.7g	68.8%
10mm	-	-	-

Table 21: Female YPR values at $F_{0.1}$ (M = 1.9% per week)

	$F_{0.1}$ (Per Week)	YPR at $F_{0.1}$	Increase in YPR
No Grading	0.037	1.2g	-
8mm	0.060	1.4g	16.7%
9mm	0.071	1.6g	33.3%
10mm	-	-	-

Table 22: Female YPR values at $F_{0.1}$ (M = 2.8% per week)

	$F_{0.1}$ (Per Week)	YPR at $F_{0.1}$	Increase in YPR
No Grading	0.060	1.0g	-
8mm	0.052	0.8g	-
9mm	-	-	-
10mm	-	-	-

Table 23: Female YPR values at $F_{0.1}$ (M = 3.8% per week)

	$F_{0.1}$ (Per Week)	YPR at $F_{0.1}$	Increase in YPR
No Grading	-	-	-
8mm	0.056	0.5g	-
9mm	-	-	-
10mm	-	-	-

10. Economic yield per recruit (€PR)

Grading of shrimp increases the average size of shrimp landed and, under certain values of M, also increases the YPR. As price per kg of shrimp also depends on shrimp size (grade) economic yield per recruit should improve over and above improvements seen in yield in weight. In the 2006-2007 fishing season prices recorded in FARs, averaged for the season, were €12.70 per kg for ungraded shrimp and €12.97, €16.48 and €19.68 for 8mm, 9mm and 10mm graders respectively (Figure 53).

Price information was used to rescale the YPR results from grams per recruit to € per recruit (€PR) (Figures 54 to 57). No improvement in €PR occurred by grading male shrimp. The average price reported by fishermen for shrimp graded at 8mm (€12.97) was similar to that for ungraded shrimp (€12.70), and as a result there was little difference in the economically scaled results at 8mm grading. However, the value of the catch after grading at 9mm increased by €3.51 per kg. This resulted in a 114% increase in €PR at $F_{0.1}$, compared to a 69% increase in YPR alone (M 1% per week). At M of 1.9% per week, the economic gains for 9mm grading were 53%, which was again greater than the 33% gained in weight alone (Tables 24 to 27).

Due to the shape of the yield curve for 10mm grading, it was not possible to calculate values of $F_{0.1}$. However, at M of 1.0% and 1.9% per week grading at 10mm can be economically beneficial at higher levels of F (Figures 54 and 55). At M of 2.8% per week, only the 9mm grader resulted in higher €PR (~10%) and then only at high values of F (Figure 56). No improvement in €PR occurred at M of 3.8% per week (Figure 57).

Figure 53: Price paid to fishermen for shrimp destined for the processing market (Co. Cork 2006-2007)

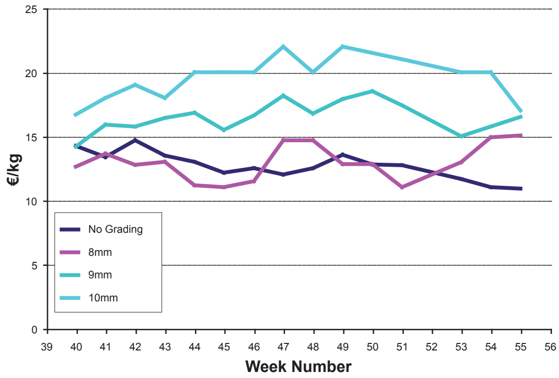


Figure 54: Female economic YPR results with weekly M of 1.0%

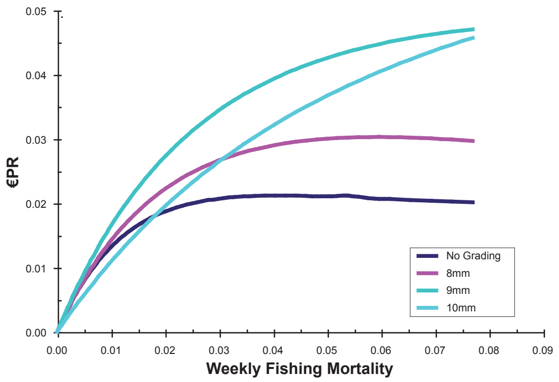


Figure 55: Female economic YPR results with weekly M of 1.9%

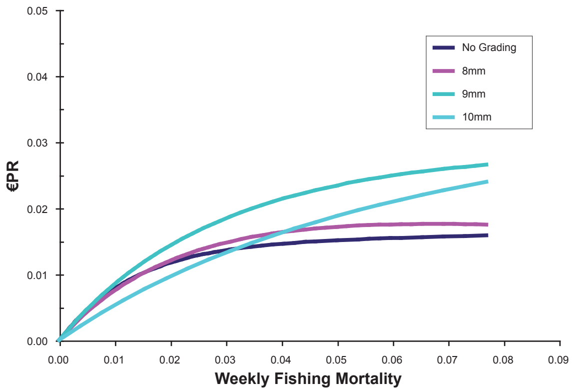


Figure 56: Female economic YPR results with weekly M of 2.8%

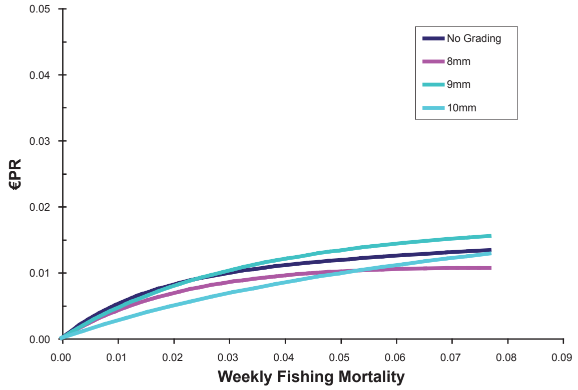


Figure 57: Female economic YPR results with weekly M of 3.8%

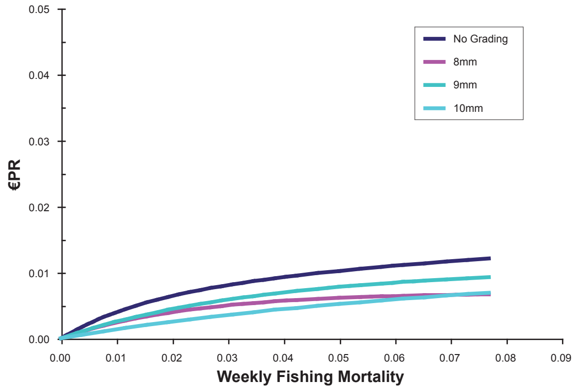


Table 24: Female economic YPR at $F_{0.1}$ (M = 1.0% per week)

	$F_{0.1}$ Per Week	€PR at $F_{0.1}$	Increase in €PR
No Grading	0.029	0.021	-
8mm	0.040	0.029	37.2%
9mm	0.060	0.045	116.2%
10mm	-	-	-

Table 25: Female economic YPR at $F_{0.1}$ (M = 1.9% per week)

	$F_{0.1}$ Per Week	€PR at $F_{0.1}$	Increase in €PR
No Grading	0.037	0.014	-
8mm	0.060	0.017	11.3%
9mm	0.071	0.026	42.1%
10mm	-	-	-

Table 26: Female economic YPR at $F_{0.1}$ (M = 2.8% per week)

	$F_{0.1}$ Per Week	€PR at $F_{0.1}$	Increase in €PR
No Grading	0.060	0.013	-
8mm	0.052	0.010	-
9mm	-	-	-
10mm	-	-	-

Table 27: Female economic YPR at $F_{0.1}$ (M = 3.8% per week)

	$F_{0.1}$ Per Week	€PR at $F_{0.1}$	Increase in €PR
No Grading	-	-	-
8mm	0.056	0.006	-
9mm	-	-	-
10mm	-	-	-

11. Egg per recruit assessment (EPR)

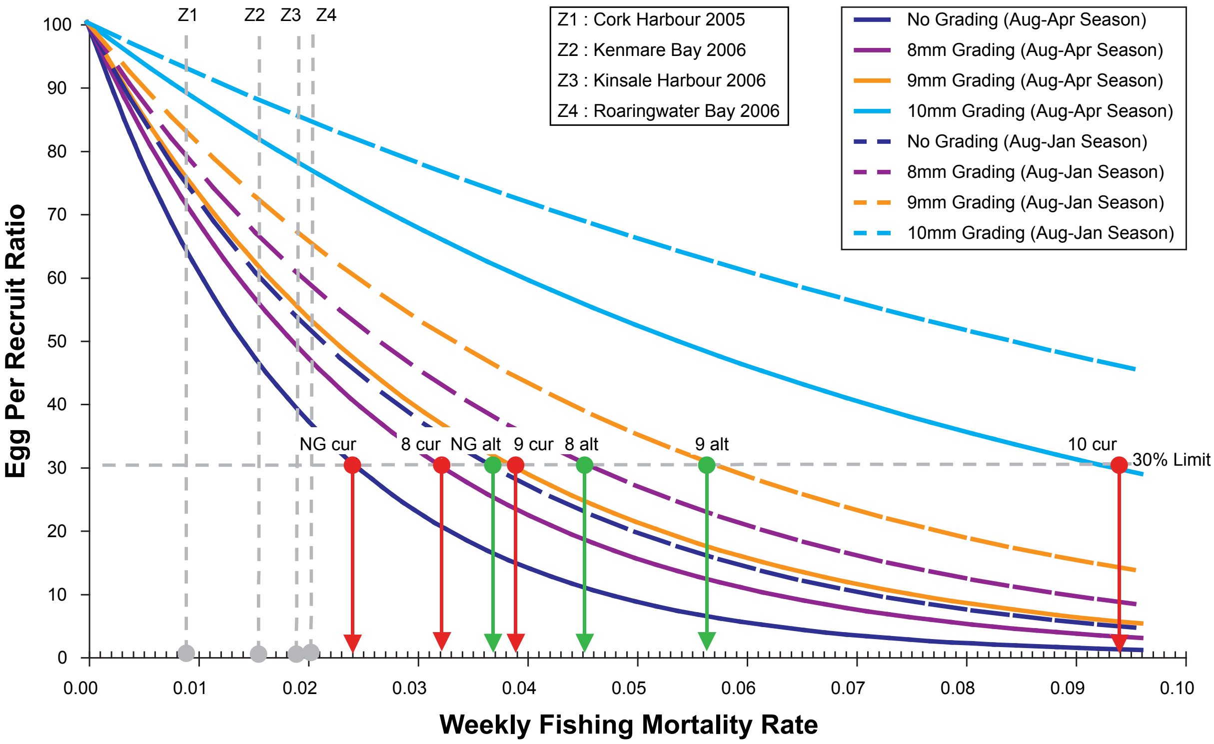
Where the stock recruitment relationship is unknown, it is generally recommended that the reproductive potential of the stock should not be reduced to less than 30% of its unexploited capacity (Mace and Sissenwine, 1993). In the present work, this limit reference point ($F_{EPR30\%}$) was reached at F of 0.024 per week when no grading was carried out (Figure 58). Grading at 8mm increased the ERP ratio to 40% for the same F, while grading at 9mm and 10mm increased the EPR ratio to 48% and 72% of the ungraded level respectively.

As grading releases the smaller berried females it may also allow greater F to be applied to the shrimp above the size of selection while remaining above $F_{EPR30\%}$. By following the 30% reference line in Figure 58 grading at 8mm would allow F to be increased from 0.024 to 0.032 per week. Likewise grading at 9mm and 10mm would allow an increase of fishing mortality to 0.039 and 0.094 per week respectively.

Analysis of depletion in catch rate of shrimp stocks in Cork Harbour in 2005 and Kenmare, Kinsale and Roaringwater Bay in 2006 indicated weekly total mortality rates (Z) of 0.007, 0.015, 0.020 and 0.021 respectively. The positions of these estimates of Z are all to the left of $F_{EPR30\%}$ with no grading and therefore the estimated mortality levels suggests that recruitment overfishing is not occurring.

Weekly fishing mortality at $F_{EPR30\%}$ could increase from 0.024 to 0.037 if the fishing season was reduced from the current August 1st - May 1st to August 1st - February 1st (Figures 58 and 59). $F_{EPR30\%}$ could increase further to 0.046 and 0.058 if shrimp were graded at 8mm or 9mm respectively and the shorter season was retained.

Figure 58: Relative Egg Per Recruit ratio (EPR at $F_{current}/F_0$) For current (cur) fishing season 1st August to 1st May and for alternative (alt) fishing season 1st August to 1st February. N.G. = no grading

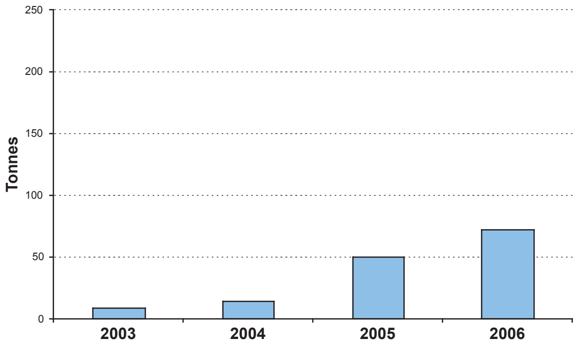


The Western Fishery

1. Landings

In 2006 the western region (Galway, Mayo and Clare) accounted for 40% of the vessels, 35% of the effort and 23% of the national landings of shrimp (Table 1 and Figure 2). There was an 8 fold increase in the landings from this region between 2003 and 2006 from 9.0 tonnes to 72.6 tonnes (Figure 59).

Figure 59: Shrimp landings from the West of Ireland 2003-2006



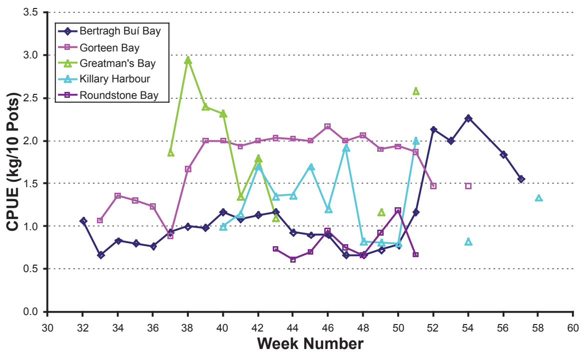
2. Analysis of CPUE data

Data were available on catch and effort for the 2007-2008 fishing season with 5 FARs received from 5 different bays in Co. Galway (Table 28). This represented a total of 135 fishing days and 22,175 pot hauls and a total catch of 3,514kg. On average the first pots were hauled during week 37 (early September) and the last were hauled on week 54 (mid January). The number of days fished per vessel ranged from 13 to 43 with an average of 27 days. Gear soak times per vessel ranged from an average of 5.0 to 10.9 days. As there was only one FAR from each bay it was not possible to standardise for vessel effects and the catch rate data are presented here as nominal values (Figure 60). CPUE ranged from 0.6kg to 3.0kg per pot haul. CPUE fluctuated during the fishing season. In Bertragh Buí Bay CPUE increased from 0.7 on week 50 to 2.5 on week 54. In Greatman's Bay CPUE declined linearly from a peak of 2.9 on week 38 to 1.1 on week 43.

Table 28: Summary statistics for fishing activity records in the western region in 2007-2008

Bay	Skipper	Start Week	End Week	Days Fished	Pots Lifted	Total Catch (kg)	Ave. Soak Time (Days)
Bertragh Buí Bay	1	32	57	34	5020	547	5.0
Gorteen Bay	2	33	54	43	6450	1115	6.8
Greatman's Bay	3	37	51	13	4790	1199	8.3
Killary	4	40	58	26	3880	501	5.0
Roundstone Bay	5	43	51	19	2035	153	10.9

Figure 60: CPUE data from Co. Galway 2007-2008



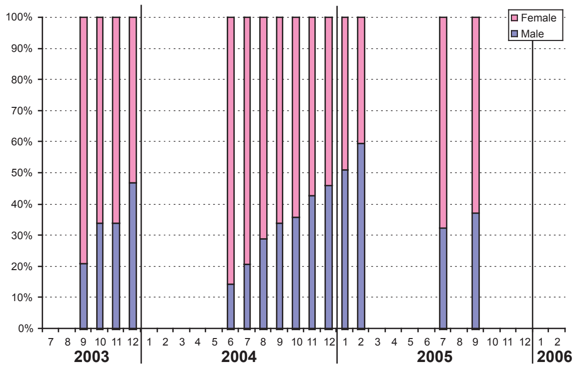
3. Age structure of the stock

From 2003-2006, 49 samples of approximately 1kg each were taken from 6 bays in Co. Galway (Table 4). No 0+ shrimp occurred in these samples. The samples generally consisted of a single year-class, except in the cases where the 2+ year class was still present early in the season. As the population of shrimp in Co. Galway persisted over the 3 years that were sampled, it is clear that recruitment of 0+ shrimp did occur, but presumably outside of the area from where the samples were taken.

4. Sex structure of the stock

The proportion of males in the samples increased during the fishing season (Figure 61). This pattern was especially clear in the 2004-2005 season when the proportion of males increased from 17% in June to 60% in February.

Figure 61: Sex structure of the shrimp stock from the western region



5. Estimation of growth parameters

Growth parameters were estimated for all bays combined. The absence of the 0+ year-class restricted the data range to 1+ and 2+ age-classes (Figure 62-63). The maximum size (L_∞) for males was estimated to be 14.1mm carapace length, which corresponds to a weight of 3.27g (Table 29). Females were estimated to reach a maximum size of 18.1mm carapace length or a weight of 6.05g (Table 30).

Figure 62: Seasonalised von Bertalanffy growth model for male shrimp in the Galway fishery

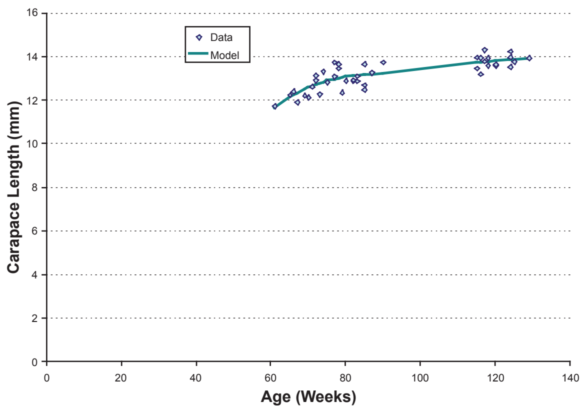


Table 29: Seasonal von Bertalanffy growth parameters for male shrimp in the Galway fishery

Parameters	Values
L_∞ (mm)	14.12
W_∞ (g)	3.27
K	0.033
t0	5.66
c	0.18
S	116.34
N	42
SD predicted CL	0.36
R^2	0.52

Figure 63: Seasonalised von Bertalanffy growth model for female shrimp in the Galway fishery

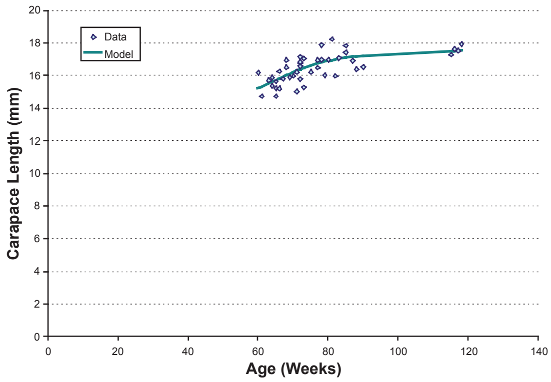


Table 30: Seasonalised von Bertalanffy growth parameters for female shrimp in the Galway fishery

Parameter	Values
L_∞ (mm)	18.05
W_∞ (g)	6.05
K	0.030
t0	-8.56
c	0.18
S	19.94
N	43
SD predicted CL	0.61
R^2	0.70

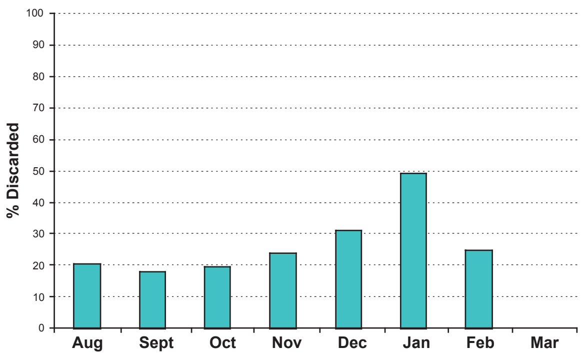
6. Size selective harvesting

During the 2007-2008 fishing season 8 FARs containing information on grading (9mm grader only) were available from the western region (Table 31). The average discard rate in this region was 26.8% (Figure 64) which is 17% lower than that from the south west. This suggests that shrimp targeted by the fishery in the west are larger than in the south west. As the growth rates between these regions are similar, this difference in size is most likely due to the absence of the 0+ cohort from the catch in the western region. However, the increase in the rate of discarding from November to January (Figure 64) suggests that recruitment of smaller shrimp to the fishery is occurring during this time or that size selective mortality, due to size selective harvesting, during this period when growth is very slow, has an effect on the size structure of the population.

Table 31. Fishing days recorded where shrimp were graded (9mm) in the western region during 2006-2007

Bay	9mm
Bertragh Buí Bay (Co. Galway)	26
Clew Bay (Co. Mayo)	27
Doohoma Bay (Co. Mayo)	9
Gorteen Bay (Co. Galway)	43
Greatman's Bay (Co. Galway)	13
Killary (Co. Galway)	19
Roundstone Bay (Co. Galway)	12
Grand Total	**149**

Figure 64: Proportion of catch discarded by weight using the 9mm grader in the western region during 2007-2008

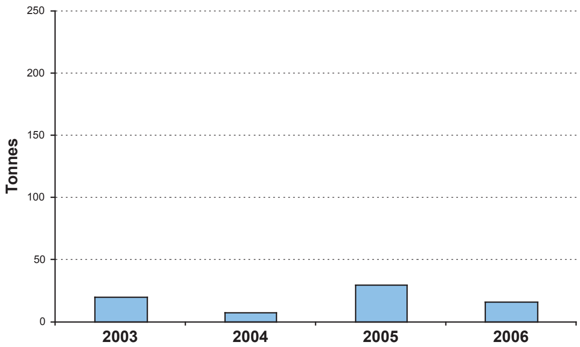


The North West Fishery

1. Landings

In 2006, 16.2 tonnes of shrimp were landed into the north west region which represented 5% of the national landings (Figure 65). This was a decrease on the 29.8 tonnes in 2005, representing 18% of the national landings, but higher than the 7 tonnes recorded in 2004.

Figure 65: Shrimp landings from the north west of Ireland 2003-2006



2. Analysis of CPUE data

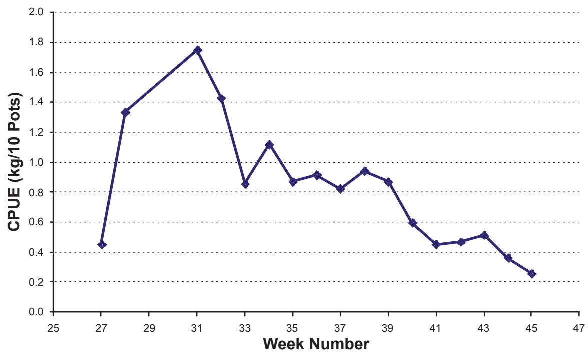
Six FARs representing a total of 274 daily summaries of fishing activity and 49,587 pot hauls were available for the 2007-2008 fishing season (Table 32). On average the fishery began in week number 31 (start of August) and finished on week number 43 (end of October). The total catch recorded by the 6 vessels was 4,826kg. The average soak time ranged from 1.5 to 2.5 days. The catch was not graded.

The CPUE from Dungloe Bay shows a clear decline from week number 31 to week number 45 (Figure 66). This time series has not been standardised and the age structure of the stock in this area is unknown so no depletion analysis was undertaken.

Table 32: Summary statistics from fishing activity records for the north west region in 2007-2008

Bay	Skipper	Start Week	End Week	Days Fished	Pots Lifted	Total Catch (kg)	Ave. Soak Time (Days)
Dungloe Bay	1	28	40	45	5310	539	1.5
Dungloe Bay	2	31	40	55	16370	2023	1.8
Dungloe Bay	3	31	45	48	7675	545	2.2
Dungloe Bay	4	31	45	58	12460	1069	2.5
Dungloe Bay	5	27	40	44	7325	569	1.9
Lough Foyle	6	39	47	24	447	81	2.4

Figure 66: CPUE data from Dungloe Bay, Co. Donegal in 2007-2008



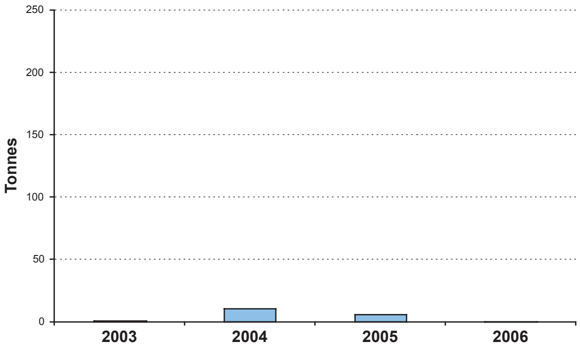
The South East Fishery

1. Landings

The annual landings of shrimp into the south east region are lower than other regions with only 500kg recorded in 2006 representing <0.2% of the national catch. The recorded landings in this region increased from 0.9 tonnes in 2003 to 10.0 tonnes in 2004 but decreased again to 5.8 tonnes in 2005 and 0.5 tonnes in 2006 (Figure 67). However, these figures may be an underestimate as the BIM fleet survey in 2006 showed that 10% of the national fishing effort and 12% of the fishing vessels are located in Waterford, Wexford and Dublin.

No catch and effort data were available for this region and the age structure, sex structure and growth rates of the stock have not been determined.

Figure 67: Shrimp landings from the south east of Ireland 2003-2006



A Regional Comparison of Shrimp Fisheries

1. Landings and effort

Between the years 2003-2006, 72% of shrimp landings in Ireland were in the south west region compared to 17%, 9% and 2% in the west, north west and south east respectively. Landings are not stable from year to year and the annual pattern of variation in landings is not consistent across regions. Large catches were recorded in the south west in 2004 and 2006 while the catches in 2003 and 2005 were poor. However, landings in the north west were higher in 2003 and 2005 than in 2004 and 2006. The landings from the western region increased year on year from 9 tonnes in 2003 to 73 tonnes in 2006. Landings from the south east were less than 1 tonne in both 2003 and 2006 with a peak of 10 tonnes in 2004. The reason for this inter annual variation by region is not known. Some of the variation is due to variability in catch rate rather than effort suggesting that strong inter annual variability in recruitment occurs. Inter annual variation in nominal catch rate in Roaringwater Bay varied 3 fold between 1998 and 2005. Variation in landings may also be driven by effort however. The fleet responds to low catch rates by switching to other fisheries or by not fishing. Total effort in any given year, however, is unknown.

Trends in landings and effort suggests that Irish shrimp stocks are exposed to a number of risks which may have increased in recent years. These are:

1. The lack of information on the stock structure: Getting the stock boundaries wrong in relation to controlling fishing mortality may expose local stocks to overexploitation
2. The lack of control on either catch or effort increases the risk of overexploiting spawning stock
3. Increased fishing on over-wintering mature female shrimp in deeper waters in recent years poses further risk to spawning biomass
4. Unfavourable environmental conditions are a significant risk to recruitment. Management of the stock needs to be sufficiently adaptive in real time to adjust fishing mortality during periods of weak recruitment to allow for recovery of recruitment when conditions improve.

2. Catch rates

There is significant variation in the standardised CPUE indices between vessels in the south west. This is probably due to spatial variability in habitat and in the local abundance of shrimp. The offshore migration of the stock later in the season can result in high catch rates in vessels which follow this migration. Catch rates are generally low at the beginning of the season, peak during November and then decline. However, there is often a short lived increase in January followed by a further decline.

Growth, recruitment and migration can mask the effect of fishing mortality on an individual cohort and the modification of the catch rate data to focus on 1+ female shrimp, which is the dominant component of the catch, is important in detecting a depletion signal due to fishing mortality. The method requires that the sex, age structure and size at age of shrimp is known.

3. Age structure

The age structure of the shrimp stock was reported only for the south west and western region. In the south west the catch was generally composed of the 1+ age class when the fishery opened, although the 2+ cohort was present early in the season in approximately 5% of observations. The recruitment of the new year class usually occurred in October and the catch was bimodal (0+ and 1+) for the remainder of the season. Exceptions to this pattern were found in Bantry Bay in 2004 and in all the samples from Co. Galway where the 0+ year class did not occur in the samples and the catch was composed of a single year-class throughout the fishing season. This presumably is due to spatial segregation of the 0+ and 1+ cohorts. However, a relatively small proportion of the fleet was sampled and it is unlikely that the fishery in Galway completely avoids catching 0+ shrimp.

4. Growth rates

The shape of the growth curves was sensitive to the temporal range of data points available, and also on the period of time, during the closed season, for which no samples were available. Because of this and as the time periods for which data are available varied between regions it is not valid to compare the entire growth curves. Analysis of variance of size at age, excluding Galway, for weeks 69 to 91 for males (Figure 68) and weeks 69 to 85 weeks for females (Figure 68) suggests no significant variation across regions (F-statistic; male 1.07, p=0.39; female 1.17, p=0.31).

Figure 68: Comparison of male growth curves across areas (age 69 to 91 weeks only)

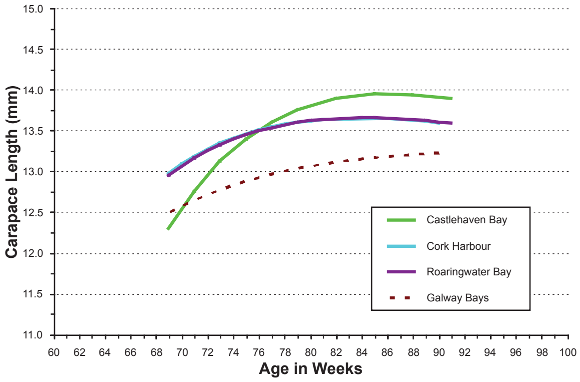
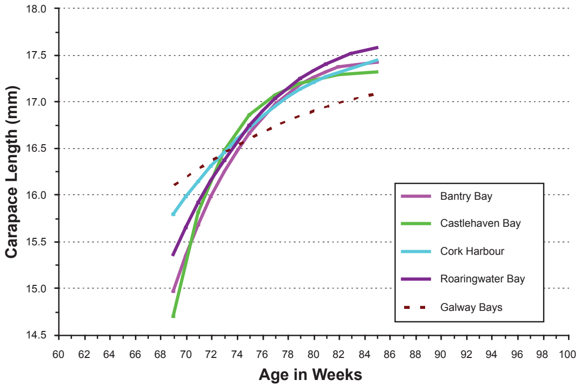


Figure 69: Comparison of female growth curves across areas (age 69 to 85 weeks only)



Research and Monitoring Priorities

The amount of information available on the biology and fishery of shrimp stocks in Ireland has increased in recent years. Methods for assessment of the resource are not well developed although the approaches taken in this report show some potential. The assessments reported here could be improved by acquiring more information on population structure and with more complete catch and effort and age structure data. Annual variability in landings and catch rate suggest that recruitment to shrimp stocks is variable on a regional (as reported here) if not local (bay) scale and that stock and recruitment may be linked locally. Limiting exploitation rates on a bay scale may therefore be important in stabilising the productivity of stocks.

Population structure can be estimated by simulating larval dispersal from coastal spawning areas using particle tracking models and by tagging adult shrimp prior to the autumn offshore migration.

Size at age data were generally not available for ages from 40 to 60 weeks. As the growth model is used in the per recruit analyses it is important that it accurately represents the actual growth for the entire life span. Therefore, future work on the growth rate of *P. serratus* in Ireland should focus on providing data on size for this missing period. A second problem is the apparent negative growth observed during the first year. As negative growth is not credible, and may be due to biased sampling, future investigation should consider how this could be avoided.

The size at age and growth rate estimates may be biased due to size selectivity of the fishing gear. Size based selection by the fishery has two effects; firstly, for age classes that are not fully selected by the gear, the catch samples are biased towards the large individuals and secondly faster growing individuals within the population are likely to experience higher fishing mortality. Size at age data from samples taken during the fishing season may not, therefore, be representative of the underlying average growth trajectory in the population. Dealing with either of these sources of bias offers considerable problems for sampling and analysis and were beyond the scope of the present investigation.

The effects of the environment (temperature and salinity) on recruitment of larval and post larval shrimp should be evaluated. Kelly (2008) modelled the survival of shrimp larvae and post larvae over a range of temperatures and salinities in a series of controlled laboratory experiments. The effects of annual variability in environmental temperature and salinity, from either modelled or empirical data, on recruitment can therefore be assessed and compared to catch rate performance in the fishery with suitable time lags.

Estimation of absolute stock sizes in each bay by depletion analysis requires a complete census of data on landings of shrimp. To improve the standardisation of the catch and effort data, age length sampling should be continued and expanded. Other variables, such as gear configuration and bait type that may affect catchability of shrimp should be included in the logbook. In addition economic data on operating costs and earnings which are determined by effort, catch rate and unit prices would provide valuable information on how the fleet should respond to recruitment variability. As the cost earnings ratio is likely to be the bottom line for management these data would enable better management planning for the fishery.

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