Population dynamics of 0-group plaice, *Pleuronectes platessa* L., on sandy beach nursery grounds in Galway Bay, the west coast of Ireland, 2002 to 2006.

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Abstract

The recruitment of 0-group plaice to sandy beach nursery grounds in Galway Bay was examined, using a Riley push-net, from February to June in 2005 and 2006. Sampling was carried out every two weeks on spring tides. Three beaches were sampled, Ballyloughan, Silverstrand and Glann na Ri. Archived 0-group plaice, for Ballyloughan and Silverstrand, from 2004, were processed. Results were compared to findings from a previous study carried out in 2002 and 2003 (Allen 2004). Otolith microstructure analysis was used to determine hatching dates, larval duration, settlement dates, post-larval age and daily growth rates of 0-group plaice in April and May 2005. Results were compared to a previous study (Allen 2004).

Hatching dates in Galway Bay ranged from late January to early April in 2005. No significant difference in hatching dates was observed between years or between beaches sampled.

Larval duration of 0-group plaice in Galway Bay ranged from 21 to 45 days for fish sampled in April and May 2005. No significant difference was observed in larval age between beaches sampled in Galway Bay or between years in April 2003 and 2005. A significant difference was observed between larval age and years in May 2003 and 2005, however no significant difference was observed between beaches.

Settlement timing was calculated using push-net data and otolith microstructure analysis. Settlement of 0-group plaice in Galway Bay generally started in early March and finished in May. Settlement patterns, calculated using otolith microstructure analysis, in 2003 and 2005, were not significantly different to one another. There was also no difference in settlement patterns between the beaches sampled. Results from the present study showed no spatial difference in the pelagic life cycle stages of fish caught in April and May 2003 and 2005.

No significant difference was noted in the post-larval age of 0-group plaice caught in April and May 2005 on the three beaches sampled. Data from 2003 (Allen 2004) was compared to data for 2005. Fish caught in April and May 2003 had a younger post-larval age than fish caught in April and May 2005. Fish on Ballyloughan in April 2003 and 2005 had a significantly older post-larval age than fish on Silverstrand. No significant difference was observed in the post-larval age of 0-group plaice between beaches in May of 2003 and 2005. Post-larval age was the first parameter in the life history of 0-group plaice that a significant spatial (between beach) difference was noted.

Peaks in abundances of 0-group plaice were significantly different between years over the study period indicating 2002 as a low settlement, hence recruitment, year and that 2004 was a high recruitment year. Densities in Galway Bay ranged from 0 $1000m^{-2}$ on occasions, to a maximum density of 900 $1000m^{-2}$ in March 2004. No significant spatial difference in abundances was ever noted. However, results did indicate small-scale spatial and temporal differences. The length range for 0-group plaice ranged from 8 to 68 mm from March to June from 2004 to 2006. Tests for significant difference revealed that lengths of 0-group plaice varied between years and between months from 2002 to 2006.

Growth rates for Galway Bay were calculated using mean increase in length of 0-group plaice over time (2004 to 2006), and otolith microstructure analysis (April and May 2005). Growth rates calculated using otolith microstructure analysis were generally higher than growth rates calculated using increase in mean length. Daily growth from 2004 to 2006 averaged 0.2mm d^{-1} during spring and early summer. Growth rates, calculated using both methods, were generally below predicted growth rates. No significant difference in growth rates was observed between beaches or months in April and May 2005.

Experimental push-netting undertaken in June 2005 and 2006 revealed that densities of 0-group plaice were significantly greater at night than during the day. There was no significant difference in the lengths of 0-group plaice between day or night samples in 2006. No significant difference was observed in the densities of 0-group plaice between spring or neap tides in April and May 2006.

Chapter 1: General introduction: Population dynamics of 0-group plaice, *Pleuronectes platessa* L., on sandy beach nursery grounds in Galway Bay, the west coast of Ireland, 2002 to 2006.

1.1 Plaice, *Pleuronectes platessa L.*, Biology and Ecology.

The plaice, *Pleuronectes platessa* L., is an economically important flatfish in Irish and European waters. Flatfish belong to the *Heterosomata* group of fishes. In European waters flatfish fall into three natural groups or families. The plaice is a member of the *Pleuronectidae* family of fishes (right eyed flounders), which also hold other common species such as flounder, *Platichthys flesus* L, dab, *Limanda limanda* L., and halibut, *Hippoglossus hippoglossus* (Wheeler 1969). The *Bothidae* family of fishes (left eyed) hold species, which are less numerous in European waters, but are economically important because of their high monetary value. Members of this family include Turbot, *Scopthalmus maximus* L., and Brill, *Scophthalmus rhombus* L. The third Family is the *Soleidae*, the soles, for example the common sole *Solea solea* L. (Wheeler 1969)

The plaice is a typical shelf species found in shallow waters from the shore line (juveniles) to 120m but not often caught below 40 meters (Wheeler 1969). Riley *et al.* (1981) stated that 0-group plaice were exclusively found in waters less than 16 meters deep. Plaice are most commonly found on sandy grounds but can also be taken from mud and gravel. The distribution of plaice ranges from the Northeast Atlantic from Greenland and Norway as far south as Morocco. It also occurs in the Mediterranean, the White Sea in Russia and in the Baltic. In European waters, spawning takes place in the early months of the year. Spawning takes place in the North Sea from December to March, in Danish waters from February to March and in Southwest Iceland from March to April (Wheeler 1969). In the Irish Sea spawning takes place between late January to early May (Armstrong *et al.* 2000 in Nash and Geffen 2000).

The larvae of plaice are larger at hatching than dab or flounder, being 6.0 to 7.5mm in length. (Russell 1976). Egg duration depends on temperature. Larval duration varies between areas and is also related to temperature (Allen 2004). Wegner *et al.* (2003) stated that generally larval phases of plaice take from 60 to 90 days. Larval durations of 50 to 82 days have been noted for the Wadden Sea (Karakiri *et al.* 1991) and a duration of 42 to 59 days for the Irish Sea (Al-Hossiani *et al.* 1989). Allen (2004) showed a larval duration of 28 to 43 days for the Galway Bay area on the west coast of Ireland. Metamorphosis, as indicated by the migration of the left eye, begins when the post-larva is 11-12mm long. Metamorphosis is usually complete at 13 – 14mm, by which time the young fish are living on the bottom (Russell 1976).

Timing of settlement varies between locations and can also vary between years. Settlement in Galway Bay was found to be in April 2002 and in March 2003 (Allen 2004). Mansoor (1982) found that on the Irish east coast, settlement started 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. Plaice have been found to start settling in the Wadden Sea generally in April (Kuipers 1977, Zijlstra *et al.* 1982) but have been found as early as February (Van der Veer 1986). In Filey bay, Yorkshire, plaice were found to settle in early to mid May (Lockwood 1974). Amara and Paul (2003) found that plaice had already settled in early April on the French coast. On the Swedish west coast, plaice were noted settling in May 1991 and in April in 1992 (Modin and Pihl 1996).

Once settlement has occurred, 0-group plaice will stay at least six months on their nursery beach (Van der veer 1986). Bergman *et al.* (1988) defined a nursery ground, for fish species, as an area where the majority of the juvenile fish population concentrate and grow up, separated from the adult population. After metamorphosis, juvenile flatfish generally grow rapidly relative to the rest of their lifespan. Nursery grounds generally provide a partial refuge from predation and a highly productive area that promotes growth (Nash and Geffen 2005). Variability in numbers of juvenile flatfish settling on the nursery grounds, the amount and quality of available prey, and environmental conditions such as temperature all contribute to variation in growth rate of juvenile flatfish on the nursery grounds (Nash and Geffen 2005).

Plaice show a preference for more sheltered beaches and are found generally in salinities between 25 and 35 (ppt) on fine sand or mud (Riley *et al.* 1981, Gibson and Robb 2000, Nasir and Poxton 2001). 0-group plaice are generally found in shallow waters less than a meter deep (Van der veer 1986, Modin and Pihl 1996) and are never found in waters deeper than 16 meters (Riley *et al.* 1981). 1-group plaice can be regularly caught in waters shallower than 10 m and II- group plaice avoid shallow water and are found down to a depth of 30m. As plaice get older, they increasingly move into deep water (Riley *et al.* 1981). Van de veer *et al.* (1990) stated that the end of the nursery ground phase for 0-group plaice is usually around August in Northern European waters.

1.2 Fisheries.

In Northern Western European waters, abundant flatfish populations occur in areas where there are large shallow sandy or muddy sand sediments. The widest areas of shallow continental shelf are found in the North Sea, the Barents Sea, the Baltic including the Skagerrak and the Kattegat and around the British Isles (Millner *et al.* 2005). In general, most flatfish fisheries occur in waters less than 200m deep. The fisheries in northern European waters are dominated by species from three families, The Pleuronectidae (of which plaice is a member), the Soleidae and Bothidae. In 1998, landings of flatfish amounted to 296 800 tonnes, with three species, plaice, *P. platessa*, common sole, *S. solea,* and Greenland halibut, *R. hippoglossoides,* accounting for more than 50% of the total weight landed (Millner *et al.* 2005).

During the first part of the twentieth century, over half the total landings of flatfish in Northern European waters consisted of plaice. In Europe, the main fisheries are in the North Sea (ICES sub-area IV) and the neighbouring areas of the Skagerrak/ Kattegat (Sub-area IIIa) and the eastern English channel (Sub-area VIId). There are also major landings of plaice from around Iceland (Sub-area Va). In the North Sea and around Britain and Ireland plaice are caught mainly by beam trawlers. This fishery occurs through the year. Seine and gill net vessels also actively target plaice in the North Sea and there is also an important gill net fishery for common sole, plaice and turbot along the Danish coast. (Millner *et al.* 2005).

West of Ireland plaice stock fall into ICES management areas VIIc and VIIb. The state of this stock is unknown. The 2005 total allowable catch (TAC) for this region was 160 tonnes with an associated Irish quota of 128 tonnes. ICES advise that catches in 2006 should be no more than recent average landings of around 65 tonnes (Anon 2005). On average, Ireland had 89% of total international landings in this area between 1997 and 2002. France accounts for the majority of other international landings. The majority of landings (90%) are taken by otter trawls. Irish estimated landings in 2004 were 38 tonnes. Landings in 2004 were the lowest observed from 1996 (Anon 2005). In the Galway region the main fishing port is Rossaveal. After landings, plaice are then usually processed locally with medium to large fish being kept for sale within Ireland and smaller fish being sent to Grimsby in England or on to Holland (Allen 2004).

1.3 Recruitment and yearly variability of 0-group plaice.

Recruitment, in fishes, is defined as the number of individuals that reach a particular age to join a specific part of the population (Van der veer *et al.* 2000). Van der Veer *et al.* (2000) also stated that scientists use recruitment processes to cover everything that affects survival between spawning and the stage of life where year class strength is more or less fixed. Annual variability in recruitment of marine fishes is a well-known phenomenon, and this recruitment variation can be enormous, which has major biological and economic implications for the management of commercial fisheries (Leggett and De Blois 1994).

In general, year class strength is already determined at an early age, long before recruitment to the adult population occurs (Van der veer 1986, Leggett and De Blois 1994). Year-class strength in marine fishes appears to be primarily determined by mortality processes operating during the pre-juvenile stage of the life history. This process appears to result from a combination of coarse controls during the egg and larval drift period. This is followed by a second interval of finer scale regulation, later in the early life history (Leggett and DeBlois 1994). Studies have shown that determination of year class strength for fishes can be species or area specific (Leggett and DeBlois 1994). Research has also shown that populations in adjacent areas have shown synchrony in year-class strength over large spatial scales (Fox *et al.* 2000). Flatfish, as a group, are characterised by a relatively low recruitment variability (Beverton 1995). For example a ten-fold difference has been noted in the annual peak densities of 0-group plaice on the Swedish coast from the late 1970s to 2000 (Wennhage *et al* 2006). Other demercal species can exhibit a 100-fold difference in numbers of juvenile fish being recruited per year (Bailey *et al* 2005).

The factors affecting recruitment in flatfish are many and varied. Certain controls, however, may be more important among groups of species with similar life history traits (Miller *et al.* 1991). Because flatfish are dependant on transport to near-shore nursery grounds, variability in these processes may be of particular importance to them (Bailey *et al.* 2005). In flatfish, recruitment to a stock appears to be related to the quantity of juvenile nursery habitats, suggesting that either larval supply or the carrying capacity of the nurseries is the limiting factor. However, information on growth of 0-group flatfish suggests that carrying capacity of nursery areas is never reached (Van der Veer *et al.* 2000).

The main factors considered as most important in plaice recruitment are reviewed below. Research has shown, through modelling, that in the North Sea circulation patterns might be a key factor in determining year class strength (Van der Veer *et al.* 1998). The strength of year class in plaice depends on successful delivery to their nursery grounds. In the North Sea, larval transport can be over long distances. Results have shown that larval density near the shore is correlated with the number of settling 0-group plaice (Bailey *et al.* 2005). This suggests that transport is a key factor in the recruitment process. Nash and Geffen (2000) showed that in the Irish Sea, where the nursery grounds are close to spawning grounds, settlement numbers are correlated with egg abundances. They also stated that larval drift was not a critical factor in this area and that year class strength may be determined in the juvenile nursery. However Fox *et al.* (2006) showed, in a modelling and field study, that despite the close proximity of plaice spawning and nursery areas in the Irish sea, the development of tidal selective behaviour by individual larvae appears to be critical to successful settlement into suitable nursery areas.

In the Kattegat / Skaggerak where tidal currents are weak, wind driven currents dominate larval transport. (Nielson et al. 1998). Pihl (1990) showed that differences in the abundances of 0-plaice were related to variations in onshore winds near the nursery grounds. Pihl (2000) also pondered whether the concentration of larvae in the water column and exchange of water in the nursery grounds determined the rate of larval delivery. He considered that this might explain some patterns of newly settling plaice along the Swedish Skagerrak archipelago.

In a review of the differences in spawning and transport – related characteristics of flatfish (Bailey *et al.* 2005) it was shown that different stocks in different areas used different strategies. In the North Sea spawning occurred 30 – 60 km offshore and transport was with bottom currents and then selective tidal stream transport was used (Van der Veer *et al.* 1998, Cushing 1990, Rjinsdorp *et al.* 1985). In the Irish Sea, spawning was near shore and the most important strategy was retention (to stay near nursery grounds) (Nash and Geffen 1999). Neilson *et al.* (1998) showed that in the Kattegat / Belt sea, wind driven currents were of most importance but that selective tidal stream transport was also used.

Gibson (1999 in Bailey *et al.* 2005) stated that, for plaice, the selection of settlement areas was determined by the hydrographic relationship between the spawning ground and the nursery area. In areas where currents are only weakly directional, spawning grounds are situated close to the nursery grounds. Where currents are strong, the choice of location of the spawning grounds must have evolved so that eggs are released at an optimum direction and distance from the settlement areas.

Density dependant mortality in the period shortly after settlement dampens the interanuall recruitment variability (Bergman *et al.* 1988, Bailey 1994, Van der Veer *et al.* 2000, Wennhage 2002). Van deer Veer *et al.* (1990) showed that in a number of nursery grounds in northwest Europe that predation on 0-group plaice was the main mortality factor. Two sources of predation were found over the whole range. These were predation by crustaceans, for example the brown shrimp *Crangon crangon,* in spring and by migratory fish in summer and autumn. This study also showed that in areas characterized by low temperatures in spring no impact from predation on year class strength was found, but that in areas of high temperature in spring crustaceans did affect recruitment. Predation by fish species had little impact on the recruitment of plaice.

Pihl *et al.* (2005) stated that concentrations of marine fishes in nurseries might act as a bottleneck during the life cycle, where quantity and quality of nurseries determine population size. During a study relating plaice recruitment to deteriorating habitat quality due to macroalgal blooms in coastal areas, it was found, using modelling, that recruitment of 0-group plaice on the Swedish Skagerrak coast could be reduced by 30 – 40% due to these alga blooms (Pihl *et al.* 2005). Kovtsova and Boitsov (1995) showed that, in the Barents Sea, year-to-year variations in plaice recruitment were significantly correlated with fluctuations in population fecundity and larval abundances. This suggested that the year class strength in the Barents Sea plaice is determined before the end of the pelagic phase.

Apart from the variations in transport pathways as a causal factor for recruitment success or failure, it should also be recognised that the relative importance of individual factors may change from year to year. These factors may also vary over the range of a species because species life history traits may vary over the range (Miller *et al.* 1991). It is considered that the low recruitment variability characteristic of flatfish is directly related to the life history characteristics of the group as a whole, and specifically to their adoption of a size-constrained (nursery zone) two-dimensional (demersal) juvenile stage (Van der Veer and Leggett 2005). Van der Veer *et al.* (2000) suggested that it is this two-dimensional concentration, which also results in density-dependant regulating processes, that is the important determining factor of the recruitment variability exhibited by flatfish.

1.4 Aims of present study.

In consideration of the fact that year class strength for 0-group plaice is determined in the early life stages, it was decided to continue sampling of 0-group plaice, which had been ongoing since 2002 (Allen 2004), on sandy beach nursery grounds in Galway Bay. It was hoped that by studying patterns of settlement and densities, over a period of years, that years of peak recruitment could be identified. If a pattern in years of high recruitment and low recruitment of 0-group plaice could be observed then this would be of great interest to fisheries biologists and fisheries managers alike. These data would be valuable in the formation of a recruitment index for plaice on the west coast of Ireland. Such an index does not presently exist. Recruitment indices require a long time series of data and this study would contribute to that time series. In respect to this, the aims of the present study were as follows:

The main focus of the present study was to increase the spatial and temporal sampling for 0-group plaice in Galway Bay. Sampling had been ongoing on two beaches (Ballyloughan and Silverstrand) in Galway Bay since 2002 (Allen 2004). Sampling was increased to two visits per month per beach. A third beach, Glann na Ri, was added in April 2005 to increase the spatial dimension of this project. Push-netting commenced in February 2005 and continued until the end of June. This sampling pattern was also carried out in 2006. Settlement patterns and densities of 0-group plaice were examined to gain information on recruitment processes at work on sandy beach nursery grounds in Galway Bay. Length data was used to examine growth rates of 0-group plaices during their first summer on the nursery grounds. Statistical tests were used to determine differences in densities and sizes of 0-group plaice between beaches, months and years in the Galway Bay area. Archived frozen 0-group plaice samples from 2004 were processed. The findings for this study can be seen in chapter 2.

Experimental push-netting was carried out to examine the effects of diel and semi-lunar tidal cycles on the abundances, or sizes, of 0-group plaice in Galway Bay (see chapter 3 for details). The aim of these experiments was to gather further information on the biology and ecology of 0-group plaice on sandy beach nursery grounds in Galway Bay. Published research on the abundances of 0-group plaice, between day and night, has shown conflicting results. Most studies show that densities of 0-group plaice are higher at night but this is not always the case (Nash *et al.* 1994, Gibson *et al.* 1996). This study would help show patterns in abundance between day and night for Galway Bay. Sampling was carried out in June in 2005 and 2006. Two beaches (Ballyloughan and Silverstrand) were visited on two night and two day periods in both years. Differences in abundance between spring and neap tides were studied. If tidal type had no effect on the abundances of 0-group plaice this would be beneficial as all routine sampling was carried out on spring tide periods only. Researchers in Galway Bay would no longer be confined to spring tide periods and could sample any time in a given month. This would also be beneficial in permitting sampling to be independent of weather. Sampling was carried out in April / May 2006. Two spring and two neap periods were sampled. These studies would aid in further understand the recruitment of 0-group plaice on nursery grounds in the Galway Bay region.

Otolith microstructure analysis (see chapter 4 for details) was used to determine hatching dates, larval duration, settlement patterns and growth for 0-group plaice in April and May 2005. Two beaches, Ballyloughan and Silverstrand, were used for this study. The assessment of growth of 0+ flatfish on nursery grounds using mean size data has a major problem, in that fish are continually settling on the nursery ground and therefore underestimation of growth occurs (Nash and Geffen 2005). To combat this problem otolith microstructure is used (Al-hossaini *et al.* 1989, Hovenkamp 1991, Modine and Phil 1994). These data were then compared to otolith microstructure work carried out in the same area for 2003 (Allen 2004).

Chapter 2. Settlement, density and growth of 0-group plaice *Pleuronectes platessa*, on sandy beach nursery grounds in Galway Bay on the west coast of Ireland from 2002 to 2006.

2.1 Abstract

A push-net sampling programme was carried out on sandy beach nursery grounds in Galway Bay in 2005 and 2006 on three beaches (Ballyloughan, Silverstrand and Glann na Ri). Archived fish from 2004, for Ballyloughan and Silverstrand, were processed. Data was compared to results gathered for 0-group plaice from a previous study, in 2002 and 2003 (Allen 2004). Two beaches, Ballyloughan and Silverstrand, were sampled in all years, whereas Glann na Ri was only added in April 2005.

First settlement of 0-group plaice was noted in March every year on all beaches sampled, with the exception of 2002 when settlement did not occur until April. Settlement generally finished in May on all beaches.

Monthly densities of 0-group plaice ranged from 0 $1000m^{-2}$ on occasions up to a maximum peak of 900 $1000m^{-2}$ noted in March 2004. Results revealed significant differences in the abundances of 0-group plaice from 2002 to 2006 in the main settlement month of March. 2002 was shown to be a low settlement, hence recruitment year, and 2004 was a high settlement year. There was no significant difference in abundances between beaches on any sampling occasion. However, interaction terms in certain analysis did indicate smaller-scale temporal and spatial differences. Peak densities of 0-group plaice also showed significantly differences between years. Timing in peak densities varied between years and beaches.

An extra sampling trip per month was added, for all beaches, in 2005 and 2006 and this allowed analysis of a stronger data set. The addition of a third beach allowed a larger spatial scale to the study (approximately 15 km in distance altogether). No significant difference was observed in the abundances of 0-group plaice in 2005 between the three beaches sampled. Tests revealed that there was a significant difference in the abundances of 0-group plaice between the first and second sampling

periods within months in March and April 2005 on Ballyloughan and Silverstrand. This revealed temporal differences on a monthly scale.

The length range for 0-group plaice ranged from 8mm in March to 68mm in June over the beaches sampled from 2004 to 2006. Significant differences were noted in the size of 0-group plaice between years and between months from 2002 to 2006. No significant differences were noted in the lengths of 0-group plaice between beaches.

The average growth rate for 0-group plaice on all beaches sampled, from 2004 to 2006, was 0.2mm d^{-1} during spring and early summer. Growth rates were similar on all beaches sampled with the exception of 2006 when Silverstrand showed a much higher growth rate than either Ballyloughan or Glann na Ri. Growth rates were generally smaller than predicted suggesting food may be a limiting factor.

Chapter 2.

2.2 Introduction

The plaice, *Pleuronectes platessa* L., is an economically important flatfish in Irish and European waters. West of Ireland plaice stock fall into ICES management areas VIIc and VIIb. In 2004, Irish landings of plaice in this region were 38 tonnes (Anon 2005). An investigation was undertaken to explore the spatial and temporal scale of annual patterns of recruitment of juvenile plaice in Galway Bay. Information gathered would contribute to the formation of a recruitment index in the future. No such recruitment index exists and it would be a valuable tool for fishery research.

Recruitment, in fishes, is defined as the number of individuals that reach a particular age to join a specific part of the population (Van der veer *et al.* 2000). Van der Veer *et al.* (2000) also stated that scientists use recruitment processes to cover everything that affects survival between spawning and the stage of life where year class strength is more or less fixed. Annual variability in marine fishes is a well-known phenomenon, and this recruitment variation can be enormous, having major biological and economic implications for the management of commercial fisheries (Leggett and De Blois 1994).

In general, year class strength is already determined at an early age, long before recruitment to the adult population occurs (Van der veer 1986, Leggett and De Blois 1994). Flatfish recruitment to a stock appears to be related to the quantity of juvenile nursery habitats, suggesting that either larval supply or the carrying capacity of the nurseries is the limiting factor. However, information on growth of 0-group flatfish suggests that carrying capacity of nursery areas is never reached (Van der Veer *et al.* 2000). The strength of year class in plaice also depends on successful delivery to their nursery grounds (Bailey *et al.* 2005). Predation on juvenile plaice, on the nursery grounds, has a dampening effect in respect to recruitment (Van der Veer *et al.* 1990).

A research program was set up to study the settlement, growth and recruitment of 0-group plaice in Galway Bay. The chosen method of sampling was a Riley push-net (Homes and McIntyre 1971). This method of sampling had been used previously in the Galway Bay area (Allen 2004). Push-nets are used to sample small fish and young individuals in tidal pools and shallow channels (Hinz 1989) and are ideal for catching fish and crustaceans in shallow waters ($\leq$ 1m)(Ruth and Berghahn 1989). Most studies, however, are carried out using a beam-trawl, as this method has known efficiencies for juvenile flatfish including plaice (Kuipers 1975, Kuipers *et al.* 1992, Wennhage *et al.* 1997). Drop traps are also a favoured sampling method for juvenile flatfish, in shallow nursery grounds. Quantitative assessments made using this method are highly accurate (Pihl and Rosenburg 1982).

Studies carried out on juvenile flatfish using push-nets include the following examples. Corlett (1967) used a 1.5m push-net, and beam-trawl, to examine young plaice and other fish in Strangford Lough and neighbouring bays in August 1963 and 1964. The push-net was used along the shore at a depth of approximately 0.60m for a "standard push" of ten minutes or about 250m. Jones (1972) also used a 1.5m push-net, and beam-trawl, to examine the ecology of 0-group and 1-group Turbot, *Scopthalmus maximus* L., in Cardiganshire, Wales between 1966 and 1968. Samples were taken at low water, at a depth of approximately 1m, over a standard 220m stretch of beach.

Wyche and Shackley (1986) carried out surveys on the feeding ecology of juvenile flatfish, including plaice, in Carmarthen Bay, south Wales between April and October 1978. Demersal trawl and push-netting were used. Push-netting was carried out from August to October in approximately 0.75m of water. Four replicate pushes were taken each lasting five minutes. On the east coast of Ireland Mansoor (1982) used push-netting to examine juvenile flatfish species. Sampling was carried out by time, ten minutes pushes, which corresponded to a length of approximately 220m. Sampling was carried out parallel to the beach at a depth about 0.5m. Two or three hauls were made per sampling visit.

Riley *et al.* (1981) carried out extensive studies using a beam trawl and a 1.5m push-net around the coasts of England and Wales to access populations of coastal fish species including juvenile flatfish, of which plaice were a main component. Density of plaice caught was expressed as numbers per $1000m^{-2}$. A study carried out at the mouth of the Gullmarsfjord on the Swedish west coast, in July 1995, studying the diel movements of juvenile plaice, used a 1m push-net and beach seine along with underwater television (Gibson *et al.* 1998). The push-net was used to depths of approximately 1m and covered a sample area of 25m^2. Wennhage and Pihl (2001) also used a 1m push-net in a study of newly settling plaice in Gullmarsfjord between 1994 and 1996. The study related settlement of 0-group plaice to larval supply and benthic predators. The push-net was used to collect *Crangon crangon* using five randomly hauls in waters approximately 0.7m deep.

Allen (2004) carried out push-net sampling on a number of sandy beach nursery grounds on the Clare and Galway coasts, in the West of Ireland, from 2002 to 2004. Sampling was carried out using a 1.5m Riley push-net at low water on a rising spring tide once a month. Four replicate samples, each approximately 50m long, were randomly taken per beach. Sampling was carried out at a depth of approximately 0.5m parallel to the shore.

For comparative purposes with other studies and also for the analysis of density-dependence, it is necessary to estimate the abundance of 0-group flatfish as near as possible in terms of sample density. This is done by calculating the number of fish 1000m^{-2} of seabed (Iles and Beverton 1991). Many published surveys give information in this format but others give numbers caught per haul or number of the total population of 0-group flatfish in a certain area (Iles and Beverton 1991). These studies leave comparison with research in other areas difficult. Examples of such studies are Mansoor (1982) who worked on 0-group flatfish, including plaice, on the Irish east coast from in 1980 to 1981; densities were not calculated and were given as % of species taken. Riley and Corlet (1965) carried out work on 0-group plaice in the Irish Sea, in May and June of 1962 and 1963 respectively. Again densities were not calculated. Another example is work carried out by Corlet (1967) in the Strangford Lough area. Sampling was carried out using beach seine and push-net. Density of 0-group plaice caught in push-netting were given as actual number caught per "standard push". In the Clyde Sea, sampling was carried out on juvenile flatfish species, using a beam trawl, in August 1973 and 1974 (Poxton *et al.* 1982). Abundances were estimated for the whole population per bay sampled.

It is important to note, when comparing studies, the way in which surveying is carried out. A majority of surveys sample at right angles to the shoreline (e.g. beach seines and some beam trawls) from the seawards limits of the 0-group flatfish to the waters edge, for example Steele and Edwards (1970), Lockwood (1980), Poxton *et al.* (1982) and Geffen *et al.* (2005). Other surveys sample parallel to the shore in varying or constant depths, an example of these are Allen (2004) and Corlett (1967). Gear efficiency is also another important factor when making comparisons between surveys (Iles and Beverton 1991).

The main focus of the present study was to extend the scale of spatial and temporal analysis of settlement, densities, growth and ultimately recruitment of 0-group plaice on sandy beach nursery grounds in the Galway Bay area, on the west coast of Ireland. It was hoped that by studying patterns of settlement and densities, over a period of years, years of peak recruitment could be identified. Data collected during this project and a previous project (Allen 2004) could then be used, in the future, in the assessment of push-netting as a method to determine a recruitment index for the west coast of Ireland; such an index does not presently exist. A large data set is required in order for such an index to be formed and the results of the present study would be a vital component in this data set. To achieve the above aims the following targets were set.

Routine push-net sampling was to be undertaken in February 2005 and continued to June. Sampling would be increased to two visits per month for each beach. The same pattern of sampling was again carried out in 2006. Archived samples from 2004 were processed.

The results of the present study were compared to results from a previous study in the same area (Allen 2004) and this allowed analysis of a unique five-year data set for the Galway Bay area and for Irish waters. Analyses were carried out to determine differences in densities and sizes of 0-group plaice between beaches, months and years. If a pattern in years of high recruitment and low recruitment of 0-group plaice could be observed then this would be of great interest to fisheries biologists and fisheries managers alike. Length data was used to examine growth rates of 0-group plaice from March to June.

2.3Methods and Materials

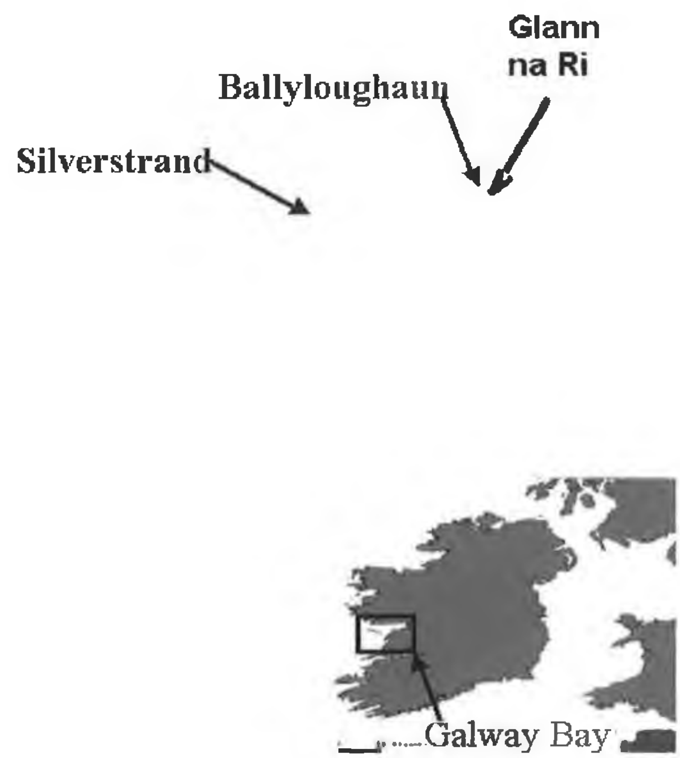
2.3.1 Study area

The two main beaches studied were Ballyloughan and Silverstrand. These two beaches had been repeatedly sampled from 2002 to 2003 in a previous juvenile fish study (Allen 2004). Archived samples were also available for Ballyloughan and Silverstrand, from March to May, in 2004. A third beach, Glan na Ri, was added in April 2005 (Figure 2.1).

Ballyloughan (54° 15.2`N, 09° 01.6`W) is a sheltered sandy beach on the eastern outskirts of Galway city. This beach is gently sloping and is approximately 400m in length and 600m in width on maximum extent. It has a strong riverine influence from the river Corrib and salinity is very variable (10 – 26). Silverstrand (53° 15.2`N, 09° 07.8`W) is a sheltered sandy shore on the western outskirts of Galway city. This is also a gently sloping beach and is approximately 400m in length and 200m in width. This beach is less influenced by the River Corrib and has a less variable salinity (22-35).

A third sampling location was added in mid April 2005 and this was Glan na Ri. This is situated approximately 1km to the east of Ballyloughan and is a sheltered beach composed of fine sand with a salinity range from 14 to 28, over the duration of the project. The beach is approximately 200m long and 50m wide. A small stream enters the sea on the eastern end of this beach and this aids in keeping salinities low (in comparison to full sea water i.e 30+). The addition of Glann na Ri increased the spatial scale of the survey area (approximately 15 km across the three beaches).

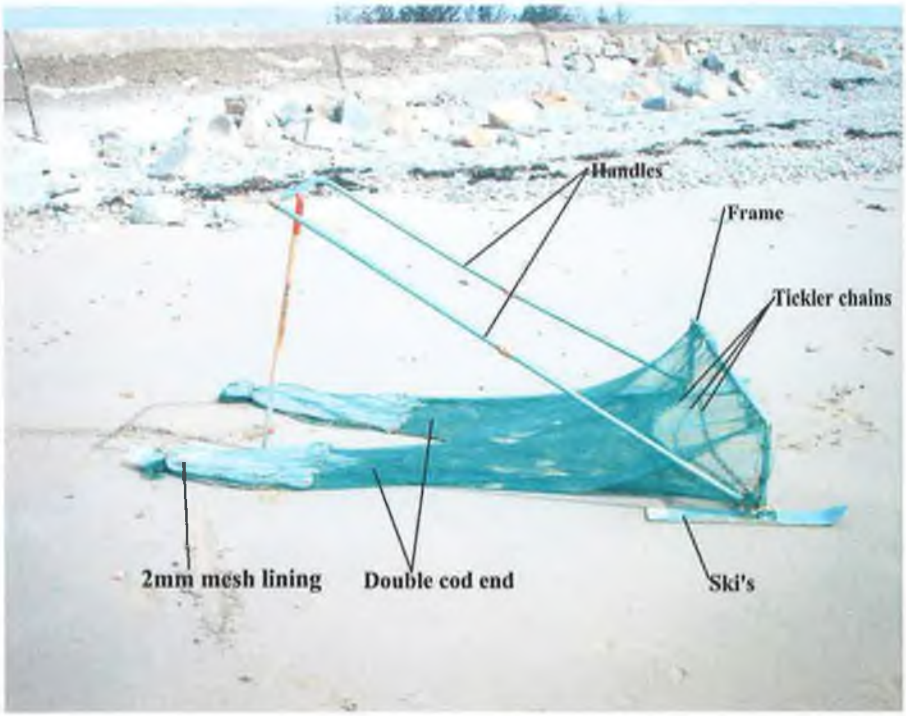
Figure 2.1: Map of Galway Bay showing sampling areas.



2.3.2 Sampling gear

Sampling was carried out using a Riley push net (Homes and McIntyre 1971)(Figure 2.2) with modifications. The push-net used was the same as described in Allen (2004) but was modified by permanently welding together the main body, except for the handles. This push-net had the following dimensions. A 1.5m x 0.3m metal frame constructed from 4cm box iron. The frame was supported on two 70cm x 7.5cm skis. A handle was attached to the frame (2m long) to enable the net to be pushed. The handle could be broken down into three parts for ease of transport. The net was a double-ended shrimp net with 10mm square mesh and 2 mm heavy-duty curtain mesh in the cod ends. Three tickler chains were attached to eyes made from cut chain links which were welded to the skis in front of the main structure. The first chain was attached to the leading edge of the net, with the other two chains free to trail.

Figure 2.2 Picture of a Riley push-net showing main features (From Allen 2004)



2.3.3 Sampling procedure

The survey team for the Riley push-net experiment consisted of two operators. Sampling procedures were taken from Allen (2004), and training was supervised by him in the field to ensure consistency amongst sampling projects. Sampling was carried out on low water spring tides (~ < 1m) as the tide was rising during daylight hours. Each beach was divided into sections, which were numbered one to eight so that random number areas of the beach could be sampled. Four random replicates were taken per beach. Each replicate was 50 paces (approx. 50m) long. Sampling was carried out at a depth of approximately 0.3-0.5m parallel to the shore. This gave a swept area of 75m^2.

Samples were sorted on the beach with all species of juvenile flatfish being taken back to the laboratory for further analysis. Other species of fish and invertebrates were recorded and released. The environmental factors of temperature and salinity were taken on most occasions. Temperature was taken using a thermometer in shallow waters approximately 20cm deep. Salinity was recorded using a hand held salinity device (Sea Test©) with a precision of ±1. Sea state and weather conditions were recorded on each visit.

2.3.4 Laboratory analysis

In the laboratory, fish were identified to species and then coded. The code used enabled each fish to be traced back to sampling visit, date and replicate. All fish in individual replicates were stored together in vials. The 0-group plaice were then measured using callipers to the nearest ± 0.02 mm. Measurements were recorded for total length (TL.) (from the tip of the mouth to the end of the caudal fin) and for standard length (SL.) (from the tip of the mouth to the start of the caudal fin). Fish that were not sampled immediately were frozen at -18°c to be processed at a later date. A sub-sample of fish had both sagittal otoliths removed for otolith microstructure work This was carried out using forceps and needles to remove the otoliths from their position in the head of the fish.

2.3.5 Statistical data analysis

The raw data for catches of 0-group plaice and the subsequent length data for 0-group plaice were coded and entered into Microsoft EXCEL worksheets (version 2000) and all data were error checked and corrected. Further data analysis was carried out using Microsoft EXCEL or MINITAB (version 14). Mean densities $1000m^{-2}$ and ± S.D were calculated using EXCEL. Mean densities were calculated as follows.

$$\textbf{Densities} = \frac{\textbf{Mn}}{\textbf{A}} \times \textbf{1000}$$

Where Mn is the mean density of 0-group plaice for four replicates. And A is the area fished ($75m^2$).

Length frequency graphs for 0-group plaice were plotted to determine the timing of settlement, the modal size within samples, the size range of fish present and to discern growth. Mean length data ± S.D were also calculated, using Microsoft EXCEL, for each visit that had enough fish present to analyse.

Frozen archived fish from 2004 were processed. Total lengths (mm) for each fish were taken and a sub sample of fish had otoliths removed for microstructure analysis.

2.3.6 Analysis of variance

All data was subjected to Ryan-Joiner normality tests and checked for homogeneity of variance using Cochran's test. If data were found not to be normal transformations were carried out. Log, Log +1 or inverse log transformations were used. Generally log +1 transformations were used when dealing with density data as a density of zero would not transform otherwise. Log transformations was generally used in length data. Inverse logs were only used once during the project. Only one method of transformation was used when data were being compared, e.g log +1 for densities and log for lengths. If data could not be normalised non-parametric tests, Kruskal-Wallis and Moods Median, for significant differences were used (Underwood 1997).

The main factors (for example years (2002 to 2006), months (February to June) and beaches (Ballyloughan, Silverstrand and Glann na Ri)) in every test were checked for significant interactions. Where a significant interaction occurred no conclusions were drawn on the main effects of the two factors (e.g. years or beaches). Interpretation of the main effects are impossible or at best unreliable when there is an interaction (Underwood 1997). If the main hypotheses were not affected, the interaction was further studied, using post hoc analysis (e.g Fishers pairwise test), if it helped to further explain the patterns observed.

2.3.6.1 Density data

To compare 2005 and 2006 data to 2004 and previous data for the region (Allen 2004) it was necessary to randomly pick one sampling visit per month to compare to earlier years as only one sampling visit per month was carried out previous to this study. This allowed comparison of data for five years. In 2002, only three replicates per sampling visit were taken so a fourth replicate, by calculating the mean of the three replicates, was produced (Underwood 1997).

Two factor or three factor ANOVAs were carried out on abundances of 0-group plaice with the factors of months, beaches and years. The null hypotheses (Ho) used for the different analysis were as follows:

(1) There is no difference in abundances of 0-group plaice between years.
(2) There is no difference in the abundances of 0-group plaice between months.
(3) There is no difference in the abundances of 0-group plaice between beaches
(4) There is no interaction between the main factors.

2.3.6.2 Length data.

Total length (mm) data for 0-group plaice was analysed for significant difference using Kruskal-Wallis and Moods Median non-parametric tests, as these data could not be normalised. Not all months or visits could be analysed due to small samples or no fish caught.

Non-parametric Kruskal-Wallis or Moods Median tests for significant difference were carried out on total lengths of 0-group plaice with the factors of months, beaches and years. The null hypotheses (Ho) used for the different analysis were as follows:

(1) There is no difference in the total lengths of 0-group plaice between years.

(2) There is no difference in the total lengths of 0-group plaice between months.

(3) There is no difference in the total lengths of 0-group plaice between beaches.

2.3.7 Growth

Observed growth was calculated as the increase in mean length of 0-group plaice over the main growth period. This period was taken to be from March (newly settling fish) to June. 0-group plaice $\leq$ 15 mm were omitted from samples from April onwards as they were considered newly settling fish and were not considered growing fish. In order to compare 2004 data to 2005 and 2006, a random sampling visit was chosen for each month in 2005 and 2006. This was done as only one sampling period was undertaken per month in 2004. The equation used for predicted growth (ΔL) in length (mm month^{-1}) of 0-group plaice was taken from Glazenburg (1983) in Van der Veer (1986).

$$\mathbf{\Delta L = 1.3 \times T + 1.7 \ (mm\ month^{-1})}$$

Where *T* is the mean monthly temperature (°C) taken from the Marine institute M1 data buoy off the west coast of Ireland.

This simple descriptive growth model obtained under excess feeding conditions is especially for small 0-group plaice up to 5cm (Van der Veer 1986). Observed and predicted growth could then be compared to one another. Daily growth was calculated by dividing the mean increase in length of 0-group plaice between samples by the number of days between samples. Daily mortality was not calculated for 2004 to 2006 as a linear decrease in 0-group plaice densities is required and this would require sampling from peak densities through to October or November (Nash and Geffen 2000).

2.4 Results

2.4.1 Abiotic factors

The environmental factors of salinity, temperature, sea state and weather conditions were taken on most occasions during the push-net surveys. Table 2.1 and 2.2 (in appendix 1) show the results for Ballyloughan and Silverstrand from 2004 to 2006. Abiotic results are also included for Glann na Ri for 2005 and 2006. Sampling frequencies for the three beaches sampled can be seen in Table 2.3.

In 2004, sampling was carried out between March and May only. This sampling was undertaken as a short contract, by B. Allen, and concentrated on the main settlement months from March to May 2004. Sampling in 2005 commenced in February and was continued until the end of July on spring tide periods (approximately every two week). Sampling also commenced in February 2006 and was also continued until late June. Ballyloughan and Silverstrand were visited ten times each during regular sampling visits per year. Glann na Ri was visited a total of fifteen times between April 2005 and June 2006 (table 2.3).

Salinity (with a precision of ± 1) during this programme ranged from 16 – 22 on Ballyloughan in 2005 and this range was also found in 2006. The salinity range on Silverstrand was from 32 – 36 in 2005 and 28 – 35 in 2006. On Glann na Ri, salinities ranged from 13 to 34. Temperature was taken each occasion from 2005 to 2006 on each beach, however, results were deemed to be inaccurate and are omitted. Temperature results for growth rate calculation were taken from the M1 data boy on the West coast of Ireland.

Table 2.3: Sampling frequency for Ballyloughan, Silverstrand and Glann na Ri from 2004 to 2006.

Beach	Years	Month	Sampling frequency
Ballyloughan	2004	March	Once per month
		April	Once per month
		May	Once per month
	2005	February	Twice per month
		March	Twice per month
		April	Twice per month
		May	Twice per month
		June	Twice per month
	2006	February	Twice per month
		March	Twice per month
		April	Twice per month
		May	Twice per month
		June	Twice per month
Silverstrand	2004	March	Once per month
		April	Once per month
		May	Once per month
	2005	February	Twice per month
		March	Twice per month
		April	Twice per month
		May	Twice per month
		June	Twice per month
	2006	February	Twice per month
		March	Twice per month
		April	Twice per month
		May	Twice per month
		June	Twice per month
Glann na Ri	2005	April	Twice per month
		May	Twice per month
		June	Once per month
	2006	February	Twice per month
		March	Twice per month
		April	Twice per month
		May	Twice per month
		June	Twice per month

2.4.2 Settlement of 0-group plaice, and initial densities in Galway Bay

In 2002, plaice first settled in April with a mean density of 18 $1000m^{-2}$ on Ballyloughan and 18 $1000m^{-2}$ on Silverstrand. In 2003, first settlement was observed a month earlier in late March at densities of 12 $1000m^{-2}$ on both Ballyloughan and Silverstrand (Allen 2004).

In 2004, only three samplings were carried out as this work was done under contract. These were carried out to cover the main settlement period. The first of these was in late March (Table 2.4). First settlement had probably already preceeded this date. The observed densities then were 900 $1000m^{-2}$ on Ballyloughan and 553 $1000m^{-2}$ on Silverstrand.

In 2005, the first fish (one fish only) was seen at the end of February on Silverstrand. The next sampling in 2005, early March, had newly settled fish on both beaches with densities of 130 $1000m^{-2}$ on Ballyloughan and 46 $1000m^{-2}$ on Silverstrand. In 2005 a new beach, Glann Na Ri, was added in mid-April with densities observed here of 380 $1000m^{-2}$. This latter result is not, however, for newly settling fish. See Table 2.4 for 2005 data.

The first fish in 2006 were observed in mid-March. The densities were 23 $1000m^{-2}$ on Ballyloughan, 20 $1000m^{-2}$ on Silverstrand and 56 $1000m^{-2}$ on Glann na Ri. See Table 2.5 for 2006 data.

In summary, settlement is generally seen in early to mid-March with the exception of 2002. Initial densities are generally low with the exception of 2004. When plaice are first caught on one beach they are caught on the other beaches sampled around the same period.

2.4.3 Peak Densities

Peak densities varied in time from year to year (Figures 2.3 and 2.4). In 2002, peak densities were in May on Silverstrand (31 $1000m^{-2}$) and June on Ballyloughan (44 $1000m^{-2}$). In 2003, peaks were in April and May (277 and 237 $1000m^{-2}$) on Silverstrand and Ballyloughan respectively (Allen 2004). In 2004, peak densities were noted in March (900 and 553 $1000m^{-2}$) on Ballyloughan and Silverstrand respectively. In 2005, peaks were in April and May (156 and 260 / $1000m^{2}$) on Ballyloughan and Silverstrand respectively (Table 2.4).

In 2005, Glann na Ri was first sampled in early April. Densities of 0-group plaice were 380 $1000m^{-2}$. It should be noted that settlement had probably commenced about one month earlier. Peak densities of 0-group plaice were noted in 2006 at the end of April for Silverstrand (126 $1000m^{-2}$) and mid-June for Ballyloughan (146 $1000m^{-2}$). Peaks in Glann na Ri were at the end of April (290 $1000m^{-2}$) (Table 2.5).

In summary, Silverstrand usually peaks in abundances before Ballyloughan and generally by about one month, but this is not always the case. Peak abundances are generally similar. Glann na Ri has not been sampled long enough to gauge a pattern in peak densities. Summary of results can be seen in figures 2.3 and 2.4 and in tables 2.4 and 2.5.

Figure 2.3: Mean peak densities $1000m^{-2}$ of 0-group plaice caught in push-net experiments, on Ballyloughan (BN) and Silverstrand (SS), from March 2002 to June 2006.

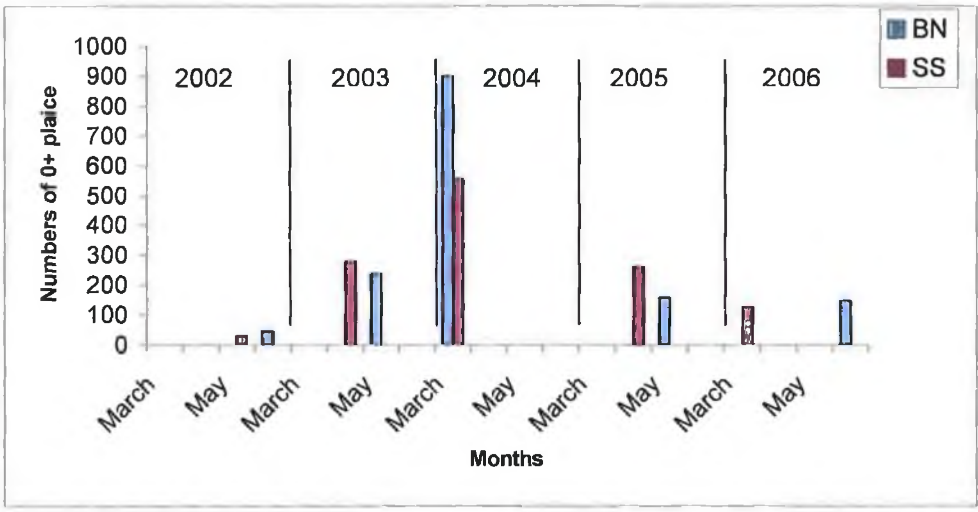
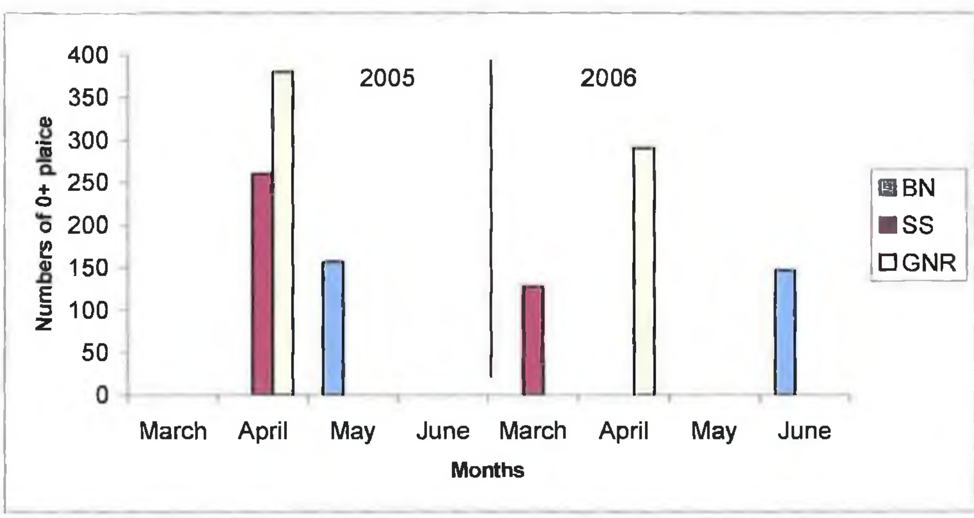


Figure 2.4: Peak densities / $1000m^{2}$ of 0-group plaice caught in push-net experiments, on Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR), from March to June in 2005 and 2006.



In figures 2.3 and 2.4, it is clear that Silverstrand peaked in densities of 0-group plaice before Ballyloughan every year from 2002 to 2006, except in 2004 when peaks were in the same sampling period. In three of the years 2002, 2003 and 2005 Silverstrand peaked one month before Ballyloughan. For 2005 and 2006 peaks can be compared for three beaches, Ballyloughan, Silverstrand and Glann na Ri. Silverstrand and Glann na Ri peak in densities of 0-group plaice before Ballyloughan. It should be noted that Glann na Ri was only sampled from April onwards in 2005 and that the true peak could already have been missed. In 2006, Silverstrand peaked three months, and Glann na Ri peaked two months before Ballyloughan.

A two factor ANOVA was used to test the hypothesis that there was no difference in peak densities of 0-group plaice sampled between the years of 2002 to 2006 or between the two beaches, Ballyloughan and Silverstrand. Results showed that there was a significant difference in peak densities of 0-group plaice between years ($p < 0.001$) but there was no significant difference between beaches ($p = 0.834$). There was no interaction between the main factors ($p = 0.483$). Fishers pairwise post hoc analysis revealed that 2002 had the smallest peak densities and was different to every other year sampled. Peak densities in 2003 were similar to 2005 and 2006 but different to 2004. Peak densities in 2004 were the highest recorded. Peak densities in 2004, 2005 and 2006 were similar to one another.

In summary, peak densities of 0-group plaice vary in time from year to year. In general, Silverstrand peaks in densities before Ballyloughan with the exception of 2004 when peaks were in the same sampling period. Glann na Ri peaked in April on both years sampled (2005 and 2006). Peak densities $1000m^2$ are generally similar between the beaches sampled.

2.4.4 Annual variation in densities

Mean monthly densities $1000m^{-2}$ of 0-group plaice were calculated for each visit on Ballyloughan and Silverstrand from 2004 to 2006 (Table 2.4 and 2.5). Mean monthly densities were also calculated for Glann na Ri from April 2005. Results can be seen graphically in figures 2.5 to 2.8. Densities of 0-group plaice ranged from 0 $1000m^{-2}$ on the three beaches sampled to a maximum peak of 900 $1000m^{-2}$ in 2004.

Table 2.4: Numbers and mean densities ± S.D of 0-group plaice, per four replicates, from Ballyloughan and Silverstrand in 2004 and 2005, and Glann na Ri in 2005. (BN = Ballyloughan, SS = Silverstrand, GNR = Glann na Ri).

Location Code	Date	Number of 0-group plaice for 4 replicates	Mean number of plaice / 4 replicates	S.D ±	Mean Densities / 1000m^2
BN 04 01	25-3-04(**March**)	270	67.5	77	900
BN 04 02	7-4-04 (**April**)	152	38	9	507
BN 04 03	18-5-04 (**May**)	64	16	5	213
SS 04 01	23-3-04(**March**)	166	41.5	24	554
SS 04 02	8-4-04(**April**)	39	9.75	4	130
SS 04 03	19-5-04 (**May**)	5	4.34	1	17
BN 05 03	9-3-05 (**March**)	39	9.75	7	130
BN 05 04	29-3-05	23	5.75	2	77
BN05 05	8-4-05(**April**)	40	10	6	133
BN05 06	27-4-05	28	7	3	93
BN 05 07	5-5-05 (**May**)	43	10.75	9	144
BN05 08	24-5-05	47	11.75	8	157
BN 05 09	8-6-05 (**June**)	9	2.25	1	30
BN 05 10	20-6-05	0			0
SS 05 01	8-2-05 (**Feb.**)	0	0		0
SS 05 02	25-2-05	1	0.25	0.5	3
SS 05 03	11-3-05(**March**)	14	3.5	4	47
SS 05 04	29-3-05	6	1.5	1	20
SS 05 05	11-4-05 (**April**)	78	19.5	19	260
SS 05 06	29-4-05	2	0.5	1	7
SS 05 07	9-5-05 (**May**)	11	2.75	3	37
SS 05 08	31-5-05	11	2.75	1	37
SS 05 09	9-6-05 (**June**)	2	0.5	1	7
SS 05 10		1	0.25	0.5	3
GNR 05 01	14-4-05 (**April**)	114	28.5	8.50	380
GNR 05 02	26-4-05	71	17.75	18	237
GNR 05 03	6-5-05 (**May**)	42	10.5	1	140
GNR 05 04	23-5-05	52	13	11	173
GNR 05 05	10-6-05 (**June**)	12	3	2	40

Table 2.5: Numbers and mean densities ± S.D of 0-group plaice, per four replicates, from Ballyloughan, Silverstrand and Glann na Ri in 2006. (BN = Ballyloughan, SS = Silverstrand, GNR = Glann na Ri.)

Location Code	Date	Number of 0-group plaice for 4 replicates	Mean number of plaice / 4 replicates	S.D ±	Mean Densities / 1000m^2
BN 06 01	13-2-06 (Feb)	0			0
BN 06 02	1-3-06 (March)	0			0
BN 06 03	15-3-06	7	1.75	1.5	23
BN 06 04	29-3-06	9	2.25	3	30
BN 06 05	10-4-06 (April)	14	3.5	1	47
BN 06 07	27-4-06	34	8.5	11	114
BN 06 09	11-5-06 (May)	32	8	3	107
BN 06 10	25-5-06	30	7.5	2	100
BN 06 11	12-6-06 (June)	44	11	2	147
BN 06 15	29-6-06	39	9.75	3	130
SS 06 01	13-2-06 (Feb)	0			0
SS 06 02	28-2-06	0			0
SS 06 03	15-3-06(March)	6	1.5	2	20
SS 06 04	29-3-06	38	9.5	7	127
SS 06 05	10-4-06 (April)	1	0.25	0.5	3
SS 06 07	28-4-06	16	4	2	53
SS 06 09	11-5-06 (May)	7	1.75	1	23
SS 06 10	25-5-06	4	1.00	1	13
SS 06 11	12-6-06 (June)	14	3.5	3	47
SS 06 15	27-6-06	19	4.75	3.5	60
GNR 06 01	14-2-06 (Feb.)	0			0
GNR 06 02	1-3-06	0			0
GNR 06 03	16-3-06(March)	17	4.25	5	57
GNR 06 04	31-3-06	36	9	11	120
GNR 06 05	11-4-06 (April)	24	6	3	80
GNR 06 06	27-4-06	87	21.75	18	290
GNR 06 07	10-5-06 (May)	20	5	4	67
GNR 06 08	23-5-06	22	5.5	1	74
GNR 06 09	15-6-06 (June)	14	3.5	3	47
GNR 06 10	29-6-06	23	5.75	3	77

Analysis of variance was carried out on mean monthly 0-group plaice density data to determine whether there was a significant variation from year to year from 2002 to 2006 (Figure 2.5 and 2.6). A three factor ANOVA was used to test the hypothesis that there was no significant difference between the densities of 0-group plaice between years, months and beaches (Ballyloughan and Silverstrand). Three months (March, April and May) were used for these tests, as these are main settlement months. Sampling in 2002 comprised of 3 replicates per beach so a fourth replicate was created using the average of the first 3 replicates (Underwood 1997), so the design would be balanced. Results showed that there was no significant difference in the densities of 0-group plaice between years ($p = 0.098$) and that there was no significant difference between months ($p = 0.077$). No significant difference was observed between beaches over the five year study ($p = 0.256$). There was an interaction between years and beaches ($p < 0.001$). There was no further investigation as a significant interaction term makes interpretation of the main hypotheses unreliable (Underwood 1997).

Figure 2.5: Mean densities of 0-group plaice caught during push-net sampling on Ballyloughan during the months of March to June 2002 to 2006. All years have ± S.D bars

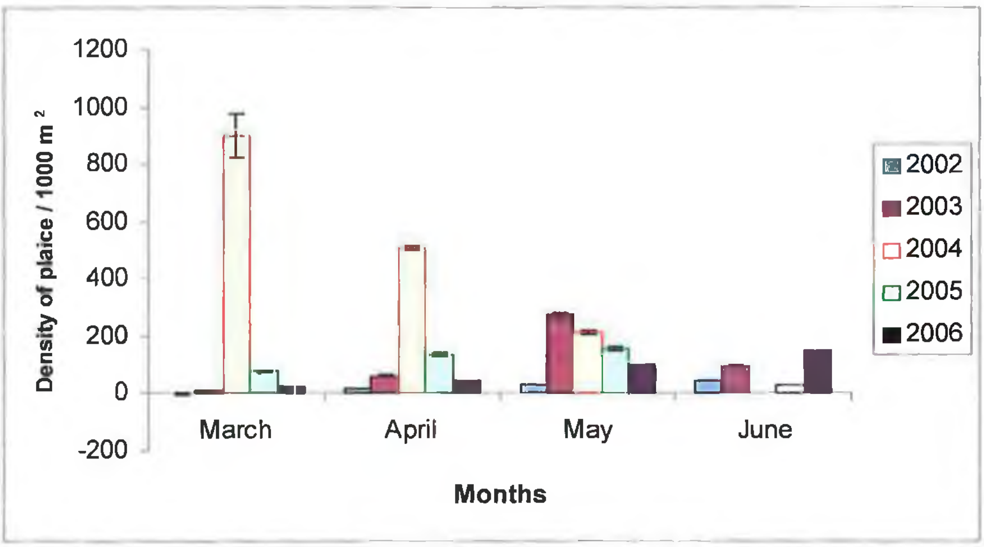
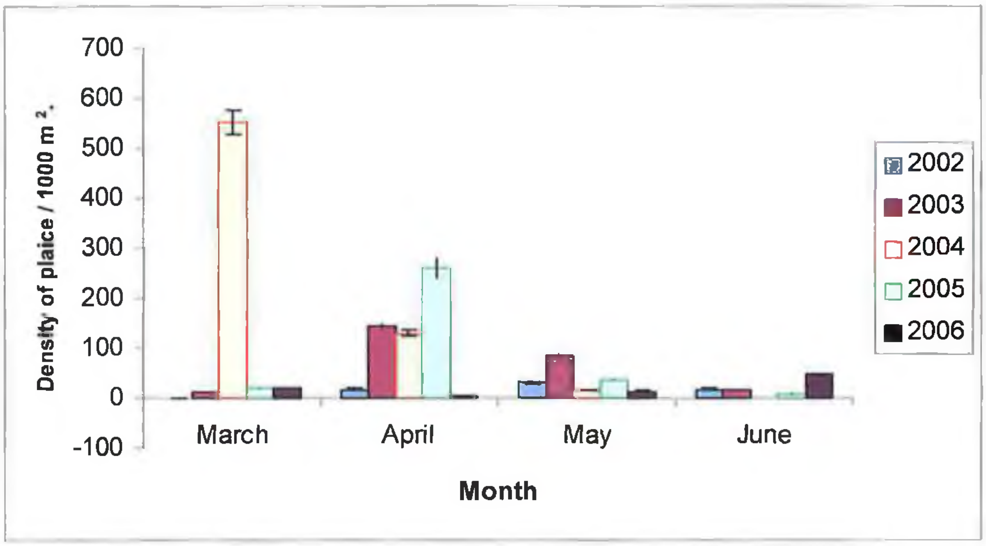


Figure 2.6: Mean densities of 0-group plaice / 1000m^2 caught during push-net sampling on Silverstrand, during the months of March to June, 2002 to 2006. All years have ± S.D bars



The peak settlement months of March and April were then used to explore the hypothesis that there no difference in the abundances of 0-group plaice, on Ballyloughan and Silverstrand, from 2002 to 2006 using three factor ANOVA's. Results revealed that there was a significant difference between years ($p = 0.021$) and between the months of March and April ($p = 0.017$). There was no significant difference noted between beaches ($p = 0.669$). No significant interaction was observed between years or beaches ($p = 0.061$). The *Post hoc* analysis (Fishers pairwise test) revealed that densities in 2002 and 2003 were similar to 2006 but not similar to 2004 or 2005. Abundances of 0-group plaice from 2004 to 2006 were similar. Comparisons of figures 2.5 and 2.6 suggest that any yearly variation in densities between years has disappeared by May.

This pattern was further studied by analysing the main settlement month of March on Ballyloughan and Silverstrand from 2002 to 2006. Data for March was found not to be normal but was homogenous therefore ANOVA could be used, as ANOVA results are robust to violations of normality (T. Crowe, U.C.D. pers. comm.).

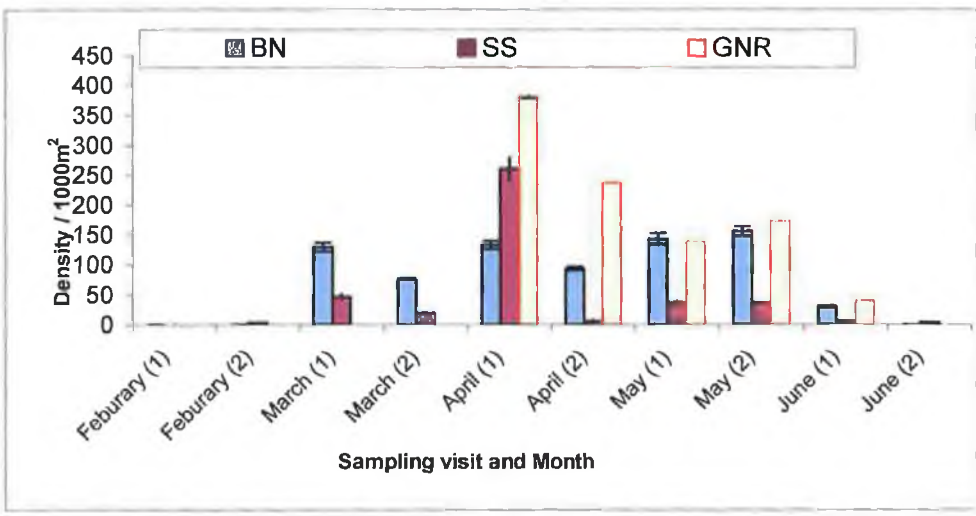
The month of March, from 2002 to 2006, showed a significant difference between years in the densities of 0-group plaice ($p = 0.015$). No significant difference was noted between beaches ($p = 0.991$). There was no significant interaction between beaches or years ($p = 0.091$). Fishers pairwise post hoc analysis revealed 2002 to have the lowest densities and 2004 to be the highest. It should be noted that settlement did not start until April in 2002.

In summary, there was a significant difference in the mean monthly densities of 0-group plaice between years on Silverstrand and Ballyloughan in the month of March from 2002 to 2006. Yearly variability had generally levelled off by May each year, figures 2.5 and 2.6 illustrate this. 2002 was shown to be a low settlement, hence recruitment, year whereas 2004 was shown to be a high settlement years. There were significant differences noted in abundances between months from 2002 to 2006. This indicated small-scale temporal and spatial variability. Density results are summarised in tables 2.4 and 2.5.

Sampling was increased to two samplings per month (two spring tide periods) in the sampling years 2005 and 2006. This was done to give a stronger data set for the beaches sampled. Preliminary test were carried on data from March and April (two main settlement months) in 2005 to see if there was a difference in abundances between spring tides in a given month. The two beaches used were Ballyloughan and Silverstrand. A three factor ANOVA (months x beaches x spring tide) was used to test the hypothesis that there was no significant difference in the abundances of 0-group plaice between months, beaches or sampling visit. Results for March and April 2005 revealed that there was no significant difference between beaches ($p = 0.185$) or months (0.407) and there was no significant interaction of the main factors ($p = 0.462$). However there was a significant difference observed between the first and second spring tides per month ($p = 0.027$). Fishers pairwise post hoc analysis revealed that the first spring tide period had greater abundances than the second spring tide period. These results reveal temporal differences at a small monthly scale.

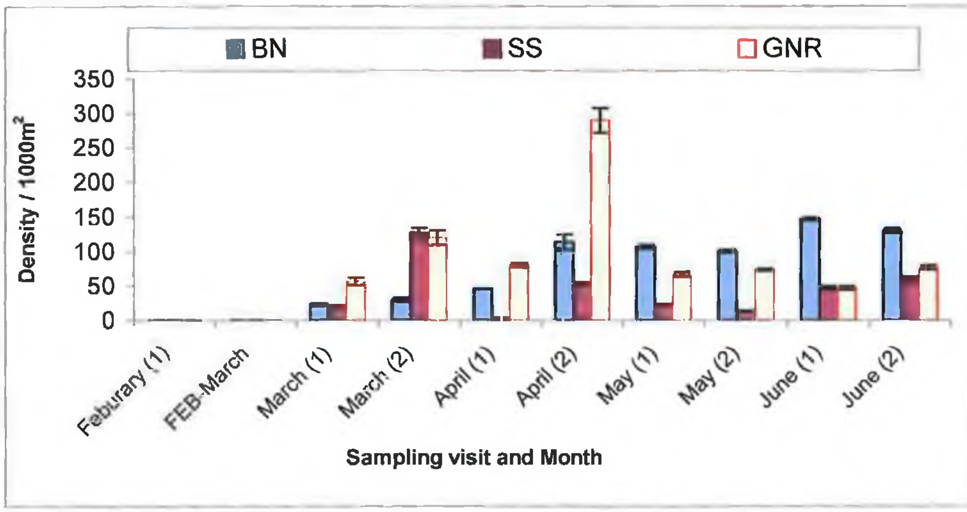
In 2005, Glann na Ri beach was added so this allowed comparison of a third beach (figure 2.7). This beach was only added in April so only the months of April and May could be examined (pooled data for two samplings per month per beach) with the hypothesis that there is no difference in the densities of 0-group plaice between beaches or between months. Tests showed that there was no significant difference in the abundances of 0-group plaice between beaches ($p = 0.074$). There was also no significant difference between months ($p = 0.445$) and there was no interaction between the main factors ($p = 0.465$).

Figure 2.7: Mean densities of 0-group plaice / 1000m^2 caught in a push-net sampling from Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR) from February to June 2005. Numbers 1 and 2 represent visits per month. Note Glann na Ri was not sampled until April 2005. All beaches have ± S.D bars.



Data for 2006 allowed the three beaches, Ballyloughan, Silverstrand and Glann na Ri to be examined for two visits per month (pooled data 2 samplings per month per beach) from February to June (Figure 2.8). A two factor ANOVA was used to test the hypothesis that there was no significant difference between the densities of 0-group plaice between beaches and months. No significant difference was found between beaches ($p = 0.227$) but there was a significant difference between months ($p = 0.015$). A significant interaction was found between beaches and months ($p < 0.001$). This makes interpretation of the main hypotheses unreliable (Underwood 1997) and no further analysis was carried out.

Figure 2.8: Mean densities of 0-group plaice / 1000m^2 caught in a push-net sampling from Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR) from February to June 2006. Numbers 1 and 2 represent visits per month. Feb-March represents an overlap in sampling between the end of February and the start of March. All beaches have ± S.D bars.



In summary, monthly densities of 0-group plaice ranged from 0 1000m^{-2} on occasions up to a maximum peak of 900 1000m^{-2} noted in March 2004. Abundances of 0-group plaice, in the month of March, were significantly different between years from 2002 to 2006. 2002 was shown to be a low settlement; hence recruitment year, and 2004 was a high settlement year. There was no significant difference noted between beaches on any sampling occasion. However some tests did show interactions between beaches and years or months and this reveals small-scale temporal and spatial differences at work. Peak densities of 0-group plaice also showed significantly differences between years. Again peak densities showed 2002 as a low recruitment year and 2004 as a high recruitment year. Timing in peak densities also varied between years. The addition of a third beach, Glann na Ri, allowed the analysis of three beaches in April and May 2005 and in the full sampling year 2006. Sampling was also increased to two sampling visits per month in 2005 and 2006 on all beaches. No significant difference was noted in the densities of 0-group plaice between the three beaches sampled in 2005. In 2006 an interaction between beaches and months meant that no interpretation of the main hypotheses could be made. Results showed that there was a significant difference in the densities of 0-group plaice between the first and second samplings per month, on Ballyloughan and Silverstrand, in March and April 2005. This result revealed temporal differences at a monthly scale.

2.4.5 Mean length data

Total length (mm) of 0-group plaice were taken for every sampling visit from 2004 to 2006. During the duration of the project 1975 0-group plaice were measured. The results for these can be seen in Tables 2.6 and 2.7 and graphically in figures 2.9 to 2.11.

From table 2.6 we can see than the mean length of 0-group plaice for Ballyloughan, in 2004, ranged from 15 ± 2mm in March to 28 ± 6mm in May. In 2004 Silverstrand had a range from 15 ± 2.11mm in March to 27 ± 8mm in May.

In 2005, plaice sampled on Ballyloughan had a range, in mean total length, from 14 ± 1.26mm in March to 40 ± 4mm in June (table 2.6). On Silverstrand, the range for plaice was from 16 ± 1mm in March to 39 ± 4mm in June. Glann na Ri had a range in mean length of 0-group plaice from 19 ± 3mm in April to 34 ± 5 in early June.

Table 2.7 shows that in March 2006 plaice on Ballyloughan had a range from 16 ± 1mm in March to 44 ± 11mm in June. Plaice on Silverstrand had a mean length of 15 ± 1 mm in March to 52 ± 6 mm in June. On Glann na Ri the range for 0-group plaice was from 16 ± 2 mm in March to 42 ± 6 mm in June.

Table 2.6: Table shows Mean total length (mm) of 0-group plaice ± S.D, taken during push-net sampling from Ballyloughan (BN) and Silverstrand (SS) in 2004 and 2005. Mean lengths are also given for Glann na Ri (GNR) 2005.

Location code	Date	Number of 0-group plaice	Mean Total Lt.	S.D ±
BN 04 01	25-3-04 (March)	97	15	2
BN 04 02	7-4-04(April)	98	18	2
BN 04 03	18-5-04 (May)	47	28	6
SS 04 01	23-3-04 (March)	163	15	2
SS04 02	8-4-04 (April)	36	15	4
SS 04 03	19-5-04 (May)	5	28	8
BN 05 03	9-3-05 (March)	20	14	1
BN 05 04	29-3-05	21	18	2.5
BN 05 05	8-4-05 (April)	25	18	3
BN 05 06	27-4-05	28	24	6
BN 05 07	5-5-05 (May)	39	27	8
BN 05 08	24-5-05	47	35	7
BN 05 09	8-6-05 (June)	9	40	4
SS 05 03	11-3-05 (March)	14	15	1
SS 05 04	29-3-05	10	15	8
SS 05 05	11-4-05 (April)	65	13	3
SS 05 06	29-4-05	3	17	1
SS 05 07	9-5-05 (May)	11	20	2
SS 05 08	31-5-05	11	38	8
SS 05 09	9-6-05 (June)	3	38	4
GNR 05 01	14-4-05 (April)	58	19	3
GNR 05 02	26-4-05	94	19	3
GNR 05 03	6-5-05 (May)	43	21	6
GNR 05 04	23-5-05	51	32	7
GNR 05 05	10-6-05 (June)	12	34	5

Table 2.7: Table shows Mean total length (mm) of 0-group plaice ± S.D, taken during push-net sampling, from Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR) during 2006.

Location code	Date	Number of 0-group plaice	Mean Total Lt.	S.D ±
BN 06 03	15-3-06 (March)	6	16	1
BN 06 04	29-3-06	8	18	2
BN 06 05	10-4-06 (April)	13	16	6
BN 06 07	27-4-06	33	21	5
BN 06 09	11-5-06 (May)	32	28	8
BN 06 10	25-5-06	29	32	9
BN 06 11	12-6-06 (June)	44	39	11
BN 06 15	29-6-06	38	43	10
SS 06 03	15-3-06 (**March**)	5	15	1
SS 06 04	29-3-06	37	16	1
SS 06 07	28-4-06 (**April**)	14	19	2
SS 06 09	11-5-06 (**May**)	7	26	4
SS 06 10	25-5-06	4	30	7
SS 06 11	12-6-06 (**June**)	13	52	6
SS 06 15	27-6-06	19	46	12
GNR 06 03	16-3-06 (**March**)	17	16	2
GNR 06 04	31-3-06	36	19	3
GNR 06 05	11-4-06 (**April**)	24	18	3
GNR 06 06	27-4-06	82	19	3
GNR 06 07	10-5-06 (**May**)	19	24	6
GNR 06 08	23-5-06	22	33	8
GNR 06 09	15-6-06 (**June**)	12	42	8
GNR 06 10	29-6-06	23	37	6

Tests for significant difference were used to test the size patterns of 0-group plaice between years, months and beaches. Non-parametric tests for significant difference were used in most cases, as data were not homogenous or normal. Where data were found to be normal ANOVA were used. When years were analysed, fish from each beach sampled were pooled together into their particular year group for comparison with other years. Where months were analysed, fish were again pooled together from each beach sampled into their particular month class regardless of year sampled. For the analysis of difference between beaches fish were separated per beach regardless of month or year sampled.

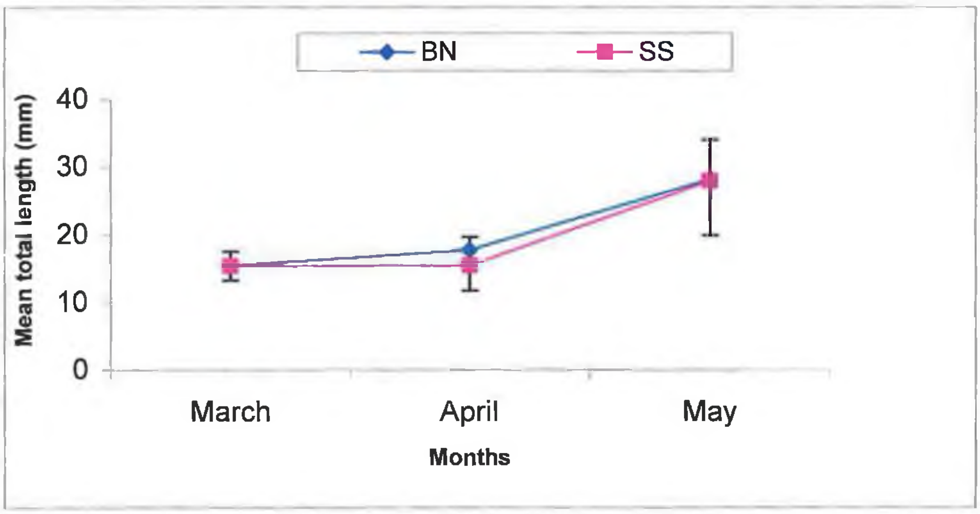
Tests for significant difference were used to examine the hypothesis that there was no difference in the total length of 0-group plaice on Ballyloughan and Silverstrand between 2002 and 2006. Not all samples or months could be analysed due to small numbers caught. Data from April and May in 2002 to 2006 were analysed using a non-parametric Kruskal-Wallis test as data could not normalised by transformations. Five fish were randomly picked per month per beach. Results showed that there was no significant difference in the lengths of 0-group plaice between Ballyloughan and Silverstrand ($p = 0.746$). Years however did show a difference in lengths of 0-group plaice ($p < 0.001$) and there was a significant difference between months ($p < 0.001$). A significant difference in the lengths of 0-group plaice between months would be expected due to growth. A Moods Median test was carried out, the resulting graphs showed that 2002 and 2003 were similar to one another (14.0 and 15.7mm median length respectively), with smaller median total lengths than 2004 to 2006. 2004 to 2006 were similar to one another in median lengths of 0-group plaice (18.3, 19.4 and 20.2mm respectively).

Analysis was carried out on five fish per month, per beach, from March to May from 2003 to 2006 only using Kruskal-Wallis tests. 2002 could not be used as no fish settled on either beach in March 2002. Results showed that there was no significant difference in the lengths of 0-group plaice between beaches ($p = 0.654$) but that there was a significant difference between years ($p = 0.022$). There was also a significant difference in months ($p < 0.001$). Again the difference in lengths between months would be expected due to growth. Moods Median test revealed that 2003 was different, with a smaller median length of 0-group plaice (15.4mm), from all other years sampled. 2004 to 2006 were similar in median length (17.0, 17.5 and 17.2 respectively). Plaice sampled in the months of March and April were found to be similar in size (15.4 and 17.5mm median length) but were different to May, which had a larger median size (25.7mm). These results show agreement with the previous set of results (2002 to 2006).

To confirm patterns seen, a larger data set from 2004, was used. A larger data set would provide a stronger test result. Data collected in 2004 was analysed for differences in 0-group plaice lengths for March and April, between Ballyloughan and

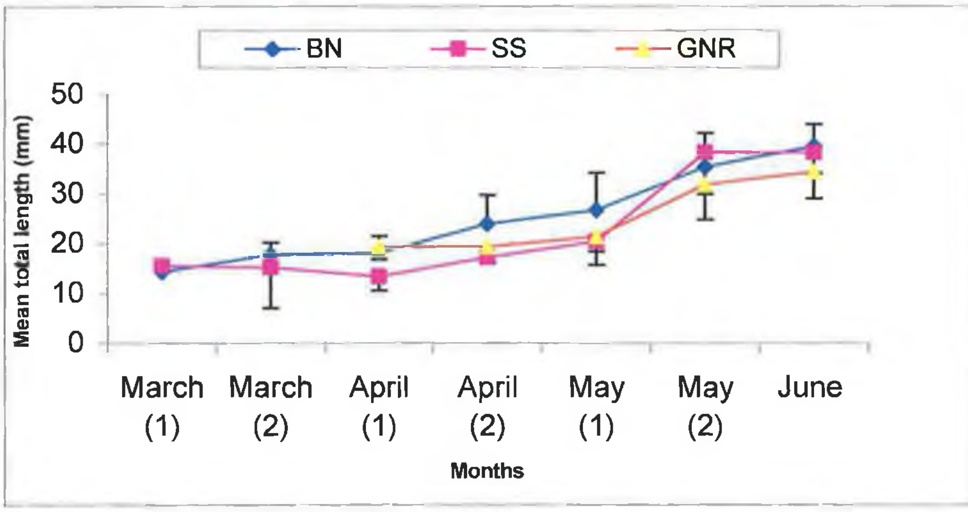
Silverstrand, using 20 fish per beach per month. Data were normal so a two factor ANOVA was used (beaches versus months). No significant difference was found between beaches ($p = 0.263$) or between months ($p = 0.333$). There was no interaction between the main factors ($p = 0.062$). Again there is agreement with the other tests carried out, in that there was no significant difference in lengths of 0-group plaice between beaches.

Figure 2.9: Mean total length (mm) of 0-group plaice, caught during push-net sampling, from Ballyloughan (BN)(+S.D) and Silverstrand (SS)(-S.D) during the months March to May 2004.



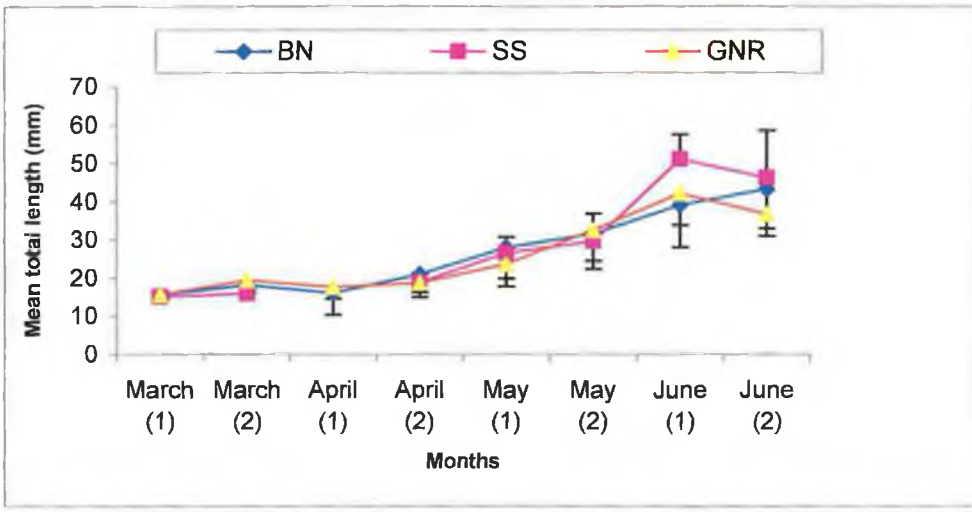
Data in 2005 and 2006 was gathered on two visits per month on Ballyloughan and Silverstrand. A Kruskal-Wallis test showed that for March to May in 2005 and 2006, using 11 fish per beach per month, there was no significant difference in 0-group plaice lengths between beaches ($p = 0.829$). There was also no significant difference between years ($p = 0.57$), however a significant difference was noticed between months ($p < 0.001$). A Moods Median test was carried out and the resulting graphs revealed that the months of March and April were similar in median length to one another (15.0 and 16.9mm respectively), but were different to the month of May (22mm median length). Again this would be expected due to growth.

Figure 2.10: Mean total length (mm) for 0-group plaice, caught during push-net sampling, from Ballyloughan (BN)(+S.D), Silverstrand (SS)(-S.D) and Glann na Ri (GNR)(-S.D) during the months March to June 2005. Note Glann na Ri not sampled until April



2006 plaice length data was analysed for three beaches (Ballyloughan, Silverstrand and Glann na Ri) using 11 fish per beach per month from March to June. Kruskal – Wallis tests revealed that there was no difference in fish lengths between beaches ($p = 0.645$) but that there was a significant difference between months ($p < 0.001$). A moods median test was carried out and the resulting graphs revealed that all months sampled from March to June, were different to one another in median length of 0-group plaice (16.1, 18.0, 26.8 and 45mm respectively).

Figure 2.11: Mean total length (mm) for 0-group plaice, caught during push-net sampling, from Ballyloughan (BN)(-S.D), Silverstrand (SS)(+S.D) and Glann na Ri (GNR)(-S.D) during the months March to June 2006.



In summary significant differences were noted in the lengths of 0-group plaice between years and months regardless of the sample size used. The difference in lengths between months would be expected due to growth. Results showed that in the months of April and May median lengths of 0-group plaice were smaller in 2002 and 2003 compared to 2004 to 2006. No significant difference was noted between beaches from 2002 to 2006 on Ballyloughan or Silverstrand. There was still no difference in the size of 0-group plaice between beaches, when a third beach was added in 2006.

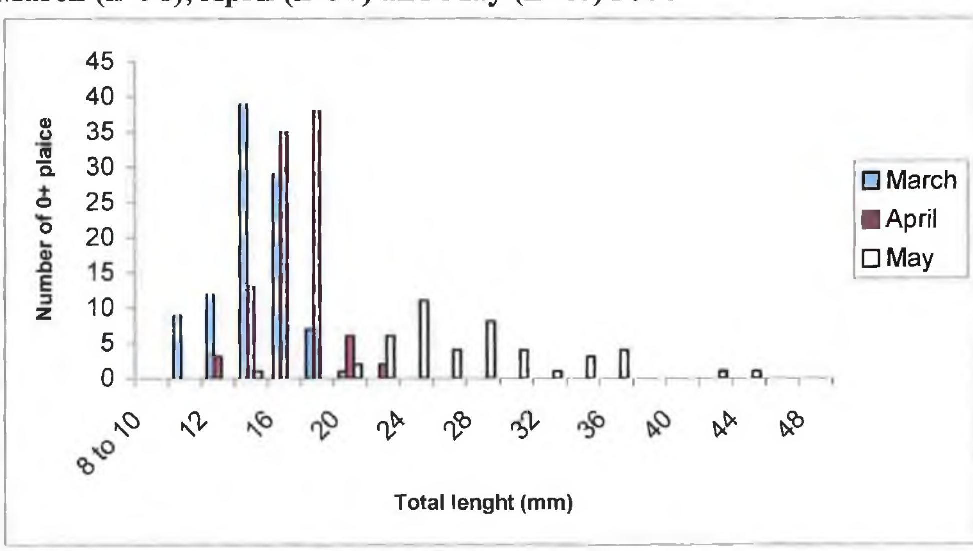
2.4.6 Length frequencies of 0-group plaice

Length frequency graphs for 0-group plaice were plotted for Ballyloughan and Silverstrand from 2004 to 2006. Plots were also produced fro Glann na Ri from April 2005 and through the sampling year in 2006. The overall length range on the three beaches sampled ranged from 8 to 68 mm over the duration of the project. Graphs aid in determining the timing of settlement on the beaches sampled. Plots would also allow the determination of the modal size within samples, the size range of fish present and display growth.

Length frequencies graphs of 0-group plaice were plotted for each month where enough fish were caught, this was taken at approximately 10 fish. Any number smaller than this was not considered, as these numbers would be too small to gauge patterns. The 2004 data represents one sampling per month. The 2005 and 2006 data for the three beaches, Ballyloughan, Silverstrand and Glann na Ri comprises of two visits per month. Pooled data was used per month in 2005 and 2006 due to small numbers per visit. A summary of all results can be seen in table 2.8.

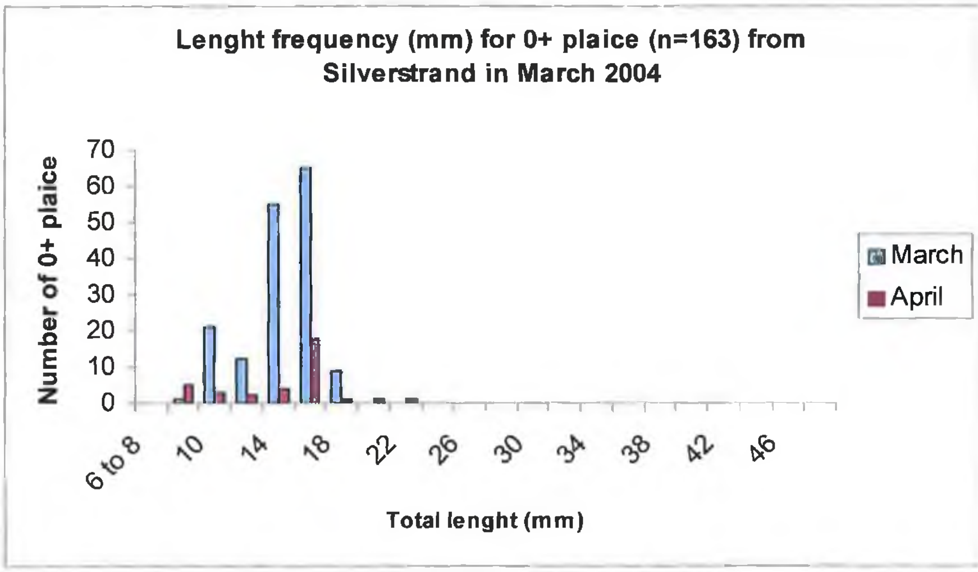
Length frequencies of 0-group plaice for 2004, Ballyloughan and Silverstrand from March to May, can be seen in figures 2.12 and 2.13.

Figure 2.12: Length frequency (mm) for 0-group plaice from Ballyloughan in March (n=98), April (n=97) and May (n=46) 2004



In March (Figure 2.12), the modal size for Ballyloughan was 15mm with a range from 10 to 21mm. The modal size in April was 19mm with a range of 12 to 23mm. In May, the modal size was 25mm with a range from 14 to 46mm. In all months, newly settling fish can be seen ($\leq$ 15mm). There is only one settling fish in May, however, and growth can be seen in all months from March onwards.

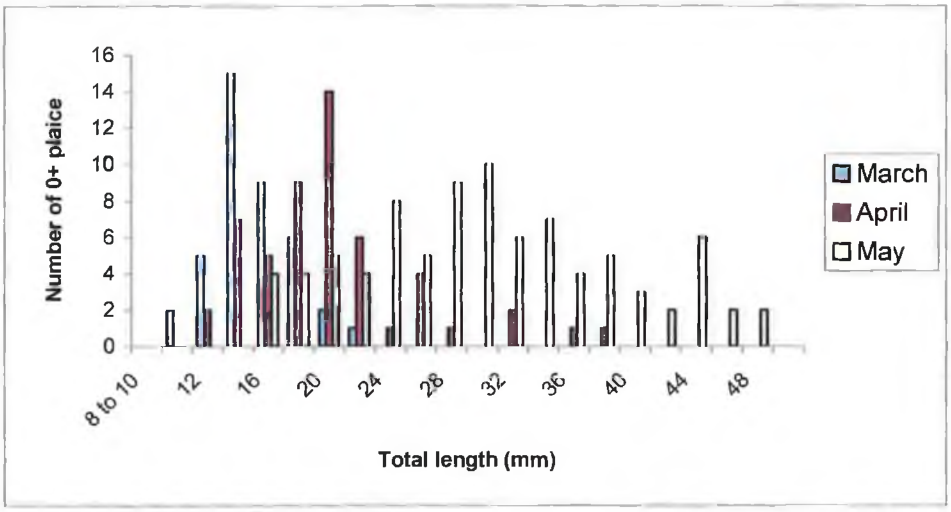
Figure 2.13: Length frequency (mm) for 0-group plaice from Silverstrand in March (n=163) and April (n=38) 2004.



The modal size for Silverstrand in March (Figure 2.13) and April was 17mm. The range in March was from 8 to 19mm and the range in April was from 8 to 23mm. May was not tabulated as to few fish were caught. The modal range for Silverstrand is larger than Ballyloughan in March and smaller than in April. The 8mm fish observed are larval fish with metamorphosis not fully completed.

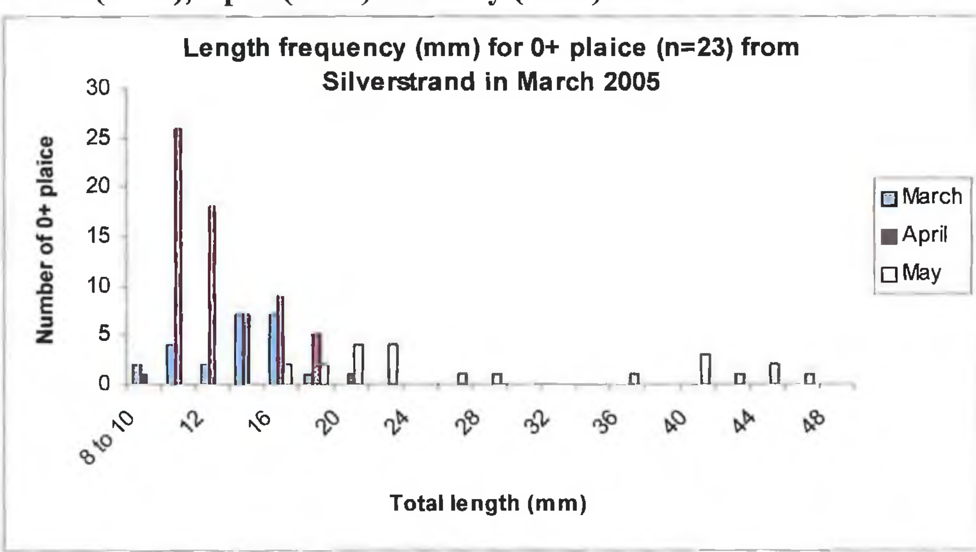
Length frequencies of 0-group plaice for 2005, Ballyloughan and Silverstrand from March to May, can be seen in figures 2.14 and 2.15. Length frequencies of 0-group plaice for Glann na Ri, April and May, in 2005 can be seen in Figures 2.16.

Figure 2.14: Length frequency (mm) for 0-group plaice from Ballyloughan in March (n=40), April (n=53) and May (n=86) 2005.



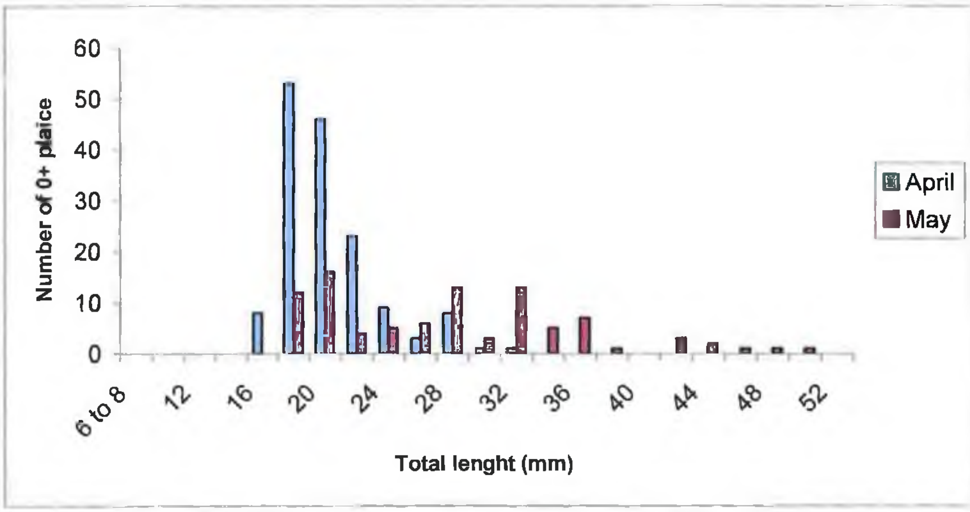
In March (Figure 2.14), the modal size for Ballyloughan was 15mm with a range from 10 to 23mm. The modal size in April was 21mm with a range of 12 to 39mm. In May, the modal size was 31mm with a range from 16 to 49mm. In all months, newly settling fish can be seen ($\leq$ 15mm). There is only one newly settled fish in May, however, and growth can be seen in all months from March onwards.

Figure 2.15: Length frequency (mm) for 0-group plaice from Silverstrand in March (n=23), April (n=67) and May (n=22) 2005.



The modal size for Silverstrand in March (Figure 2.15) was from 15 – 17mm. The range in March was from 8 to 19mm. The modal size for Silverstrand in April was 11mm and the range was from 8 to 21mm. May had a modal value from 21 - 23mm and a range from 16 to 47mm. Newly settled fish could be seen in all months and growth can also be seen in April and May.

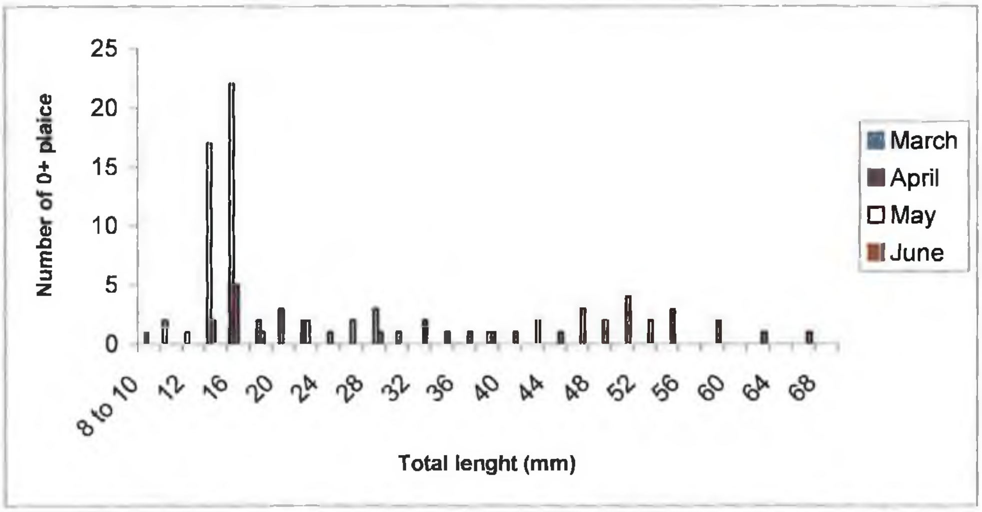
Figure 2.16: Length frequency (mm) for 0-group plaice from Glann na Ri in April (n=152) and May (n=94) 2005.



The modal size for Glann na Ri in April (Figure 2.16) was from 19mm with a range from 16 to 33mm. This was the first year that Glann na Ri was sampled. The modal size for Glann na Ri in May was 19mm and the range was from 16 to 55mm. Growth can be seen in May and newly settled fish can be seen in both April and May.

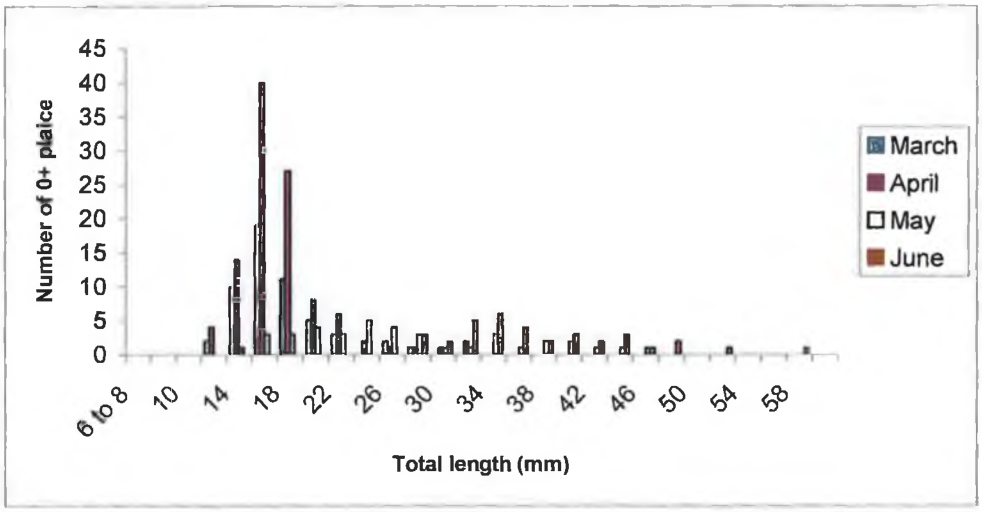
Length frequencies of 0-group plaice for 2006, Ballyloughan, Silverstrand and Glann na Ri from March to May, can be seen in figures 2.17 to 2.19.

Figure 2.18: Length frequency (mm) for 0-group plaice from Silverstrand in March (n=42), April (n=14), May (n=11) and June (n=28) 2006.



In March (Figure 2.18), the modal size for Silverstrand was 17mm with a range from 14 to 21mm. The modal size in April was 17mm with a range of 8 to 24mm. In May, the modal value was 29mm. The range was from 18 to 39 mm. June 2006 had sufficient numbers of 0-group plaice present to construct length frequency graphs. In June, a modal value of 51mm was seen and the range was from 28 to 68mm. In March, April and May newly settling fish can be seen ($\leq$15mm). No newly settled fish could be seen in May and June. Growth can be seen in months from March onwards

Figure 2.19: Length frequency (mm) for 0-group plaice from Glann na Ri in March (n=53), April (n=106), May (n=39) and June (n=35) 2006.



In March (Figure 2.19), the modal size for Glann na Ri was 17mm with a range from 12 to 29mm. The modal size in April was 17mm with a range of 12 to 33mm. In May, the modal value was 25mm. The range was from 14 to 48mm. June 2006 had sufficient numbers of 0-group plaice present to construct length frequency graphs. In June, a modal value of 35mm was seen and the range was from 28 to 68mm. In March, April and May newly settling fish can be seen ($\leq$ 15mm). No newly settled fish could be seen in June. Growth can be seen in all months from March onwards.

In summary, newly settling fish can be seen in the month of March on all beaches sampled from 2004 to 2006. Settling fish can be seen on every beach until May. Growth can be seen in all months from March onwards with fish being considerably bigger in May and June. A summary of all results can be seen in table 2.8.

Table 2.8: Range in total lengths of 0-group plaice and Modal length from length frequency graphs from Ballyloughan (BN) and Silverstrand (SS) from 2004 to 2006. Table also shows results from Glann na Ri (GNR) from 2005 to 2006.

Location Code and year	Month	Range of total length of 0-group plaice (mm)	Modal size (mm)
BN 2004	March	10 – 12	15
BN 2004	April	12 – 23	19
BN 2004	May	14 – 45	25
SS 2004	March	8 – 19	17
SS 2004	April	8 - 23	17
BN 2005	March	10 – 23	15
BN 2005	April	12 – 39	21
BN 2005	May	16 – 49	31
SS 2005	March	8 – 19	15 – 17
SS 2005	April	8 – 21	11
SS 2005	May	16 - 47	21 – 23
GNR 2005	April	16 – 33	19
GNR 2005	May	16 - 55	19
BN 2006	March	14 – 21	17
BN 2006	April	10 – 39	19
BN 2006	May	18 – 50	21 and 29
BN 2006	June	24 – 58	39
SS 2006	March	10 – 18	17
SS 2006	April	8 – 24	17
SS 2006	May	18 – 39	25
SS 2006	June	28 – 67	35
GNR 2006	March	12 – 30	17
GNR 2006	April	12 – 34	17
GNR 2006	May	14 – 48	25
GNR 2006	June	28 - 60	35

2.4.7 Growth

Observed growth rates, which was taken as the increase in mean total length per month, were compared to predicted growth rates using a simple descriptive growth model obtained under excess feeding conditions for especially small plaice (Glazenburg 1983 in Van der Veer 1986). Average observed daily growth rates in Galway Bay area from 2004 to 2006 were approximately 0.2 $mm.d^{-1}$. Observed growth rates were found to be smaller than predicted growth rates (Figures 2.20 to 2.22). Only in the month of March, in the years sampled, was the observed 0-group plaice size approximately the same size as predicted. After March in each year from 2004 to 2006, observed growth was considerably smaller than predicted.

Daily growth rates (Table 2.9) on Ballyloughan from 2004 to 2006 were relatively constant with an average daily growth rate from March to May in 2004 of 0.21mm d^{-1}. In 2005 and 2006, the average daily growth rate from March to June were 0.27 and 0.25mm d^{-1} respectively. On Silverstrand, during the same time frame, the average daily growth rate was 0.19, 0.24 and 0.47mm d^{-1} from 2004 to 2006 respectively. On Glann na Ri, the average growth rate from April to May in 2005 was 0. 23mm d^{-1} and in 2006 the average growth rate from March to June was 0.26mm d^{-1}.

Overall, the three beaches were quite similar in growth patterns to one another with the exception of 2006 when Silverstrand showed a mean length approximately 14 mm larger than Ballyloughan and a daily growth rate approximately twice that observed on either Ballyloughan or Glann na Ri. Glann na Ri showed a pattern comparable to Ballyloughan.

Table 2.9: Mean monthly temperature °C for Galway Bay from the M1 data buoy, Daily observed growth rates for Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR)(mm.d^{-1}) and predicted daily growth rates (Glazenburg 1983 in Van der Veer 1986) (mm.d^{-1}) for 0-group plaice in Galway Bay, from 2004 to 2006. N/A means not applicable.

Year	Month	Mean Monthly Temp. °C	Observed daily growth (mm.d^{-1}) on BN	Observed daily growth (mm.d^{-1}) on SS	Observed daily growth (mm.d^{-1}) on GNR	Predicted Daily growth (mm.d^{-1})
2004	March	10.6	N/A	N/A	N/A	0.51
	April	10.8	0.19	0.14	N/A	0.52
	May	11.9	0.24	0.24	N/A	0.57
2005	March	10	N/A	N/A	N/A	0.49
	April	10.8	0.15	0.06	N/A	0.52
	May	11.7	0.28	0.1	0.09	0.56
	June	13.7	0.39	0.57	0.23	0.65
2006	March	10	N/A	N/A	N/A	0.49
	April	10.4	0.14	0.08	0.1	0.50
	May	11.2	0.27	0.58	0.17	0.54
	June	13.9	0.34	0.71	0.51	0.65

Figure 2.20 Observed growth (mean total length (mm) ± S.D) compared to a predicted growth (Glazenburg 1983 in Van der Veer 1986) for 0-group plaice from Ballyloughan in 2004 (March to May), 2005 (March to June) and 2006 (March to June).

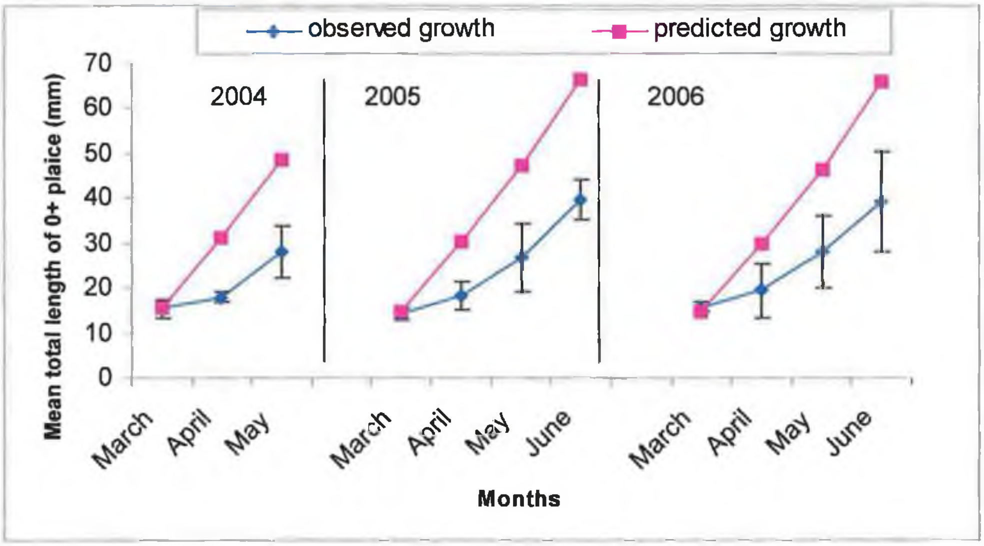


Figure 2.21 Observed growth (mean total length (mm) ± S.D) compared to a predicted growth (Glazenburg 1983 in Van der Veer 1986) for 0-group plaice from Silverstrand in 2004 (March to May), 2005 (March to June) and 2006 (March to June).

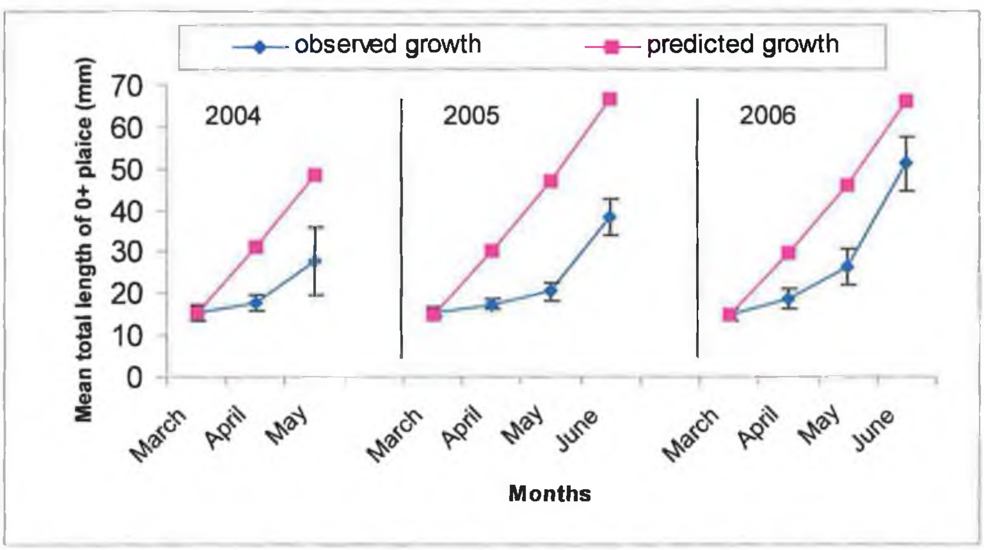
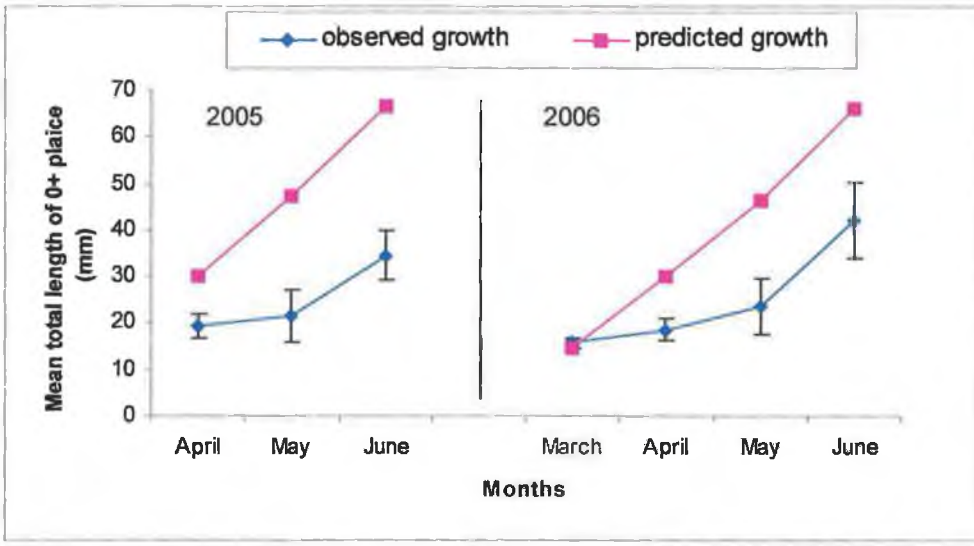


Figure 2.22 Observed growth (mean total length (mm) ± S.D) compared to a predicted growth (Glazenburg 1983 in Van der Veer 1986) for 0-group plaice from Glann na Ri in 2005 (April to June) and 2006 (March to June).



2.5 Discussion

2.5.1 Settlement timing

The present study recorded newly settled fish in March of every year from 2004 to 2006 on Ballyloughan and Silverstrand. One 0-group plaice was caught on Silverstrand at the end of February 2005 and this was the earliest observed newly settled plaice from this area. Allen (2004) found newly settled plaice in Galway Bay in April 2002 and a month earlier in March 2003. Newly settling plaice were observed in March 2006 on Glann na Ri beach. From the work carried out in the Galway Bay area it is clear that settlement of 0-group plaice generally begins in early to late March and ends in May. A summary of these results and results for other European waters can be seen in table 2.10.

Hyder and Nash (1998) found that settlement in the Irish Sea varied from early April on a cold year to late March on a warmer year. Geffen (2005) stated that settlement period in the eastern Irish Sea is relatively consistent between years with settlement starting around the beginning of April and ending around mid June. However, settlement seemed to start earlier in the most southern area and the duration of settlement was longer. Mansoor (1982) found that, on the Irish east coast, settlement started in March.

In Loch Ewe on the coast of Scotland, newly settling 0-group plaice were found in the month of April, every year, from 1965 to 1968 (Steele and Edwards 1970). In the Clyde Sea area of Scotland, settling plaice were caught in April 1973 but not till May in 1972 and 1974 (Poxton 1982).

0-group plaice were observed settling on sandy beach nursery grounds from mid-March to early June in northern France in 2000 (Amara and Paul 2003). Zijlstr *et al.* (1982) stated that settlement of 0-group plaice in the Wadden Sea generally took place in April and May and occasionally in March from 1973 to 1978. Kuipers (1977) also found settlement started in April in 1973 in the Wadden Sea. Van der Veer

(1986) found, in the same area, that settlement mostly started in late February to March from 1980 to 1982.

Pihl and Rosenburg (1982) found that first settlement of 0-group plaice occurred in April from 1977 to 1980 in various shallow water sites sampled from the Western Swedish coast. Modine and Pihl (1996) found settling plaice in mid-May 1991 and late April 1992 on the coast of Sweden. Wennhage and Pihl (2001) found that settlement of 0-group plaice varied between years and between locations in Gullmarsfjord from 1994 to 1998. Generally, settlement commenced in April and very high settlement was noted in 1998. In Icelandic waters Hjorleifsson and Palson (2001) found settlement of metamorphosing 0-group plaice, in small numbers, from May 1999.

In overview, first settlement in Galway Bay corresponds to first settlement in other areas but is at the earlier end of the scale with a majority of areas showing the start of settlement in early April. The beaches in Galway Bay show relative constant patterns for first settlement of 0-group plaice, except for 2002, however, in other areas it is not uncommon to see variation in the timing of settlement between years (Table 2.10).

Table 2.10: Settlement timing of 0-group plaice in European waters (including findings of present study).

Location	Settlement timing	Years	Reference
Galway Bay	Generally early March, April (2002)	2002 to 2006	Allen (2004), Present study
Irish Sea	Late March to early April	1963 to 1996	Hyder and Nash (1998)
Irish east coast	March	1981	Mansoor (1982)
Lough Ewe, Scotland.	April	1965 to 1968	Steele and Edwards (1970)
Clyde Sea	Generally May, occasionally April	1972 to 1974	Poxton (1977)
North French coast	Mid-March to early June	2000	Amara and Paul (2003)
Wadden Sea	Generally April or May, occasionally March.	1973 to 1978	Zijlstr *et al.* (1982)
Wadden Sea	April	1973	Kuipers (1977)
Wadden Sea	Late February to March	1980 to 1982	Van der Veer (1986)
Sweden	April	1977 to 1980	Pihl and Rosenburg (1982)
Sweden	Later April and early May	1991 and 1992	Modin and Pihl (1996)
Sweden	Generally April	1994 to 1998	Wennhage and Pihl (2001)
Iceland	May	1999	Hjorleifsson and Palson (2001)

2.5.2 Peak densities and mean monthly densities

Peak densities in Galway Bay varied from year to year and from beach to beach. On Ballyloughan peak densities varied from the month of March in 2004 (900 $1000m^{-2}$) to June in 2002 and 2006 (44 $1000m^{-2}$ and 146 $1000m^{-2}$ respectively). Silverstrand also showed peaks in abundance of 0-group plaice ranging from the month of March in 2004 (553 $1000m^{-2}$) to May in 2002 and 2005 (260 $1000m^{-2}$ and 31 $1000m^{-2}$ respectively). Glann na Ri was sampled for the first time in April 2005 and this sampling proved to be the peak in 0-group plaice numbers for 2005 (380 $1000m^{-2}$), however, the peak could already have passed. In 2006, peak density of 0-group plaice occurred again in April (290 $1000m^{-2}$). Interannual variability in peak numbers is common in plaice and has been seen in many European waters, including the Irish Sea (Nash and Geffen 2000), the Wadden Sea (Bergman *et al.* 1988, Van der Veer *et al.* 1990), and the Swedish coast (Modine and Pihl 1994). See table 2.11 for details.

Peak densities of 0-group plaice, in Galway Bay, were found to be significantly different between 2002 and 2006. No significant spatial difference was noted over the five-year study for peak densities. It must be noted that not every year had the same sampling effort therefore other peaks may have been missed, but since the most important months of settlement were analysed every year this is unlikely. Tests revealed 2002 as a low settlement, hence recruitment, year and 2004 was found to be a high settlement year. Densities in March 2004 were approximately 3.5 times greater than years of more normal settlement. This scale in difference of abundances between years has been noted in other European waters (Steele and Edwards 1970, Nash and Geffen 1999).

Mean monthly densities of 0-group plaice for Ballyloughan and Silverstrand were analysed using abundance data from 2002 to 2006. Significant differences in the abundances of 0-group plaice were noted in the month of March over the five years study. Results also revealed that March was the month of most variation in the abundances of 0-group plaice between years. This would probably be expected, as this is the month when initially fish start to settle, and any variation in larval numbers will be noticed. Density dependant factors, for example predation or competition for food, probably reduce numbers significantly in this first settlement month. These results showed a similar pattern of annual variability seen in the peak density data. Again 2002 was shown to be a low recruitment year (i.e numbers of fish per haul were in single figures or less) and 2004 was a high recruitment year (i.e numbers of fish per haul ranged from double figures up to hundreds). The months of March to May were also studied for the five-year data set, however, significant interactions amongst the main factors made interpretation of results unreliable. These interactions, however, indicate smaller scale temporal and spatial differences. Graphical representation of the data revealed that in most years the abundances on Ballyloughan and Silverstrand were similar by the month of May. Other studies have shown that in years of high settlement numbers of 0-group plaice decrease, due to mortality, down to numbers similar to more normal years by the end of the summer period (Steele and Edwards 1970, Nash and Geffen 2000). A third beach was added in April 2005. This beach added more spatial scale to the survey and made a stronger data set for Galway Bay. Two samplings per month were carried out in 2005 and 2006. Results revealed that there was no significant difference in the abundances of 0-group plaice between the three beaches sampled in April or May in 2005. Results for the three beaches in 2006 show a significant interaction between beaches and months so no interpretation of the main hypothesis could be made. Tests revealed that there was a significant difference in the abundances of 0-group plaice between the first and second samplings per month in March and April in 2005 on Ballyloughan and Silverstrand. This revealed temporal differences in abundances on a monthly scale. The results gained from these tests are important as it helps confirm that larval processes in Galway Bay seem to be generally consistent with no significant difference in abundances between areas on the spatial scale sampled. Processes at work on each beach, for example predation, appear to be similar.

From all of the above results, it is possible to discern a pattern of recruitment of 0-group plaice to sandy beach nursery grounds in Galway Bay. Temporal differences in the abundances of 0-group plaice can be seen both in peak densities and in the initial settlement month of March. Yearly variation in the abundances of 0-group plaice are generally dampened by the month of May. In general Ballyloughan and Silverstrand show similar patterns in abundances of 0-group plaice from February to June. Glann na Ri, in the period sampled, has also shown a similar pattern in abundances with the other beaches. Research in other areas of Europe has shown variances in both timing and abundances of 0-group plaice. A summary of densities and results for other European waters can be seen in Table 2.11.

Table 2.11: Peak density ranges for of 0-group plaice 1000m^{-2} in European waters (including findings of the present study).

Location	Years	Months	Peak Density 1000m^{-2}	Gear used	References
Galway Bay	2002 to 2006	February to June (most years)	31 to 900	Riley push-net	Allen (2004), Present study
Cork	1976, 1978 and 1979	June	3 to 63	Beach seine	Markham (1981)
Irish Sea	1992 to 1996	April to October	400 to 3000	Beam trawl	Nash and Geffen (2000)
Lough Ewe, Scotland	1965 to 1968	April to November	30 to 170	Beam Trawl	Steele and Edwards (1970)
Yorkshire	1968 to 1973	Summer Autumn	23 to 1172	Beam trawl	Lockwood (1980)
North French coast	1998	May to July	15 to 36	Beam trawl	Amara *et al.* (2001)
North French coast	2000	April	400 to 5300	Beam trawl	Amara and Paul (2003)
North French coast	1998 to 1999	May to October	8 to 28	Beam trawl	Amara (2003)
Wadden Sea	1973	March to October	10 to 109	Beam trawl	Kuipers (1977)
Wadden Sea	1973 to 1979	April to October	11 to 475	Beam trawl	Zijlstra *et al.* (1982)
Wadden Sea	1982	July	22 to 298	Beam trawl	Berghahn (1986)
Wadden Sea	1980 1982	February to July	150 to 350	Beam trawl	Van der Veer (1986)
Wadden Sea	1993 to 1999	April to October	250 to 1250	Beam trawl	Van der Veer (2000)
Wadden Sea	1992	April to November	2 to 45	Beam trawl	Jager *et al.* (1993)
Sweden	1977 to 1980	April to August	300 to 2400	Drop trap	Pihl and Rosenberg (1982)
Sweden	1977 to 1990	June	50 to 3400	Drop trap	Pihl and Van der Veer (1992)
Sweden	1991 and 1992	April to August	80 to 10 000	Drop trap	Modin and Pihl (1996)
Sweden	1994 to 1998	April to June	200 to 13 500	Drop trap	Wennhage and Pihl (2001)
Iceland	1999	May to October	100	Beam trawl	Hjorleifsson and Palsson (2001)

0-group plaice were sampled on Sherkin Island, Co. Cork, in late June only, in 1976, 1978 and 1979 using a beach seine (Markham 1981). Abundances of plaice varied between areas sampled ranging from 3 $1000m^{-2}$ to 63 $1000m^{-2}$. Nash and Geffen (2000) recorded a range of peak densities for 0-group plaice in the Irish Sea ranging from 400 $1000m^{-2}$ in 1993 to 3000 $1000m^{-2}$ in 1996. Nash and Geffen (2000) stated that in years of extremely high settlement, 1992 and 1996, density-dependant processes regulated numbers such that by July numbers of 0-group plaice were similar to years of normal settlement. Numbers of 0-group plaice decreased steadily on the nursery grounds until October.

In Scottish waters, peak densities of 0-group plaice ranged from approximately 30 $1000m^{-2}$ (1968) to 170 $1000m^{-2}$ (1965) (Steele and Edwards 1970). After peaks were observed abundances decreased down to approximately 10 $1000m^{-2}$ in October of every year sampled. 1965 was a year of high densities and the peak in this year was approximately 2.5 times greater than peaks in more normal settlement years. By July, 1965 abundances of 0-group plaice were similar to years of normal settlement suggesting density-dependant mortality (Steel and Edwards 1970). See Table 2.11 for details.

Lockwood (1980) described peak densities of 0-group plaice, caught in a beam trawl, from Filey Bay, Yorkshire from 1968 to 1973. Peak densities ranged from a low of 23 $1000m^{-2}$ in 1968 to 1172 $1000m^{-2}$ in 1969 and usually occurred in the month of July. Densities decreased steadily from July to October.

Amara *et al.* (2001) described densities of 0-group plaice for the northern French coast from May to July 1998. Sampling was carried out using beam trawl. Densities of 0-group plaice ranged from 36 $1000m^{-2}$ in May to 15 $1000m^{-2}$ in July Also on the French coast peak densities of 5300 $1000m^{-2}$ to 400 $1000m^{-2}$, depending on the area sampled, were recorded for 0-group plaice using a beam trawl in April 2000 (Amara and Paul 2003). Amara (2003) described densities of juvenile plaice $1000m^{-2}$ captured per season, using a beam trawl, on the northern French coast between May 1998 and May 1999. Spring densities of 0-group plaice were calculated at 8 $1000m^{-2}$, summer densities were 28 $1000m^{-2}$ and autumn densities were 8 $1000m^{-2}$. See table 2.11 for details.

In a study on 0-group plaice carried out, using a beam trawl, in Icelandic waters (Hjorleifsson and Palsson 2001) from May to October 1999, peak densities were recorded at 100 $1000m^{-2}$ at the end of June. Densities decreased steadily until the end of August when they were less than 20 $1000m^{-2}$.

Extensive work has been carried out on juvenile and 0-group plaice populations in the Wadden Sea. Kuipers (1977) described 0-group plaice densities, caught by beam trawl, in the Balgzand region of the Wadden Sea, in numbers $1000m^{-2}$, from mid-March to the end of October 1973. Densities ranged from 11 $1000m^{-2}$ in April to a peak of 499 $1000m^{-2}$ in May with another peak noted in August. After August numbers steadily decreased to the end of October.

Research was carried out in the Balgzand region of the Wadden Sea from 1973 to 1979 (Zijlstra *et al.* 1982). This survey was carried out using beam trawl to study the settlement, growth and mortality of post-larval plaice. Peak densities ranged from 11 to 475 $1000m^{-2}$. In 1974 densities of plaice $1000m^{-2}$ were calculated as 11 $1000m^{-2}$ in April, which was also the peak density, steadily decreasing down to 0.4 $1000m^{-2}$ in October. There was also a second peak in numbers of 0-group plaice in July.

Berghahn (1986) carried out research on tidal flats in the north Friesian Wadden Sea in 1981 and 1982 using a beam trawl and fyke nets. 0-group plaice densities were calculated at population level for the whole area sampled, however densities per $1000m^{-2}$ were calculated for July 1982. Densities of 0-group plaice $1000m^{-2}$ ranged on the tidal flat from 22 to 298 individuals.

Van der Veer (1986) reported peak densities of 0-group plaice from the Wadden sea of 150, 300 and 350 $1000m^{-2}$ from 1980 to 1982 respectively. Peaks occurred in April 1980 and in May in the preceding years. This survey was carried out using plankton nets and a beam trawl. Van der Veer (2000) reported densities of 0-group plaice in the Wadden Sea from 1993 to 1999. An exceptionally strong year class was noted in April 1996 with a peak density of 1250 $1000m^{-2}$. In the other years studied peak densities ranged from approximately 250 to 450 $1000m^{-2}$. See Table 2.11 for details.

A study was carried out on the distribution of 0-group flatfish, including plaice, in relation to abiotic factors in the Ems estuary, Wadden Sea, in 1992 (Jager *et al.* 1993). Sampling was carried out from April to November using beam trawl. Peak numbers of 0-group plaice were observed at the end of April at a density of 45 $1000m^{-2}$. Numbers decreased steadily to a density of approximately 2 $1000m^{-2}$ in October.

Gullmarsfjord is situated in western Sweden and this area was used in a study of the abundances and production of epibenthic marine fauna, including plaice, from 1977 to 1980 (Pihl and Rosenberg 1982). Sampling was carried out using drop traps. Maximum average densities were calculated for every year sampled and these ranged from 600 0-group plaice $1000m^{-2}$ in 1977 to 2400 $1000m^{-2}$ in 1979. The lowest maximum average density recorded was in 1980 with a density of 300 $1000m^{-2}$. These numbers are quite high and it was thought that this could be related to the relatively small area on offer to settling 0-group plaice and the efficiency of the sampling method (Pihl and Rosenberg 1982). See Table 2.11 for details.

Exposure and habitat structure were examined in relation to 0-group plaice densities in coastal nursery areas in Sweden (Pihl and Van der Veer 1992). Data on 0-group plaice densities from 1977 to 1990 were analysed in exposed, semi-exposed and protected nursery grounds. All sampling was carried out using drop traps in June of each year. Highest densities were recorded in semi-exposed areas with a range from 100 to 3400 0-group plaice $1000m^{-2}$. In protected areas the range was from 50 to 250 0-group plaice $1000m^{-2}$ and in exposed areas the range was from 200 to 1000 $1000m^{-2}$.

In 1991 and 1992 the distribution of juvenile plaice and flounder *Platichthys flesus* were compared in relation to predatory shrimps in a shallow Swedish bay (Modin and Pihl 1996). Sampling was carried out from April to August in both years using drop traps. In 1991, densities of 0-group plaice ranged from 80 $1000m^{-2}$ in April to a peak of 1090 $1000m^{-2}$ in June. Numbers of plaice steadily decreased thereafter until sampling stopped in August. In 1992 initial densities in April were 1830 $1000m^{-2}$

increasing to 10000 $1000m^{-2}$ in May. Densities slowly decreased from May to August, were at final sampling densities of 0-group plaice were 1060 $1000m^{-2}$. See table 2.11 for details.

Also in Sweden, settlement patterns of newly settling plaice were examined from 1994 to 1998 using plankton sampling and drop traps (Wennhage and Pihl 2001). Densities were found to vary by a factor of ten, both among years and among nursery grounds. Sampling was carried out from April to the end of settlement, June, each year. Densities ranged from approximately 200 $1000m^{-2}$ to a peak, in 1998, of 13 500 $1000m^{-2}$.

Wennhage *et al.* (2006) reviews various works carried out on the Swedish coast in respect to distribution and quality of plaice nursery grounds. Densities of 0-group plaice were found to vary between locations and years. Density ranged, in September, from 100 to 2000 $1000m^{-2}$ over seven areas sampled. Densities of newly settling fish in May ranged from 500 to 6750 $1000m^{-2}$.

From the above examples of studies carried out in European waters on 0-group plaice it is obvious that densities can vary greatly both between years and between locations (see Table 2.11 for details). Peaks in densities of 0-group plaice have been shown to differ greatly from years of normal settlement to years of high settlement. In the Irish Sea densities of 0-group plaice in years of high settlement have been 3.5 times greater than years of normal settlement (Nash and Geffen 1999). In Scottish waters the difference in densities between years of high settlement and years of normal settlement have been 2.5 times greater (Steele and Edwards 1970) whereas in Swedish waters the difference has been ten fold (Wennhage and Pihl 2001). In Galway Bay from 2002 to 2006 the densities in a year of high settlement (2004) were approximately 3.5 times greater than in other years.

In this respect Galway Bay shows patterns of yearly variation in plaice densities, which are comparable to other studies. General densities in Galway Bay are comparable to densities observed in the Irish Sea, North Sea and Icelandic waters. Densities of 0-group plaice in Sweden, however, are higher than most other areas in Europe and this is thought to relate to the small number of suitable nursery grounds and probably the efficiency of the sampling method (drop trap) (Pihl and Rosenberg 1982). A summary of the above mentioned works can be seen in table 2.11.

2.5.3 Growth.

The study of fish size, e.g. length, and growth of larval or juvenile fish is important in respect to recruitment. A larval or juvenile fish that is comparatively smaller, possibly as a result of slower growth, is believed to be at a disadvantage with respect to both its ability to evade predators and forage effectively, and to have a reduced probability of recruiting to the adult population (Power *et al.* 2006). Juvenile plaice exhibit seasonal growth patterns with rapid growth during late spring and summer, a growth arrest during autumn and winter and a restart of growth in March (start of their second year) (Amara 2003).

0-group plaice in Galway Bay had a size range from 8 to 68 mm in total length, from March to June, from 2004 to 2006. Length data from a previous study in 2002 and 2003 (Allen 2004) allowed the analysis of a unique five-year data set. Significant differences were noted in the lengths of 0-group plaice between years and months from 2002 to 2006, regardless of the sample size used. These differences could be attributed to fish settling later in some years, for example in 2002 fish did not settle until April. Another factor could be increased growth rates in some years compared to others. No significant difference was noted in lengths of 0-group plaice between beaches from 2002 to 2006 on Ballyloughan or Silverstrand. The addition of a third beach in 2005 (Glann na Ri) allowed further spatial scale to this study. There was still no difference noted in the size of 0-group plaice between beaches, when a third beach was added.

All of the above findings reveal that even though there can be a difference in the lengths of 0-group plaice between years there is no difference between beaches. This shows that larval supply to both beaches appears to be similar and for 2006 this applied across three beaches. Extensive work has been carried out on plaice in European waters and a vital part of this work includes examinations on length and growth. A summary of length and growth in European waters can be seen in Table 2.12. It should be noted that a majority of studies are carried out in late summer or autumn, and these projects are therefore studying fish that are generally older than fish sampled in Galway Bay.

Observed growth rates in Galway Bay were smaller than predicted growth rates using a simple descriptive growth model obtained under excess feeding conditions for especially small plaice (Glazenburg 1983 in Van der Veer 1986). Only in the month of March, in the years sampled, was the observed 0-group plaice size approximately the same size as predicted. After March in each year from 2004 to 2006, observed growth was considerably smaller than predicted. Since water temperatures in the Galway Bay area are high in comparison to other areas in European waters (Allen 2004) this means that temperature is not restricting growth. Therefore factors limiting growth in Galway Bay are likely to be food related. Allen (2004) found that observed growth was very similar to predicted growth and on occasions observed growth was greater than predicted. This was summer growth however, May to August, using a different growth equation (Fonds *et al.* 1992). It should be noted that larger 0-group plaice were observed escaping from the push-net, in small numbers, from mid-May onwards in 2005 and 2006 and this would reduce growth estimates.

Average daily growth rates for Galway Bay were 0.2mm d^{-1} from March to June from 2004 to 2006. Growth rates were relatively similar on the three beaches, in 2005 and 2006, with the exception of Silverstrand in 2006, which showed higher growth rates. This suggests that conditions on Silverstrand were better for growth in 2006, which also suggests better feeding conditions. Also the average observed growth rate on Silverstrand in 2006 was closer to the predicted average daily growth rate, 0.54mm.d^{-1}, than any other time from 2004 to 2006.

Overall daily growth rates are in the same range as seen in the Isle of Man (Nash *et al.* 1994) and Scotland (Steele and Edwards 1970), but are smaller than observed in France (Amara 2003), Sweden (Wennhage *et al.* 2006) and Iceland (Hjorleifsson and Palsson 2001). A summary of length frequency ranges and daily growth rates for the present study and other European waters can be seen in Table 2.12.

Table 2.12: Length ranges (mm) and daily growth rates ($mm.d^{-1}$) for 0-group plaice in European waters (including findings of the present study). N/S Means not stated.

Location	Years	Months	Length range (mm)	Growth ($mm.d^{-1}$)	Reference
Galway Bay	2002 to 206	February to June	8 to 68	0.2 average in spring and early summer	Allen (2004), Present study
Cork	1976, 1978-1979	Late June	64.6 to 68	N/S	Markham (1981)
Strangford Lough	1963 and 1964	August	44.4 to 64.8	N/S	Corlett (1967)
Irish Sea	1988 to 1992	July	40 to 50	N/S	Nash *et al.* (1994)
Lough Ewe, Scotland	1965 to 1968	April to November	15 to 70	0.16 – 0.47 in June, 0.23 – 0.45 in Sept.	Steele and Edwards (1970)
Clyde Sea	1973 and 1974	August	33 to 103	N/S	Poxton *et al.* (1982)
Argyle	1976	September	125	N/S	Joblin (1982)
North French coast	1998	May to July	32 to 70	0.55 in May 0.81 in July	Amara *et al.* (1998)
North French coast	1998 and 1999	Spring and Summer	N/S	0.64 in spring 0.59 - summer	Amara (2003)
North French coast	1997	May to July	40.2 to 56.6	N/S	Harlay *et al.* (2001)
Belgium	1996	June to October	28 to 59	N/S	Beyst *et al.* (1999)
Wadden Sea	1991	July and August	62.5 July 72.5 August	N/S	Berghahn *et al.* (1995)
Jutland	1957	May and June	13 to 42	N/S	
Wadden Sea	1973	April to October	14 to 90	N/S	Kuipers (1977)
Wadden Sea	1973 to 1970	July to September	30 July 85 August	N/S	Zijlstra *et al.* (1982)
Wadden Sea	1980 to 1982	April to July	9 to 16 April 50 to 60 July	N/S	Van der Veer (1986)
Sweden	1991 and 1992	April to August	12 to 16 April 35 to 55 Aug.	N/S	Modin and Pihl (1996)
Sweden	1998	April to June	12 to 20 April 20 to 44 June	N/S	Wennhage and Pihl (2001)
Sweden	1970s to 2000 (Review)	May to September	N/S	0.5	Wennhage *et al.* (2006)
Iceland	1999	May to August	9 to 14 May 15 to 25 June	0.6 in July	Hjorleifsson and Palsson (2001)

In overview length ranges for 0-group plaice in Galway Bay are comparable to other European Waters (see Table 2.12 for details). Growth rates for Galway Bay are comparable to findings in the Isle of Man and Scotland but are smaller than growth rates observed in France, Sweden and Iceland. See table 2.12 for further details.

2.5.4 Conclusions:

The present study contributes to the knowledge of 0-group plaice population dynamics and recruitment in Galway Bay, on the west coast of Ireland. Results on abundances of 0-group plaice reveal differences and variations in peak abundances, which have also been noted for this species in other European waters. In general Ballyloughan and Silverstrand show similar patterns in abundances in 0-group plaice from February to June. Glann na Ri, in the period sampled, has also shown a similar pattern in abundances with the other beaches. Settlement timing and duration for Galway Bay was found to be similar to the Wadden Sea, but slightly earlier than the Irish Sea and Swedish waters.

A significant difference was noted in abundances of 0-group plaice, in the main settlement months of March between 2002 and 2006. Results revealed 2002 as a low recruitment year and 2004 as a high recruitment year. Peaks in abundances of 0-group plaice were significantly different between years, again indicating 2002 as a low settlement, hence recruitment, year and that 2004 was a high recruitment year. Temporal variability was also observed in peak density timing. Research in other areas of Europe has also shown variances in both timing and abundances of 0-group plaice. Results showed that in a year of high settlement (2004) abundances returned to normal levels by summer, as observed in other studies (Steele and Edwards 1970, Nash and Geffen 2000). This suggests density- dependant mortality factors at work, for example predation.

The length range for 0-group plaice in Galway Bay was found to be similar to other European waters. Overall, daily growth rates are in the same range as seen in the Isle of Man (Nash *et al.* 1994) and Scotland (Steele and Edwards 1970), but are smaller than observed in France (Amara 2003), Sweden (Wennhage *et al.* 2006) and

Iceland (Hjorleifsson and Palsson 2001). A difference in growth rates was observed between beaches in Galway Bay in 2006 and this may have been related to better feeding conditions. Tests for significant difference revealed that lengths of 0-group plaice could vary between years and between months. However no significant difference in the lengths of 0-group plaice was found between beaches and this reveals that larval on shore processes to all beaches sampled were similar regardless of yearly variation.

Chapter 3. Effects of Diel and Semi-lunar cycles on the catches of 0-group plaice in Galway Bay, on the West coast of Ireland.

3.1 Abstract

Experimental push- netting was carried out in Galway Bay in 2005 and 2006 to test the hypotheses that there was no difference in the catches of 0-group plaice between daytime and nighttime. Day and night sampling was carried out on two beaches (Ballyloughan and Silverstrand) in Galway Bay. Experiments were run on spring tides in June of both years. Highest densities of 0-group plaice were recorded during night visits on both beaches over both years. A significant difference was recorded between day and night catches in both years. Total lengths of 0-group plaice were taken during these experiments. No significant difference in the length of 0-group plaice was observed between day and night samples, or between beaches in 2006.

Experimental push-netting was carried out to test the hypotheses that there was no difference in the abundances of 0-group plaice between spring and neap tides in Galway Bay. Two beaches were used, Ballyloughan and Silverstrand. This experiment was carried out over two spring and two neap tides running consecutively in April / May 2006. No significant difference was noted between tidal types (spring and neaps). A significant difference was observed in the lengths of 0-group plaice over the duration of the experiment. This result could be explained by growth.

Effects of Diel and Semi-lunar cycles on the catches of 0-group plaice, *Pleuronectes platessa* L., in Galway Bay, on the West coast of Ireland.

3.2 Introduction

Research has been carried out for many years on diel (day / night) variability in catch rates of invertebrates and juvenile fin fish species in various parts of the world. Examples of these works include Bedard *et al.* 2005 (Canada), Casey and Myers 1998 (Newfoundland) Hampel *et al.* 2003 (Netherlands), Morison *et al.* 2002 (New Zealand), Pierce 2001 (USA), and Ross *et al.* 1987 (Mexico). In general, these studies have shown that densities from night time sampling for different species are higher than those recorded during daylight hours. Other studies have also shown that species richness has been greater for night samples than for day samples (e.g. Gibson *et al.* 1996, Methven *et al.* 2001, Nash and Santos 1998). In contrast to these results however some studies have shown no diel effect on the abundances of fishes (Nash and Santos 1998, Nash *et al.* 1984, Van der Veer and Bergman 1986).

Any field studies carried out on diel variability in marine environments have to take into consideration tidal influences and semi – lunar rhythms as these are confounding factors which can all effect the abundances of fishes. Species ecology and biology / behaviour have to be taken into consideration when examining day and night variations. Factors used to explain differences in abundances can range from feeding to predator avoidance (Gibson *et al.* 1998), animals being mostly nocturnal (Nash *et al.* 1994, Beyst *et al.* 2002), to environmental factors such as temperature and reduced oxygen at night (van der Veer and Bergman 1986). The depth samples are taken can also affect the numbers, and sizes, of fish caught (Gibson 1973, Gibson *et al.* 1996).

In European waters, due to their relative abundance, juvenile plaice have been used as a model species by various researchers, for example Beyst *et al.* (2002), Gibson (1973,1998) and Nash *et al.* 1994, to explore the variations in day / night catches on sandy beaches. Gibson (1997) and Burrows (2001) found that juvenile plaice move inshore at sunset and leave at sunrise but this pattern is modulated by an onshore migration with each tide (Gibson 1973, Kuipers 1973, Van de veer and Bergman 1986, Berghahn 1987). Gibson (1997) states that for plaice two types of rhythm were dominant in the fishes life. These were circatidal and circardian in nature. Field studies have shown that the main rhythm is tidal for 0-group plaice but that this becomes entrained to a light / dark cycle as the get older (Nash *et al.* 1994). Laboratory based studies have shown, however, that the basic rhythm in young plaice is circadian in nature, but that this can be entrained to keep in phase with the tides (Gibson 1973b). Burrows (2001) showed, in laboratory-based experiments on juvenile plaice, that they showed depth selection behaviour that was consistent with depths expected during tides. These experiments also showed that the plaice showed behaviour consistent with offshore migration by day and onshore migration by night. A review of the above mentioned works on abundances of fishes and invertebrates in relation to diel and semi-lunar periods follows and these are summarised in Tables 3.1 and 3.2.

A study carried out at the mouth of the Gullmarsfjord on the Swedish west coast, in July 1995, studied the diel movements of juvenile plaice in relation to predators, competitors and food availability (Gibson *et al.* 1998). This study was carried out using underwater television (fish ~ 10cm) and two forms of conventional nets, a 1m push-net and a beach seine. Results obtained by push-netting showed that for two of the three areas sampled, there was a significant difference between the abundances of 0-group plaice between day and night. This nursery ground was described as being microtidal (~20cm) in nature. Young plaice were observed moving up shore at dusk and returning to deeper water at dawn. The study also suggested that changes in light intensity triggered the timing of immigration and emigration of young plaice and not the phase of the tidal cycle. It was also unlikely that upshore movement of plaice was solely related to feeding. Two reasons for upshore migration considered were predator avoidance and the maintenance of a constant water temperature. The analysis of length data taken using the push-net showed a total length range from 22 to 68mm. There was no significant difference in the median lengths of plaice between day and night samples.

Van der Veer and Bergman (1986) showed, during a study on 0-group plaice in the western Wadden Sea in 1980 and 1981, that no consistent difference was seen between the abundances of 0-group plaice between day and night catches. This survey was carried out using a 1m beam trawl that was pulled by operators in shallow waters

(~ 0.5m) and used with a dinghy in deeper waters. Sampling was carried out, in 1980, over 24 hour sampling periods from February to September once a week. In 1981, sampling was carried out on low and high water periods only and this was done every two weeks from January to June. 0-group plaice caught at high and low water showed no consistent differences in total lengths between these periods.

In 1997, a study was carried out on an exposed sandy shore on the Belgian coast (Beyst *et al.* 2002). The aim of this study was to observe the tidal, diurnal and semi-lunar distribution patterns in macrocrustaceans and demersal fishes. Special emphasis was given to juvenile plaice. Sampling was carried out using a 2m beam trawl and a hyperbenthic sledge. Both gears were pulled by operators at a depth of ~ 1m parallel to the shore. This survey revealed clear tidal (e.g. juvenile plaice *Pleuronectes platessa*, brown shrimp *Crangon crangon*) and diurnal (e.g. juvenile sole *Solea solea* at night) periodicities of different species. 0-group plaice were observed in numbers below the inter-tidal while 1+ fish were observed to migrate higher up the beach during flood tides. 0-group plaice may stay below the inter-tidal to avoid predation or it could be due to the influence of strong surf zone currents. Length frequency data showed that two cohorts of plaice were captured during the survey. The median values were 30 and 70mm respectively, which probably represented 0-group and I-group plaice (Beyst *et al.* 2002).

Nash *et al.* (1994) found in a beach seining survey carried out in the Isle of Man that in May/June 1991, that there was no significant difference between the mean catch of 0-group plaice between day and night, but that in September of the same year there was a significant difference in the catches rates of 0-group and I-group plaice between day and night. Nash *et al.* (1994) stated that this could be linked to shorter darkness hours in May / June and longer dark hours during September. This survey covered a period ranging from neap tides to spring tides, and the catches over these periods were not linearly related to tidal height over the lunar cycle. From length frequency studies, it was shown that samples taken in May and June were dominated by I-group fish, and that samples collected in September were dominated by 0-group plaice (Nash *et al.* 1994).

A seine net and beam trawl survey was carried out on a sandy beach in Ardmucknish bay on the west coast of Scotland in June to August (Gibson *et al.* 1996). It was found that densities of fish, especially plaice, were similar between day and night catches in June but a significant difference in abundances were observed in August. 0- group plaice were caught in similar numbers, during day and night samples in trawls, but were more abundant in seines at night. I-group plaice were significantly more abundant at night in both trawls and seines. It was also noted, however, that no evidence existed for distinct day or night communities. Species richness was also noted to be higher at night. There was no significant difference in the lengths of 0-group or I-group plaice between day or night in the trawls carried out.

In the Netherlands in August 1994, sampling of an intertidal salt marsh creek in the Westerschelde estuary showed that for invertebrates and small fish that total densities were higher during night samples. This survey was carried out using a stow net over seven complete tidal cycles (Hampel *et al.* 2003).

Work carried out on Senegal sole, *Solea senegalensis,* in inter-tidal mudflats in the Tagus estuary, Portugal, showed that a semi-lunar activity pattern was detected (Vinagre *et al.* 2006). This research showed that the highest average densities occurred during full moon (spring tides) at dusk / dawn, whilst on neap tides abundances peaked during the day.

Similar research has been carried out on day versus night, and spring versus neap abundances of fishes and invertebrates in various parts of the world. In Porto Pim, the Azores, it was discovered that during 24h sampling periods (once per month) from July 1989 to June 1990, in a beach seine program, there was no significant difference in mean densities between day and night catches in juvenile wide-eyed flounder, *Bothus podas* (Nash *et al.* 1994). It was also revealed for other small fish species that generally greater numbers of individuals were caught during daytime (Nash and Santos 1998).

Extensive research surveys, on fish species, were carried out on the Newfoundland and Labrador coasts from 1972 to 1995. These studies were trawl based and the diel variation of over 50 species was examined. It was found that nonmigrating species, such as flatfish and skates, which rely on visibility of the trawl as a means of escapement, were caught in higher proportions during the night (Casey and Myres 1998)

A block seine net survey carried out on Horn Island, in the northern Gulf of Mexico, showed that the standing crop and average weight of fishes increased significantly in night samples. This survey was carried out on a surf zone beach from July 1978 to August 1979. It was found that the average weight of individual fish was significantly greater between the hours of 23.00 to 06.00. The median weight for fish at night was 72.0g compared to 2.6 g for day time (Ross *et al.* 1987).

In Manukau Harbour, New Zealand, a survey was carried out to gauge the diurnal and tidal variation in the abundance of the fish fauna of a tidal mud flat. This survey consisted of two sampling methods. In March 2000 a beach seining program was run and two months later in May an outrigger trawl (a form of push-net) was used. For the beach seine, low water night samples had the greater species diversity and abundances. Over day and night low water had greater species diversity and abundances than high tides. For the outrigger trawl, catch rates were higher at night for many species (Morison *et al.* 2002).

The fact that catches rates for fishes can be greater at night is not confined to marine habitats. A survey was carried in two fresh water lakes in northwest Iowa, USA, using two sampling methods, to compare the influence of diel period on the abundance and size structure of Bluegills, *Lepomis macrochirus.* The two methods used were beach seine and electrofishing. Both gears produced significantly greater species richness at night than during the day. Total catch per unit effort for electrofishing was significantly greater for night time than for daytime samples. However diel differences in total density for seining samples, were not statistically significant. Few diel differences in fish size were found, but the two gears generally produced differing size distributions. Diel differences were more prevalent for electrofishing, whereas differences among sites were more apparent for seines. (Pierce *et al.* 2001).

Table 3.1 Summary of research carried out on the effects of diel and semi-lunar periods on abundances of species in European waters. N/S means not studied.

Country	Time of year	Gear used	Species	Diel effects on abundances of species	Tidal or lunar effects on abundances or species	Diel or tidal effect on species size	Reference
Sweden	July	Underwater camera, push-net, beach seine	Plaice	Significant difference in most areas	Migration with tides	No difference in median length	Gibson *et al.* 1998
Holland	Feb-Sep 1980, Jan – June 1981	Beam trawl	Plaice	No consistent differences	Migration with tides	No difference in lengths at low or high water	Van der Veer and Bergman 1986
Belgium	Spring	Beach seine	Plaice, *Crangon*, Sole	Sole nocternal	Plaice and *Crangon* tidal effect	N/S	Beyest *et al.* 2002
Isle of Man	May/June, September	Beach seine	Plaice	No difference May/June. Significant difference September	No linear relationship to lunar period	1+ dominant in May/June, 0+ dominant in September	Nash *et al.* 1994
Scotland	June/August	Beach seine, Beam trawl	Plaice and other species	Abundances the same in June. Significant difference in August in trawls	N/S	No significant difference in length in trawls for day / night	Gibson *et al.* 1996
Netherlands	August	Stow net	Invertebrates and small fishes	Abundances higher at night	N/S	N/S	Hampel *et al.* 2003
Portugal	June / July	Encircling nets, Beam trawl	Senegal Sole	Dusk and dawn had higher abundances	Higher abundances during spring tides	N/S	Vinagre *et al.* 2006

Table 3.2 Summary of research carried out on the effects of diel and semi-lunar periods on abundances of species in waters through the world. N/s means not studied, N/A means not applicable.

Country	Time of year	Gear used	Species	Diel effects on abundances of species	Tidal or lunar effects on abundances or species	Diel or tidal effect on species size	Reference
Azores	July to following June	Beach seine	Wide eyed flounder	No significant difference	N/S	N/S	Nash and Santos 1998
Newfoundland and Labrador	1972 to 1995	Trawl surveys	Flatfish and skates	Higher densities at night	N/S	N/S	Casey and Myres 1998
Mexico	July 1978 to August 1979	Block seine net	Invertebrates and small fishes	Standing crop greater at night	N/S	Weight of fish significant greater at night	Ross *et al* 1987
New Zealand	March / May	Beach seine, outrigger trawl	Small fish species	Catches for many species higher at night in trawls	Low water greatest numbers for day and night	N/S	Morison *et al.* 2002
U.S.A, Iwoa	June / July	Beach seine, electrofishing	Bluegills and small fish species	Greater abundances at night using electrofishing, species richness greater at night	N/A	Few size differences found	Pierce *et al.* 2001

During a push-net survey carried out in Galway Bay from 2005 to 2006 the diel variation in catches of juvenile plaice was examined. Results compared to a previous day versus night push-net study carried out in the same area (Allen 2004). In 2006, it was also decided to examine the variation in abundances of 0-group plaice between spring and neap tides. This was important as routine sampling was carried out on spring tides and this study would allow comparisons of abundances and sizes of 0-group plaice between different semi-lunar periods.

3.3 Methods and materials

3.3.1 Study area

The two beaches studied during the day versus night and the spring versus neap experiments were Ballyloughan and Silverstrand. These two beaches are situated on the northern shore of Galway Bay and have been repeatedly sampled from 2002 to 2006 in various push-net surveys.

Ballyloughan (54° 15.2`N, 09° 01.6`W) is a sheltered sandy beach on the eastern outskirts of Galway city. This beach is gently sloping and is approximately 400m in length and 600m in width at maximum extent. This beach has a strong riverine influence from the river Corrib and surface salinity can be very variable (10 – 26). Silverstrand (53° 15.2`N, 09° 07.8`W) is a sheltered sandy shore on the western outskirts of Galway city. This beach is also a gently sloping beach and is approximately 400m in length 200m in width. This beach is less influenced by the river Corrib and has a narrower salinity range (22-35).

3.3.2 Sampling gear

Sampling was carried out using a riley push net (Homes and Mc Intyre 1971) with modifications. The push-net used was the same as described in Allen (2004) except that the main structure was peramantially welded together. The push-net had the following dimensions; A 1.5m x 0.3m metal frame was constructed from 4cm box iron. The frame was supported on two 70cm x 7.5cm skis. A handle was attached to this frame (2m long) to enable the net to be pushed. The handle could be broken down into three parts for ease of transport. The net was a double-ended shrimp net with 10mm square mesh and 2 mm heavy-duty curtain mesh in the cod ends. Three tickler chains were attached to eyes made from cut chain links, which were welded to the skis in front of the main structure. The first chain was attached to the leading edge of the net with the other two chains free to trail.

3.3.3 Sampling procedure

Day versus night experiments were carried out in June 2005 and June 2006 (Table 3.3 in appendix). When a spring tide period had been chosen all available days and nights in that period were considered for sampling. Two-day periods and two night periods were chosen so as to be random and independent of one another. Each beach would be visited on the chosen day or night and this would give two day visits and two night visits per beach for a total of four visits per beach in each year.

The spring versus neap experiment ran for four weeks from April to May 2006. Two spring periods and two neaps were chosen to examine this. The spring and neap periods were run consecutively. Sampling was carried out at low water as for regular visits. Consideration for naturally changing abundances and size of fish over time had to be considered when planning this study.

Sampling procedures were taken from Allen (2004). Sampling was carried out on low water as the tide was rising. Each beach was divided into sections, which were numbered 1 to 8, so that random numbered areas of the beach could be sampled. Four random replicates per beach were taken. Each replicate was 50 paces (approx. 50m) long. Sampling was carried out at a depth of approximately 0.3-0.5m parallel to the shore.

Samples were sorted on the beach with all species of juvenile flatfish being taken back to the laboratory for further analysis. Other species of fish and invertebrates were recorded and released. The environmental factors of temperature and salinity were taken on most occasions. Temperature was taken using a thermometer in shallow waters approximately 20cm deep. Salinity was recorded using a hand held salinity device (Sea test©) with a precession of ±1. Sea state and weather conditions were recorded on each visit.

Laboratory analysis 3.3.4

In the laboratory fish were identified to species and then coded. The code used enabled each fish to be traced back to sampling visit, date and replicate. All fish in individual replicates were stored together in vials. The 0-group plaice were then measured using callipers to the nearest ± 0.02 mm. Measurements were recorded for total length (TL.) (From the tip of the mouth to the end of the caudal fin) and for standard length (SL.) (from the tip of the mouth to the start of the caudal fin). Fish that were not sampled immediately were frozen at -18°C to be processed at a later date.

Statistical data analysis 3.3.5

Preliminary analysis

The raw data for catches of 0-group plaice and the subsequent length data for 0-group plaice were coded and entered into Microsoft EXCEL worksheets (version) and all data were error checked and corrected. Further data analysis was carried out using EXCEL or MINITAB (version 14).

Mean densities ± S.D were calculated using EXCEL. Mean densities $1000m^{-2}$ were calculated as follows.

$$\textbf{Densities} = \frac{\textbf{M n}}{\textbf{A}} \times \textbf{1000}$$

Where Mn = Mean number, A = area fished ($75m^2$)

The relationship between predicted height of low water (m) and densities of 0-group plaice were assessed using regression analysis. A scatter plot of the two variables was produced and the line or curve of best fit was fitted. Goodness of fit was assessed by the coefficient of determination (r^2), which measures the proportion of variability in one variable, which is accounted for by variability in another (Fowler *et al.* 1998).

3.3.6 Statistical tests

Further analysis of data was carried out using MINITAB (version 14)

All data were subjected to Ryan-Joiner normality tests and checked for homogeneity of variance using Cochrans test. If data was found not to be normal transformations were carried out. Log +1 transformations were used (Underwood 1997).

On normal data analysis of variance (ANOVA) was carried out. Two factor or three factor ANOVAs were carried out with the factors of month's beaches and years. The null hypotheses (Ho) used for the different experiments were as follows:

Day versus night experiment:

The null hypotheses for the three factor orthogonal ANOVAs were:

(1) There is no difference in abundances of 0-group plaice between day and night samples.
(2) This is no difference in this pattern of abundances over beaches and years.
(3) There is no interaction between the main factors.

Spring versus neap tides experiment:

The null hypothesis for the ANOVAs were:

(1) There are no differences in abundances of 0-group plaice between spring and neap tides.
(2) There is no variation in this pattern of abundances over beaches.
(3) There is no interaction between the main factors.

3.3.7 Mean lengths and length frequency analysis

Total lengths (mm) for 0-group plaice were taken during day and night experiments and spring versus neap tides experiments. Length frequency graphs were also produced where enough fish were caught to warrant analysis. Tests for significant differences in the lengths of 0-group plaice were also carried out where enough fish had been caught.

ANOVAs were used on total length data to test the following hypotheses:

(1) There is no difference in the lengths of 0-group plaice between day and night samples.

(2) There is no difference in the lengths of 0-group plaice between spring and neap periods.

Results 3.4

Abiotic factors 3.4.1

The environmental factors of temperature, salinity, sea state and weather conditions were taken during the day versus night push-net experiment. Table 3.3 and 3.4 (In appendix) show the results for Ballyloughan and Silverstrand in 2005 and 2006 respectively.

Day versus night sampling ranged over eight days in June 2005 and six days in June 2006. Salinity during this experiment ranged from 16 – 22 on Ballyloughan in 2005 and this range was also found in 2006. The salinity range on Silverstrand was from 32 – 36 in 2005 to a range of 28 – 35 in 2006. Temperature on Ballyloughan ranged from 13.5 – 22°C in 2005 to 14.4 – 15°C in 2006. Silverstrand ranged from 13 – 22°C in 2005 to 13.5 – 15°C in 2006.

Environmental factors were also recorded during the spring versus neap experiment 2006 (Table 3 .5 in appendix). Salinity and temperature were only taken for approximately half the trips due to material constraints. Salinity, on Ballyloughan, ranged from 10 – 26. On Silverstrand, salinities ranged from 26 – 31 ppt. Ballyloughan had a mean temperature of 13.5°C, on Silverstrand temperature was only taken once, 13°C.

3.4.2 Mean densities

The results for the mean densities of 0-group plaice $1000m^{-2}$ during the day versus night experiments are presented in Figures 3.1 and 3.2. In 2005, densities ranged on Ballyloughan from 0 (day) to 120 (night) $1000m^{-2}$. The range on Silverstrand was from 3 (day) to 60 (night) $1000m^{-2}$. In 2006 the range for Ballyloughan was from 146 (day) to 327 (night) $1000m^{-2}$ and in Silverstrand the range was from 47 (Day) to 130 (night) $1000m^{-2}$.

Analysis of variance was carried out on the 0-group plaice density data during the day versus night push-net experiments in June 2005 and 2006. A three factor ANOVA was used to test the hypothesis that there was no significant difference between day and night samples. Results showed that there was a significant difference between day and night visits ($p < 0.001$). Results also showed that there was no significant difference between years ($p = 0.249$), and that there was no significant difference between beaches ($p = 0.543$). There was also a significant interaction between years and beaches ($p < 0.001$). This shows that some of the beaches were different in some of the years. An interaction here however does not affect the day versus night results. Fishers pairwise post hoc analysis revealed that densities of 0-group plaice on Ballyloughan were different (smaller) in 2005 compared to 2006 (Figure 3.1 and 3.2). Densities on Silverstrand were similar in both years. This accounts for the interaction between years and beaches. This reveals that there was a temporal difference in densities at a small local scale.

Figure 3.1: Mean densities of 0-group plaice 1000m-^{2} (± S.D) caught in a day versus night push-net experiment on Ballyloughan (BN) and Silverstrand (SS) during June 2005. (Note: no fish caught on Ballyloughan during day visits).

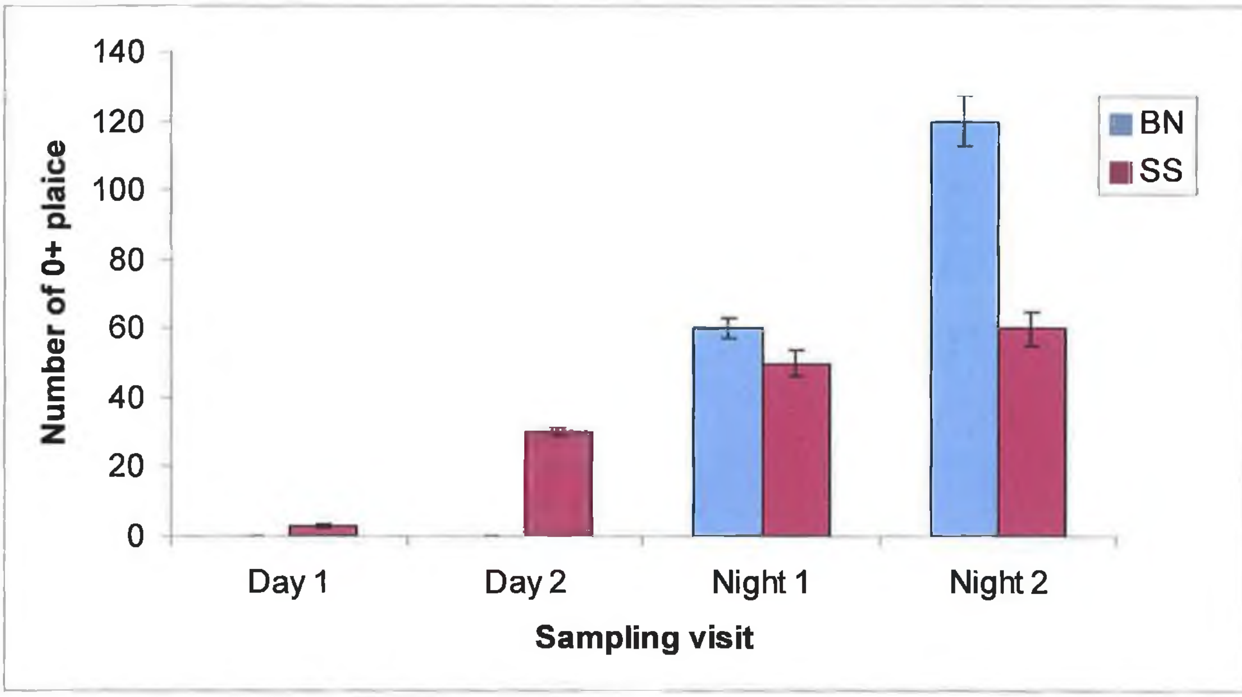
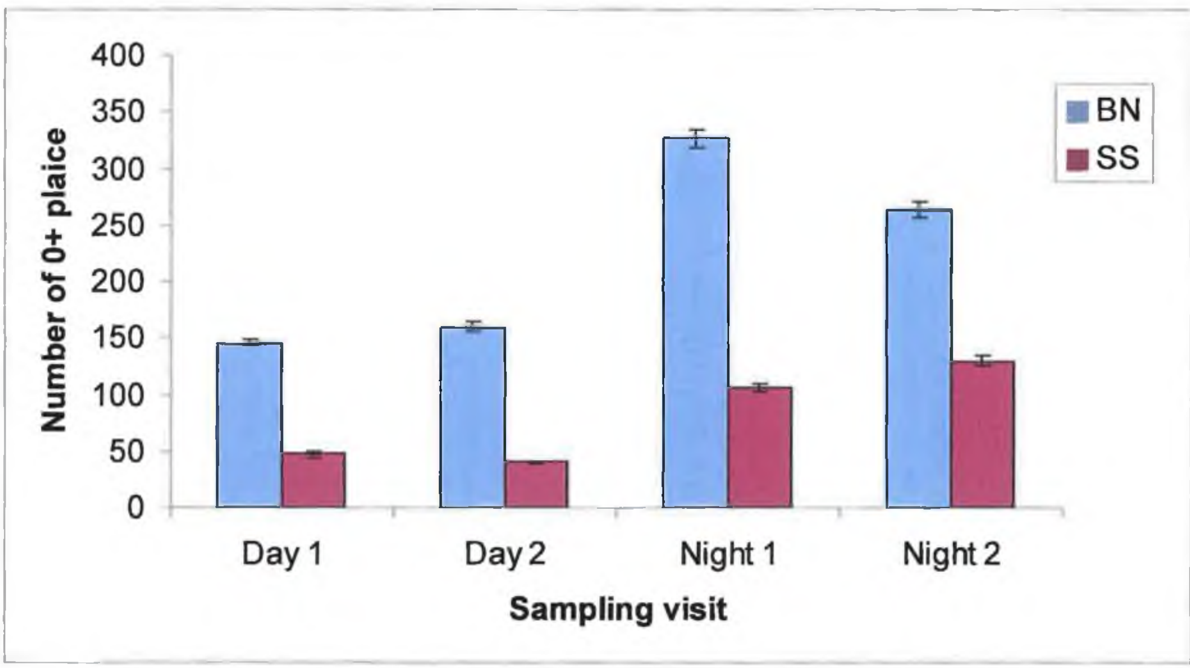


Figure 3.2: Mean densities of 0-group plaice 1000m-^{2} (± S.D) caught in a day versus night push-net experiment on Ballyloughan (BN) and Silverstrand (SS) during June 2006.



Density data of 0-group plaice were also obtained during a neap versus spring tide experiment in April / May 2006 (Figure 3.3). The densities here ranged from 36 – 133 0-group plaice $1000m^{-2}$ on Ballyloughan to 3 – 53 $1000m^{-2}$ on Silverstrand.

The abundances of 0-group plaice between spring tides and neap tides during April / May 2006 were also tested for significant differences. A two factor ANOVA was used to test beaches and tidal type for any interactions between the main factors. These tests showed there was no significant difference between beaches ($p = 0.071$) or between tidal type ($p = 0.126$), and no interaction between these two factors ($p = 0.741$). A scatter plot of densities of 0-group plaice versus predicted tidal height at low water for spring and neap tides showed an inverse relationship between these two factors (Figure 3.4). On Ballyloughan this relationship had an $r^2 = 0.87$ and on Silverstrand a value of $r^2 = 0.75$. This result was found not to be significant ($p = 0.132$)

Figure 3.3: Mean densities of 0-group plaice $1000m^{-2}$ (±S.D) caught in a spring versus neap tides push-net experiment, on Ballyloyghan and Silverstrand (SS), during April and May 2006.

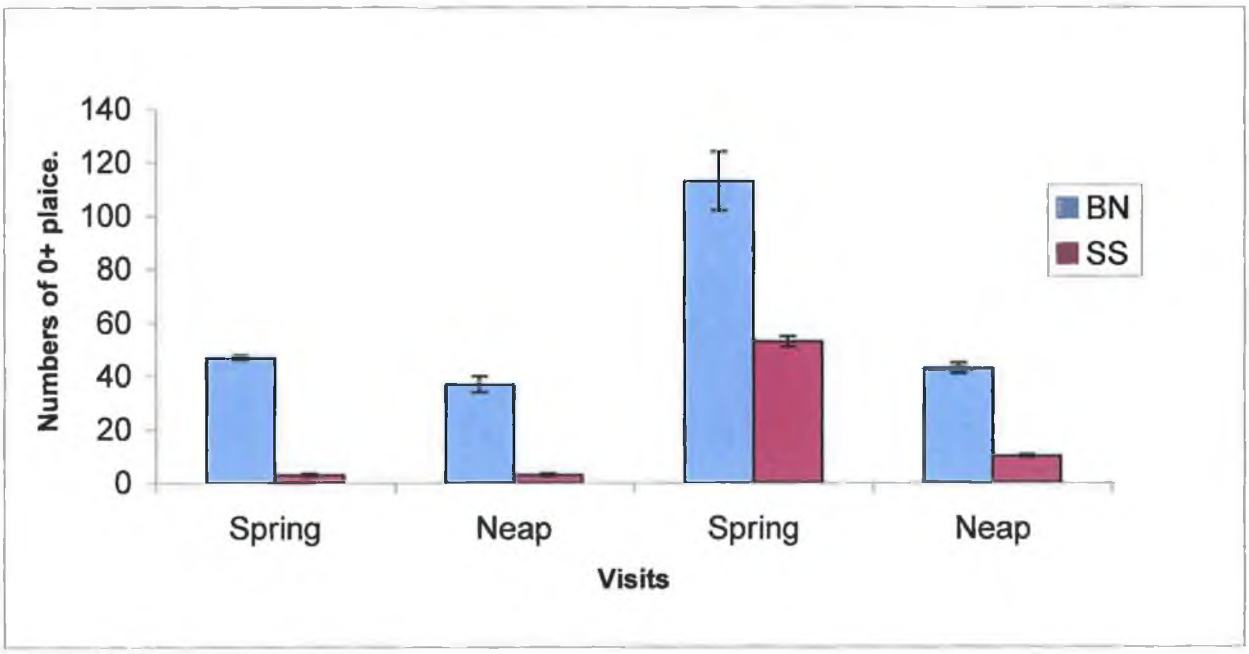
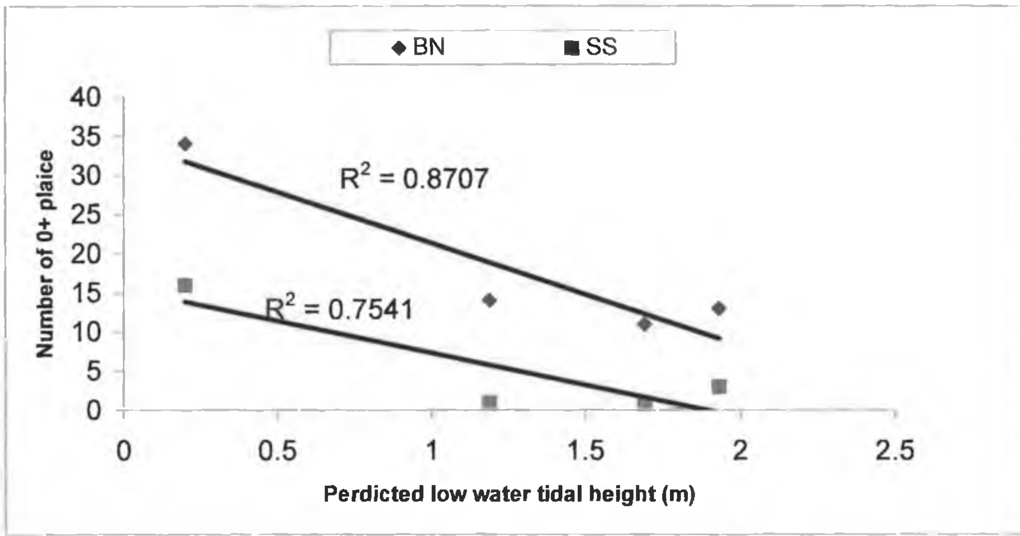


Figure 3.4: Total numbers of 0-group plaice caught during a neap versus spring push-net experiment in April / May 2006 versus the predicted low water depth (m), for each visit, for Ballyloughan (BN) and Silverstrand (SS).



3.4.3 Length frequency analysis

During the day versus night experiments in 2005 and 2006, total lengths of 0-group plaice were taken (Table 3.6). In 2005, some visits caught no fish so no further analysis of these data could be carried out. In 2006, all visits yielded fish so data could be further analysised. Mean total lengths ranged from 37.92 ± 10.5mm during a day visit on Ballyloughan to 40.79 ± 9.64mm on a night visit. On Silverstrand the range was from 41.35 ± 8.2mm on a night visit to 51.19 ± 6.44mm on a day visit.

Length frequency graphs (Figures 3.5 and 3.6) were produced for each beach for day and night samplings during June 2006. The modal size for Ballyloughan on days was 26 – 29mm with a range from 24 to 61mm. The modal value at night was 33mm with a range from 26 to 67mm. Silverstrand had a modal value of 55mm during day visits and a range from 32 to 63 mm. During night visits the modal value was 37mm and the range was 28 to 67mm.

ANOVAs were carried out on total lengths of 0-group plaice against day and night visits. No significant difference was observed between day and night samples ($p = 0.716$), and no significant difference was seen between beaches ($p = 0.243$). There was an interaction between beaches and diel period ($p = 0.018$). This indicated that some of the beaches were different some of the times. This shows small-scale temporal or spatial differences.

Table 3.6: Mean total lengths (mm) for plaice from Ballyloughan and Silverstrand in June 2005 and 2006 during a day versus night experiment. (BN = Ballyloughan, SS = Silverstrand, D = day, N = night)

Location Code	Date	Total number of 0-group plaice	Mean Total length (mm)	S.D ±
BN 0511 (N)	23-6-05	17	45	5.5
BN 0512 (N)	25-6-05	36	48	5.5
SS 0511 (N)	23-6-05	15	38	4
SS 0512 (N)	25-6-05	17	38	4
SS 0513 (D)	27-6-05	9	45	9
BN 06 11 (D)	12-6-06	44	39	11
BN 06 12 (D)	13-6-06	47	38	10.5
BN 06 13 (N)	15-6-06	97	41	10
BN 06 14 (N)	16-6-06	79	39	10
SS 06 11 (D)	12-6-06	13	51	6
SS 0612 (D)	13-6-06	11	48	10
SS 06 13 (N)	15-6-06	32	41	8
SS 06 14 (N)	16-6-06	39	45	9

Figure 3.5: Length frequency (mm) for 0-group plaice from Ballyloughan during day versus night experimental push-netting in June 2006.

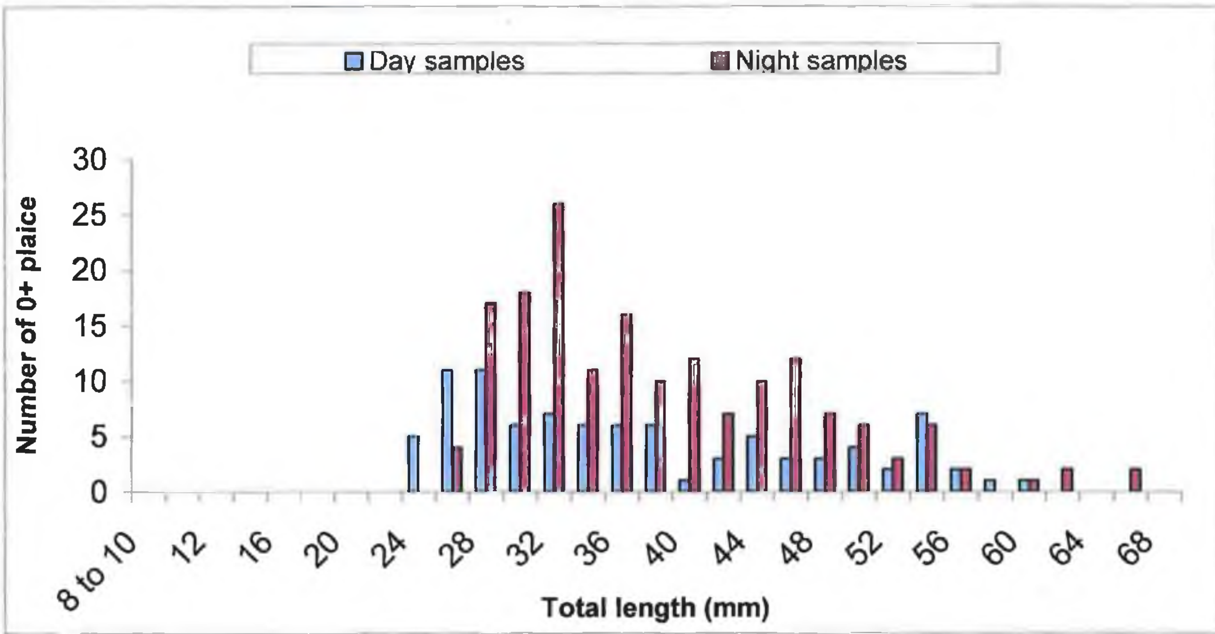
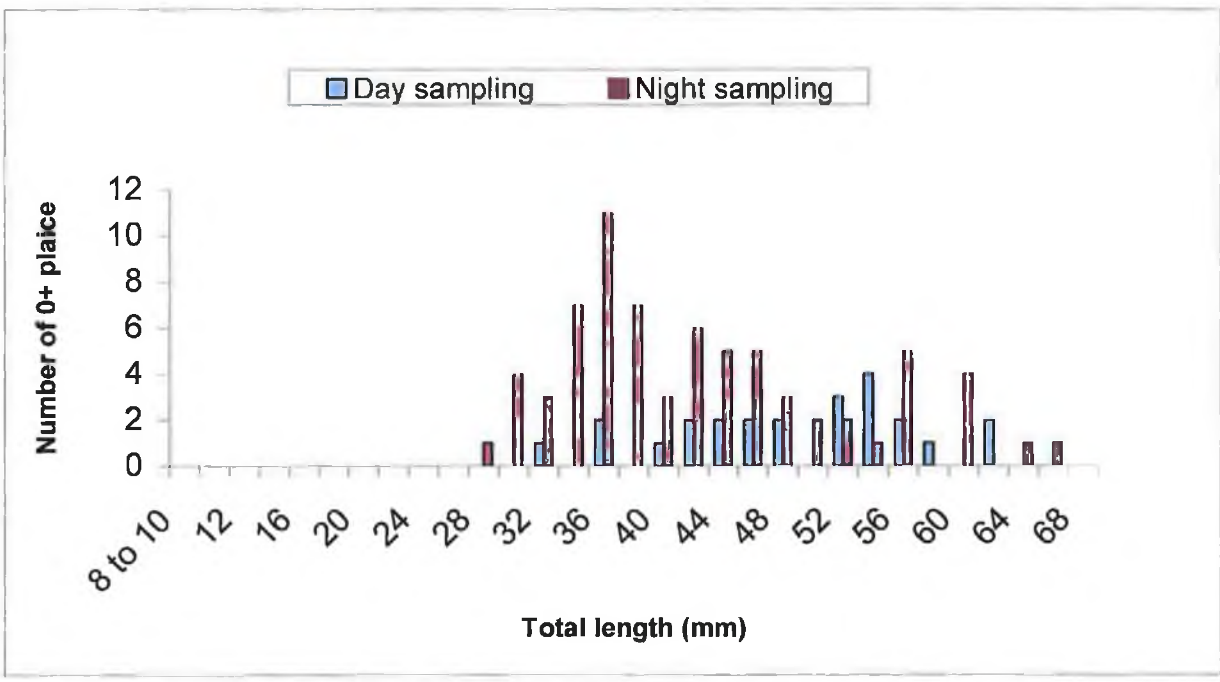


Figure 3.6: Length frequency (mm) for 0-group plaice from Silverstrand during day versus night experimental push-netting in June 2006.



During the spring versus neap tides experiment in 2006 total lengths of 0-group plaice were also taken (Table 3.5). Ballyloughan had a range, for mean total lengths of 0-group plaice, of 19.91 mm ± 3.71mm S.D at the start of this experiment to 23.59 ± 4.08mm S.D at the end of the experiment. Silverstrand had only one fish in each of the first two visits so no mean total length data could be obtained. The last two samplings ranged from 18.87 mm ± 2.40mm S.D to 18.52 mm + 8.34mm S.D.

A one factor ANOVA was carried out on Ballyloughan data to test the hypotheses that there was no significant difference between the lengths of 0-group plaice over the duration of the experiment. The results showed there was a significant difference in the lengths of 0-group plaice between visits. Fisher's pair wise test was used for *post hoc* analysis. Results showed that the first visit (spring tide) was different from the other 3 visits. Visit two (neap tide) was similar to visit three (spring tide) but was different to visit four (neap tide). Visits three and four were similar.

Table 3.5:Table showing mean total lengths (mm) for plaice from Ballyloughan and Silverstrand in April / May 2006 in a spring versus neap tides experiment. (BN = Ballyloughan, SS = Silverstrand, D = day, N = night). N/A means not applicable in this case.

Location Code	Date	Total number of 0-group plaice	Mean Total length (mm)	S.D ±
BN 06 05	10-4-06 (S)	14	16	6
BN 06 06	19-4-06 (N)	10	19	4
BN 06 07	27-4-06 (S)	34	21	5
BN 06 08	5-5-06 (N)	13	24	4
SS 06 05	10-4-06 (S)	1	N/A	N/A
SS 06 06	19-4-06 (N)	1	N/A	N/A
SS 06 07	28-4-06 (S)	16	19	2
SS 06 08	5-5-06 (N)	3	19	8

3.5 Discussion

During day versus night push-net experiments in Galway Bay in June 2005 and 2006, highest mean densities of 0-group plaice were recorded during night visits. These densities were shown to be significantly different ($p < 0.001$). Allen (2004) found that during August 2003 that highest densities were recorded during night from Ballyloughan and these results were also found to be significantly different. During the 2005 and 2006 day versus night experiments, there was no significant difference in densities between years or between beaches. There was however a significant interaction between years and beaches. Further analysis showed that densities of 0-group on Ballyloughan were smaller in 2005 compared to 2006, whereas Silverstrand showed similar densities in both years. This revealed that there was a temporal and spatial difference at a local scale. In 2006, there was no significant difference noted in the lengths (mm) of 0-group plaice between night and day samples ($p = 0.716$) or between beaches ($p = 0.243$). The findings of this project seem to generally agree with findings in other projects (Gibson *et al.* 1998, Gibson et al. 1996).

Research carried out on juvenile plaice in European waters have given many varying reasons for the differences in abundances between day and night samples. These can vary from feeding behaviour (Kuipers1973) to predator avoidance (Gibson *et al.* 1998), unfavourable environmental conditions (Van deer Veer and Bergman 1986) to a preference for a certain depths regardless of diel period (Gibson 1973). In some areas light intensity (Gibson *et al.* 1998) can be of most importance, for up-shore migration, whereas tidal cues are more important in others (Beyst 2002). Nash *et al.* 1994 found that seasonal effect had an influence on the abundances between day and night samples. Casey and Myres (1998) stated that for trawl surveys that non-migratory fish species, such as flatfish and skates, were caught in greater numbers at night because fishing gears could not be detected as easily in the dark.

Physical oceanographic factors can be very different in each area and this has also to be taken into consideration. For example Gibson *et al.* (1998) was working on a microtidal bay in Sweden with little tidal or wave variation as opposed to a study carried out by Beyst *et al.* (2002) which was conducted on an exposed surf zone beach on the Belgian coast. It is notable that research carried out on this one species, *P.*

platessa, reveals that for populations in different areas explanations for fluctuations in numbers between day and night vary significantly among researchers. It is generally accepted that juvenile plaice move up and down the shore with the rise and fall of the tides regardless of diel effect (e.g. Gibson 1973, Kuipers 1973), but that they move increasingly into shallower waters as dusk approaches with a peak migration just before sunset (Burrows 2001).

During a spring versus neap tides experiment on Ballyloughan and Silverstrand in 2006, no significant difference was recorded between densities of 0-group plaice ($p = 0.126$). It should be noted, however, that the data set used was relatively small. These results are important as regular sampling in the Galway Bay area was always carried out on spring tide periods only. It was feared that by sampling on spring tides only the researchers might be biasing their results. These results now mean that researchers can sample anytime during the month. This will be of great benefit in the early season as bad weather can often hamper sampling.

Other factors have to be considered when looking at studies carried out on variability in abundances of species during diel and semi-lunar periods. Sampling gear and sampling methods are one major factor. Casey and Myres (1998) stated that flatfish and skates were caught in greater numbers at night, which was probably due to the fact that trawls could not be avoided as easily in the dark. In the present study, 0-group plaice were seen actively avoiding the net from mid to late May onwards in 2005 and 2006 respectively. This factor has then to be taken into consideration as a factor for increased numbers at night. Gear types used have also given varying results in different studies. Pierce *et al.* (2001) showed that electrofishing gave significantly higher abundances of fish at night in two lake systems, but beach seine did not show a significant difference. Gibson (1996) show that species composition of two gear types (2m beam trawl and beach seine) differed in a study carried out in Scotland. This present study only applied one method of sampling.

Another important aspect between diel or semi lunar cycles of 0-group plaice is the size of fish in relation to these factors. Few studies take this into consideration and tend to concentrate purely on the variation in abundances. Two studies (Gibson *et al.* 1998, Gibson *et al.* 1996) show similar results to the findings in this present study.

In a study carried out in Sweden (Gibson *et al.* 1998) in July 1995, it was found that there was no difference in the median length of plaice between day and night samples. A study carried out in Scotland also showed that there was no significant difference, for juvenile plaice, in lengths between day and night samples (Gibson *et al.* 1996). Van der Veer and Bergman (1986) showed that there was no consistent difference in the length of 0-group plaice, on tidal flats in the western Wadden Sea, between low and high water. Ross *et al.* (1987) stated that the weight of fish caught in block seine nets on a sandy beach in Mexico, were much larger at night. When fish length or size is taken into consideration for the present study it would have been expect that fish length at night might have been larger, as larger fish had been seen actively avoiding the net around this period on day sampling. However the results indicate that this is apparently not the case and two previous studies on juvenile plaice in European waters show similar results.

To fully study the effects of diel and semi-lunar effects on the abundances of 0-group plaice in Galway Bay would require a complex sampling schedule if the influences of tidal and day versus night effects are to be separated. Tides, diel and semi-lunar effects are confounding factors, which make the interpretation of results more difficult. Gibson (1996) stated that to separate tidal and diel effects night sampling had to cover a high tide and a low tide period at midnight. Nash *et al.* (1994) stated that during a day versus night experiments carried out in the Isle of Man sampling was carried out over a period covering spring and neap tides. The abundances of plaice showed no linear relationship with tidal heights. Beyst *et al.* (2002) stated that to cover all tidal, diurnal and semi lunar patterns that 3 consecutive twenty-four hour cycles should be sampled. The constraints of the present study did not allow for complex environmental and biological questions to be asked. The aims of the study were achieved by showing that a difference between abundances of 0-group plaice does exist, over the period sampled, for day and night samples and no significant difference was observed over spring and neap tides. To further analyse these questions in Galway Bay sampling would have to cover all combinations of tidal, diurnal and semi lunar distribution patterns.

3.5.1 conclusions

During the day versus night experiments in June 2005 and 2006, it was observed that densities of 0-group plaice in June were significantly higher at night and that no difference between the two beaches sampled existed. Smaller scale temporal and spatial differences were however indicated due to an interaction between years and beaches. Studies carried out in different parts of the world on various sandy shore fish species and invertebrates generally show a pattern for higher species densities and species richness at night It was also shown that there was no difference in the length of 0-group plaice in 2006 between day and night on Ballyloughan and Silverstrand and that no difference occurred between beaches. This shows that the animals on the beaches at night were not significantly bigger or older than those seen during the day visits. No conclusions could be drawn on the reason for the differences in day and night on the beaches sampled. Gear efficiency could be a factor at night, as animals cannot physically see the push-net. 0-group plaice had been seen avoiding the net during day light sampling from mid May onwards so it would be expected that larger animals were able to avoid the net during daylight hours but this was not the case as there was no significant size difference noted between day or night samples.

Experimental fishing during spring versus neap tides revealed that there was no significant difference between densities of 0-group plaice between these two periods. This is an important result as it shows that, at least for this period, that no significant differences were detected in densities and that to sample on spring tides alone, as done in regular sampling, is giving a general pattern of 0-group plaice densities. Length data revealed that there was a difference in the length of 0-group plaice during the duration of this experiment and this could be explained for by growth.

Overall these experiments reveal information on the biology and ecology of 0-group plaice on sandy beach nursery grounds in Galway Bay and these studies can then be used to more fully understand the recruitment of 0-group plaice on nursery grounds in this region.

Chapter 4. The determination of hatching periods, larval age, settlement periods and growth of 0-group plaice in Galway Bay using otolith microstructure analysis.

4.1 Abstract

Otolith microstructure analysis for 0-group plaice caught on three beaches in Galway Bay (Ballyloughan, Silverstrand and Glann na Ri) in April and May 2005 were used to determine: (1) hatching dates (2) larval duration and larval growth (3) settlement periods (4) post larval age and growth and (5) total age of 0-group plaice from hatching to capture date. Data from a previous study (Ballyloughan and Silverstrand only) (Allen 2004) would allow the comparison of 0-group plaice hatching and settlement periods, larval and post-larval ages and juvenile growth in the months of April and May between the years of 2003 and 2005.

Hatching dates in Galway Bay ranged from late January to early April in 2005. Results on hatching periods in Galway Bay from 2003 and 2005 revealed no significant difference between years or between beaches sampled. A significant difference was noted in hatching dates between April and May 2005.

Larval duration of 0-group plaice in Galway Bay in April and May 2005 ranged from 21 to 45 days. No significant difference was observed in larval age between beaches sampled in Galway Bay or between years in April 2003 and 2005. A significant difference was observed between larval age and years in May 2003 and 2005 however no significant difference was observed between beaches.

Settlement period ranged from late March to mid May in 2005. Settlement patterns in 2003 and 2005 were not significantly different to one another. There was also no difference in settlement patterns between the beaches sampled. Settlement dates were significantly different between the months of April and May in 2005.

Hatching, larval duration and settlement are all part of the juvenile flatfishes pelagic lifecycle. No spatial effect was found in any of these lifecycle stages over the

two years (2003 and 2005) on Ballyloughan or Silverstrand or over the three beaches sampled in 2005.

No significant difference was noted in the post-larval age of 0-group plaice caught in April and May 2005 on the three beaches sampled. Data from 2003 for Ballyloughan and Silverstrand were compared to data for April and May 2005. Fish caught in April and May 2003 had a younger post-larval age than fish caught in April and May 2005. Fish on Ballyloughan in April 2003 and 2005 had a significantly older post-larval age than fish on Silverstrand. No significant difference was observed in the post-larval age of 0-group plaice between beaches in May of 2003 and 2005.

Growth for 0-group plaice was greatest on Ballyloughan in 2005, compared to Silverstrand and Glann na Ri, and mean otolith increment widths seem to verify these results. ANOVA revealed no significant difference between beaches or months. Ballyloughan generally showed greater observed daily growth rates than predicted daily growth rates. Silverstrand and Glann na Ri showed poorer observed growth than predicted growth in April 2005. All beaches showed improved growth in May 2005.

Chapter 4

The determination of hatching periods, larval duration, settlement periods and growth of 0-group plaice in Galway Bay using otolith microstructure analysis.

4.2 Introduction

The collection of age-structure information has always been a major preoccupation of fisheries scientists. Age, growth rate and mortality rates are three of the most influential life history characteristics controlling the productivity of fish populations (Campana and Thorrold 2001). Both growth and mortality rates are based on age information. Fish are relatively easy to age in comparison to other animals. Bony or calcified structures have been used to examine seasonal or annual growth patterns since the late 1800s (Nash and Geffen 2005). Structures used in the ageing of fish include scales, spines, opercular bones, the pectoral girdle and vertebrae. However growth rates on these structures were found not to be as distinctive as those on otoliths (Nash and Geffen 2005).

Major resources in time and money worldwide are allocated to the age and growth determination of fish. A survey of 30 fisheries laboratories through the world revealed that a minimum of 800 000 otoliths were aged world wide in 1999 with a much larger number of scales and vertebrae also aged (Campana and Thorrold 2001). Otolith research can be broken into three divisions. These are described as (1) otolith annuali analysis, (2) otolith microstructure analysis and (3) otolith chemistry analysis. Primary publications annually show that approximately 20 % of otolith research is concerned with otolith microstructure analysis since the 1990s (Campana and Thorrold 2001).

Many of the early studies on flatfish age and growth were concerned with north Atlantic species, in particular plaice (Nash and Geffen 2005). The focus of the present study is directed at analysing the patterns of age and growth in the larval and post larval stages of 0-group plaice, in the Galway Bay on the west coast of Ireland using otolith microstructure analysis. Microstructure analysis allows the estimation of individual age at different stages during early life history of juveniles. Validation studies have confirmed that primary increments are formed daily in the otoliths of larval and juvenile flatfish (Nash and Geffen 2005). However some species have shown non-daily increment formation during larval stages; an example of such species in European waters is the turbot (*Scopthalmus maximus* L.) (Geffen 1982). Experimental studies have supported the use of primary increment counts to estimate age for wild larvae of plaice (Hovenkamp 1990) and other juvenile flatfish species, for example common sole, *Solea solea* L.; Karakiri and Westernhagan (1989) showed that daily increments in plaice were first laid down 4 to 6 days before hatching in laboratory-reared fish. An important part of any study involving otolith microstructure analysis is validation of the readings carried out. Many studies generally carry out a minimum of two readings, and usually three or more on every otolith read (Al-Hossaini and Pitcher 1988, Hovenkamp 1990, Gilliers *et al.* 2004). This enables readers to gauge how consistent their readings are.

Individual variation in growth rates is a significant factor in larval and juvenile flatfishes, including plaice (Karakiri *et al.* 1989, Hovenkamp 1990, Karakiri *et al.* 1991, Modin and Pihl 1994). Larval growth in flatfish can be affected by hatch timing, food, predation, water temperature and density dependant factors (Nash and Geffen 2005).

Larval duration for 0-group plaice varies between areas and has been shown to be related to temperature (Van der Veer 1990, Allen 2004). Wegner *et al.* (2003) stated that generally larval phases of plaice take from 60 to 90 days. Larval durations of 50 to 82 days have been noted for the Wadden Sea (Karakiri *et al.* 1991) and a duration of 42 to 59 days for the Irish Sea (Al-Hossiani *et al.* 1989). Allen (2004) showed a larval duration of 28 to 43 days for the Galway Bay area on the west coast of Ireland.

Metamorphosis in juvenile flatfish heralds the start of settlement and thus the beginning of a benthic lifestyle. Metamorphosis, as indicated by the migration of the left eye, begins when the post-larva is 11-12mm long. Metamorphosis is usually complete at 13 – 14mm, by which time the young fish are living on the bottom (Russell 1976). During metamorphosis, the shape of the otolith changes dramatically.

Accessory growth centres are formed at points on the surface of the otolith. These tend to shape the growing otolith into the flattened rectangular shape characteristic of the adults (Nash and Geffen 2005). The formation of the growth centres, also known as primary accessory primordium, is clearly associated with metamorphosis. Modin *et al.* (1996) stated that in plaice the first of the accessory growth centres form when the body is already flattened and the eyes have completely migrated. Modin *et al.* (1996) showed that the use of accessory primordial in combination with ageing techniques to back-calculate time to and from metamorphosis of juvenile plaice was valid. Growth rate and size do not seem to affect settlement timing in plaice. Hovenkamp and Witte (1991) stated that larval plaice may grow quickly and metamorphose at a small size or grow slowly and metamorphose at a large size. In some species, there is a size threshold for settlement and this can lead to almost synchronised settlement. Growth in larval plaice has been shown, in experimental studies, to slow down around metamorphosis and settlement (Nash and Geffen 2005).

Timing of settlement varies between locations and can also vary between years. Settlement in Galway Bay was found to be in April in 2002 and March in 2003 (Allen 2004). In the Irish Sea, first settlement has been recorded from March to early April (Mansoor 1982, Hyder and Nash 1998). Plaice have been found to start settling in the Wadden Sea generally in April (Kuipers 1977, Zijlstra *et al.* 1982) but have been found as early as February (Van der Veer 1986). In Filey bay, Yorkshire, plaice were found settling in early to mid May (Lockwood 1974). Amara and Paul (2003) found that plaice had already settled in early April on the French coast. On the Swedish west coast, plaice were noted settling in May in 1991 and in April in 1992 (Modin and Pihl 1996). Separate settlement cohorts of different ages have been identified in plaice (Al-Hossaini *et al.* 1989). Allen (2004) showed three separate settlement cohorts for 0-group plaice in Galway Bay.

Researchers are not certain that increments formed within the accessory growth centres (accessory primordium) represent daily growth, and it is not clear whether the otolith area between growth centres continues to produce daily increments (Nash and Geffen 2005). Researchers, however, generally count these growth increments as daily growth rings as is done in the present study. Once the individual growth centres expand and come into contact with one another new material is once again laid down over the whole surface (Nash and Geffen 2005). In most juvenile flatfish species, post-metamorphic otolith increments are formed daily and therefore estimates derived from these counts are considered valid. Validation work on daily otolith growth for plaice has been carried out by Al-Hossaini and Pitcher (1988).

Growth rates of flatfish on nursery grounds can be affected by many factors including the density of fish settling on the nursery ground, the amount and availability of prey and environmental factors particularly temperature (Nash and Geffen 2005). A majority of studies in the past on growth of juvenile flatfish used the increase in mean length over a specified time as an indicator of growth. A major problem associated with this approach is the continual arrival of newly settling fish on the beach leading to inaccurate growth rates (Nash and Geffen 2005). Otolith increment analysis has been used to combat this problem. Otolith microstructure analysis can reveal the presence of sub-cohorts and the different growth rates associated with these cohorts (Al-Hossaini *et al.* 1989, Hovenkamp 1991, Modin and Pihl 1994, Allen 2004).

The aims of the present study were to use otolith microstructure analysis for 0-group plaice caught in Galway Bay in April and May 2005 to determine the following: (1) Hatching periods, (2) Larval duration and larval growth, (3) Settlement periods, (4) Post larval duration and growth and (5) total age of 0-group plaice from hatching to capture date. These results would allow the comparison of age and growth rates between beaches (Ballyloughan, Silverstrand and Glann na Ri) and between months. Data from a previous study (Allen 2004) would allow the comparison of 0-group plaice hatching and settlement periods, larval and post-larval durations and juvenile growth in the months of April and May between the years of 2003 and 2005 (Ballyloughan and Silverstrand only). Overall this present study extends the spatial (by adding Glann na Ri) and temporal scale of otolith microstructure analysis for 0-group plaice in Galway Bay.

4.3 Methods and materials

4.3.1 Study area and sampling procedure.

Three beaches were sampled in April and May 2005 in Galway Bay using a Riley push-net. These beaches were Ballyloughan, Silverstrand and Glann na Ri.

Ballyloughan (54° 15.2`N, 09° 01.6`W) is a sheltered sandy beach on the eastern outskirts of Galway city. This beach is gently sloping and is approximately 400m in length and 600m in width on maximum extent. The beach has a strong riverine influence from the River Corrib and salinity can be very variable (10ppt – 26ppt).

Silverstrand (53° 15.2`N, 09° 07.8`W) is a sheltered sandy shore on the western outskirts of Galway city. This beach is also a gently sloping beach and is approximately 400m in length 200m in width. Silverstrand beach is less influenced by the River Corrib and has a more stable salinity (22-35).

Glann na Ri is situated approximately half a mile to the east of Ballyloughan and is a sheltered beach composed of fine sand with a salinity range from 14 to 28 ppt. The beach is approximately 200m long and 50m wide. A small stream enters the sea on the eastern end of this beach and this keeps salinities low (14 – 28).

Sampling procedure was carried out as described in chapter 2 using four random replicates per beach per visit.

4.3.2 Laboratory analysis

In the laboratory, fish were identified to species and then coded. The code used enabled each fish to be traced back to sampling visit, date and replicate. All fish in individual replicates were stored together in vials. The 0-group plaice were then measured using callipers to the nearest ± 0.02 mm. Measurements were recorded for total length (TL.) (From the tip of the mouth to the end of the caudal fin) and for standard length (SL.) (from the tip of the mouth to the start of the caudal fin). Fish that were not sampled immediately were frozen at -18°C to be processed at a later date.

A sub-sample of fish from each sample was randomly picked for otolith microstructure analysis and had both Sagittal otoliths removed. Otoliths were removed using needles from their position in the head of the fish. Otoliths were then cleaned by dipping in water and stored dry in vials for processing at a future date. On commencing processing, otoliths were again randomly picked from available vials so as to balance experimental design.

4.3.3 Otolith preparation.

In order to carry out otolith microstructure analysis, the 0-group plaice otoliths required polishing. The polishing technique used was that described by Brophy and Danilowicz (2002) for juvenile herring and also carried out by Allen (2004) on 0-group plaice. Otolith embedding and mounting was carried out as in Allen (2004), as follows:

Otoliths were embedded in TAAB© transmit resin used in light microscopy. Otloiths were placed concave side down in caps from 0.5ml micro centrifuge tubes, which were used as moulds. The resin was then dried at 70°C for approximately 15 hours. The block of resin, containing the otolith, was then removed from the mould and attached to glass slides using glue under heat.

Polishing was carried out using 2000 and 4000-grit silicon. Polishing was continued until post-larval daily increments were seen. Polishing was carried out cautiously after this point so as not to damage the otoliths. Further polishing revealed larval growth rings, hatch mark and the otolith core.

Microstructure analysis was carried out using an Olympus CX41 light microscope under 40X and 100X (oil immersion) magnification. The digital camera used was an Olympus Camedia C-3040 with Olympus DP-Soft 3.2 image analysis software.

4.3.4 Otolith microstructure analysis

Otolith microstructure analysis allowed the determination of: (1) hatch check (2) daily larval growth increments (3) first accessory primordium and (4) post larval growth increments (Figures 4.1 and 4.2). The author carried out three replicate readings of each otolith analysed, on different occasions, for validation purposes.

The hatch check is situated approximately 10 μm from the otolith core (Hovenkamp 1990). From the hatch check larval duration (age in days) can be calculated by counting the daily growth rings (Figure 4.2) up to the edge of the first accessory primordium. The start of the first accessory primordium denotes the end of metamorphosis and thus settlement (Alhossaini *et al.* 1989, Modin *et al.* 1996). Counting daily growth increments from the start of the first accessory primordium to the edge of the otolith will give post-settlement duration (age in days).

Hatch date and settlement dates were calculated using the above information. Hatch dates were calculated by counting all daily growth increments from the hatch check to the otolith edge. This result (number of days) was subtracted from the date of capture to reveal hatch date. Settlement dates were calculated by counting the post-larval daily growth increments from the start of the first accessory primordium to the edge of the otolith. Settlement dates could then be calculated by subtracting the post-larval duration in days from the date of capture. No correction was made for the fact that daily increments are reported to be deposited in 0-group plaice 4 to 6 days before hatching (Karakiri and Westernhagen 1989). These increments were not observed in this project however.

Figure 4.1: Picture of a 0-group plaice otolith taken under 40x magnification with first accessory primordium and otolith core indicated.

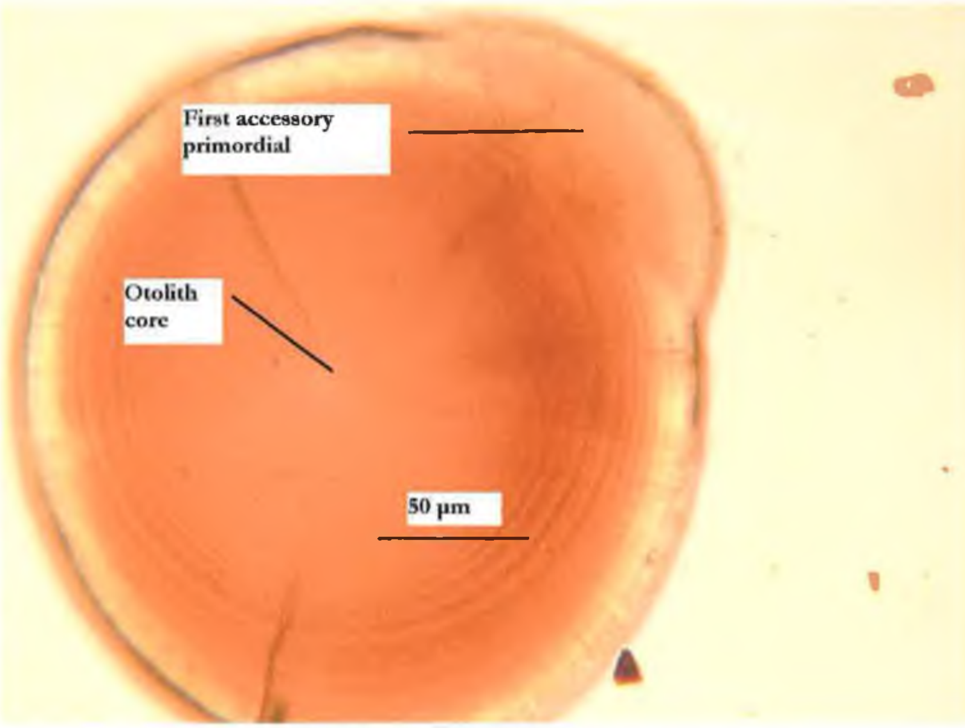
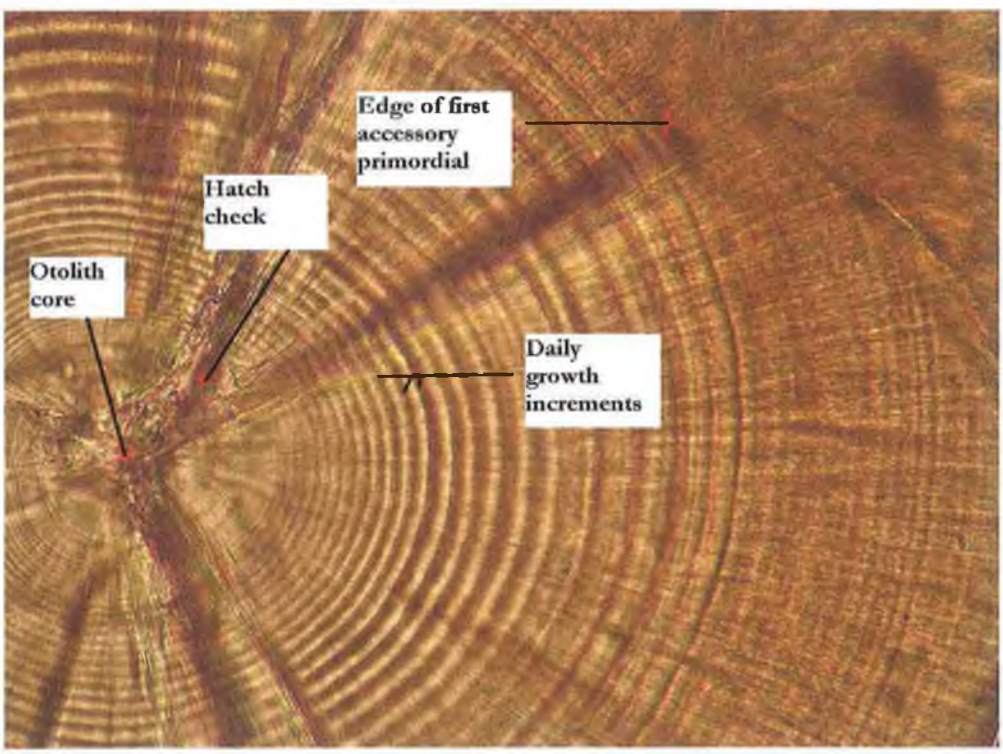


Figure 4.2: Picture of 0-group plaice otolith taken under 100x magnification (oil immersion) with otolith core, hatch check, daily growth increments and the edge of the first accessory primordium indicated.



4.3.5 Daily growth rates

Otolith increment widths were measurements were taken using Olympus DP-Soft 3.2 image analysis software. Every daily growth increment was measured from the hatch check to the outer edge of the otolith. Increment widths (μm) from day 20 to 25 after hatching were used for comparison of daily larval growth rates.

Daily growth rates ($mm.d^{-1}$) for 0-group plaice after metamorphosis in Galway Bay were calculated from Amara and Paul (2003).

$$\mathbf{G = (TL_{catch} - TL_{metamorphosis}) / Age\ after\ metamorphosis}$$

Where TL is the total length at catch and metamorphosis respectively. TL at metamorphosis used for calculation was 12mm (Ryland 1966 in Amara and Paul 2003). This would allow comparison between growth rates.

Observed daily growth rates were then compared to predicted daily growth rates. The equation used for predicted growth (ΔL) in length ($mm\ mo^{-1}$) of 0-group plaice was taken from Glazenburg (1983) in Van der Veer (1986).

$$\mathbf{\Delta L = 1.3 \times T + 1.7\ (mm\ mo^{-1})}$$

T is the mean monthly temperature (°C) taken from the Marine institute M1 data buoy off the west coast of Ireland.

This simple descriptive growth model obtained under excess feeding conditions is specifically for small 0-group plaice up to 5cm (Van der Veer 1986). Daily predicted growth was calculated by dividing the predicted monthly growth by 30.

4.3.6 Data analysis

Data management

The raw data collected during otolith microstructure analysis on 0-group plaice were coded and entered into Microsoft EXCEL worksheets (version 2000) and all data were error checked and corrected. Further data analysis was carried out using EXCEL or MINITAB (version 14).

The relationship between total age from hatching and total lengths (mm) of 0-group plaice was assessed using regression analysis. A scatter plot of the two variables was produced and the line or curve of best fit was fitted. Goodness of fit was assessed by the coefficient of determination (R^2), which measures the proportion of variability in one variable, which is accounted for by variability in another (Fowler *et al.* 1998). Pearsons correlation test was then carried out on the data set.

4.3.7 Statistical tests

Further analysis of data was carried out using MINITAB (version 14). All data were subjected to Ryan-Joiner normality tests and checked for homogeneity of variance using Cochran's test. If data was found not to be normal transformations were carried out. Log transformations were used (Underwood 1997).

On normal data, ANOVA tests were carried out. These were either two factor ANOVA (months x beaches) or three factor ANOVA (years x months x beaches). If a significant difference was found, where ANOVA was used, Fishers pairwise post hoc analysis was used to further analyse these results.

If normality could not be achieved non- parametric Kruskal-Wallis tests for significant difference were used. Moods –median tests were used for post hoc analysis where significant differences were observed.

. The null hypotheses (Ho) used for the different experiments, using three factor ANOVA or non-parametric tests for significant difference, in 2003 (data from Allen (2004)) and 2005, on Ballyloughan and Silverstrand, were as follows:

(1) There is no difference in hatch dates of 0-group plaice between years, months or beaches.
(2) There is no difference in larval duration between years, months or beaches.
(3) There is no difference in settlement dates between years, months or beaches.
(4) There is no difference in the post-larval duration between years, beaches or months.
(5) There is no difference in the total age since hatching of 0-group plaice between years, months and beaches.

All of the above ANOVA tests were analysed for the presence of interactions among the main factors. Where a significant interaction occurred no conclusions were drawn on the main effects of the two factors (e.g. years or beaches). Interpretation of the main effects are impossible or at best unreliable when there is an interaction (Underwood 1997). Further analysis was only carried out, after an interaction was discovered, if it helped further explain patterns observed.

Test for significant difference were also carried out on 2005 data only. This was done due to the addition of a third beach (Glann na Ri). The addition of a third beach added extra spatial dimension to the project. The null hypotheses, using two factor ANOVA (months x beaches) were as follows.

(1) There is no difference in hatch dates of 0-group plaice between months or beaches.
(2) There is no difference in larval duration between months or beaches.
(3) There is no difference in settlement dates between months or beaches.
(4) There is no difference in the post-larval duration between months or beaches.
(5) There is no difference in the total age since hatching of 0-group plaice between months and beaches.

Again all of the above ANOVA tests were analysed for the presence of interactions among the main factors. Where a significant interaction occurred no conclusions were drawn on the main effects of the two factors as above.

4.4 Results

4.4.1 Sample information

Sampling dates, locations, number of 0-group plaice randomly picked and the number of days between samples can be seen in table 4.1. These data were used for all analysis. Data for 0-group plaice from April and May 2003 were taken from Allen (2004).

Table 4.1: Sampling dates and locations, numbers of 0-group plaice and numbers of days between samples, for Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR).

Location	Months	Dates	Numbers of 0-group plaice	Number of days between samples
BN 0505	April	8-4-05	10	
BN 0508	May	24-5-05	10	46
SS 0505	April	11-4-05	10	
SS0508	May	31-5-05	10	50
GNR 0501	April	14-4-05	10	
GNR 0504	May	23-5-05	10	39

The author carried out three readings, on different occasions, on each otolith sampled in order to validate results. A one-way ANOVA was carried out on larval duration to test the hypothesis that there was no significant difference between the readings. No significant difference was observed over the three readings on larval duration ($p = 0.417$). Kruskall-Wallis tests were carried out on the three readings of post-larval duration, as data were not normal, to test the hypothesis that there was no significant difference in the three readings. Results revealed that there was no significant difference between the three readings ($p = 0.620$). Thus the author was consistent in age determination, both on the pelagic (larval) and benthic (post-larval) stages.

4.4.2 Hatching dates

Hatching times and ranges for Ballyloughan, Silverstrand and Glann na Ri in April and May 2005 can be seen in table 4.2 and graphically in figure 4.3 and 4.4 Combined data for the three beaches for 2005 are also included (figure 4.4).

Table 4.2: Mean hatching times and the range of hatching times of 0-group plaice from Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR) for April and May 2005 (Combined data is also shown.)

Locations	Months	Mean hatch dates (±) S.D	Range of hatch dates
BN 0505	April	20-Feb (±) 7	11-Feb – 7-Mar
BN 0508	May	12-Mar (±) 6	2-Mar – 19-Mar
SS 0505	April	25-Feb (±) 5	18-Feb – 3-Mar
SS0508	May	15-Mar (±) 18	11-Feb – 3-Apr
GNR 0501	April	15-Feb (±) 11	31-Jan – 2-Mar
GNR 0504	May	19-Mar (±) 10	4-Mar – 4-Apr
Combined data	April	20-Feb (±) 9	31-Jan – 7-Mar
	May	15-Mar (±) 12	11-Feb – 4-Apr

Hatch dates of 0-group plaice caught in April 2005 on the three beaches ranged from the 31st of January to the 7th of March (Table 4.2). The mean hatch date for Ballyloughan was the 20th of February ± 7 days. On Silverstrand the mean hatch date was the 25th of February ± 5 days and on Glann na Ri the mean hatch date was the 15th of February ± 5 days. In May 2005, hatch dates of 0-group plaice, on the three beaches sampled, ranged from the 11th of February to the 4th of April. On Ballyloughan, the mean hatch date was the 12th of March ± 6 days. The mean hatch date on Silverstrand was the 15th of March ± 18 days and on Glann na Ri the mean hatch date was the 19th of March ± 10 days. All hatch dates were transformed into Julian days using Microsoft EXCEL spreadsheets. This allowed further statistical analysis.

Figure 4.3: Hatch dates for 0-group plaice from Ballyloughan (BN), Silverstrand (SS) and Glann na Ri sampled during April and May 2005 (n = 60).

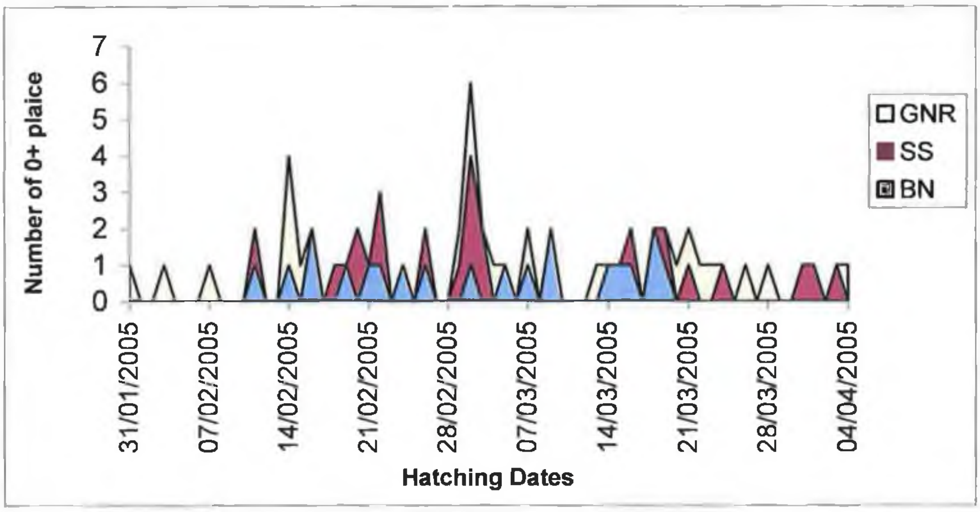
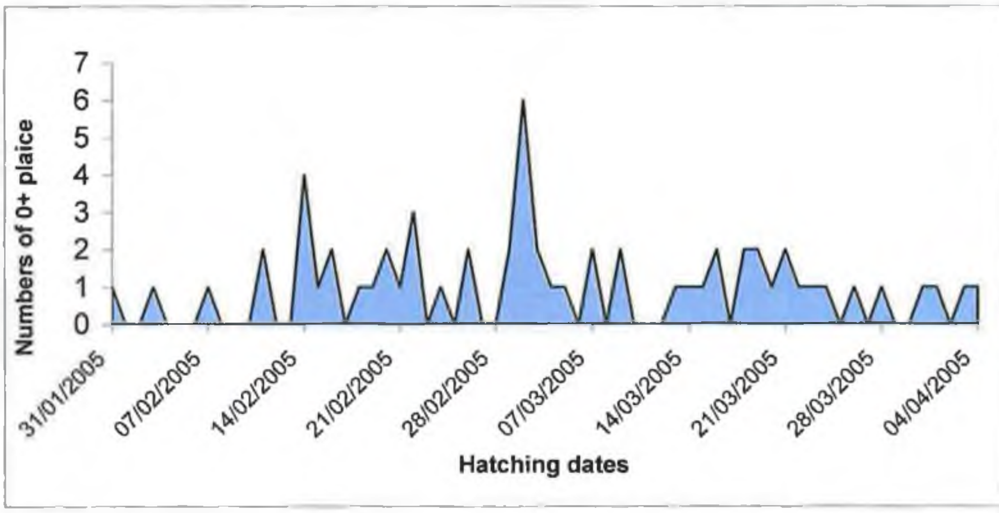


Figure 4.4: Hatch dates for 0-group plaice from Galway Bay (three beaches combined) sampled in April and May 2005.



Peaks in hatching fish were noted around the 21st to the 28th of February on Silverstrand and on the 14th to the 28th of February on Glann na Ri. No real pattern could be discerned for Ballyloughan (figure 4.3). Data from the three beaches was combined to reveal hatching patterns for Galway Bay (figure 4.4). Peaks in hatching fish were noted around the 14th and the 28th of February.

A two factor ANOVA (months x beaches) was used to test the hypothesis that there was no significant difference in hatch dates between April and May 2005 on the three beaches sampled. Results showed that there was no significant difference between beaches ($p = 0.330$) and there was no interaction between the main factors ($p = 0.283$). However there was a significant difference in hatch dates between months ($p = 0.016$). Fishers pairwise post hoc analysis showed that April caught fish had hatched earlier than May caught fish (table 4.2). This would be the expected result.

Hatch dates in 2003 and 2005, for Ballyloughan and Silverstrand, were tested for significant difference using Kruskal-Wallis tests, as data were not normal and would not transform. When yearly variation was being tested the data from all beaches and all months were pooled together into their particular year. When comparison between months was being tested all fish regardless of beach or year were pooled together into their particular month category. For the analysis of beach data, all fish from a particular beach, regardless of month or year were pooled together

Results showed that there was no significant difference in hatch dates between years ($p = 0.089$) or between beaches ($p = 0.392$). A significant difference was noted between months ($p = 0.040$). Moods median test ($p = 0.044$) revealed that April had a significant earlier hatch period over both years tested. Again this was the expected result.

In summary, hatching dates for fish caught on the three beaches sampled in April and May 2005 ranged from the end of January to early April. No significant difference was noted in hatching dates between beaches. A significant difference however was recorded between months, which would be expected. Fish caught in April 2005 had earlier hatch dates than fish caught in May 2005. Hatching dates for Ballyloughan and Silverstrand were compared for April and May in 2003 and 2005. No significant difference was noted between years or between beaches. However a significant difference was noted between months, with fish caught in April again having earlier hatch dates than May caught fish.

4.4.3 Larval duration.

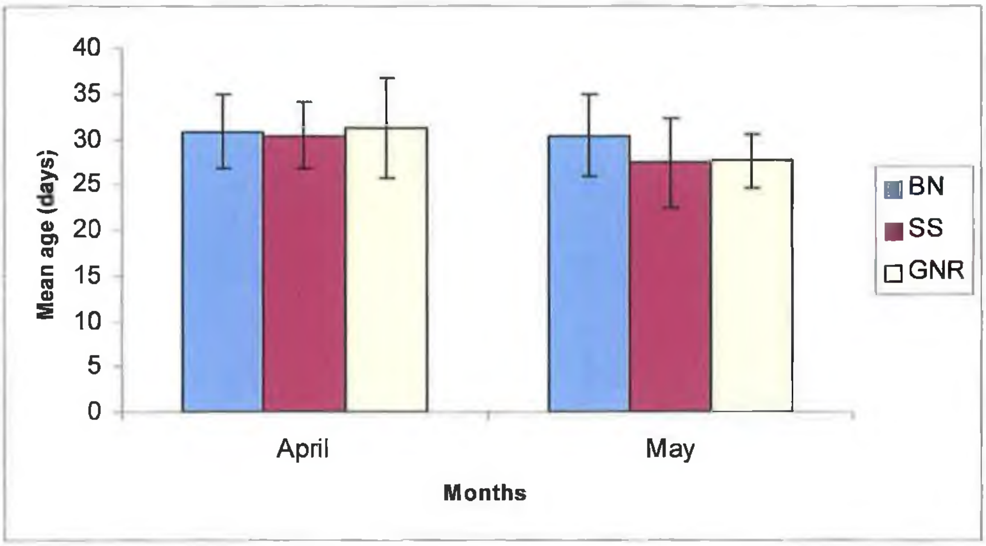
Mean larval duration (from the hatch check to the edge of the first accessory primordium) for Ballyloughan, Silverstrand and Glann na Ri can be seen in figure 4.5.

Table 4.3: Mean larval duration (days) and ranges for 0-group plaice in April and May 2005 on Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR). Combined data for the three beaches is also shown.

Locations	Months	Mean larval duration (days) (±) S.D	Range of larval durations (days)
BN 0505	April	31 (±) 4	21 - 40
BN 0508	May	30 (±) 5	26 - 45
SS 0505	April	30 (±) 4	21 - 35
SS0508	May	27 (±) 5	22 - 35
GNR 0501	April	31 (±) 5	21 - 40
GNR 0504	May	28 (±) 3	21 - 35
Combined Data	April and May	30 (±) 4	21 - 45

The larval duration of 0-group plaice on Ballyloughan in April 2005 ranged from 21 to 40 days with a mean of 30 ± 4 days (table 4.3). In May, the larval duration ranged from 26 to 45 days with a mean of 30 ± 5 days. In April 2005, the larval duration on Silverstrand ranged from 21 to 35 days with a mean value of 30 ± 4 days. The larval duration range in May was from 22 to 35 days with a mean of 27 ± 5 days. The larval duration of 0-group plaice on Glann na Ri ranged from 21 to 40 days in April 2005 with a mean value of 31 ± 5 days. In May, the range was from 21 to 35 days with a mean value of 28 ± 3 days. In overview larval duration for 2005 (April and May combined) ranged from 21 to 45 days with a mean value of 30 ± 4 days over the three beaches sampled. The mean larval duration for the three beaches in April and May 2005 can be seen in figure 4.5.

Figure 4.5: Mean larval duration of 0-group plaice from Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR) from samples caught in April and May 2005.



An orthogonal two-way ANOVA (months x beaches) was carried out on larval duration to test the hypothesis that there was no significant difference between months or beaches for April and May 2005 on the three beaches sampled. Results revealed that there was no significant difference in larval duration between months ($p = 0.094$) or beaches ($p = 0.124$). No significant interaction occurred between the main factors ($p = 0.628$).

Larval duration data from 2003 and 2005 were used to test the hypothesis that there was no significant difference in larval duration between years and between beaches (Ballyloughan and Silverstrand). April and May samples were tested separately, as data for May was found not to be normal. April data were normal and was analysed using a two factor ANOVA (years x beaches). No significant difference was noted between years ($p = 0.473$) or between beaches ($p = 0.632$). No interaction was observed between the main factors ($p = 0.236$).

Kruskal-Wallis tests were used to analyise larval duration data for May 2003 and 2005, as data were not normal and would not transform. Data from both beaches was pooled together into their yearly group. Results showed that there was no significant difference between beaches ($p = 0.071$). However a significant difference was noted between larval duration and years ($p < 0.002$). Moods median test ($p < 0.003$) revealed that larval duration in 2003 (29 days median value) was shorter than in 2005 (32 days median value).

In summary, larval duration in Galway Bay ranged from 21 to 45 days for fish caught in April and May 2005 on the three beaches sampled. No significant difference was noted in larval duration between months or beaches, for fish caught in April and May 2005 on Ballyloughan, Silverstrand and Glann na Ri. Data for Ballyloughan and Silverstrand were compared to results from April and May 2003. No significant difference in larval duration was noted between years or beaches in April, however a significant difference was noted in larval duration in May between 2003 and 2005. It was revealed that fish in May 2005 had a longer larval life than fish in May 2003.

4.4.4 Settlement dates

Settlement dates and ranges for Ballyloughan, Silverstrand and Glann na Ri in April and May 2005 can be seen in Table 4.4 and graphically in figures 4.6 and 4.7 Combined data for the three beaches is also included. Settlement data were interoperated by counting the number of daily increments from the start of the first primary primordium to the edge of the otolith, and subtracting this number (days) from the capture date. Settlement date was then transformed into Julian days using Microsoft EXCEL spreadsheets in order to carry out statistical tests.

Table 4.4: Mean settlement times and ranges for 0-group plaice from Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR) for Aril and May 2005 (Combined data is also shown).

Locations	**Months**	**Mean Settlement dates (±) S.D**	**Range of settlement dates**
BN 0505	April	23-Mar (±) 5	16-Mar – 2-Apr
BN 0508	May	13-Apr (±) 8	2-Apr – 26-Apr
SS 0505	April	28-Mar (±) 4	21-Mar – 4-Apr
SS0508	May	13-Apr (±) 21	7-Mar – 12-May
GNR 0501	April	17-Mar (±) 7	6-Mar – 24-Mar
GNR 0504	May	16-Apr (±) 10	28-Mar – 3-May
Combined data	April	22-Mar (±) 7	6-Mar – 4-Apr
	May	14-Apr (±) 14	7-Mar – 12-May

Settlement dates of 0-group plaice caught in April 2005 on the three beaches ranged from the 6th of March to the 4th of April (Table 4.4). The mean settlement date for Ballyloughan was the 23rd of March ± 5 days. On Silverstrand the mean settlement date was the 28th of March ± 4 days and on Glann na Ri the mean settlement date was the 17th of March ± 7 days. See Figure 4.6.

In May 2005, settlement dates of 0-group plaice, on the three beaches sampled, ranged from the 7th of March to the 12th of May. On Ballyloughan, the mean settlement date was the 13th of April ± 8 days. The mean settlement date on Silverstrand was also the 13th of April ± 21 days and on Glann na Ri the mean hatch date was the 16th of April ± 10 days. See Figure 4.6.

Figure 4.6: Settlement dates for 0-group plaice from Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR) from samples taken in April and May 2005.

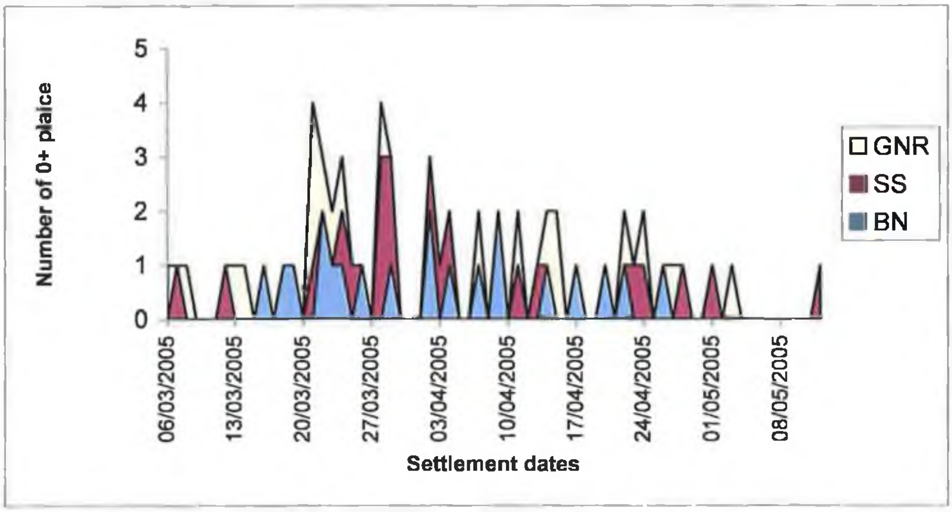
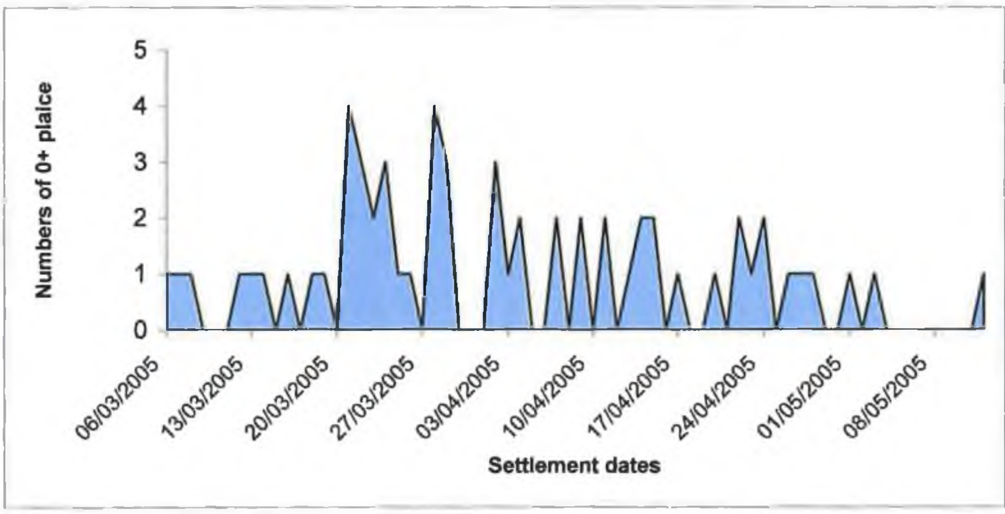


Figure 4.7: Settlement dates for 0-group plaice for Galway Bay (three beaches combined) from samples taken in April and May 2005.



Peaks in settling fish was noted around the 20th of March and the 3rd of April on Ballyloughan and on the 27th of March and the 3rd of April on Silverstrand (Figure 4.6). Relatively high numbers of settling fish were noted from Glann na Ri on 20th and the 27th of March. Data from the three beaches was combined to reveal settlement patterns for 0-group plaice in Galway Bay in 2005 (Figure 4.7). In summary, peaks in settling fish were noted around the 20th of March to the 3rd of April 2005.

A two factor orthogonal ANOVA (months x beaches) was carried out on settlement dates of 0-group plaice from the three beaches sampled, to test the null hypothesis that there was no significant difference in settlement dates between months and beaches in April and May 2005. Results revealed that there was no significant difference noted in settlement dates between beaches ($p = 0.475$). However there was a significant difference noted between months ($p = 0.020$). Fishers pairwise post hoc revealed that fish caught in April had earlier settlement dates than fish caught in May, which would be expected. No significant interaction was noted between the two factors. It should be noted that this is the same pattern observed for hatch dates (see section 4.4.2)

Data on settlement dates from 2003 and 2005 in the months of April and May were analysed to test for significant difference between years, month and beaches. A three factor ANOVA (years x months x beaches) was used. No significant difference was observed between years ($p = 0.640$) or beaches ($p = 0.251$). A significant difference was noted between settlement dates and months ($p < 0.001$). Post hoc analysis revealed that fish caught in April settled earlier than fish caught in May. Again this is similar to the pattern observed for hatch dates (see section 4.4.2). No significant interaction was observed between the main factors ($p = 0.523$).

In summary, settlement dates for fish caught in April and May 2005 ranged from early March to mid-May. No significant difference was noted in settlement dates between the three beaches sampled in April and May 2005. However there was a significant difference in settlement dates between April and May 2005, which would be expected. Fish caught in April had earlier settlement dates than fish caught in May. Data for Ballyloughan and Silverstrand were compared for April and May 2003 and 2005. No significant difference was noted between years or beaches. Again there was a significant difference in settlement dates between months with fish caught in April having earlier settlement dates than fish caught in May, again this would also be expected. This pattern is similar to the pattern noted for hatch dates.

4.4.5 Post-larval age

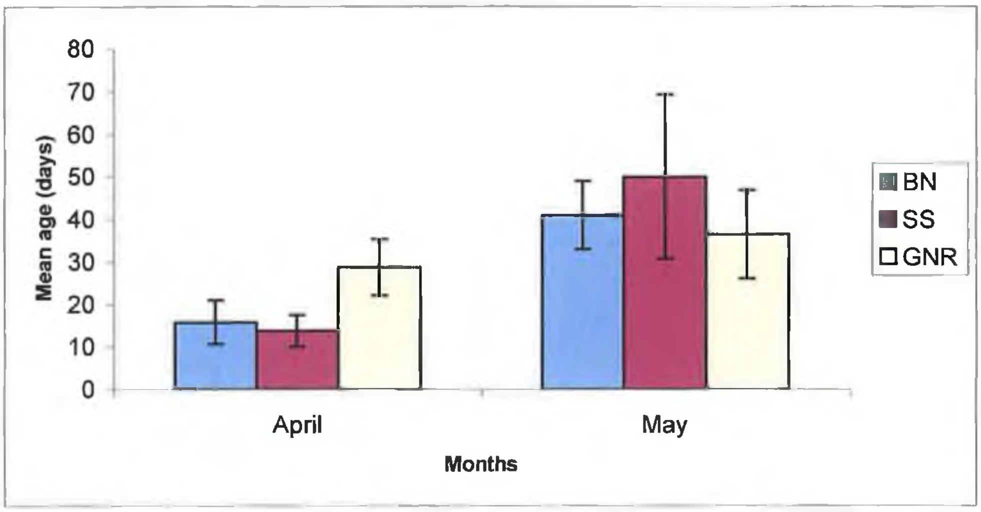
Post-larval duration data (From the start of the first accessory primordium to the edge of the otolith) for 0-group plaice from Ballyloughan, Silverstrand and Glann na Ri can be seen in Table 4.5. Post larval age is the number of days spent on the beach from settlement to capture date. Mean post larval age for the three beaches sampled can be seen in Figure 4.8.

Table 4.5: Mean post-larval age (days) ± S.D and ranges for 0-group plaice in April and May 2005 on Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR).

Locations	Months	Mean post-larval duration (days) (±) S.D	Range of post-larval durations (days)
BN 0505	April	16 (±) 5	6 - 23
BN 0508	May	41 (±) 8	28 - 52
SS 0505	April	14 (±) 4	8 - 18
SS0508	May	50 (±) 19	30 - 85
GNR 0501	April	29 (±) 7	21 - 39
GNR 0504	May	37 (±) 10	20 - 56

The post-larval age of 0-group plaice on Ballyloughan in April 2005 ranged from 6 to 23 days with a mean value of 16 ± 5 days. In May, the post-larval age ranged from 28 to 52 days with a mean of 41 ± 8 days. In April 2005, the post-larval age on Silverstrand ranged from 8 to 18 days with a mean value of 14 ± 4 days. The post-larval age range in May was from 30 to 85 days with a mean of 50 ± 19 days. The post-larval age of 0-group plaice on Glann na Ri ranged from 21 to 39 days in April 2005 with a mean value of 29 ± 7 days. In May the range was from 20 to 56 days with a mean value of 37 ± 10 days. In summary, post-larval age ranged from 6 to 85 days for fish caught in April and May 2005 on Ballyloughan, Silverstrand and Glann na Ri. The data suggests that the fish caught in May are older than fish caught in April (Figure 4.8).

Figure 4.8: Mean post-larval age of 0-group plaice ± S.D from Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR) in April and May 2005.



Post-larva age data of 0-group plaice for April and May 2005, for the three beaches sampled, was tested using ANOVA. The null hypothesis tested stated that there was no difference in post-larval age between beaches and between months. Data were found to be normal after log transformation and therefore an orthogonal two-way ANOVA (months x beaches) was used. Results revealed that there was no significant difference in post-larval age between months ($p = 0.087$) or between beaches ($p = 0.558$). A significant interaction was noted between the main factors ($p < 0.001$). This interaction means that some of the beaches were different in some of the months. This may indicates a difference at a smaller local temporal and spatial scale. Figure 4.8 suggests that fish on Ballyloughan and Silverstrand are older in May than in April but that fish on Glann na Ri have a similar post-larval age in April and May. Figure 4.8 also indicates small-scale spatial differences. Fishers pairwise post hoc analysis revealed that in April 2005 Ballyloughan and Silverstrand were similar (16 ± 5 and 14 ± 4 days respectively). Silverstrand was different to Glann na Ri (29 ± 7 days). Ballyloughan and Glann na Ri were similar. In May post hoc analysis revealed that that Ballyloughan, Silverstrand and Glann na Ri were similar (50 ± 19 days, 41 ± 8 days and 36 ± 10 days respectively).

Post-larval age data from 2003 and 2005 were used to test the hypothesis that there was no significant difference in post-larval age between years and between beaches. April and May samples were tested separately. April 2003 and 2005 data were found to be normal and were analysed using a two factor ANOVA (years x beaches). A significant difference was noted between years (p = 0.002) (figure 4.9) and between beaches (p = 0.005) (figure 4.10). Further analysis revealed that fish caught in April 2003 had a shorter post-larval age than fish caught in April 2005 (Figure 4.9). Post hoc analysis also revealed that Ballyloughan had a longer post-larval age compared to Silverstrand in April 2003 and 2005 (figure 4.10). No significant interaction was observed between the main factors (p = 0.076).

Figure 4.9: Post–larval age (days) of 0-group plaice (Ballyloughan and Silverstrand combined) in April 2003 and 2005.

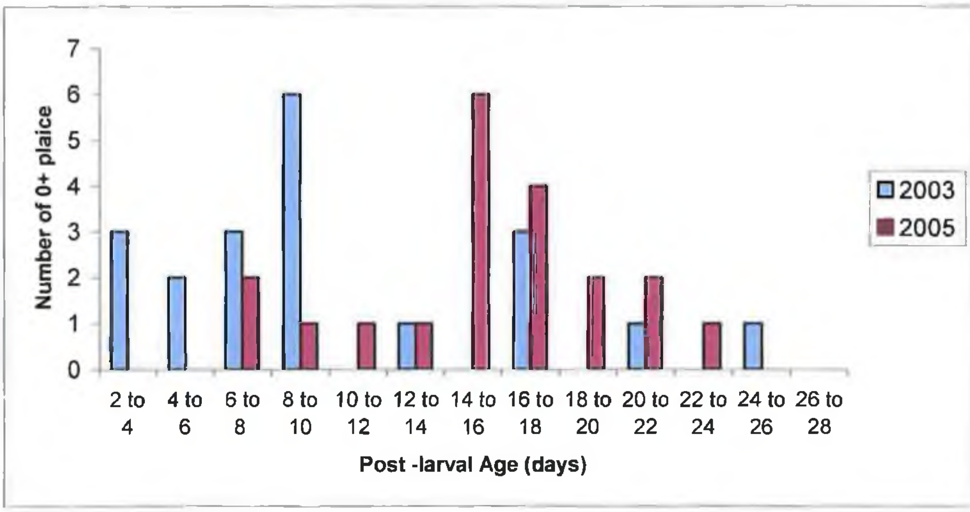
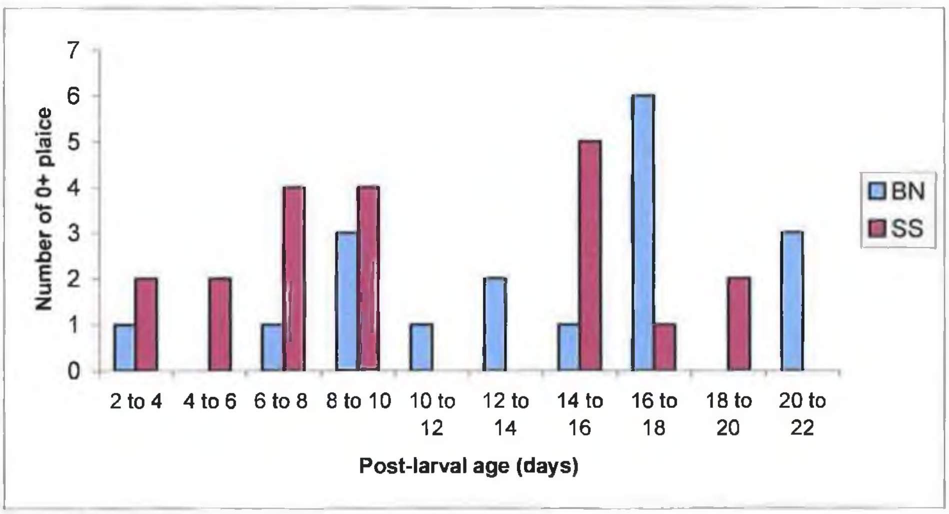


Figure 4.10: Post-larval age (days) of 0-group plaice from Ballyloughan (BN) and Silverstrand (SS) in April 2003 and 2005 (2003 and 2005 data are combined).



Data on post-larval age from May 2003 and 2005 were also analysed using an orthogonal two-way ANOVA (years x beaches). Results revealed that there was a significant difference in post-larval age between years ($p < 0.001$). Fishers pairwise analysis revealed that fish caught in May 2003 had a shorter post-larval age than fish caught in May 2005. No significant difference was noted between beaches ($p = 0.057$). No significant interaction was observed between the main factors ($p = 0.965$). Fishers pairwise post hoc analysis also revealed that 2005 had a longer post larval age than 2003.

In summary, post-larval age ranged from 6 to 85 days for fish caught in April and May 2005. No significant difference was noted in post-larval age between Ballyloughan, Silverstrand and Glann na Ri in April or May 2005. Data for 2005 was compared to data from 2003 for Ballyloughan and Silverstrand. A significant difference was noted in post-larval age between years and beaches in April 2003 and 2005 (Figures 4.9 and 4.10). In May 2003 and 2005 a significant difference was observed, in post-larval age, between years. However no significant difference was noted between beaches. Post larval age for 0-group plaice showed some spatial and temporal differences in Galway Bay.

4.4.6 Total age from hatching

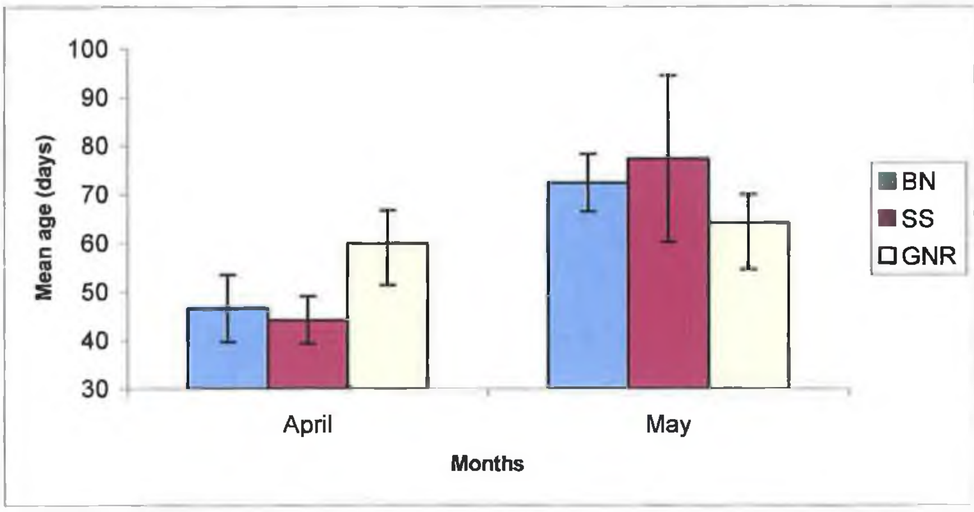
Total age data (age in days from the hatch check) for 0-group plaice from Ballyloughan, Silverstrand and Glann na Ri in 2005 can be seen in table 4.6. Mean total age for the three beaches sampled can be seen in figure 4.11.

Table 4.6: Total age (days) from hatching ± S.D and ranges for 0-group plaice in April and May 2005 on Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR).

Locations	Months	Mean post-larval duration (days) (±) S.D	Range of post-larval durations (days)
BN 0505	April	47 (±) 7	32 - 56
BN 0508	May	72 (±) 6	66 - 83
SS 0505	April	44 (±) 5	39 - 52
SS0508	May	77 (±) 17	61 - 109
GNR 0501	April	60 (±) 9	45 - 74
GNR 0504	May	64 (±) 10	56 - 80

The total age from hatching of 0-group plaice on Ballyloughan in April 2005 ranged from 32 to 56 days with a mean value of 47 ± 7 days. In May the total age ranged from 66 to 83 days with a mean of 72 ± 6 days. In April 2005 the total age on Silverstrand ranged from 39 to 52 days with a mean value of 44 ± 5 days. The total age range in May was from 61 to 109 days with a mean of 77 ± 17 days. The total age of 0-group plaice on Glann na Ri ranged from 45 to 74 days in April 2005 with a mean value of 60 ± 9 days. In May the range was from 56 to 80 days with a mean value of 64 ± 10 days. In summary the total age of 0-group plaice caught on the three beaches in April and May 2005 ranged from 32 to 109 days old from hatching. Fish caught in May were older than fish caught in April. Mean total ages are shown graphically in Figure 4.11.

Figure 4.11: Mean total age of 0-group plaice from hatching ± S.D on Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR) in April and May 2005.



A two factor ANOVA (months x beaches) was used to test the null hypothesis that there was no significant difference in total age of 0-group plaice between the three beaches sampled in April and May 2005. Results revealed that there was no significant difference noted between beaches ($p = 0.496$) or months ($p = 0.077$). However there was an interaction between the main factors ($p = 0.004$). This interaction means that some of the beaches are different in some of the months. Figure 4.11 reveals that mean ages for Ballyloughan and Silverstrand seem different in April and May. However mean ages for Glann na Ri is similar in both months. This pattern is the same as seen for post-larval age (Figure 4.8) and would be expected as one age is relative to the other.

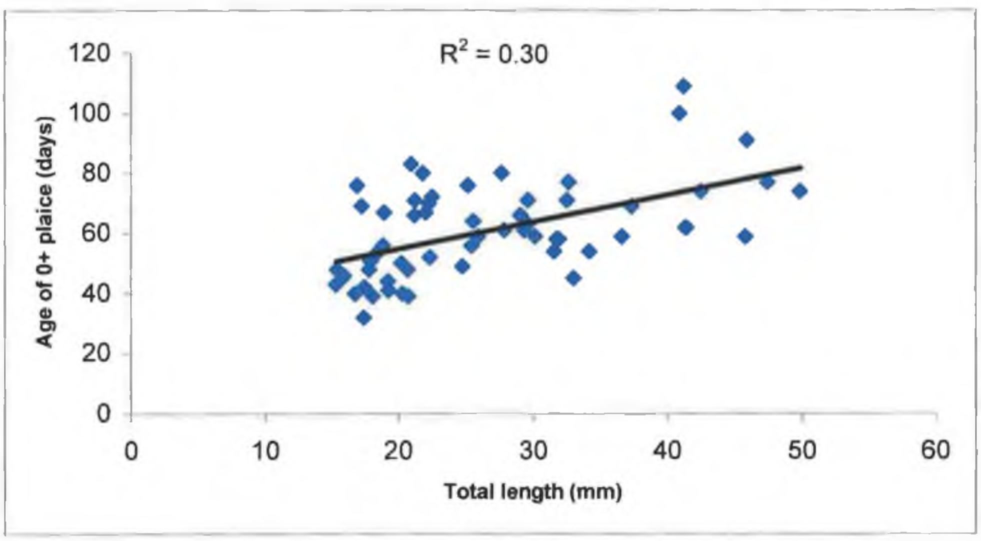
Data on total ages of 0-group plaice from Ballyloughan and Silverstrand in April and May 2003 and 2005 were analised separately. A two factor ANOVA (years x beaches) was used to test the hypothesis that there was no significant difference in total ages of 0-group plaice in the month of April between years and beaches. No significant difference was observed between years ($p = 0.238$) or beaches ($p = 0.238$) and there was no interaction of the main factors ($p = 0.413$).

Total age of 0-group plaice since hatching were also analysed for the month of May in 2003 and 2005. A two factor ANOVA was used to test the hypothesis that there was no significant difference in total ages of 0-group plaice between years and between Ballyloughan and Silverstrand. Results showed no difference between years ($p = 0.106$) or between beaches ($p = 0.248$). There was no interaction between the main factors ($p = 0.452$).

In summary, total ages of 0-group plaice ranged from 32 to 109 days for fish caught in April and May 2005 on the three beaches sampled. No significant difference was noted in total ages of 0-group plaice between beaches or months, on the three beaches sampled in April or May 2005. However there was a significant interaction between the main terms. Data on total ages of 0-group plaice from Ballyloughan and Silverstrand, in April and May 2005, were compared to results from April and May 2003. No significant difference was noted between years or beaches.

Total age of 0-group plaice was compared to total length (mm) at capture using regression analysis (Figure 4.12). A relationship of $r^2 = 0.30$ was observed. Pearsons correlation test gave a value of 0.548 and a p-value of ($p < 0.001$). This graph clearly reveals the variation in growth rates among individual 0-group plaice.

Figure 4.12: Total age (days) of 0-group plaice (n=60), from hatching to capture date, versus total length (mm) on Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR) in April and May 2005.



4.4.7 Growth

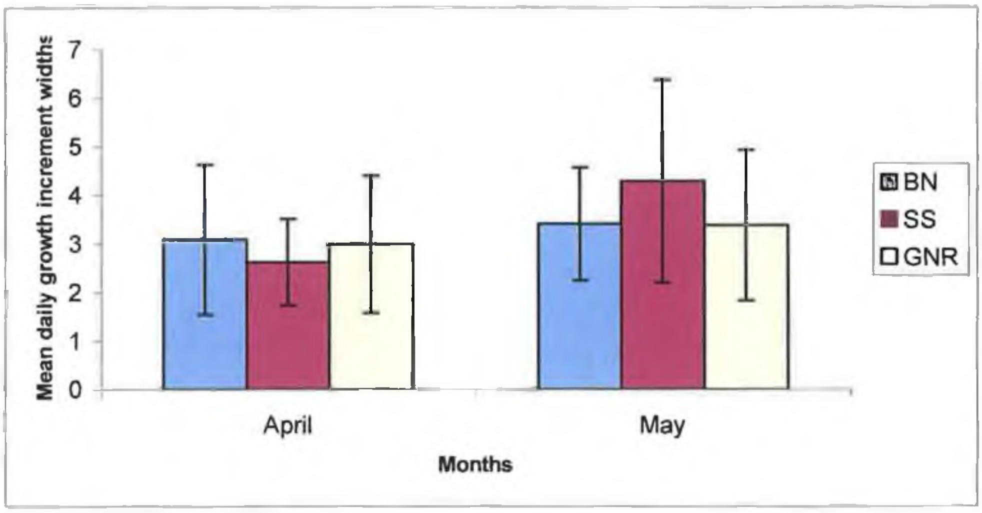
Otolith increment width (µm) was used as an index of larval growth (Table 4.7 and Figure 4.13) (Karakiri *et al.* 1991, Gilliers *et al.* 2004). Increment widths were taken from day 20 to 25, from the hatch check, for the 60 fish sampled.

Table 4.7: Daily growth increment widths (µm) ± S.D and ranges for 0-group plaice from day 20 to 25, from the hatch check, in April and May 2005 on Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR).

Locations	Months	Daily growth increment widths µm (±) S.D	Range of increment widths (µm) for all three beaches
BN 0505	April	3.09 (±) 1.54	1.02 – 7.84
BN 0508	May	3.41 (±) 1.16	0.7 – 9.7
SS 0505	April	2.62 (±) 0.89	1.02 – 7.84
SS0508	May	4.29 (±) 2.09	0.7 – 9.7
GNR 0501	April	2.99 (±) 1.41	1.02 – 7.84
GNR 0504	May	3.38 (±) 1.55	0.7 – 9.7

The daily increment widths from day 20 to 25 from hatching, for the three beaches sampled, ranged from 1.02 to 7.84 µm in April and 0.7 to 9.7 µm in May. On Ballyloughan, the mean increment width from day 20 to 25 was 3.09 ± 1.54 µm in April and 3.41 ± 1.16 µm in May. Silverstrand had a mean daily increment width of 2.62 ± 0.89µm in April and 4.29 ± 2.09 µm in May. For Glann na Ri the daily increment widths had a mean value of 2.99 ± 1.41 µm in April and 3.38 ± 1.55 µm in May. In summary, mean growth rates are slightly greater in May for all beaches sampled (Figure 4.13).

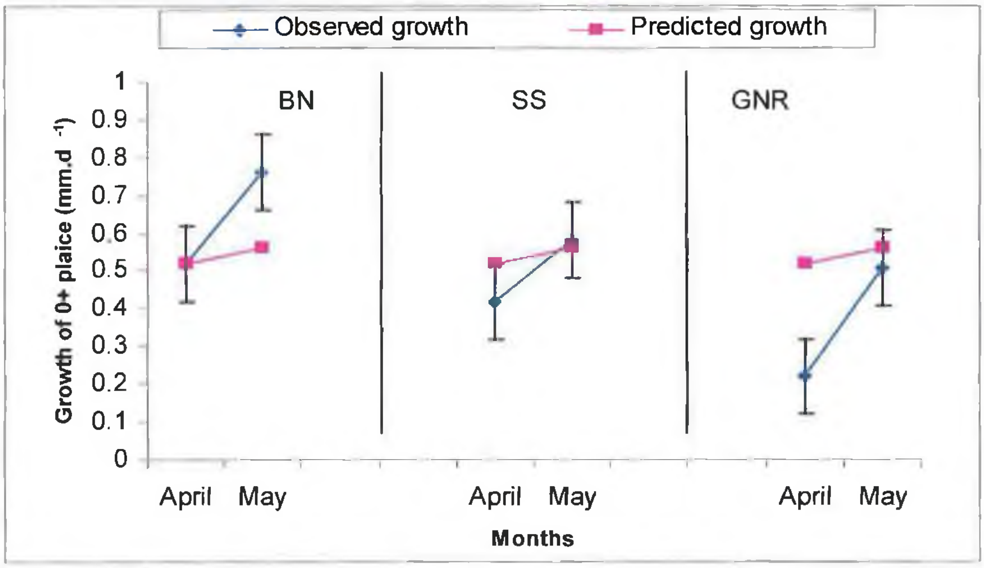
Figure 4.13: Mean daily growth increment widths (µm) ± S.D for 0-group plaice from day 20 to 25, from the hatch check, in April and May 2005 on Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR).



A two-way ANOVA (months x beaches) was used to test the hypothesis that there was no difference in otolith increment widths between months and beaches from day 20 to 25 of larval life. There was no significant difference observed between months ($p = 0.151$) or beaches ($p = 0.861$). However there was a significant interaction observed between the main factors ($p = 0.004$). This indicates that otolith increment widths were different on some of the beaches in some of the months. This may point to small-scale temporal and spatial differences.

Post-larval daily growth rates were calculated for 0-group plaice from Ballyloughan, Silverstrand and Glann na Ri using growth calculations from Amara and Paul (2003). Observed post-larval daily growth was compared to predicted growth (Figure 4.14) using a simple descriptive growth model obtained under excess feeding conditions (Glazenburg (1983) in Van der Veer 1986).

Figure 4.14: Observed post-larval growth rates (mm.d^{-1}) compared to predicted growth rates (Glazenburg 1983) for Ballyloughan (BN), Silverstrand (SS) and Glann na Ri (GNR) in April and May 2005. All beaches have ± S.D bars.



The average daily growth rate on Ballyloughan (Figure 4.13) in April 2005 was 0.52 ± 0.18 mm d^{-1} and in May the average daily growth rate was 0.76 ± 0.22 mm d^{-1}. On Silverstrand the average daily growth rate was 0.42 ± 0.29 mm.d^{-1} in April and 0.58 ± 0.25 mm d^{-1} in May. For Glann na Ri the average daily growth rate was 0.22 ± 0.07 mm d^{-1} in April and 0.51 ± 0.16 mm d^{-1} in May.

Observed daily growth was greater on Ballyloughan compared to Silverstrand and Glann na Ri. Here observed growth was equal to predicted growth in April 2005 and greater than predicted in May. Both Silverstrand and Glann na Ri showed smaller daily growth rates compared to predicted growth in April 2005 but both beaches showed similar growth rates compared to predicted in May. All beaches showed improved growth rates in May. Daily growth rates on Glann na Ri were the smallest observed over the three beaches.

A two-way ANOVA (months x beaches) was used to test the hypothesis that there was no significant difference in daily growth rates for 0-group plaice from the three beaches sampled in April and May 2005. No significant difference was noted between months ($p = 0.610$) or beaches ($p = 0.898$). However there was a significant interaction between the main factors ($p < 0.001$). This means that some of the beaches had different growth rates in April and May.

In summary no significant difference was noted in larval or post larval daily growth rates between beaches (Ballyloughan, Silverstrand and Glann na Ri) or months (April and May) in 2005. However there was a significant interaction between beaches and months. Overall growth rates were highest on Ballyloughan and lowest on Glann na Ri. Observed growth rates on Ballyloughan were generally greater than predicted. Observed growth rates on Silverstrand and Glann na Ri were generally lower than predicted. All beaches showed improved growth in May 2005.

4.4.8 Conclusions

Hatching, larval duration, larval growth and settlement are all part of the fishes pelagic life cycle. No spatial difference was noted in the pelagic stages for 0-group plaice in April or May in 2003 or 2005. Temporal difference, however, were noted. Post-larval age, post-larval growth and total age are all part of the benthic lifecycle of 0-group plaice. Here both spatial and temporal differences were noted in April and May in 2003 and 2005.

4.5 Discussion

4.5.1 Hatching period

Hatching period for 0-group plaice in Galway Bay (Ballyloughan, Silverstrand and Glann na Ri) in 2005 ranged from the end of January to early April. No significant difference was noted between the three beaches sampled; however there was a difference in hatch dates between April and May. Fish caught in April had earlier hatch dates than fish caught in May. This would be expected. April and May samples probably captured fish that hatched at different ends of the spawning period. The majority of fish that were on the beaches in April had probably suffered mortalities and were replaced by later hatching fish. High mortality is common among early stage juvenile flatfish species, due mainly to predation from invertebrate species (Wennhage and Pihl 2001, Bailey *et al.* 2005). Data from the present study were compared to a previous study in April and May 2003 (Ballyloughan and Silverstrand) (Allen 2004). No significant difference was noted between hatch dates in 2003 and 2005 for the months of April and May. Again there was no significant difference noted between beaches.

No evidence could be found for the presence of distinct cohorts during the present study. Analyses of hatching period graphs reveal relatively high numbers in hatching approximately around the 14^{th} and 28^{th} of February, over the three beaches sampled. Allen (2004) found the presence of three cohorts in Galway Bay in 2003. Sampling in 2003 however involved a larger data set (85 fish) and samples were taken from March to May. This larger data set over a longer period would be more likely to pick up evidence of individual cohorts. The present study using 60 fish over a two-month period would not be as sensitive to these patterns. A summary of hatching results for the present study and other European waters can be seen in Table 4.8.

Research on hatching periods using otolith microstructure analysis has been carried out in other European waters on 0-group plaice. Al-Hossaiani *et al.* (1989) showed a similar pattern of hatching periods for 0-group plaice in the Irish Sea in

1986 and 1987 ranging from late January to mid-April. Karakiri *et al.* (1991) also showed a similar pattern in hatching, starting in early February, in the Dutch Wadden Sea in 1988. Van der Veer *et al.* (2000) found a significant difference in hatching dates in the Dutch Wadden Sea between 1995 and 1996. Hatching range in 1995 was from early January to early March. The 1996 hatching period ranged from Mid January to early April. The later hatching dates in 1996 were related to colder temperatures and stronger year class.

In summary, results on hatching periods in Galway Bay from 2003 and 2005 revealed no significant temporal (between years) or spatial (between beaches) differences. Three cohorts of 0-group plaice were observed in 2003 but no evidence could be found for cohorts in the present study. This is probably related to sample size and sampling regime. Results obtained for Galway Bay were found to be similar to results from other European Waters.

4.5.2 Larval age and duration

The larval duration for 0-group plaice in Galway Bay, on Ballyloughan, Silverstrand and Glann na Ri, ranged from 21 to 45 days. In April, the larval age range was from 21 to 40 days over the three beaches and in May this range was 21 to 45 days. No significant difference in larval age was noted between the three beaches. Data for Ballyloughan and Silverstrand from April and May 2003 (Allen 2004) allowed comparison between years. Again no significant difference was found between beaches; however there was a significant difference between years for the May data. Analysis revealed that larva caught in May 2005 had a significantly longer larval life than fish caught in May 2003. This could be related to hydrographical conditions affecting larval supply to the beaches (Bailey *et al.* 2005). A summary for larval ages for the present study and other European waters can be seen in table 4.8.

The range in larval period observed in 2005 was similar to that observed by Allen (2004) in 2003 but fish with younger larval ages were observed in 2005. The larval age in Galway Bay is shorter than larval ages for plaice in other European waters. Al-Hossiani *et al.* (1989) showed the larval duration for 0-group plaice caught in the Irish Sea in 1986 and 1987 had mean values ranging from 50 to 53 days respectively. Larval ages of plaice ranging from 55 to 70 days were observed in the North Frisian Wadden Sea in 1981 and 1982 (Karakiri *et al.* 1989). Larval ages of 50 to 82 days were observed for the Dutch Wadden Sea in 1988 (Karakiri *et al.* 1991). Wegner *et al.* (2003) stated that the larval age in the North Sea is generally from 60 to 90 days. Difference in larval age between locations is probably temperature related.

Allen (2004) reviewed findings of larval age in Galway Bay in the light of data from published works in other European waters. Observations revealed that the shorter larval life in Galway Bay was probably due to relatively higher temperatures in the waters on the West coast of Ireland compared to other European waters. Fox *et al.* (2000) reviewed a time series of data on surface sea temperatures ranging from the 1950s to 1995 in waters around the United Kingdom. Sea temperature between January and June were described 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). Mean Sea temperatures in the Galway Bay area were 11.1°C in 2003 and 11.2°C in 2005.

Allen (2004) found that there was a significant difference in larval age between Ballyloughan and Silverstrand in April and May 2003. However analysis of the two years data in the present study did not show a difference in larval ages between beaches. A significant difference was shown for the month of May between years however. The conflicting results obtained in these two studies could be related to the smaller sample size used in the 2005 experiment (10 fish per beach), or to hydrographical conditions affecting larval supply in the different years. Karakiri *et al.* (1989) found no significant difference in the larval age of plaice from different locations in the North Frisian Wadden Sea in 1981 and 1982. However a difference in larval ages was observed between locations in the Dutch Wadden Sea for 0-group plaice in 1988 (Karakiri *et al.* 1991). Fish in some areas had hatched earlier in the season and had shorter larval periods than in other areas.

In overview, the range in larval ages for 2005 in Galway Bay in April and May were from 21 to 45 days. This is lower than observed in other European waters. No significant spatial difference was observed in larval age in Galway Bay. This is similar to findings for hatch dates. No significant difference was observed between years in April 2003 and 2005. A significant difference was observed between larval age and years in May 2003 and 2005. This could be related to hydrographical conditions affecting larval supply to the beaches (Bailey *et al.* 2005). Again no significant difference was observed between beaches.

4.5.3 Settlement period and post-larval age

Settlement dates of 0-group plaice caught in April and May 2005 on Ballyloughan, Silverstrand and Glann na Ri beaches ranged from the 6th of March to the 12th of May. Results revealed that there was no significant difference in settlement dates between the three beaches sampled, in 2005, but there was a significant difference in the settlement periods between months. Fish caught in April had earlier settlement dates than fish caught in May, as expected.

Results on settlement periods for Ballyloughan and Silverstrand from a previous study in April and May 2003 (Allen 2004) were compared to the current study. There was no significant difference in settlement dates between the two years sampled, however a significant difference was noted between settlement dates and months. Again fish caught in April had earlier settlement dates than fish caught in May, which again would be the expected result.

Analysis of settlement period graphs reveal relatively high numbers in settlement, for the three beaches sampled, approximately around the 20th of March to the 3rd of April in 2005. A relatively high number of settling fish was noted approximately 5 weeks after relatively high numbers in hatching. Allen (2004) noted peaks in settlement approximately one month after hatching periods in 2003. A summary for settlement dates for the present study and other European waters can be seen in Table 4.8.

Al-Hossaini *et al.* (1989) showed a similar pattern of settlement for 0-group plaice using otolith microstructure in the Irish Sea. Settlement period was from mid-April to late June in 1986 and late March to early June in 1987. Settlement continues for about one month longer than observed in Galway Bay.

On the French coast, otolith microstructure analysis of 0-group plaice revealed that peak settlement occurred between late March and mid-April (Amara and Paul 2003). This is very similar to the peaks in settlement noted in Galway Bay in 2005.

In the Wadden Sea, Karakiri *et al.* (1991) found differences in the settlement patterns of 0-group plaice between areas in 1988. Peak settlement was noted between April and May depending on location. In 1991 peak settlement was recorded in the third and fourth weeks of May in the Wadden Sea (Berghahn *et al.* 1995). This is later than settlement patterns observed in Galway Bay in 2003 and 2005.

In summary, settlement patterns in 2003 and 2005 were not significantly different to one another. There was also no difference in settlement patterns between the beaches sampled. Again there was no spatial difference as noted for hatch dates and larval duration. Settlement dates were different between the months of April and May. Plaice are batch spawners, and spawning can be prolonged, and this may explain differences in settlement dates (Nash and Geffen 2005). Settlement period was similar to patterns observed on the French coast (Amara and Paul 2003), and in the Irish Sea (Al-Hossaini *et al.* 1989).

Post larval age of fish caught in April and May 2005, on the three beaches sampled, ranged from 6 to 85 days. No significant difference was observed in post larval age between the three beaches or months in 2005. However there was a significant interaction between the main factors, which indicated that some of the beaches were different in April and May. Graphical and post hoc analysis revealed that Ballyloughan and Silverstrand seemed to be different in both months but Glann na Ri was similar in the two months studied. This revealed that there were small-scale temporal and spatial differences at work. Data for April and May 2005 (Ballyloughan and Silverstrand) were compared to data from April and May 2003 (Allen 2004). Results revealed that, for the month of April, there was a significant difference in post larval life between years (2003 and 2005) and between beaches (Ballyloughan and Silvrstrand Further analysis revealed that fish caught in April 2003 had a younger post-larval age than fish caught in April 2005. Graphical representation of this data showed that 2003 had a modal value of 9 days post-larval age and 2005 had a modal value of 15 days post–larval days. This was a significant result; however the difference in age was relatively small. Which would be expected considering that there was no significant difference in settlement dates between 2003 and 2005. Results also revealed that fish on Ballyloughan had an older post-larval age in April 2003 and 2005 compared to Silverstrand. Graphical analysis showed than Silverstrand had a majority of fish less than 10 days post-larval age with a modal value of 15 days. Ballyloughan however had the majority of fish from 12 to 22 days post-larval age, with a modal value of 17 days. The age difference represents approximately 10 days. No significant difference was noted in post-larval age between beaches for fish caught in May 2003 and 2005. However a significant difference was noted between years, with fish caught in May 2003 having a shorter post larval age than fish caught in 2005, again this could be hydrographical conditions affecting larval supply to the beaches (Bailey *et al.* 2005). The important factor in post-larval life is that this is the first time that a significant spatial (between beach) difference is noted.

4.5.4 Growth

Otolith increment width, from day 20 to day 25 after hatching, was used as an indicator of larval growth (Al-Hossaini and Pitcher 1988, Karakiri *et al.* 1989, Karakiri *et al.* 1991, Gillers *et al.* 2004). Results showed an increment width ranging from 0.7 μm to 9.7 μm over April and May 2005 on Ballyloughan, Silverstrand and Glann na Ri. No significant difference was observed in daily increment widths between months or between beaches. However there was an interaction between beaches and months. These results show that larval growth rates were similar for 0-group plaice in April and May. In summary, mean increment widths were generally larger on Ballyloughan indicating higher growth rates. The smallest mean increment widths were observed on Glann na Ri. A summary for juvenile growth for the present study and other European waters can be seen in table 4.8.

When compared to findings of surveys in other European waters larval growth rates are relatively similar in Galway Bay. Al-Hossaini and Pitcher (1988) described daily increments for tank reared post-metamorphic plaice (fish older than present study) as ranging from 0.86 μm for slow growing fish to 3.2 μm for fast growing fish. Al-Hossaini and Pitcher (1988) review unpublished works on increment widths of 0-group plaice from Loch Ewe, Scotland, Filey Bay, Yorkshire and Red wharf bay, Anglesey. These studies on wild juvenile plaice showed increment width ranges from 3.5 to 16.6 μm.

Karakiri *et al.* (1989) carried out otolith microstructure analysis on 0-group plaice from varying locations in the North Frisian Wadden Sea in 1981 and 1982. Increment widths were measured for post-metamorphic plaice. Increment widths laid down after metamorphosis were much larger than the larval increment widths, with most fish showing widths ranging from 4 μm to 8 μm. However there was great difference among areas and among years with some fish showing mean increment widths of 1μm. Some larval increments, before settlement were as small as 0.4 μm. Karakiri et al. (1991) described the otolith microstructure of 0-group plaice caught in the Dutch Wadden Sea in 1988. Otolith daily increments just after hatching were found to range in width from 0.2 to 0.8μm depending on location. Increment widths measured during that survey revealed slow growth rates in that year. Otolith microstructure analysis was used on the Northern French coast in 1999 as part of a survey to determine quality of juvenile flatfish nursery grounds (Gilliers *et al.* 2004). 0-group plaice of approximately 90 days old were sampled. Otolith increment widths from day 80 to 90 after hatching ranged from 6.60 to 11.57μm.

Observed daily growth rate ($mm.d^{-1}$) for post-larval 0-group plaice was calculated from Amara and Paul (2003). Observed growth was then compared to predicted growth ($mm.d^{-1}$) for 0-group plaice under excess feeding conditions using a growth model (Glazenburg 1983 in Van der Veer 1986). Results showed a range in mean daily growth rates ranging from 0.22 to 0.52 $mm.d^{-1}$ on the three beaches sampled in April 2005 and a range from 0.51 to 0.76 $mm.d^{-1}$ in May 2005. Daily growth rates in Galway Bay in 2005 were in a similar range to that reported by Allen (2004) for the same area in 2003. Tests revealed that there was no significant difference in daily growth rates between the three beaches sampled in April and May 2005. Growth rates calculated by otolith microstructure were generally higher (approximately twice) than growth rates calculated by increase in mean length. Otoliths are a better indicator of growth rates as individual fish can be analysed, compared to using mean increase in length over time witch tend to underestimate growth rates (Nash and Geffen 2005).

In general, Ballyloughan showed greater growth than Silverstrand or Glann na Ri. Glann na Ri had the smallest growth rates overall. Ballyloughan showed similar growth rates to predicted in April 2005 and better growth than predicted in May. Both Silverstrand and Glann na Ri shower smaller growth rates than predicted in April 2005 but similar growth to predicted in May. The results suggest that growing conditions for 0-group plaice were best on Ballyloughan in April 2005 and mean otolith increment widths seem to verify this. All beaches showed increased growth rates in May 2005. This could be related to faster growth in later settling fish due to improving temperatures or food availability (Van der Veer 1986, Al-Hossaini *et al.* 1989, Amara and Paul 2003, Nash and Geffen 2005). Variability in growth rates among cohorts has also been observed in other flatfish species. In the Tagus estuary, Portugal, differences in growth rates among cohorts were noted, in 2003 and 2004, for two species of juvenile Sole (*Solea solea* and *Solea senegalensis*) (Fonseca *et al.* 2006). Overall daily growth rates observed in Galway Bay in 2005 are within the same range observed in other European waters

Al-Hossaini *et al.* (1989) recorded growth rates for three separate cohorts ranging from 0.36 to 0.58 $mm.d^{-1}$ in 1986 and 1987 in the Irish Sea using otolith microstructure analysis. Amara and Paul also used otloiths to calculate growth rates on the French coast in 1999. Mean growth rates of 0.38 $mm.d^{-1}$ were recorded. Growth rates were found to be smaller than predicted growth. Berghahn *et al.* (1995) found daily growth rates of 0.56 $mm.d^{-1}$ in the Wadden Sea in 1991.

Total age of 0-group plaice, from hatching, were compared to total length of 0-group plaice at capture for 60 fish. Regression analysis revealed a value of $r^2 = 0.30$. Pearsons correlation test gave a value of 0.54 and a p-value of ($p < 0.001$). This graph gave a good indication of the varying growth rates achieved by individual fish from the three beaches sampled. Generally an increase in length can be seen the older a fish gets. Karakiri *et al.* (1989) produced graphs that also demonstrated the variability in growth rates among individuals.

4.5.5 Conclusion

Hatching period in Galway Bay ranged from late January 2005 to early April. Results on hatching periods in Galway Bay from 2003 and 2005 revealed no significant difference between years or between beaches sampled. Fish caught in April 2005 had earlier hatching dates than fish caught in May 2005; this however was the expected result. Three cohorts of 0-group plaice were observed in 2003 but no evidence could be found for cohorts in 2005. This is probably related to sample size and sampling regime. Results obtained for Galway Bay were found to be similar to results from other European Waters.

The range in larval duration for 2005 in Galway Bay in April and May were from 21 to 45 days. This is lower than observed in other European waters. No significant difference was observed in larval duration between beaches sampled in Galway Bay or between years in April 2003 and 2005. A significant difference was observed between larval age and years in May 2003 and 2005 however no significant difference was observed between beaches. This may be related to the hydrographical supply of larva to the nursery grounds in the different years.

Settlement period ranged from late March to mid-May in 2005. Settlement patterns in 2003 and 2005 were not significantly different to one another. There was also no difference in settlement patterns between the beaches sampled. Settlement dates were different between the months of April and May with fish caught in April settling earlier than fish caught in May, which was the expected result. Settlement period was similar to patterns observed on the French coast (Amara and Paul 2003), and in the Irish Sea (Al-Hossaini *et al.* 1989).

Hatching, larval duration, larval growth and settlement are all part of the juvenile flatfishes pelagic lifecycle. The important thing to note is that there was no spatial effect found in any of these lifecycle stages over the two years on Ballyloughan or Silverstrand or over the three beaches in 2005. All of this information indicates that juveniles from all beaches sampled seem to go through relatively the same conditions at sea (Bailey *et al.* 2005). This also probably indicates that the fish on the three beaches are from the one stock. There were some temporal difference between years but there was still no spatial difference which emphases the earlier findings.

Post larval age of fish caught in April and May 2005 ranged from 6 to 85 days. No significant difference was noted in post-larval age between the three beaches sampled in April and May 2005. Data for 2003 and 2005 were compared using fish from Ballyloughan and Silverstrand. A significant difference in post-larval age was noted in the month of April between years and between beaches. Results revealed that fish in April 2003 had a younger post larval age than fish in 2005 and that fish from Ballyloughan had an older post-larval age than fish from Silverstrand. The age difference were however relatively small approximately from 1 to 2 weeks. For fish caught in May 2003 and 2005 there was no significant difference between beaches, however there was a significant difference between years. Fish caught in May 2003 had a younger post larval age than fish caught in May 2005.

Growth for 0-group plaice was greater on Ballyloughan in 2005, compared to Silverstrand and Glann na Ri, and mean otolith increment widths seem to verify these results (Gilliers *et al.* 2004). ANOVA revealed no significant difference between beaches or months. Ballyloughan generally showed better-observed daily growth rates than predicted. Silverstrand and Glann na Ri showed poorer observed growth than predicted growth in April 2005. All beaches showed improved growth in May 2005. This may be related to faster growth in the later settling fish due to improving temperatures or food availability. Overall daily growth rates observed in Galway Bay in 2005 are within the same range observed in other European waters.

Post-larval duration and post larval growth are part of the juvenile plaice benthic stage. Here for the first time both spatial and temporal differences were noted. This indicates that the juvenile plaice are now encountering different conditions on their respective nursery grounds. Differences in predation, food supply and growth are common among nursery grounds even on a small spatial scale (Gillers *et al.* 2004, Nash and Geffen 2005).

Table 4.8 Summary of hatching dates, larval duration, settlement dates and juvenile growth for 0-group plaice for the present study and other European waters, determined using otolith microstructure analysis. N/S means not studied.

Location	Years	Hatching dates	Larval age (days) range	Otolith increment width range (µm)	Settlement dates	Post-larval growth ($mm.d^{-1}$) range	Reference
Galway Bay	2002 to 2006	Late January to early April	21 to 45	0.7 to 9.7	Early march to mid-May	0.22 to 0.76	Allen (2004), present study
Irish Sea	1986 to 1987	Late January to Mid April	50 to 53	N/S	April to June	0.36 to 0.58	Al-Hossaiani *et al.* (1989)
Wadden Sea	1988	Started early February	50 to 82	0.2 to 0.8	April and May	N/S	Karakiri *et al.* (1991)
Wadden Sea	1995 and 1996	Early January to early March	N/S	N/S	N/S	N/S	Van der Veer *et al.* (2000)
Frisian Wadden Sea	1981 and 1982	N/S	55 to 70	0.4 to 8	N/S	N/S	Karakiri *et al.* (1989)
North French coast	2000	N/S	N/S	N/S	Late march and Mid April	0.38	Amara and Paul (2003)
Wadden Sea	1991	N/S	N/S	N/S	Late May	0.56	Berghahn *et al.* (1995)
North French coast	1999	N/S	N/S	6.6 to 11.5	N/S	N/S	Gilliers *et al.* (2004)

Chapter 5

5.1 General Discussion

0-group plaice populations in Galway Bay over the five years studied (2002 – 2006) show patterns in abundances and size structure similar to studies carried out in other European Waters (e.g. Steel and Edwards 1970, Van der Veer 1986, Modin and Pihl 1996). Densities of 0-group plaice in Galway bay ranged from 0 $1000m^{-2}$ on occasions to a maximum peak of 900 $1000m^{-2}$ in March 2004. In general Ballyloughan and Silverstrand show similar patterns in abundances of 0-group plaice, from February to June in years sampled. Glann na Ri, in the period sampled from 2005 to 2006, showed a similar pattern in abundances with the other beaches sampled.

A significant difference was noted in the abundances of 0-group plaice, in the main settlement months of March between 2002 and 2006. Results revealed 2002 as a low recruitment year and 2004 as a high recruitment year. Peaks in abundances of 0-group plaice were also significantly different between years. Again, 2002 was shown to be a low settlement, hence recruitment, year and 2004 as a high recruitment year. Patterns of high and low recruitment between years have been recorded in many studies (e.g Van der Veer 1986, Wennhage and Pihl 2001). High densities of 0-group plaice noted in March 2004 had reduced by early summer. Predation can cause dampening effects on a nursery ground and years of high recruitment can show relatively similar numbers of plaice, compared to more normal years, by the end of the first summer (Steele and Edwards 1970, Nash and Geffen 2000). Overall, no significant spatial difference was noted in the abundances of 0-group plaice in the study area; however, results indicated smaller-scale spatial and temporal differences. Densities of 0-group plaice in Galway Bay over the five years studied are comparable to findings in other European waters. It has to be taken into consideration, however, when comparing densities to results in other areas the fact that sampling is carried out in many different ways in other studies. Also, the majority of other studies do not use push-netting as a sampling method. The efficiencies of the different methods used can greatly affect the estimates of abundances.

Hatching periods for Galway Bay were assessed using otolith microstructure analysis. Hatching period ranged from late January to early April. No significant difference was noted in hatching dates for fish caught in 2003 and 2005. No spatial difference was noted in hatching dates in either year. Three cohorts of hatching were noted in 2003 but no evidence of cohorts could be found in 2005. This could be due to sample size and sampling regime in 2005. Hatching dates were similar to results from other European waters (Al-Hossaiani *et al.* 1989, Karakiri *et al.* 1991, Van der Veer *et al.* 2000).

Larval duration for 0-group plaice in Galway Bay was calculated using otolith microstructure analysis. Larval duration ranged from 21 to 45 days for fish sampled in April and May 2005. These were similar to results for April and May 2003 (Allen 2004). No spatial difference was observed in larval duration between three beaches (Ballyloughan, Silverstrand and Glann na Ri) in 2005 or between two beaches (Ballyloughan and Silverstrand) in 2003 and 2005. Larval duration was found to be shorter in Galway Bay than in other European waters and was considered related to relatively high water temperatures in the Galway Bay region (Allen 2004).

Settlement of 0-group plaice was calculated using push-net observations and microstructure analysis. Patterns discerned by both methods were similar. Settlement was generally in early March, with the exception of 2002, when first settlement occurred in April. Settlement generally continued into May. These patterns of settlement are similar to other European waters. No significant difference in settlement dates, using otolith microstructure, was recorded between 2003 and 2005 or between the beaches sampled.

Hatching, larval duration and settlement are all part of the juvenile flatfishes pelagic lifecycle. An important factor to note is that there was no spatial effect found in any of these lifecycle stages over the two years on Ballyloughan or Silverstrand or over the three beaches in 2005. All of this information indicates that juveniles from all beaches sampled seem to go through relatively the same conditions at sea (Bailey *et al.* 2005). This also probably indicates that the fish on the three beaches are from the one stock. There were however, some temporal differences between years.

Post larval age of fish caught in April and May 2005, on the three beaches sampled, ranged from 6 to 85 days. No significant difference was observed in post larval age between the three beaches or months in 2005. Data for 2005 for Silverstrand and Glann na Ri were compared to data from April and May 2003 (Allen 2004). Results revealed that, for the month of April, there was a significant difference in post larval age between years (2003 and 2005) and between beaches (Ballyloughan and Silverstrand). Further analysis revealed that fish caught in April 2003 had a younger post-larval age than fish caught in April 2005. This was a significant result; however the difference in days was relatively small and may be explained by hydrographical effects on larval supply to the beaches (Bailey *et al.* 2005). Results also revealed that fish on Ballyloughan had an older post-larval age in April 2003 and 2005 compared to Silverstrand. The age difference represents about 10 days. Again hydrographical effects on larval supply to the beaches may explain this result. No significant difference was noted in post-larval age between beaches for fish caught in May 2003 and 2005. However a significant difference was noted between years, with fish caught in May 2003 having a shorter post larval age than fish caught in 2005. This is the first time that a significant spatial (between beach) difference is noted in the early life history. Post-larval duration and post larval growth are part of the juvenile plaice benthic stage. Here for the first time both spatial and temporal differences were noted. This indicates that the juvenile plaice are now encountering different conditions on their respective nursery grounds. Differences in predation, food supply and growth are common among nursery grounds even on a small spatial scale (approximately 16 km in Galway)(Gillers *et al.* 2004, Nash and Geffen 2005).

The length frequency distributions of 0-group plaice in Galway Bay were found to be similar to other European waters. Significant differences were noted in the size of 0-group plaice between years and between months. This was thought to be related to late settlement of 0-group plaice in some years and better growth conditions in other years (Van der Veer 1986).

Growth of 0-group plaice in Galway Bay was assessed using length frequencies and otolith microstructure analysis. Average growth rate, calculated using mean increase in length over time, in Galway Bay during spring and early summer, from 2004 to 2006, were $0.2 mm.d^{-1}$. A difference in growth rates was observed between beaches in Galway Bay in 2006 using length frequency analysis. Silverstrand showed greater growth rates than either Ballyloughan or Glann na Ri. Growth rates in 2004 and 2005 did not reveal differences between beaches using length frequencies. And observed growth rates were smaller than predicted growth rates using length frequencies. This suggests that food may be a limiting factor on the beaches sampled. Growth rates in 2003, in Galway Bay, were found to be similar to predicted (Allen 2004) and it was suggested that food was not a limiting factor. It should be noted that different growth equations were used during the two surveys. One was for summer growth (Fonds *et al.* 1992) used by Allen (2004) and the other was specifically for smaller plaice (Glazenburg 1983), used in the present study. Overall, daily growth rates are in the same range as seen in the Isle of Man (Nash *et al.* 1994) and Scotland (Steele and Edwards 1970), but are smaller than observed in France (Amara 2003), Sweden (Wennhage *et al.* 2006) and Iceland (Hjorleifsson and Palsson 2001).

Otolith microstructure analysis revealed the Ballyloughan showed post-larval growth rates that were higher than predicted in April and May 2005, whereas Silverstrand and Glann na Ri showed poorer growth rates compared to predicted growth. However, no significant difference in growth rates was recorded between beaches in 2005. Growth rates calculated by otolith microstructure were generally higher than growth rates calculated using mean increase in length (approximately by a factor of two). Otoliths are a better indicator of growth rates as individual fish can be analysed, compared to using mean increase in length over time which tends to underestimate growth rates (Nash and Geffen 2005).

Experimental push- netting was carried out in Galway Bay in 2005 and 2006 to examine the hypothesis that there was a difference in the abundances of 0-group plaice between daytime and nighttime. Day and night sampling was carried out on Ballyloughan and Silverstrand. A significant difference was recorded between day and night catches in both years with catches at night being significantly larger. Many studies have shown greater numbers of 0-group plaice captured during night sampling compared to day sampling, however this is not always the case (Nash *et al.* 1994, Gibson *et al.* 1996). No significant difference in the lengths of 0-group plaice was observed between day and night samples, or between beaches in 2006. This was not expected, as gear avoidance, for larger fish, would have been a reason considered for the difference in abundances between day and night (Casey and Myers 1998).

Experimental push-netting was also carried out to test the hypothesis that spring or neap tides had no effect on the abundances of 0-group plaice in Galway Bay. Ballyloughan and Silverstrand were again used. No significant difference was noted between tidal types (spring and neaps).

The fact that no significant difference exists in the abundances of 0-group plaice between spring and neap tides is important as regular sampling was always carried out during spring tide periods. These results now mean that researchers are not constrained to spring tide periods and can sample at any time during a given month. Another benefit is that bad weather can be avoided more easily. A significant difference was observed in the lengths of 0-group plaice over the duration of the spring versus neap experiment. This result could be explained for by growth. It should be noted that diel and tidal effects are confounding factors and it is difficult to study one factor in isolation from the other as both tidal and diurnal patterns have an effect on plaice migration (Gibson 1973, Van der Veer and Bergman 1986, Gibson *et al.* 1996).

Push-netting as a method of studying flatfish ecology / biology in the Galway Bay region has been shown to be an efficient and reliable method. This method allowed the detection of density patterns and size structure of juvenile plaice. Limiting factors to this method are water depth ($\leq$ 1m), wave exposure and weather conditions. As juvenile flatfish stay in shallow waters until the end of their first summer this does not cause a problem for sampling with a push-net (Heinz 1989, Geffen and Nash 1995). However, escaping 0-group plaice were noted from mid-May onwards in 2005 and 2006 and this naturally affects population size estimates. This indicates that this sampling method has probably lost its effectiveness from the month of June onwards, as older fish either escape or starts to migrate to deeper waters (Gibson 1973). The beaches sampled in Galway Bay are also relatively sheltered and gently sloping which make them ideal for push-net sampling.

This study adds vital information on the recruitment of 0-group plaice to sandy beach nursery grounds in the Galway Bay area. This is important as the state of the plaice stock in this area is unknown (ANON 2005). Information obtained in this study will be beneficial in the formation of a recruitment index in the future. This study also adds to an ever-expanding data set on the ecology of 0-group plaice, in varying regions, on the west coast of Ireland collected by researchers in G.M.I.T. Galway.

Future research on 0-group plaice in the Galway Bay region should incorporate research on larval ecology of 0-group plaice offshore, as larval supply is a vital component affecting yearly variability and recruitment (Bailey *et al.* 2005). Also, research on predation by various species, in particular the brown shrimp *Crangon crangon* (Nash and Geffen 2005), would be beneficial. This research would help in understanding the fluctuations in 0-group plaice densities due to mortality. Another vital part of future research would be the inclusion of diet studies and more detailed analysis on the affect of environment factors on the ecology and biology of 0-group plaice in Galway Bay. Experimental fishing during different stages of the ebb and flowing tides would also reveal valuable information relating to the effects of tides on 0-group plaice populations.

Appendix 1

Chapter 2

Table 2.1: Environmental data recorded during Push-net sampling visits on Ballyloughan (BN), Silverstrans (SS) and Glann na Ri in 2005. "N/T" shows that no data was collected.

Location code	Date	Salinity (ppt)	Weather	Sea state
BN 05 01	8-2-05	12	Sunny, cold	Calm
BN 05 02	23-2-05	25	Cold,cloudy	Calm
BN 05 03	9-3-05	28	Cloudy, dry	Calm
BN 05 04	25-3-05	17	Sunny, dry	Calm
BN 05 05	8-4-05	30	Very cold	Force 3+
BN 05 06	27-4-05	7	Cloudy	Force 3+
BN 05 07	5-5-05	28	Cloudy	Force 4
BN 05 08	24-5-05	29	Warm	Calm
BN 05 09	8-6-05	16	Warm	Calm
BN 05 10	20-6-05	17	Warm	Force 4+
SS 05 01	8-2-05	16	Sunny, cold	Calm
SS 05 02	25-2-05	30	Sunny	Force 4
SS 05 03	11-3-05	31	Cold	Force 3+
SS 05 04	29-3-05	27	Cloudy, dry	Calm
SS 05 05	11-4-05	35	Cloudy, dry	Force 3+
SS 05 06	29-4-05	30	Warm, dry	Force 4
SS 05 07	9-5-05	35	Warm	Calm
SS 05 08	31-5-05	22	Wet, cloudy	Force 3+
SS 05 09	9-6-05	31	Warm	Calm
SS 05 10	20-6-05	36	Warm	Force 4+
GNR 05 01	14-4-05	25	Cloudy	Calm
GNR 05 02	26-4-05	19	Showers	Force 3+
GNR 05 03	6-5-05	28	Showery	Calm
GNR 05 04	23-5-05	22	Showers	Force 3+
GNR 05 05	10-6-05	33	Warm	Calm

Table 2.2: Environmental data recorded during Push-net sampling visits on Ballyloughan (BN), Silverstrand (SS) and Glann na Ri in 2006. "N/T" shows that no data was collected.

Location code	Date	Salinity (ppt)	Weather	Sea state
BN 06 01	13-2-06	14	Cloud	Force 2
BN 06 02	1-3-06	N/T	Sunny	Calm
BN 06 03	15-3-06	N/T	Cloudy	Calm
BN 06 04	29-3-06	N/T	Sunny	Calm
BN 06 05	10-4-06	N/T	Sunny	Calm
BN 06 07	27-4-06	26	Sunny	Force 3+
BN 06 09	11-5-06	26	Sunny, dry	Calm
BN 06 10	25-5-06	N/T	Sunny	Calm
BN 06 11	12-6-06	16	Cloud	Force 4+
BN 06 10	25-5-06	22	Wet	Force 3+
SS 06 01	13-2-06	25	Mild	Force 2
SS 06 02	28-2-06	32	Sunny	Force 2
SS 06 03	15-3-06	N/T	Cloudy	Calm
SS 06 04	29-3-06	N/T	Sunny, dry	Force 3
SS 06 05	10-4-06	N/T	Sunny	Calm
SS 06 07	28-4-06	31	Sunny	Calm
SS 06 09	11-5-06	28	Sunny, dry	Calm
SS 06 10	25-5-06	22	Sunny	Calm
SS 06 11	12-6-06	35	Cloudy	Force 4+
SS 06 15	27-6-06	29	Sunny	Calm
GNR 06 01	14-2-06	14	Cloudy	Force 3
GNR 06 02	1-3-06	N/T	Sunny, cold	Calm
GNR 06 03	16-3-06	N/T	Showers	Calm
GNR 06 04	31-3-06	N/T	Showers	Force 2
GNR 06 05	11-4-06	N/T	Cloudy	Force 3+
GNR 06 06	27-4-06	28	Sunny	Calm
GNR 06 07	10-5-06	22	Sunny	Calm
GNR 06 08	23-5-06	14	Showers	Force 4
GNR 06 09	15-6-06	25	Sunny	Calm
GNR 06 10	29-6-06	16	Showers	Force 3+

Table 3.3: Environmental data recorded, at every visit, during day versus night experiments in June 2005. "N/T" shows that no data was collected.

Location code	Date	Visit	Salinity (ppt)	Water Temp (°c)	Weather	Sea state
BN 05 10	20-6-05	Day	16	19	Warm	Force 4,
BN 05 11	23-6-05	Night	N/T	N/T	Warm	Force 4
BN 05 12	25-6-05	Night	22	13.5	Warm	Calm seas
BN 05 13	27-6-05	Day	16	22	Warm	Very calm
SS 05 10	20-6-05	Day	36	16	Warm	Force 4
SS 05 11	23-6-05	Night	N/T	N/T	Warm	Force 4
SS 05 12	25-6-05	Night	32	13	Warm	Calm seas
SS 05 13	27-6-05	Day	32	22	Warm	Very calm

Table 3.4: Environmental data recorded, at every visit, during day versus night experiments in June 2006. "N/T" shows that no data was collected.

Location code	Date	Visit	Salinity (ppt)	Water Temp(°c)	Weather	Sea state
BN 06 11	12-6-06	Day	16	14.5	N/T	Force 4
BN 06 12	13-6-06	Day	22	15	Warm, dry	Force 4
BN 06 13	15-6-06	Night	22	15	Warm	Calm seas
BN 06 14	16-6-06	Night	22	15	Warm	Calm sea
SS 06 11	12-6-06	Day	35	14.5	N/T	Force 4
SS 06 12	13-6-06	Day	32	15	Warm, dry	Force 4
SS 06 13	15-6-06	Night	28	13.5	Warm	Calm seas
SS 06 14	16-6-06	Night	32	14	Warm	Calm sea

Table 3.3: Environmental data recorded, at every visit, during day versus night experiments in June 2006. "N/T" shows that no data was collected.

Location code	Date	Visit	Salinity (ppt)	Water Temp(°c)	Weather / sea state	Sea state
BN 06 05	10-4-06	Spring	N/T	N/T	Sunny	Calm
BN 06 06	19-4-06	Neap	N/T	14	Sunny	Force 3+
BN 06 07	27-4-06	Spring	26	13	Sunny	Force 4
BN 06 08	5-5-06	Neap	10	N/T	Sunny	Force 3+
SS 06 05	10-4-06	Spring	N/T	N/T	Sunny	Calm
SS 06 06	19-4-06	Neap	N/T	13	Sunny	Force 3+
SS 06 07	28-4-06	Spring	31	N/T	Sunny	Force 4
SS 06 08	5-5-06	Neap	26	N/T	Sunny	Force 3+

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