Distribution, seasonal occurrence, recruitment and growth of juvenile commercial flatfish species on the west coast of Ireland

By

Brendan M. Allen

M.Sc in Fisheries Ecology/ Biology
Galway-Mayo Institute of Technology

Supervisors of Research
Dr. David McGrath
Dr. Pauline A. King

Submitted to the Higher Education and Training Awards Council
July 2004

Distribution, seasonal occurrence, recruitment and growth of juvenile commercial flatfish species on the west coast of Ireland

Brendan M. Allen

Abstract

The population dynamics of juvenile flatfish were investigated on the west coast of Ireland. Firstly, beach seining was carried out to assess spatial and temporal variations in flatfish assemblages, on sandy beach nursery grounds, in two regions, on the west coast of Ireland, Galway Bay (2002 to 2003) and Dingle Co. Kerry (2000 to 2003). In both locations 0+ plaice generally were numerically dominant in the catches. This is consistent with flatfish assemblages in European waters. There was a significant difference between beaches in the species composition and plaice densities in Galway Bay, while no annual differences could be discerned. Secondly, a push-net survey was carried out in Galway Bay from 2002 to 2003, to determine the settlement, seasonal occurrence, growth and mortality of 0+ plaice. Settlement occurred in late April in 2002, and in late March of 2003. Higher peak densities were recorded in 2003. Growth rates were similar to a predicted growth model obtained at optimal feeding conditions. Daily mortality rates were within that recorded elsewhere in European waters. Experimental push-netting showed that depth does not influence the catches of 0+ plaice in shallow water. Sampling at night produced significantly higher densities of 0+ plaice. Thirdly, otolith microstructure was used to determine hatching dates, larval period, settlement dates and growth of 0+ plaice in Galway Bay in 2003. Hatching time ranged from late January to late March. The larval period for fish ranged from 28 to 43 d, the lowest recorded in Europe. This was consistent with sea temperature, where higher temperatures have lower larval periods. Settlement period was longer than that determined by sampling, ranging from early to mid March to late April. Three cohorts of settlement were noted, which corresponded to pulses in hatching. Observed growth was similar to predicted growth and a strong inverse relationship was noted between growth and density.

Table of contents

Chapter 1

1.1 General introduction

Flatfish are an important component in the demersal fishery on the west coast of Ireland (ICES area VIIb). Important quota species include sole (*Solea solea* Linnaeus) and plaice (*Pleuronectes platessa* Linnaeus). In 2002, on the Irish west coast plaice and sole were worth €0.1m and €0.6m respectively (Anon 2003). Important non-quota species are turbot (*Psetta maxima* Linnaeus) and brill (*Scopthalmus rhombus* Linnaeus). In 2002 turbot were worth €2.0m to the Irish fishery, while brill were worth €0.7m. Non-commercial species encountered on the Irish west coast are flounder (*Platichthys flesus* Linnaeus.), dab (*Limanda limanda* Linnaeus) and sandsole (*Pegusa lascaris* Risso). Of these, flounder are important in angling tourism and are listed as one of the top beach angling species on the west coast of Ireland (URL 1).

Research on flatfish stocks on the Irish west coast is limited. Existing research is mostly aimed at the population dynamics in the adult phase of the life cycle. Knowledge of earlier stages of the life history brings a new approach to determining population dynamics of flatfish stocks on the west coast of Ireland. Flatfish use shallow intertidal areas such as sandy beaches as nursery grounds (Riley *et al.* 1981, Gibson 1994, 1997). This provides an opportunity to assess the flatfish stocks at the juvenile stage and relate this to the adult stocks to help to predict future trends in the fisheries.

This thesis is formatted as a series of self-contained chapters each dealing with a different aspect of juvenile flatfish ecology and biology. The main objectives for each chapter are as follows:

In Chapter 2, the abundance and species composition of commercially important flatfish species on sandy beach nursery grounds around the Dingle Peninsula (Co. Kerry) and around the greater Galway Bay area on the west coast of Ireland were assessed. Surveys were carried out to develop a method of quantifying local flatfish stocks, and to determine year-class strength for the management and protection of the commercial stocks. Beach seining was chosen as the preferred method of sampling.

In Chapter 3, the assessment of juvenile flatfish nursery grounds was carried out monthly using a push-net sampling programme. The main aims of this push-net survey were to assess the importance of sandy beaches as nursery grounds for 0+ plaice, determine the critical settlement periods, quantify the abundance and to assess the growth and mortality of 0+ plaice on these nursery grounds.

In Chapter 4, otolith microstructure was used to define hatching dates, larval period, exact settlement timing and growth of 0+ plaice in Galway Bay. Also, the existence of cohorts in settlement as seen in others areas, were investigated. This was carried out on two beaches in Galway City with the intention of assessing spatial differences in the measured parameters.

The results of these studies are discussed separately and then a general discussion combines the three studies, which contribute to an overall analysis, which fills a significant gap on the early life history of flatfish on the west coast of Ireland.

Chapter 2: Assessment of spatial and temporal variation in flatfish populations on nursery grounds on the west coast of Ireland using beach seining: with particular emphasis on plaice (*Pleuronectes platessa* L.).

2.1 Abstract

A beach seining survey was carried out on the west coast of Ireland to assess spatial and temporal variations in flatfish populations, with particular emphasis on plaice, on sandy beach nursery grounds. This was carried out on two locations. In Dingle Co. Kerry, surveying commenced in 2000, while in Galway Bay surveys started in 2002. Sampling was mostly carried out in September.

The results from both locations show that 0+ plaice generally dominated the catches. Other species include turbot, brill, flounder, dab, sandsole and common sole. This was similar to species compositions recorded in other studies in European waters. Cluster analysis of the flatfish community data failed to show any consistent differences between beaches or between years in both locations. MANOVA's contradicted the cluster analysis in Galway Bay, showing a significant difference in the flatfish composition between beaches but agreed with the cluster analysis in that no between year difference were noted. In Dingle, the MANOVA found that there was significant interaction between beach and year. Mean plaice densities ranged from 0.3 ± 0.4 ($1000m^{-2}$) on Fanore in May 2003 to 27.8 ± 13.8 ($1000m^{-2}$) on Gurteen in September 2003 in Galway Bay and from 4.3 ($1000m^{-2}$) on Inch in September 2000 to 64 ± 25.4 $1000m^{-2}$ on Inch in September 2001 in Dingle. Densities differed between beaches but not between years in Galway Bay, and in Dingle a significant interaction was noted between beaches and years. Other studies have recorded both spatial and yearly variation. However, most of the literature merely observed differences in densities and did not statistical analyze these differences. A statistical interaction was noted between beach and year for the mean length of plaice in both locations, therefore no general conclusions could be drawn. No correlation was detected between the mean length and density of plaice in the September samples for all years in both locations, this was not consistent with patterns noted in other studies. For flatfish communities excluding plaice there was a significant difference between beaches but not between years which is consistent with analysis where plaice were included in Galway, while for the same analysis in Dingle an interaction was noted.

2.2 Introduction

Beach seining is a common method for assessing the abundance and species composition of littoral zone fish communities, and has been used widely in freshwater, marine, and estuarine habitats (Pierce *et al.* 1990, Methven *et al.* 2001, Kubecka and Bohm 1991, Nash and Santos 1998, Abookire *et al.* 2000, Ross & Lancaster 2002 and Morrison *et al.* 2002).

Beach seining is most frequently used to assess fish assemblages. It can be used to target flatfish species. However beam trawling and push-netting are more popular methods for sampling flatfish (Ruth and Berghahn 1989). Beach seining was used to observe the population abundance of young flatfish in Sherkin Island Co. Cork Ireland (Markham 1981). Four flatfish species were caught on these surveys. Mansoor (1982) assessed flatfish nursery grounds on the east coast of Ireland using a combination of beach seining and push-netting and found that plaice was the most abundant flatfish of seven species caught. Nash *et al.* (1994b) assessed the variation in beach seine catches of juvenile flatfish between day and night in Port Erin, Isle of Man and Porto Pim Bay, Faial, Azores. In Port Erin, plaice was the most abundant flatfish with dab, flounder, turbot and brill also recorded in the catches. Gibson *et al.* (1993) used beach seining and beam trawling to assess the seasonal and annual variation in the abundance and species composition of fish. In this latter study, flatfish were caught using the two methods, with plaice the most common flatfish, while dab, flounder, brill, turbot and sole were of low occurrence in the beach seine samples. Abookire *et al.* (2000) used beam trawling and beach seining to assess a near shore fish distribution and found flatfish to be the most common fish caught with the beam trawl, while very few flatfish were caught with the beach seine. Differences between beach seining and outrigger trawling as methods to assess fish communities were observed by Morrison *et al.* (2002). It was found that low tide beach seine samples provided the most cost-effective means of quantifying species diversity and population size structures. Ruth and Berghahn (1989) described beach seining as an active method of sampling demersal and pelagic fish. They stated that beach seines should be preferred in analysing populations in small gullies and creeks with water depth down to two meters. A drawback of this method is that only a limited number of hauls can be carried out in a single tidal period. Several hauls however can be made by push-netting or beam trawls in short time intervals (Ruth and Berghahn 1989). Also, Wilding *et al.* (2000) stated that beach seines are less efficient at sampling benthic species than beam trawls but are preferable where only a localised area is free of obstruction and where a beam trawl could not easily operate.

Beach seining can be used to collect additional samples when catch efficiencies of other gears decrease (Sogard *et al.* 2001). Sogard *et al.* (2001) used a beach seine with an extra tickler chain added to catch extra *P. americanus* individuals and found the gear to adequately sample the flatfish. It was also possible to calculate densities from standardised hauls. Cabral *et al* (2002) and Prisco *et al.* (2001) used beach seining to specifically target flatfish to assess their feeding behaviour. However, catches were not quantified in these latter studies.

Catches of fish using seining methods are generally greater at night than during the day (Nash and Santos 1998, Abookire *et al.* 2000, Pierce 2001 and Morrison *et al* 2002). Nash *et al.* (1994b) found no difference in the numbers of plaice caught in the day and night samples at the start of the summer but did find a difference in September day and night samples with higher catches at night. Nash *et al.* (1994b) also found that other species (dab, flounder, turbot and brill) had a higher occurrence at night in September samples. Layman (2000) found no difference between numbers of fish caught in day and night samples on the Virginia coast in the U.S.A., however, a significant difference was observed in species richness. In the latter study, summer flounder (*Paralichthys dentatus* Linnaeus) were one of the most common species caught at night and were absent in daytime sampling. Morrison *et al.* (2002) sampled at low and high tides during daylight and night hours in a New Zealand estuary. The highest abundance of flatfish was caught at low tide and two out of three flatfish species yielded higher numbers at night.

Beach seining has varied efficiencies depending on the species, fish abundance, fish size and bottom type (Wilding *et al.* 2000, Pierce 2001). Pierce *et al.* (1990) found that beach seining had a higher efficiency for mid-water (75%) than for the benthic fish (50%) in freshwater habitats. Nash *et al.* (1994b) observed that flatfish escape under the footrope of the beach seine due to wave action lifting the net. Nash (1998) stated the major problem with beach seining is the lack of detailed information on its overall efficiency, and the lack of efficiency data at species level for marine fish.

Sandy beaches are important grounds for juvenile flatfish species (Riley *et al.* 1981, Gibson 1994, 1997). The majority of flatfish species spawn eggs that are planktonic and the distribution patterns of eggs after spawning are completely dependent on hydrodynamic forces (Gibson 1997). Developing eggs and larvae are transported by the residual currents (Bergman *et al.* 1988). Larvae have limited powers of locomotion that increase as they grow (Gibson 1997). Cushing (1974) in Bergman *et al.* (1988) stated that at the end of the larval period, most of the larvae move towards the coastal zone, probably by a combination of behaviour and a coastwards direction bottom current. After the larval period, the flatfish metamorphose and adopt the benthic way of life (Steele and Edwards 1970). Following metamorphosis, many flatfish species spend at least the first six months of their life in coastal nursery grounds (Gibson 1997). Gibson (1997) also stated that in autumn the juveniles of several coastal species move into deeper water and may not return the following spring. The proportions of flatfish settled into the demersal phase that survive to attain sexual maturity are known as recruited fish (Gibson 1994). Alternatively, Wegner *et al.* (2003) defined recruitment of flatfish as the entry of newcomers into a defined compartment of the adult or fished stocks.

Different flatfish species utilise sandy beaches at different times of the year. Juvenile plaice commonly occur on sandy beaches in spring to early winter (Kuipers 1977, Steele and Edwards 1970, Berghahn 1988, Zijlstra *et al.* 1982, Van der Veer 1986, Amara and Paul 2003). Flounder arrive onto the beach later in the year (May to June) and are present until early winter (Modin and Pihl 1996). Juvenile sole were found on sandy beach nursery grounds from April onwards in an estuary in the Bay of Biscay (Amara *et al.* 2000), while in the North Sea, sole were recorded from May onwards (Van der Veer *et al.* 2001).

Knowledge of the recruitment levels in flatfish populations is a key component in the management and prediction of flatfish stocks. Wegner *et al.* (2003) stated that recruitment of flatfish is the crucial unknown in stock management and thus of the outmost practical importance. Recruitment of flatfish varies from year to year (Van der Veer *et al.* 2000). Recruitment processes cover everything that affects survival between spawning and the stage of life where year-class strength is more or less fixed (Van der Veer *et al.* 2000). Indices of the number of juveniles of a specific year class surviving between spawning and recruitment are called year-class strength estimates (Van der Veer *et al.* 2000).

Year-class strength and recruitment can be either predicted or estimated in various ways depending on the species under investigation. For example, Nash and Geffen (2000) used mean catches of 1-year old plaice from beam trawl surveys in the Irish Sea and compared these catches to 0+ plaice, and found that the 1+ year-class strength of plaice is determined in the 0+ population by July of their first year. Van der Veer *et al.* (1990) analysed the fluctuations in recruitment of plaice in various nursery areas by estimating the coefficient of variation in abundance and mortality during the early life history in the North Sea populations. Rijnsdorp *et al.* (1992) found a positive relationship between relative recruitment, mean, maximum and the approximate surface area of the nursery grounds for sole stocks in the North Sea. Here, they suggest that using 1-year old catch data rather than Virtual Population Analysis output for 1-year old sole abundance avoids bias due to the analytical technique used to estimate population size. This "nursery size hypothesis" was also found to be valid for plaice stocks in the North Sea (Van der Veer *et al.* 2000). Bolle *et al.* (2001) found that recruitment variability in dab could be defined as the coefficient in year-class strength at age 2 (Bolle *et al.* 2001). Myers *et al.* (1997) used sequential population analysis of commercial catches to assess the recruitment of marine and freshwater fish and found recruitment variability to be greater in marine species.

The main species encountered on inshore nursery grounds on the west coast of Ireland are plaice, common sole, sandsole, turbot, brill, flounder and dab. Of these species plaice, common sole, turbot and brill are commercially important in the Irish fishing industry. On the west coast of Ireland, plaice and common sole are important quota species. For plaice, Ireland's share of the total international landings was 95 percent between 1993 and 2001. Plaice are normally caught in mixed species otter trawl fisheries in ICES areas (VIIb,c). Little is known about the state of the stock on the Irish west coast. Catches have declined since 1995 to an historic low in 2001. In 2001, the value of the Irish quota was €0.5m. The average weight of the landings in recent years was 160 tonnes. As with plaice, common sole catches in Ireland contributed 95 percent of the total international landings between 1993 and 2001. The value of the sole fishery on the west coast of Ireland was €0.6m in 2002 and the quota for 2004 is 55 tonnes. Important non-quota species to the Irish fishing industry are turbot and brill. Turbot commands high market prices and is always in high demand, making it a very important non-quota species. Turbot have previously been fished using tangle nets, although beam trawls, otter trawls and seines were also used. Presently very little is known about the biology of wild turbot in Irish waters. In 2002 turbot was worth almost €2.0m to the Irish fishing industry - a 13% increase from 2001. Brill are caught principally as a by-catch in demersal otter trawls. It is also important for small inshore vessels. Brill can be caught in tangle nets. The price per ton of brill varied over the last ten years from €2,600 in 1992 to €7,500 in 2001. In 2002, however, there was a slight decrease to €6,700. In 2002, Irish vessels caught 99 t of brill with a value of €0.7m. Flounder have no commercial value to the demersal fishery, however they are important to the sea angling tourism in Ireland. Flounder are listed as one of the five best beach angling species on the west of Ireland beaches, which are known as some of the best in Europe (URL 1).

In 2000, juvenile flatfish surveys were set up to assess the abundance and species composition of commercially important flatfish species on sandy beach nursery grounds around the Dingle Peninsula (Co. Kerry) and in 2002 around the greater Galway Bay area on the west coast of Ireland (Figure 1). The surveys were carried out to develop a method of quantifying local flatfish stock, and to determine year-class strength, for the management and protection of the commercial stocks. Beach seining was chosen as the preferred method of sampling. Factors influencing the choice of gear were cost and relative ease in sampling from the beach. 0-group flatfish were sampled in May and September of the first year (2000) but in September only for subsequent years, due to the poor return in May 2000 in Dingle. In Galway, sampling was carried out in September 2002 and May and September 2003. Species composition and abundance between beaches and between years is assessed separately for Dingle and Galway Bay.

2.3 Materials and Methods

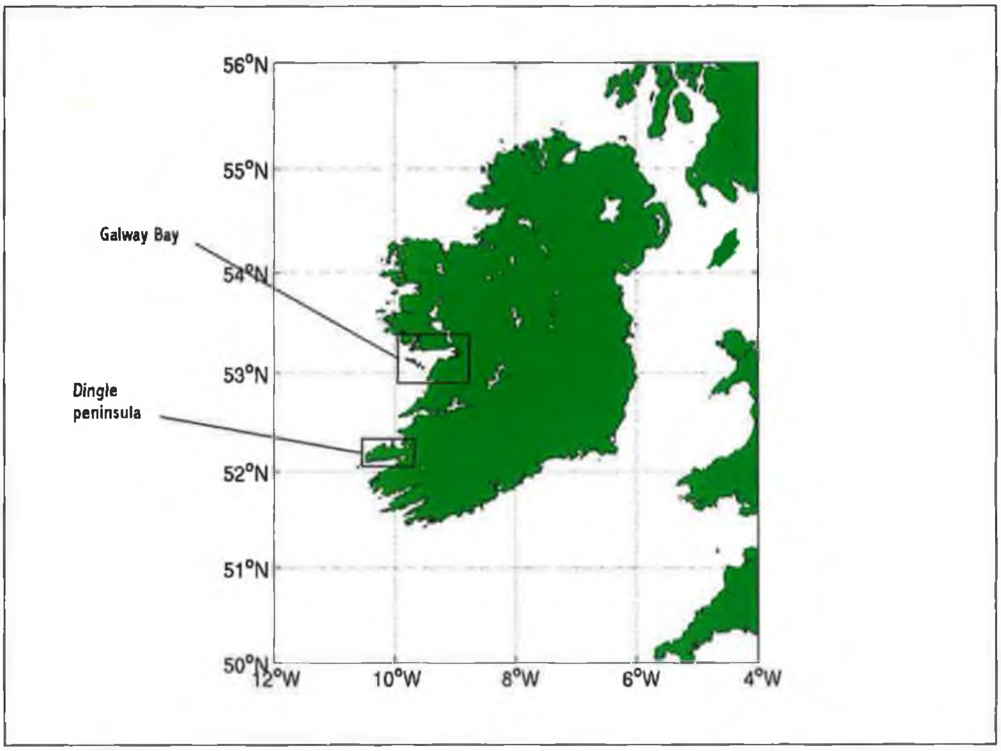
2.3.1 Study area

Beach seining surveys were carried out in the greater Galway Bay area on the mid west coast and around the Dingle Peninsula (Co. Kerry) on the south west coast of Ireland (Figure 1). Sampling took place on sandy beaches in Dingle, in May and September 2000 and also in September 2001, 2002 and 2003. In the Galway Bay region samples were taken on sandy beaches in September 2002, May 2003 and September 2003.

The principle beaches assessed in Dingle were Inch (52° 07`N 09° 58.8`W) – which is an exposed shore at the end of Dingle Bay; Brandon (52° 15`N 09° 01.6`W) - an exposed shore to the north of the peninsula; Ventry (52° 07.5`N 10° 22.2`W) - a sheltered bay on the south and Smerwick (52° 10.7`N 09° 01.6`W) - a sheltered bay to the north of the peninsula.

Beaches selected in Galway Bay were Lahinch (52° 56`N 09° 20.8`W) - an exposed shore on the Co. Clare coast south of Galway; Fanore (53° 07.2`N 09° 07.6`W) – which is north of Lahinch and south of Black Head but with the same exposure as Lahinch; Ballyloughaun (54° 16.2`N 09° 01.6`W) and Silverstrand (53° 15.2`N 09° 07.8`W) – sheltered shores near Galway city with estuarine influences from the River Corrib. The most northerly points sampled were Gurteen (53° 22.6`N 09° 57.6`W) and Dogsbay (53° 22.8`N 09° 58`W) – semi enclosed shores at Roundstone, Connemara Co. Galway.

Figure 1: Map of Ireland indicating the two surveyed areas of Galway Bay on the mid west coast and the Dingle peninsula on the south west coast.

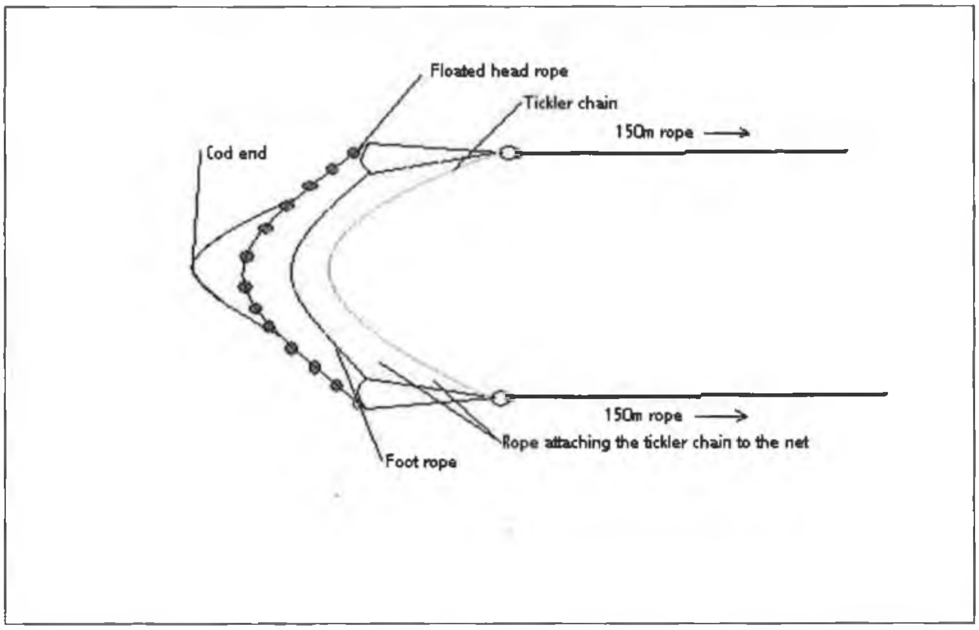


2.3.2 Sampling procedure

On a daily basis during the surveys, log sheets were completed recording the environmental and sample conditions. The occurrence of weed in the hauls was analysed visually using the options of low, medium or high abundance of weed.

The gear used was a Danish style drag seine net (Figure 2) with a bag in the centre, 20m in length and 2m deep with a 13 x 13mm mesh size. It was equipped with a weighted footrope and a floated head rope. Extra tickler chain was added to the footrope to increase sediment disturbance, and increase the catch efficiency for flatfish. Two 150m ropes were attached to each end of the net for hauling. The net had an approximate swept area of 1380 m^2, which allowed relative densities to be calculated.

Fig 2: Drawing of the Danish style drag seine net used for the Dingle and Galway surveys



The gear was shot from an inflatable boat (4m with an 8hp engine). One of the ropes was held on shore while the boat travelled directly offshore until the first 150m rope was deployed. The net was then shot parallel to the shore, the boat returned with the second rope and the seine was hauled ashore ensuring an equal pull on both sides. The hauling ropes floated and did not disturb the sediment to the sides of the hauling area. In Dingle, the net was hauled by hand in 2000 and by four wheeled motorbikes (quad bikes) for the following years (2001 to 2003). In Galway Bay the hauling was carried out by hand for both years (2002 and 2003). A lighter tickler chain was used when the seine was hauled by hand as opposed to a heavier chain used when hauling with quad bikes.

A minimum of two hauls was carried out on any given beach, with a maximum of six. The positions of the hauls were selected at the operators' discretion for 2000 to 2002 to ease sampling procedure (i.e. avoiding rocks or excess weed). For subsequent years the position of the hauls were randomly selected using random number tables from the shore. This was the case for both Galway and Dingle.

All fish were identified and measured on the shore. For all Galway samples and 2003 Dingle samples, fish were kept from each site for further analysis at the laboratory.

Flatfish greater than 15cm were tagged and released by Marine Institute personnel using a standard floy tag.

2.3.3 Laboratory fish analysis

Each fish was given a unique code so that it could be traced back to its location on capture and the date when caught.

The standard length (SL) (from the tip of the mouth to the end of the body just before the caudal fin begins) and total length (TL) (from the tip of the mouth to the distal end of the tail) was taken to the nearest 0.1cm for 1+ fish or greater and to the nearest 0.01cm for the 0+ fish. Wet weight was taken to the nearest 0.01g. The sagittal otoliths were removed from the vestibular apparatus by making a lateral incision to the posterior of the eyes. The otoliths were then removed using forceps, cleaned of any material and were stored dry in otolith boxes. Ageing was carried out under a stereoscopic microscope against a black background with the otoliths immersed in distilled water.

2.3.4 Data Analysis

Multivariate analysis was carried out on the data to assess the similarities between beaches and flatfish populations. Cluster analysis was used for the ordination of the data. All data sets were tested for normality with Ryan-Joiner tests for homogeny of variance with a Bartlett's test. Where needed, data was normalised using log, inverse log, log+1 or inverse log +1 transformations. Monotonic log and inverse log transformations were used for non-homogenous data (Underwood 1997). Most of the data analysed was unbalanced, hence General Linear Models were used for ANOVA's. Other parametric tests carried out include Pearson's correlation.

Analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA) were carried out. When Two-Way ANOVA's and MANOVA's between beach and year were carried out three null hypotheses were considered. These were:

(1) there is no difference in the measured parameter between beaches

(2) there is no difference in the measured parameter between years

(3) there is no interaction between beach and year.

Where an interaction occurred, there may be significant differences between certain beaches in any one year, or significant differences between years in certain beaches, but no consistent general patterns can be discerned. Hence, no conclusions were drawn on the two main hypothesis (differences between beaches or differences between years) because interpretations of the main effects were impossible or at best unreliable when there is an interaction (Underwood 1997). When an interaction was present no further analysis was carried out.

Post hoc analysis to compare pairs of means was carried out using Fisher's pairwise comparison. All tests were calculated on Minitab version 13.1.

2.4 Results

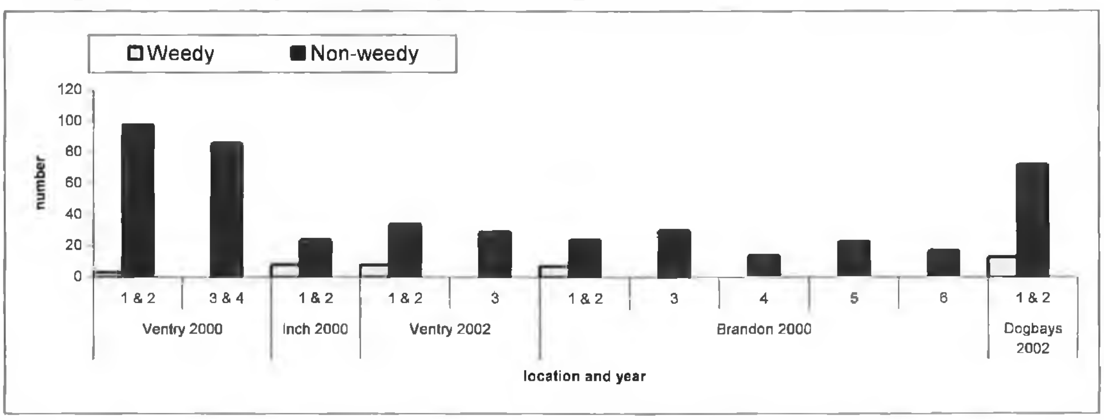
2.4.1 Effect of weed on gear efficiency

Table 1 and Figure 3 show the number of flatfish caught in hauls with a low or no weed and numbers of flatfish (usually just one haul) in hauls with a high abundance of weed throughout all surveys in both Dingle and Galway. The difference between the numbers of flatfish in weedy samples and non-weedy samples is highly significant ($p < 0.001$ One-way ANOVA) with fewer fish caught in weedy samples. Because of this significant difference, all hauls with a high abundance of weed present are not taken as representative due to a lower catch efficiency. All samples taken from Gurteen in 2003 had a high catch of weed and a low number of flatfish. They were not included in the analysis below because of the absence of comparative data.

Table 1: Number of flatfish for hauls with and without weed present for all surveys carried out. "*" indicates no data

Location	Year	Mean number of flatfish Weedy	Non-weedy
Ventry	2000	3	98
		0	86
Inch	2000	8	24
Ventry	2002	8	34
		*	29
Brandon	2000	7	24
		*	30
		*	14
		*	23
		*	17
Dogsbay	2002	13	72
Gurteen	2002	0	*
		1	*

Figure 3: Numbers of flatfish in weedy and non-weedy samples for beaches throughout all surveys in Galway and Dingle.



2.4.2 Galway Bay

2.4.2.1 Flatfish distribution

The species composition of flatfish caught with the beach seine for all surveys is given in Table 2. The species are listed in order of abundance. Plaice were the most common fish caught with flounder second, followed by turbot. Brill, dab, sandsole and the scaldfish, *Arnoglossus thori* (Kyle), all had low abundance. The three most abundant flatfish were caught on all beaches. Dab, brill, and sandsole only occurred on a few beaches, while *A. thori* was only found in Dogsbay.

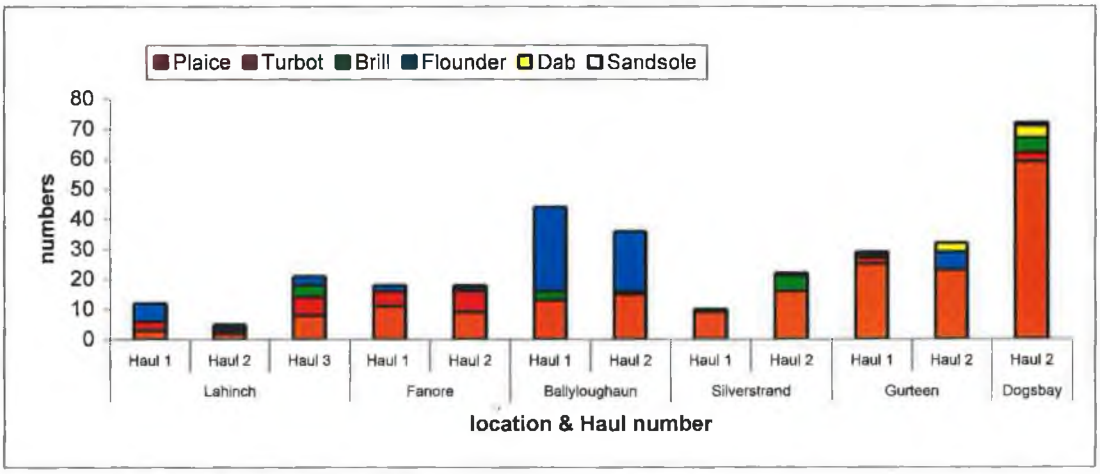
Table 2: Species list of flatfish caught in the Galway Bay beach seining survey from 2002 - 2003. Total numbers are given for each survey. Location codes are: Lh = Lahinch, Fe = Fanore, Bn = Ballyloughaun, Ss = Silverstrand, Gn = Gurteen and Db = Dogsbay.

Species name	Common name	Sep-02	May-03	Sep-03	Total	Location
Pleuronectes platessa	plaice	199	91	230	520	Lh, Fe, Bn, Ss, Gn, Db
Platichthys flesus	flounder	70	38	45	153	Lh, Fe, Bn, Ss, Gn, Db
Psetta maxima	turbot	28	20	30	78	Lh, Fe, Bn, Ss, Gn, Db
Scophthalmus rhombus	brill	23	3	6	32	Lh, Bn, Ss, Db
Limanda limanda	dab	9	0	10	19	Gn, Db
Pegusa lascaris	sandsole	3	2	8	13	Fe, Ss, Gn, Db
Arnoglossus thori	scaldfish	0	0	1	1	Db

2.4.2.1a September 2002

The numbers of flatfish species caught on each beach are shown as a frequency distribution for the September 2002 beach seining (Figure 4). The total number of flatfish for this survey was 332. Haul 2 in Dogsbay (Db2) had the highest catch of flatfish (n = 72), with the majority being plaice (n = 59). However, a low catch (n = 13) was recorded in haul 1 (Db1). This haul had a high catch of weed and hence a low net efficiency (Table 1). Ballyloughaun had high catches of fish (n = 44 and 36). These samples were made up of plaice and flounder. Low numbers of flatfish were noted in Lahinch (n = 12, 5 and 21) and Fanore (n = 18 and 17), these samples included plaice, turbot, flounder and brill. Intermediate numbers were recorded in haul two on Silverstrand (n = 22) and two hauls on Gurteen (n = 29 and 30).

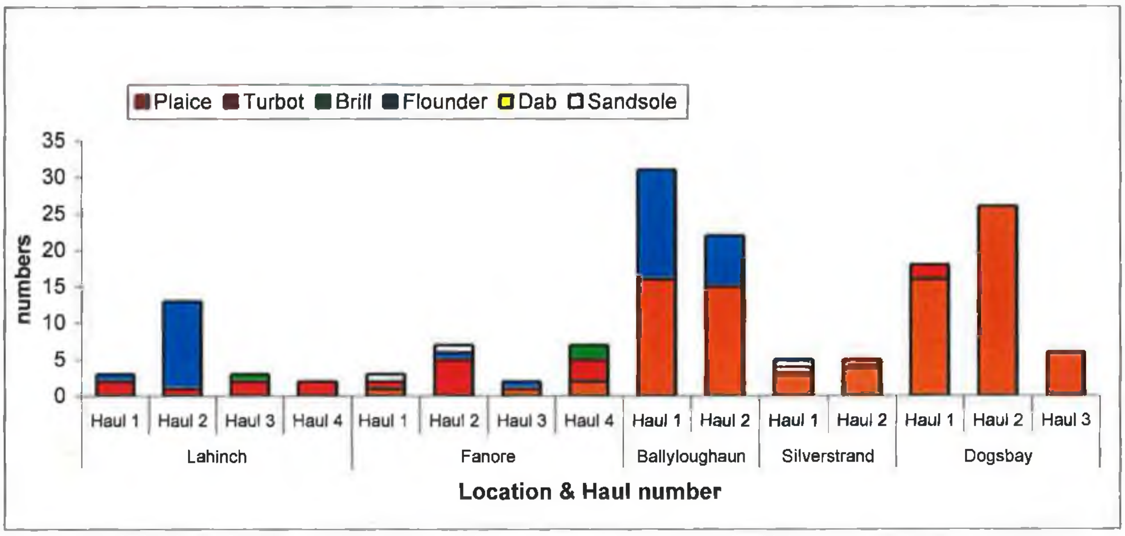
Figure 4: A frequency distribution of all flatfish species caught in Galway Bay using beach seining in September 2002.



2.4.2.1b May 2003

Sampling was carried out in May 2003 (Figure 5). The total number of flatfish caught was 154. Plaice was the most abundant species overall (n = 91). The highest occurrence of flatfish was recorded in Ballyloughaun (n = 31 and 22) and Dogsbay (n = 18 and 26). The third haul of Dogsbay had a low catch of 6 flatfish. The lowest numbers of flatfish were recorded in Lahinch (n = 3, 13, 2 and 3) and Fanore (n = 3, 7 and 2), with turbot, flounder sole and brill making up the catches. The highest catch of plaice was in Ballyloughaun and Dogsbay. Flounder were mostly caught on Ballyloughaun and haul two of Lahinch. Only one flatfish was caught in two hauls carried out in Gurteen. Both hauls here had weed present and were disregarded from the analysis due to the low net efficiency associated with a high weed abundance

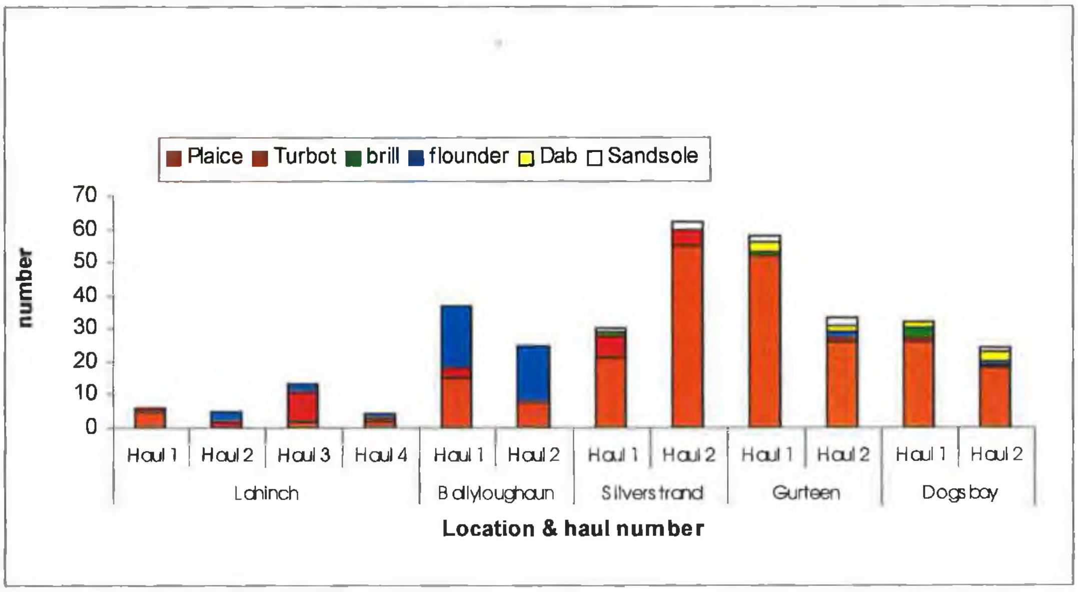
Figure 5: Frequency distribution for flatfish species caught in Galway Bay using beach seining in May 2003.



2.4.2.1c September 2003

September 2003 recorded the highest catch from all surveys (n = 520). Numbers of flatfish caught are given in Figure 6. Fanore was not sampled this month due to adverse weather conditions. Lahinch produced the fewest flatfish (n < 13). The highest catches were recorded on Gurteen (n = 58) and Silverstrand (n = 62). Intermediate numbers were noted elsewhere. Plaice made up the majority of the catches with the exception of Ballyloughaun when flounder were dominant. Also, haul three in Lahinch recorded more turbot than any other flatfish.

Figure 6: A frequency distribution of all flatfish caught in the Galway Bay beach seining survey in September 2003.



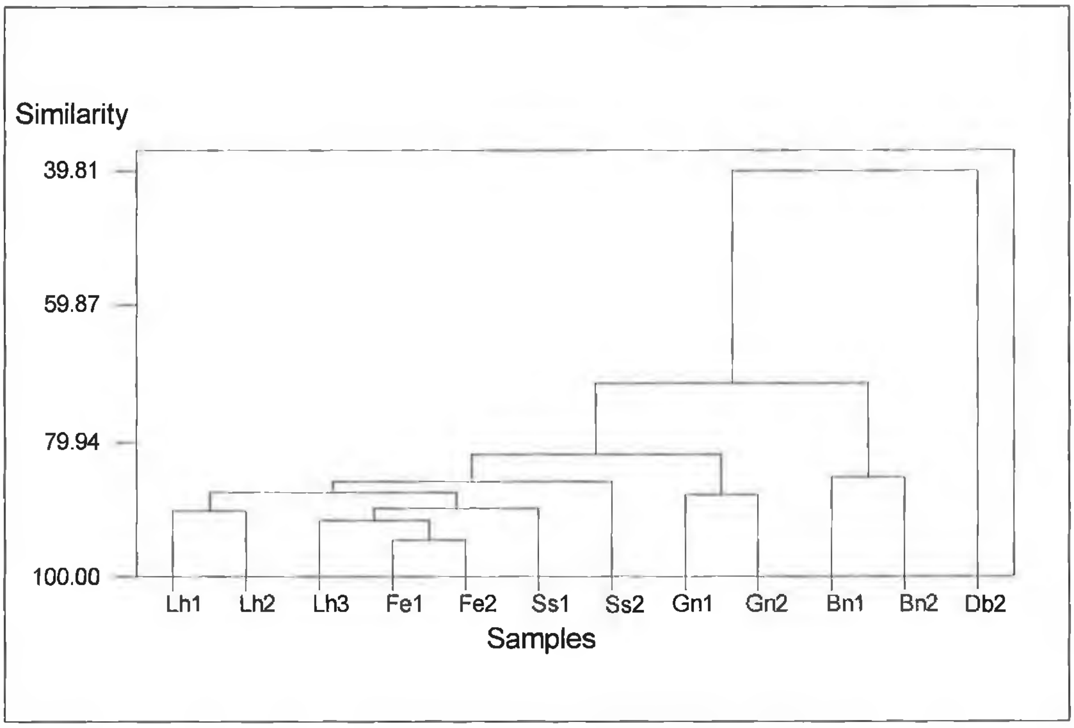
From the results of the beach seining, it can be seen that plaice are the dominant species (with a few exceptions) in the Galway Bay area. Occasionally flounder dominated catches (i.e. September in the Ballyloughaun samples and one May sample in Lahinch). In general, the highest number of flatfish tended to occur on Silverstrand, Ballyloughaun, Gurteen and Dogsbay, while lower numbers tended to occur on the exposed shores of Fanore and Lahinch.

2.4.2.2 Multivariate analysis: Cluster analysis

2.4.2.2a September 2002

With the exception of replicate 2 from Dogsbay, beaches showed a high similarity to each other in September 2002, clustering at a value of 71 percent (Figure 7). Ballyloughan samples separated from the remaining beaches at that value. Replicate hauls clustered together for three beaches, Ballyloughaun, Gurteen and Fanore. However, for the remaining three beaches, difference between beaches was less than the difference between replicates.

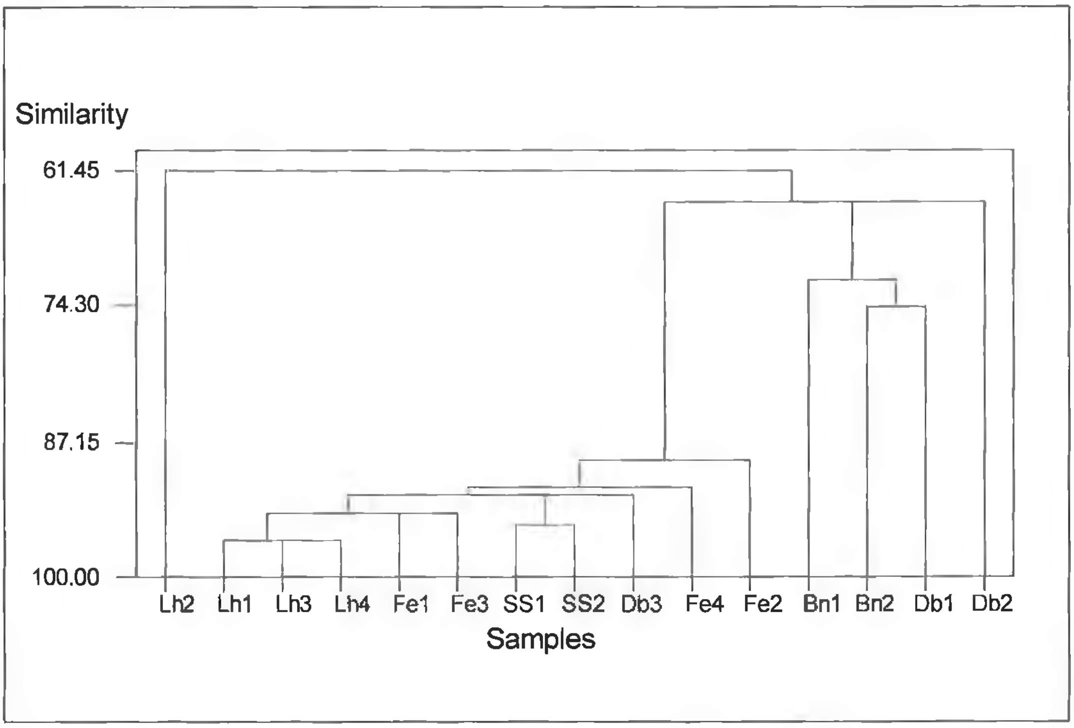
Figure 7: A dendrogram of the cluster analysis carried out on September 2002 beach seining data. Codes are: Lh = Lahinch, Fe = Fanore, Bn = Ballyloughaun, Ss = Silverstrand, Gn = Gurteen and Db = Dogsbay. The numbers correspond to the haul number.



2.4.2.2b May 2003

In May 2003, four replicates separated from the remaining hauls at a similarity of 64% (Figure 8). Here, the only replicates that clustered together were from Silverstrand. For all other beaches, there was greater similarity between beaches than between replicates.

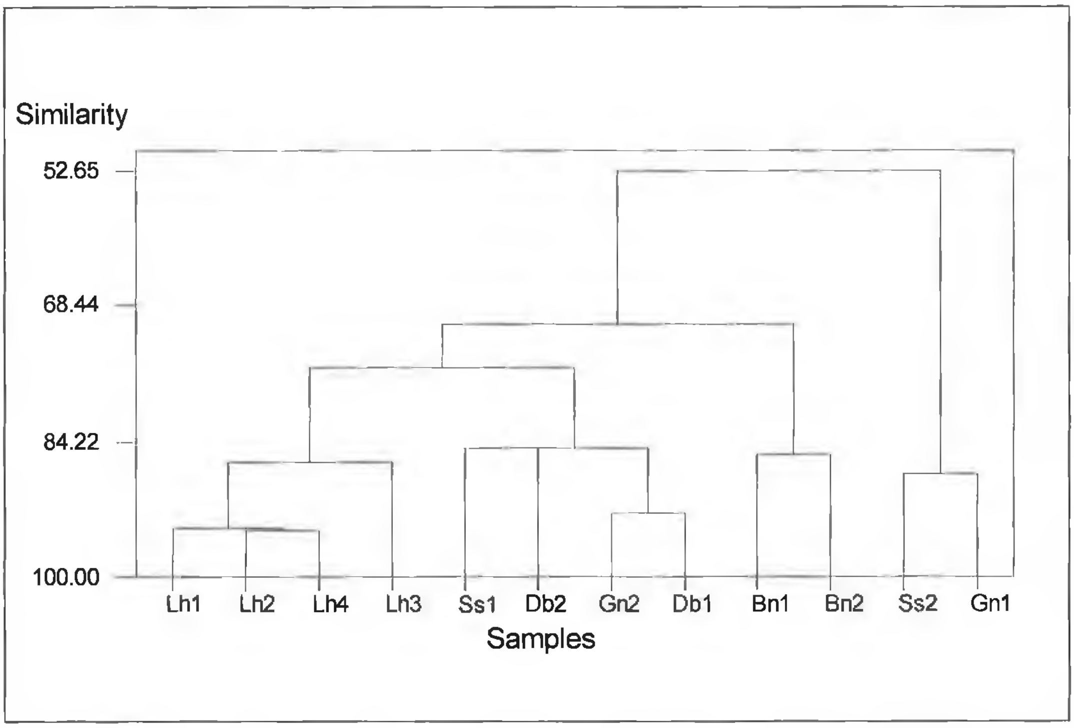
Figure 8: A dendrogram of cluster analysis carried out on May 2003 beach seining data. Codes are: Lh = Lahinch, Fe = Fanore, Bn = Ballyloughaun, Ss = Silverstrand, Gn = Gurteen and Db = Dogsbay. The numbers correspond to the haul number.



2.4.2.2c September 2003

In September 2003, a replicate from each of two different beaches, Gurteen and Silverstrand, showed little similarity to the remaining hauls, clustering with them at 53 percent (Figure 9). The only beaches where replicates clustered together were Ballyloughaun at 86 percent and Lahinch at 87 percent. On all other beaches, similarity between replicates was less than that between beaches.

Figure 9: A dendrogram expressing the results of the cluster analysis on the September 2003 beach seine data. Codes are: Lh = Lahinch, Bn = Ballyloughaun, Ss = Silverstrand, Gn = Gurteen and Db = Dogsbay. The numbers correspond to the haul number.

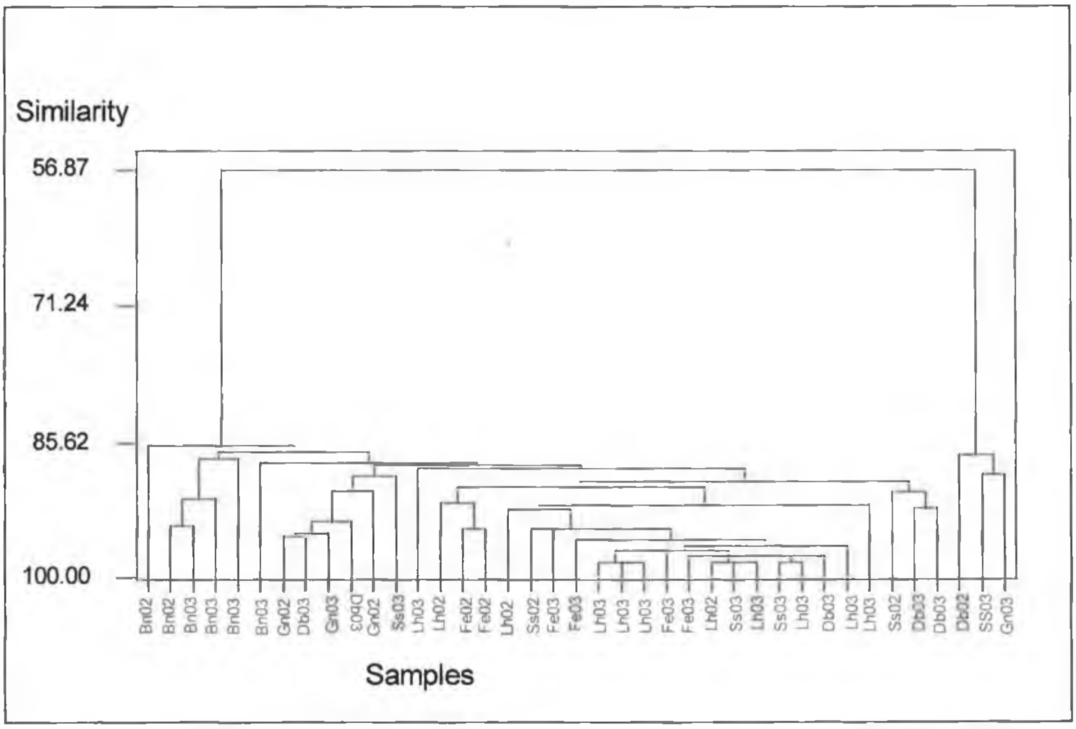


Over the three surveys, the beaches showed a high level of similarity (>70 percent) except for occasional replicates. Ballyloughan showed a high level of consistency of replicates but for September samples only. It should be noted that weedy samples, which might account for high levels of within beach variability have been excluded from the analysis. There was no obvious separation using the cluster analysis of the beaches in terms of exposure to wave action in the composition of the flatfish fauna.

2.4.2.2d Overall analysis

When replicates from all three surveys are analysed together (except weedy hauls) there was a high overall similarity (86 percent) between all replicates from all beaches with the exception of three hauls from three different beaches (Dogsbay, September 2002, Gurteen and Silverstrand, September 2003). Replicate hauls on beaches did not tend to form clusters together (Figure 10). All hauls from Fanore and all except one from Lahinch grouped together with a high similarity of 90 percent. Also, two hauls from Silverstrand in May 2003, one haul from Dogsbay May 2003 and one haul from Silverstrand in September 2002 were included in this cluster. Four out of six hauls from Ballyloughaun clustered separately. However, one replicate from September 2002 and one replicate from in May 2003 showed higher similarity to other beaches than to Ballyloughaun. Other groupings included remaining hauls from Silverstrand, Gurteen, Dogsbay and Ballyloughaun. Replicates from particular beaches did not generally cluster together nor were any yearly signals detected.

Figure 10: Cluster analysis for all replicates in September 2002, 2003 and May 2003. September 2002 is indicated with blue font, May 2003 in green font and September 2003 is in red font



2.4.2.3 Multivariate analysis: MANOVA

The cluster analysis detected no consistent difference in flatfish community between beaches or between years. However, a MANOVA carried out on September surveys data only, showed a highly significant difference in the flatfish composition between beaches ($p < 0.001$). A difference between years was not detected ($p = 0.137$), There was no interaction between beach and year ($p = 0.855$). The MANOVA contradicts the cluster analysis which shows a high similarity between beaches, while it agrees with the cluster analysis that no yearly differences are present. When a univariate analysis of variance (Two way ANOVA) was carried out for each species separately, no interaction between beach and year was present for any species. A significant difference between beaches was observed for plaice ($p = 0.026$), brill ($p = 0.044$), flounder ($p < 0.001$) and dab ($p < 0.001$), while a significant between year difference was noted with brill only ($p = 0.028$). These results are analysed in more detail below.

2.3.2.4 Plaice density

Densities were calculated for the 0+ plaice only. The swept area of the beach seine was approximately $1380m^2$. The densities of plaice for each beach as numbers $1000m^{-2}$ on each survey are given in Table 3.

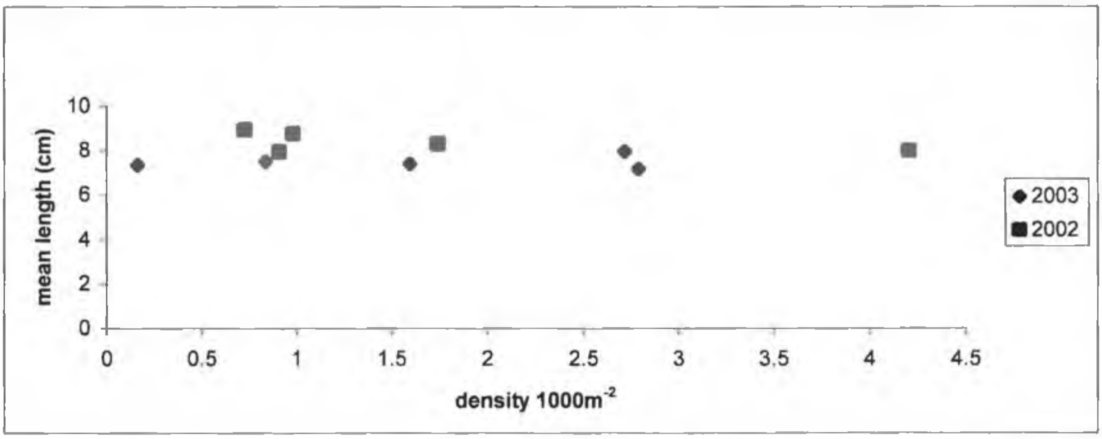
Table 3: Densities ±SD $1000m^{-2}$ for 0+ plaice for beach seining surveys from 2002 to 2003. All numbers are given as means with the exception of Dogsbay in 2002 which is a single value

	Sep-02 **Mean density $1000m^{-2}$ ±S D**	***May-03*** **Mean density $1000m^{-2}$ ±S D**	***Sep-03*** **Mean density $1000m^{-2}$ ±S D**
Lahinch	2.8 ± 2.5	0	1.6 ± 1.4
Fanore	7.2 ± 1.0	0.3 ± 0.4 1	N/S
Ballyloughaun	9.7 ± 1.5	11.2 ± 0.5	8.3 ± 3.5
Silverstrand	9.0 ± 3.5	0	27.1 ± 17.9
Gurteen	17.3 ± 1.0	N/A	27.8 ± 13.8
Dogsbay	42.0 ± N/A	8.9 ± 8.5	15.9 ± 4.0

Mean densities ranged from 0.3 ± 0.4 ($1000m^{-2}$) on Fanore in May 2003 to 27.8 ± 13.8 ($1000m^{-2}$) on Gurteen in September 2003. The highest density was observed in Dogsbay (42 $1000m^{-2}$). This value is from one haul, as the other haul on Dogsbay from the month was disregarded because of a high catch of weed. The lowest densities tended to occur in May 2003, with the exception of Ballyloughaun which had a mean density of 11.2 ± 0.5 $1000m^{-2}$. Lahinch had the lowest density in both September samples. Gurteen and Silvertsrand had increasing densities from 2002 to 2003, while the opposite trend was noted for Dogsbay and Ballyloughaun.

No correlation was observed between the mean length and the density of 0+ plaice in September samples on all beaches (Pearson's correlation on ranked data $R^2 = -0.030$, $p = 0.934$, Figure 11).

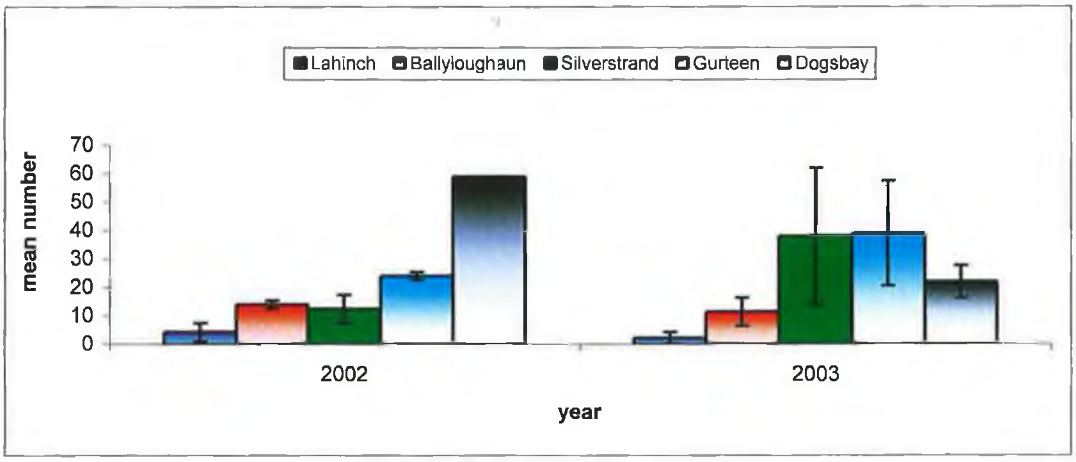
Figure 11: Mean density plotted against mean length of 0+ plaice from all beaches in September of 2002 and 2003.



2.3.2.5 Plaice: Year and beach variation in densities

The mean abundance of plaice in September 2002 and 2003 was analysed for differences in abundance between years. Silverstrand, and Gurteen showed slight variation in mean numbers from year to year (Figure 12), while little variation was noted in Lahinch and Ballyoughaun. A Two-way ANOVA on transformed data was used to compare all plaice densities between years and between beaches from 2002 and 2003. There was no interaction between beach and year ($p = 0.435$). Also, it was found that the variation between years was not significant ($P = 0.595$). There was however, a significant difference in the density of plaice between beaches ($p = 0.026$ Two-Way ANOVA). A One-Way ANOVA ($p < 0.001$) on the beach data only followed by the Fisher's pairwise comparison, found that Lahinch had a significantly lower density than all other all other beaches in both years.

Figure 12: Abundance of plaice for September 2002 and 2003 in Galway bay beach seining. All values are means ±SD with the exception of Dogsbay 2002 where only one representative haul was taken.



2.4.2.6 Plaice: size frequency and age

The size frequency distributions are for 0+ fish only. 0+ fish made up the majority of the catches. Table 4 shows the number of 0+ plaice as a percentage of all the plaice caught. Analysis was only carried out on September data as the May survey did not produce enough 0+ fish to warrant analysis.

Table 4: The number of 0+, ≥1+ and mean size of 0+ plaice caught in the Galway Bay beach seining from 2002 - 2003.

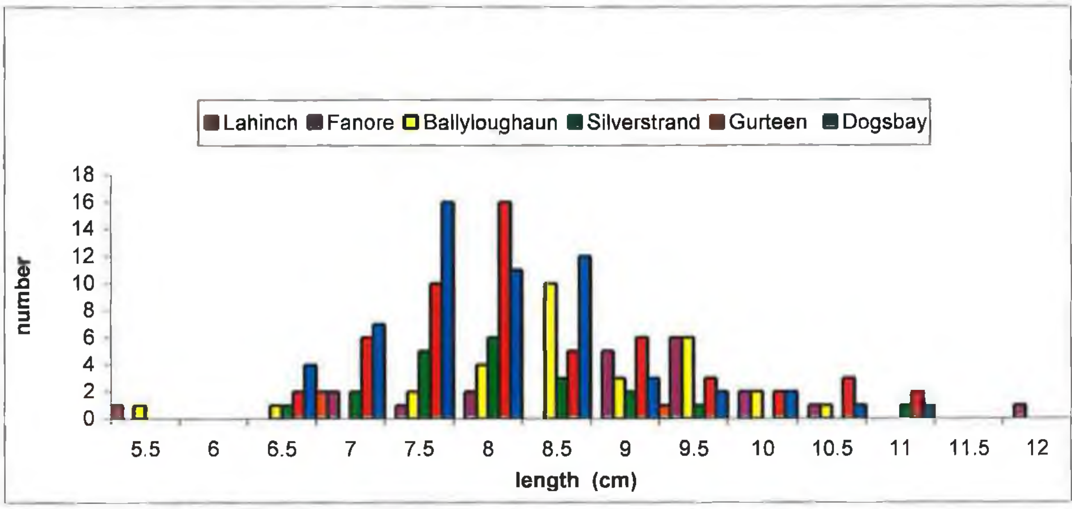
	No. of 0+	No. of ≥1+	% 0f 0+	0+Mean size (cm) ±SD
Sep-02	197	10	95	8.3 ± 1.11
May-03	70	18	79.5	4.4 ± 0.82
Sep-03	221	2	99	7.5 ± 1.34

In the September samples from both years (2002 and 2003), 0+ fish ranged in size from 5cm to 11cm total length (TL), with a mean in 2002 of 8.3cm ± 1.11 and 7.5cm ± 1.34 in 2003 (Table 4). The size range for 0+ in the May sample was between 3 and 6cm, with a mean of 4.4cm (± 0.82). Size frequency distributions for September surveys are given in Figure 13 and 14.

2.4.2.6a September 2002

Dogsbay and Gurteen had peak numbers at lengths (TL) of 7.5 and 8cm respectively and a size range of 6.5 to 11cm, in September 2002 (Figure 13). The majority of the 0+ fish caught in Ballyloughaun where 8.5cm, while in Silverstrand the modal size was noted at 8cm. The range in sizes was from 5.5 to 10.5cm in Ballyloughaun and 6.5 to 11cm on Silverstrand. Fanore fish were larger with the modal size at 9.5cm with a range from 7 to 10.5cm. Not enough 0+ plaice (n < 20) were caught in Lahinch to warrant analysis.

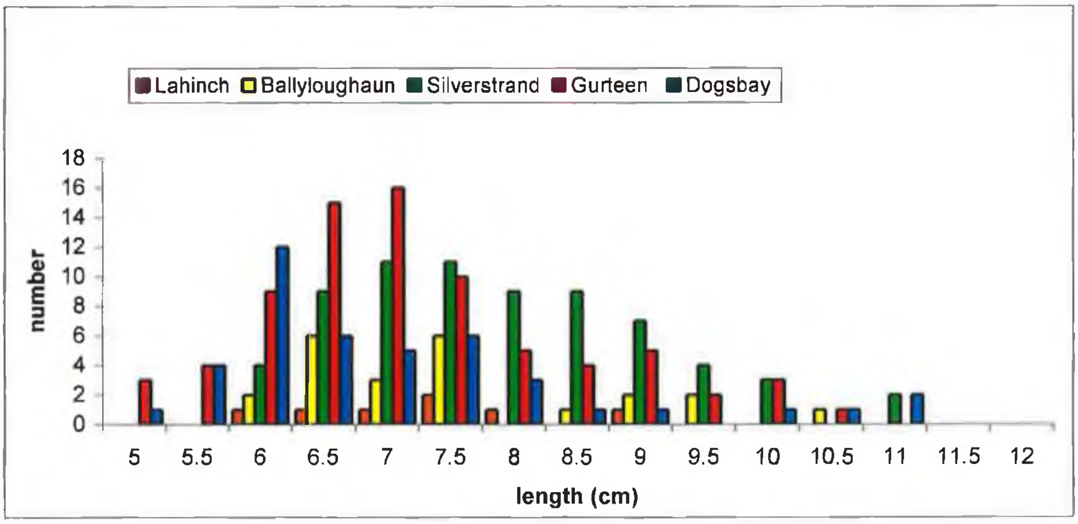
Figure 13: Size frequency distribution of 0+ plaice sampled in the Galway Bay beach seining in September 2002



2.4.2.6b September 2003

In September 2003, the mean size of 0+ plaice was 7.5cm (± 1.34), 0.8cm less than 2002 (8.3cm ± 1.11). Gurteen and Silverstrand showed a similarity with modal sizes at 7cm (Figure 14). The modal size in Dogsbay was 6cm, with Ballyloughaun modal sizes at both 6.5 and 7.5cm. Larger fish were caught on Silverstrand and Gurteen, and smaller fish were captured on Dogsbay and Gurteen. As in 2002, Lahinch did not produce enough juvenile plaice to warrant further analysis. Fanore was not sampled during the September 2003 survey.

Figure 14: Size frequency distribution of 0+ plaice sampled in the Galway Bay beach seining in September 2003. Fanore was not sampled on this survey.



2.4.2.7 Plaice: Variation in size between beaches and between years

The variation in the mean size of 0+ plaice was assessed for September samples only. Lahinch 2003 samples were not included in the analysis due to low numbers caught. The results are shown in Table 5.

Table 5: Mean size ± SD for 0+ plaice on beaches sampled by beach seining in September 2002 and 2003. N/S = the beach was not sampled on this survey. Lahinch is not included in the table as numbers did not exceed 20

	Sep-02	***Sep-03***
	mean size (cm) ± SD	**mean size (cm) ± SD**
Fanore	8.94 ± 0.99	N/S
Ballyloughaun	8.77 ± 1.25	7.52 ± 1.23
Silverstrand	7.95 ± 0.74	7.87 ± 1.19
Gurteen	8.3 ± 1.11	7.19 ± 1.25
Dogsbay	8 ± 0.96	7.41 ± 1.62

There was a significant interaction between beach and year for mean length data ($p = 0.022$ Two-Way ANOVA) No general conclusions can be drawn about the differences between years and between beaches due to the interaction.

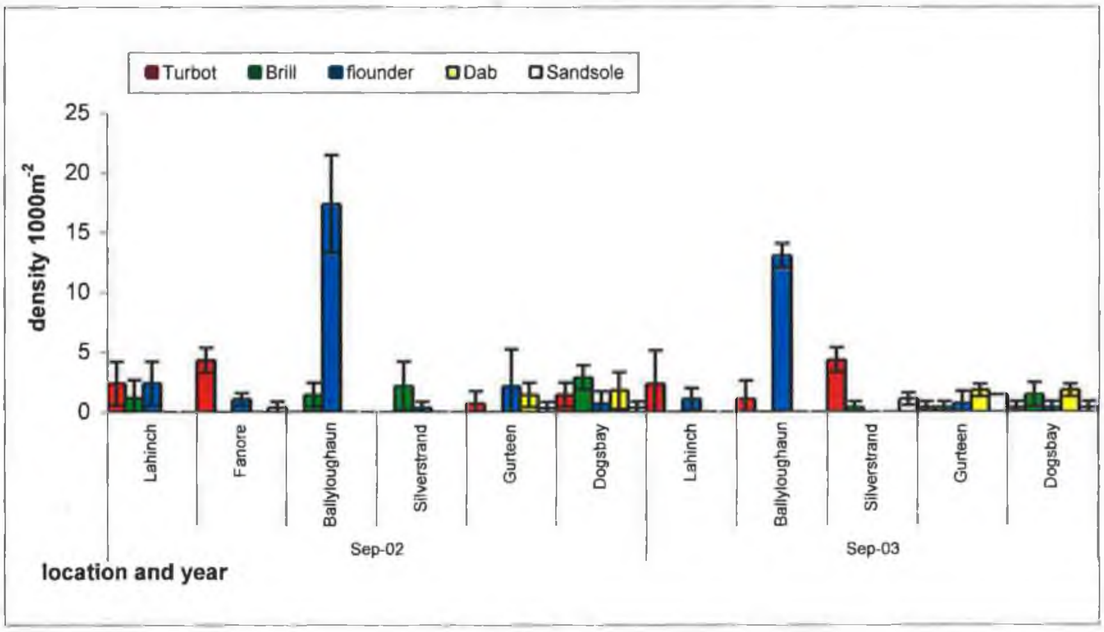
2.4.2.8 Densities of other flatfish species

Other flatfish caught in the beach seine sampling included turbot, flounder, dab, brill and sandsole. These were all of secondary importance to the dominant plaice. The mean densities (± SD) were calculated for all beaches sampled in September of 2002 and 2003. The densities are of all age groups of the species listed. However, there was a dominance of 0+ fish for all flatfish in the September samples. May samples are not included here as numbers were small and no yearly comparison was possible.

The mean densities of turbot, flounder, brill, dab and sandsole are shown in Figure 15. Brill, dab and sandsole had the lowest densities throughout, ranging from 0.36 to 1.81 $1000m^{-2}$. Dab had the most confined distribution, only occurring on Gurteen and Dogsbay on both years. Sandsole occurred in Silverstrand, Fanore, Gurteen and Dogsbay over the two years, while brill had the widest distribution of the three least common fish. Brill were caught on all beaches with the exception of Fanore. Turbot densities ranged from a high of 4.35 $1000m^{-2}$ on Fanore and Silverstrand in 2002 and 2003 respectively to a low of 0.36 $1000m^{-2}$ recorded on both Gurteen and Dogsbay in 2003. Turbot occurred on all beaches over the two-year period. Flounder had the highest densities recorded for flatfish other than plaice. In 2002, a density of 17.3 $1000m^{-2}$ was recorded in Ballyloughaun, while in 2003 a density of 13 $1000m^{-2}$ was recorded on the same beach. With the exception of Silverstrand in 2003, flounder were caught on all others visits to all beaches on both years.

A MANOVA carried out on the data showed that variation in the composition of flatfish excluding plaice between beaches was highly significant ($p < 0.001$), while no yearly variation over all beaches was observed ($p = 0.067$). There was no interaction between beach and year ($p = 0.835$). A Two-Way ANOVA was carried out on each species to find which species differ between beaches and between years. There was no interaction between beach and year for all species. No difference was observed between beaches for turbot ($p = 0.611$) and brill ($p = 0.141$). Flounder, dab and sandsole showed significant differences between beaches ($p < 0.001$, $p < 0.001$ and $p = 0.010$ respectively). Ballyloughaun had significantly higher densities of flounder than all other beaches (Fisher's pairwise *post hoc* analysis). Also, Silverstrand differed significantly from Lahinch for the same fish. The same analysis showed no difference in dab densities between Gurteen and Dogsbay, but these two beaches were different to all other beaches. Analysis of sandsole showed that differences were between Silverstrand and Lahinch and Silverstrand and Ballyloughaun. Thus, differences between beaches can be attributed to significant differences in densities of plaice, flounder, dab and sandsole. Brill was the only flatfish to show a yearly difference with higher numbers found overall in 2002.

Figure 15: Mean density (±SD) of turbot, brill, flounder, dab and sandsole for September samples in the Galway Bay area



2.4.2.9 Summary

Plaice were the dominant flatfish caught in the Galway samples. The plaice population were numerically dominated by 0+ year class. Cluster analysis of the flatfish community data failed to show any consistent differences between beaches or between years. MANOVA's contradicted the cluster analysis in showing a significant difference in the flatfish composition between beaches but agreed with the cluster analysis in that no between year differences were noted. The between beach difference was attributed to variations in the density of plaice, brill, dab and flounder. Plaice densities differed between beaches but not between years. This significant difference between beaches was restricted to Lahinch where densities were low. An interaction was noted between beach and year for the mean length of plaice, therefore no general conclusions can be drawn. No correlation was detected between the mean length and density of plaice in the September samples. For flatfish communities excluding plaice there was a significant difference between beaches but not between years which is consistent with analysis where plaice were included.

2.4.3 Dingle Co. Kerry

2.4.3.1 Flatfish distribution

The species composition for all flatfish recorded using beach seining from 2000 – 2003 is given in Table 6. Species are listed in order of abundance, with the numbers given for each survey. The location indicates where fish were caught. In this case all fish were caught on all beaches at some stage over the four-year period. *P. lascaris* and *S. solea* were not differentiated from each other on some occasions, so their numbers were pooled together under the common term "sole". Plaice where the most common flatfish in all years, turbot was second with flounder third. Dab occurred in occasional high numbers throughout the survey period, while sole and brill mostly occurred in small numbers.

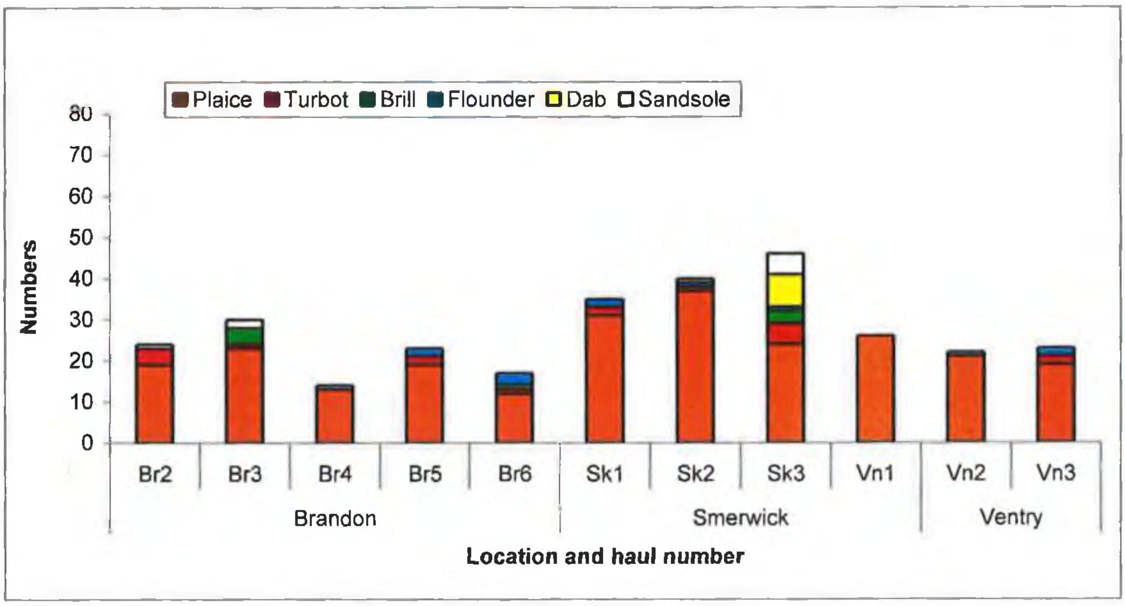
Table 6: Species list of all flatfish recorded in Dingle beach seining from 2000 - 2003. Numbers for each survey are given. Location codes are: In = Inch, Br = Brandon, Vn = Ventry & Sk = Smerwick.

		Numbers caught each survey					
Species name	**Common name**	***May-00***	***Sep-00***	***Sep-01***	***Sep-02***	***Sep-03***	**Location**
Pleuronectes platessa	plaice	248	453	869	790	372	In, Br, Vn, Sk
Psetta maxima	turbot	20	46	99	163	42	In, Br, Vn, Sk
Platichthys flesus	flounder	13	17	70	34	42	In, Br, Vn, Sk
Limanda limanda	dab	9	21	6	52	41	In, Br, Vn, Sk
Pegusa lascaris or Solea solea	sole	9	0	10	18	12	In, Br, Vn, Sk
Scophthalmus rhombus	brill	8	7	6	8	9	In, Br, Vn, Sk

2.4.3.1a May 2000

The beach seining surveys commenced in May 2000. On this occasion Brandon, Smerwick and Ventry were sampled. Figure 16 shows the frequency distribution for all flatfish caught. The total number of flatfish caught was 307. Six hauls were carried out in Brandon with numbers ranging from 7 to 30. However, the low catch recorded on this beach had a high occurrence of weed, which was deemed to have an effect on catch efficiency. Smerwick produced higher numbers with a low of 35 and a high of 46. Ventry had consistent catches throughout with numbers of flatfish caught ranging between 23 to 26.

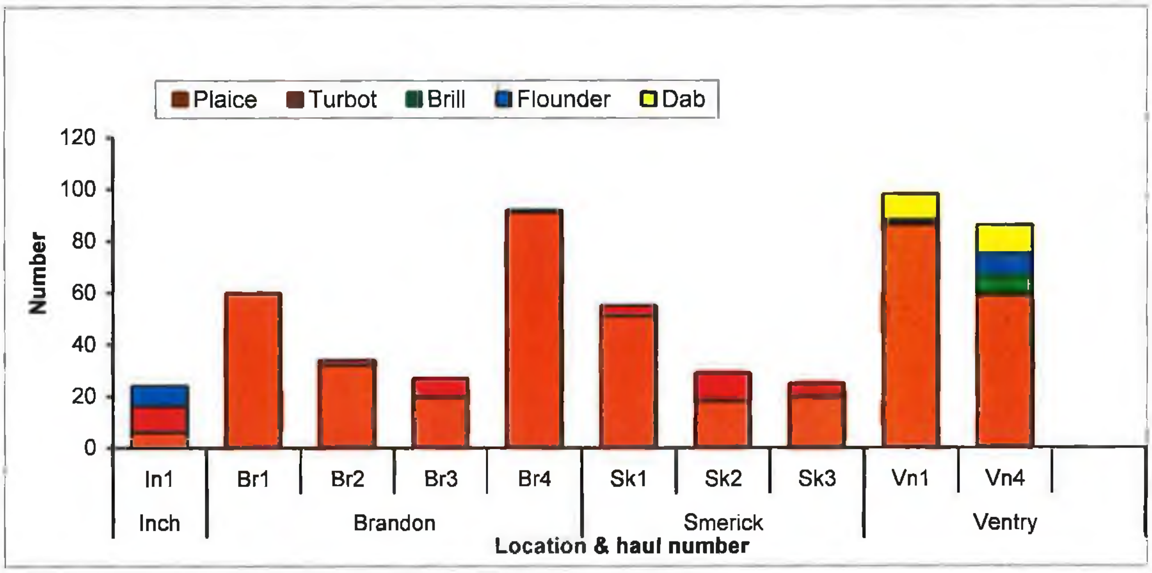
Figure 16: Frequency distribution of all flatfish caught in Dingle using beach seining May 2000. Beach codes are: Br = Brandon, Vn = Ventry and Sk = Smerwick. The numbers correspond to the haul number on the beach.



2.4.3.1b September 2000

In September 2000, more flatfish (n = 544) were caught when compared to the May 2000 survey. Inch was included in this survey. Figure 17 shows the frequency distribution of flatfish in Dingle. Low numbers were recorded on Inch (n = 24) for the two hauls. However, haul 2 (In2, n = 8) had a high abundance of weed and so was not included in the analysis. This was also the case for Ventry (Vn2 and Vn3). Two hauls from Brandon (n = 60 and n = 92), and Ventry (n = 98 and n = 86) and one haul from Smerwick (n = 55) had the highest numbers. Moderate numbers were recorded in all other hauls.

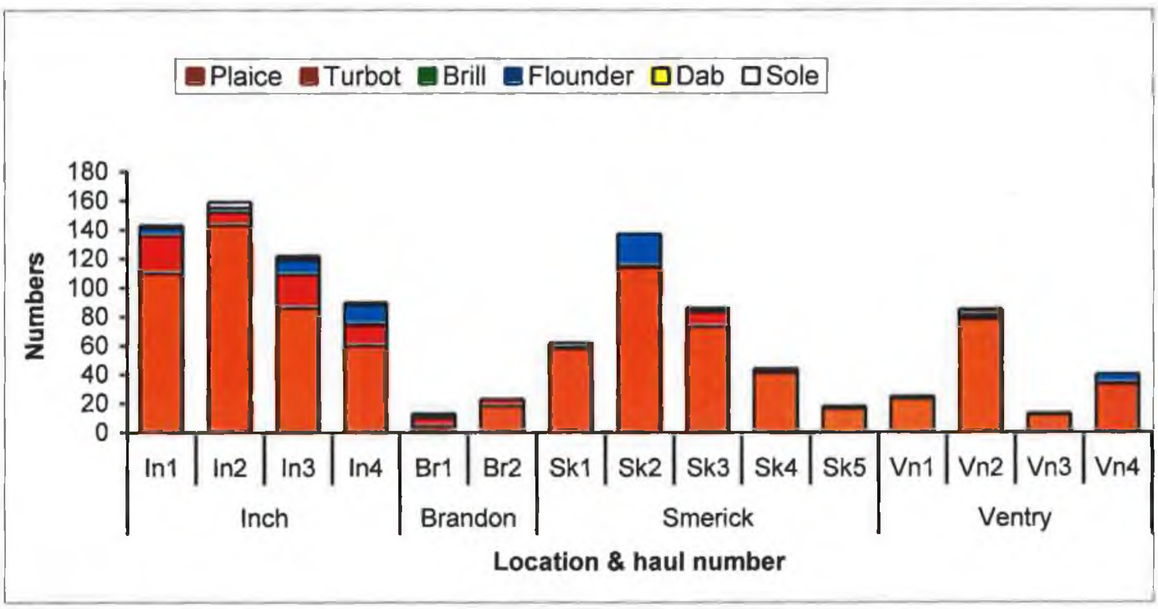
Figure 17: Frequency distribution of all flatfish caught in Dingle using beach seining, September 2000. Beach codes are: In = Inch, Br = Brandon, Vn = Ventry and Sk = Smerwick. The numbers correspond to the haul number on the beach.



2.4.3.1c September 2001

In 2001, the May sampling was dropped from the protocol (due to low numbers recorded) while the September sampling was continued. The frequency distribution for September 2001 is given in Figure 18. The total number of flatfish caught in this survey was 1060. In contrast to September 2000, Inch had the highest catch of flatfish (n = 90 to n = 159), with three hauls from Smerwick second. Here numbers ranged from 62 to 157 flatfish. In Brandon, low numbers were caught (n = 13 and 23). High (n = 85), moderate (n = 40) and low (n = 13) numbers of flatfish were recorded in Ventry.

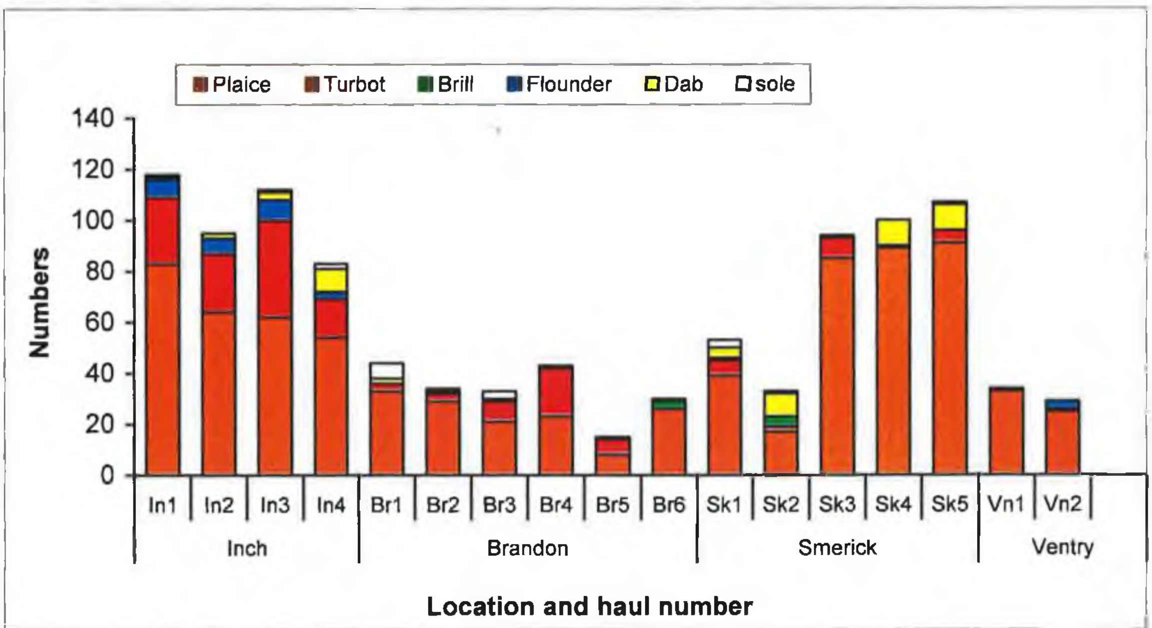
Figure 18: Frequency distribution of all flatfish caught in Dingle using beach seining, September 2001. Beach codes are: In = Inch, Br = Brandon, Vn = Ventry and Sk = Smerwick. The numbers correspond to the haul number on the beach.



2.4.3.1d September 2002

Figure 19 shows the frequency distribution for flatfish caught in 2002. The total catch for the survey was 1065 flatfish. Inch and Smerwick produced the highest numbers of flatfish again in September 2002 with all hauls except Sk2 having catches between 53 and 118. Greater numbers of dab, turbot and sole were caught this year as opposed to other years. Inch was the most productive beach for turbot. Haul 3 from Ventry had the lowest occurrence due to a high abundance of weed and hence this haul was disregarded. Five hauls from Brandon, the remaining two hauls from Ventry and the first two hauls from Smerwick (Sk1 and Sk2) had consistent catches ranging from 30 to 53. Br5 had the lowest catch of flatfish, 15.

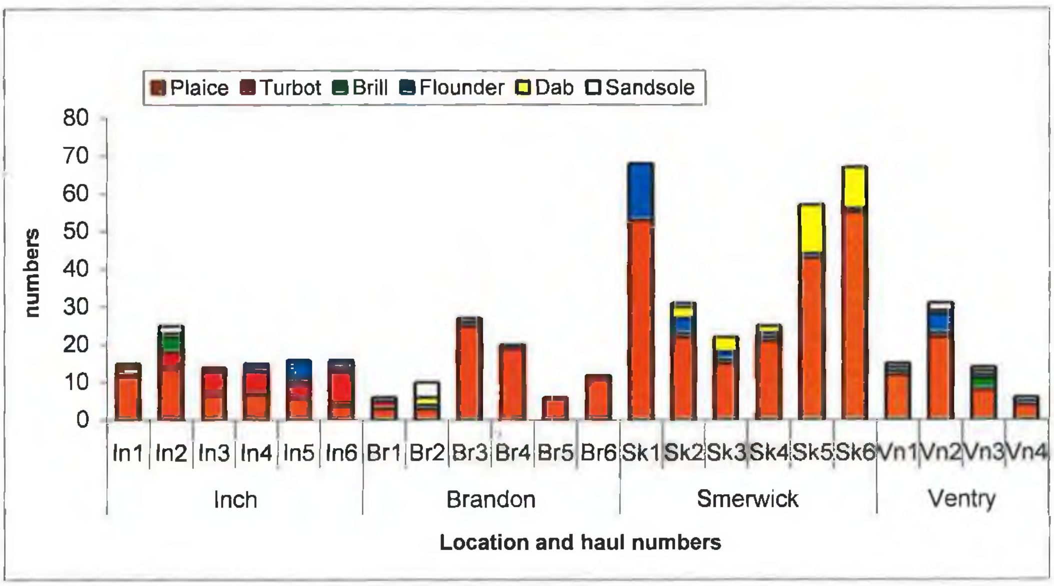
Figure 19: Frequency distribution of flatfish caught in the Dingle beach seining September 2002. Beach codes are: In = Inch, Br = Brandon, Vn = Ventry and Sk = Smerwick. The numbers correspond to the haul number on the beach.



2.4.3.1e September 2003

In September 2003 the catches of plaice and turbot were less than that recorded in previous September samples (Table 6). In this year the total number of flatfish caught (n = 518) was the lowest of all September sampling despite having the highest sampling effort (most beach seine hauls). Figure 20 shows the frequency distribution of flatfish throughout Dingle in September 2003. Numbers in Inch were lower than the previous two years with a range from 14 to 25. Low and moderate numbers were caught in Brandon (n = 6 to 27) and Ventry (n = 6 to 31), while in Smerwick moderate and high numbers were observed (n = 22 to 68).

Figure 20: Frequency distribution of flatfish caught in the Dingle beach seining September 2003. Beach codes are: In = Inch, Br = Brandon, Vn = Ventry and Sk = Smerwick. The numbers correspond to the haul number on the beach.



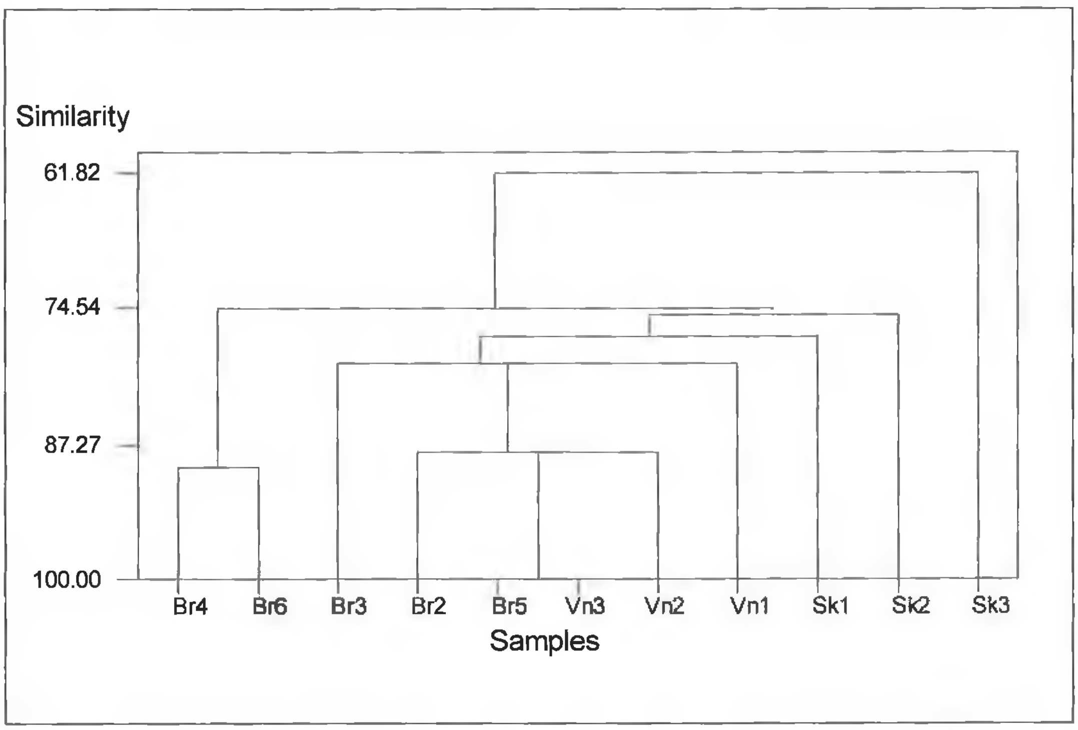
In summary, as with the Galway surveys, plaice were the numerically dominant flatfish species caught with the beach seine. This was the case on all beaches sampled. Turbot were most abundant on Inch in 2002. Flounder and dab had a sparse occurrence on each survey. The total numbers of flatfish caught in September samples increased from 2000 to 2001. However, numbers steadily reduced over the next three years with the lowest overall numbers recorded in 2003, which had the highest sampling effort.

2.4.3.2 Multivariate analysis: Cluster analysis

2.4.3.2a May 2000

Cluster analysis for the May 2000 survey shows (Figure 21) that, with the exception of Sk3, the beaches had a high overall similarity of 75 percent. On all beaches, some replicates showed a lower similarity than the similarity between beaches.

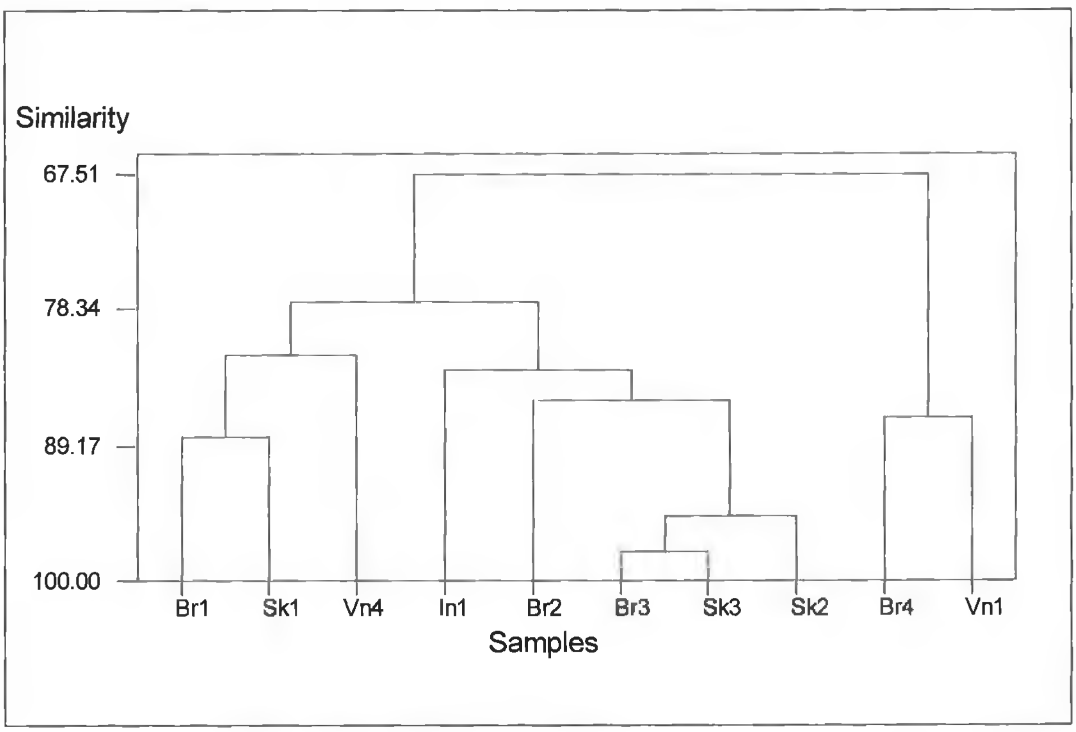
Figure 21: A dendrogram of the cluster analysis carried out on the May 2000 data for the Dingle beach seining. Beach codes are: In = Inch, Br = Brandon, Vn = Ventry and Sk = Smerwick. The numbers correspond to the haul number on the beach. Br1 was excluded due to a high catch of weed



2.4.3.2b September 2000

In September 2000, the overall similarity for all beaches was 67 percent (Figure 22). The second haul from Inch and Vn2 and Vn3 from Ventry were not included in the analysis due to a high catch of weed. From the rest of the hauls, it can seen that as with the May samples, replicates did not cluster together with more similarity between beaches than between replicates.

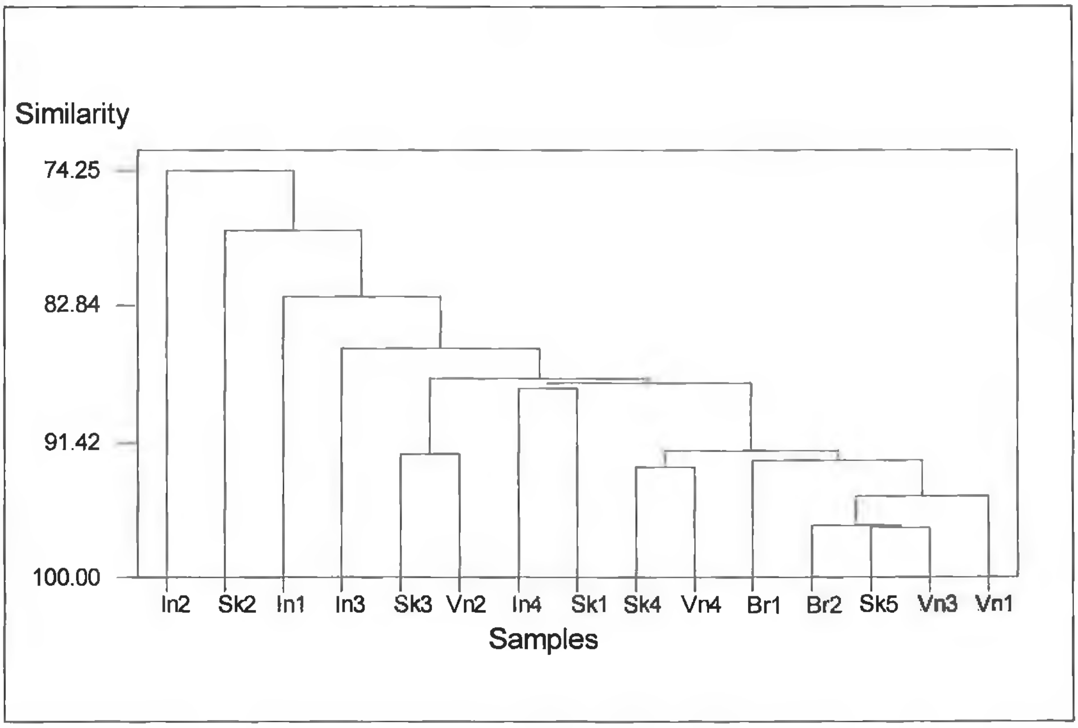
Figure 22: A dendrogram of the cluster analysis carried out on the Dingle beach seining September 2000. Beach codes are: In = Inch, Br = Brandon, Vn = Ventry and Sk = Smerwick. The numbers correspond to the haul number on the beach. In1, Vn2 and Vn3 were not included due to a high catch of weed



2.4.3.2c September 2001

A similar pattern was noted in 2001 as to that seen in previous surveys (Figure 23). Replicates from the same beach did not cluster together. Again similarities between beaches were greater than similarities between replicates within beaches. The overall similarity between all hauls was 74 percent.

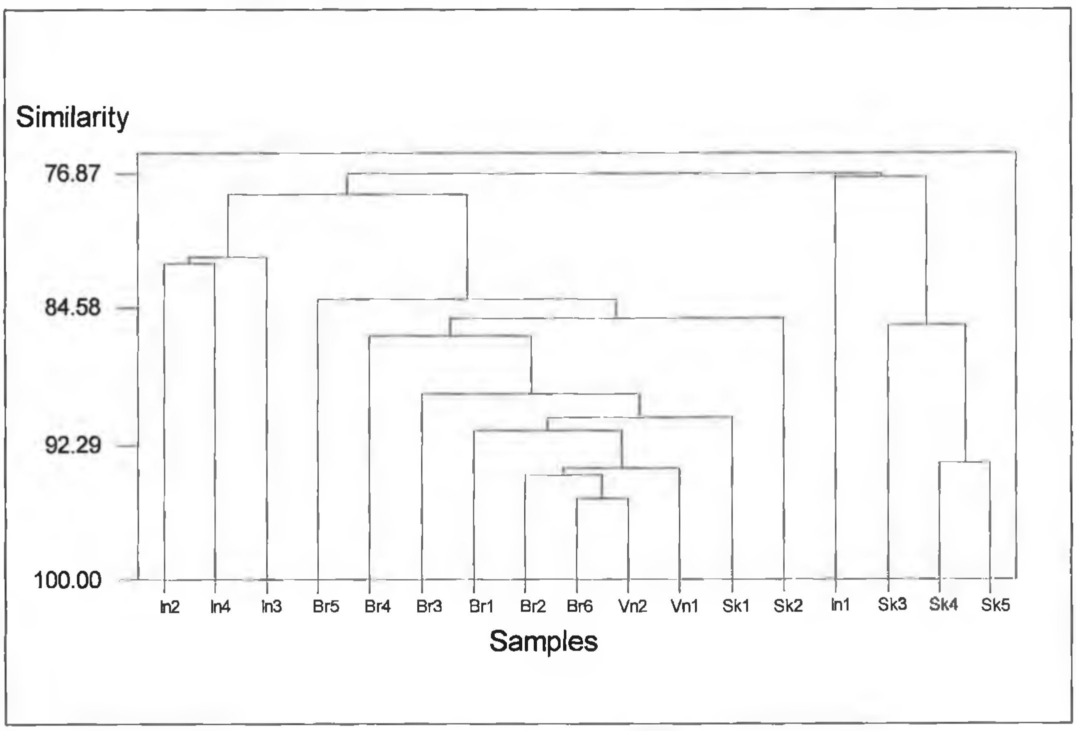
Figure 23: A dendrogram of the cluster analysis carried out on the Dingle beach seining September 2001. Beach codes are: In = Inch, Br = Brandon, Vn = Ventry and Sk = Smerwick. The numbers correspond to the haul number on the beach



2.4.3.2d September 2002

In 2002, the overall similarity was 77 percent (Figure 24). Three groups emerged in the analysis. Three out of four Inch hauls clustered together at 82 percent, the other Inch haul and three from Smerwick clustered together at 77 percent, and a large group containing all other hauls had a similarity of 84 percent. As with 2001, between beach similarities were greater than similarities between replicates.

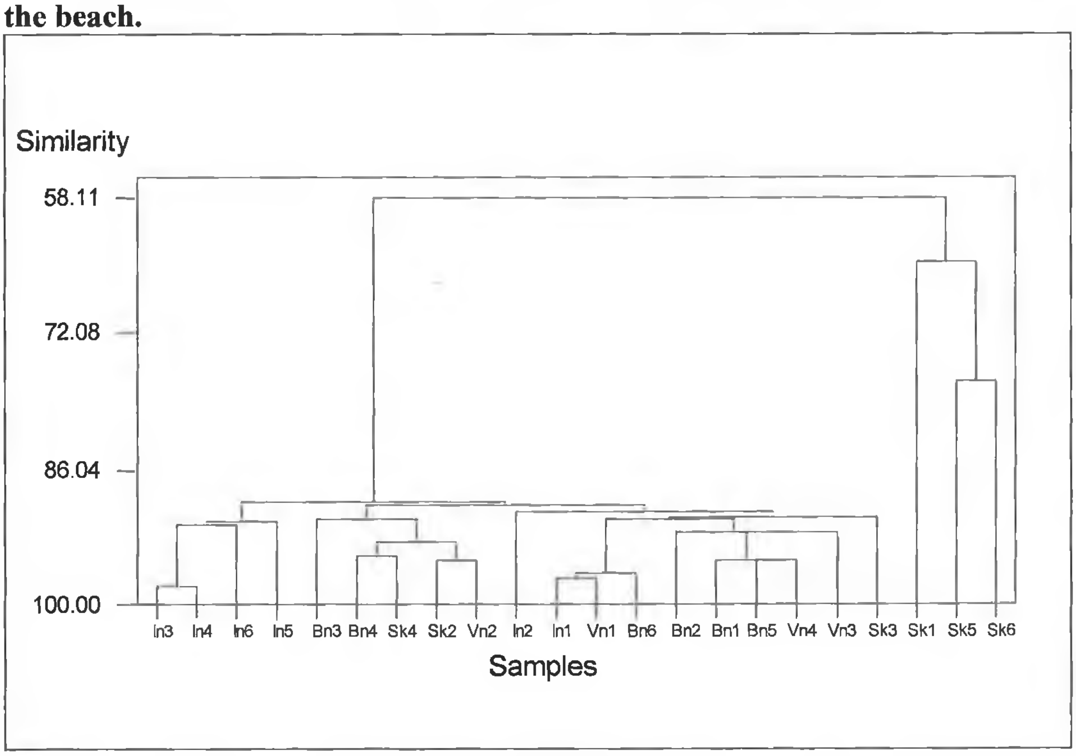
Figure 24: A dendrogram of the cluster analysis carried out on the Dingle beach seining September 2002. Beach codes are: In = Inch, Br = Brandon, Vn = Ventry and Sk = Smerwick. The numbers correspond to the haul number on the beach. Vn1 and Br1 were excluded due to a high catch of weed



2.4.3.2e September 2003

The cluster analysis for September 2003 (Figure 25) showed that with the exception of three Smerwick hauls, the overall similarity was 89 percent. Sk1, Sk5 and Sk6 showed a similarity of 58.1 percent to the main group. On no occasion did all replicates from the same beach cluster together. This follows the results of all past surveys, in that replicates within beaches showed less similarity than samples from different beaches.

Figure 25: A dendrogram of the cluster analysis carried out on the Dingle beach seining September 2003. Beach codes are: In = Inch, Br = Brandon, Vn = Ventry and Sk = Smerwick. The numbers correspond to the haul number on the beach.

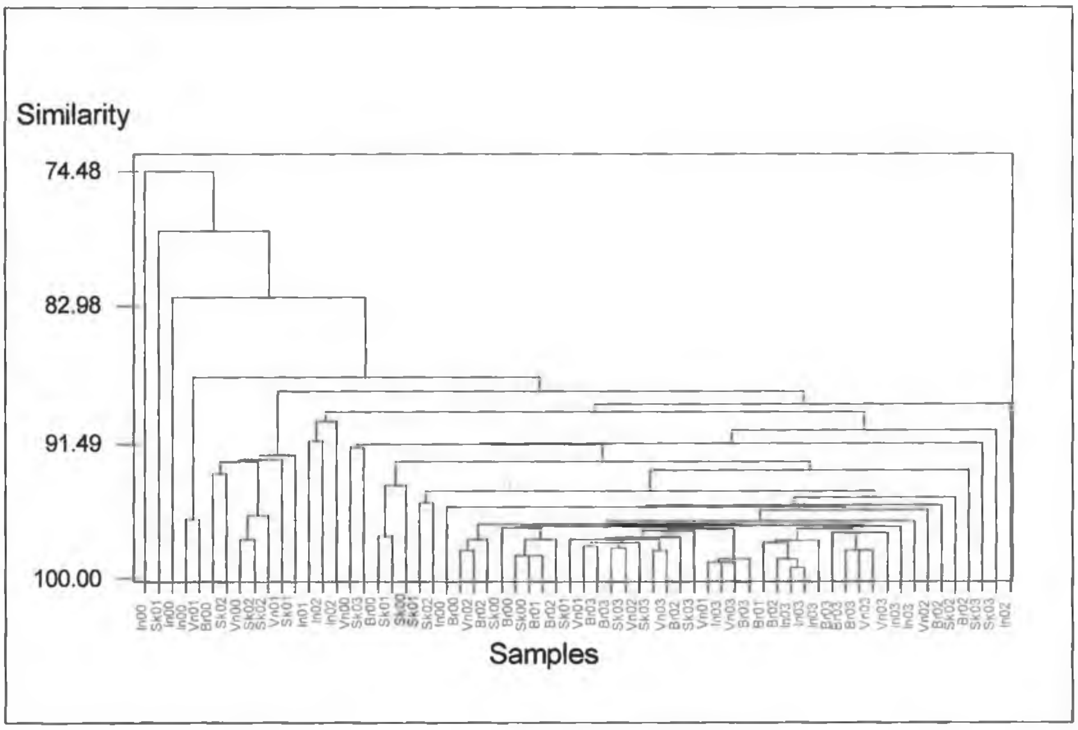


From the cluster analysis, it was noted that over the four-year period all hauls from any given beach failed to cluster together. This signifies that within beach similarity on Dingle beaches is low. However, this type of result indicates that between beach similarity is high, with hauls from various beaches clustering together.

2.4.3.3 Overall analysis

All replicates from all September surveys (except weedy samples) were pooled together for an overall cluster analysis (Figure 26). With the exception of three hauls, two from 2000 and one from 2001, all hauls had a high similarity of 87 percent. No clear pattern was seen in this analysis. The replicates did not separate out by beach. Also, no yearly separation was apparent.

Figure 26: Overall analysis of replicate from the September surveys. Weedy samples were excluded here.



2.4.3.4 Multivariate analysis: MANOVA

Cluster analysis showed that over the four-year period there was no obvious difference between beaches or between years. A MANOVA carried out on September survey data found that there was a highly significant interaction between beach and year ($p < 0.001$). Therefore no general conclusions can be drawn on the differences between beach and between years.

2.4.3.5 Plaice densities

Densities per $1000m^{-2}$ were calculated for 0+ plaice only. The results are given in Table 7.

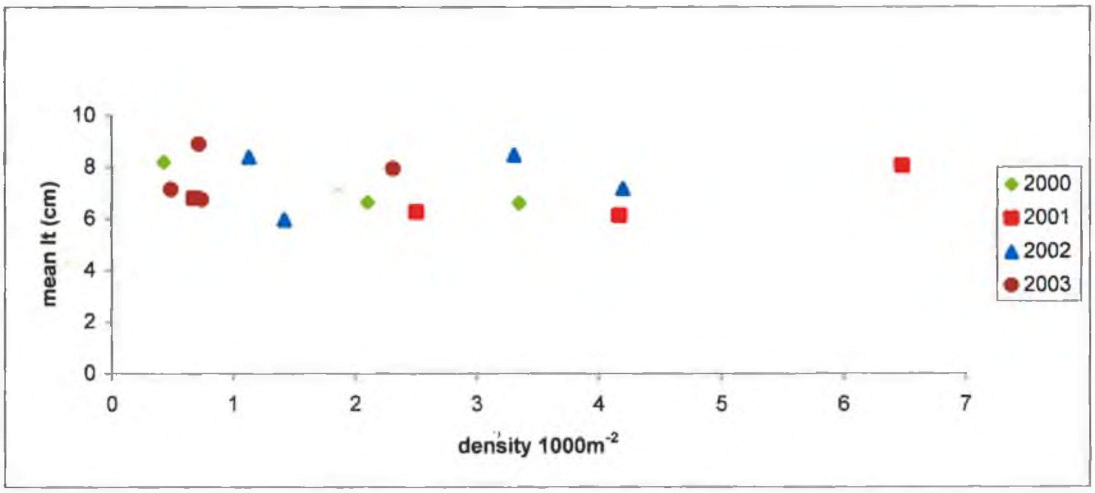
Table 7: Mean densities per $1000m^{-2}$ for 0+ plaice caught in the beach seining surveys from 2000 to 2003 in Dingle. N/S = location not sampled. N/A = not applicable here.

	May-00 Mean ±SD $1000m^{-2}$	***Sep-00*** Mean ±SD $1000m^{-2}$	***Sep-01*** Mean ±SD $1000m^{-2}$	***Sep-02*** Mean ± SD $1000m^{-2}$	***Sep-03*** Mean ± SD $1000m^{-2}$
Inch	N/S	4.3	64.8 ± 25.4	33.1 ± 8.3	4.9 ± 2.9
Brandon	6 ± 2.7	33.5 ± 23	6.8 ± 6.6	11.3 ± 5.1	7.2 ± 6.2
Smerwick	10.3 ± 3	21 ± 14	41.7 ± 25.8	42 ± 24.1	23.1 ± 11.8
Ventry	14.4 ± 3.8	51 ± 13	25 ± 19.1	14.2 ± 9.4	7.4 ± 4.5

Mean densities ranged from 4.3 $1000m^{-2}$ on Inch in September 2000 to 64 ± 25.4 $1000m^{-2}$ on Inch in September 2001. Densities were lower on Inch in 2002 (33.1 ± 8.3) and then very low in 2003 (4.9 ± 2.9 $1000m^{-2}$). Low densities were also recorded in May. Densities in Smerwick were very similar in 2001 (41.7 ± 25.8 $1000m^{-2}$) and 2002 (42 ± 24.1 $1000m^{-2}$), while in 2003 the mean density was lower at 23.1 ± 11.8 $1000m^{-2}$. In Brandon mean densities ranged from a high of 33.5 ± 23 $1000m^{-2}$ in September 2000 to a low of 6.8 ± 6.6 $1000m^{-2}$ in September 2001. Lowest densities were recorded in 2003 in Ventry with the highest densities in September 2000.

As with the Galway results, no correlation was observed between the mean length and the density of 0+ plaice in the September samples on all beaches (Pearson's correlation on ranked data R^2 = -0.288, p = 0.279, Figure 27).

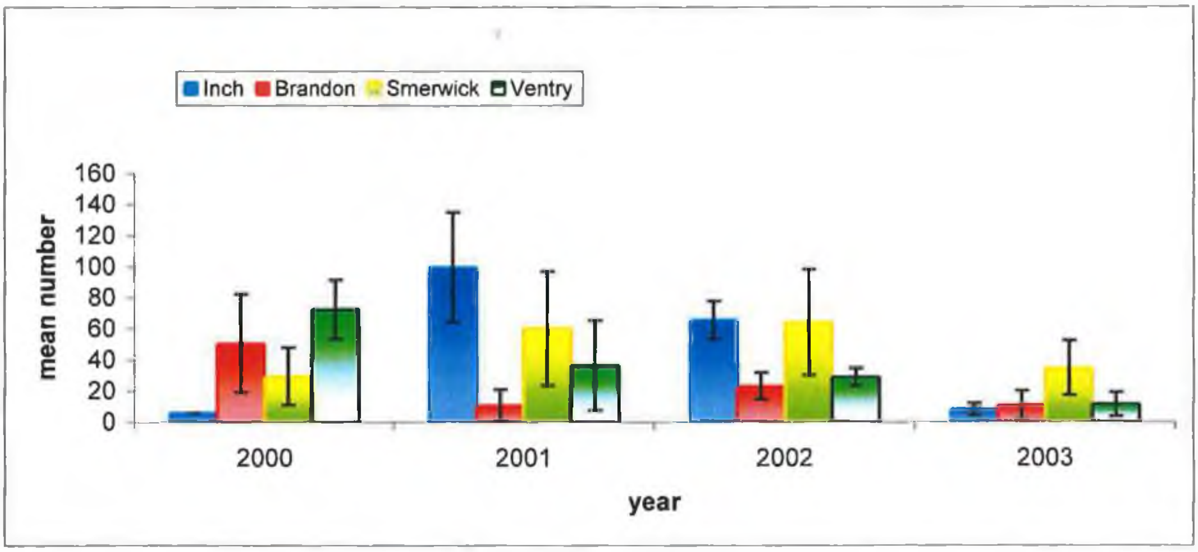
Figure 27: Mean densities plotted against mean length of 0+ plaice from all beaches for the September surveys 2000 to 2003



2.4.3.6 Plaice: Year and beach variation in densities

The mean abundance of plaice caught in all September surveys was analysed for yearly variation in catches. Figure 28 shows the mean abundance (± SD) for each year on all beaches sampled. Inch and Smerwick showed a decline in numbers from 2001 to 2003. Brandon and Ventry recorded decreasing numbers from 2000 to 2003. A Two-Way ANOVA on beach and year plaice densities showed that there was a very highly significant interaction ($p < 0.001$) between beach and year. Therefore no general conclusions can be drawn.

Figure 28: The mean abundance (± SD) of 0+ plaice caught in the Dingle beach seining from 2000 to 2003. May sample is not included.



2.4.3.7 Plaice: size frequency and age

As with the Galway data, size frequencies analysis for Dingle was carried out on plaice only, due to low catches of all other species. Dingle length classes were measured to the nearest 1cm as opposed to the 0.5cm used in Galway. Only the 0+ plaice were used, as these constitute the majority of the catches (Table 8).

Table 8: The number of 0+, ≥1+, 0+ as a percentage and the mean size of 0+ plaice caught in the Dingle Beach seining from 2000 - 2003

	No. of 0+	No. of ≥1+	% of 0+	mean size (cm)	±SD
May-00	151	97	61	4.5	0.84
Sep-00	427	18	96	6.5	1.88
Sep-01	859	63	93	7	1.66
Sep-02	623	142	81	7.6	1.54
Sep-03	337	39	90	7.9	1.44

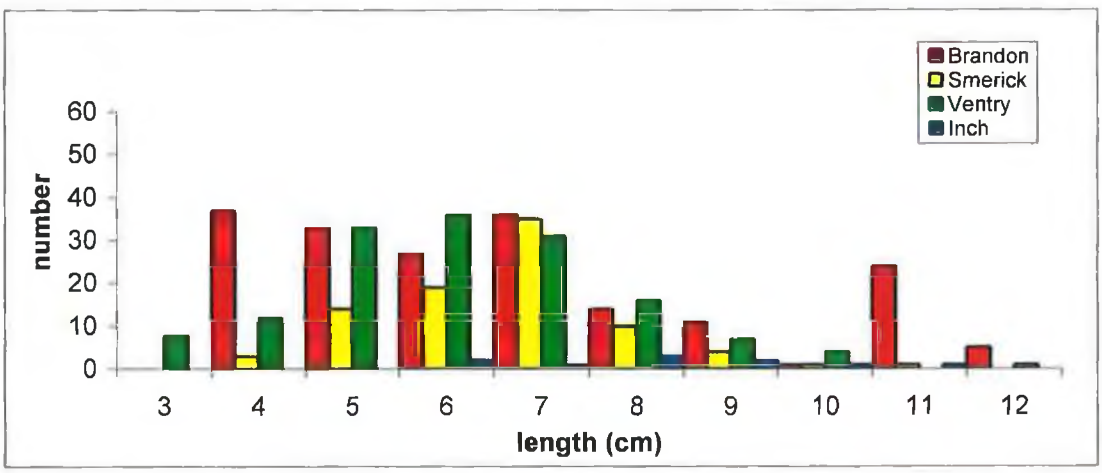
Dingle age data are only available for September 2003, as all fish were returned in previous years. Therefore for 2000, 2001 and 2002 the assumption was made (from length frequency analysis) that the size range of 0+ plaice was the same or similar as that taken from September 2003 in Dingle and from the Galway data i.e. all fish ≤ 11cm were considered to belong to the 0+ age group. In May 2000, the 0+ fish ranged in size from 3 – 7cm. In the September samples the smallest 0+ fish recorded was 3cm while the largest 0+ fish was 11cm.

In May 2000 the mean size of a juvenile plaice was 4.5cm ± 0.84 SD. Further analysis of the data was not carried out due the low numbers recorded in the May samples.

2.4.3.7a September 2000

The mean length for 0+ plaice in September 2000 was 6.5cm ± 1.88. Ventry showed modal size at 6cm and the sizes ranged from 3 to 10cm. The range in Brandon and Smerwick was 4 to 11cm, and they both shared the same modal size of flatfish at 7cm (Figure 29). However, Brandon also had high numbers at 4cm and 11cm. Not enough plaice were caught on Inch to detect any size structure of the 0+ fish.

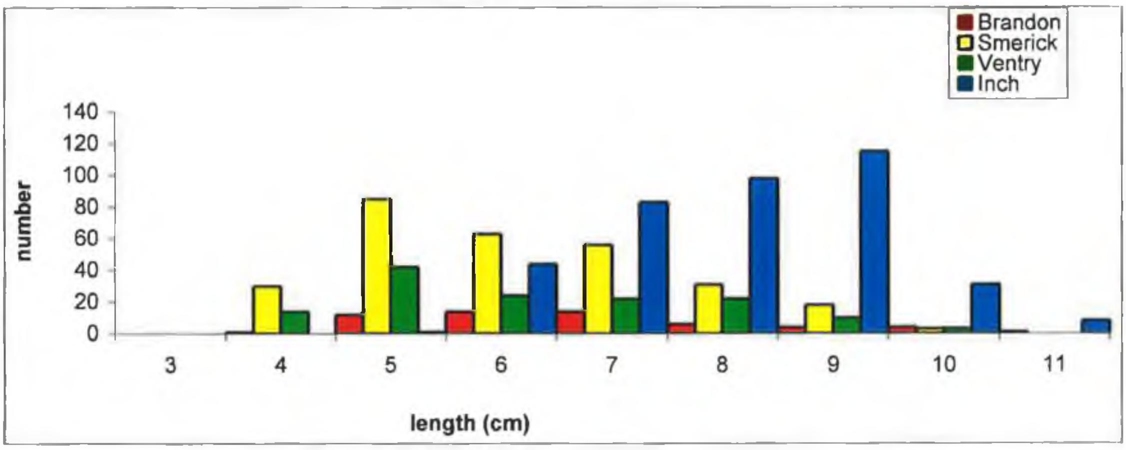
Figure 29: Size frequency distribution of 0+ plaice sampled in the Dingle beach seining in September 2000



2.4.3.7b September 2001

The mean size for juvenile plaice in 2001 was 7cm ± 1.66 SD an increase of 0.5cm from 2000. In this year the modal size of flatfish on Smerwick and Ventry was 5cm (Figure 30). The size of flatfish on these beaches ranged from 4 to10cm. The modal size in Inch was at 9cm, while the smallest fish caught here were 6cm. Low returns in Brandon showed no distinct pattern in the size frequency for that beach.

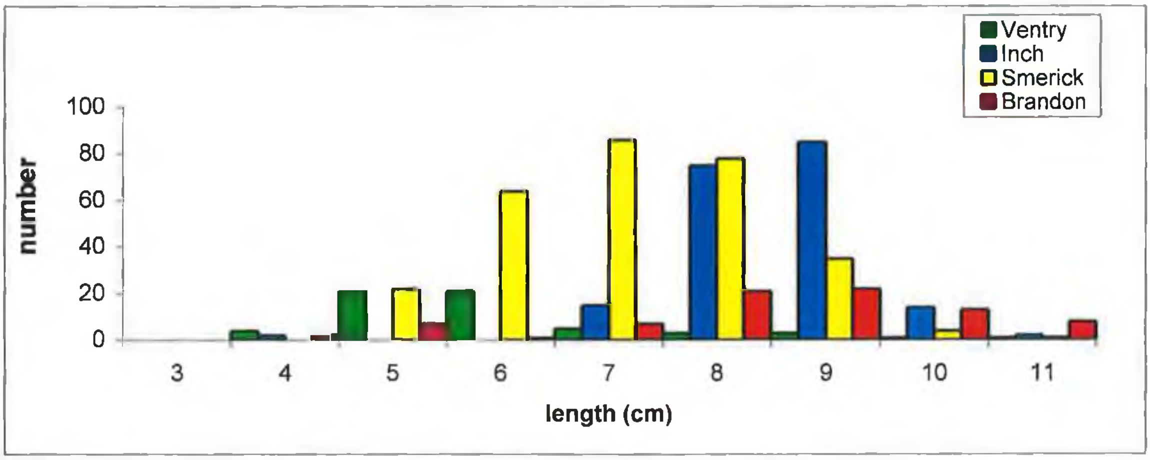
Figure 30: Size frequency distribution of 0+ plaice sampled in the Dingle beach seining in September 2001



2.4.3.7c September 2002

The mean size for the 0+ fish was 7.6cm ± 1.54 SD, again an increase (0.6cm) from the previous year. Figure 31 shows the size frequency distribution. A similar pattern to that seen in 2001 occurred in 2002 in that larger fish were caught on Inch. Again the modal size on Inch was in the 9cm length class. Smerwick's modal size was 7cm, which is a 2cm increase from the previous year. The range here was from 5 to 10cm. From the small numbers caught in Brandon it can be seen that larger fish (8,9 and 10cm) occur here. In contrast Ventry recorded greater numbers of smaller fish (5 and 6cm).

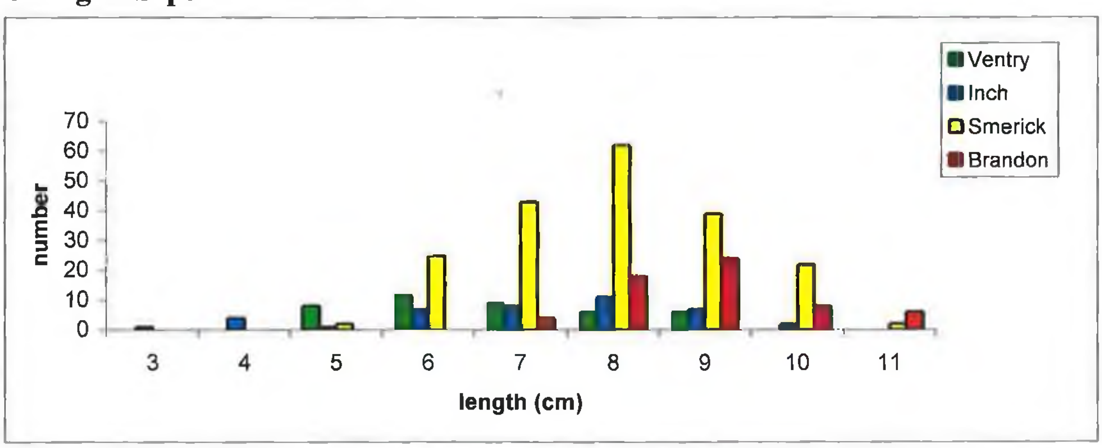
Figure 31: Size frequency distribution of 0+ plaice sampled in the Dingle beach seining in September 2002



2.4.3.7d September 2003

The mean length for 0+ plaice in 2003 was 7.9cm ± 1.44, which is another increase (0.3cm) from the preceding year. The modal size in Smerwick was at 8cm, with a range of 5 to 11cm (Figure 32). Brandon had a similar distribution to 2002 with a modal size of 9cm and a range of 7 to 11cm. Not enough fish were captured in Ventry and Inch to identify size frequency signals.

Figure 32: Size frequency distribution of 0+ plaice sampled in the Dingle beach seining in September 2003



2.4.3.8 Plaice: Variation in mean length between beaches and between years

The difference in the mean size of 0+ plaice on each beach was assessed for the September samples for all years. Table 9 shows the mean size of 0+ plaice for the Dingle beach seining.

Table 9: Mean size (cm) ± S D of 0+ plaice for all September beach seining samples from Dingle 2000 – 2003.

	Sep-00 Mean length ± SD (cm)	*Sep-01* Mean length ± SD cm)	*Sep-02* Mean length ±SD (cm)	*Sep-03* Mean length ±SD (cm)
Inch	8.2 ± 1.61	8.07 ± 1.23	8.49 ± 0.9	7.14 ± 1.72
Brandon	6.62 ± 2.24	6.8 ± 1.61	8.41 ± 1.72	8.9 ± 1.05
Smerwick	6.64 ± 1.28	6.13 ± 1.42	7.19 ± 1.19	7.94 ± 1.25
Ventry	6.12 ± 1.59	6.27 ± 1.57	6 ± 1.45	6.75 ± 1.33

An interaction between beach and year was noted ($p < 0.001$ Two-Way ANOVA). This indicates that beach and year are not independent of each other. Hence no general conclusions can be drawn on differences between beaches and year.

2.4.3.9 Densities of other flatfish species

Densities for other flatfish caught (i.e. turbot, flounder, brill, dab and sole) were calculated for all the September surveys. Due to lower numbers of these flatfish overall, all age groups were included in the analysis. However, the majority of fish caught were juveniles (0+). All the above species were of secondary importance to the dominant plaice.

Mean densities $\pm$ SD are shown in Figure 33. Turbot had the highest density particularly on Inch and Brandon. On Inch, turbot density ranged from 3.7 ± 1.7 $1000m^{-2}$ in 2003 to 18.4 ± 6.8 $1000m^{-2}$ in 2002, while in Brandon densities ranged from a low of 0.6 ± 0.5 $1000m^{-2}$ in 2003 to a high of 4.7 ± 2 $1000m^{-2}$ in 2002. The highest occurrence of turbot, on Smerwick, was in 2000 with a mean density of 4.8 ± 2.7 $1000m^{-2}$. Few turbot were caught on Ventry.

Brill had a low occurrence throughout. The highest density was recorded in Ventry in 2000 (2.5 ± 2.5 $1000m^{-2}$), while the lowest density was noted on Smerwick in 2001 (0.15 ± 0.35 $1000m^{-2}$).

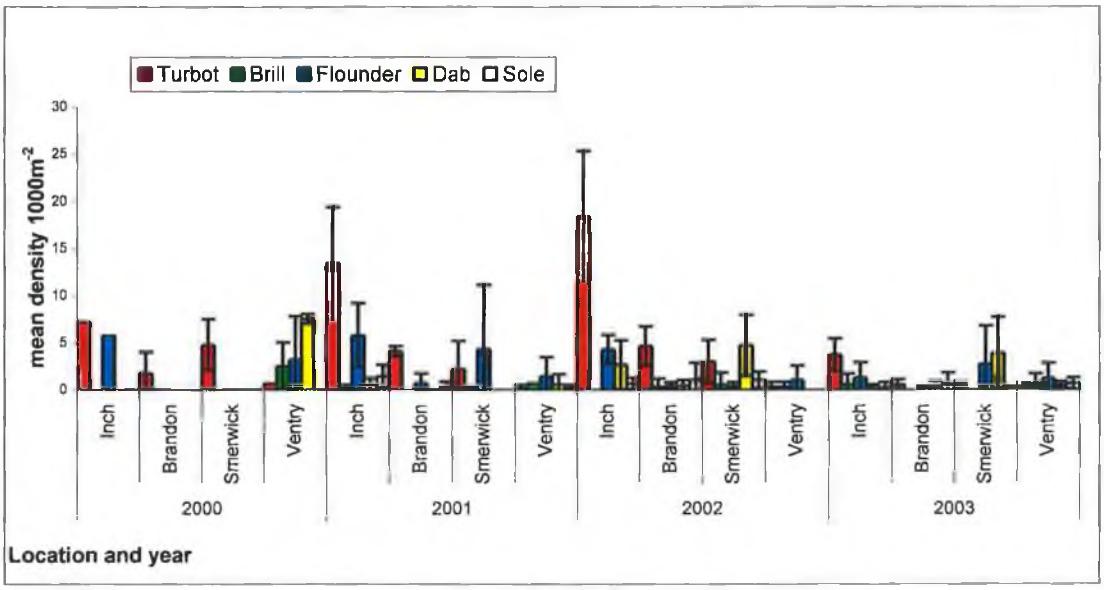
Flounder were caught in moderate numbers throughout. The highest recorded density was on Inch in 2001 (5.8 ± 3.4 $1000m^{-2}$), with the lowest density noted on Brandon in 2003 (0.12 ± 0.2 $1000m^{-2}$). Flounder were caught on all beaches with the exception of Inch, Brandon and Smerwick in 2000.

The highest densities of dab were recorded on Ventry in 2000 (7.6 ± 4.6 $1000m^{-2}$), Inch and Smerwick in 2002 (2.7 ± 2.6 $1000m^{-2}$ and 4.7 ± 3.2 $1000m^{-2}$ respectively) and Smerwick again in 2003 (3.9 ± 3.8 $1000m^{-2}$). Other occurrences of dab had very low densities.

Sole had the lowest occurrence of all flatfish caught. The highest density recorded was on Inch in 2001 (1.5 ± 1.2 $1000m^{-2}$), with the lowest density noted on Smerwick in 2003 (0.12 ± 0.2 $1000m^{-2}$).

A MANOVA on the flatfish densities excluding plaice, showed that there was a highly significant interaction between beach and year ($p = 0.001$). No further analysis was undertaken here.

Figure 33: Mean densities ±SD ($1000m^{-2}$) of turbot, brill, flounder, dab and sole for all beaches sampled in the Dingle beach seining from 2000 to 2003



2.4.3.10 Summary

Plaice were the dominant species and 0+ plaice were the dominant age group. Cluster analysis showed that no between beach or between year difference existed in the flatfish composition. The MANOVA found that there was significant interaction between beach and year. Therefore beach and year were not independent of each other and no general conclusions were drawn. Plaice densities and mean lengths showed significant interactions between beach and year. Thus, no further analysis was undertaken. No correlation was detected between mean length and density in the September samples. For the flatfish composition, excluding plaice, again there was a significant interaction between beach and year, which is consistent with the analysis when plaice were included.

2.4.3.11 Galway and Dingle overall analysis

No significant yearly difference was detected in flatfish composition, plaice density, plaice mean size and flatfish composition, excluding plaice, in either location over the four years of the study. A significant difference between beaches was detected in Galway but not in the Dingle area. Also, the composition of flatfish excluding plaice was significantly different between beaches in Galway but this was not detected in the Dingle samples. No correlation was detected between the mean length of plaice and the density in the September samples in both locations.

2.5 Discussion

Weed had a negative effect on the numbers of flatfish caught by the beach seine. Wilding *et al.* (2000) stated that the beach seine becomes inefficient catching less fish with the presence of weed. This effect of weed on the gear efficiency could be due to the absence of flatfish where weed is present, or a large amount of weed effecting the hauling speed of the seine and hence capture efficiency. Also, visibility of the beach seine may increase with the presence of weed.

The species of flatfish recorded in Galway and Dingle were plaice, turbot, flounder, brill, dab, and sole (either *Solea solea* or *Pegusa lascaris*). This composition of flatfish is very similar to that recorded by Riley *et al.* (1981) in British waters and Harlay *et al.* (2000) off the Opale coast, north of France. However, Riley *et al.* (1981) also caught solenette (*Buglossidium luteum* Risso), which was not recorded in any of the beach seine samples off the west coast of Ireland. The flatfish composition noted by Mansoor (1982) in the Irish Sea was identical to that recorded by Riley *et al.* (1981). On the south west coast of Ireland Markham (1981) recorded plaice, flounder, turbot and brill in beach seine samples with no sole or dab occurring. In Gibson *et al.* (1993), the flatfish composition caught off Scotland using a beach seine was very similar to the composition noted in Galway and Dingle. However, the beam trawl sampling carried out by Gibson *et al.* (1993) had a more diverse catch of flatfish species than that of the beach seining. This is an indication that beach seining is selective in sampling flatfish (due to depth and sediment disturbance) and could misrepresent the coastal flatfish composition. Lower numbers of flatfish were caught in May opposed to the September sampling. This could be due to the size selectivity of the beach seine for 0+ fish which are still undergoing settlement in May.

Plaice were the numerically dominant flatfish species caught in the majority of hauls in the Dingle and Galway regions. There were a few exceptions to this, where flounder were the dominant flatfish. Flounder mostly dominated in the estuarine influence beach of Ballyloughaun where salinities were recorded down to 11. Also, one haul in Lahinch had a high catch of flounder. Again this haul was located close to a river. Mansoor (1982) found plaice to dominate the numbers of flatfish caught in beach seine samples on the east coast of Ireland with the exception of one location where brill was the dominant species. Markham (1981) showed 0-group plaice and flounder to alternate in dominance depending on the sampling location around Sherkin Island Co. Cork. Nash *et al.* (1994b) found that plaice were the dominant flatfish species caught in beach seine samples in Port Erin, Isle of Man. In Scottish waters, Gibson *et al.* (1993) recorded plaice as the dominant flatfish using beam trawling and beach seining. Amara and Paul (2003) found that plaice were the most abundant flatfish species recorded in beam-trawl surveys carried out on the French coast of the Eastern channel, while Harlay *et al.* (2000) noted that plaice were the dominant flatfish in an intertidal area sampled off the Opale coast (North of France).

0+ group individuals dominated the plaice populations. This is usually the case in the intertidal area (Riley *et al.* 1981). The mean densities of 0+ plaice on beaches on the west coast of Ireland ranged from 1.6 to 64 $1000m^{-2}$ in the September samples. Kuipers (1977) found a mean density of 6.8 $1000m^{-2}$ in September beam trawl sampling in the Wadden Sea, within the range recorded on the Irish west coast. Also, in the Wadden Sea, Zijlstra *et al.* (1982) recorded the density of juvenile plaice at 1.7 $1000m^{-2}$ in 1974. The mean September densities over a four-year period ranged between 10 and 40 $1000m^{-2}$ in Scottish waters (Steele and Edwards 1970), while off the French coast the September density was recorded at 1.0 $1000m^{-2}$ (Amara and Paul 2000). The beach seining carried out on the west coast of Ireland therefore produced densities of plaice similar or within ranges noted in other locations.

Significant spatial variation was noted for 0+ plaice in Galway Bay. However, in the Dingle, significant interactions were noted between beaches and years. Mansoor (1982) observed a difference in the abundance of flatfish (dominated by plaice) between beaches, exposed shores had the fewest flatfish, with more sheltered shores having higher abundances. Mansoor (1982) had two years data and the differences were merely noted, without any statistical analysis of their significance. Markham (1981) found the abundance of plaice on a once off survey to vary between beaches, again, however, no statistical analysis was carried out here. Pihl *et al.* (2000) noted that densities in May 1998, on the Swedish Shagerrak archipelago, differed significantly over four regions by an order of magnitude with higher densities in the northern areas than in the southern. Also, spatial variations were detected within these regions. These differences were analysed by nested ANOVA's. Pihl and Van der Veer

(1992) found the high plaice densities in exposed beaches to significantly differed using One-Way ANOVA's, from protected (sheltered) areas by a factor of ten, while the most productive beaches for plaice were semi-exposed. In the present study, the exposed beaches (Lahinch, Fanore) were the least productive in Galway Bay, while, in Dingle, the highest and lowest recorded densities were in Inch (exposed shore similar to Lahinch) on alternate years. Zijlstra *et al.* (1982) noted spatial variation in the abundance of settling plaice in the Wadden Sea and found that the variation was closely associated with fine sand and moderate silt type sediment having a high biomass of macro-benthic animals. Zijlstra *et al.* (1982) did not however, subject their data to any statistical analysis. Pihl *et al.* (2000) stated that the density of plaice on a nursery ground could be due to differential larval supply, habitat selection at settlement, differences in post-settlement mortality and/or migration after settlement. Pihl and Van der Veer (1992) suggested that on the Swedish coast, larval supply to the nurseries is rather constant, and therefore, the ultimate density seems at least partly to be determined by processes acting within the nurseries during and after settlement. Other reasons causing spatial variation could be varying efficiencies of the beach seine on the different types of beaches. Mansoor (1982) stated that beach seining efficiency was poorer on exposed shores due to wave action lifting the net and temporary offshore migration of the fish. Also, Wilding *et al.* (2000) stated that one of the disadvantages of beach seining is that rough conditions make it difficult to deploy and hence the efficiency might be decreased. Nash *et al.* (1994b) found that in Port Erin wave action probably did influence the plaice catch, due either to the plaice burying in the sand to a greater extent than normal, moving offshore or a combination of both. In the case of the exposed shores in Galway and Dingle offshore movement is more likely to contribute to low catches as the addition of an extra tickler chain on the beach seine is likely to disturb all flatfish. However, the impact of wave action on beach seine efficiency has not been experimentally addressed in any investigations.

The beach seine provides an estimate of 0+ year-class strength for west of Ireland plaice. Significant interactions of plaice numbers between beach and year were noted in Dingle from 2000 to 2003. In Galway Bay, no significant difference was detected between 2002 and 2003. Gibson *et al.* (1993) reported differences in year-class strengths for plaice both in beach seine and beam trawl samples in Scottish waters over a four-year period in the eighties. Gibson *et al.* (1993) found the beam trawl to catch higher numbers of plaice than the beach seine, but the two gears detected similar differences between years. These reported differences were not, however, statistically analysed. Gibson *et al.* (1993) described plaice as a periodic species (only present on the beach at certain times of the year) and found periodic species to vary from year to year, more so than the regular species found on the beach year round. Van der Veer and Bergman (1987) found that shrimp predation appears to act as a fine control mechanism in the Wadden Sea, reducing between year variations in year class strength generated in the egg or larval stages in the open sea. Similar processes may be working on the west coast of Ireland. However, shrimp densities were not estimated in the current survey. Also the processes which operate in the Wadden Sea may be different to those operating on nursery grounds around the Irish Sea and Scottish waters (Van der Veer *et al.* 1990). Steele and Edwards (1970) suggested that settlement does not determine population densities at the end of the summer growth phase before the flatfish start to emigrate to deep water. There have been no investigations examining the efficiency of beach seining in determining numbers of juvenile plaice recruiting to the fishery. On the west coast of Ireland it is not possible to determine the value of beach seining as a recruitment index due to the unknown efficiencies of the beach seine and the relative short time series available. To do this, a longer time series is required and this could then be compared to data on the adult stocks.

The overall mean sizes of 0+ plaice ranged from 7.19 ± 1.2 to 8.94 ± 0.9cm in Galway and 6 ± 1.4 to 8.9 ± 1.0cm in Dingle. In Icelandic waters, Hjorleifsson and Palsson (2001) found the mean size of plaice in September to be approximately 7cm. To the south, Steel and Edwards (1970) noted a range of mean sizes of 5.5 to 7cm in September over a four year period in Scottish waters. The most southern data available is from the Wadden Sea, where the mean size of plaice in September was recorded at 9.7cm (Kuipers 1977). A pattern is noted here of smaller mean sizes recorded in September sampling in northern areas to larger fish in September sampling in more southern locations. The west of Ireland results fit into this pattern of increasing mean size of 0+ plaice with lower latitudes. Bergman *et al.* (1988) suggested that the difference in mean length in autumn 0-group plaice could be due to differences between years in water temperature and in length at the start of the growth season just after settling. Timing of settlement may also have a bearing on the mean length in autumn. Steele and Edwards (1970) noted that the differences in the mean length of the populations in different years are partly a consequence of the different patterns of settlement earlier in the year. Hence, the mean size of plaice in Galway and Dingle samples could be due to the varying age of fish, as opposed to faster growth rates or a combination of both.

It is suggested that growth of 0-group plaice in the Wadden Sea is affected by the density of the fish, because of an inverse relationship observed between abundance of the juvenile plaice and their mean length at the end of the growing season (Rauck and Zijlstra 1978 in Zijlstra *et al.* 1982). Zijlstra *et al.* (1982) found a similar relationship between mean length and abundance of plaice. Nash *et al.* (1994a) noted lower growth rates at higher densities for plaice. In the present west of Ireland study, no correlation was found between the mean length and density of plaice. A correlation may not exist on the west coast of Ireland. However the above studies used different fishing techniques to those used in the current survey and hence there could be an underestimation of densities due to the unknown efficiency of beach seines in the sampling of 0+ plaice.

Chapter 3: Settlement, seasonal occurrence, growth and mortality of 0-group plaice (*Pleuronectes platessa* L.) in Galway Bay on the west coast of Ireland.

3.1 Abstract

In March of 2002, a monthly push-netting sampling programme was set up to determine the settlement timing, seasonal occurrence, growth and mortality of 0+ plaice in Galway Bay. Sampling was carried out on Silverstrand and Ballyloughaun near Galway city. Settlement of 0+ plaice occurred in late April in 2002, while in 2003 the first settlers were noted a month earlier in March. This was consistent with settlement patterns recorded in European waters. Peak densities on Silverstrand were 31 and 237 $1000m^{-2}$ from 2002 to 2003 respectively. In Ballyloughaun peak densities were 44 and 277 $1000m^{-2}$ over the two year period. The peak densities were noted in May and June in Silverstrand and Ballyloughaun in 2002 respectively. In 2003 the peaks were in April and May. After peak densities occurred there was a steady decline in the density of plaice into the autumn months. This seasonal pattern is the same as that recorded on nursery grounds in other areas around Europe. Growth rates were similar on Silverstrand and Ballyloughaun in 2002. However, in 2003 the growth rate observed in Silverstrand was higher than that observed in Ballyloughaun. When the observed growth rates were compared to a model growth rate obtained at optimum feeding conditions it was found that the observed growth was similar to predicted growth. Daily mortality rates calculated show that the highest mortality recorded in 2002 was on Silverstrand, and in 2003 on Ballyloughaun. Growth and mortality rates were within the ranges recorded elsewhere in Europe. Experimental push-netting carried out showed that depth does not influence the catches of 0+ plaice in shallow water. However, the experimental work proved that sampling at night produced significantly higher densities of 0+ plaice.

3.2 Introduction

Plaice are an important commercial species in Ireland. On average, Ireland had 95 percent of the total international landings of this species between 1993 and 2001 (Anon 2003). Plaice are normally caught in mixed species, otter trawl fisheries and are a very economically important component in ICES area VIIb (Irish west coast). Little is known about the state of the stock on the Irish west coast. Catches declined since 1995 to a historic low in 2001. In 2001 the value of the Irish quota was €0.5m. The current management advice for this stock is that catches in 2003 be no more than the recent average (1998-2000) of around 160 t in order to avoid an expansion of the fishery until there is more information to facilitate an adequate assessment (Anon 2003). In the Galway region, once landed, the plaice are usually processed locally. Medium-large fish are kept for sale within the country, with high demands in Dublin and Cork. Smaller plaice are exported to Grimsby, England or to Holland (Pers comm. Dr. Pete Tyndall B.I.M. Galway).

In general, plaice spawn in offshore waters. In the North Sea spawning takes place from December to March (Bergman *et al.* 1988) while in the Irish Sea the spawning period extends from late January to early May (Armstrong *et al.* 2000 in Nash and Geffen 2000). After hatching, the larvae are distributed to local nursery areas by residual currents (Bergman *et al.* 1988). The number of plaice larvae reaching suitable beaches is determined by drift and diffusion of eggs and larvae from offshore grounds where spawning takes place (Steele and Edwards 1970). At the end of the larval period, metamorphosis takes place and the fish adopt a benthic mode of life. This metamorphosis is termed settlement.

The settlement of plaice onto nursery grounds occurs when the fish are between 10 – 15mm in length (Bergman *et al.* 1988). The timing of this settlement varies depending on the location. Hjorleifsson and Palsson (2001) noted newly settled plaice in low numbers at the end of May in Icelandic waters. On the Swedish west coast Modin and Pihl (1996) observed juvenile plaice in mid May of 1991, while in 1992 the fish were first noted in late April. In the Wadden Sea, in the period from 1972 to 1975 settlement generally started in April (Kuipers 1977, Zijlstra *et al.* 1982). Van der Veer (1986) found newly settled plaice to occur as early as February in the period 1980 to

1982 in the Wadden Sea. Lockwood (1974) found the settlement of plaice to take place in early-mid May in Filey Bay, Yorkshire. On the Irish east coast, Mansoor (1982) found that the start of the settlement period occurred in March. In the Irish Sea, Hyder and Nash (1998) recorded that settlement varied from early April on a cold year to late March on a warmer year. Amara and Paul (2003) found that plaice settlement had already begun in early April off the French coast. In this latter study, back-dating based on otolith microstructure analysis showed that peak settlement occurred in late March to mid April.

After settlement, the juveniles remain on coastal nursery grounds for at least the first six months of their life. Juvenile plaice dominate inshore sandy beach nursery grounds on the west coast of Ireland (see Chapter 2). In such areas, the environment is frequently dominated by tides and plaice show clear tidally synchronised patterns in movement (Gibson 1994). Such tidally influenced behaviour has been investigated in the past (Kuipers 1973, Van der Veer and Bergman 1986). Van der Veer and Bergman (1986) showed that the complete 0-group population left the intertidal area during ebb tide to return with the flood tide, both day and night. Kuipers (1973) suggests that these movements are feeding migrations.

Interannual variability in population size is common in juvenile plaice populations (Bergman *et al.* 1988, Van der Veer *et al.* 1990, Modin and Pihl 1994, Nash and Geffen 2000). Studies on juvenile plaice in the North Sea report that variability in year-class strength is generated during pelagic egg and larval stages (Zijlstra *et al.* 1982, Van der Veer 1986, Van der Veer and Witte 1999). Cause of fluctuations can be separated into density-independent processes related to fluctuations in the physical environment and density-dependent processes caused either by predation or food competition (Van der Veer 1986).

In the Wadden Sea, 0+ plaice suffer heavy predation for a rather short period just after settling (Bergman *et al.* 1988). Van der Veer and Bergman (1987) showed that this mortality is largely due to predation by shrimps, usually *Crangon crangon* (Linneaus). Steele and Edwards (1970) found predation to be the main cause of mortality, and that variation in the rate of predation from year to year may depend on the varying populations of predators in Loch Ewe. Van der Veer and Bergman (1987) also found that shrimp predation appears to act as a fine control mechanism in the Wadden Sea, reducing between year variations in year-class strength.

Factors affecting the rate of survival of 0+ plaice, between spawning and the stage of life where year-class strength is more or less fixed are known as recruitment processes (Van der Veer *et al.* 2000). When these processes are complete and after a summer of growth on the sandy beaches, the plaice then migrate during autumn and winter to deeper water (Modin and Pihl 1996).

The chosen method for assessing juvenile plaice stocks on sandy beaches in the Galway Bay area was a Riley push-net. The push-net is used for sampling small and young individuals in tidal pools and shallow channels (Hinz 1989). However, push-nets are limited by depth ($\leq$1m), catching mainly small demersal fish and crustaceans (Ruth and Berghahn 1989). One of the advantages of push-netting is that, as a consequence of the short trawl hauls associated with scientific sampling, fish caught are usually undamaged and in good condition, particularly if the net is emptied into a container of water (Wilding *et al.* 2000). The push-net is not a widely used method, as the beam-trawl has known efficiencies for plaice (Kuipers 1975, Rogers and Lockwood 1989, Kuipers *et al.* 1992, Wennhage *et al.* 1997).

Riley *et al.* (1981) used the Riley push-net with a distance measuring wheel attached, to sample flatfish which were dominated by 0+ plaice. In this latter study, the densities of flatfish were calculated to numbers $1000m^{-2}$. Mansoor (1982) used push-netting controlled by time (10min pushes) as opposed to covering a definite area, on the east coast of Ireland. Corlett (1967) used the same technique for capturing juvenile plaice in Strangford Lough with densities expressed per unit time.

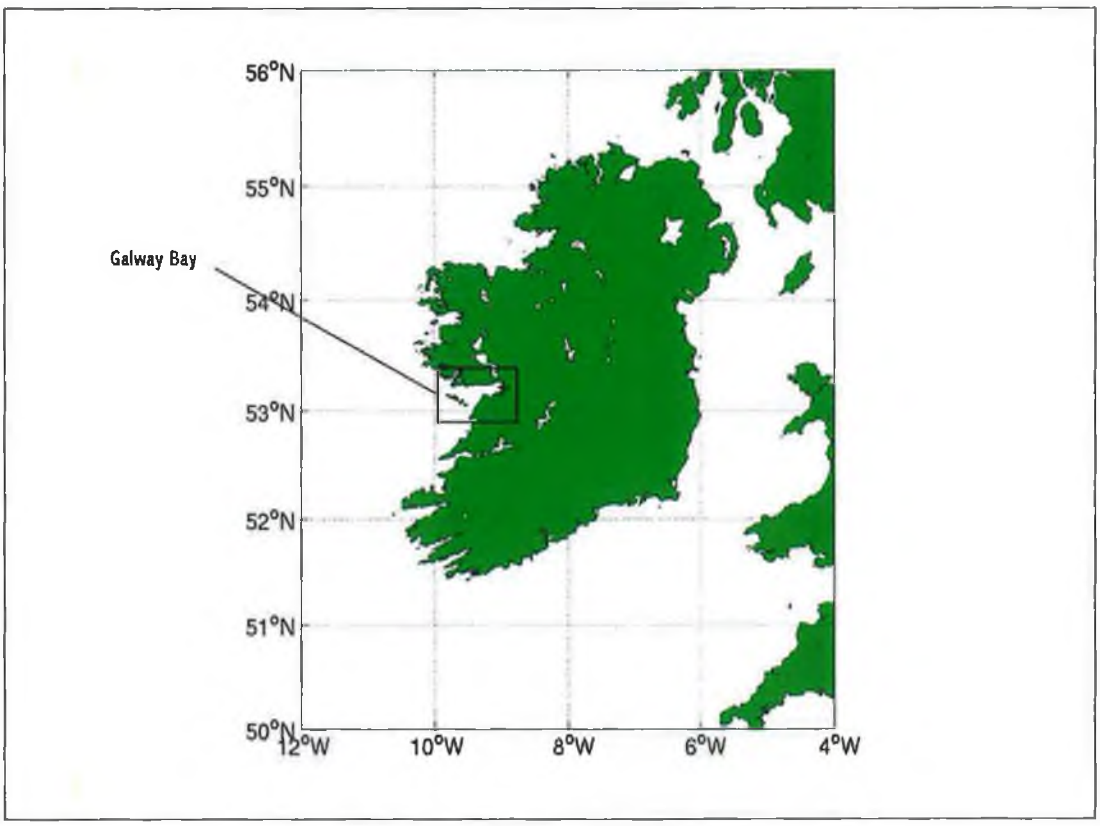
As part of a larger project on the assessment of juvenile flatfish nursery grounds, a monthly push-net sampling programme was set up in Galway Bay in 2002. The main aims of this push-net survey were to assess the importance of sandy beaches as nursery grounds for 0+ plaice; determine the critical settlement periods; quantify the abundance and assess the growth and mortality of 0+ plaice on these nursery grounds. Few studies have been carried out in Irish waters (Corlett 1962, Markham 1981, Mansoor 1982) and currently nothing has been published on the early life history of plaice on the west coast of Ireland.

3.3 Material and Methods

3.3.1 Study area

Push netting was carried out monthly from February 2002 to August 2003 in Galway Bay (Figure 34). The most southerly beach sampled was Fanore (53° 07.2`N 09° 07.6`W), an exposed shore south of Galway on the Co. Clare coast. This beach was sampled from March 2002 to September 2002 and was discontinued thereafter due to difficulty of sampling and poor returns. Bishopsquarter (53° 09.1`N 09° 07.4`W), which is north of Fanore on the Co. Clare coast, was also sampled. This is a semi-exposed beach and was sampled from May 2002 to September 2002. The latter was also omitted from the sampling protocol, for the same reasons as Fanore.

Figure 34: Map of the Irish west coast showing sampling location

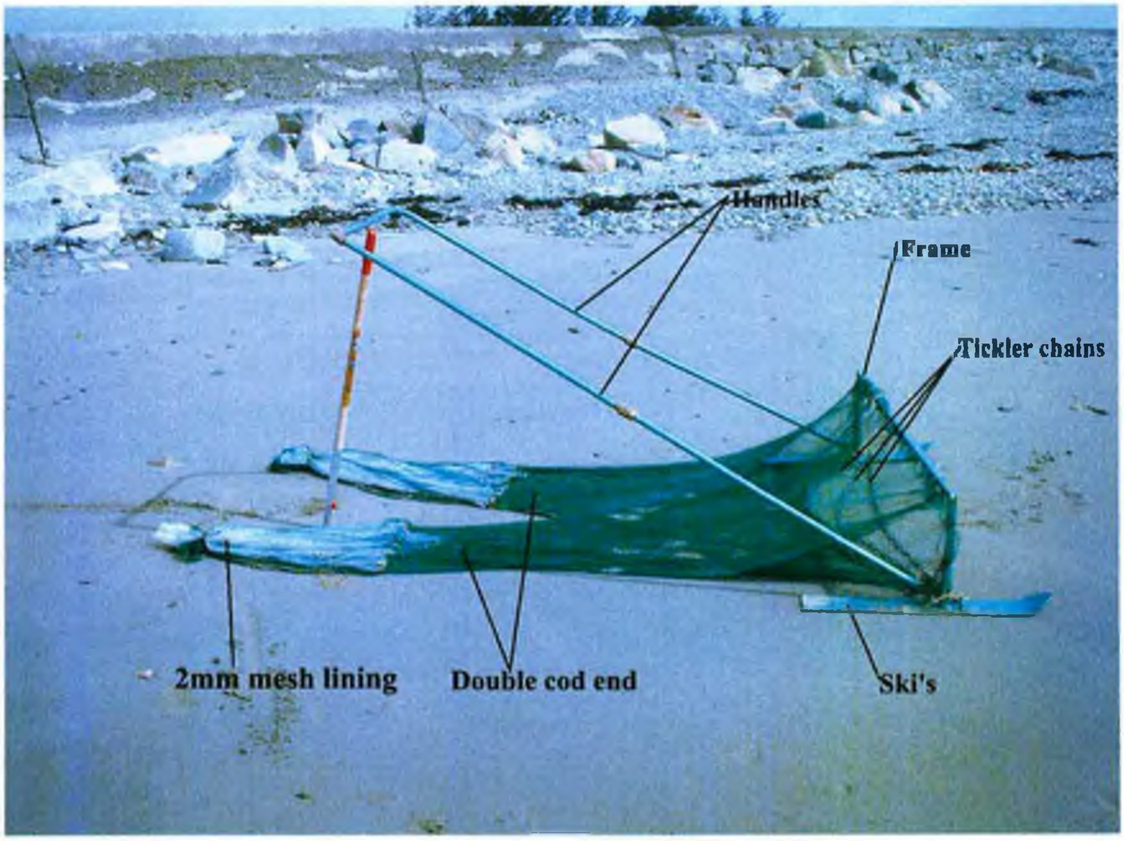


The two main sites sampled were Ballyloughaun (54° 16.2`N 09° 01.6`W) and Silverstrand (53° 15.2`N 09° 07.8`W). These beaches are sheltered shores located in or near Galway city, with strong estuarine influences from the River Corrib. Sampling was undertaken monthly from February 2002 with the exception of November and December 2002 until August 2003.

3.3.2 Sampling gear

Sampling was carried out using a Riley push-net (Holmes and McIntyre 1971) (Figure 35). Modifications made to the Riley push-net reflect the availability and cost of materials to the survey programme. The push-net constructed had a 1.5m x 0.3m frame made from 4cm box iron. This frame was mounted on two skis made from 0.4cm thick sheet metal. The skis were 7.5cm x 70cm, with the leading edge bent upwards in a smooth curve. This edge was fully rounded and sharp edges were removed. The frame was attached to the skis by placing the legs into 5cm^2 box iron brackets which were welded to the skis. Both the legs and the brackets are drilled to allow the structure to be bolted together. A handle was attached to the structure, which stretched 2m back from the upright fixture. The latter consisted of 5cm copper piping bent into a U shape and capable of being dismantled in three places. It was fixed to the main structure by using 5cm of box iron, drilled and welded to the skis. The leading edges of the handles were flattened and drilled, which allowed the attachment of the handle to the ski's using bolts. The net was a 10mm square mesh shrimp net, lined with a 2mm heavy-duty curtain mesh and was divided into a double cod-end. Two eyes made from cut chain links, were welded to the skis in front of the upright fixture, and to these, three tickler chains were added. The first tickler chain was attached to the leading edge of the net in order to weigh it down. The net was designed to disassemble and thereby ensure easy transportation.

Figure 35: Picture of the Riley push-net.

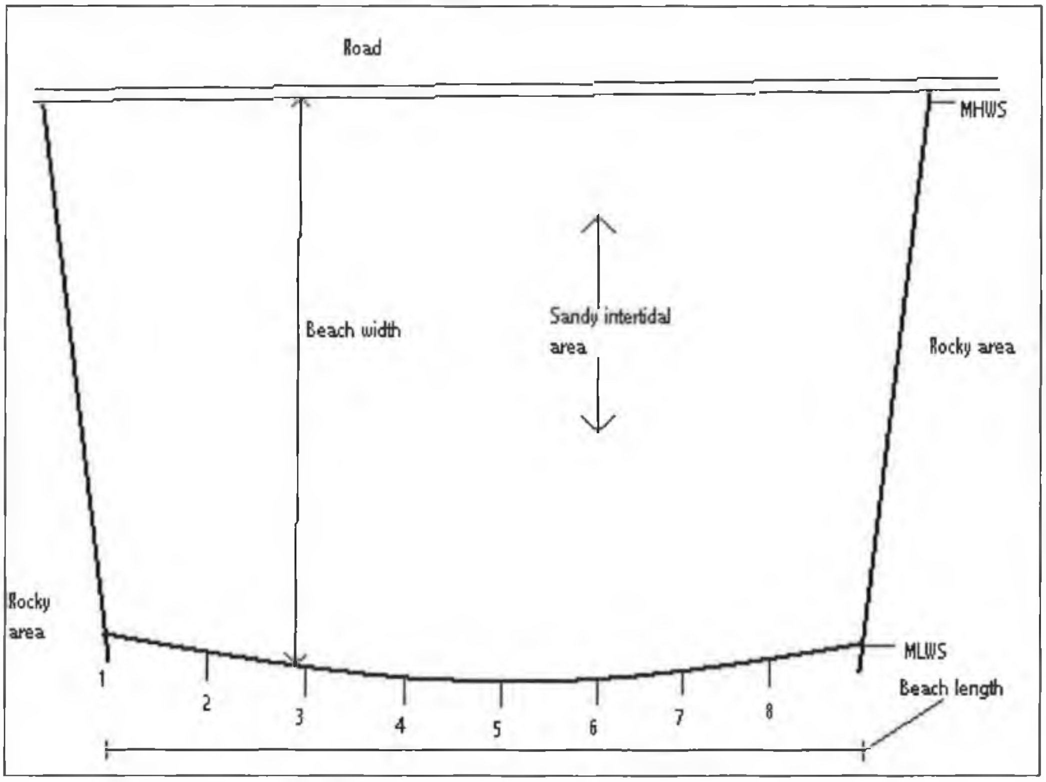


3.3.3 Sampling procedure

Sampling was carried out in calm – moderate conditions (sea state force 4 or less) during daylight hours on a rising low spring tide (<1m). Beach length and width (Figure 36) were taken on the first visit to each beach. On regular visits the following procedure was followed:

The beach was divided up into eight segments (Figure 36). Numbers from one to eight were selected off random tables and these were the start points for each replicate. Throughout the sampling period there was a minimum of three replicates and a maximum of eight per beach. However, after the experimental phase of fieldwork, four replicates per beach was taken as the standard.

Figure 36: A diagram showing the possible sampling sites on the Galway Bay beaches.



Each replicate was 50 paces (approx. 50m) long. The length of the replicate was marked using bamboo poles. At the start point the net was carried out to approximately 0.3 -0.5m in depth (knee height) and pushed (in either direction) parallel to the shore at a walking pace. The contents of each replicate were placed into mesh bags and sorting took place on return to the laboratory. A survey sheet was completed on every visit to a beach. All samples were frozen immediately at –18 °C.

Hand netting was carried in pools above the low tide mark (Figure 37) before the tide started to rise, and before the push netting commenced. Fish caught in the hand-net samples were used for length frequency analysis only.

Figure 37: Picture of hand netting carried out in pools

3.3.4 Experimental push-netting

3.3.4.1 Effects of sampling depth on push-net catches of 0+ plaice

During the settlement period, an experiment was undertaken to test the effect of sampling depth on push-net catches of plaice. The null hypothesis here is that there is no difference in the numbers of juvenile flatfish caught in deep (50cm) and shallow (≤10cm) water at low tide. This experiment was carried out on Silverstrand and Ballyloughaun on a low spring (< 1m) rising tide, in March and April of 2003.

When the spring tides of the month were identified a beach was randomly selected. A sampling date (within the spring tides) was also randomly selected for that beach. Eight replicates of four shallow and four deep were randomly selected and carried out from start points selected as for the normal surveying. Shallow and deep samples were temporally interspersed.

3.3.4.2 Effects of day-time and night-time sampling on the catches of 0+ plaice

This experiment was set up to assess the variation in 0+ plaice catches with the push-net between day-time and night-time. The null hypothesis here is that there is no difference in abundance of 0+ plaice caught between night-time and day-time samples. This experiment was carried out on Ballyloughaun only, on a low spring (< 1m) rising tide, during both night and day. During spring tides four days were selected. The date of sampling for each night and day sample (within the four day period) was also randomly selected. Standard field procedures were carried out for each visit for the duration of this experiment. This survey was carried out in August of 2003.

3.3.5 Fish analysis

Each fish was given a unique code so it could be traced back to its location of capture and the date when caught.

The standard length (SL) (from the tip of the mouth to the end of the body just before the caudal fin begins) and total length (TL) (from the tip of the mouth to the distal end of the tail) were taken to the nearest 1mm for 1+ fish or greater and to the nearest 0.1mm for the 0+ fish. The sagittal otoliths were removed from the vestibular apparatus using two methods. For smaller (<15mm) fish the otoliths were pried from the head using fine forceps, under a stereoscopic microscope. They were then transferred to vials for storage. For the larger fish a lateral incision was made posterior to the eyes. The otoliths were then removed using forceps and stored in labelled otolith boxes.

3.3.4.1 Growth

Observed growth rates were taken as the increase in mean length over the main growth period. For this project, the main growth period was taken as the time at which settlement was near an end, which was from the start of June onwards. Predicted growth (ΔL) in length (mm d^{-1}) of 0+ plaice was calculated from the equation taken from Fonds *et al.* (1992) in Nash *et al.* (1994a) for fish > 15mm.

$$\mathbf{\Delta L = 0.014\, \mathit{T}^{1.5} - 6.10^{-9}\, \mathit{T}^{6}}$$

Where: T is the mean monthly temperature taken from the M1 Marine Institute data buoy located off the west coast of Ireland.

Predicted monthly growth was then calculated by multiplying daily growth by the number of days between sampling dates. Predicted and observed growths were then compared.

3.3.4.2 Mortality

Daily mortality rates (Z) for the 0+ plaice were calculated from Zijlstra *et al.* (1982) based on the linear decrease in plaice densities. The mortality calculations assume that migrations during late spring and summer do not interfere with the abundance of 0+ plaice. Mortality rates were taken from the decline in densities from peak numbers in spring to the densities obtained in autumn months (usually August). Z was obtained from:

$$Z = \frac{1}{t} \ln \frac{n_o}{n_t}$$

Where t = the time in days, n_o is the density in June and n_t is the density noted in August.

3.3.5 Data analysis

All data were subjected to Ryan-Joiner normality tests and a Bartlett's test for homogeneity of variances. If data were not normal, transformations were carried out. Either, log, inverse log, log + 1 or inverse log + 1 transformations were used. Monotonic log and inverse log transformations were used for non-homogenous data (Underwood 1997). If transformations did not normalise or homogenous the data, non-parametric Mann-Whitney tests were used.

Analysis of variance (ANOVA) was used on normal data. One-Way, balanced Two-Way and Three-Way ANOVA's were carried out on month, beaches and years.
The null hypotheses for the Two-Way ANOVA were:

(1) there is no difference in the measured parameter between beaches
(2) there is no difference in the measured parameter between years
(3) there is no interaction between the two main factors

The null hypotheses for the Three-Way ANOVA were:

(1) there is no difference in the measured parameter between months
(2) there is no difference in the measured parameter between beaches
(3) there is no difference in the measured parameter between years
(4) there is no interactions between the main factors

Where an interaction occurred, there may be significant differences between certain beaches in any one year, or significant differences between years in certain beaches, but no consistent general patterns can be discerned. Hence, no conclusions are drawn on the two/three main hypothesis (differences between months, beaches or years) because interpretations of the main effects are impossible or at best unreliable when there is an interaction (Underwood 1997). When an interaction was present no further analysis was carried out. When One-Way ANOVA's were used *post hoc* analysis followed using a Fisher's pairwise comparison test. All analyses were calculated on Minitab version 13.1.

3.4 Results

3.4.1 Abiotic factors

During the push-netting surveys, temperature, salinity (using a Sea Test©), weather conditions and sea state were all recorded. These results are given for Silverstrand and Balyloughaun only (Tables 10 and 11 respectively).

3.4.1.1 Silverstrand

On Silverstrand, the water temperature was recorded in March and April only in 2002. Temperature was recorded in all months in 2003. Salinity was only recorded in 2003. The water temperature in 2003 ranged from a low of 4°C in January to a high of 17.5°C in late April. The lowest salinity was recorded in February (11) with the highest salinity recorded August (32.5). Wind strength ranged from calm to moderate and the sea state mostly varied from very calm to calm with moderate wave action on occasions.

Table 10: Environmental data recorded for each sampling visit to Silverstrand in 2002 and 2003. "mod" corresponds to moderate as regards to wind or sea state. "n/t" indicates no data was recorded

Year	month	Water temp (°C)	salinity(ppt)	wind	sea state
2002	*Early M*	*n/t*	*n/t*	*mod*	*calm*
	Late M	*8.5*	*n/t*	*calm*	*calm*
	A	*10.5*	*n/t*	*calm*	*v calm*
	M	*n/t*	*n/t*	*calm*	*calm*
	J	*n/t*	*n/t*	*calm*	*calm*
	J	*n/t*	*n/t*	*mod*	*mod*
	A	*n/t*	*n/t*	*calm*	*v calm*
	S	*n/t*	*n/t*	*calm*	*v calm*
	O	*n/t*	*n/t*	*calm*	*calm*
2003	*J*	*4*	*23*	*calm*	*very calm*
	F	*4.7*	*11*	*calm*	*mod*
	M	*11.5*	*23*	*calm*	*v calm*
	Early A	*13.6*	*31*	*calm*	*calm*
	Late A	*17.5*	*31*	*calm*	*calm*
	M	*12.2*	*31*	*calm*	*calm*
	J	*16.5*	*29*	*mod*	*mod*
	J	*15*	*31*	*calm*	*calm*
	A	*17*	*32.5*	*calm*	*v calm*

3.4.1.2 Ballyloughaun

Environmental data for Ballyloughaun is shown in Table 11. Water temperatures were only recorded in March, April and May in 2002 and all sampled months in 2003. Salinities were recorded in 2003 on all occasions with the exception of July were it was not taken. The water temperature ranged from 4°C in January to 20.9°C in August. Salinity varied from a low of 11 in August to a high of 29 in January 2003. The wind strength was mostly calm but on occasion moderate to strong.

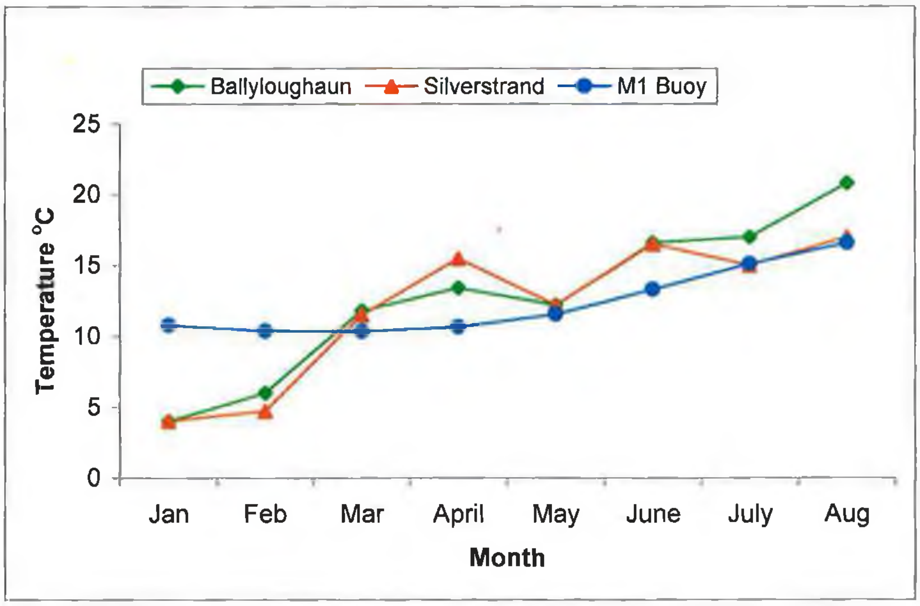
Table 11: Environmental data recorded for each sampling visit to Ballyloughaun in 2002 and 2003. "mod" corresponds to moderate as regards to wind or sea state. "n/t" indicates no data was recorded

year	month	temp (°C)	salinity (ppt)	wind	Sea state
2002	*Early M*	*n/t*	*n/t*	*mod*	*calm*
	Late M	*9*	*n/t*	*calm*	*calm*
	A	*11.5*	*n/t*	*calm*	*v calm*
	M	*13.2*	*n/t*	*calm*	*calm*
	J	*n/t*	*n/t*	*mod*	*calm*
	J	*n/t*	*n/t*	*calm*	*calm*
	A	*n/t*	*n/t*	*calm*	*v calm*
	S	*n/t*	*n/t*	*calm*	*v calm*
	O	*n/t*	*n/t*	*calm*	*calm*
2003	*J*	*4*	*29*	*calm*	*v calm*
	F	*6*	*19*	*calm*	*v calm*
	M	*11.8*	*13*	*calm*	*v calm*
	A	*13.4*	*21*	*calm*	*calm*
	M	*12.2*	*23*	*mod/s*	*mod/s*
	J	*16.6*	*14*	*strong*	*mod/s*
	J	*17*	*n/t*	*calm*	*v calm*
	A	*20.9*	*11*	*calm*	*v calm*

3.4.1.3 Open sea temperatures

Open sea temperatures are recorded on a constant basis off the west coast of Ireland by The Marine Institute data buoy (M1) located at 53° 07.6' N 11° 12' W. The mean monthly open sea temperatures are compared with the water temperature data recorded on each sampling occasion in Ballyloughaun and Silverstrand in Figure 38. The lowest temperature for the open sea was recorded in March (10.34°C), however, this was only fractionally lower than February's mean at 10.35°C. From March onwards there was a steady increase in the mean monthly temperature to a high in August of 16.56°C. The inshore temperatures showed more fluctuations with the lowest temperature recorded at 4°C and the highest at 20.8°C.

Figure 38: Monthly water temperatures recorded on sampling dates from both Ballyloughaun and Silverstrand in 2003 compared with the mean monthly open sea temperatures taken from The Marine Insitute M1 data buoy on the Irish west coast



3.4.2 Settlement and seasonal distribution

3.4.2.1 Settlement timing

The first newly settled plaice were noted in April of 2002 with a density of 17.8 $1000m^{-2}$ on Silverstrand and a density of 18 $1000m^{-2}$ on Ballyloughaun (Table 12). In 2003, the start of the settlement period was noted a month earlier than 2002 with 0+ plaice recorded in late March at densities of 12 $1000m^{-2}$ on both Silverstrand and Ballyloughaun. Peak densities varied from year to year. In 2002 the peak densities were in May and June (31 and 44 $1000m^{-2}$) on Silverstrand and Ballyloughaun. In 2003 the peaks were recorded in April and May (277 and 237 $1000m^{-2}$) in Silverstrand and Ballyloughaun respectively.

Table 12: The abundance of 0+ plaice caught with the Riley push-net throughout the sampling period on Ballyloughaun and Silverstrand. Actual numbers and densities ($1000m^{-2}$) are given. "N/S" means the beach was not sampled on this date.

		Silverstrand			*Ballyloughaun*		
Year	Month	No. of fish captured	Mean /replicate ± SD	No /$1000m^{-2}$	No. of fish captured	Mean /replicate ± SD	No /$1000m^{-2}$
2002	March	0	0	0	0	0	0
	April	4	1.3 ± 0.6	18	4	1.3 ± 2.3	18
	May	7	2.3 ± 0.6	31	7	2.3 ± 1.2	31
	June	4	1.3 ± 1.2	18	10	3.3 ± 4	44
	July	3	0.8 ± 0.5	10	12	2.0 ± 2.6	27
	Aug	1	0.3	3	7	1.8 ± 0.5	23
	Sept	2	0.5	7	0	0.0	0
	Oct	0	0	0	0	0.0	0
2003	Jan	0	0	0	0	0.0	0
	Feb	0	0	0	0	0.0	0
	March	7	0.9 ± 0.6	12	7	0.9 ± 0.8	12
	Early Apr	32	4.0 ± 3.5	53	37	4.6 ± 2.4	62
	Late Apr	71	17.8 ± 14.2	237	N/S	N/S	N/S
	May	25	6.3 ± 2.6	83	83	20.8 ± 6.8	277
	June	5	1.3 ± 1	17	29	7.3 ± 4.3	97
	July	6	1.5 ± 1.7	20	10	2.5 ± 1.9	33
	Aug	2	0.5	7	2	0.5 ± 0.6	7

3.4.2.2 Seasonal occurrence

The seasonal distribution of 0+ plaice on Silverstrand and Ballyloughaun is shown in Figure 39. After the initial settlement of juveniles the density increased to peak numbers in May 2002 and late April 2003 on Silverstrand. In Ballyloughaun the peaks were noted in June 2002 and May 2003. Thereafter, a steady decline was noted in the density of the 0+ plaice in both locations for each year. No juvenile plaice were recorded with the push-net from October onwards in 2002. The densities of plaice on Silverstrand and Ballyloughaun are very similar throughout. However, there was a delay of one month in the occurrence of peak densities on Ballyloughaun for both sampling years. This was not due to sampling time in 2002, however, in 2003 this phenomenon may be due to sampling dates as extra sampling was carried out on

Silverstrand in late April and no comparable sample was taken in Ballyloughaun at this time.

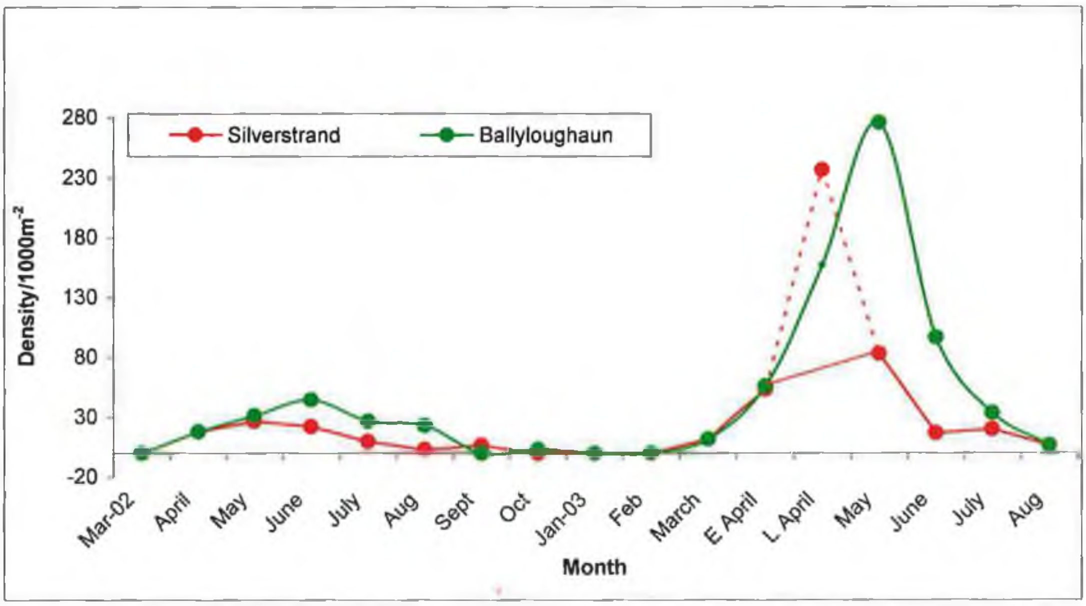
A Three-Way ANOVA was carried out on the plaice densities to test the following null hypotheses: there is no difference between months, there is no difference between beaches, there is no difference between years and there is no interaction between the three main factors. Data from the critical settlement period on the beaches from April to June was used. The late April sample on Silverstrand was not included here. The results show that there was no difference between months ($p = 0.815$), beaches ($p = 0.827$) or years ($p = 0.318$). The only significant interaction to occur was between months and beaches, which indicates that there may be differences between some beaches in some months. A One-Way ANOVA was then carried out for the critical months separately for each beach on each year, and these results are shown below.

On Silverstrand there was no significant difference in the monthly densities of 0+ plaice ($p = 0.296$) in 2002. In 2003, again no significant difference was noted in densities between months ($p = 0.086$ ANOVA). However, when the results of the late April sampling were added, a significant difference ($p = 0.034$) occurred. Fisher's pairwise *post hoc* analysis showed densities in late April were different to those recorded in early April and June, but not different to the densities recorded in May.

In Ballyloughaun there was no significant difference in the monthly densities in 2002 ($p = 0.692$). In 2003 a highly significant difference was noted in the monthly densities from April to June ($p < 0.001$). The *post hoc* analysis (Fisher's pairwise test) showed the high densities in May were different to April and June.

Thus, statistically significant peak densities were not observed in 2002 on either beach, but were found in 2003 on both beaches. There was, therefore, a significant difference in mean densities between the two years.

Figure 39: Seasonal distribution of 0+ plaice on Silverstrand and Ballyloughaun in 2002 and 2003. Densities $1000m^{-2}$ are given for all months sampled with the push-net. The broken line indicates the extra sampling date on Silverstrand



3.4.2.3 Other beaches sampled

Fanore and Bishopsquarter in Co. Clare were not sampled as regularly as the local beaches (Silverstrand and Ballyloughaun). Data for these beaches is shown in Table 13. Fanore was sampled first in March 2002. Sampling was carried out monthly until August with the exception of June, which was not sampled due to adverse weather conditions. The first 0+ plaice were caught on Fanore in April at a density of 8.9 $1000m^{-2}$. No juvenile plaice were captured in May. The highest density of 0+ plaice was noted in July with a density of 17.8 $1000m^{-2}$. Push-netting was carried out in Bishopsquarter in May, July and August in 2002 and in January and February in 2003. May and July samples yielded a similar density of 44.4 $1000m^{-2}$. The maximum density was recorded in August (50 $1000m^{-2}$). This was the highest density recorded from all beaches including Silverstrand and Ballyloughaun in 2002.

Table 13: The abundance of 0+ plaice on Bishopsquarter and Fanore caught using the Riley push-net. Actual mean numbers and densities ($1000m^{-2}$) are given. N/S means the beach was not sampled on this date.

		Bishopsquarter			*Fanore*		
Year	Month	No. fish captured	Mean /replicate	No /$1000m^{-2}$	No. fish captured	Mean/replicate	No./$1000m^{-2}$
2002	March	N/S	N/S	N/S	0	0	0
	April	N/S	N/S	N/S	2	0.67	8.9
	May	6	2.0	44.4	0	0	0
	July	12	2.0	44.4	4	1.33	17.8
	Aug	9	2.2	50	0	0	0
2003	Jan	0	0	0	N/S	N/S	N/S
	Feb	0	0	0	N/S	N/S	N/S

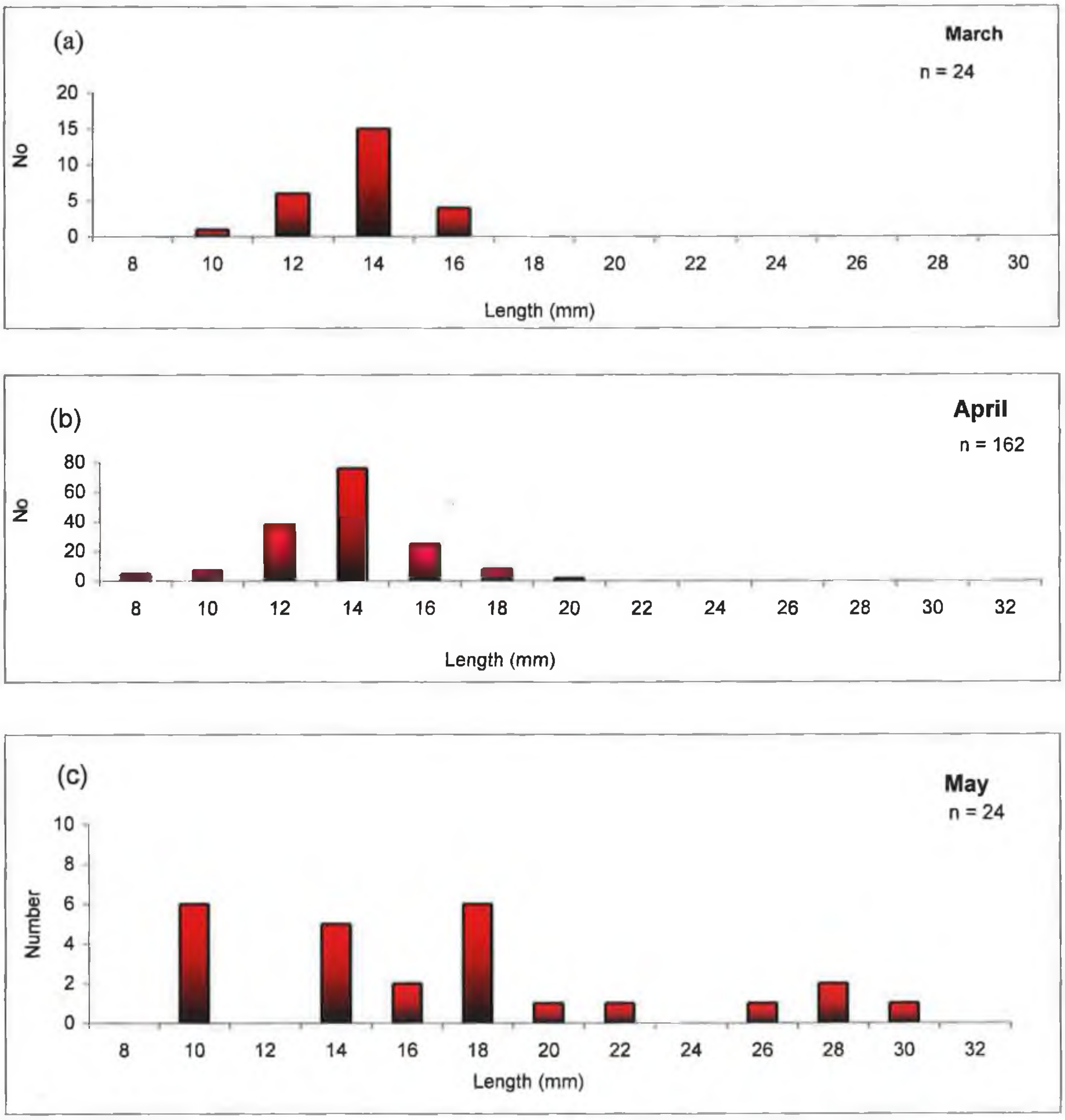
3.4.3 Growth and length frequency

3.4.3.1 Length frequency

Length-frequency distributions are given for each month sampled in 2003 when ≥ 25 0+ plaice occurred for Ballyloughaun and Silverstrand (Fig40a, b, and c for silverstrand and Fig 41a, b, and c for Ballyloughaun). Months shown range from March to June, thereafter not enough fish were caught. The distributions are not given for 2002 as not enough fish were caught to detect signals from length frequency plots.

3.4.3.1a Silverstrand

Fig 40a, b, c, and d: Length frequency distributions for 0+ plaice on Silverstrand in March (a), April (b), May (c) and June (d) 2003

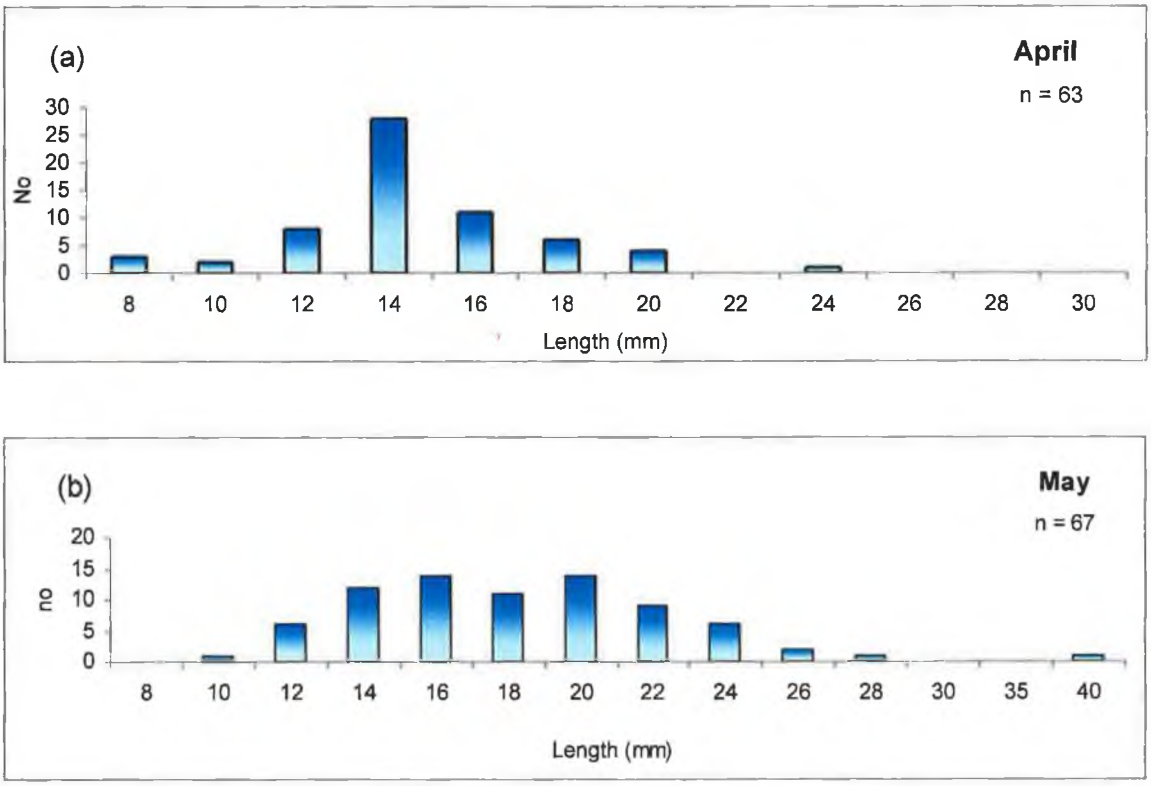


In March, and April the modal size was at 14mm with the fish ranging from 8mm (April and May) to 20mm (April). In May, low numbers were recorded with fish most frequently captured at lengths of 10mm, 14mm and 18mm. The range of size classes in this month was from 10mm to 30mm. All months show that fish were settling (fish < 15mm) onto the beach, however, this settlement was at its lowest in May where evidence of growth can be seen with larger fish occurring.

3.4.3.1b Ballyloughaun

Length frequency distributions for Ballyloughaun from April and May 2003 are shown in Fig 41a and b. Not enough 0+ plaice were caught in the March and months after May for analysis.

Fig 41a, and b: Length frequency distributions of 0+ plaice on Ballyloughaun in April (a), May (b) 2003



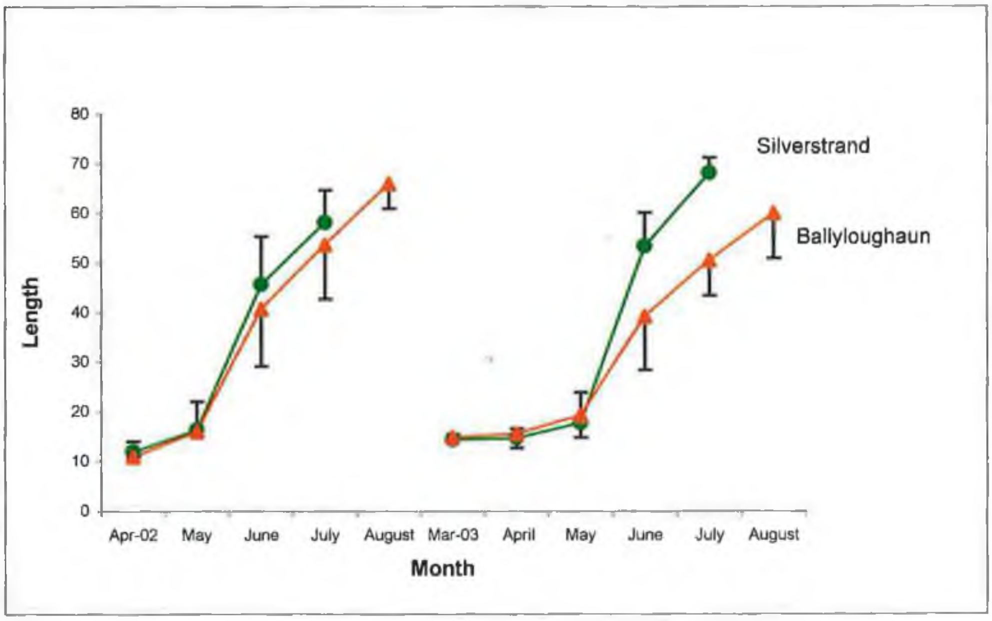
The peak in April for Ballyloughaun was at 14mm (Figure 41a). A double peak was noted in May in Ballyloughaun at 16mm and 20mm, with high numbers at 14 and 18mm length classes also. The range of size classes recorded in May was from 10mm to 28mm, while one individual of 40mm was caught.

In summary, both beaches have similar length frequency distributions over the settlement period. Newly settled fish were present on both beaches from March to May. Months from April onwards showed fish larger than 15 mm, which suggests that 0+ plaice are growing.

3.4.3.2 Growth

The mean length of 0+ plaice was analysed for Silverstrand and Ballyloughaun in 2002 and 2003. Fanore and Bishopsquater were not included in this analysis due the small number of samples. The mean length, from when 0+ plaice first occurred on the beaches, through the main growth period into the autumn is shown in Figure 42.

Figure 42: The mean length of 0+ plaice on Silverstrand (green line with + SD) and Ballyloughaun (orange line with – SD) for April to August 2002 and March to August 2003.



3.4.3.2a Growth: 2002

The mean length for juvenile plaice when they were first noted in April 2002 was 12 ± 2 mm in Silverstrand and 11 ± 0.09 mm in Ballyloughaun (Figure 42). From this point on the mean length increased over the summer months. In the June sample, a slight between beach difference was noted with a value of 47.5 ± 9.61mm in Silverstrand and a lower mean of 40.75 ± 11.5mm recorded in Ballyloughaun. This difference was noted again in July with a difference of 5.4mm between the beaches. No plaice were caught in the August sample on Silverstrand while in Ballyloughaun the mean size observed was 66 ± 5.06 mm.

3.4.3.2b Growth: 2003

In 2003 the first plaice were recorded in March with mean lengths of 14.4 ± 1mm on Silverstrand and 14.85 ± 0.85 on Ballyloughaun (Figure 42). The mean lengths between beaches were similar until May. However, from May onwards Silverstrand had a higher mean length with a mean of 53.4 ± 6.7 mm in June as opposed to 39.18 ± 10.8 mm recorded on Ballyloughaun. The maximum difference noted throughout the summer samples was noted in July 2003 with the mean size of fish in Silverstrand 18.4mm greater than the mean recorded in Ballyloughaun.

3.4.4 Difference in mean length between beaches

The difference in mean length of plaice between beaches was analysed for each sampled month. A nonparametric Mann-Whitney U test was used, as the results could not be normalized by transformations. These results are given in Table 14.

Table 14: Mean length ± SD and the significance value for the difference between beaches observed for each sampled month using a Mann-Whitney U test. "N/C" indicates that no 0+ plaice were caught. "N/A" = not applicable here. A significant difference is marked with a "*". A highly significant difference in indicated by ""**

Year	Month	*Silverstrand* Mean length (mm) ±SD	*Ballyloughaun* Mean length (mm) ±SD	Percentage difference	Significance (p value)
2002	April	12 ± 2	11 ± 0.09	9	0.915
	May	16.4 ± 5.68	16 ± 0.81	2.5	0.809
	June	45.7 ± 9.61	40.75 ± 11.59	11	0.090
	July	58.2 ± 6.5	53.66 ± 10.99	8	0.101
	August	N/C	66 ± 5.06	N/A	N/A
2003	March	14.4 ± 1	14.85 ± 0.85	3	0.415
	April	14.75 ± 1.82	15.62 ± 2.95	5	0.010*
	May	17.8 ± 6.1	19.3 ± 4.5	7	< 0.001**
	June	53.4 ± 6.7	39.18 ± 10.8	26	0.022*
	July	68.1 ± 3.1	50.5 ± 7.1	25	0.001*
	August	N/C	60 ± 9.1	N/A	N/A

The growth of 0+ plaice was similar on both Silverstrand and Ballyloughaun in 2002. The growth rate in 2003 however was different between beaches, with significant differences in the mean length noted in April, May, June and July (Table 14). In April and May 2003 the mean length of plaice was greater in Ballyloughaun than in Silverstrand. These differences were minimal and $\leq$ 7 percent. From June onwards, during the main growth period, a higher mean length was noted in Silverstrand. The difference noted in these months was more substantial (both > 20 percent).

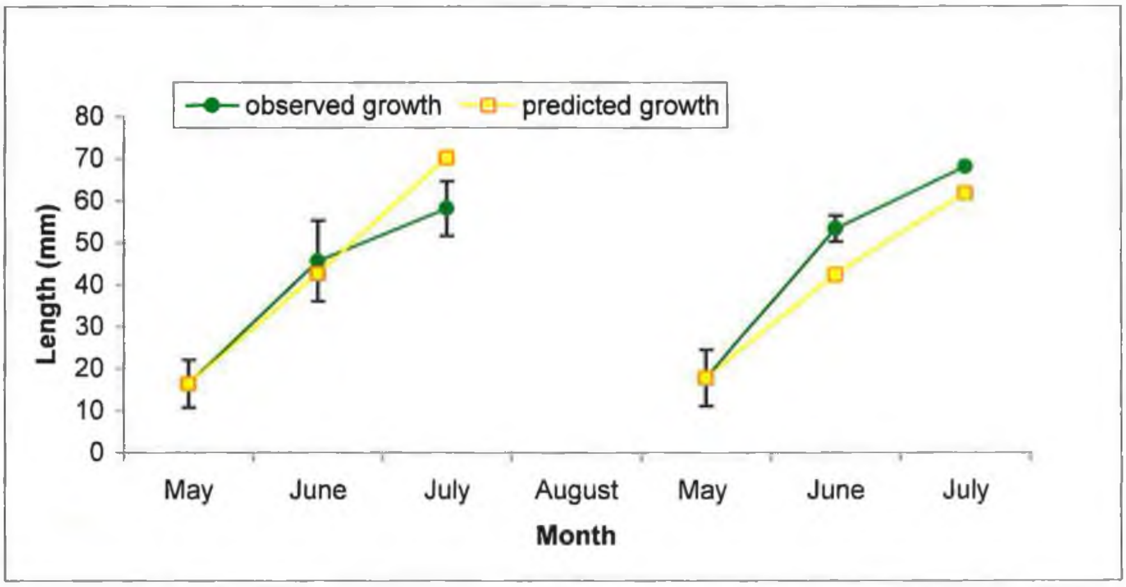
3.4.5 Summer growth

The observed increase in mean length in the summer of 2002 and 2003 was compared to simulated values obtained using a simple descriptive growth model obtained under excess feeding conditions for small 0+ plaice (Fonds *et al.* 1992 in Nash *et al.* 1994). Figure 43 and 44 show the actual growth plotted with predicted growth dependent on temperature for both beaches.

3.4.5.1 Silverstrand

The observed growth of 0+ plaice in Silverstrand was similar to the predicted growth in June 2002 but less than predicted growth in July. (Figure 43). In 2003 observed growth was greater than predicted in both June and July.

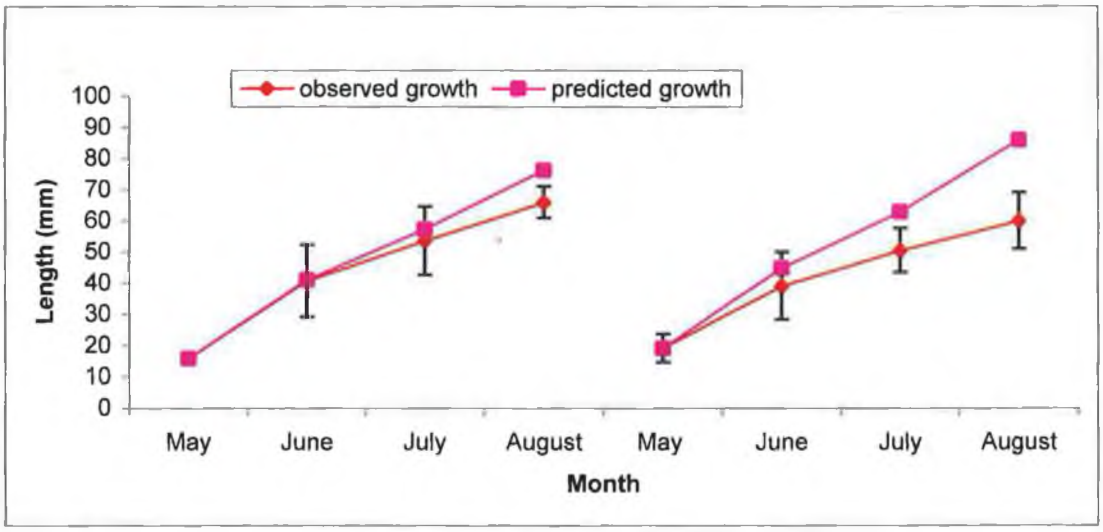
Figure 43: Actual growth as increase in mean length ± SD throughout the main growth periods in 2002 and 2003 plotted with predicted growth from Fonds *et al.* (1992) for Silverstrand. August was not included here due to low numbers of fish caught.



3.4.5.2 Ballyloughaun

In June 2002 observed mean length was the same as predicted, otherwise predicted growth was greater than observed growth in all months in both years (Figure 44).

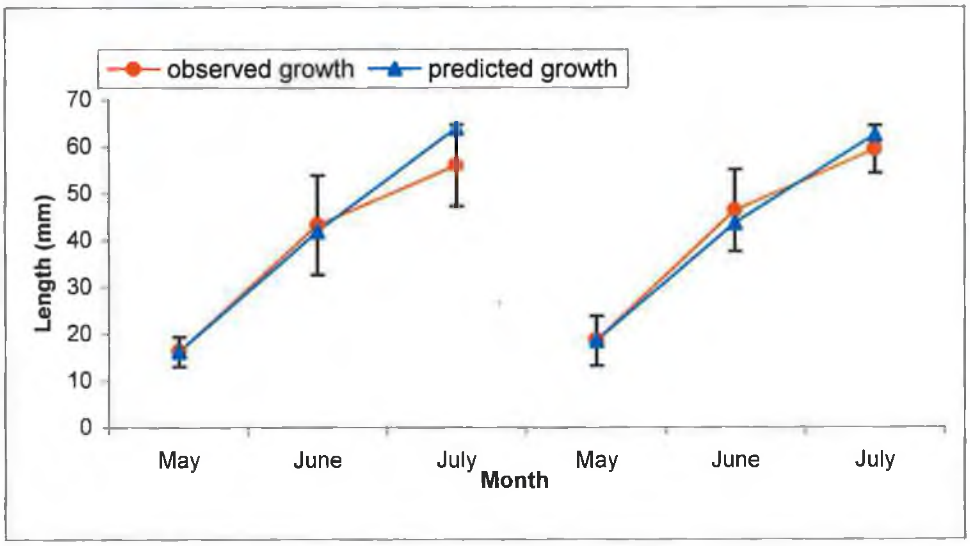
Figure 44: Actual growth as increase in mean length ± SD throughout the main growth period plotted with predicted growth from Fonds *et al.* (1992) for Ballyloughaun.



3.4.5.3 Galway Bay growth

The results from Silverstrand and Ballyloughaun were pooled together for an estimate of the growth rate in Galway Bay. The observed growth is compared to the predictive model in Figure 45. As can be seen, predicted growth lies within one standard deviation of observed growth for all months.

Figure 45: Mean length of plaice ±SD caught in the Galway Bay area in 2002 and 2003 plotted with the predicted growth from Fonds *et al.* (1992) for the same period.



The overall growth for Galway Bay shows a higher similarity to the predicted model than individual beaches did. Actual growth and predicted growth were very similar in May and July of both years. However, actual growth was higher than predictive growth in June of both years.

3.4.6 Mortality

Daily mortality rates were calculated for the 0+ plaice on Ballyloughaun and Silverstrand for each year, over the period from June to August i.e. when densities tend to decline slowly. This decline tends to be linear and the R^2 values for this relationship are shown in Table 15. This period has a minimal influence on settlement into the stock, as few fish < 15mm are present. Also, the assumption is made that major migrations offshore have not yet taken plaice.

Daily mortality was highest in Ballyloughaun were a loss of plaice of 0.048 d^{-1} was recorded in 2003. Second highest was Silverstrand in 2002 (0.032 d^{-1}). These samples showed the greatest decrease in density. Lower mortality rates were noted in Silverstrand in 2003 and Ballyloughaun in 2002 at 0.012 and 0.011 d^{-1} respectively.

Table 15: Daily mortality rates for 0+ plaice on Silverstrand and Ballyloughaun in 2002 and 2003. R^2 values are given for the decline in densities from June to August in each case

Year	Beach	Date	Densities $1000m^{-2}$	Mortality (d^{-1})	R^2 value
2002	Silverstrand	25/6 - 20/8	18 – 3.0	0.0320	0.972
	Ballyloughaun	26/6 - 20/8	44.4 – 23.3	0.0117	0.865
2003	Silverstrand	17/6 - 29/8	17.0 – 7.0	0.0122	0.5192
	Ballyloughaun	18/6 - 12/8	97.0 – 6.7	0.0486	0.9476

3.4.7 Experimental push-netting

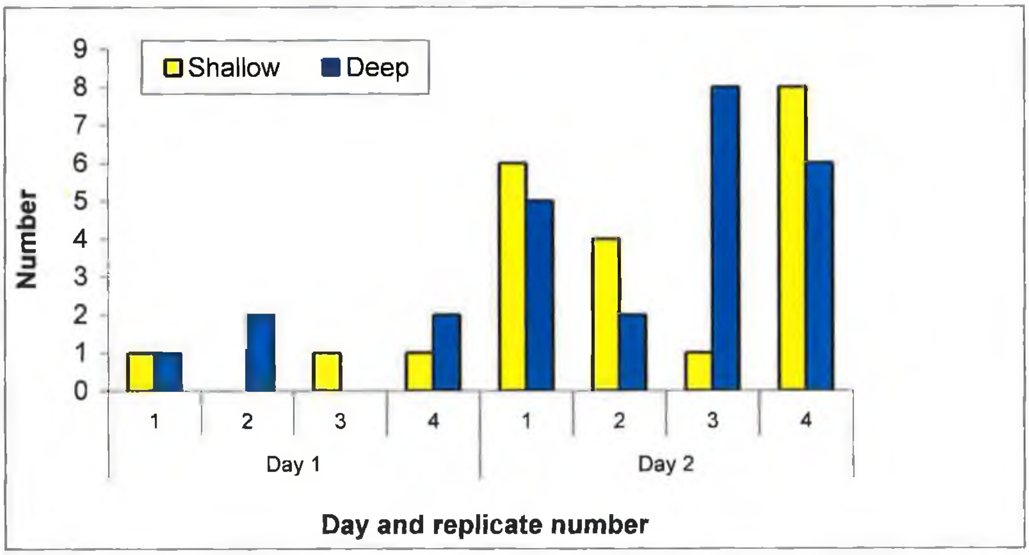
3.4.7.1 Effects of sampling depth on the catch of 0+ plaice with the push-net

This survey was carried out in the spring of 2003. A sampling programme was set up to investigate catch rates of 0+ plaice in shallow (< 10cm) and deep (~ 50cm) water. This was carried out in Ballyloughaun and Silverstrand. Two visits were made to each beach and eight replicates (four shallow and four deep) were taken on each visit.

3.4.7.1a Ballyloughaun

The numbers of plaice caught in the shallow and deep experimental push-net samples in Ballyloughaun are shown in Figure 46. Numbers ranged from 0 to 8 fish per sample.

Figure 46: Results of the shallow versus deep experimental push-netting carried out in Balllyloughaun. Numbers of 0+ plaice are given. Eight replicates were carried out each sampling day, four deep and four shallow.

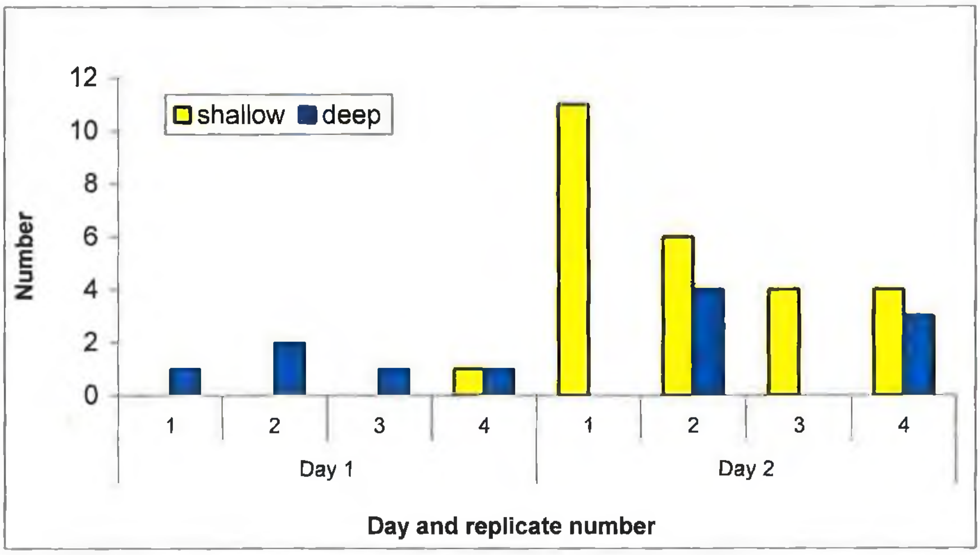


3.4.7.2b Silverstrand

The numbers of plaice caught in the shallow and deep experimental push-net samples in Silverstrand are shown in Figure 47. Numbers ranged from 0 to 11 fish per sample.

A balanced Two-Way ANOVA was carried out on the data from the two beaches. Three hypotheses were tested as follows: there was no difference in plaice density between beaches, there was no difference in plaice densities with depth and there was no interaction between beach and depth. Depth was taken as a fixed factor. The results of the ANOVA shows, that there is no significant difference between beaches (p = 0.677), between the two depths sampled (p = 0.677) and there was no significant interaction between beach and depth (p = 0.279).

Figure 47: Results of the shallow versus deep experimental push-netting carried out in Silverstrand. Numbers of 0+ plaice are given. Eight replicates were carried out on each sampling day, four shallow and four deep.



3.4.7.1 Effect of day-time and night-time sampling on the catch of 0+ plaice

In August of 2003, a day-night sampling programme was set up investigate the variation in 0+ plaice catches between day and night. This was carried out in Ballyloughaun only. The results are shown in Figure 48.

Figure 48: Results of the day-night experiment at Ballyloughaun. Two day and two night-time samples were carried out. On each occasion four replicates were obtained. Replicates with 0 fish caught are marked.

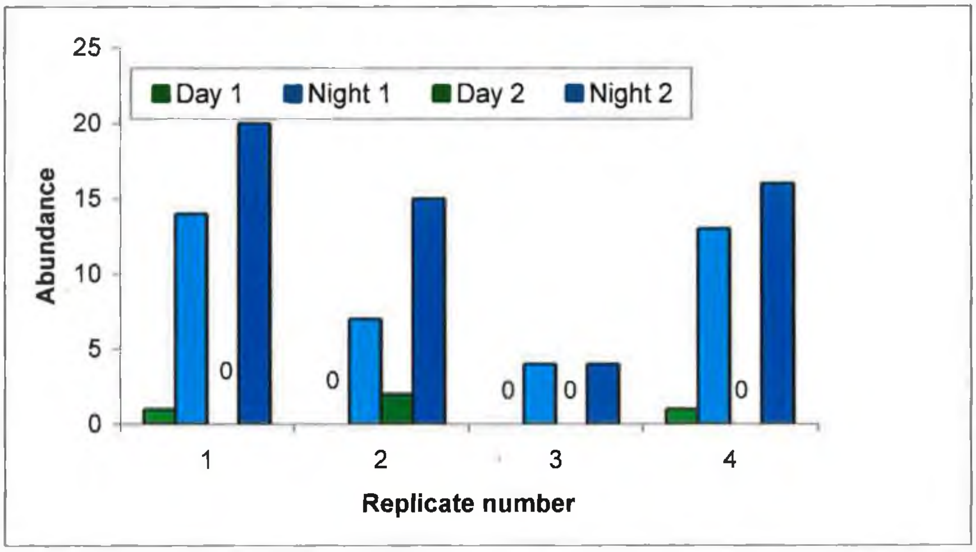


Figure 48 shows night-time sampling produced higher numbers of 0+ plaice than day-time samples. The highest number of 0+ plaice recorded in a single replicate was 20 at night, with 4 the lowest number recorded at night-time. In the day-time samples, the highest catch of plaice in one replicate was 2, while over the entire survey 5 day-time replicates recorded zero fish. By contrast, plaice were recorded in all replicates at night. The difference between plaice numbers caught in day and night samples was very highly significant ($p < 0.001$ Mann-Whitney U test).

3.4.8 Summary

Settlement of 0+ plaice occurred in late April in 2002 while in 2003 the first settlers were noted a month earlier in March. Peak densities in Silverstrand ranged from 31 to 237 $1000m^{-2}$ from 2002 to 2003 respectively. In Ballyloughaun peak densities varied from 44 to 277 $1000m^{-2}$ over the two year period. The peak densities were noted in May and June in Silverstrand and Ballyloughaun in 2002 respectively. In 2003, the peaks were in April and May in Silverstrand and Ballyloughaun respectively. After peak densities, there was a steady decline in the density of plaice into the autumn months on both beaches.

Growth rates were similar on Silverstrand and Ballyloughaun in 2002. However, in 2003 the growth rate observed in Silverstrand was greater than that observed in Ballyloughaun. When the actual growth rates were compared to a model growth rate obtained at optimum feeding conditions it was found that in Silverstrand the actual growth rate was higher than predicted growth. In Ballyloughaun a different pattern was observed, with the actual and predicted growth rates similar in 2002 and the predicted growth rates higher than actual growth in 2003. Daily mortality rates calculated show that the highest mortality was recorded in 2002 on Silverstrand, and in 2003 on Ballyloughaun.

Experimental push-netting carried out showed that depth does not have an influence on the catches of 0+ plaice. However, the experimental work did show that sampling at night produced significantly higher densities of 0+ plaice.

3.5 Discussion

0+ Plaice were first caught in April of 2002 and March of 2003 in Galway Bay. Peak densities were recorded in April or May depending on the beach or the year. After the peak densities occurred there was a steady decline in numbers into the autumn months. No 0+ plaice were recorded on any beaches in the winter months. The same seasonal pattern has been recorded on a regular basis on nursery grounds in other regions, with settlement times and peak densities the varying between geographically areas. Hjorleifsson and Palsson (2001) found the first newly settled plaice at the end of May in Icelandic waters. In this study, the same seasonal pattern as that in Galway Bay occurred with decreasing numbers in the summer, to very low numbers in the autumn. On the Swedish coast, Modin and Pihl (1996) caught newly settled plaice in mid May of 1991 and late April of 1992. Thereafter, the same seasonal pattern was recorded as in Galway Bay. A similar pattern was recorded in Loch Ewe, off the coast of Scotland, where Steele and Edwards (1970) found newly metamorphosed plaice in April of each year studied. Also on the Scottish coast, Poxton (1982) caught the first settlers in April of 1973 in the Clyde Sea area. However, in 1972 and 1974 they were not recorded until May. In the Wadden Sea, Zijlstra *et al.* (1982) reported that settlement generally took place in April and May and on occasion significant settlement took place in March from 1973 to 1978. In the same area from 1980 to 1983, Van der Veer (1986) found that settlement mostly started in February or March. In 1973, Kuipers (1977) did not record any settlement in March, while settlement did start in April of that year. Difference in settlement times is closely linked to the winter sea temperatures (Van der Veer 2000) and the Galway Bay results are as expected, due to its geographic location.

Peak densities of 0+ plaice were 31 1000m^{-2} in May, 2002 and 237 1000m^{-2} in April, 2003 in Silverstrand. In Ballyloughaun the densities were 44 1000m^{-2} in 2002 and 277 1000m^{-2} in 2003. Peak densities within the range noted on the Irish west coast, were recorded in Icelandic waters (110 1000m^{-2}) in June of 1999 (Hjorleifsson and Palsson 2001). In Scottish waters, Steele and Edwards (1970) noted peak densities ranged from approximately 170 1000m^{-2} to 30 1000m^{-2} from 1965 to 1968. These peaks mostly occurred in May or June. Riley and Corlett (1965) reported peak numbers in May and June of 1962 – 1963, in Port Erin Bay, Isle of Man. However, densities were not calculated here. Nash and Geffen (2000) recorded a range of peak densities over the study period from 400 $1000m^{-2}$ in 1993 to 3000 $1000m^{-2}$ in 1996. Mansoor (1982) noted peak numbers in May, 1981 on the Irish east coast. Again, densities were not calculated in this latter study. On the Swedish coast, Modin and Pihl (1996) recorded maximum densities (1400 $1000m^{-2}$ in 1991 and 10,000 $1000m^{-2}$ in 1992) higher than any noted on the Irish west coast. The peaks in both these years were noted in mid-late May. Extensive studies have been carried out in the Wadden Sea. Zijlstra *et al.* (1982) recorded peak densities of approximately 125 to 475 $1000m^{-2}$ from 1973 to 1979 in the Wadden Sea. These peaks occurred from March to June depending on the year. Also in the Wadden Sea, Kuipers (1977) noted a peak density of 499 $1000m^{-2}$ in May of 1973. Van der Veer (1986) recorded maximum densities of 0+ plaice at 150 $1000m^{-2}$ in 1980, 350 in 1981 and 300 in 1982. April recorded the maximum density in 1980, while in the other two years the peak densities were in May. More recently Van der Veer (2000) reported on the density of plaice in the Wadden Sea from 1993 to 1999. In this latter study, an exceptionally strong year class was recorded in 1996 with a peak density of 1250 $1000m^{-2}$ noted in April. In the other years maximum densities varied between approximately 450 and 250 $1000m^{-2}$ in March, April or May. On the French coast, Amara and Paul (2003) recorded maximum densities of 5300 to 400 $1000m^{-2}$ depending on the area sampled, in April of 2000. All densities mentioned above were obtained from beam-trawl surveys with the exception of Modin and Pihl (1996) who used drop-traps as their sampling method. The Irish west coast densities were much lower than those recorded on the Swedish coast (Modin and Pihl 1996), off the French coast (Amara and Paul 2003) and in Port Erin in the Irish Sea (Nash and Geffen 2000). However, peak densities recorded elsewhere in some years were comparable to the Irish west coast densities.

A significant difference was noted in the peak densities between years on the two beaches sampled in Galway Bay. In 2002, the mean densities were 31 $1000m^{-2}$ and 44 $1000m^{-2}$ on Silverstrand and Ballyloughaun, while in 2003, peak densities were 237 and 277 $1000m^{-2}$ respectively. Interannual variability in recruitment is common in plaice (Bergman *et al.* 1988, Van der Veer *et al.* 1990, Modin and Pihl 1994, Nash and Geffen 2000). In the Irish Sea, Nash and Geffen (2000) found that densities in 1996 were the highest over the period of 1991 to 1999. Van der Veer *et al.* (2000) also noted this exceptionally strong year class in 1996 in the Wadden Sea, which is south of Port Erin. Van der Veer *et al.* (2000) found that this exceptionally strong year class in plaice was generated after a very cold winter, and stated that this relationship with temperature is likely to be an indirect one acting via predation. As mentioned above temperature variation in Galway Bay between 2002 and 2003 was very small and not of the order of 4°C noted by Van der Veer *et al.* (2000). Hence, interannual variability noted on the west coast of Ireland could be due to some other factors, biotic, abiotic or oceanic as opposed to temperature.

The mean length of 0+ plaice caught early in the year in Galway Bay was comparable to that found in other locations. Steele and Edwards (1970) recorded the mean length of plaice in Scottish waters in April 1965 to 1968 to range between 14mm to 18mm, depending on the year. The April mean length in Galway Bay from 2003 (15.1mm ± 2.35) fits into this range, however, the mean length noted in 2002 was lower (12.5mm ±1). In the Wadden Sea, Kuipers (1977) recorded the mean length of 0+ plaice at approximately 15mm, again, close to the value recorded in April 2003 in Galway Bay, but higher than the 2002 value. The difference in April mean lengths between years in Galway Bay is probably due to differences in settlement times, with the 2002 cohort settling later, though there is no evidence for this.

Observed growth rates obtained from the increase in mean length over the main growth period were compared with a predicted growth model (Fonds *et al.* 1992 in Nash *et al.* 1994a) obtained at varying temperatures, under optimal feeding conditions. Mean length of 0+ plaice on the two locations combined in Galway Bay reached 5.5cm ± 8.7 in 2002 and 5.9cm ± 5.5 in 2003 by July. The predicted growth (6.3cm in 2002 and 6.2cm in 2003) for this month was very similar to observed growth in both years. This suggests that the food conditions in Galway Bay are optimal for growth of 0+ plaice. In Icelandic waters, plaice had reached approximately 3.8cm in July and observed and predicted growth rates were similar (Hjorleifssoon and Palsson 2001), which shows that the growth rate is lower than in Galway Bay, due probably to colder temperatures. Growth rates in Loch Ewe (Steele and Edwards 1970) were slightly lower than Galway Bay, with July mean lengths between 4 and 5cm, depending on the year. In this later study, one of the lower mean lengths was from fish settled earlier than other years. Settlement timing may therefore not have a major influence on the size of fish in the summer months. In the Irish Sea, Nash *et al.* (1994a) recorded the July mean lengths as ranging between approximately 4 and 5cm in 1988 to 1992, again slightly lower than Galway Bay. The growth rates in the Wadden Sea (Zijlstra *et al.* 1982, Van der Veer 1986) were similar to Galway Bay. In both these studies in the Wadden Sea, sizes in July ranged between approximately 5 and 6cm. Zijlstra *et al.* (1982) found the predicted growth to be generally lower than the observed growth between 1973 and 1978, while Van der Veer (1986) noted that predicted growth was slightly higher than observed growth from 1980 to 1983. However, two different growth models were used in these latter studies and could explain the varying results. The data shows that growth rates decline northwards with colder water temperatures. Galway growth rates fit into this geographical pattern with higher growth rates than Icelandic and Scottish waters and similar growth rates to the Wadden Sea.

Mortality rates were obtained from June to August in both years in Galway Bay. These ranged from 0.032 to 0.012 d^{-1} on Silverstrand in 2002 and 2003 and from 0.011 to 0.048 d^{-1} on Ballyloughaun in 2002 and 2003 respectively. Mortality rates recorded in Galway Bay are within the range noted by Iles and Beverton (1991) for European waters (0.007 to 0.052 d^{-1}). The latter review covered all studies in European waters up to 1990. Hjorleifsson and Palsson (2001) noted a mortality rate of 0.03 d^{-1} on the Icelandic coast, which is within the Galway Bay range. In Port Erin, mortality rates of 0.011 to 0.052 d^{-1} were noted by Nash and Geffen (2000). Again the Galway Bay mortality rates are within this range. The major cause of mortality of 0+ plaice in the Wadden Sea is predation by *C. crangon* and to a lesser extent *Carcinus maenas* (Linnaeus) (Amara and Paul 2003, Bergman *et al.* 1988, Van der Veer and Bergman 1987, Steel and Edwards 1970). However, Nash and Geffen (2000) found no relationship between mortality and *C. crangon* densities and stated that this could be indicative of a different predation mechanism working in the Irish Sea as opposed to that in the Wadden Sea. The main cause of mortality on the Irish west coast cannot be determined here, as no such studies have been undertaken to date.

Experimental push-netting carried out during the settlement period in Galway Bay found that differences in depth in shallow water ($\leq$0.5m) does not have a significant effect on the catches of 0+ plaice. No previous comparable work in this depth range has been carried out. Across wider depth ranges, 0+ plaice show variation in numbers with depth. In British waters, Riley *et al.* (1981) found that the abundance of 0-group flatfish (including plaice) is profoundly influenced by water depth. In the latter, study 0+ plaice were sampled from 0 to 16m depth, with a decrease in abundance recorded with depth. Gibson *et al.* (1996) noted a significant decrease in the abundance of 0+ plaice with depths ($\leq$4m) on the Scottish coast. Also, on the Scottish coast, Poxton *et al.* (1982) recorded the same pattern, stating that the majority of 0+ plaice are within the 4m-depth contour. The same relationship between 0+ catches and depth ($\leq$2m) was found by Hinz (1989) in the Wadden Sea. The results of the Galway Bay study do not contradict these studies, as the depth range was much smaller. However, it does suggest that the variation in the 0+ plaice numbers between 0 and 0.5m is negligible and does not affect the overall numbers caught in the push-net.

Experimental push-netting showed a very highly significant difference in day and night catches of 0+ plaice, with higher densities obtained at night in Galway Bay. This was carried out in August of 2003, which was outside the main settlement period. In Port Erin, Isle of Man, Nash *et al.* (1994b) noted no significant difference in day and night catches of 0+ plaice in May, but did record a significant difference in September samples. A beam trawl survey by Gibson *et al.* (1996) found the number of fish (which included plaice as one of the dominant species) in day and night samples to be similar in June, but catches in August were much higher at night in Scottish waters. In contrast to the studies above, in the Wadden Sea, Hinz (1989) noted that 0+ plaice numbers caught in fyke-nets, were significantly higher during the day than at night. Hinz (1989) suggests that diurnal differences in catches are not caused by different distribution patterns, but by light-dependent variations in fish activity and gear efficiency. From Nash *et al.* (1994b), it is apparent that differences in diel catches of 0+ plaice are seasonal. Nash *et al.* (1994b) suggests that in the earlier part of the year the over-riding rhythm is tidal as opposed to diurnal for 0+ plaice, while later in the year plaice are entrained to a light/dark cycle. Reasons for the difference in 0+ plaice catches between day and night samples are unknown for the Galway Bay study, but it is probably a combination of gear efficiency and fish behaviour. It is important to note that the evidence points to there being no difference between night and day catches during the settlement period.

In summary, the seasonal occurrence of 0+ plaice in Galway Bay was similar to that recorded in Icelandic waters, Swedish waters, Port Erin, Isle of Man and the North Sea. Peak densities recorded were within the ranges noted in Icelandic waters, Scottish waters and the Wadden Sea. However, peak densities recorded on the French coast, the Swedish coast and in the Irish Sea where higher than those recorded in Galway Bay. Growth rates in more northern areas were lower than in Galway Bay, while growth in the Wadden Sea was similar to Galway Bay growth rates. The mortality rates in Galway Bay were within the ranges noted for all other studies in western European waters. The effect of depth on sampling was negligible within the 0.5m contour during the settlement period, while day and night sampling did had a significant effect on catches of 0+ plaice in August.

Chapter 4: Hatching, larval period, settlement and growth of 0+ plaice (*Pleuronectes platessa L.*) determined using otolith microstructure in Galway Bay off the Irish west coast

4.1 Abstract

Hatching dates, larval period, settlement and growth of 0+ plaice were determined using otolith microstructure. Samples were taken from Silverstrand and Ballyloughaun, both located in Galway Bay in March to May 2003. A total of 85 fish otoliths were polished and examined under a light microscope. Hatching dates ranged from late January to late March, with peaks in hatching occurring in early and late February. Hatching dates were similar to those noted in other studies in European waters. The larval period for fish caught on Ballyloughaun ranged from 28 to 38 d. On Silverstrand, the larval period ranged from 29 to 43 d. A significant difference in the larval period was noted between beaches in April and May, but not in March. This larval period was shorter than those recorded in other studies due to higher sea temperatures on the Irish west coast. Settlement time ranged from early to mid March to late April. Three cohorts of settlement were noted, which correspond to pulses in hatching. Mean settlement date of fish caught in the three months was significantly different, showing that the majority of fish sampled in March were from the first settlement cohort, April fish were mostly from the second settlement cohort and fish caught in May were mostly from the third settlement cohort. The post-larval age of plaice caught on Silverstrand ranged from 2 d in March to 50 d in May. In Ballyloughaun this range was from 2 d to 29 d. No conclusions could be drawn on differences in juvenile fish age, between beaches and months because of a significant interaction following a Two-Way ANOVA. Observed growth was similar to predicted growth. There was no difference in growth between months on both beaches and no between beach difference was noted. A strong inverse relationship was noted between growth and density.

4.2 Introduction

Plaice (*Pleuronectes platessa* L.) spawn in offshore waters and, after hatching, the larvae are distributed to local nursery areas by residual currents (Bergman *et al.* 1988). At the end of the larval period, metamorphosis takes place. At metamorphosis plaice move from a relatively dilute, three-dimensional environment to a relatively concentrated two-dimensional environment (Nash and Geffen 2000). This metamorphosis is termed settlement. Plaice are of great commercial importance on the Irish west coast (ICES area VII b,c) and knowledge of the early life history is very important in the management and prediction of future stocks.

The knowledge of fish age and growth is fundamental to fisheries science (Jones 1992). Daily increment analysis of fish otoliths provides important information about early life events in studies on population dynamics (Brothers and McFarland 1981, Victor 1982 in Karakiri *et al.* 1989). Since Pannella (1971) first described daily growth increments in fish otoliths, several studies have been conducted on this subject (Karakiri *et al.* 1989).

Otoliths are small calcified structures that show annual, and, for younger fish daily patterns, and therefore form a permanent record of life history events (Jones 1992). Three pairs of otoliths are located posteriorly in the head of the fish and these are called the lapilli, sagittae and the asterisci (Secor *et al.* 1992). In the present study, all work was carried out on the sagittal pair of otoliths. The microstructure of the otolith includes a hatch check, which in plaice is laid down at approximately 10μm from the center of the otolith, which indicates the time of hatching from the egg (Hovenkamp 1990). Increments are then laid down daily during the larval period. When the larval phase is complete, the transition to the demersal (bottom dwelling) phase of the life cycle is marked by 4 to 6 Accessory Primordia (AP) (Modin *et al.* 1996). These AP are secondary growth centers and their presence allow us to back-calculate date of settlement. Thereafter, increments deposited after the transition to the bottom living stage are much wider than the larval ones (Karakiri *et al.* 1989). In Port Erin Bay, Isle of Man, Geffen and Nash (1995) recorded check formation on the microstructure of otoliths and linked the occurrence of checks to tidal and light cycles. Thus, analysis of otolith microstructure in a fish population can provide data on hatching dates, length of larval cycle (larval period), settlement date, post-larval age and juvenile growth rates.

In general, otolith growth is proportional to somatic growth and both are influenced by temperature and food supply. In the Wadden Sea, Karakiri *et al.* (1989) used otolith microstructure of 0+ plaice to assess the growth rate between regions. Karakiri *et al.* (1989) identified differences in growth rate between areas with a limited and unlimited food supply, by measuring increment widths, and found that plaice from an area with a limited food supply grew slower than those from an area of unlimited food. Berghahn *et al.* (1995) also compared the growth rate (calculated from otolith microstructure) from two areas in the Wadden Sea, one area of poor food conditions and another area of rich food conditions for 0+ plaice. They found significantly higher growth in the rich food conditions. Karakiri *et al.* (1991) compared larval growth, date of settlement and subsequent growth of 0+ plaice from two different locations in the Wadden Sea and found differences in hatching times, larval period, settlement and growth rates between various locations.

Growth and mortality of 0+ plaice in the Irish Sea was analysed using otolith microstructure (Al-Hossaini *et al.* 1989). Al-Hossaini *et al.* (1989) also determined the settlement and hatching times, and found three sub-cohorts at settlement, with most fish caught in September, coming from the third cohort in spring. Modin and Pihl (1994) also found three settlement cohorts on the Swedish coast. They noted decreasing growth rates for the later cohorts, and suggested that this was a strong indication of density-dependent growth of 0+ plaice.

With otolith microstructure, it is possible to calculate exact hatching and settlement dates for plaice. Van der Veer *et al.* (2000) defined exact hatching dates for 0+ plaice in the Wadden Sea using otolith microstructure. In this latter study, two years of high and low settlement rates were compared, and it was found that in the year with higher settlement, hatching occurred later in that year. On the French coast, Amara and Paul (2003) used otolith microstructure for back-dating settlement times and also to calculated growth of 0+ plaice.

This study forms part of a larger research project on the assessment of juvenile flatfish nursery grounds in the Galway Bay area. Otolith microstructure was used to define hatching dates, larval period, exact settlement timing and growth of 0+ plaice in Galway Bay. Also, the existence of cohorts in settlement as seen in other areas was investigated. This was carried out on two beaches in Galway City with the intention of assessing spatial differences in the measured parameters. Currently there are no published data on otolith microstructure of 0+ plaice in Irish waters.

4.3 Materials and methods

4.3.1 Survey area

0+ plaice were sampled from March to May in 2003. Quantitative sampling was carried out using a Riley push-net (Holmes and McIntyre 1971). Fish were collected from two locations i.e. Silverstrand (53° 15.2`N 09° 07.8`W) and Ballyloughaun (54° 16.2`N 09° 01.6`W) which are both sheltered, flat, sandy beaches located in or near Galway city. These beaches have some estuarine influence from the River Corrib. This estuarine influence is limited on Silverstrand where low salinities were not recorded during this survey as frequently as those recorded on Ballyloughaun. Sampling procedures are already described in section 3.3.3 (Chapter 3).

4.3.2 Fish analysis

Each fish was given a unique code so it could be traced back to its location on capture and the date when caught.

The total length (TL) (from the tip of the mouth to the distal end of the tail) was taken to the nearest 0.1mm for 0+ plaice. For each sampled month, a sub-sample of fish was haphazardly selected for otolith microstructure analysis. The sagittal otoliths were removed from the vestibular apparatus by prying from the head using a fine forceps, under a stereoscopic microscope. These were then transferred to vials and stored dry pending further analysis.

4.3.3 Otolith preparation

In order to identify the daily growth increments, the otoliths required polishing. The polishing technique used was that described by Brophy and Danilowicz (2002) for juvenile herring.

The otoliths were mounted in TAAB transmit resin for light microscopy. Caps for 0.5ml micro centrifuge tubes were used as moulds for the resin. Otoliths were placed into the resin with the concave side down. The resin was dried at 70 °C for approximately 15 hours. The otoliths were removed from the caps (embedded in the resin) and attached to glass slides using glue. Polishing was carried out using 4000 and 2000-grit silicon carbide paper, until the post-larval daily increments were visible. Further polishing of the otolith allowed measurement of larval growth rings at the otolith core.

Otoliths were examined through an Olympus CX41 light microscope with X40 and X100 (oil immersion) lenses. Further analysis was carried out using an Olympus camedia C-3040 Zoom digital camera and an Olympus DP-Soft 3.2 image analysis package.

4.3.4 Otolith interpretation

Otoliths were polished until the hatching check (Figure 49) was visible, which is approximately 10μm from the centre of the otolith (Hovenkamp 1990). From this hatch mark, the daily growth rings were enumerated up to the occurrence of the first Accessory Primordium (AP) and this was taken as the larval period. Daily increments from the first AP to the otolith edge were then counted to obtain the post-larval age of the fish. Figure 50 shows the AP that occurs when settlement is complete. Counts were taken from the longest and clearest axis. At least 4 counts were carried out on the same axis on each otolith to assess the precision of age estimates.

Thus, five parameters were measured:

1. Larval life. Hatch check to accessory primordium (L)
2. Post-larval life. Accessory primordium to edge (P)
3. Total age (T) = L + P days

4. Settlement date = Sampling date - P
5. Hatching date = Sampling date - T

Figure 49: Picture of a polished otolith at X1000 magnification. The hatch check and daily growth increments are visible here.

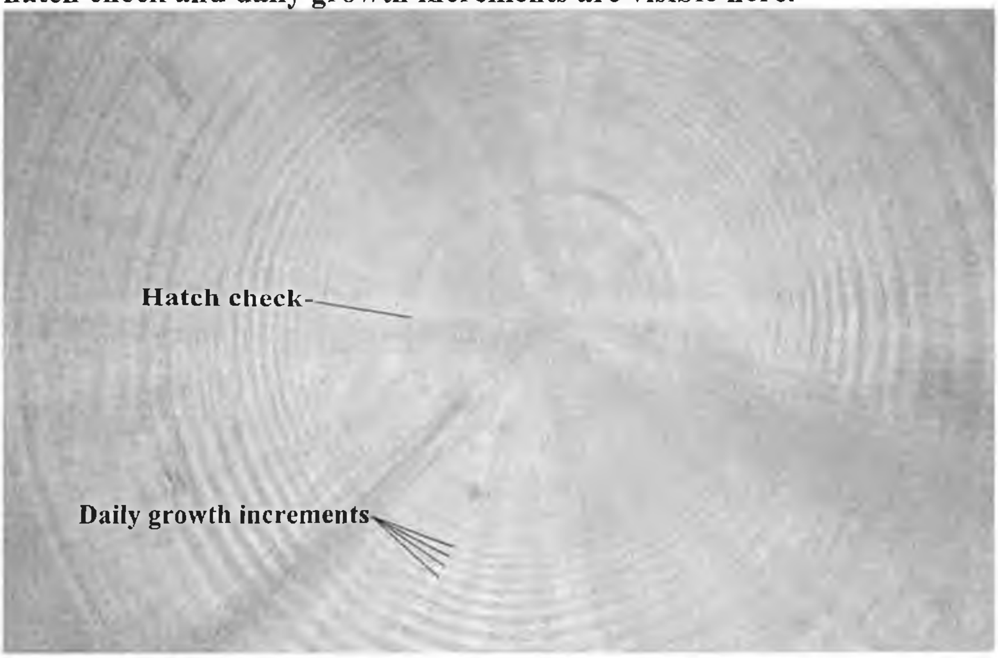
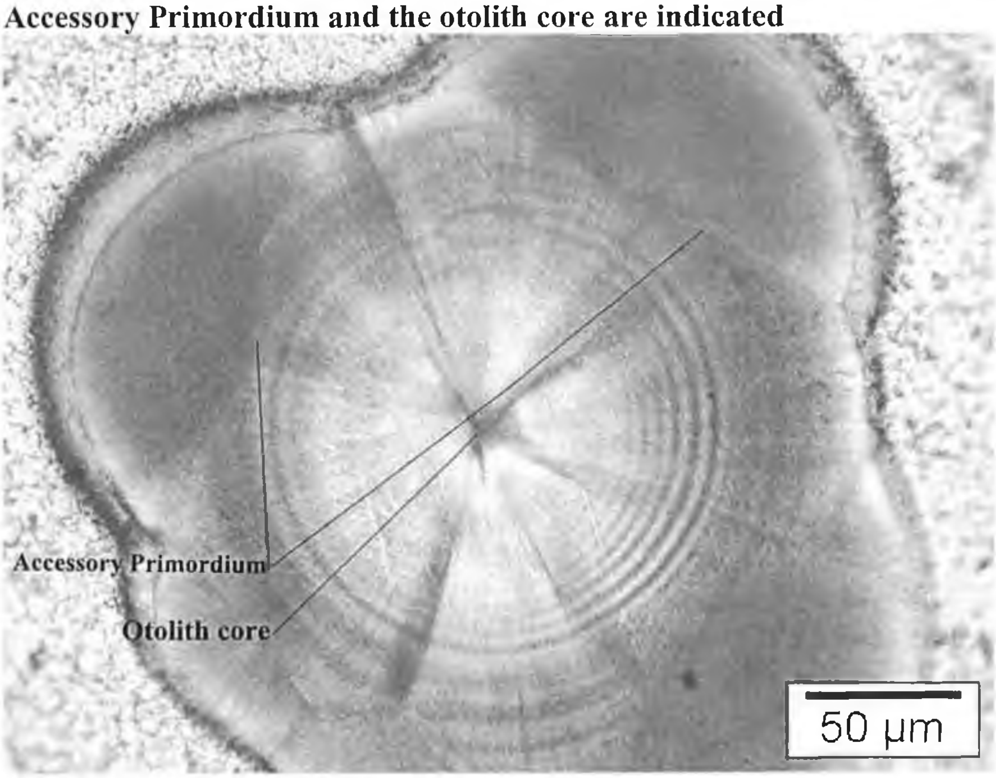


Figure 50: Picture of a polished otolith at X400 magnification. The Accessory Primordium and the otolith core are indicated



4.3.5 Growth estimates

Observed and predicted growths were calculated for 0+ plaice in Galway Bay. Observed growth (Gr_o) was calculated (mm d^{-1}) from Berghahn *et al.* (1995):

$$\mathbf{GR_o = (TL_{catch} - TL_{metamorphosis})/\text{age after metamorphosis (post-larval age)}}$$

Where TL is the total length at the time of catch and at metamorphosis, respectively. Length (TL) at metamorphosis used for the calculation was 12mm (Ryland 1966, in Berghahn *et al.* 1995).

Predicted growth (ΔL) in length (mm d^{-1}) of 0+ plaice was calculated from the equation taken from Fonds *et al.* (1992) in Nash *et al.* (1994a):

$$\mathbf{\Delta L = 0.014\ T^{1.5} - 6.10^{-9}\ T^{6}}$$

Where: T is the mean monthly temperature taken from the M1 Marine Institute data buoy located off the west coast of Ireland.

4.3.6 Data analysis

All data were subjected to Ryan-Joiner normality tests and a Bartlett's test for homogeneity of variances. If data were not normal or homogenous, transformations were carried out. Either log, inverse log, log + 1 or inverse log + 1 transformations were used for normalisation. If transformations did not normalise, the non-parametric Kruskal-Wallis and Mann-Whitney U tests were used. Were a Kruskal-Wallis was significant a Moods-Median test was used for *post hoc* analysis. When data was non-homogenous, monotonic (Log or inverse log) transformations were carried out (Underwood 1997). When transformations were unsuccessful non-parametric analysis was used where possible. When non-parametric analyses were not applicable, parametric analyses (ANOVA) were carried out. However, results of the main hypothesis in these analyses should be treated with caution due to the risk of a Type I error (rejection of null hypothesis where it is true) associated with heterogeneous data.

A test where the data are unbalanced and where the variances are non-homogenous, the risk of a Type 1 error is less (Underwood 1997).

Analysis of variance (ANOVA) tests were used on normal data. One and Two-Way ANOVA's were used. *Post hoc* analysis was carried out using a Fisher's pairwise comparison test. When Two-Way ANOVA's between months and beaches were carried out three null hypotheses were considered. These were:

(1) there is no difference in the measured parameter between months
(2) there is no difference in the measured parameter between beaches
(3) there is no interaction between month and beach.

Where an interaction occurred, there may have been significant differences between certain months on any beach, or significant differences between beaches in certain months, but no consistent general patterns could be discerned. Hence, no conclusions were drawn on the two main hypothesis (differences between beaches or differences between years) because interpretations of the main effects were impossible or at best unreliable when there was an interaction (Underwood 1997). When an interaction was present no further analysis was carried out. All analyses were calculated on Minitab version 13.1.

4.4 Results

4.4.1 Sampling times

Table 16: Sampling dates numbers of fish examined and number of days between samples for Silverstrand and Ballyloughaun in 2003

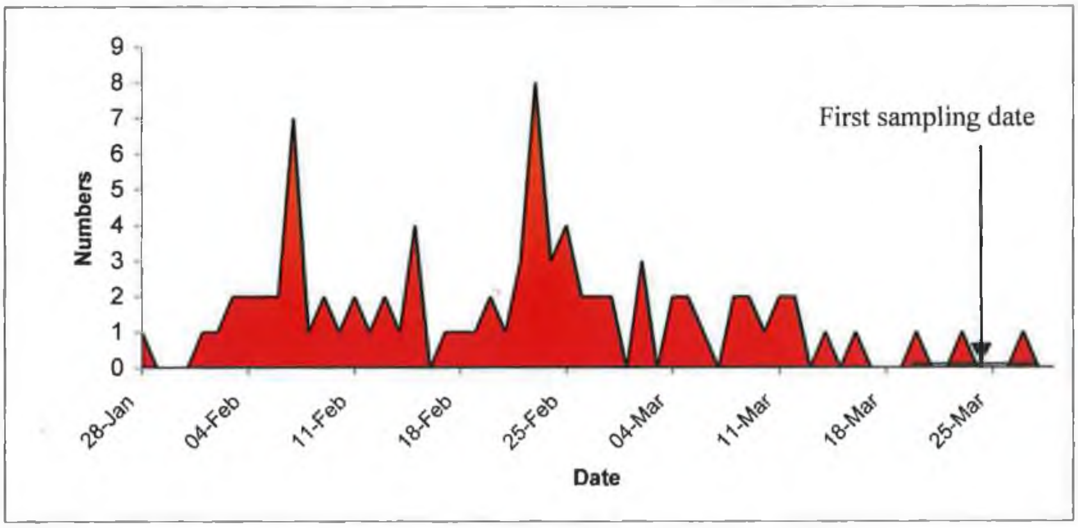
Beach	Month	Number examined	Date sampled	Months	Number of days between samples
Silverstrand	March	18	19/03/2003	Mar - Apr	15
	April	18	03/04/2003	Apr - May	29
	May	13	02/05/2003	Mar - May	44
Ballyloughaun	March	6	26/03/2003	Mar - Apr	9
	April	13	04/04/2003	Apr - May	27
	May	17	01/05/2003	Mar - May	36

Table 16 shows the dates of sampling, numbers of fish examined and the number of days between samples for all months.

4.4.2 Hatching times

In order to estimate the main hatching period for Galway 0+ plaice, data from both locations were pooled together and this is shown in Figure 51. Hatching started in late January and continued through to late March. The peak hatching times occurred from early February to mid February and again from mid-late February to early March. Thereafter, numbers of fish hatching declined. Table 17 shows the mean hatching dates and hatching date range for Silverstrand, Ballyoughaun and both beaches combined in March, April and May of 2003. From Table 17 it can be seen that the mean hatching date got progressively later for each month sampled on both beaches.

Figure 51: Hatching times of 0+ plaice caught in Silverstrand and Ballyloughaun in spring of 2003.



Variation in hatching dates between months and beaches (Table 17) was investigated using a Two-Way ANOVA. No interaction between months and beaches was observed ($p = 0.099$). A significant difference was observed in the hatching times of plaice caught in different months ($p = 0.040$), while no between beach difference was detected ($p = 0.331$). The monthly difference recorded here should be treated with caution as the data did not have homogeneous variances. A One-Way ANOVA with Fisher's pairwise comparison was then carried out on the monthly data and this showed that all months differed from each other with earlier hatch dates for fish caught in March. Thereafter, mean hatching dates got progressively later for fish caught in the April and May 2003 ($p = < 0.001$).

Table 17: Mean hatching times (± SD) and the hatching range for Silverstrand, Ballyloughaun and both beaches combined for 0+ plaice caught in March, April and May 2003.

Beach	Month	Mean hatching date (± SD)	Range of hatching dates
Silverstrand	March	5-Feb ± 4	28-Jan - 12-Feb
	April	22-Feb ± 4	15-Feb - 28-Feb
	May	4-Mar ± 17	7-Feb - 25-Mar
Ballyloughaun	March	12-Feb ± 5	7-Feb - 18-Feb
	April	20-Feb ± 8	7-Feb - 6-Mar
	May	12-Mar ± 9	27-Feb - 30-Mar
Both beaches combined	March	08-Feb ± 4	28-Jan - 18-Feb
	April	21-Feb ± 6	7-Feb - 6-Mar
	May	08-Mar ± 13	7-Feb - 30-Mar

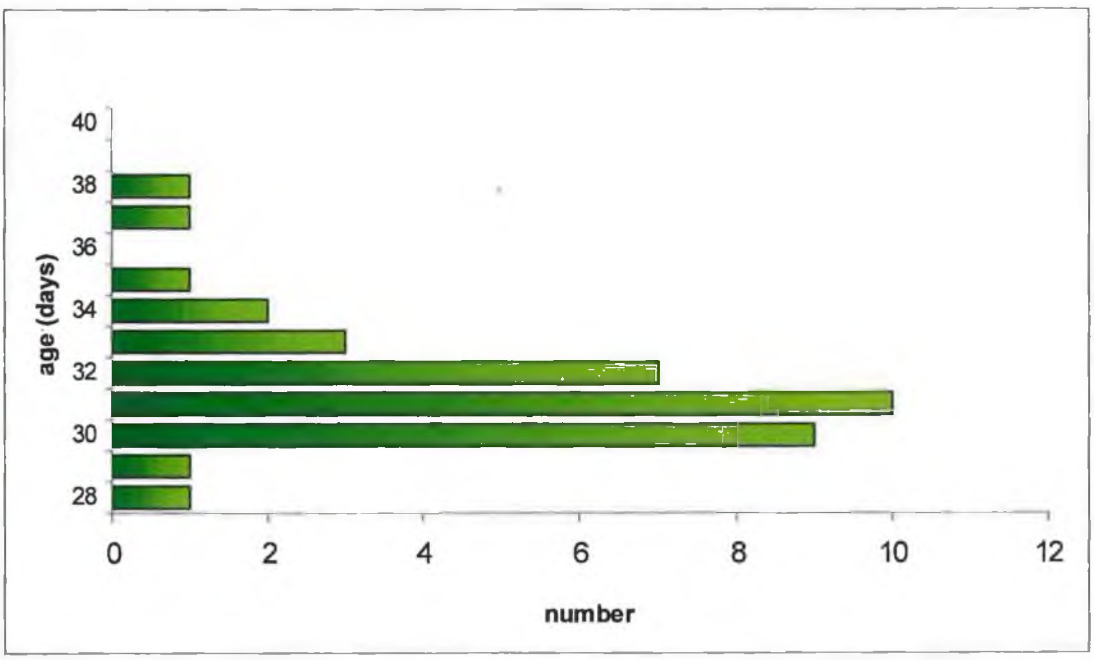
4.4.3 Larval period

The larval period is from the hatch check to the first AP. In this section nonparametric test were used, because the data could not be normalised by transformations.

4.4.3.1 Ballyloughaun

All months were pooled together to analyse the larval period of plaice settling onto Ballyloughaun. This is shown in Figure 52. The larval period ranged from 28 d to 38 d on this beach, with the majority of fish as larvae for 30 - 32 d. The mean larval period was 31 ± 2 d. Larval period data were not normally distributed but skewed due to the presence of a small group of fish which had a longer larval period. There was no difference in the larval period of plaice caught between months sampled ($p = 0.141$, Kruskal-Wallis test).

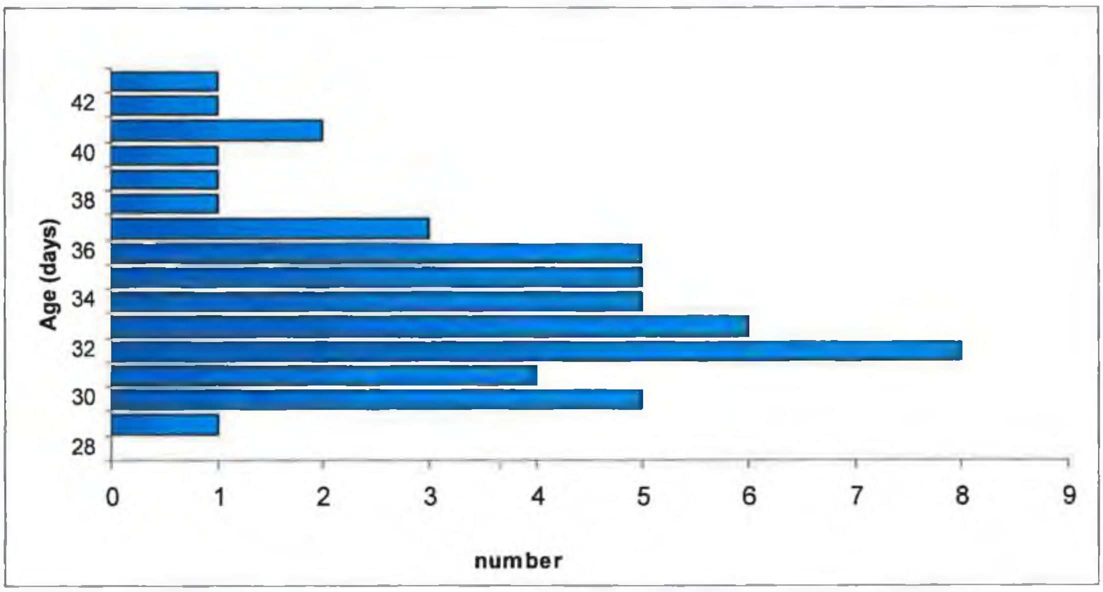
Figure 52: Larval period in days of 0+ plaice caught on Ballyloughaun in the spring of 2003.



4.4.3.2 Silverstrand

Data on the larval period of plaice caught in Silverstrand is shown in Figure 53. On this beach the larval period had a wider range than that on Ballyloughaun with fish aged from 29 d to 43 d. Again the data are skewed and not normally distributed. The majority of plaice had a larval period of 30 d to 36 d, with peak numbers at 32 d. The mean larval period here was 34 ± 3 d. A significant monthly difference was detected ($p = 0.011$, Kruskal-Wallis test), and a Mood's Median test ($p = 0.003$) showed that fish caught in April had undergone a shorter larval period (32.5 d) than those caught in March and May 2003 (35.9 and 34.1 d respectively).

Figure 53: Larval period in days of 0+ plaice caught on Silverstrand in the spring of 2003.

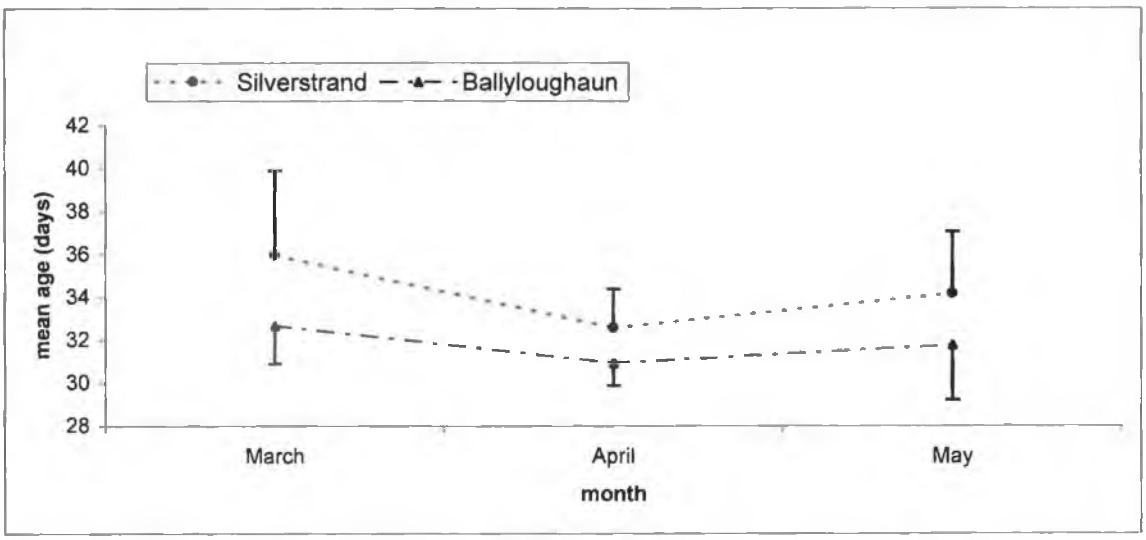


4.4.3.3 Difference in the larval period between beaches

Figure 54 shows the mean larval period (± SD) for each month sampled on Silverstrand and Ballyloughaun. Both beaches showed a similar pattern, with the highest mean larval period recorded in March and the lowest recorded in April. Between beach differences were assessed separately for each month using a Mann-Whitney U test, as the data could not be normalised.

No significant difference was detected between the March samples ($p = 0.057$). However, significant differences were detected in April ($p = 0.012$) and May ($p = 0.004$), with Silverstrand having longer larval periods. Overall, larval life for fish settling on Silverstrand was longer than those on Ballyloughaun by 1.6 to 3.3 days.

Figure 54: The mean larval period for each month sampled on Silverstrand (red with + SD) and Ballyloughaun (green with –SD) in 2003.



4.4.5 Settlement

Settlement was determined by the occurrence of the first AP, which is laid down when settlement is complete (Modin *et al.* 1996). Exact dates when settlement was complete were calculated by subtracting the post-larval growth in days from the capture date. Settlement times ranged from early March to late April.

No difference was observed in settlement dates between the two beaches ($p = 0.600$, Two-Way ANOVA). A significant difference was observed between months ($p = 0.035$) and there was no interaction between months and beaches ($p = 0.117$). This monthly difference should be treated with caution as the data did not have homogeneous variances. A One-Way ANOVA, with a Fishers pairwise *post hoc* test, was then carried out to find which months differed. Results here mirrored that seen with hatching times with all months very highly significantly different from each other ($p < 0.001$). The earliest settlers were caught in March, while fish caught in April and May were from progressively later settlements.

Figure 55 shows the settlement times of 0+ plaice in Silverstrand and Ballyloughaun combined, while Figure 56 shows the settlement dates for fish sampled in each month. The first peak in settlement was noted 36 days after the first peak in hatching. The second peak was 34 days later. Three settlement cohorts were observed, one in mid March, the second in late March and the third in early April. March catches, as expected, consisted exclusively of the first settlement cohort, while catches in April were dominated by the second cohort, with some fish (approx. 5 – 6) from the first cohort also occurring. In May, fish from all three cohorts occurred in the catch with the majority originating from the third cohort (Figure 56).

Figure 55: Settlement of 0+ plaice in the Galway Bay region in 2003. Peaks in settlement are marked with the number of days since the equivalent peak in hatching.

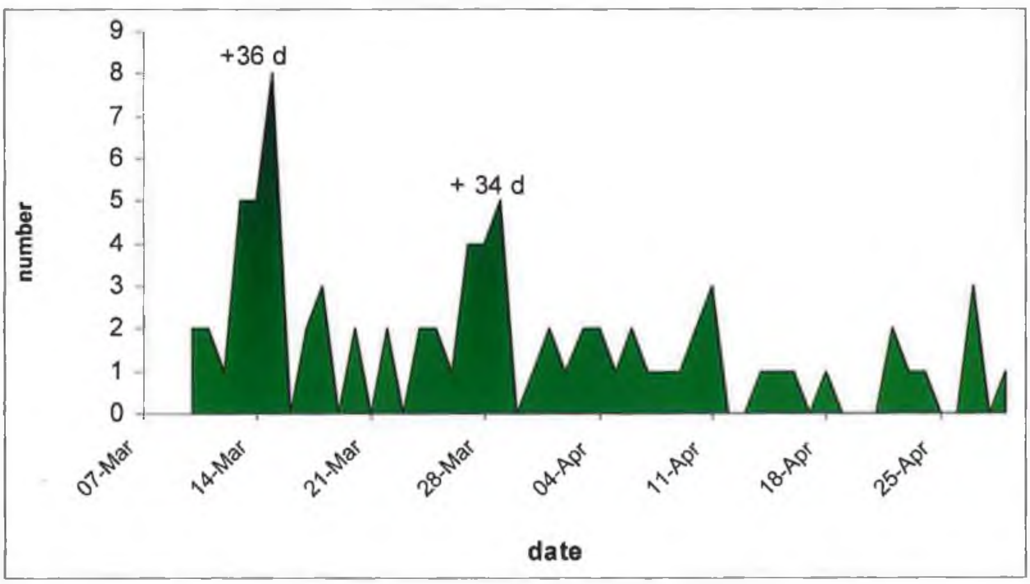
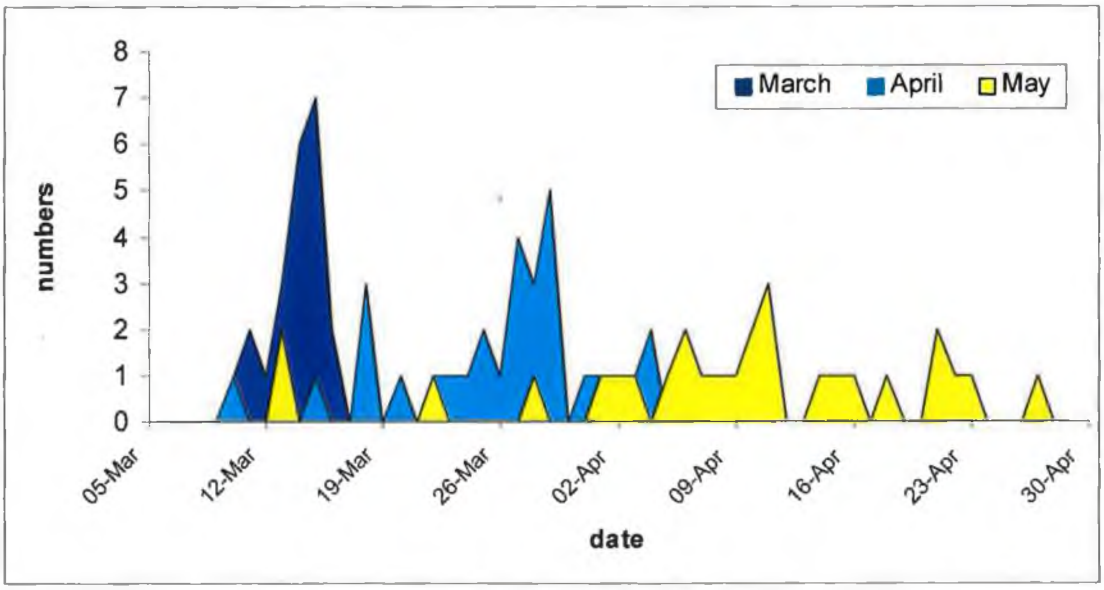


Figure 56: Settlement dates for fish caught in each month for Silverstrand and Ballyloughaun pooled.



4.4.6 Post-laval age

Overall numbers of fish examined, mean total age and mean length for each month is shown in Table 18.

Table 18: Numbers of 0+ plaice examined, mean age in days (± SD) and mean length (± SD) for each month sampled on Silverstrand and Ballyloughaun in 2003.

Beach	Month	Mean age ± SD	Mean length (mm) ± SD
Silverstrand	March	41 ± 4.0	14.6 ± 0.10
	April	39 ± 3.8	14.9 ± 0.11
	May	59 ± 17.2	19.2 ± 0.48
Ballyloughaun	March	42 ± 5.4	15.0 ± 0.08
	April	42 ± 7.8	16.4 ± 0.23
	May	50 ± 8.9	18.2 ± 0.42

The post-larval age of the 0+ plaice on both beaches are given in Figures 57, 58 and 59 for Ballyloughaun and Figures 60, 61 and 62 for Silverstrand. Age is expressed in

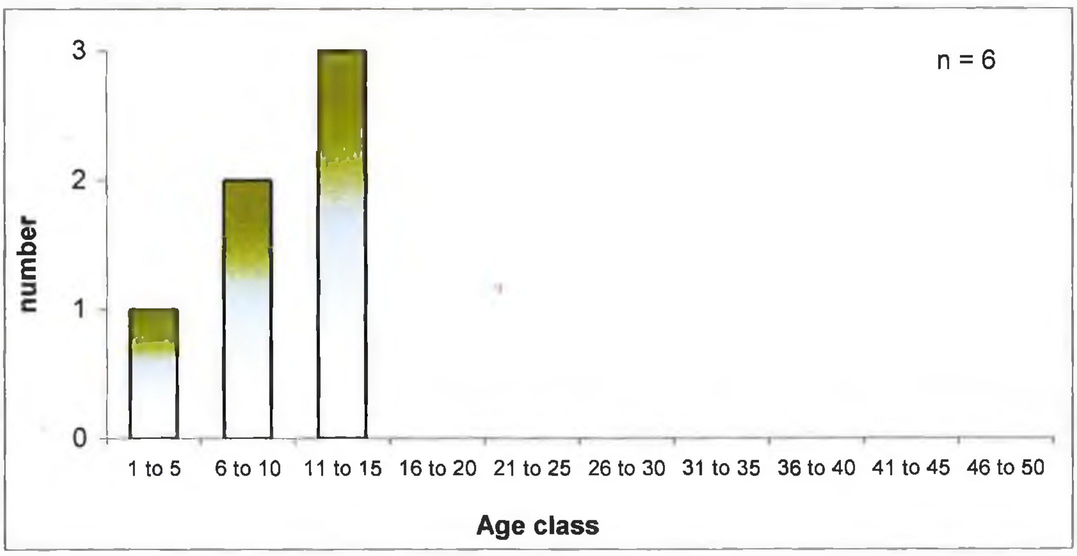
5-day age classes. On both beaches mean total age is very similar in March and April. This reflects the lack of fish from the first settlement cohort in April (see above). Mean total age increases on both beaches in May. Here, the fish are from all three settlement cohorts.

4.4.6.1 Ballyloughaun

4.4.6.1a March

Figure 57 shows the post-larval age in days of 0+ plaice captured in March of 2003. A low number of 0+ plaice where caught in this month. A total of 6 fish were aged. Post-larval age ranged from 2 to 15 days.

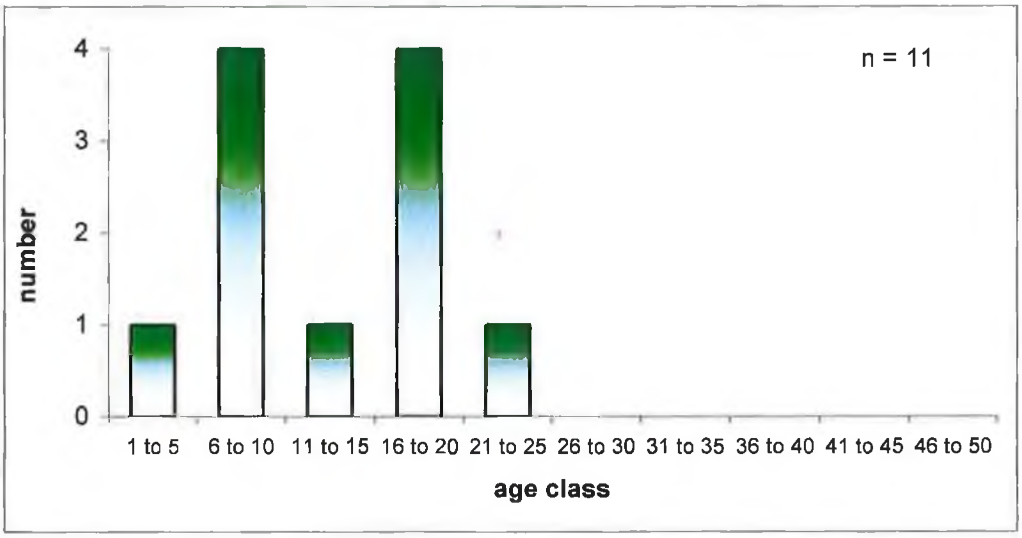
Figure 57: Post-larval age in days of 0+ plaice caught on Ballyloughaun in March of 2003



4.4.6.1b April

In April 2003, a sub sample of 13 plaice was analysed. Here, post-larval age ranged from 0 d to 25 d (Figure 58). Two fish had no post larval growth. The modal ages of fish were 6 – 10 d and 16 – 20 d. Table 16 shows that the numbers of days between sampling in March and April was 9 d. This indicates that some fish caught in April could be from the cohort of fish captured in March. Examination of the settlement age data shows that all fish in the pooled data from Figure 56 caught in April, but settled during the early March period were from Ballyloughaun.

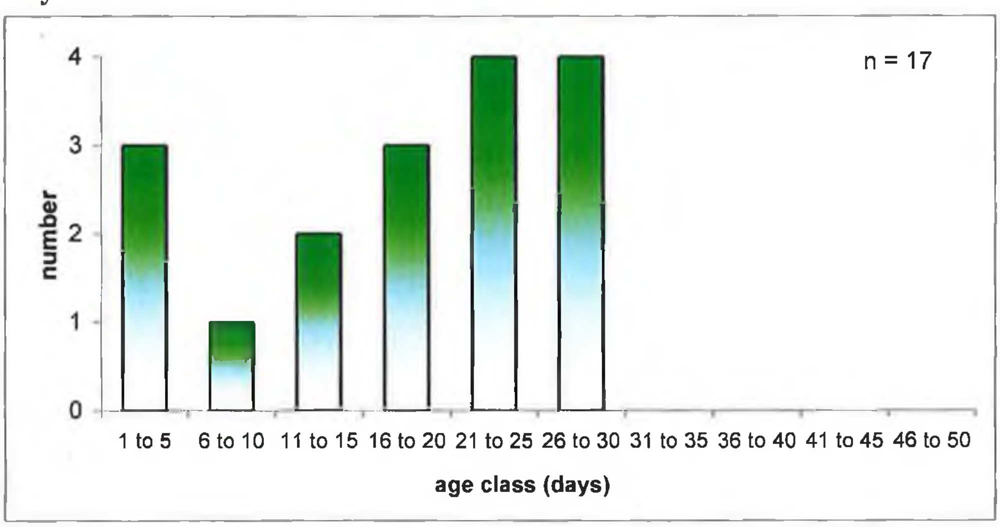
Figure 58: Post-larval age in days of 0+ plaice caught on Ballyloughaun in April of 2003



4.4.6.1c May

In May, the range of post-larval age classes was from 1 - 5 d to 26 - 30 d from 17 fish assessed (Figure 59). The majority of fish were in 21 – 25 d, 26 – 30 d age classes. The number of days between April and May samples was 27 (Table 16). It is unlikely that the individual fish from the cohort sampled in April were caught in May.

Figure 59: Post-larval age in days of 0+ plaice caught on Ballyloughaun in May of 2003

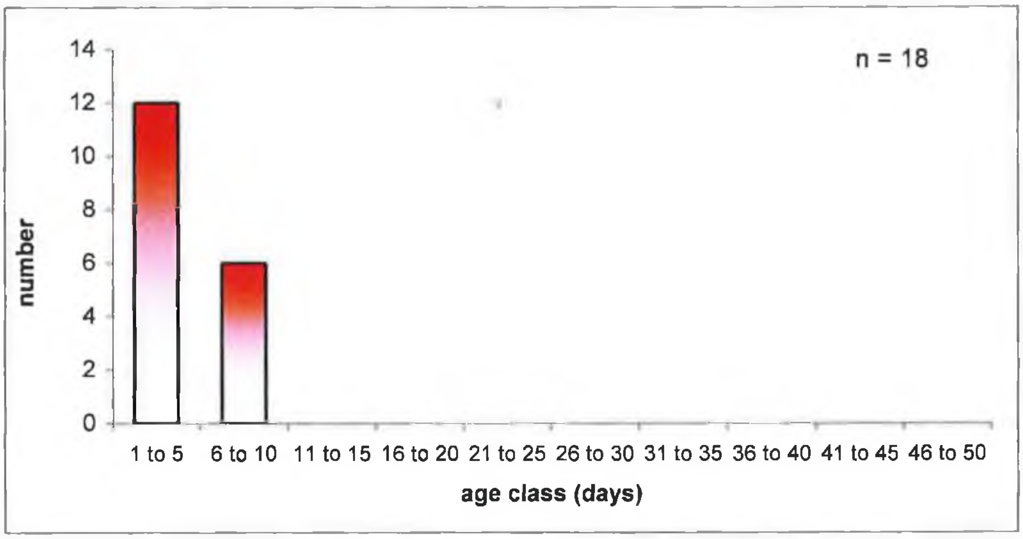


4.4.6.2 Silverstrand

4.4.7.2a March

The post-larval age in days of plaice caught in March is shown in Figure 60. Here, the fish ranged in age class from 1 - 5 d to 6 – 10 d, with the majority of plaice caught in the 1 – 5 age class. A total of 18 plaice were analysed in this sampling month.

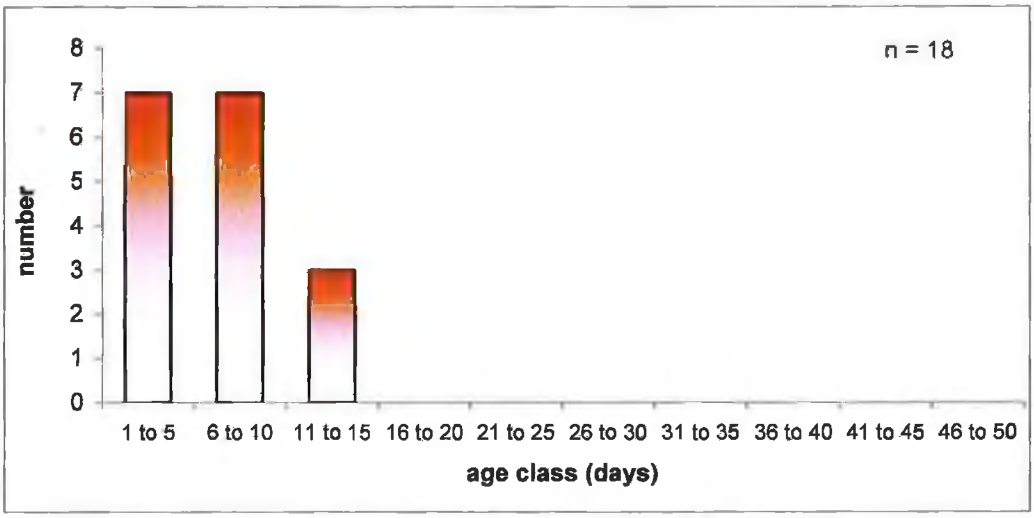
Figure 60: Post-larval age in days of 0+ plaice caught on Silverstrand in March of 2003



4.4.7.2b April

Figure 61 shows the post-larval age structure of 0+ plaice caught in April. The range of age classes was 1 – 5 and 6 – 10. One fish had no post larval growth. Again, as with March in Silverstrand 18 fish were examined. There was 15 days between March and April sampling. This suggests that all April caught fish on Silverstrand were from the second settlement cohort. This is confirmed by examination of the raw date from Figure 56.

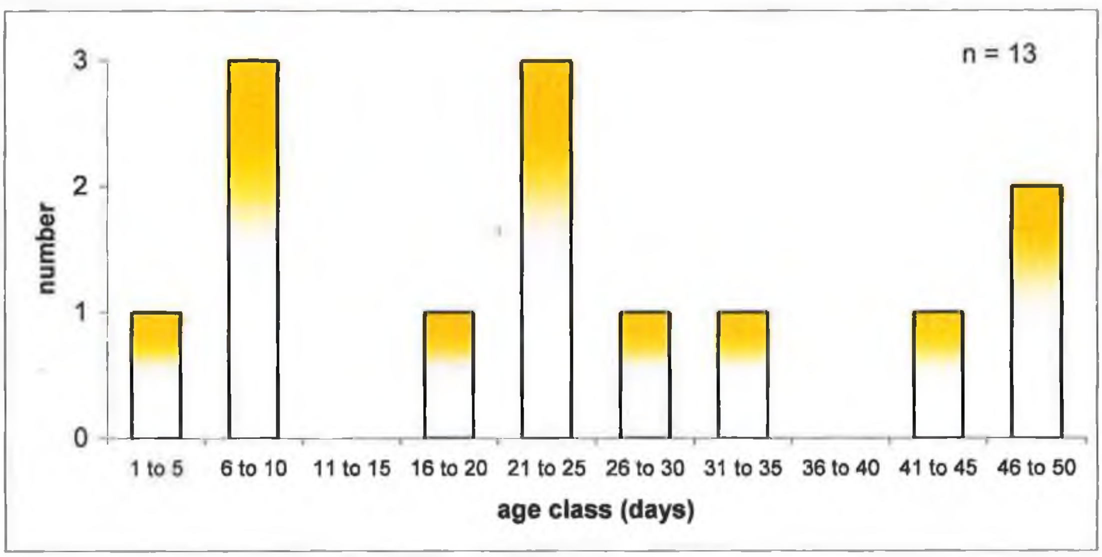
Figure 61: Post-larval age in days of 0+ plaice caught on Silverstrand in April of 2003



4.4.6.2c May

Figure 62 shows the post-larval age in days of 0+ plaice capture in May on Silverstrand. From 13 fish examined the range of settlement ages was from 5 to 50 d. The highest numbers were recorded in the 6 – 10 d and 21 – 25 d age classes. In May, fish caught could be from all three settlement cohorts, with the majority coming from the third cohort.

Figure 62: Post-larval ages in days of 0+ plaice caught on Silverstrand in May of 2003

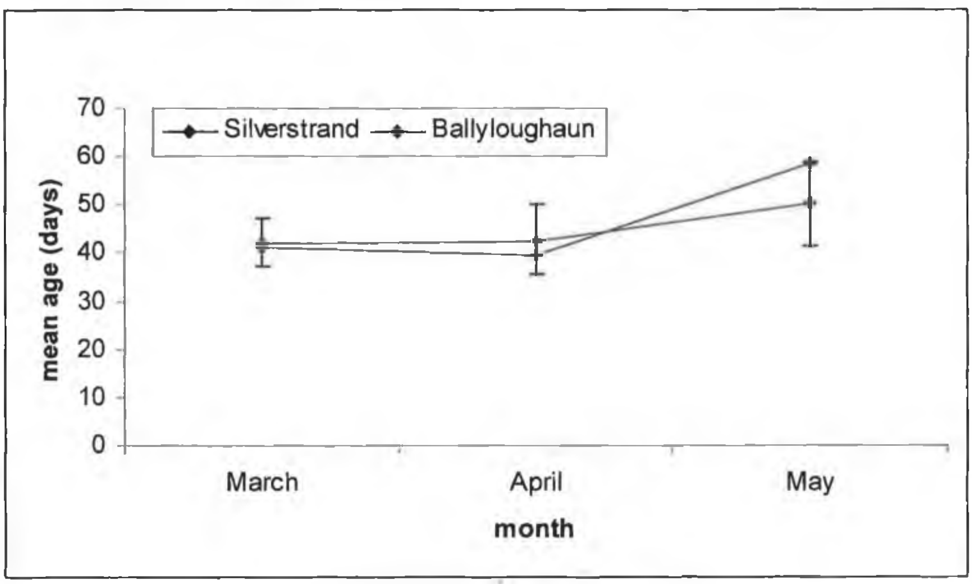


In summary, fish from the first settlement cohort appear on the nursery grounds of Silverstrand and Ballylougaun in March, but are very poorly represented in catches in April and May. Fish from the second settlement cohort appear in the nursery grounds in April, and a few appear again in May. The May catch is comprised mainly of third cohort settlers.

4.4.6.3 Difference in total age between months and beaches

The larval and post-larval age were combined to give a total age. The mean total age for each beach and month was compared (Figure 63). Both beaches depicted a similar pattern with the mean total age of plaice in March and April similar, while on both locations the mean age increased in May. A Two-Way ANOVA on differences between months and beaches was showed that there was a significant interaction between month and beach ($p = 0.040$). Thus, the main factors were not independent of each other. Any differences between months therefore, would depend on the beach or visa versa, differences between beaches would depend on the month.

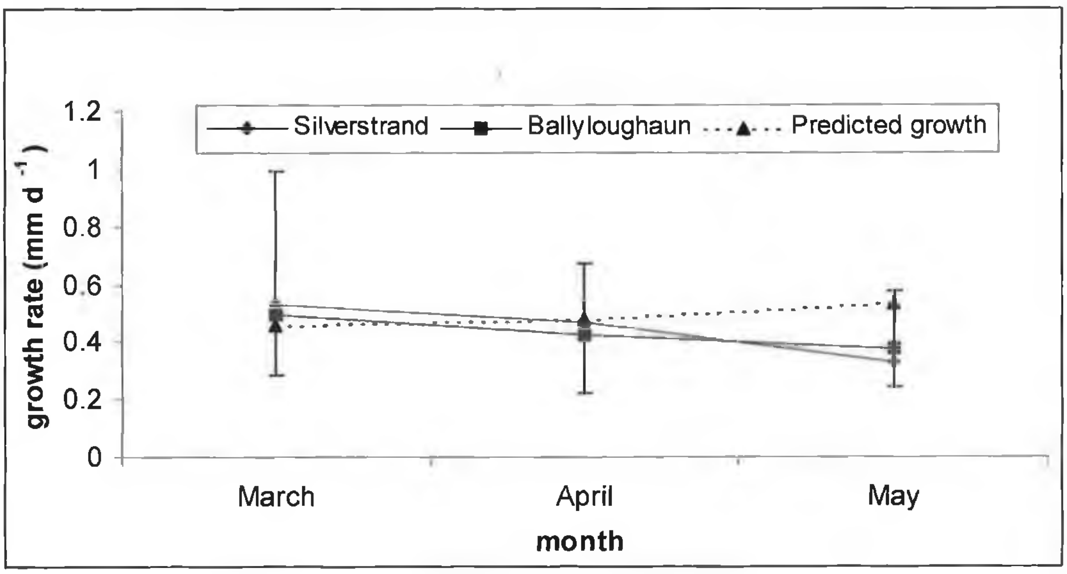
Figure 63: Mean total age in days of 0+ plaice caught on March, April and May of 2003 in Ballyloughaun (Green line with + SD) and Silverstrand (Blue line with – SD).



4.4.7 Growth

The growth rate (mm d^{-1}) was calculated from Amara and Paul (2003) for all months on both beaches. The observed growth rates were compared to the predicted growth from Fond *et al.* (1992) in Nash *et al.* (1994a) and are given in Figure 64. In March the observed growth on both locations (0.528 and 0.494 mm d^{-1} on Silverstrand and Ballyloughaun respectively) was similar to predicted growth (0.458 mm d^{-1}). In April, the predicted growth (0.477 mm d^{-1}) was similar to that on Silverstrand (0.463mm d^{-1}), while in Ballyloughaun the growth rate was slightly lower at 0.420 mm d^{-1}. Growth rates continued to decrease on Silverstrand (0.327 mm d^{-1}) and Ballyloughaun (0.371 mm d^{-1}) in May, while the predicted growth (0.535 mm d^{-1}) increased in the same month. However, predicted mean length generally lies within one standard deviation of observed mean length.

Figure 64: Mean monthly growth rates (± SD) for 0+ plaice caught on Silverstrand (red line with + SD) and Ballyloughaun (green with – SD) plotted with the predicted growth for the same months calculated from Fonds *et al.* (1992).



4.4.7.1 Difference in growth between beaches and months

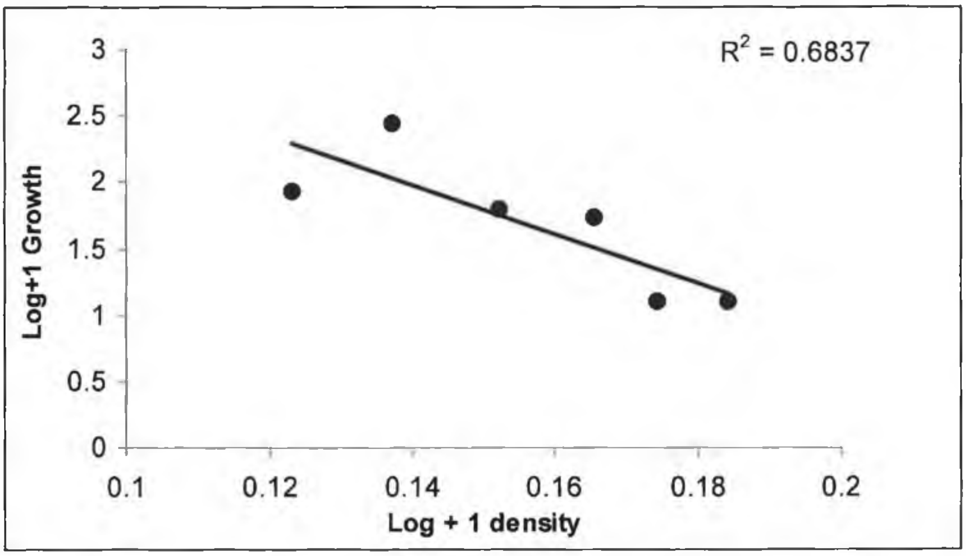
Growth rates for each month were compared separately for each beach using nonparametric analysis, as the data could not be normalised by transformations. There was no significant difference in growth rates between months on Silverstrand (p =

0.086) or Ballyloughaun (p = 0.784, Kruskal-Wallis test). All values from the three months were pooled together to compare growth between beaches. A Mann-Whitney U test found no difference between the two locations (p = 0.200).

4.4.7.2 Relationship between growth and density

The density of 0+ plaice for March, April and May, were plotted against the growth rates for these months. Figure 65 shows the relationship of density with growth rate. Regression analysis found the density and growth rate to have a strong inverse relationship (R^2 = 0.684, p = 0.041).

Figure 65: The relationship between density ($1000m^{-2}$) and growth rate of 0+ plaice on Silverstrand and Ballyloughaun in spring of 2003.



4.4.8 Summary

Hatching time ranged from late January to late March, with peaks in hatching in early and late February. There was a significant difference in the hatching time of fish caught in each month, which showed that hatching time was progressively later for fish caught in April and May. The larval period for fish caught on Ballyloughaun ranged from 28 to 38 d, with the majority of fish having a larval period of 30 – 32 d. On Silverstrand, the larval period range from 29 to 43 d, with most fish having a larval period of between 30 – 36 d. A significant difference in the larval period was noted between beaches in April and May, but not in March 2003.

Settlement time ranged from early to mid March to late April. Three cohorts of settlement were noted, which correspond to pulses observed in hatching. Settlement timing of fish caught in the three months was significantly different, and showed that the majority of fish sampled in March were from the first cohort, April fish were from the second cohort and fish caught in May were from the third cohort of settlement.

The post-larval age of plaice caught on Silverstrand ranged from 2 d in March to 50 d in May 2003. In Ballyloughaun this range was from 2 d to 29 d. No conclusions were drawn on the difference in total age between months or beaches, as there was an interaction between beach and month.

Observed growth rates on each beach declined slightly from March to April, while the predicted growth increased in these months. There was no difference in growth between months on both beaches and no between beach difference was noted. A strong inverse relationship was noted between growth and density for Silverstrand and Ballyloughaun in spring 2003.

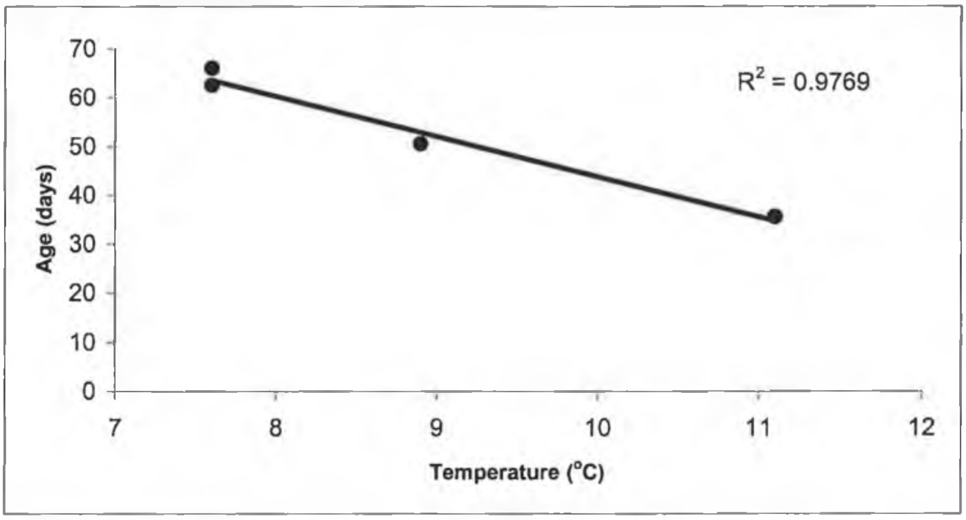
4.5 Discussion

Hatching dates for 0+ plaice in Galway Bay in 2003 ranged from late January to late March with peaks in early and late February. A similar range in hatching dates was noted by Karakiri *et al.* (1991) in the Wadden Sea and Al-Hossaini *et al.* (1989) in the Irish Sea. Van der Veer *et al.* (2000) found a statistically significant difference in hatching dates between 1995 and 1996. The later hatching dates of 1996 were associated with colder temperatures and the stronger year-class. The Galway Bay 2003 hatching data were most similar to Van der Veer *et al.* (2000) 1996 results and 2003 was also the stronger year-class in the Galway Bay study (Chapter 3).

The larval period of Galway Bay plaice varied from 28 to 43 d. Most fish had a larval period of 30 to 35 d. Also, a significant difference in larval periods was noted between the two locations in April and May of 2003, with the larval period of fish caught on Silverstrand longer than that of fish caught on Ballyloughaun. The larval period noted in Galway Bay in 2003 was shorter than that recorded in the Wadden Sea by Karakiri *et al.* (1991). In this latter study, larval periods of 50 to 82 d were recorded. Karakiri *et al.* (1989) noted larval periods for plaice of 55 to 70 d in the North Frisian Wadden Sea. Again, this is longer than those seen in Galway Bay. In the North Sea, Wegner *et al.* (2003) stated that the general larval phase of plaice takes from 60 – 90 d. The larval period noted in the Irish Sea (Al-Hossiani *et al.* 1989) was closer to, but still higher than that recorded in Galway Bay. Al-Hossaini (1989) noted a larval period range from 42 to 59 d, with mean larval period from 50 to 53 d. This spatial variation between western European waters is probably due to temperature differences and the subsequent effect on the rate of development of eggs and larvae. Fox *et al.* (2000) described average sea temperatures between January and June as coolest (7.6°C) in the North Sea, intermediate in the Irish Sea (8.9°C) and warmest in the Celtic Sea (10.5°C) from 1950 - 1995. The average temperature recorded in the 2003 survey, on the west coast of Ireland was 11.1°C. This variability in temperature fits the scales of variability in the larval period between the Wadden Sea (locate in the North Sea), Irish Sea and the Irish west coast.

This pattern of longer larval periods with lower temperatures over different regions was tested for any correlation. Figure 66 shows the relationship of mid range of the larval period in the Wadden Sea (Karakiri *et al.* 1989, 1991), the Irish Sea (Al-Hossaini *et al.* 1989) and Galway Bay, with the winter sea temperatures taken from Fox *et al.* (2000). Winter sea temperatures for the west coast of Ireland are from the current study. There was a very strong inverse relationship between larval period and winter sea temperatures (R^2 = 0.9769, p = 0.012). The Wadden Sea was the coldest and had the longest larval period, while in 2003, Galway Bay had a shorter larval period and this corresponded to a higher winter sea temperature.

Figure 66: The relationship between mid range of the larval period and temperature for the Wadden Sea, Irish Sea and results from the current study.



Differences were noted in the larval period between Silverstrand and Ballyloughaun, in April and May of 2003. Karakiri *et al.* (1989) found no significant difference in the larval period of plaice from varying locations in the North Frisian Wadden Sea. In contrast, Karakiri *et al.* (1991) found a difference in larval period in different parts of the Wadden Sea. In this latter study, it was suggested that differences in the larval period were due to fish coming from different spawning stocks. Different spawning stocks are not likely to explain the difference in larval period seen between the two Galway Bay beaches as these are within 13 km of each other within the same bay. Karakiri *et al.* (1991) worked on a wider geographical area than in the present study. Creutzberg *et al.* (1978) in Bergman *et al.* (1988) suggested that larval searching for food could be a key factor in the delay of larval settlement. This suggests that larvae may not be settling immediately in Silverstrand due to less favourable food conditions than those on Ballyloughaun, where fish had a shorter larval period. However more sampling is needed to confirm this pattern over a temporal scale.

Settlement time for plaice in Galway Bay in 2003 was from early to mid March to late April. Three main cohorts in settlement were identified. The first in mid March, the second in late March, and the third in early April. A similar pattern was recorded by Al-Hossaini *et al.* (1989) in the Irish Sea. The settlement period in the Irish Sea was from mid April to late June in 1986 and late March to early June in 1987. The 1987 settlement period was similar to that recorded in Galway Bay in 2003. However, the end of the settlement period may not be well defined in Galway Bay. Analysis of June samples might show the settlement period to be longer. In the Wadden Sea, Berghahn *et al.* (1995) recorded peak settlement of plaice (using otolith microstructure) in the third and forth week of May in 1991. In this Wadden Sea survey, different cohorts in settlement, as seen on the Irish west coast during the present study and the Irish Sea (Al-Hossaini *et al.* 1989) were not identified. Also in the Wadden Sea, Karakiri *et al.* (1991) determined settlement times to peak in April or May depending on the area sampled. This spatial separation of early and late settlers is likely to be attributed to variations in food conditions and differences in the hydrographic situation during settling (Bergman *et al.* 1989 in Karakiri *et al.* 1991). On the French coast, Amara and Paul (2003) used back-dating from otoliths to determine peak settlement, which was identified from late March to mid April. This peak settlement corresponds to the second cohort noted in Galway Bay 2003. Settlement determined by otolith microstructure in Galway Bay was not compared to settlement determined from densities obtained by sampling only, in other studies, as settlement range and peaks determined from sampling alone, may be shorter than that determined by otolith microstructure, due to the timing of sampling, which might not detect certain cohorts. In Chapter 3, settlement was deemed to have started in late March from the sampling data, while otolith microstructure showed that settlement actually started one to two weeks earlier.

The peaks in hatching and settlement dates may possibly reflect the sampling frequency if post-larval mortality is very high in the nursery environment. This mortality is known to be very high (Van der Veer 1986). Alternatively plaice are known to be batch spawners (Wegner *et al.* 2003) and this could be responsible for these peaks. The same pattern of settlement has been noted in the Irish Sea (Al-Hossaini *et al.* 1989).

Growth rates from the early juvenile stage ranged from 0.327 to 0.528 mm d^{-1} from March to May in 2003 on Silverstrand and Ballyloughaun. Observed growth and predicted growth were similar in March and April, but in May predicted growth was faster, with observed growth decreasing slightly in May. No difference was noted in growth rates between months or beaches. Few studies have discussed the growth of the early juveniles during the settlement period. Otolith microstructure allows growth rates to be calculated during this period. As fish can be assessed individually, and recruitment and mortality do not effect the results. A mean growth rate of 0.56 mm d^{-1} was recorded by Berghahn *et al.* (1995) in the Wadden Sea, using the same technique as in the Galway Bay study. This Wadden Sea growth rate is slightly faster than that recorded in Galway Bay. On the French coast, Amara and Paul (2003) also used the same technique for calculating growth and recorded a mean growth rate of 0.38 mm d^{-1} for fish $\leq$30mm. In this latter study, the growth rate for plaice $\leq$30mm was slower than predicted growth. In the Irish Sea, Al-Hossaini *et al.* (1989) recorded a range of growth rates in three cohorts in 1986 and 1987 of 0.36 to 0.58 mm d^{-1}. The authors also found that the third cohort had the slowest growth rate in both years. This range in the Irish Sea is similar to the Galway Bay range. Also the slowest growth rates were noted in the last cohort in Galway Bay. This pattern was also noted, by Modin and Pihl (1994) who recorded the slowest growth rate from the last cohort in 1992 on the Swedish coast.

In Galway Bay there was a strong inverse relationship between growth and density, which suggests that growth in the early juvenile stage is density-dependent in Galway Bay. The slowest growth rates from the last cohort correspond to the highest densities recorded (Chapter 3). In the Wadden Sea, Zijlstra *et al.* (1982) also found evidence of density-dependent growth in juvenile plaice and suggests that food limitations at higher densities is the main cause of this slower growth. This same pattern was noted in Van der Veer (1986), in the Wadden Sea. Amara and Paul (2003) did not investigate the possibility of density dependent growth, but did state that differences in growth might be due to food abundance and quality, and intra or interspecific competition. However, not all plaice populations show this density-dependent growth due to food limitations. Van der Veer *et al.* (1990) stated that differences in mean length between the nursery areas are largely explained by differences in the time of larval immigration in combination with the local water temperatures.

Chapter 5

5.1 General Discussion

In the beach seining surveys, plaice were the most abundant flatfish species on the Irish west coast. This was the case on the majority of beaches. The few exceptions were flounder dominated. Flounder occurred mostly in estuarine influenced areas. Push-netting also found plaice to dominate in the majority of catches. Again, with this sampling, flounder occasionally dominated the catch in Ballyloughaun which has a strong estuarine influence.

Plaice densities from push-netting in Silverstrand and Ballyloughaun can be compared to beach seining for the same beaches. On Silverstrand in 2002, densities of 7 $1000m^{-2}$ recorded with the push-net and 9 $1000m^{-2}$ with the beach seine were very similar. In May of 2003 the beach seine caught 0 and 11 $1000m^{-2}$ on Silverstrand and Ballyloughaun respectively, while in the push-net survey, densities of 83 and 277 $1000m^{-2}$ respectively were recorded in the same month. The two sampling gears have varying efficiencies when sampling 0+ plaice. The push-net is restricted by depth, but it can be used at a constant depth (from 0 – 1m), while the beach seine fishes a ranged of depths, anything from 3 – 4m to the waters edge. The push-net is size selective and is only appropriate for fish from 15 – 90mm (Geffen and Nash 1995), whereas, the beach seine with a 13mm cod end would allow small 0+ fish to escape. In May the difference in catches is probably due to the size selectivity of the sampling gears. Beach seining does not catch the smallest juveniles in spring due to the large mesh size used, while the push-net is specifically designed to catch these small juveniles with a fine mesh net. Thus, beach seining should only be used in September as an indication of year-class strength of 0+ plaice.

No relationship between growth as indicated by mean length, and density of plaice was observed from samples taken in September with the beach seine. Zijlstra *et al.* (1982), Van der Veer (1986) and Nash *et al.* (1994a) all found an inverse relationship between growth and density. The lack of correlation between growth and density of plaice on the west coast of Ireland might be because a relationship does not exist or, alternatively, because beach seining does not give an precise estimate of true densities. Efficiencies of 15 to 33 percent have been calculated in the past for beam trawls (Wennhage *et al.* 1997). Gibson *et al.* (1993) noted that the beam trawls caught more plaice than the beach seine in Scottish waters. Hence, it is possible that the beach seine has a very low efficiency for 0+ plaice. Using growth rates calculated from otolith microstructure, it was found that there was a strong inverse relationship between growth and density in the earlier part of the year for plaice on the Irish west coast. It may be that density-dependent growth only exists in the earlier stage of the life history.

Time of settlement was defined in two ways in this project. Firstly, sampling was undertaken to recorded the numbers of 0+ plaice on the sandy beaches. This gave an estimation of the settlement period by simply noting the size range and occurrence of fish during sampling in the springtime. In 2003, the settlement period ranged from mid-late March to May. More detailed information was obtained from otolith microstructure analysis. This found that the settlement actually started one to two weeks earlier than the first sampling date, when newly settled plaice were first noted, in the spring of 2003. This was the case for the two locations. Also, this analysis found three cohorts of settlement, which sampling densities alone would not detect. Sampling densities provide limited information, while otolith microstructure analysis provides a great deal more data on early life history, such as hatching times, larval phase and growth rates for individual fish. Both sampling and otolith microstructure have their advantages and disadvantages. Sampling is inexpensive, while analysis of otolith microstructure can be expensive due to labour costs and expensive equipment.

Beach seining did not detect any difference between years in 0+ plaice densities in Galway Bay. However, in the earlier (settlement period) part of the year, push-netting did detect a yearly difference in peak densities of 0+ plaice between 2002 and 2003. A reason why both sampling gears did not detect a between year difference might be due to density dependent mortality, as noted by Zijlstra *et al.* (1982), Van der Veer (1986) in the Wadden Sea and Nash and Geffen (2000) in the Irish Sea. These all found that mortality rates increase at higher densities in the early life stage of 0+ plaice. Nash and Geffen (2000) found that year-class strength of 0+ plaice was not fixed until July. If similar processes act on west of Ireland plaice, as those on Irish Sea plaice, it would suggest that interannual variability is greater before July, as seen with push-netting, than after July, as seen with beach seining. Van der Veer and Bergman (1987) found that shrimp predation appears to act as a fine control mechanism in the Wadden Sea, reducing between year variations in year class strength generated in the egg or larval stages in the open sea. Similar processes to the Wadden Sea could be working on the Irish west coast. However, there is no evidence for this. Further studies would be required to establish predator prey interactions on these sandy beach nursery grounds.

Growth of 0+ plaice was analysed from two periods in the nursery ground phase. Growth during the settlement period was calculated using otolith microstructure, while summer growth was obtained from the increase in mean length during summer months from push-net samples. Observed growth from Galway Bay was compared to a growth model obtained under optimal feeding conditions at varying temperature (Fonds *et al.* 1992 in Nash *et al.* 1994a). The observed and predicted growths were similar during both periods. This suggests that food is not a limiting factor for west of Ireland plaice, on nursery grounds.

Overall, the combination of all these studies carried out on the west coast of Ireland, provides valuable knowledge on the previously unknown life history of the plaice in this area. Plaice are by far the most important flatfish on the Irish west coast in terms of abundance. Spatial differences in densities do exist in the early life history of plaice. This is probably due to beach type (Pihl and Van der Veer 1992). All juveniles probably join the same stock in deeper water at the end of the nursery ground phase. However, there is no evidence for this and it poses the question as whether plaice on the west coast of Ireland are a single stock or numerous small stocks. Evidence from Galway Bay and other studies from other areas, suggest that yearly variation is dampened, more than likely due to a fine control mechanism like predation as seen in the Wadden Sea (Van der Veer and Bergman 1987). The value of push-netting and beach seining as an indication of year-class strength, or as a recruitment index is unknown. A longer time series, more experimental fieldwork, and an estimate of recruits to the fished stocks for means of comparison to the juvenile stage are all essential components in the development of a precise, cost effective and labour efficient recruitment index. It is important to develop this research further to help predict future trends in plaice stocks, as they have significant commercial value on the west coast of Ireland. This study could open the way for a new dynamic approach to the assessment and management of flatfish stocks on the west coast of Ireland

References

Abookire, A. A., Piatt, J. F., and Robards M. D. (2000). Nearshore fish distributions in an Alaskan Estuary in relation to stratification, temperature and salinity. *Estuarine, Coastal and Shelf Science* **51:** 45-59.

Al-Hossaini, M., Liu, Q. and Pitcher, T. J. (1989). Otolith microstructure indicating growth and mortality among plaice, *Pleuronectes platessa* L., post-larval sub-cohorts. *Journal of Fish Biology* **35**(a)**:** 82 - 90.

Amara, R., and Paul, C. (2003). Seasonal patterns in the fish and epibenthic crustaceans community of an intertidal zone with particular reference to the population dynamics of plaice and brown shrimp. *Estuarine, Coastal and Shelf Science.* **56:** 807 – 818.

Amara, R., Lagardere, F., Deasaunay, Y., and Marchand, J., (2000). Metamorphosis and estuarine colonisation in the common sole, *Solea solea* (L.): implications for recruitment regulation. *Oceanologica Acta.* **23:** 469 – 484.

ANON (2003). *The stock book.* Report to the Minister for Communications, Marine and Natural Resources. Annual review of fish stocks in 2002 with management advice for 2003. Marine Fisheries Services Division, Marine Institute, Dublin.

Berghahn, R. (1986). Determining abundance, distribution, and mortality of 0-group plaice (*Pleuronectes platessa* L.) in the Wadden Sea. *Journal of Applied Ichthyology.* **2**(1)**:** 11-22.

Berghahn, R., Ludemann, K. and Ruth, M. (1995). Differences in individual growth of newly settled 0-group plaice (*Pleuronectes platessa* L.) in the intertidal of neighbouring Wadden Sea areas. *Netherlands Journal of Sea Research.* **34**(1-3)**:** 131 - 138.

Berghahn, R. (2001). Estimated intensity needed for sampling flatfish assemblages in reference areas of tidal mud flats systems may be disproportionately costly and deleterious. *Journal of Sea Research* **45**(3-4)**:** 281-291.

Bergman, M. J. N., Van der Veer, H. W., and Zijlstra, J. J. (1988). Plaice nurseries: effects on recruitment. *Journal of Fish Biology* **33:** 201 - 218.

Bolle, L. J., Rijnsdorp, A. D. and Van der Veer, H. W. (2001). Recruitment variability in dab (*Limanda limanda*) in the southeastern North Sea. *Journal of Sea Research.* **45:** 3-4.

Brophy, D. and Danilowicz, B. S. (2002). Tracing populations of Atlantic herring (*Clupea harengus* L.) in the Irish and Celtic Seas using otolith microstructure. *ICES Journal of Marine Science.* **59:** 1305 - 1313.

Cabral, H. N., Lopes, M. and Loeper, R. (2002). Trophic niche overlap between flatfish in a nursery area on the Portuguese coast. *Scientia Marina* **66**(3)**:** 293 - 300.

Chambers, R. C., Witting, D. A. and Lewis S. J. (2001). Detecting critical periods in larval flatfish populations. *Journal of Sea Research* **45:** 3-4.

Corlett, J. (1967). Young plaice and other fish in Strangford Lough and neighboring Bays in August, 1963 and 1964. *Irish Naturalist Journal.* **15:** 249 - 254.

Fox, C. J., O'Brien, C. M., Dickey-Collas, M. and Nash, R. D. M. (2000). Patterns in the spawning of cod (*Gadus morhua* L.), sole (*Solea solea* L.) and plaice (*Pleuronectes platessa* L.) in the Irish Sea as determined by generalized additive modelling. *Fisheries Oceanography* **9**(1)**:** 33-49.

Fox, C. J., Planque, B. P. and Darby, C. D. (2000). Synchrony in the recruitment time-series of plaice (*Pleuronectes platessa* L) around the United Kingdom and the influence of sea temperature. *Journal of Sea Research.* **44:** 1-2.

Geffen, A. J. and Nash, R. D. M. (1995). Periodicity of otolith formation in the juvenile plaice *Pleuronectes platessa* L. In: D. H. Secor, J. M. Dean and S. E. Campana.. *Recent developments in fish otolith research.* Baruch library in Marine science, No. 19. University of South Carolina press.

Gibson, R. N., Ansell, A. D. and Robb, L. (1993). Seasonal and annual variations in abundance and species composition of fish and macrocrustacean communities on a Scottish sandy beach. *Marine Ecology Progress Series.* **98:** 89 - 105.

Gibson, R. N. (1994). Impact of habitat quality and quantity on the recruitment of juvenile flatfishes. *Netherlands Journal of Sea Research.* **32**(2)**:** 191-206.

Gibson, R. N., Robb, L., Burrows, M. T. and Ansell, A. D. (1996). Tidal, diel and longer term changes in the distribution of fishes on a Scottish sandy beach. *Marine Ecology Progress Series.* **130:** 1 - 17.

Gibson, R. N. (1997). Behaviour and the distribution of flatfishes. *Journal of Sea Research* **37:** 3-4.

Harlay, X., Koubbi, P., and Grioche, A. (2001). Ecology of plaice (*Pleuronectes platessa*) in fish assemblages of beaches of the Opale coast (north of France) during spring 1997. *Cybium* **25**(1)**:** 67-80.

Hinz, V. (1989). Monitoring the fish fauna in the Wadden Sea with special reference to different fishing methods and effects on wind and light on catches. *Helgolander Meeresuntersuchungen* **43:** 447 - 459.

Hjoerleifsson, E. and Palsson, J. (2001). Settlement, growth and mortality of 0-group plaice (*Pleuronectes platessa*) in Icelandic waters. *Journal of Sea Research.* **45:** 3-4.

Holmes, N. A., & McIntyre, A. D. (1971). *Methods for study of marine benthos*. Oxford: Blackwell scientific.

Horwood, J. (2001). Population biology and ecology of the sole. *Natural Resource Modeling* **14**(2)**:** 233-256.

Hovenkamp, F. (1990). Growth differences in larval plaice *Pleuronectes platessa* in the Southern Bight of the North Sea as indicated by otolith increments and RNA/DNA ratios. *Marine Ecology Progress Series.* **58:** 205 - 215.

Hyder, K. and Nash, R. D. M. (1998). Variation in settlement pattern of Irish Sea plaice (*Pleuronectes platessa* L.) as determined from a simulation model. *Journal of Sea Research.* **40:** 59 - 71.

Iles, T. C. and Beverton, R. J. H. (1991). Mortality rates of 0-group plaice (*Pleuronectes platessa* L.), dab (*Limanda limanda* L.) and turbot (*Scophthalmus maximus L.*) in European waters. I. Statistical analysis of the data and estimation of parameters. *Netherlands Journal of Sea Research.* **27** (3/4)**:** 217 – 235.

Jones, C. M. (1992). Development and application of otolith increment technique. In Stevenson, D. K. and Campana, S. E. Otolith microstructure examination and analysis. *Canadian Special Publication of Fisheries and Aquatic Sciences*. 1 - 11.

Karakiri, M., Berghahn, R., and Westernhagen, H. (1989). Growth differences in 0-group plaice *Pleuronectes platessa* as revealed by otolith microstructure analysis. *Marine Ecology Progress Series.* **55:** 15 – 22.

Karakiri, M., Berghahn, R. and Van Der Veer, H. W. (1991). Variations in settlement and growth of 0-group plaice (*Pleuronectes platessa* L.) in the Dutch Wadden Sea as determined by otoltih microstructure analysis. *Netherlands Journal of Sea Research.* **27**(3/4)**:** 345 - 351.

Kubecka, J. and Bohm, M. (1991). The fish fauna of the Jordan reservoir, one of the oldest man-made lakes in central Europe. *Journal of fish biology.* **38:** 935 – 950.

Kuipers, B. (1973). On the tidal migration of young plaice (*Pleuronectes platessa*) in the Wadden sea. *Netherlands Journal of Sea Research.* **6**(3)**:** 376-388.

Kuipers, B. (1975). On the efficiency of a two-metre beam trawl for juvenile plaice (*Pleuronectes platessa*). *Netherlands Journal of Sea Research.* **9**(1)**:** 69-85.

Kuipers, B. (1977). On the ecology of juvenile plaice on a tidal flat in the Wadden Sea. *Netherlands Journal of Sea Research.* **11** (1)**:** 56 – 91.

Layman, C. A. (2000). Fish assemblage structure of the shallow ocean surf-zone on the eastern shore of Virginia Barrier Islands. *Estuarine, coastal and Shelf Science.* **51:** 201 – 213.

Lockwood, S. J. (1974). The Settlement, distribution and movements of 0-group plaice *Pleuronectes platessa* (L.) in Filey Bay, Yorkshire. *Journal of fish biology.* **6:** 465 - 477.

Lockwood, S. J. and Lucassen, W. (1984). The recruitment of juvenile plaice (*Pleuronectes platessa* L.) to their parent spawning stock. *Journal du Conseil International pour l'Exploration de la Mer.* **41**(3)**:** 268-275.

Mansoor, K. Y. (1982). *Investigation of the distribution, growth and feeding of marine flatfish on the east coast of Ireland.* Unpublished MSc Thesis. National University of Ireland, Dublin.

Markham, D. F. (1981). Observations on the population abundance and food consumptions of young flatfish at Sherkin Island. *Journal of Sherkin Island.* **1**(2)**:** 93 - 99.

Methven, D. A., Haedrich, R. L., and Rose, G. A., (2001). The fish assemblages of a Newfoundland estuary: Diel, Monthly and Annual variation. *Estuarine, Coastal and Shelf Science.* **52:** 669 – 687.

Modin, J., Fagerholm, B., Gunnarsson, B., and Pihl, L. (1996). Changes in otolith microstructure at metamorphosis of plaice, *Pleuronectes platessa* L. *ICES Journal of Marine Science* **53**(4)**:** 745-748.

Modin, J. and Pihl, L. (1994). Differences in growth and mortality of juvenile plaice, *Pleuronectes platessa* L., following normal and extremely high settlement. *Netherlands Journal of Sea Research.* **32**(3-4)**:** 331-341.

Modin, J. and Pihl, L. (1996). Small-scale distribution of juvenile plaice and flounder in relation to predatory shrimp in a shallow Swedish bay. *Journal of Fish Biology* **49**(6)**:** 1070-1085.

Morrison, M. A., Francis, M. P., Hartill, B. W., and Parkinson, D. M. (2002). Dinural and tidal variation in the abundance of the fish fauna of a temperate tidal mudflat. *Estuarine, coastal and Shelf Science.* **54:** 793 – 807.

Myers, R. A., Mertz, G., and Bridson, J. (1997). Spatial scales of interannual recruitment variations of marine, anadromous, and freshwater fish. *Canadian Journal of Fisheries and Aquatic Sciences.* **54:** 1400 - 1407.

Nash, R. D. M., Geffen, A. J., and Hughes, G. (1994a). Individual growth of juvenile plaice (*Pleuronectes platessa* L.) on small Irish Sea nursery ground (Port Erin Bay, Isle of Man, UK). *Netherlands Journal of Sea Research.* **32**(3-4)**:** 369-378.

Nash, R. D. M., Santos, R. S., Geffen, A. J., Hughes, G. and Ellis, T. R. (1994b). Diel variability in catch rate of juvenile flatfish on two small nursery grounds (Port Erin Bay, Isle of Man and Porto Pim Bay, Faial, Azores). *Journal of fish biology.* **44:** 35 - 45.

Nash, R. D. M. and Santos, R. S. (1998). Seasonality in diel catch rate of small fishes in a shallow-water fish assemblage at Porto Pim Bay, Faial, Azores. *Estuarine, Coastal and Shelf Science*. **47:** 319 - 328.

Nash, R. D. M. and Geffen, A. J. (2000). The influence of nursery ground processes in the determination of year-class strength in juvenile plaice *Pleuronectes platessa* L. in Port Erin Bay, Irish Sea. *Journal of Sea Research*. **44:** 1-2.

Pannella, G. (1971). Fish otoliths: daily growth layers and periodical patterns. *Science*. **173:** 1124 - 1127

Pauly, D. (1994). A framework for latitudinal comparisons of flatfish recruitment. *Netherlands Journal of Sea Research*. **32**(2): 107-118.

Pepin, P. and Penney R. (2000). Feeding by larval fish community: impact on zooplankton. *Marine Ecology Progress Series*. **204:** 199 - 212.

Pierce, C. L., Corcoran, A. M., Gronbach, S. H., Mullarkey, B. J., and Schwartzhoff, A. J. (2001). Influence of diel period on electrofishing and beach seining assessments of littoral fish assemblages. *North American Journal of Fisheries Management*. **21:** 918 - 926.

Pierce, C. L., Rasmussen, J. B. and Legget, W. C. (1990). Sampling littoral fish with a seine: Corrections for variable capture efficiency. *Canadian Journal of Fisheries and Aquatic Sciences*. **47:** 1004 - 1010.

Pihl, L., Modin, J., and Wennhage, H. (2000). Spatial distribution patterns of newly settled plaice (*Pleuronectes platessa* L.) along the Swedish Skagerrak archipelago. *Journal of Sea Research*. **44:** 1-2.

Pihl, L. and Rosenberg, R. (1982). Production, abundance, and biomass of mobile epibenthic marine fauna in shallow waters, western Sweden. *Journal of Experimental Marine Biology and Ecology.* **57:** 273 - 301.

Pihl, L. and Van der Veer, H. W. (1992). Importance of exposure and habitat structure for the population density of 0-group plaice, *Pleuronectes platessa* L., in coastal nursery areas. *Netherlands Journal of Sea Research.* **29** (1-3)**:** 145 – 152.

Prisco, A. R., de la Rosa, S. B. G. and de Astarlou, J. M. D. (2001). Feeding ecology of flatfish juveniles (Pleuronectiformes) in Mar Chiquita coastal lagoon (Buenos Aires, Argentina). *Estuaries* **24**(6a)**:** 917 - 925.

Rijnsdorp, A. D., Van Beck, F. A., Flatman, S., Millner, R. M., Riley, J. D., Giret, M., and De Clerk, R. (1992). Recruitment of sole stocks, *Solea solea* (L.) in the northeast Atlantic. *Netherlands Journal of Sea Research.* **29:** 173 – 192

Riley, J. D. and Corlett, J. (1965). The numbers of 0-group plaice in Port Erin Bay, 1964-66. *Report of Marine Biology Station, Port Erin.* **78:** 51 - 56.

Riley, J. D., Symonds, D. J., and Woolner, L. (1981). On the Factors Influencing the Distribution of 0-Group Demersal Fish in Coastal Waters. *Rapports et Procés verbaux des Reunions. Conseil international pour l'Exploration de la Mer.* **178:** 223 – 228

Poxton, M. G., Eleftheriou, A. and McIntyre, A. D. (1982). The population dynamics of 0-group flatfish on nursery grounds in the Clyde Sea area. *Estuarine, Coastal and Shelf Science.* **14:** 265 - 282.

Rogers, S. I. and Lockwood, S. (1989). Observations on the capture efficiency of a two-metre beam trawl for juvenile flatfish. *Netherlands Journal of Sea Research.* **23**(3)**:** 347 - 352.

Ross, S. W., and Lancaster, J. E. (2002). Movements and site fidelity of two juvenile fish species using surf zone nursery habitats along the southeastern North Carolina coast. *Environmental Biology of Fishes.* **63:** 161 – 172.

Ruth, M. and Berghahn, R. (1989). Biological monitoring of fish and crustaceans in the Wadden Sea - potential and problems. *Helgolander Meeresuntersuchungen.* **43**(3-4)**:** 479-487.

Secor, H. D., Dean, J. M., and Laban, E. H. (1992). Otolith removal and preparation for microstructural examination. In: Stevenson, D. K. and Campana, S. E. Otolith microstructure examination and analysis. *Canadian Special Publication of Fisheries and Aquatic Sciences.* 19 – 57.

Sogard, S. M., Able, K. W., and Hagan, S. M. (2001). Long-term assessment of settlement and growth of juvenile winter flounder (*Pseudopleuronectes americanus*) in New Jersey estuaries. *Journal of Sea Research.* **45:** 3-4.

Steele, J. H. and Edwards, R. R. C. (1970). The ecology of 0-group plaice and common dabs in Loch Ewe. IV. Dynamics of the plaice and dab populations. *Journal of Experimental Marine Biology and Ecology.* **4:** 174 - 187.

Underwood, A. J. (1997). *Experiments in ecology: their logical design and interpretation using analysis of variance.* Cambridge, Cambridge University Press.

Van der Veer, H. W. (1986). Immigration, settlement, and density-denpendent mortality of a larval and earyly post-larval 0-group plaice (*Pleuronectes platessa*) population in the western Wadden Sea. *Marine Ecology Progress Series.* **29:** 223 - 236.

Van der veer, H. W., Berghahn, R., Miller, J. M., and Rijnsdorp, A. D. (2000). Recruitment in flatfish, with special emphasis on North Atlantic species: Progress made by the Flatfish Symposia. *ICES Journal of Marine Science.* **57**(2)**:** 202-215.

Van der Veer, H. W. and Bergman, M. J. N. (1986). Development of tidally related behaviour of a newly settled 0-group plaice (*Pleuronectes platessa*) populations in the western Wadden Sea. *Marine Ecology Progress Series.* **31:** 121 - 129.

Van der Veer, H. W. and. Bergman M. J. N (1987). Predation by crustaceans on a newly settled 0-group plaice *Pleuronectes platessa* population in the western Wadden Sea. *Marine Ecology Progress Series.* **35:** 203 - 215.

Van der Veer, H. W., Geffen, A. J., and Witte, J. I. J. (2000). Exceptionally strong year classes in plaice *Pleuronectes platessa*: are they generated during the pelagic stage only, or also in the juvenile stage. *Marine Ecology Progress Series.* **199:** 255 - 262.

Van der Veer, H. W., Pihl, L., and Bergman, M. J. N. (1990). Recruitment mechanisms in North Sea plaice *Pleuronectes platessa*. *Marine ecology progress series.* **64**(1-2)**:** 1-12.

Van der Veer, H. W. and Witte J. I. (1999). Year-class strength of plaice *Pleuronectes platessa* in the Southern Bight of the North Sea: A validation and analysis of the inverse relationship with winter seawater temperature. *Marine Ecology Progress Series.* **184:** 245-257.

Van der Veer, H. W., Dapper, R and Witte, J. I. J. (2001). The nursery function of the intertidal areas in the western Wadden Sea for 0-group sole *Solea solea* (L.). *Journal of Sea Research.* **45**(3-4)**:** 271-279.

Wegner, G., Damm, U., and Purps, M. (2003). Physical influences on the stock dynamics of plaice and sole in the North Sea. *Scientia Marina.* **67** (Suppl 1)**:** 219 – 234.

Wennhage, H., Gibson, R. N., and Robb, L. (1997). The use of drop traps to estimate the efficiency of two beam trawls commonly used for sampling juvenile flatfishes. *Journal of Fish Biology.* **51**(2)**:** 441-445.

Wilding, T. A., Gibson. R. N., and Sayer, M. D. J. (2000). *Procedural guideline no. 4-3 Sampling benthic and demersal fish populations on sediments.* Marine monitoring handbook. Natura 2000.

Zijlstra, J. J., Dapper, R., and Witte, J. I. (1982). Settlement. Growth and mortality of post-larval plaice (*Pleuronectes platessa*) in the western Wadden Sea. *Netherlands Journal of Sea Research.* **15** (2): 250 – 272.

Websites

Url 1: http://www.cfb.ie. Website of the Irish Central Fisheries Board, Dublin.

Acknowledgements

I would sincerely like to thank my supervisors Dr. David McGrath and Dr. Pauline King for their help, support and guidance throughout this project. Your dedication, encouragement, advice, input into decisions and ideas made this project possible. I would also, like to thank Dr. Deirdre Brophy for her help and advice.

Thanks to Imelda, Joan, Steve, Marianne, Jennifer, Brain, Iulian, Karen, Linda, Noreen, Gavin, Deirdre, Pat Dinneen, Mary, Tara, Eoin, Catriona, Brendan Allard, Olivia and Derek who without their help with fieldwork this project would not be possible. I am grateful to Mark Hemer for supplying maps.

I wish to thank Mark Norman of Taidhge Mara Teoranta for financial support and lending equipment and personnel for beach seining. Also, thank you to Paul Casburn for his help and advice with beach seining. Thank you to Dr. Oliver Tully of Bord Iascaigh Mhara (BIM) for his financial assistance and advice. Also, in BIM, thank you to Dr Pete Tyndall, Declan Nee and Eoin Kelly for your help. I appreciate the help of Selene Hoey, Turlough Smith, Robb Bunn and Dr. Rick Officer of the Marine Institute for partaking in beach seining surveys. Also, thank you to the Marine Institute for supplying open sea temperatures from the M1 data buoy.

I am very grateful to Steve Barrett, Mary Veldon and Brendan Forde of GMIT for their technical assistance and help in locating equipment and ordering supplies. Thanks to Celia, Mary, Peggy, Marian and Ann Murphy for their help with administration. Also thank you to Tom Conlon of the industrial liaisons office in GMIT for sorting any problems that occurred. Thanks to the Library staff in GMIT and especially Mary O'Rourke and Marie Barret in Inter-Library loans.

Other people in GMIT that I would like to thank are Brian Ottway for help from time to time, the heads of school previously Dr. Malachy Thompson and Dr. Gerry Quinn and currently Dr. Des Foley and Dr. Seamus Lennon.

Finally thank you to all my family and friends especially my parents Sean and Iris and also to Olivia for their endless support with everything throughout my time at GMIT.